– ABSTRACT BOOK –
17th International Workshop on Low Temperature Detectors

Kurume, Fukuoka, Japan

June 28, 2017

Preface

The International Workshop on Low Temperature Detectors (LTD) is the biennial meeting to present and discuss latest results on research and development of cryogenic detectors for radiation and particles, and on applications of those detectors. The 17-th workshop will be held at Kurume City Plaza in Kurume city, Fukuoka Japan from 17th of July through 21st.

The workshop will be organized with the following six sessions:

1. Keynote talks
2. Sensor Physics & Developments,
    - TES, MMC, MKIDS, STJ, Semiconductors, Novel detectors, others
3. Readout Techniques & Signal processing
    - Electronics, Multiplexing, Filtering, Imaging, Microwave circuit, Data analysis, others
4. Fabrication & Implementation Techniques
    - Fabrication process, MEMS, Pixel array, Microwave wirings, others
5. Cryogenics and Components
    - Refrigerators, Window techniques, Optical Blocking Filters, others
6. Applications
    - Electromagnetic wave & photon (mm-wave, THZ, IR, Visible, X-ray, Gamma-ray), Particles, Neutrons, CMB, Dark Matter, Neutrinos, Particle & Nuclear Physics, Rare Event Search, Material Analysis & Life Science

Kurume is a fabulous location for the workshop. It is known by good local foods and good Sake (Japanese rice wine), and also for traditional fabric called Kurume Gasuri. The LTD17 workshop provides you a wonderful opportunity to exchange your ideas and extend your experience on the low temperature detectors. We hope you will join and enjoy.

LOC of 17th International Workshop on Low Temperature Detectors

Contents

Oral presentations

Keynote talks

O-1 Low Temperature Detectors (for Dark matter and Neutrinos) 30 Years ago. The Start of a new experimental Technology.

Franz von Feilitzsch[1]

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The beginning of a new exciting development in fundamental and applied physics is reviewed. With the first LTD Workshop at the Ringberg Castle in Bavaria, a new conference sequence was started in march 1987 and reached with LTD17 30th anniversary. In this presentation we try to remember some of the exiting new ideas presented at the time, which by now reached unprecedented results and perspectives.

category : Keynote talk

O-2 X-Ray Microcalorimeters in Space - Today and Tomorrow

Richard L Kelley[1]

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The application of X-ray calorimeters for high-resolution spectroscopy of individual celestial x-ray sources finally reached its fulfillment in early 2016 with the launch of the Soft-X-Ray Spectrometer (SXS) on the Hitomi observatory. The instrument was used to obtain the first ever x-ray spectrum of a cluster of galaxies with a resolution sufficient to detect turbulence in the intracluster medium, and demonstrated the power of the technology for measuring velocity structure with extraordinary precision. It was found that the velocity dispersion corresponding to the turbulent motion of the gas in the Perseus Cluster is only 160 km/sec with an overall uncertainty of just 12 km/sec down to a physical scale approaching the size of our own galaxy. In my talk, I will present the overall design and performance of the Hitomi Soft X-Ray Spectrometer (SXS). The instrument used a 36-pixel array of x-ray microcalorimeters at the focus of a grazing-incidence Soft X-Ray Telescope (SXT). The instrument was designed to achieve an energy resolution better than 7 eV over the 0.3-12 keV energy range and operate for more than 3 years in orbit. The actual energy resolution of the overall instrument was 4-5 eV as demonstrated during extensive ground testing prior to launch and in orbit. This is consistent with the predicted detector resolution allowing for spectral broadening due to instrument- and observatory-level terms. The in-orbit measured mass flow rate of the liquid helium cryogen and fill level at launch predicted a lifetime of over 3 years assuming steady mechanical cooler performance. Cryogen-free operation was successfully demonstrated prior to launch. The successful operation of the SXS in orbit, including the first observations of the velocity structure of the Perseus cluster of galaxies, demonstrated the viability and power of this technology as a tool for astrophysics.

category : Keynote talk

O-3 CMB B-mode polarization - Probe the era before the Big Bang

Hitoshi Murayama[1]
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How did the Universe begin? It is believed that the whole Universe we see today was born much smaller than the size of an atom. Then it was stretched to a macroscopic size by a period of accelerated expansion called cosmic inflation.

The hot Big Bang came after the inflation. We do know the Universe was hot because we can see it using the cosmic microwave background. How do we “ see ” the inflationary period? The rapid stretching of the Universe must have caused the space to “ wobble, ” namely it let out gravitational waves. These gravitational waves can be indirectly detected through the polarization of the cosmic microwave background.

In this talk, I will review what we can learn about the Universe from CMB observations, and then talk about observations with emphasis on the space project, LiteBIRD. Uniform all sky coverage and the low temperature detectors are crucial for this project.

category : Keynote talk

MKIDS 1

O-4 Performance of a 961 pixel Kinetic Inductance Detector system for future space borne observatories

Jochem Baselmans[1], Juan Bueno[2], Stephen Yates[3], Ozan Yurduseven[4], Nuria Llombart[5], Kenichi Karatsu[6], Andrey Baryshev[7], Lorenza Ferrari[8], Akira Endo[9], David Thoen[10], Pieter de Visser[11], Reinier Janssen[12], Vignesh Murugesan[13], Eduard Driessen[14], Gregoire Coiffard[15], Jesus Martin-Pintado[16], Peter Hargrave[17], Matt Griffin[18]

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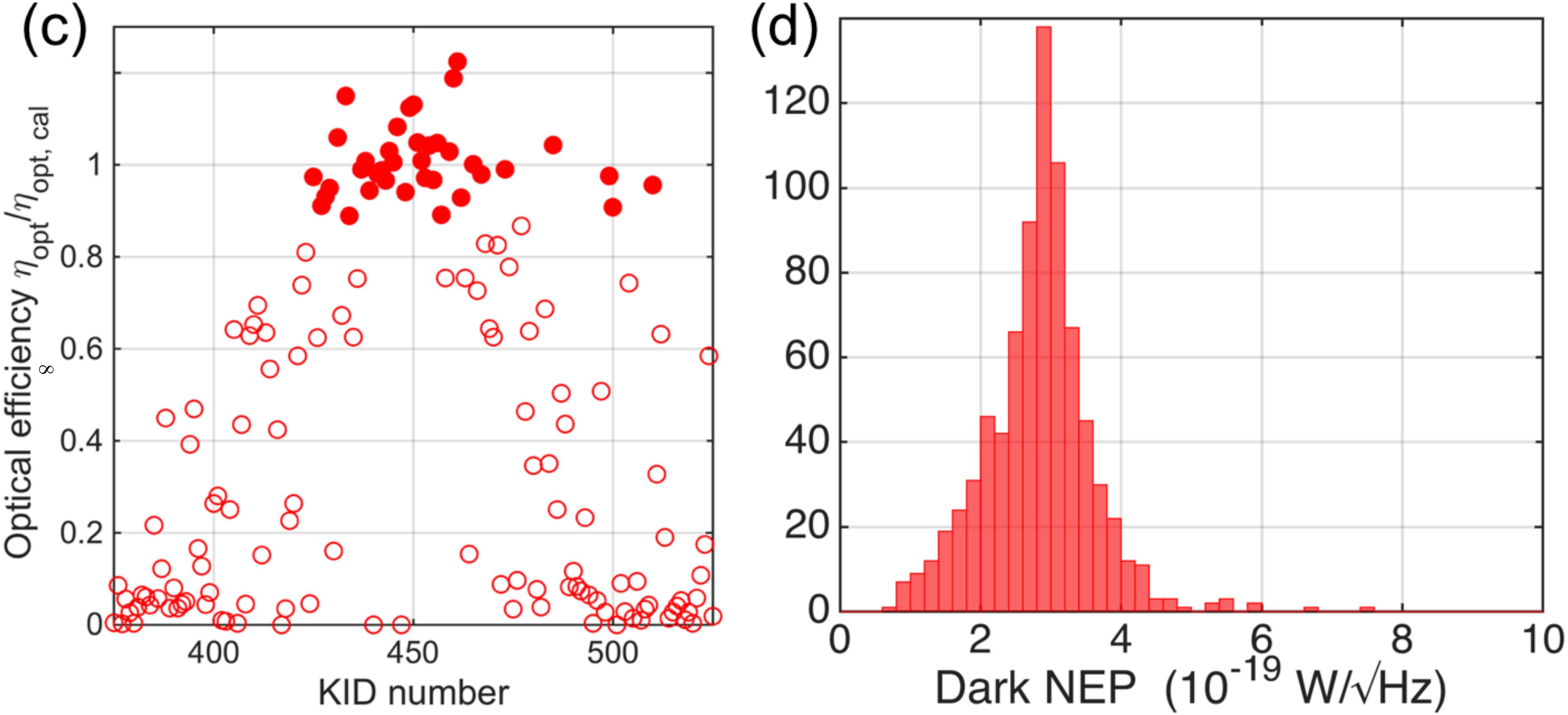
Future astrophysics and cosmic microwave background space missions operating in the far-infrared to millimeter part of the spectrum will require very large arrays of ultra-sensitive detectors in combination with high multiplexing factors and efficient low-noise and low-power readout systems. We have developed a demonstrator system suitable for such applications. The system combines a 961-pixel imaging array based upon Microwave Kinetic Inductance Detectors (MKIDs) with a readout system capable of reading out all pixels simultaneously with only one readout cable pair and a single cryogenic amplifier. A microscope image of part of the array chip is given in panel a) of the figure, showing some of the MKID pixels coupled to the feedline used for read-out. An image of the assembled detector package is given in panel b). We evaluate, in a representative environment, the full system performance in terms of sensitivity, dynamic range, optical efficiency, cosmic ray rejection, pixel-pixel crosstalk and overall yield at an observation center frequency of 850 GHz and 20% fractional bandwidth. The overall system has an excellent sensitivity, with an average detector sensitivity NEP_{det} = 3x10^{-19} W/rt(Hz) measured for the central pixels of the array using a thermal calibration source. Additionally, the optical coupling efficiency matches the calculated value, as shown in panel c) of the figure. The electrical NEP can be obtained for all pixels and is identical to the value obtained using the thermal calibration source. The histogram of the measured sensitivity is given in panel d) of the figure. At a loading power per pixel of 50 fW we demonstrate white, photon noise limited detector noise down to 300 mHz. The dynamic range allows the detection of 1 Jy bright sources within the field of view without tuning the readout of the detectors. The expected dead time due to cosmic ray interactions, when operated in an L2 or a similar far-Earth orbit, is found to be <4%. Additionally, the achieved pixel yield is 83% and the crosstalk between the pixels is <-30dB. This demonstrates that MKID technology can provide multiplexing ratios on the order of a 1000 with state-of-the-art single pixel performance, and that the technology is now mature enough to be considered for future space based observatories and experiments.

category : Sensor Physics & Developments


(c)
Optical efficiency $\eta_{opt}/\eta_{opt,\ cal}$
0
0.2
0.4
0.6
0.8
1
400
450
500
KID number
(d)
0
20
40
60
80
100
120
0
2
4
6
8
10
Dark NEP (10^{-19} W/√Hz)

O-5 The sub-gap KID (SKID): on-chip spectroscopy at centimetric wavelengths

Alessandro Monfardini[1], Olivier Dupre[2], Alain Benoit[3], Martino Calvo[4], Andrea Catalano[5], Johannes Goupy[6], Christophe Hoarau[7], Thierry Klein[8], Kevin Le Calvez[9], Benjamin Sacepe[10], Florence Levy-Bertrand[11], Alicia Gomez[12]

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We have fabricated planar indium oxide superconducting resonators (Tc around 3 K) that are sensitive to frequency-selective radiation in the range 7?10 GHz. Those values lay more than 20 times below the equivalent superconducting gap that is worth about 200 GHz. We show that the detected frequency can be adjusted by modulating the total length of the superconducting resonator. The measured spectral resolution is of the order of thousands. We attribute those observations to the excitation of higher-order resonance modes. The coupling between the fundamental (lumped) and the higher order (distributed) resonances is related to the kinetic inductance non-linearity. These devices, that we have called Sub-gap Kinetic Inductance Detectors (SKID), are to be distinguished from the standard kinetic inductance detectors in which quasi-particles are generated when incident light breaks down Cooper pairs. We present our preliminary results in the band 7-10 GHz and the plans for developing an instrument to monitor the water vapour line at 22GHz.

category : Sensor Physics & Developments

O-6 Moving optical MKIDs to lower temperature: preliminary characterization of Hafnium resonators

Giulia Collura[1], Gregoire Coiffard[2], Bruce Bumble[3], Paul Szypryt[4], Benjamin A. Mazin[5]

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We have fabricated hafnium MKID test arrays with 15 resonators on A-plane sapphire wafers. Hafnium is an elemental type I superconductor. It has a bulk Tc of 128 mK, lower than Tc 800mK of sub-stoichiometric TiN and PtSi or Tc 1K of Al used in current MKID instruments, corresponding to a smaller Cooper Pair binding energy. This should lead to increased sensitivity and spectral resolution. Our Hafnium films transition around 460 mK and we have measured quasiparticle lifetimes of about 50 us at 20 mK. We observe Hafnium resonators with internal quality factors up to 500k that are photosensitive to 800-1350 nm light, exhibiting a spectral resolution R 9 at 808nm. The internal quality factors and energy resolution observed are comparable to those of optimized PtSi MKID resonators, making Hf a very promising material for MKID development. We also expect Hf films to have a more uniform surface inductance than films made of compound materials, and we will report on uniformity measurements.

category : Sensor Physics & Developments

O-7 Suppression of in-detector-chip stray radiation for large arrays of lens-antenna coupled microwave kinetic inductance detectors

Stephen J.C. Yates[1], Andrey M. Baryshev[2], Ozan Yurduseven[3], Juan Bueno[4], Kristina K. Davis[5], Lorenza Ferrari[6], Willem Jellema[7], Nuria Llombart[8], Vignesh Murugesan[9], David Thoen[10], Jochem J.A. Baselmans[11]

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With increasing detector array size, it becomes more important to control stray radiation inside the detector chips themselves. We show that such stray light is a problem in focal plane arrays of 880 lens-antenna coupled Microwave Kinetic Inductance Detectors (MKIDs). The arrays are measured with reimaging optics, allowing near field measurements of the optical response versus the position on the array of a reimaged optical source. We demonstrate that the optical response of a detector in these arrays saturates off-pixel at the -30 dB level compared to the peak pixel response. The result is that the power detected from a point source at the pixel position is almost identical to the stray response integrated over the chip area. If used on sky with such a stray light contribution, it would be impossible to measure extended sources; while the point source response is degraded due to an increase of the stray loading. However, we show that by incorporating an on-chip stray light absorber this effect is reduced at least a factor 10, with the optical response now limited by the fore-optics and not the detector chip.

category : Sensor Physics & Developments

MKIDS 2

O-8 Counting Near Infrared Photons with Microwave Kinetic Inductance Detectors

Lianfu Wei[1]

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We demonstrate photon counting at 1550 nm wavelength using microwave kinetic inductance detectors (MKIDs) made from TiN/Ti/TiN trilayer films with superconducting transition temperature Tc ? 1.4 K. The detectors have a lumped-element design with a large interdigitated capacitor covered by aluminum and inductive photon absorbers whose volume ranges from 0.4 μ m3 to 20 μ m3 . The energy resolution improves as the absorber volume is reduced. We achieved an energy resolution of 0.22 eV and resolved up to 7 photons per optical pulse, both greatly improved from previously reported results at 1550 nm wavelength using MKIDs. Further improvements are possible by optimizing the optical coupling to maximize photon absorption into the inductive absorber.

category : Sensor Physics & Developments

O-9 Characterizing millimeter wave Thermal Kinetic Inductance Detectors with a novel readout system

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We are developing Thermal Kinetic Inductance Detectors (TKIDs) at Caltech/JPL for Cosmic Microwave Background observations, targeting deployment of a 250GHz BICEP Array camera. TKIDs inherit the scalability of traditional KIDs via radio frequency domain multiplexing with passive cold electronics, but offer design flexibility similar to what has allowed TES bolometers to be so highly sensitive. In particular, our design allows us to independently optimize the absorbing efficiency and resonator sensitivity in a manner that is drop-in compatible to existing antenna-coupled architectures. In this talk, we will describe detailed noise studies of several island released prototype devices that contain integrated DC heaters in close thermal contact with KID inductor/thermistors. These heaters allow for a straightforward calibration of efficiency and noise spectra. We will describe contributions of leg phonon (G), quasiparticle gr, amplifier and TLS noise and explain how these can be controlled for background limited performance for our planned application. We will also describe a novel general-use readout system we are using for these measurements and will use for characterization of other resonator-based detectors under development at JPL. Our warm readout electronics uses a thin FPGA layer for generic data acquisition, but implements data processing and reduction in our computer 's GPU. This system can be easily reconfigured without the need for detailed HDL code, facilitating the variety of measurements we have performed on our TKIDs.

category : Sensor Physics & Developments

O-10 Photon Counting Kinetic Inductance Detectors for THz/Submillimeter Space Spectroscopy

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Photon-counting direct detectors are highly desirable for reaching the $\sim 10^{-20}$ W/rt Hz power sensitivity enabled by the Origins Space Telescope (OST), a notional cryogenic facility inspired by NASA 's Astrophysics Roadmap. We are developing Kinetic Inductance Detectors (KIDs) with photon counting capability in the far-infrared/THz combined with integrated spectrometers suitable for the OST facility. To reach the required sensitivity we are experimenting with single-layer superconducting resonators made from aluminum films that are 10 nm thick on single-crystal Si substrates. Small-volume inductors made from such thin Al films have the potential to become ultra-sensitive to single pair-braking far-IR photons (¿90 GHz) under the right conditions. Understanding the physics of these superconducting films and superconductor-dielectric systems is critical to achieving detector performance with ultra low-loss and low-noise substrates.

In our measurements of these resonators, we have achieved very high internal quality factors (Qi $\sim 7 \times 10^6$ for 25 nm Al, and 1.1×10^6 for 10 nm Al) at $\sim 10^6$ microwave photon drive power. At single-photon drive powers both films remarkably maintain a very high Qi $\sim 0.5 \times 10^6$, by far the highest known value for such thin films reported in literature. For our 10-nm films we have measured a residual QP density of < 0.2 /μm^3, which is sufficient for our application. We have obtained quasi-particle (QP) lifetimes of 1.0 ms for 100 nm Al on Si resonators, another critical parameter for reaching photon-counting sensitivity. Our testbed was optimized for ultra-low stray radiation, which was confirmed by measurements. To realize a practical device, we are integrating these films with our Silicon-on-Insulator (SOI) process to form microstrip-style elements on single-crystal dielectric. Our analysis shows that two-level system noise is not a limiting factor to sensitivity in our design. Based on a detailed physical model, where we simulated the detector output time stream when illuminated with random photon events, our results show that photon counting with $> 95\%$ efficiency at 0.5 THz and 1.0 THz is indeed possible.

We report on these developments and discuss our plans to implement these devices into optically coupled ultra-sensitive KIDs suitable for photon counting in space.

category : Sensor Physics & Developments

O-11 Low-Loss, Low-Noise, Crystalline Silicon Dielectric for Superconducting Microstriplines and Kinetic Inductance Detector Capacitors

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A number of technology developments in superconducting sensors for mm/submm astronomy require low-loss dielectric thin films with loss tangents well below the 1e-3 level seen in SiO2 and SiNx conventionally used. To this end, we are pursuing the development of crystalline silicon and hydrogenated amorphous silicon dielectrics, which promise loss tangents 10 to 1000 times better.

Examples of mm/submm technologies that use low-loss dielectric films include:

* Microstrip-coupled superconducting mm/submm detectors, which rely on superconductor-dielectric-superconductor microstrip transmission line to transmit optical power from a coherent reception element (feedhorn, lens coupled antenna, phased-array antenna) to detectors;

* Superconducting spectrometers (SuperSpec, TIME, MicroSpec), which use such microstrip to route optical power to detectors and to define spectral channels;

* Kinetic inductance detectors (KIDs), which use capacitors.

Dielectric loss, quantified by the loss tangent, is critical to these technologies: it determines the optical loss in the microstrip, the resolution of spectral channels, and the two-level-system (TLS) dielectric fluctuation noise of the KID capacitor. Currently, the amorphous dielectrics SiO2 and SiNx are used for the first two because they are most convenient for fabrication. These amorphous dielectrics have tan delta 1e-3. This loss tangent is acceptable for microstripline but severely limits the possible architectures and spectral resolving power, and it is too large for KID capacitors (necessitating the use of interdigitated capacitors on crystalline substrates). Lower loss dielectric would result in a quantum leap in capability, specifically enabling new architectures incorporating microstripline (such as remote detectors and multiscale antennas), higher-resolution superconducting spectrometers, and KIDs using compact parallel-plate capacitors.

We are pursuing hydrogenated amorphous silicon (a-Si:H) and crystalline silicon (cSi) (from silicon-on-insulator wafers) for low-loss films. Crystalline silicon intrinsically has tan delta ¡5e-6, 200 times lower than SiO2 and SiNx. a-Si:H has been demonstrated with tan delta ¡ 5e-5, not as good as cSi but still 20 times better than SiO2 and SiNx. Improvement in loss tangent to 1e-4 would provide significant gains, and further improvements would open new possibilities, especially for KID noise. We are pursuing the both materials due to their complementary advantages and challenges.

We use niobium parallel-plate LC resonators to measure the microwave (1-3 GHz) loss tangent and noise. We have demonstrated that 1 um, 2 um, and 5 um crystalline silicon on SOI wafers have high-power loss tangents of 3e-6 to 3e-5, ¡ 1e-6, and 2 to 5e-6, respectively, and that the 5 um material has low-power loss tangent of 1 to 3e-5. To be used in microstrip geometries, crystalline silicon must undergo a wafer-bonding process that may degrade the material. We have thus made measurements for wafer-bonded 5 um crystalline silicon, obtaining low and high power loss tangents of 6 to 12e-5 and 1 to 3e-5, respectively. We will report on measurements of the properties of wafer-bonded 1 um and 2 um silicon and also on TLS noise measurements for virgin and wafer-bonded material. We will also report on progress toward a-Si:H RF test devices and cSi and a-Si:H mm-wave test devices.

category : Sensor Physics & Developments

O-12 Kalliope-based High-Speed Neutron imager by a delay-line current biased kinetic inductance detector

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Neutron imaging is crucial for non-destructive examination because of the high penetrating capability in most materials, and has been developed to date[1]. The recent progress in high intensity pulsed spallation neutron sources allows us to perform a high spatial resolution neutron imaging. We have been developed the superconducting sensor based neutron detectors aiming for a novel neutron imager[2, 3, 4]. The present detector consists of stacking layers of a superconducting Nb ground plane, orthogonal x and y Nb meanderlines and ^{10}B neutron absorption layer. The nuclear reaction between an incident neutron and ^{10}B induces the transient change of the kinetic inductance of Cooper pairs in x and y meanderlines. It excites voltage pulses under a DC-bias current and the excited signals propagate as electromagnetic wave toward both sides with opposite polarity along the meanderline. The signals are detected by a Kalliope-DC, which is a high time and temporal resolution multichannel detector concomitant with wide time window. We successfully obtained energy dispersive high spatial resolution neutron images from quartets of signal detection times by applying the delay-line method. We call this detector the delay-line current biased kinetic inductance detector (CB-KID). The delay-line CB-KIDs allow us to obtain a neutron imaging by using only four lead wires. It has definitive advantage in reducing the heat leak to the low temperature stage through the lead wires. The delay-line CB-KID is one of a superconducting ^{3}He-free neutron detector, and has capability to enhance the spatial resolution without any discontinuity by using a high-speed time to digital converter based on the Kalliope-DC systems even with the present sensor chip.

This work is supported by a Grant-in-Aid for Scientific Research (No. 23226019, No.16H02450) from JSPS, the foundation fabricator (CRAVITY) and a Cadence software of VDEC at the University of Tokyo.

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category : Sensor Physics & Developments

18

Application - Astronomy

O-13 First light of DARKNESS: a pathfinder for exoplanet imaging with Microwave Kinetic Inductance Detectors

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High-contrast imaging is a powerful technique for the study of extrasolar systems, allowing the direct observation of exoplanets and circumstellar disks by using a combination of extreme Adaptive Optics and coronagraphy to suppress the light from their host star. The primary obstacle to imaging faint planets and disks is bright " speckles " in the focal plane caused by unsensed and uncorrected optical errors. While techniques exist to reliably correct static speckles from diffraction and instrumental aberrations, speckles resulting from residual atmospheric aberrations are especially troublesome - with decorrelation times on the order of 1s, they average slowly over long exposures and impose the current state-of-the-art contrast limits of $\sim 10^{-6}$ from the ground (roughly corresponding to detectable planet masses ¿ $1M_{Jup}$). Optical and near-infrared Microwave Kinetic Inductance Detectors (MKIDs) offer great potential for overcoming this limitation: read-noise free photon counting enables real-time focal plane wavefront control at frame rates much faster than the atmospheric speckle decorrelation time, and intrinsic energy resolution enables wavefront correction over a broad bandwidth. DARKNESS (the DARK-speckle Near-infrared Energy-resolving Superconducting Spectrophotometer) is the first of several planned integral field spectrographs to demonstrate the use of optical/near-infrared MKIDs for high-contrast astronomy. DARKNESS saw first-light in July 2016 at Palomar Observatory, and has subsequently travelled to Palomar in November 2016 and April 2017 for ongoing commissioning and science verification. Here we present an overview of the instrument and early science results, including a study of temporospatial speckle correlations across millisecond to hour timescales, with implications for using these statistics to discriminate speckles from true faint companions.

category : Applications

O-14 Development of 'DESHIMA on ASTE': towards a field test of a submillimeter wave superconducting on-chip filterbank spectrometer based on kinetic inductance detectors

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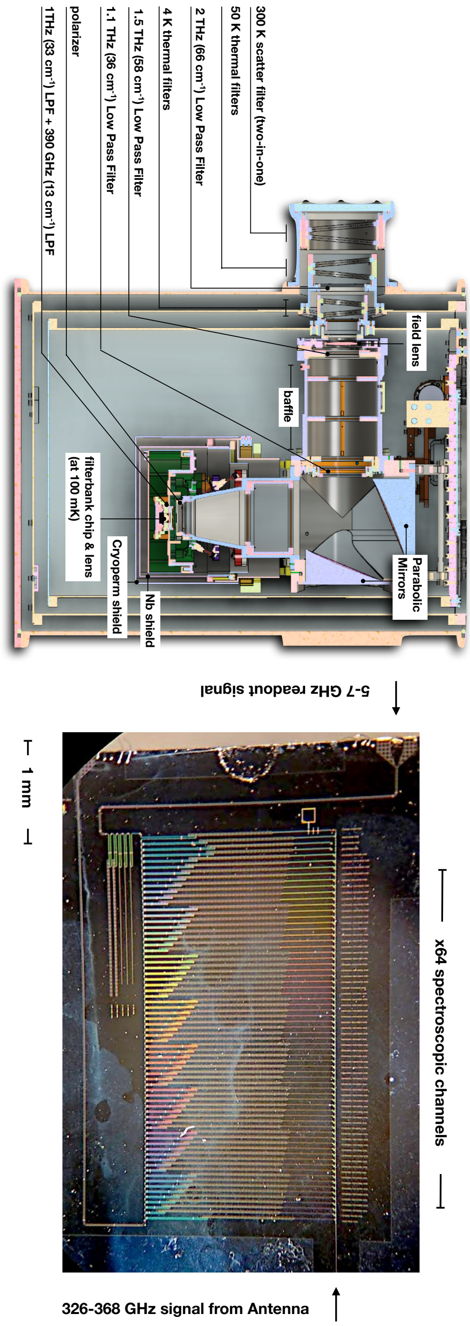
The redshift distribution and physical evolution of dusty star forming galaxies is an essential ingredient to the history of cosmic star formation and galaxy evolution, yet large redshift surveys of such ' submillimeter galaxies ' have been hampered by the narrow bandwidth of widely-used heterodyne spectrometers in the millimeter-submillimeter band. DESHIMA (Deep Spectroscopic High-redshift Mapper) is a project to develop a multi-pixel on-chip filterbank spectrometer with an instantaneous bandwidth of 240-720 GHz and a frequency resolution of $F/\Delta F = 500$, using kinetic inductance detectors. Here we report on the recent development of a 326-368 GHz, single pixel prototype DESHIMA system for the first field test on the ASTE (Atacama Submillimeter Telescope Experiment). Located near the ALMA site in Chile, the 10 m single dish ASTE telescope combines excellent atmospheric transmission and sufficient collecting area for detecting even high-redshift galaxies. In the conference, we will report on the development of the DESHIMA-on-ASTE system, consisting of the filterbank chip, the ADR-based 100 mK cryostat, the optical chain, readout electronics, control software, calibration strategy, and operation plans.

Figure: (Left) Cross section of the DESHIMA cryostat. (Right) Micrograph of the prototype superconducting on-chip spectrometer. With 64 channels, the filterbank covers the frequency range of 326-368 GHz, in which the atmospheric transparency is high.

category : Applications



300 K scatter filter (two-in-one)
50 K thermal filters
2 THz (66 cm-1) Low Pass Filter
4 K thermal filters
1.5 THz (58 cm-1) Low Pass Filter
1.1 THz (36 cm-1) Low Pass Filter
polarizer
1THz (33 cm-1) LPF + 390 GHz (13 cm-1) LPF
field lens
baffle
Parabolic Mirrors
filterbank chip & lens (at 100 mK)
Cryoperm shield
Nb shield
5-7 GHz readout signal
x64 spectroscopic channels
1 mm
326-368 GHz signal from Antenna

O-15 The NIKA2 instrument at 30-m IRAM telescope: performance and results

Andrea Catalano[1], NIKA Core Team[2]
[1]CNRS, [2]No affiliation

The New IRAM KID Array 2 (NIKA 2) is a dual-band camera operating with three frequency multiplexed kilo-pixels arrays of Lumped Element Kinetic Inductance Detectors (LEKID) cooled at 100 mK. NIKA is designed to observe the intensity and polarisation of the sky at 250 and 150 GHz from the IRAM 30 m telescope. It represents one step further with respect the NIKA pathfinder instrument which has already shown state-of-the-art detectors and photometric performance. NIKA 2 is an IRAM resident instrument for studies of the Intra Cluster Medium from intermediate to distant clusters and so for the follow-up of Planck satellite detected clusters, high redshift sources and quasars, early stages of star formation and nearby galaxies emission. We present an overview of the instrument performance and the first scientific results.

category : Applications

O-16 Sensitivity, Dynamic Range, and Multiplexing Requirements of FIR Detectors for the Origins Space Telescope (OST)

Johannes G Staguhn[1]

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The Origins Space Telescope is the mission concept for the Far-Infrared Surveyor, one of the four science and technology definition studies to be submitted by NASA Headquarters to the 2020 Astronomy and Astrophysics Decadal survey. The observatory will provide orders of magnitude improvements in sensitivity over prior missions, in particular for spectroscopy, enabling breakthrough science across astrophysics. The observatory will cover a wavelength range between 6 μ m and 600 μ m in order to enable the study of the formation of proto-planetary disks, detection of bio-signatures from extra-solar planet's atmospheres, characterization of the first galaxies in the universe, and many more.

Key technologies enabling the mission include large cryogenic optics (the 10 m telescope will be cooled to 4 K) and the associated cryo-coolers, plus sub-Kelvin coolers for the science instruments using superconducting detectors for the incoherent far-infrared imager/polarimeter and spectrometers. The five instruments that are currently studied are two imaging far-infrared spectrometers using incoherent detectors, providing up to R $\sim 10^5$ spectral resolution, one far-infrared heterodyne instrument for even higher spectral resolving powers, one far-infrared continuum imager and polarimeter, plus a mid-infrared coronograph with imaging and spectroscopy mode. In particular, current superconducting detector technologies will need to be matured significantly in terms of sensitivity, dynamic range and multiplexability while the warm readout electronics will need to operate within the low power constraints provided by the observatory.

After a brief summary of the anticipated OST scientific capabilities, I will provide an overview of the technological developments needed for the far-infrared instruments with focus on the detectors and readout.

category : Applications

O-17 The Athena X-ray Integral Field Unit (X-IFU)

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The X-ray Integral Field Unit (X-IFU) on board the Advanced Telescope for High-ENergy Astrophysics (Athena) will provide spatially resolved high-resolution X-ray spectroscopy from 0.2 to 12 keV, with 5 arcsec pixels over a field of view of 5 arcmin equivalent diameter and a spectral resolution of 2.5 eV up to 7 keV. We will first present how the core scientific objectives of Athena drive the main performance parameters of the X-IFU, namely the spectral resolution, the field of view, the effective area, the count rate capabilities, and the instrumental background. Then we will describe how the performance can be met using a 3840 microcalorimeters array operated at 50 mK and present the key system issues driving the design of the instrument.

The X-IFU will be provided by an international consortium led by France, The Netherlands and Italy, with further ESA member state contributions from Belgium, Finland, Germany, Poland, Spain, Switzerland and two international partners from the United States and Japan.

category : Applications

O-18 Design and status of TIME, a mm-wavelength spectrometer array for [CII] intensity mapping

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TIME is a mm-wavelength spectrometer array that will map fluctuations of the 157.7 μ m emission line of singly ionized carbon ([CII]) during the Epoch of Reionization (redshift z 5 to 9). A 14 x 0.43 arcmin instantaneous field of view corresponding to 16 x 1 spatial pixels is sampled by two banks single-polarization grating spectrometers (32 spectrometers total). Each spectrometer consists of an input feedhorn, a parallel-plate waveguide, and a curved diffraction grating (similar to that used in Z-Spec) with resolving power R = 170 and spectral range 183 to 326 GHz. The output arc of each spectrometer is sampled at R 100 with 60 TES bolometers, of which 16 on the band edges are used for atmospheric monitoring and removal. The TESs (1920 total) are designed in close-packed buttable arrays of 8 spatial x 12 spectral (high frequency) or 8 spatial x 8 spectral (low frequency) pixels, and will be operated from a 250 mK base temperature with a photon-noise-dominated NEP 1e-17 W/sqrt(Hz). Each bolometer consists of gold absorber on a 3 x 3 mm silicon nitride micro-mesh suspended near the corners by 1 x 1 x 500 um silicon nitride legs. Absorbed radiation is thermally coupled to elemental Al and Ti TESs connected in series (Al is used in higher-loading lab conditions). Detector readout uses SQUIDs and time-domain multiplexing.

This talk will briefly motivate the science objectives of TIME and will detail the design and status of the TIME instrument. The optical and mechanical design of the spectrometer and detector arrays will be highlighted, including results from laboratory tests of prototypes. Additionally, the detector magnetic shielding design and the operation of a pair of 3He sorption fridges for continuous 350 mK cooling will be discussed.

category : Applications

MKIDS 3

O-19 Modelling the Performance of Single-Photon Counting Kinetic Inductance Detectors

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A principal goal of the next generation of space-based astronomy will be dedicated to the characterisation of extra-solar planets (exoplanets). Of the 1000s discovered only a handful have been characterised beyond their size and mass, thus there is increasing interest in new exoplanet missions aiming to carry out spectroscopy on very low intensity light and shallow transit light curves. Energy-resolving, single-photon counting detectors provide an elegant solution for carrying out spectroscopy without the need for gratings, prisms or combinations thereof.

The Lumped Element Kinetic Inductance Detector (LEKID) is a proven technology capable of counting and energy-resolving single-photon events at optical and near infra-red wavelengths. Furthermore, LEKIDs can be multiplexed into large format arrays with over a 1000 detectors being read out on a single pair of coaxial cables. The combination of exquisite sensitivity and high multiplexing ratios makes spectroscopic imaging possible, using a LEKID focal plane and simple imaging optics.

While sensitivities yielding noise equivalent powers (NEPs) of order $10^{-19}\frac{W}{Hz^{-\frac{1}{2}}}$ have been demonstrated in arrays of order 10^3 pixels at sub-mm wavelengths, the corresponding theoretical energy resolution due to single-photon events has yet to be met. Using conventional superconductor theory we discuss and validate a model that describes the energy-resolving performance of an Aluminum LEKID to single-photon absorption events. While Aluminium is not the optimum material to use in single-photon counting applications, this material is well understood and is used to understand the underlying device physics of these detectors. We conclude by discussing how we can apply the steps required to adapt this model for use with more suitable materials; such as Titanium Nitride or bi-layer superconducting films.

category : Sensor Physics & Developments

O-20 Ultrasensitive kilo-pixel imaging array of photon noise limited Kinetic Inductance Detectors over an octave of bandwidth for THz astronomy

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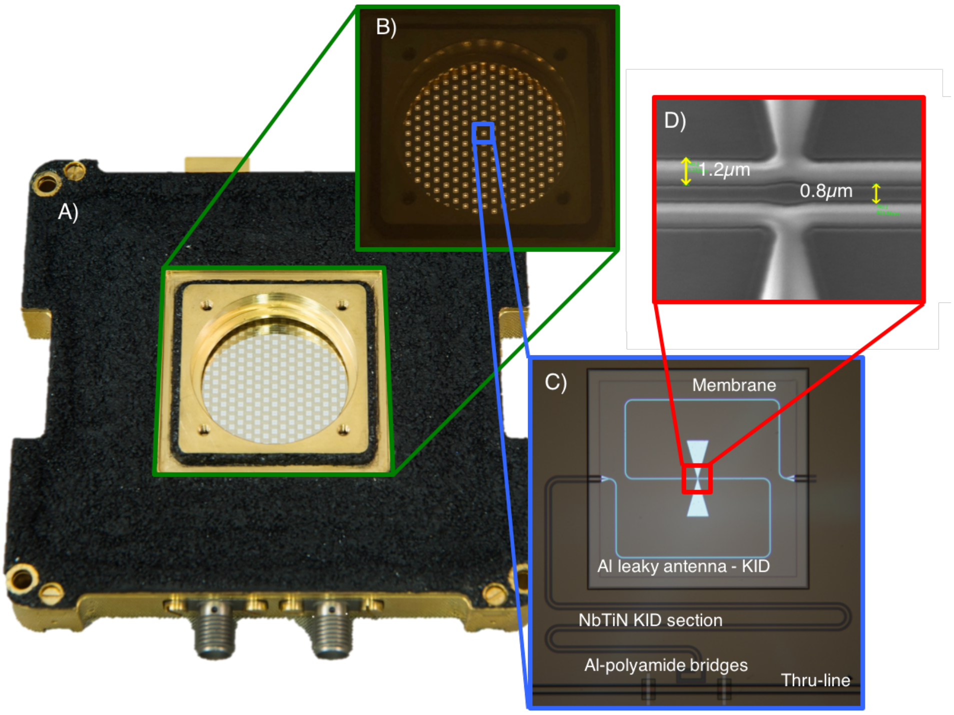
We present the development of an ultra-sensitive kilo-pixel imaging array of ultra-wide bandwidth, background limited kinetic inductance detectors (KIDs) suitable for THz astronomy applications to be used in space based observatories. The array consists of 989 KIDs, in which the THz radiation is coupled via a leaky lens antenna, covering the frequency range between 1.4 and 2.8 THz. The single pixel performance is fully characterised using a representative small array in terms of sensitivity, optical efficiency, beam pattern and frequency response, matching very well its expected performance. These results have been submitted to Applied Physics Letters. The kilo-pixel array is characterised electrically, with a very good overall performance. It has a yield larger than 90% and an averaged noise-equivalent power lower than 3x10^{-19} W/Hz$^{1/2}$. The expected dead time due cosmic ray interactions, when operated in an L2 or a similar far-Earth orbit, is found to be lower than 0.5%. The figure shows an ultrasensitive kilo-pixel imaging array: A) Photograph of the kilo-pixel array in its holder; B) Back illuminated optical image of the centre area of the array. The light goes through the membrane, where both the antenna and the Al section of the KID are fabricated; C) Back and front illuminated optical image of a single pixel. The bright square indicates the area of the membrane, where illumination from the chip backside brightens the image. The NbTiN section of the KID and the transmission line are fabricated on the solid substrate; D) SEM image of the centre of the antenna where the narrow Al line can be resolved. This work demonstrates that KID technology can provide mature enough technology to be considered for future space based observatories.



category : Sensor Physics & Developments

O-21 Development of Multi-Chroic MKIDs for Next-Generation CMB Polarization Studies

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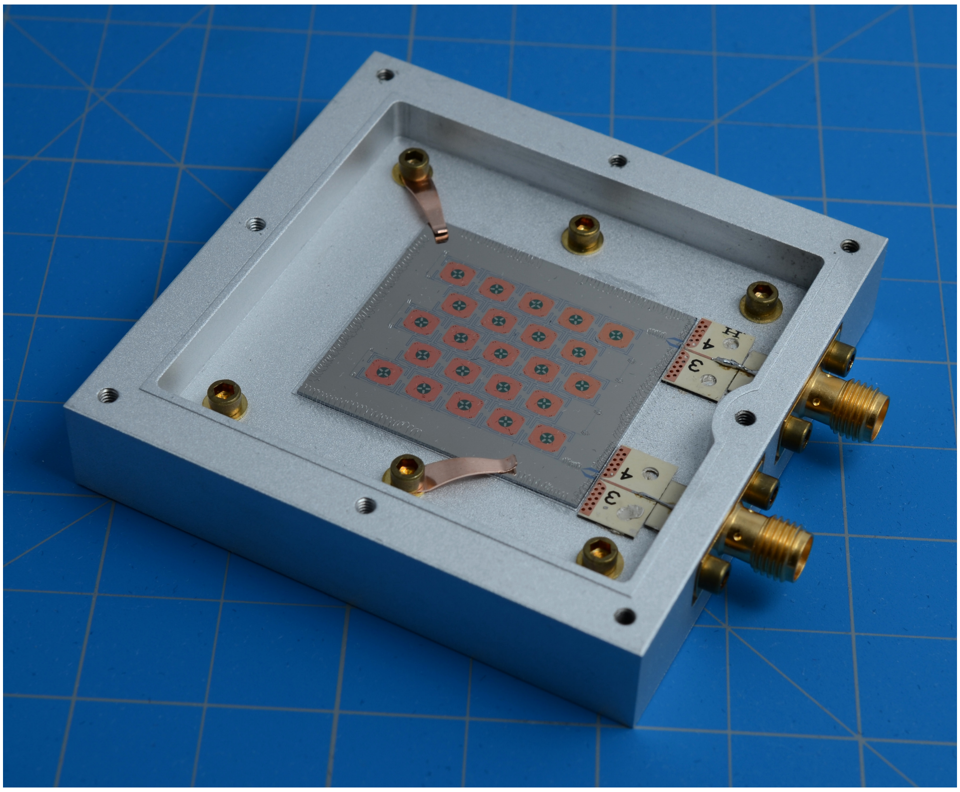
We report on the status of an ongoing effort to develop 23-element prototype arrays of horn-coupled, polarization-sensitive microwave kinetic inductance detectors (MKIDs) that are each sensitive to two spectral bands between 130 and 280 GHz. These multi-chroic MKID arrays are tailored for the next-generation, large-detector-count experiments that are being designed to simultaneously characterize the polarization properties of both the cosmic microwave background (CMB) and Galactic dust emission. Our horn-coupled device design builds from the successful transition edge sensor (TES) bolometer architecture that is now being used in Advanced ACTPol. Our research program has focused on (i) developing and testing the required microstrip-to-CPW coupling between the on-chip polarimeter circuit and the CPW MKID, (ii) transferring the design to a SOI-based construction to minimize TLS noise, and (iii) demonstrating that the performance of theses arrays is competitive with arrays of similar TES-based devices. We present our device design and show results from laboratory-based characterization measurements of our first array. The 23-element prototype arrays we are building contain 92 MKIDs, so we are currently demonstrating a multiplexing factor of 92. However, the bandwidth of our ROACH-2-based readout system should ultimately allow multiplexing factors of approximately 1000 or more, so as part of this program we are pushing forward the multiplexing capabilities that will be needed in next-generation experiments. Finally, we will discuss our plans for scaling up our prototype arrays. The prototype array design in hand is directly scalable to 331 elements, so for example, seven of these future arrays could be tiled into a 9268 detector array.



category : Sensor Physics & Developments

O-22 Millimeter-Wave Polarimeters Using Kinetic Inductance Detectors for TolTEC and Beyond

Jason Edward Austermann[1], Jiansong Gao[2], Johannes Hubmayr[3], Michael Vissers[4], James Beall[5], Bradley Dober[6], Shannon Duff[7], Weijie Guo[8], Gene Hilton[9], Christopher McKenney[10], Joel Ullom[11], Jeff Van Lanen[12]

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Microwave Kinetic Inductance Detectors (MKIDs) provide a compelling path forward to the large-format polarimeter, imaging, and spectrometer arrays needed for next-generation experiments in millimeter-wave cosmology and astronomy. In this presentation, we describe the development and lab measurement of feedhorn-coupled, background-limited MKID polarimeters for the TolTEC millimeter-wave imager being constructed for the 50-meter Large Millimeter Telescope (LMT) and beginning observations in late 2018. TolTEC will comprise over 6,000 polarization sensitive MKIDs and will represent the first MKIDs fabricated and deployed on monolithic 150 mm diameter silicon wafers – a critical development towards future large-scale experiments with O(10^5) detectors. TolTEC will operate in observational bands of 1.1, 1.4, and 2.1 mm and will use dichroics to define a physically independent focal plane for each passband, thus allowing the polarimeters to use simple, direct-absorption inductive structures that are impedance matched to incoming radiation. This work is part of a larger program headed by NIST-Boulder in the development of MKID-based detector technologies for use at a wide range of photon energies, from millimeter wavelengths to X-rays. We describe the detailed pixel design and the results of a large array of simulations used to optimize the polarimeter performance. We present measurements of prototype devices and compare the measured optical performance to the simulated predictions of absorption and polarization efficiency. We also present characterization of the detector noise performance, bandpass response, responsivity, and properties of the superconducting materials used in these devices. Additionally, we discuss our fabrication processes and the resulting uniformity of material properties and detector characteristics across 150 mm diameter wafers.

category : Sensor Physics & Developments

TES 1

O-23 Quantitatively characterizing sources of energy resolution degradation in TES microcalorimeters AC-biased at MHz frequencies.

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MHz frequency-domain SQUID multiplexing (FDM) is potentially an attractive readout architecture to increase the multiplexing factor and reduce wiring complexity to large arrays of TES microcalorimeters. This readout concept, currently baselined as the readout for the ATEHNA XIFU, requires the TESs to be AC-biased. However, multiple groups have reported that devices tested under AC bias exhibit poorer energy resolution than similar sensors under DC bias. Currently, it is not thoroughly understood why the energy resolution degrades under AC bias, and whether this observed degradation is inherent to the technique. In this presentation, we describe two factors that are believed to contribute to the energy resolution degradation: AC loss in the TES 's superconducting state and AC weak-link Josephson Junction effects. We present results from a recent study of the importance of these two effects to device resolution and describe efforts to mitigate them.

The dissipation observed in the superconducting state of the TES under AC bias is thought to reduce alpha (the logarithmic derivative of the TES resistance with respect to temperature) and therefore degrade energy resolution. It has been suggested that this superconducting loss is caused by inductive coupling between the bias leads and normal metal structures on the TES. The data so far is qualitatively consistent with this hypothesis, but the complex TES designs under consideration for ATHENA XIFU are difficult to model and compare quantitatively with the theory. We have fabricated a variety of simple devices to quantitatively test this hypothesis without the need for numerical models. In addition, we explore some proposed routes towards reducing the AC superconducting loss in TES devices: using higher resistivity materials for the normal metal structures, positioning the leads further away from the TES, and adjusting the geometry of the normal metal structures.

AC weak link effects arising from the interaction between the TES and the higher Tc leads create non-linear features in the current-voltage relation of the TES. This non-linear structure makes pulse shapes difficult to analyze and may be an additional source of noise. A TES is in the two-fluid/phase-slip line regime when its transition is dominated by physics in the TES itself and not interaction with the leads. Because the TES is operated near its critical temperature, long range weak link effects may persist even as the TES length is increased beyond the geometries that have been measured so far. To explore the regime of negligible weak link effects, we have characterized TESs with normal metal structures designed to completely decouple the TES from the leads. We will discuss whether these devices exhibit the undesirable non-linearities observed in strongly weak link devices.

While previous studies of TES calorimeter performance under MHz frequency AC bias have used MHz FDM readout, here we read out the TESs with high-bandwidth microwave SQUID readout circuits.?This will allow us to separate for the first time the intrinsic performance of the TES under AC bias from any effects due to the MHz FDM readout.

category : Sensor Physics & Developments

O-24 Josephson effects in frequency domain multiplexed TES microcalorimeters and bolometers

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Frequency-division multiplexing (FDM) is the baseline readout system for large array of superconducting transition-edge sensors (TES's) under development for the X-ray and infrared instruments like X-IFU (Athena) and SAFARI (SPICA), respectively. In this multiplexing scheme, the sensors are AC biased at different frequencies from 1 to 5 MHz and operate as amplitude modulator. Weak superconductivity is responsible of the complex TES resistive transition, experimentally explored in the very details so far, both with DC and AC biased read-out schemes. In this paper we will review the current status of our understanding of the physics of the TES's and their interaction with the FDM circuit. In the past, we have shown that an AC biased TES can be described by non-linear, first order differential equations derived from the resistively shunted junction model. The analytical solution of these equations have been used to describe the experimental observations in TiAu TES bolometers biased at MHz frequencies. We have recently shown from the numerical solutions of the same equations that we can obtain a qualitative explanation of the phenomena observed in the I-V characteristic of AC biased TES microcalorimeters.

We are studying the behavior of the TES non-linear impedance, along the superconducting transition, for several detector families, namely: high normal resistance TiAu TES bolometers, low normal resistance MoAu TES microcalorimeters and high normal resistance TiAu TES microcalorimeters. In this paper we will report on the progress of this comparison. In particular we will focus on the influence of the FDM read-out circuit on the single pixel impedance.

category : Sensor Physics & Developments

O-25 Development of TES microcalorimeters for 10-50 keV using a gold absorber

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TES microcalorimeter are high-energy-resolution spectrometers not only in soft X-ray energy range (0.3-10 keV), but also in hard X- ray energy range (up to $\sim$ 100 keV). We have developed TES microcalorimeters with gold absorber as a soft X-ray spectrometer for a scanning transmission electron microscope to determine the emission lines from most of low-Z atoms (H.Muramatsu et al., 2016). On the other hand, in the energy range of 10 to 50 keV there are some K lines of high Z atoms and some nuclear transition lines of interest (K.Maehata et al., 2015). TES microcalorimeters can be useful to resolve fine structure of lines and to detect weak lines in this range. We studied whether we can simply extend our microcalorimeters to this energy range. We first studied the energy resolution in 10 to 50 keV energy range using the present detectors. Although the detection efficiency is low, it may not be a problem in some of applications. The small heat capacity of soft X-ray TES has an advantage in intrinsic energy resolution, i.e. energy resolution at 0 eV. However, the energy resolution will be degraded by two reasons; energy-dependent of pulse shape and non-linear response in energy to pulse height. We can avoid those effect by using larger heat capacity device. We compered the performances of a TES microcalorimeter (A) with 0.6 pJ/K heat capacity whose design value of intrinsic energy resolution is 4.3 eV, and a TES microcalorimeter (B) with 3.7 pJ/K heat capacity whose intrinsic energy resolution is 14 eV. As expected, device (A) strongly suffered from signal saturation and nonlinear response above $\sim$ 10 keV, while device (B) did not. After correcting for the pulse saturation and non- linear response, we obtained 16 eV and 25 eV energy resolutions at 18 keV and 26 keV for device (A), while it was constant at 22 eV for device (B). We consider that it is worth using TES microcalorimeters in the energy rage where it starts to saturates, depending on the application and the energy range.

category : Sensor Physics & Developments

TES 2/Bolometer

O-26 Noise equivalent power and energy resolution of transition-edge sensors with complex thermal models

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Sometimes transition-edge sensors (TES) have thermal circuits with more than one heat capacity, I call those thermal models complex. In previous publications, I have discussed analytical equations and numerical examples for the complex impedance, responsivity and noise of such devices [1]. Here, I continue that work and calculate the noise equivalent power and energy resolution for such complex devices, arguably the most interesting parameters for detectors. The implications of the differences of the models are discussed, concentrating on the following questions: How do we get optimal performance out of such devices? Can there be any benefits of complex thermal circuits? The focus will be kept mostly on the " simplest complex " models with two heat capacities.

[1] I. J. Maasilta, AIP Advances 2, 042110 (2012)

category : Sensor Physics & Developments

O-27 Exploring the effects of size and geometry of normal metal features on the transition shapes and performance of transition-edge sensor microcalorimeters

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The spectral resolution of transition-edge sensor (TES) microcalorimeters is very sensitive to the specific dependencies of the resistance R in the superconducting transition on the current I, magnetic field B, and temperature T. In particular, it has been shown that transitions that are very steep in (R,T) space lead to a significant noise term, in excess of conventional expectations. This so-called ‘ unexplained noise ’ is known to be reduced by the addition of normal metal stripes across the TES perpendicular to the direction of current flow. These normal metal stripes have been shown to drastically alter the oscillatory patterns seen in measurements of the critical current as a function of magnetic field. However, there are many remaining questions about the exact impact of the stripes on current distributions within the TES, the oscillatory field pattern and, therefore, the shape of the R(I, B, T) surface.

Through measurements of the resistance under DC bias of TES devices of various sizes, with different stripe patterns and dimensions, we will discuss how these stripes can affect the R(I, B, T) surface. In addition, using measurements and analysis of the noise spectra of various devices we will present how these changes to the stripe pattern may affect the performance of the TES. In particular, we will discuss strategies to reduce the presence of localized discontinuities in the derivative of R, associated with increased noise, while maintaining the globally low levels of unexplained noise currently achieved with conventional metal stripe patterns. Implementing these strategies is a path towards producing large arrays with highly uniform transitions and high spectral resolution. These large uniform arrays will be required for future x-ray astronomy applications, such as the X-IFU on ATHENA.

category : Sensor Physics & Developments

O-28 Dependence of transition width on current and critical current in transition-edge sensors

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In transition-edge sensor (TES) X-ray detectors we observe that as we increase the thermal conductance (G) to the heat bath, α (T/R ∂R/∂T at constant I) decreases, indicating that the resistive transition has broadened. Consequently, the energy resolution for single-photon detection worsens. Using a two-fluid model for the superconducting-to-normal transition and the Ginsburg-Landau expression for $I_c(T)$ in a thin film, we show that α can be written as a function of $(I_0/I_{c0})^{2/3}$, where I_0 is the TES bias current, and I_{c0} is the film 's critical current at zero temperature. Therefore, the broadening observed as G increases can be attributed to the larger current (I_0) necessary to bias the TES at a given point in the transition. To recover a sharper transition, we fabricated rectangular devices with varying numbers of normal-metal bars while keeping G constant. Increasing the normal resistance reduces I_0, and increasing the spacing between normal-metal bars increases I_{c0}. By independently varying both I_0 and I_{c0}, we show that it is possible to manipulate the transition width and G independently, thus enabling fast sensors with excellent energy resolution. We also show that the effects on the transition shape of commonly used normal-metal features such as bars across the TES bilayer can be well predicted from their effect on I_{c0}.

Using this new theoretical understanding, we have demonstrated sensors with thermal time constants below 100 μs while maintaining 1.05 eV resolution at 1.25 keV. We will present characterization data, including fits to noise and complex impedance, that predict resolution of 0.7 eV when operating in the linear regime below 1 keV. This level of performance is required for the TES array for the recently approved soft x-ray microcalorimeter spectrometer for the Linac Coherent Light Source upgrade (LCLS-II) x-ray free electron laser at SLAC National Accelerator Laboratory. This instrument, being jointly developed by SLAC and Stanford University, aims to maintain approximately 1 eV resolution while operating with photon fluxes generated from the 10 kHz repetition rate of LCLS-II. Building on these results, we will discuss techniques for designing sensors that optimize resolution and throughput collecting at a given photon rate.

category : Sensor Physics & Developments

O-29 Characterization of Mid-Frequency Arrays for Advanced ACTPol

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The Advanced ACTPol upgrade on the Atacama Cosmology Telescope aims to improve the measurement of the cosmic microwave background polarization anisotropies, using four new dicroic detector arrays fabricated on 150 mm Si wafers. These bolometric cameras use AlMn transition edge sensors coupled to feedhorn with orthomode transducers. The first camera, sensitive to both 150 GHz and 230 GHz, has been deployed and in operation. Here we present the lab characterization of the dark thermal parameters and optical efficiencies on the two newest fielded arrays, each sensitive to both 90 GHz and 150 GHz. The level of systematic uncertainties is evaluated to assess the parameter uniformity across each array. Lastly, we show their initial optical performances in the field.

category : Sensor Physics & Developments

O-30 Characterization of Si-membrane TES bolometer arrays for the HIRMES instrument

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The High Resolution Mid-Infrared Spectrometer (HIRMES) instrument will fly onboard NASA's airborne Stratospheric Observatory for Infrared Astronomy (SOFIA) in 2019. HIRMES will provide astronomers with a unique observing window (25-122 μm) for exploring the evolution of protoplanetary disks into young solar systems, and the composition of our Solar System. There are two focal plane detector arrays for the instrument: a high-resolution ($\frac{\lambda}{\Delta\lambda}$ = 100,000) 8×16 detector array, with a target noise-equivalent power, NEP $\leq 3 \times 10^{-18}$ $W/\sqrt{Hz}$; and a low-resolution ($\frac{\lambda}{\Delta\lambda}$ = 2,000-19,000) 16×64 detector array with a target NEP $\leq 2 \times 10^{-17} W/\sqrt{Hz}$. The detectors for both of these arrays are superconducting Mo/Au bilayer transition edge sensor (TES) bolometers on thin suspended single-crystal silicon membranes. Here we present our characterization results for the detectors in both arrays, including measurements of thermal conductance with comparison to phonon transport models, saturation power, noise, and array uniformity.

category : Sensor Physics & Developments

O-31 Characterization of optical transition-edge sensors

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Optical transition edge sensor (TES) detectors which can resolve an energy of a single optical photon have proven desirable in quantum information and biological imaging. We have developed a gold-titanium bilayer TES embedded in cavity structure designed to detect photons in a few eV range and lower than this. The TES is formed on a mirror, covered by an anti-reflection coating. The detector has achieved high detection efficiency, nearly 100 % at 1,550 nm (0.8 eV), and an energy resolution of 0.2 eV for 0.8-eV photons. Higher energy resolution is required for an application of the TES in multicolor fluorescence microscopy. To improve the energy resolution, understanding the physics of the optical TES is necessary. Because of unique features of the optical TES, the underlying physics may be different from that of TESes designed to be used in other applications. The optical TES is characterized by: (1) its small size (typically 5 to 10 μm) to be sensitive to the low-energy photons and (2) a fast response time ($\tau \sim 200$ ns) determined by the heat capacity and weak thermal coupling between electrons and phonons in the detector. Measurements of a complex impedance (response to a small voltage signal) of the TES can reveal a thermal model of the TES and provides an expected energy resolution based on the measured parameters of the detectors. We have measured the complex impedance up to 20 MHz to examine the fast detector response. We will show the results and discuss the properties of the TES.

category : Sensor Physics & Developments

O-32 Eliminating anomalous low energy tails in hard X-ray TES microcalorimeters using electroplated bismuth

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The theoretical energy resolution achievable with a transition edge sensor (TES) microcalorimeter is proportional to the square root of heat capacity. Since the efficient detection of hard X-rays generally requires thick absorbers, high-Z and low heat capacity materials are desirable. Bismuth (Bi) is one such material for X-ray TES absorbers. In particular, evaporated Bi has been extensively used for X-ray TES spectrometers. However, many TESs with evaporated Bi absorbers exhibit low energy tails in their spectral response, which complicates X-ray line shape analysis and degrades the detectability of weak emission lines at lower energies relative to stronger emission lines. While the precise mechanism is uncertain, it is clear that thermalization effects in the evaporated Bi are responsible for the low energy tailing. In order to eliminate the tails from Bi absorbers, we have developed a Bi electroplating process. In order to facilitate the comparison, we fabricated TESs with absorbers composed of gold (Au), Au with evaporated Bi and Au with electroplated Bi from the same wafer. Here we present heat capacity and energy spectra measurements for these devices. The evaporated and electroplated Bi devices exhibit comparable heat capacities and no measurable addition to the total heat capacity budget with respect to the devices with Au only absorbers. Yet, our results confirm the presence of a low energy tail in the evaporated Bi devices, while both the Au and electroplated Bi devices show little evidence of such tails. This work definitively demonstrates the superiority of electroplated Bi over evaporated Bi. Microscopy on the Bi films shows that the grain size of electroplated Bi films is significantly larger than for evaporated films, which may contribute to improved x-ray thermalization.

category : Sensor Physics & Developments

O-33 A Static and Dynamic Physical Model for Deposition of Energy via Cosmic Rays into Sub-Kelvin Bolometric Detectors

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Cosmology space missions are particularly sensitive to systematic effects resulting from interaction between cosmic rays and their highly sensitive bolometric detectors. This cosmic ray signal is superimposed to the signal of interest resulting from CMB mapping and from the much larger foreground components in the sky. To remove this signal, one must first understand the deposition of energy into these detectors. Since Planck, empirical study, resulting from laboratory measurements on spare bolometers, has been made to remove the cosmic ray signal, or ' glitch ', from science data. However, a complete physical model for the energy deposition by cosmic rays into these detectors has remained unrealised. Using a well-known NTD germanium bolometer from the ground-based DIABOLO experiment, we simulate the effect of cosmic rays using a radioactive source in the laboratory, and develop in parallel a physically-motivated model which reproduces the signal of a cosmic ray ' glitch '. Through analysis of experimental data, we find that the glitch signal shape is a function of incoming particle position and angle, as well as the incoming particle energy. We report also on nonlinear effects in the detector and their origin, as well as their reproducibility in a dynamic physical model of the bolometer. Once such a physical model is established, we intend to apply it to new generations of detectors in candidates for future CMB missions such as PIXIE and LiteBIRD.

category : Sensor Physics & Developments

Application - Dark matter, neutrino and related physics 1

O-34 New-generation cryogenic detectors for dark matter and coherent neutrino scattering

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Cryogenic particle detectors have been constantly improved over the last decades and nowadays find broad application in rare-event searches. In recent years, there was significant progress in lowering the energy threshold for nuclear recoils to the 100eV-regime and below. These detectors enable new experimental approaches, in particular the detection of sub-GeV dark matter particles and coherent neutrino-nucleus scattering. In the talk, I discuss the current and next-generation detector technology of cryogenic dark matter experiments and review recent results. Furthermore, I would like to point out the high potential of cryogenic devices for a discovery of coherent neutrino-nucleus scattering.

category : Applications

O-35 Using defect creation to discriminate dark matter signal in phonon-mediated detectors

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Rare event experiments strive to develop detector technologies with the potential to discriminate signals from the radioactive backgrounds to significantly boost sensitivity. Experiments seeking to detect dark matter or Coherent Elastic Neutrino Nucleus Scattering (CENNS) are particularly interested in discriminating nuclear recoils originating from signal and electron recoils due to the radioactive background. So far, dual measurement methods such as those developed by the Cryogenic Dark Matter Search (CDMS) or the Cryogenic Rare Event Search with Superconducting Thermometers (CRESST) have been the dominant techniques to provide this discrimination. Those methods generally fail at very low energies, wherein second measurement fundamental noise prevents experiments from reaching the required thresholds. We examine commonly used material response to low energy nuclear recoils using numerical simulations of their respective classical interatomic potentials. These simulations, alongside more precise density functional theory simulations and experiments, predict a nonisotropic, nonlinear energy loss that never produces phonons due to the nonzero energy required to form defects. Experiments such as the Cryogenic Dark Matter Search (CDMS) and the Mitchell Institute Neutrino Experiment at Reactor (MINER) are actively developing detectors to reach the resolutions necessary to observe this effect. We argue that defect creation from nuclear recoil interactions distorts the expected spectra in such a way that, statistically, one can discriminate nuclear recoils from electron recoils with only phonon measurements, especially in the mass range below 10 GeV/c^2.

category : Applications

O-36 The CUORE and CUORE 0 experiments at LNGS: detector performance and physics results

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The Cryogenic Underground Observatory for Rare Events (CUORE) is the first bolometric experiment searching for neutrinoless double beta decay that has been able to reach the 1-ton scale. The detector consists of an array of 988 TeO2 crystals arranged in a cylindrical compact structure of 19 towers. The construction of the experiment and, in particular, the installation of all towers in the cryostat was completed in August 2016 and commissioning started in fall 2016. The experiment has just completed the pre-operation phase and data taking is commencing. In this talk we will present the achievements of the CUORE construction phase and the performance of the detector during pre-operation. Special emphasis will be given on the operation of the CUORE large mass macrobolometers, their characterization and the performance of the low noise readout system. Physics results from CUORE-0, the first CUORE-style tower operated in 2013-2015, will also be updated.

IMPORTANT NOTE: The Abstract is submitted by the Speakers Board of the CUORE Collaboration on behalf of the Collaboration. The speaker will be selected as soon as the talk is confirmed.

category : Applications

O-37 Status and Prospects of the EDELWEISS-III Direct WIMP Search Experiment

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The EDELWEISS collaboration is performing a direct search for WIMP dark matter using an array of up to twenty-four 860g cryogenic germanium detectors equipped with a full charge and thermal signal readout. The experiment is located in the ultra-low radioactivity background of the Modane underground laboratory, in the French-Italian Frejus tunnel. We present the analysis of data obtained in extended data taking periods. WIMP limits, background rejection factors and measurements of cosmogenic activation are used to assess the performance of the third generation of EDELWEISS detectors in view of the search for WIMPs in the mass range from 1 to 20 GeV/c2. The developments in progress to pursue this goal in the coming years are also presented.

category : Applications

O-38 XMASS; A Dark Matter Search Experiment with Liquid Xenon

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Recently many dark matter direct search experiments have been conducted. Among them, the detectors with noble liquids, especially liquid Xe detectors, gave the best limits on the dark matter-nucleus cross section so far. First, I would like to review the principle of direct searches with noble liquid technologies. Then, I will explain the recent results of XMASS-I. XMASS is a multi-purpose experiment using a single-phase liquid xenon technology located underground at Kamioka Observatory in Japan. XMASS-I detector aims at direct detection of dark matter particles with 832 kg of liquid xenon. The key concept of XMASS is to use liquid xenon itself for shielding. The detector has been performed stable operation over 3 years with a very high light yield of 15 photoelectron/keVee. A new result by annual modulation with 1 keVee energy threshold will be shown with 800 live days x 832 kg exposure in total.

category : Applications

Application - Dark matter, neutrino and related physics 2

O-39 Low temperature detectors for neutrinoless double beta decay experiments

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Search for neutrinoless double beta decay (0 ν β β) is a key experiment to answer unresolved properties of neutrino. Experimental observation of 0 ν β β will provide a direct answer to the particle type of neutrino (i.e., the Dirac-or-Majorana question), validate lepton number violation in the field of particle physics, and confine the absolute mass scale of neutrino. A number of large scale experiments have been searching, and are planned to search for 0 ν β β . Low temperature detectors (LTDs) based on thermal calorimetric measurement have been playing a major role in the effort to probe the rare event. In the presentation, current 0 ν β β search experiments are introduced with their main detection technologies. Advantages and challenges using LTD technologies are discussed in comparison with other technologies used for 0 ν β β . In this review, we summarize past, present and future experiments of LTDs to search for 0 ν β β .

category : Applications

O-40 Search for hidden photon cold dark matter using radio telescopes

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Hidden photon (HP) is a candidate for dark matter (DM). DM plays an essential role in forming galaxies in Cosmology. Most popular candidate of DM is weakly interactive massive particles (WIMPs). Many experiments have attempted to detect signal from an interaction between WIMPs and atomic nuclei. But there is no evidence for the presence of WIMP. We focus on alternative candidates of DM, hidden photon cold dark matter (HPCDM). HP is a gauge boson which arises by introducing extra U(1) gauge field. HPs and ordinary photons have kinetic mixing. As a result, HPs induce emission of ordinary photons at a reflecting surface. According to Snell's law, the induced photons are emitted almost perpendicularly to the mirror. The direction is indifferent of the incoming direction of HPs because the velocity is small for CDM ($v/c \sim 10^{-3}$). Some groups have attempted to detect the HPCDM to measure light from spherical mirrors or combination of plane mirrors and focusing systems.

We suggest a novel method of searching for HPCDM using radio telescopes and low-temperature detectors. Telescopes are designed to concentrate parallel light on detectors in general. All we have to do is to put a plane mirror in front of the telescope 's window and we can realize the HPCDM search experiment. Diversion of telescopes have an advantage in addition to shortening of development time: the telescopes have abilities to change the direction of the mirrors using pointing system. The direction of the induced photons ' propagation has a slight deviation from perpendicular to the mirrors depending on the incident angle to the surface, which provides a way to discriminate the HPCDM signal from background noise. The wavelength of the induced photon corresponds to the HP mass. It is meaningful for the expansion of HP mass range to use various detectors which have the sensitivity to the different wavelengths.

We already searched for HPCDM with the mass of around 10^{-4} eV. We used a millimeter wave spectrometer for sensing of the atmospheric water vapor, KUMODeS. Its sensitivity to the mixing parameter will be five times stronger than the current limit. In the conference, we report the status of the analysis and show a future plan to use a telescope developed for observation of CMB polarization, GroundBIRD.

category : Applications

O-41 Enhanced Calorimetry Using Helium Evaporation and Field Ionization

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The measurement of small energy deposits in calorimeters having large heat capacities is a challenge faced in a number of different low temperature experiments. For example, the observation of rare events in searches for low-mass dark matter by direct detection is limited by the threshold energy that can be measured. As an alternative to methods presently used, we propose a technology for dark matter detection based on the evaporation of helium atoms either from superfluid helium or from an adsorbed layer of atoms on crystalline solids in which the phonon mean free path is long. It is well known that thermal excitations in liquid helium (phonons and rotons) that have energy greater than the binding energy of an atom to the liquid (0.62 meV) can evaporate a helium atom from a free surface in a 1 to 1 process called quantum evaporation. The same is true in a solid with phonons having energies greater than the adsorption energy of helium to the surface. The evaporation process transfers energy deposited as thermal excitations in a massive calorimeter into free helium atoms in vacuum. Presently, evaporated atoms can be detected calorimetrically upon their adsorption to a low mass wafer.

A more sensitive detection technique is to employ field ionization. Helium atoms can be ionized in a strong electric field in the vicinity of an anode array of sharp tips, whereupon the released positive ions can impinge on a cathode with an energy per ion of several keV. In this way an energy deposit of less than 1 meV can be amplified to more than 1 keV. This detection scheme opens up new possibilities for the direct detection of dark matter particles of mass down to about 1 MeV/c^2. The detection efficiency of field ionization depends on the collection of atoms in the high field region of a large array of tips and is dependent in part on the polarization of the atoms and their resulting attraction to high field regions. Recent developments in nanotechnology for the fabrication of tip arrays provide a method for obtaining high collection efficiency of atoms in the high field region of the tip array, upon which the overall detection efficiency for sensing evaporated atoms depends. Whether or not helium evaporation together with field ionization can be used with other calorimetric experiments that require large masses, such as searches for neutrinoless double beta decay or gamma ray spectroscopy, depends on properties of helium atom detection not discussed here, namely, the achievable energy resolution. This is a property that must be investigated experimentally.

The technique of evaporation and field ionization for detection of small energy depositions in large calorimeters is not limited to helium. Other atoms or molecules with relatively low binding energies to surfaces, and which have lower ionization potentials and larger polarizabilities than helium may have utility in certain applications.

category : Applications

O-42 Status of the HOLMES experiment to directly measure the electron neutrino mass

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The assessment of neutrino absolute mass scale is still a crucial challenge in today particle physics and cosmology. Beta or electron capture spectrum end-point study is currently the only experimental method which can provide a model independent measurement of the absolute scale of neutrino mass. HOLMES is an experiment funded by the European Research Council to directly measure the neutrino mass. HOLMES will perform a calorimetric measurement of the energy released in the electron capture decay of the artificial isotope ^{163}Ho.

In a calorimetric measurement the energy released in the decay process is entirely contained into the detector, except for the fraction taken away by the neutrino. This approach eliminates both the issues related to the use of an external source and the systematic uncertainties arising from decays on excited final states. The most suitable detectors for this type of measurement are low temperature thermal detectors, where all the energy released into an absorber is converted into a temperature increase that can be measured by a sensitive thermometer directly coupled with the absorber. This measurement was originally proposed in 1982 by A. De Rujula and M. Lusignoli, but only in the last decade the technological progress in detectors development allowed to design a sensitive experiment.

HOLMES plans to deploy a large array of low temperature microcalorimeters with implanted ^{163}Ho nuclei. The resulting neutrino mass statistical sensitivity will be as low as 0.4 eV, thereby making HOLMES an important step forward in the direct neutrino mass measurement with a calorimetric approach as an alternative to spectrometry. HOLMES will also establish the potential of this approach to extend the sensitivity down to 0.1 eV and lower. In order to reach a sub-eV sensitivity HOLMES must collect about 3×10^{13} decays with an instrumental energy resolution of about 1 eV FWHM and a time resolution of about 1μs. To achieve this in three years of measuring time, HOLMES is going to deploy 16 sub-arrays of TES microcalorimeters. Each sub-array is composed by 64 pixels and each pixel has an activity of 300 Bq due to ion implanted ^{163}Ho nuclei. The TES arrays are read out using microwave multiplexed rf-SQUIDs in combination with a ROACH2 based digital acquisition system.

The commissioning of the first implanted sub-array is scheduled for the end of 2017 and it will provide precious data about the EC decay of ^{163}Ho together with a first limit on the neutrino mass.

In this contribution we outline the HOLMES project with its physics reach and technical challenges, along with its status and perspectives. In particular we will present the status of the HOLMES activities concerning the ^{163}Ho isotope production and purification, the TES pixel design and optimization, the multiplexed array read-out characterization, the cryogenic set-up installation, and the setting up of the system for the isotope embedding in the TES absorbers.

category : Applications

O-43 The Electron Capture in ^{163}Ho experiment

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The Electron Capture in ^{163}Ho (ECHo) experiment is designed to investigate the electron neutrino mass with sub-eV sensitivity by the analysis of the electron capture energy spectrum of ^{163}Ho. The sensitivity on the electron neutrino mass is crucially related to the energy available for the decay which has been precisely determined by the ECHo collaboration. The first phase of the experiment, ECHo-1k, for 1 kBq of high purity ^{163}Ho source will be implanted in multiplexed arrays of low temperature metallic magnetic calorimeters are presently running. The goals of the current phase are the precise characterization of the parameters describing the spectrum, optimizing the implantation process of the ^{163}Ho into the detector arrays as well as the optimization of the detectors production and the identification and reduction of the background. Within 1 year of measuring time, a limit on the electron neutrino mass below 10 eV will be reached. The results achieved in ECHo-1k will pave the way to the next phase of the experiment addressed to reach a sub-eV sensitivity on the electron neutrino mass. Furthermore, the high statistics and high resolution measurement of the 163Ho electron capture spectrum will allow to investigate the existence of eV sterile neutrinos and keV-scale sterile neutrinos. In this contribution, a general overview of the ECHo will be given as well as a description of the current status and of the future perspectives.

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category : Applications

SSPD and related detectors

O-44 A distributed superconducting nanowire single photon detector for imaging

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Superconducting nanowire single-photon detectors (SNSPDs) can have near unity detection efficiency, sub 20 ps timing jitter, low dark counts and wide response spectrum. Modified nanowire architectures can further improve the performance of an SNSPD. For instance, arranging nanowires in parallel can increase the output signals and thus reduce jitter and simplify readout. These modifications of an SNSPD usually use a lumped electrical model of an SNSPDs, which is taken as a simple inductor in series with a photon-triggered nonlinear resistor. This treatment is valid because conventional SNSPDs have short lengths and strong coupling between adjacent wires. However, with our recent experimental results we found that the effective electrical length of a superconducting nanowire was a few percent of the vacuum wavelength at microwave frequencies and electromagnetic waves propagated along it with a velocity of a few percent of the speed of light in vacuum. This strange behavior is a consequence of the large kinetic inductance of the wire. Therefore, in this circumstance one should use a transmission line and treat the nanowire as a distributed element.

I will report our recent results in which we used the distributed features of a nanowire to detect photon absorption positions and arrival times simultaneously. We slowed down the velocity of pulse propagation to $\sim 2\%$ of the speed of light. Therefore, photon detection pulses were guided in the nanowire, enabling the readout of position and time of photon absorption from the arrival times of the detection pulses at the nanowire 's two ends. In a 19.7-mm-long nanowire meandered across an area of 286 μ m × 193 μ m, we resolved $\sim$ 590 effective pixels with sub-20 μ m spatial resolution while simultaneously having a temporal resolution of 50 ps full-width-at-half-magnitude. A distributed electrothermal model will be introduced to analyze our experimental results.

category : Sensor Physics & Developments

O-45 Four-Lead Superconducting Detector Developed for Neutron Radiography

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A superconducting Nb nanowire detector biased by a constant DC current I_b works in the wide temperature and the bias current range by probing an abrupt change in local kinetic inductance. The nanowire has a magnetic inductance L_m and a kinetic inductance L_k, but we only sense a voltage as $I_b \mathrm{d}\Delta L_k/\mathrm{d}t$ generating by a time-dependent $\Delta L_k(t)(\ll L_k)$ originating from a mesoscopic excitation (hot spot) [1,2,3,4,5]. A hot spot generates not only a positive pulse traveling toward one electrode but also a negative pulse traveling toward another electrode at a certain fraction of the light velocity. The sign of each pulse depends on the direction of DC bias current fed to the detector. We observed the four complete signal shapes at the four electrodes to know the XY position of the hot spot appeared in the orthogonally-superimposed meanderlines by using a 4-channel 400-ps-clock digital oscilloscope. We confirm the validity of our delay-line imaging technique by two demonstrations after analyzing the four signals from the superconducting detector.

First, we succeeded in recovering the University emblem written by a focused laser spot (20ps, 1.55 μm, 15.8 MeV/pulse) on our XY delay-line detector biased by a DC current at 4K [6]. Second, we were able to observe the neutron absorption image of the ^{10}B dot (100μm in diameter, 50μm in thickness) array by superimposing a ^{10}B conversion layer on top of our detector. This is because the reaction of ^{10}B(n,α)^{7}Li dominantly releases the energy of 0.84-MeV ^{7}Li ion and 1.47-MeV ^{4}He ion to create a hot-spot of restricted geometry in the effective area 10 mm $\times$ 10 mm. Actually, we obtained clear recovery of 100-μm ^{10}B dots by irradiating pulsed neutrons at J-PARC [6]. We also give a theoretical explanation of signal generation and transmission in our delay-line detector by means of a superconducting waveguide of S-I-S structure model [6]. We derive a basic equation for the superconducting phase difference defined between the two superconducting layers in the waveguide to explain the voltage pulse propagations in the directions opposite to each other at the Swihart velocity [6]. This successfully gives us a sound theoretical basis of the operation principle of the delay-line detector.

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category : Applications

O-46 Electrothermal modeling of amorphous WSi nanowires

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Superconducting nanowire single photon detectors (SNSPDs) made from amorphous WSi are an emerging technology for fabricating large area, high efficiency single photon counting detectors in the near infrared. Despite their successful demonstration in both the laboratory and field, a complete electrothermal model describing energy flow in amorphous WSi nanowires has not been developed. We describe our efforts in modeling the behavior of WSi nanowires and compare simulated results to experimental measurements.

Electrothermal models for superconducting nanowires have been developed for polycrystalline NbN [1] and Nb [2]. In these formulations, an energy balance approach couples electron and phonon systems. Published SNSPD electrothermal models use linearized formulations which are only rigorous in the limit of small temperature deviations between the electrons, phonons, and the substrate. Based on these models, the temperatures of the electrons and phonons can reach temperatures exceeding the substrate temperature by more than 5 K during a detection event [1], which violates this assumption. Our model corrects this simplification by using the appropriate nonlinear coupling between systems. In addition, the model explores the two-phonon approach [3] where the phonons are divided into escaping and bottlenecked populations. The escaping phonons lie within the critical escape cone of the nanowire-substrate interface leading to rapid thermalization with the substrate. Conversely, the bottlenecked phonons must scatter into the critical cone before thermalizing. The expanded model also considers the influence of thermal transport in the substrate and the impact of the amorphous structure of WSi on the phonon system.

Three experimental metrics are used to evaluate the performance of the electrothermal model. WSi nanowires were fabricated from a 5 nm thick film on 240 nm of thermally oxidized silicon and capped with 110 nm of passivating SiO_2. The latching behavior of these nanowires was studied as the primary mechanism for determining the dynamic response of the system. In this experiment, devices of different kinetic inductance were fabricated and the switching current measured under illumination. Suppression of the switching current at low device inductance was due to latching. Despite the strong temperature dependences of phonon scattering mechanisms, we measure that the latching behavior is independent of bath temperature. This result suggests that fast WSi devices that typically latch at low temperature could be operated at high temperature without experiencing any reduction in critical current compared to slow devices. The hotspot current at various bath temperatures provides a measure of the steady state performance of the model. Finally, a thermometry scheme was used to estimate the temperature profile and thermal conductivity of the SiO_2 substrate. Comparison to simulations suggests the importance of excess heat capacity in the phonon system due to the amorphous structure.

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category : Sensor Physics & Developments

O-47 High efficiency and low dark-count-rate superconducting nanowire single-photon detectors

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Superconducting nanowire single-photon detectors(SNSPDs) with both high system detection efficiency (SDE) and low dark count rate (DCR) have significant implements in quantum communication and many other applications. The background dark counts of the SNSPD are generally caused by the black-body radiation and stray light transmitted through the fiber coupled to the device. As a result, a cold filter with minimal insert-loss will be necessary to suppress the background DCR. We designed and fabricated a low-loss bandpass filter (BPF) integrated on a single-mode fiber end-face, with a typical passband from 1540 to 1579 nm and a transmittance of over 0.98 at 1567-nm wavelength. SNSPD with high SDE was fabricated on a distributed Bragg reflector. Coupled with the fiber integrated with the BPF on the fiber end-face, the device showed a SDE of 80% with DCR of 0.5 Hz. Compared with the normal fiber without BPF, the DCR was reduced over 13 dB with SDE decrease of less than 2%.

category : Sensor Physics & Developments

O-48 Electron-phonon relaxation time in ultrathin tungsten silicon film

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We have shown that conventional two-temperature model becomes inadequate for description of energy exchange between thin metal film and acoustically rigid substrate. We found that the rate of energy exchange in this situation may substantially slow down as a result of internal phonon bottle-neck effect. This effect is important for both 3D and 2D phonon systems and originates from splitting of phonon spectrum into sets of non-escaping and escaping modes. The electrons and non-escaping phonons may form a unified subsystem, which is cooled down only due to interactions with subsystem of escaping phonons either due to direct phonon conversion as a result of elastic scattering or indirect sequential interaction with electronic system. The identified regime is qualitatively different both from the electron heating and the bolometric regime. In contrast with pure electron heating, the energy relaxation time is not the electron-phonon time but is enlarged compared to the former, due to the fact that only escaping phonons provide the efficient pathway for energy relaxation. In contrast with bolometric regime, the energy relaxation time in not set by heat conductance of film-substrate interface and, in particular, should be independent on thickness for sufficiently thin films. Using amplitude-modulated absorption of sub-THz radiation we studied electron-phonon interaction in amorphous WSi by measuring the response signal vs modulation frequency in the temperature range 1.8-3.4 K. We observed the specific change of slope on the signal tail indicating split of phonon sustem into two subsystems. We found that experimental data can only be simulated under assumption of lattice heat capacity in WSi being substantially increased compared to Debye model at low temperature. We show that the excess phonon density of states in amorphous WSi together with effects of phonon quantization in thin film are likely to be responsible for the observed $\sim T^{-3}$ dependence of electron-phonon relaxation time versus temperature. We demonstrate good agreement between experiment and simulations.

category : Sensor Physics & Developments

O-49 Single microwave-photon detector based on superconducting quantum circuits

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Single-photon detection is essential to many quantum-optics experiments, enabling photon counting and its statistical and correlational analyses [1]. It is also an indispensable tool in many protocols for quantum communication and quantum information processing [2]. In the optical domain, various kinds of single-photon detectors are commercially available and commonly used [1,3]. However, the detection of a single microwave photon in an itinerant mode remains a challenging task due to its correspondingly small energy.

In this presentation, we demonstrate an efficient and practical single microwave-photon detector based on the deterministic switching in an artificial Λ-type three-level system implemented using the dressed states of a driven circuit-quantum electrodynamics system [4]. The detector features a high quantum efficiency 0.66 ± 0.06, a low dark-count probability 0.014 ± 0.001, a bandwidth $\sim 2\pi \times 16$ MHz, and a fast reset time ~ 400 ns. The efficiency limited by a relaxation time (T_1) of the qubit can readily exceed 0.9 by improving T_1 [5]. Although the detector operates in a time-gated mode, we demonstrate "continuous" or "real-time" detection of itinerant microwave photons by coupling two microwave resonators to a flux qubit.

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category : Sensor Physics & Developments

Other low-temperature detectors

O-50 Physics and Applications of Metallic Magnetic Calorimeters

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Metallic magnetic calorimeters (MMCs) are calorimetric low-temperature particle detectors that are currently strongly advancing the state-of-the-art in energy-dispersive single particle detection. MMCs are typically operated at temperatures well below 100 mK and make use of a metallic, paramagnetic temperature sensor to transduce the temperature rise of the detector upon the absorption of an energetic particle into a change of magnetic flux. The latter can be precisely measured using a superconducting quantum interference device (SQUID). This outstanding interplay between a high-sensitivity magnetic thermometer and a near quantum-limited amplifier results in a very fast signal rise time reaching values well below 100 ns, an excellent energy resolution which is competitive to the resolving power of wavelength-dispersive crystal spectrometers, a large energy dynamic range, a high quantum efficiency as well as an almost ideal linear detector response. For this reason, a growing number of groups located all over the world is developing MMC arrays of various sizes which range from a few to several thousand pixels. These arrays are routinely used in a variety of applications and often appear to be a key technology for measurements that require high-resolution and wideband energy-resolving detectors. Famous examples are the investigation of the X-ray emission of highly-charged ions, the search for the neutrinoless double beta decay, the investigation of the electron neutrino mass, metrology, nuclear safeguards or mass spectrometry.

In this overview talk, we give an introduction into the physics of MMCs and summarize existing detector geometries, detector microfabrication as well as readout schemes for single-channel detectors as well as large-scale MMC arrays. We discuss the performance of state-of-the-art MMCs and point out strategies to increase the energy resolving power $E/\Delta E_{\mathrm{FWHM}}$ to values well beyond 10,000. Finally, we highlight the use of micro-fabricated MMCs in several applications in the fields of atomic, molecular and particle physics where it was shown that MMCs yield a wealth of new information that are hardly accessible with conventional detector systems.

category : Sensor Physics & Developments

O-51 Single Photon Detection of 1.5THz Radiation with the Quantum Capacitance Detector

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The Quantum Capacitance Detector (QCD) is a new high-sensitivity direct detector under development for low background applications such as far-infrared spectroscopy from a cold space telescope. The QCD has demonstrated an optically-measured noise equivalent power of $2x10^{-20}$ W $Hz^{1/2}$ at 1.5THz, making it among the most sensitive far-IR detectors systems ever demonstrated, and meeting the requirements for spaceborne spectroscopy. Under these low-background conditions, the photon arrival rate is of the order of 100Hz making it possible to detect individual photons, provided the detector has enough speed. In this work we describe a new fast readout technique for the QCD that enabled single photon detection and counting at 1.5THz. Single photon detection and counting of single photons was demonstrated between 100Hz and 10 kHz. The QCD also demonstrates high absorption efficiency: both the photon arrival rate in counting mode, and the statistics of the shot noise in the non-counting mode indicate a total photon absorption and detection rate which is within a few percent of that expected for the experimental setup. Our measurements provide further confidence in the QCD as a detector approach for future ultrasensitive far-IR instrumentation.

category : Sensor Physics & Developments

O-52 Development of STJ with FD-SOI cryogenic amplifier as a far-infrared single photon detector for COBAND experiment

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The COBAND collaboration has proposed an experimental search for the COsmic BAckground Neutrino Decay, and has been developing far-infrared (FIR) photo-detectors. The cosmic background neutrino is predicted as a relic of the big bang in the standard cosmology, and a heavier neutrino is possible to decay to a lighter neutrino with a FIR photon, even though its lifetime is expected to be much longer than the age of the universe. Neither the cosmic background neutrino nor the neutrino decay is, however, established experimentally yet. Only a lower limit in the order of 10^{12} years is given on the neutrino lifetime. We, thus, search for photons coming from the cosmic background neutrino decays. The photon spectrum from the cosmic background neutrino decays is expected to have a unique signature with a sharp edge at a wavelength of around 50μm depending on the heaviest neutrino mass. To identify the signature against the overwhelming zodiacal emission (ZE) foreground as well as the cosmic infrared background (CIB), the candidate photo-detectors are required to have an ability to measure the FIR spectrum around 50μm with sufficient precision.

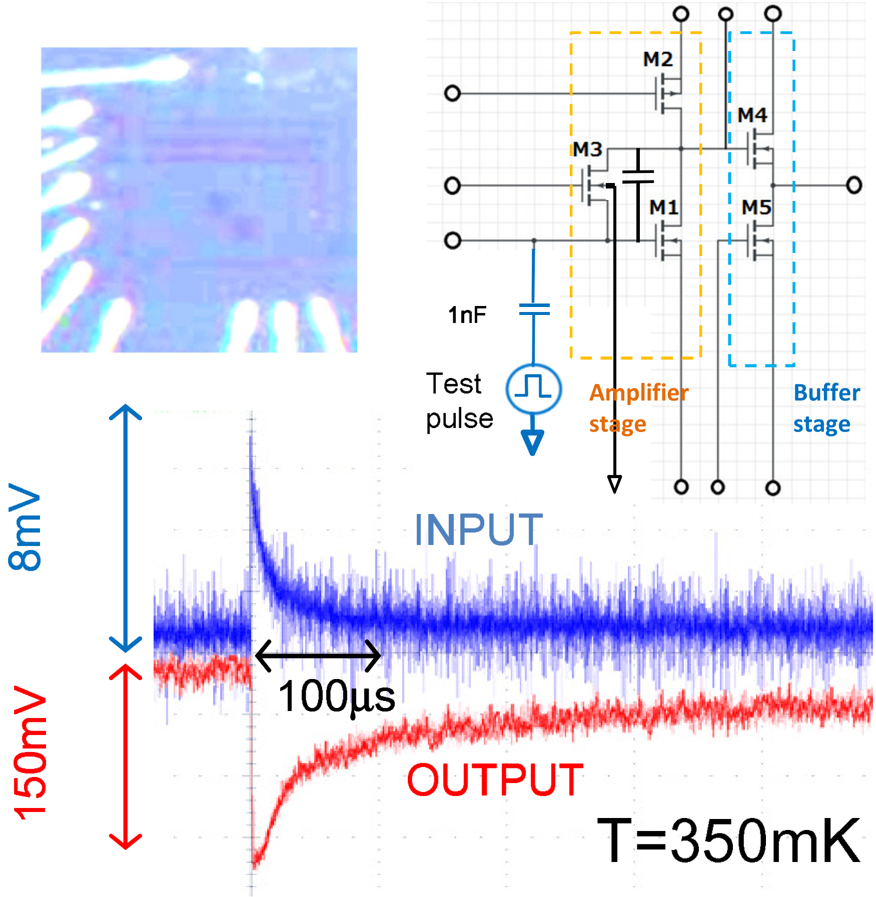
There are several FIR photo-detectors around 50μm already used in practical astronomical measurements, which are based on photoconductors such as Ge:Ga and typically have noise-equivalent-powers (NEPs) of around $10^{-17}\mathrm{W}/\sqrt{\mathrm{Hz}}$. In this collaboration, however, we aim at developing a photo-detector with a NEP better than $10^{-19}\mathrm{W}/\sqrt{\mathrm{Hz}}$ to achieve a sensitivity to the neutrino lifetime in the order of 10^{14} years for a 200-second measurement with a telescope of 15cm-diameter in a sounding rocket experiment. Thus, we employ superconductor based detectors and low noise cryogenic amplifiers for their signal readouts to attain a FIR photon-by-photon spectrometry for the improvement of the photo-detector NEP.

One of the promising choices for the photo-detector is a combination of a diffraction grating and an array of niobium-aluminum superconducting tunneling junction (Nb/Al-STJ) pixels, where each STJ pixel is capable of the detection of a FIR single-photon delivered to each pixel per its wavelength by the grating. Also, the cryogenic amplifier which can be deployed in close proximity to the STJ are expected to reduce the readout noise drastically. We employ an amplifier circuit using MOSFETs based on the Fully-depleted Silicon-On-Insulator (FD-SOI) technology that have been proven to function below 3K.

In the development, we use Nb/Al-STJs which are fabricated at a facility dedicated for fabrications of superconductor-based devices, Clean Room for Analog & Digital superconductiVITY (CRAVITY) at AIST, and we found the Nb/Al-STJs to have a sufficiently high quality to fulfill our requirements. In this presentation, we mainly focus on the status of the developments of FD-SOI proto-type cryogenic amplifiers and their tests with practical input signals from the STJ illuminated by laser pulses.

category : Sensor Physics & Developments

Test of SOI cryogenic amplifier at 350mK



Readout Techniques & Signal processing 1

O-53 Progress in microwave SQUID readout for calorimetric and bolometric sensors

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The Microwave SQUID Multiplexer uses rf-SQUIDs to modulate superconducting microwave resonators, encoding the signal from each input channel in its own microwave tone, summing many tones onto a common output channel. Compared to existing multiplexing technologies, it provides much larger available output bandwidth ($\sim$ 4 GHz) per cable. This increased bandwidth allows the multiplexed readout of large numbers of low-temperature detectors, and also of faster detectors than could be practically multiplexed before.

This talk will review the basic theory and the design considerations of a microwave SQUID multiplexer. It will survey the state of the art in terms of parameters like readout noise, speed, crosstalk, and channel density. Finally, it will discuss current challenges and future directions. It will also showcase results from various experiments using the technology, such as the readout of 128 gamma-ray TES microcalorimeters on a single coaxial cable.

category : Readout Techniques & Signal processing

O-54 A large-scale demonstration of microwave SQUID multiplexing: the SLEDGEHAMMER TES gamma-ray microcalorimeter instrument

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Steady progress has been made over the last 10 years developing large-format arrays of Transition-Edge Sensor (TES) microcalorimeters to perform gamma-ray spectroscopy [1,2]. These arrays have significantly better energy resolution than state-of-the-art High-Purity Germanium (HPGe) detectors and therefore could become tools for analyzing complex mixtures of actinide isotopes found in the nuclear fuel cycle. Previous gamma-ray measurements with TES arrays have demonstrated lower statistical errors than HPGe [3,4]. However, TES arrays with much higher count rate capability are needed to (1) match the measurement speed of HPGe, and (2) assess and minimize the systematic errors in deduced material composition. To address the need for higher count rate capability, we are developing the SLEDGEHAMMER pathfinder instrument, which will consist of an array of 512 TES microcalorimeters read out using microwave SQUID multiplexers. This instrument will be taken to Los Alamos National Laboratory and Savannah River National Laboratory, where it will be used to measure the isotopic content of a wide variety of samples relevant to actinide accounting during the nuclear fuel cycle. We describe the development of this instrument, including its assembly and a recently completed demonstration of undegraded, simultaneous readout of 128 channels using a single HEMT amplifier and widely available ROACH2 electronics. The average TES resolution during this demonstration was 55 eV FWHM at 97 keV. This is the first large-scale demonstration of microwave SQUID readout using calorimetric sensors. We also present a detailed characterization of prototype TES microcalorimeters with bulk superconducting absorbers covering a wide range of thermal response times.

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category : Readout Techniques & Signal processing

O-55 Microwave SQUID Multiplexing for TES micro-Calorimeters in the High-Speed Limit

James P Hays-Wehle[1], Daniel Becker[2], Douglas A Bennett[3], John D Gard[4], Joseph W Fowler[5], Gene C Hilton[6], J. A. Benson Mates[7], Carl D Reinstema[8], Daniel R Schmidt[9], Daniel S Swetz[10], Leila R Vale[11], Joel N Ullom[12]

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Future TES microcalorimeter arrays are being developed for high event rate environments. The requirements of these experiments push the technology in two directions: larger multiplexing factors, and faster pixels that can handle high per-pixel event rates. Experiments such as HOLMES for neutrino mass measurement and x-ray spectrometers at high intensity facilities such as LCLS-II are targeting kilopixel arrays and 100 microsecond pulse decay times. Multiplexing techniques that provide high bandwidth help with both goals because fundamentally both are demands on the same readout bandwidth. Microwave SQUID multiplexing is a particularly attractive readout technique because it provides several GHz of bandwidth per amplifier chain. In an optimized experiment, pixel speeds are pushed right up to the limits imposed by the multiplexing system.

For microwave SQUID multiplexing, this optimization entails the careful matching of the resonator bandwidth, the resonator spacing, the flux ramp modulation rate, and the frequency content of the detector signal. Each stage of this process is a balance between wasted bandwidth and loss of signal fidelity. For example, a detector that is too fast for its ramp rate will exhibit non-linear distortions, while a ramp rate that is too fast for the resonator bandwidth will increase noise levels. And finally, a resonator with too much bandwidth for its spacing may cause crosstalk.

This presentation will detail the mechanisms that cause various speed limits, as well as the results of experiments performed to explore the parameter space near these limits. It describes microwave SQUID readout circuits developed at NIST with resonator bandwidths of 300 kHz, 2 MHz, and 30 MHz, in particular highlighting recent measurements of TES pulses with 20 microsecond peaking times in a configuration that allows for 33 channels per 512 MHz of room temperature bandwidth. We will also discuss future readout and analysis techniques meant to enable even faster pixels without sacrificing multiplexing factor.

category : Readout Techniques & Signal processing

O-56 Optimized Readout Electronics for Microwave SQUID Multiplexed MMC Arrays

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Detection of single particles with energies of a few eV up to several MeV plays a prominent role in many areas of physics. Conventional detectors such as semiconductor detectors or crystal spectrometers either offer a high dynamic range with limited resolution or vice-versa. In contrast, cryogenic detectors such as metallic magnetic calorimeters (MMCs) combine high spectral and temporal resolution while covering a broad energy range at the same time. Modern magnetic calorimeters as used for soft X-ray spectroscopy offer an energy resolution of 1.6 eV at 6 keV particle energy, a signal rise time below 100 ns, an energy bandwidth of several 10 keV and an almost ideal linear detector response. For the readout of MMCs, superconducting quantum interference devices (SQUIDs) are used since they provide a high system bandwidth and low noise. The latter two properties are mandatory for detectors with a high temporal and spectral resolution.

In addition to these, many experiments require spatial resolution to determine the location of an event or to collect a lot of events for high statistics. Both requirements can be fulfilled by using multi-channel detector systems, which contain a lot of independent pixels. But at the same time, the readout of such multi-channel detector systems turns out to be challenging. Microwave SQUID multiplexing as previously introduced by Irwin et al. for reading out arrays of superconducting transition edge sensors turns out to be a very promising approach. Here, non-hysteretic rf-SQUIDs are used to modulate the pixels ' information on different carrier frequencies in the GHz range. However, the requirement of processing of the readout electronics imposed by MMC arrays is more demanding as compared to reading out transition edge sensor arrays due to the fast signal rise time of MMCs.

For this reason, a customized readout system for microwave SQUID multiplexed MMC arrays will be presented in this contribution. The readout system is based on software defined radio. All digital processing is implemented on an FPGA. Fast Digital-to-Analog-Converters (DAC) and Analog-to-Digital-Converters (ADC) are used for creating and digitizing the MHz frequency comb which is sent to the multiplexer and modulated according to the actual state of the detectors. A customized high-frequency front-end electronics performs the up- and down-mixing of the frequency comb to the targeted frequency range of 4-8 GHz. Each of the three parts has been developed, implemented, integrated and evaluated. The first version of the system was successfully used to interface a 64 pixel MMC detector array. This solution allowed for the very first true multiplexed readout of a metallic magnetic calorimeters, i.e. to record events on various independent channels in parallel, by just using one pair of coaxial cables into the cryostat. Moreover, we will show, how this system architecture can be extended to the readout of thousands of channels in parallel. Eventually, we target the simultaneous readout of up to 100 k channels with this approach.

category : Readout Techniques & Signal processing

O-57 64 pixel metallic magnetic calorimeter based detector array with integrated microwave SQUID multiplexer

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Microwave SQUID multiplexing (µ MUXing) appears to be the most promising readout technique for large arrays of low-temperature microcalorimeters requiring a large bandwidth per pixel. It is therefore highly suited for reading out metallic magnetic calorimeters (MMCs) that combine an intrinsic fast signal rise time, an excellent energy resolution, a large dynamic range, a quantum efficiency close to 100% as well as a highly linear detector response. Each channel of a microwave SQUID multiplexer consists of an unshunted, non-hysteretic rf-SQUID which is used for detector readout and which is inductively coupled to a superconducting microwave $\lambda/4$ resonator with a unique resonance frequency. Due to the magnetic flux dependence of the SQUID inductance as well as the mutual interaction between SQUID and resonator, the detector signal is transduced into a resonance frequency shift of the related resonator. Consequently, by coupling many channels capacitively to a common transmission line and using software defined radio, it is possible to monitor the resonance frequency shifts of all resonators simultaneously and therefore the actual states of the detectors.

In this contribution we present the successful demonstration of a µ MUXing based MMC readout. The tested device consists of two 32 pixel detector arrays that are optimized for soft X-ray spectroscopy and are each read out by an integrated, on-chip multiplexer. Each MMC consists of two meander-shaped pickup-coils which are connected in parallel and form a first order gradiometer. Each coil is equipped with a AgEr300ppm sensor and a 5 ??m thick gold absorber on top. Both coils are connected in parallel to the current-sensing rf-SQUID which is a second-order parallel gradiometer. The multiplexer features a common flux modulation coil which is coupled to all SQUIDs and allows for static flux biasing or flux modulation of all SQUIDs. The resonance frequencies of the superconducting coplanar waveguide resonators range from 4 GHz to 8 GHz and provide a bandwidth of about 1 MHz per channel which allows resolving signal rise times well below 1 µ s. According to our detector and multiplexer models, the expected energy resolution for all pixels within this array is $\Delta E_{\mathrm{FWHM}} \approx 5\,\mathrm{eV}$ at an operating temperature of 20 mK.

We present a detailed characterization of the device. In particular, we show that its performance is as expected when considering the geometry of the detector, the thermodynamical properties of the sensor material as well as our multiplexer model. In addition, we summarize the status of the development of a software defined radio based readout electronics as well as our advances concerning flux ramp modulation which we will use for linearizing the multiplexer output signal. Finally, we present our recently developed next-generation multiplexer which will allow reading out 32 channels with one room temperature readout electronics and discuss first experimental results.

category : Readout Techniques & Signal processing

O-58 Advanced Time- and Code-Division Multiplexers for X-Ray Spectrometer Arrays

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We present a new generation of advanced SQUID-based time-division multiplexers (TDM) and code-division multiplexers (CDM) for superconducting x-ray spectrometer arrays including the Athena X-IFU. TDM and CDM x-ray microcalorimeter arrays are presently the most mature x-ray TES multiplexers, with excellent performance with multiplex factors up to 40 pixels and progress towards larger multiplex factors. We describe a new generation of designs implementing advanced features for cross-talk reduction, robustness for flight instruments, and increased multiplex factors. These advances include the implementation of error correction codes (ECC) for CDM multiplexers to eliminate the risk of single-point failure for flux-trapping in first-stage SQUIDs, active Josephson circuits to mitigate small inductive crosstalk sources from flux feedback, and improvements to reduce noise and switching times for larger multiplex factors. We describe designs, fabricated devices, and experimental results including successful error correction of CDM in TES calorimeter spectra.

category : Readout Techniques & Signal processing

Readout Techniques & Signal processing 2

O-59 SiGe Integrated Circuit Developments for SQUID/TES Readout

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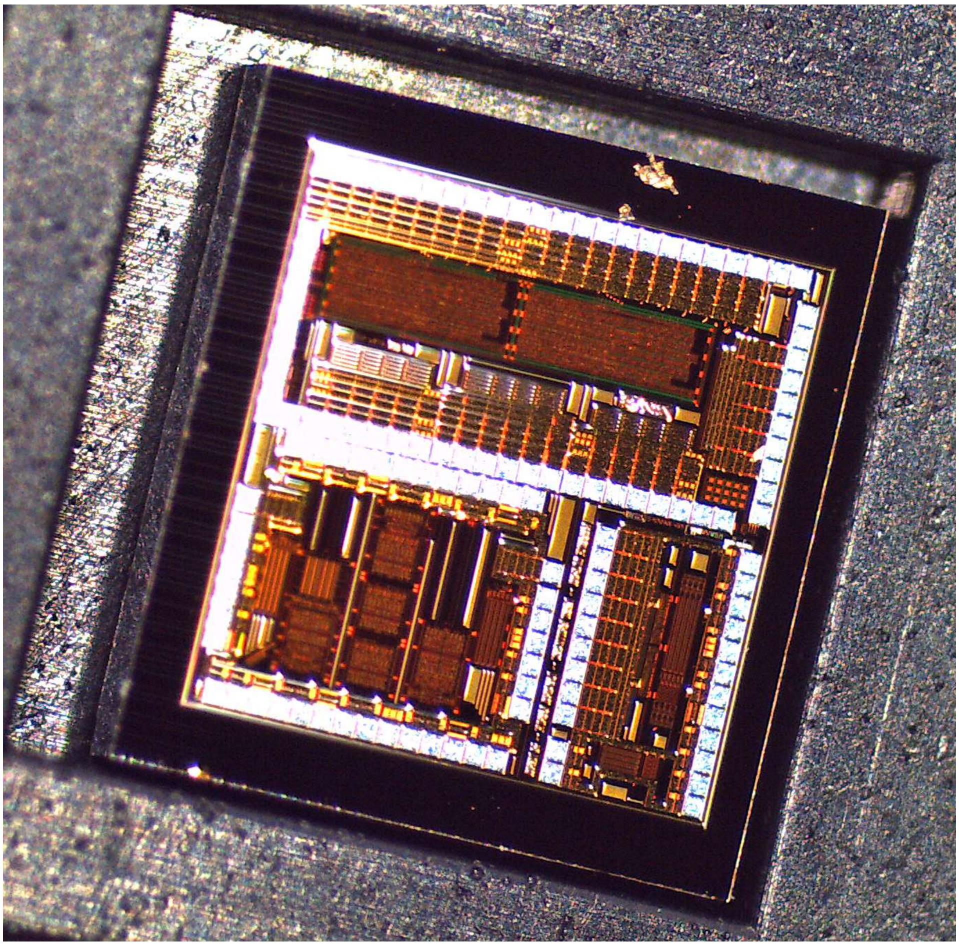
Since more than 10 years, APC develops SiGe integrated circuit dedicated to the readout of superconducting bolometer arrays for astrophysics. Whether for Cosmic Microwave Background observations with the QUBIC ground based instrument or to implement the Hot and Energetic Universe science theme with the X-IFU instrument on-board of the ATHENA space mission, lot of Transition Edge Sensor (TES) arrays are investigated and deployed.
Such superconducting detector array currently implements readout schemes mainly based on Time and Frequency Domain Multiplexers (TDM and FDM) using SQUID technology. In addition to SQUID devices and deep cryogenic filter devices, SQUID multiplexers need low noise biasing and amplifications. A smart integration of these last functions can be obtained using BiCMOS SiGe technology in an Application Specific Integrated Circuit (ASIC).
Indeed, ASIC technology allows integration of very optimized circuit specifically designed for a unique application. Moreover, SiGe bipolar transistor can be used to reach very low noise and wide band amplifications for operations both at room and cryogenic temperatures. We propose to present in the LTD17, a short review of the use of SiGe integrated circuit for SQUID/TES readout and give an update of the last developments done for the QUBIC telescope and for the X-IFU instrument.
QU Bolometric Interferometer for Cosmology (QUBIC) uses 2 TES focal plans (one for 150 GHz and one for 220 GHz) of 1?k pixels each. A TDM cryogenic readout has been realized for these TES arrays. 3 generations of cryogenic SiGe ASIC (down to 2 K) has been successfully used to readout the QUBIC TESs. The most recent SQmux128 evo provides a 128-multiplexing factor in cryogenic environment and is actually implemented in the QUBIC cryostat. A 5MHz 0.2nV/$\sqrt{}$ Hz low noise amplifier, a sequentially addressed SQUID current sources and a digital clocking of the full multiplexer is operating for the QUBIC experiment.
The X-ray Integral Field Unit (X-IFU) instrument build for the ATHENA ESA space mission (to be launched in 2028) uses a micro-calorimeter/TES focal plan of 4 k pixels. A FDM cryogenic readout based of LC filters and 2 SQUID stages is biased and low-noise amplified by a warm ASIC (named AwaXe) placed outside the cryostat. This warm front-end electronic uses BiCMOS SiGe technology for the SQUID biasing, the adjustment of the biasing of each SQUID stage and for the 10MHz 1nV/$\sqrt{}$ Hz amplification tacking into account challenging gain stability and linearity constraints.
Both Integrated circuits SQmux128 and AwaXe will be described showing the interest of such SiGe technology for SQUID multiplexer controls.

category : Readout Techniques & Signal processing



O-60 Frequency domain multiplexed readout of TES X-ray microcalorimeters for X-IFU on board of Athena

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We are developing frequency domain multiplexing (FDM) readout of TES X-ray microcalorimeter for X-IFU instrument on board of the X-ray astronomical satellite Athena. FDM is currently baseline readout system for the X-IFU instrument. In FDM, TESs are biased with alternating current (AC bias) at MHz frequencies and their signal from each TESs are distributed by high-quality passive LC filters. Due to strong limitations of electrical and cooling power on the satellite, a multiplexing factor of 40 pixels/channel in a frequency range from 1 to 5 MHz is required.

Utilizing SRON in-house manufactured LC filters and room-temperature electronics, and a low-noise SQUID system provided by VTT, we have demonstrated 5 pixel FDM readout of Mo/Au TES calorimeters with Au/Bi absorbers. The current technical limitation to realizing multiplexing for the X-IFU instrument on the scale of 40 pixels/channel is the so-called AC-losses in the TES pixels. This additional resistive loss acts as a temperature insensitive resistance within the TES, which suppresses the detector responsivity. The losses are presumably generated by Eddy currents induced in the Au/Bi absorber by the bias currents flowing in the Nb bias leads. Due to the nature of the eddy currents, the impact on the performance is getting larger at higher bias frequencies. Recently, we also have started developing a new setup for the demonstration of 40x2 pixels FDM readout, which matches with the requirement of a demonstration model of the X-IFU instrument. The mechanical construction was just finalized, and first cool down with dry dilution cooler. After several cooling downs, a 1000-pixels TES array will be installed and characterised under FDM configuration.

In this contribution, we report on the recent progresses of FDM readout at SRON including single pixel characterizations, the performance of these pixels under FDM configuration and the current status of 40-pixel readout demonstrator.

category : Readout Techniques & Signal processing

O-61 Traveling-wave, lumped-element kinetic inductance parametric amplifier for detector readout

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We describe the development of a broadband, high-dynamic-range, and near-quantum-limited parametric amplifier based on the nonlinear kinetic inductance of superconducting NbTiN thin films. We show artificial (lumped-element) transmission-line architectures with two separate phase-matching implementations: periodic impedance loading and resonator phase shifters embedded periodically along the line. The lumped-element designs possess several advantages over previous CPW-based designs, including intrinsic 50 ohm characteristic impedance, natural suppression of higher harmonics from a low-pass cutoff, a factor of 3 reduction in required pump power, a factor of 10 reduction in center trace length, and improved fabrication yield [1]. For both designs, we demonstrate 15 dB gain over a few GHz of bandwidth. We discuss preliminary noise measurements and implications for the readout of MKIDs and microwave SQUID multiplexers.

[1] S. Chaudhuri, D. Li, K.D. Irwin, C. Bockstiegel, J. Hubmayr, J.N. Ullom, M.R. Vissers, and J. Gao, Appl. Phys. Lett. 110(15), 152601 (2017).

category : Readout Techniques & Signal processing

O-62 Lithographed superconducting resonator development for next generation frequency multiplexing readout of transition-edge sensors

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Ground-based Cosmic Microwave Background (CMB) experiments are currently undergoing a period of exponential growth. Current experiments are observing with 1,000-10,000 detectors, and the next generation experiment (CMB stage 4) is proposing to deploy approximately 500,000 detectors. This order of magnitude increase in detector count will require a new approach for readout electronics. We have developed superconducting resonators for next generation frequency domain multiplexing (fMUX) readout architecture. Our goal is to reduce the physical size of resonators, such that resonators and detectors can eventually be integrated on a single wafer. To reduce the size of these resonators, we have designed spiral inductors and interdigitated capacitors that resonate around 10-100 MHz, an order of magnitude higher frequency compared to current fMUX readout systems. This would also enable higher multiplexity than the current 50 detectors per readout channel. We will report on the simulation, fabrication method, characterization technique, and measurement of quality factor of these resonators.

category : Readout Techniques & Signal processing

Fabrication & Implementation Techniques 1

O-63 Design and Fabrication of Large-Area Transition Edge Sensor Detector Arrays for Cosmic Microwave Background Polarimetry

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Mapping the polarization of the Cosmic Microwave Background (CMB) to constrain inflationary physics and the sum of the neutrino masses requires ever larger arrays of highly uniform low-temperature detectors with increased packing density. To address this need, we are developing 150-mm-diameter feedhorn-coupled superconducting microwave polarimeter arrays based on AlMn Transition-Edge Sensor (TES) bolometers. We present an improved design and fabrication process and report results from the application of this process for two CMB experiments which have very different constraints ? Advanced ACTPol (AdvACT) and SPIDER. AdvACT is a ground-based CMB telescope observing from the Atacama Desert in Chile in which the detectors are operated at 100 mK. We have delivered one high frequency (HF) 150/230 GHz multichroic array, two mid-frequency (MF) 90/150 GHz multichroic arrays, and a low frequency (LF) 27/39 GHz multichroic array is under development. In contrast, SPIDER is a balloon-borne experiment optimized to take advantage of the low photon loading conditions of a space-like environment. We have produced three 280 GHz arrays, to be operated at 300 mK, in which the thermally isolating legs of the bolometer have an extreme cross-sectional area-to-length aspect ratio to achieve 3 pW saturation powers. Our design and fabrication process has the versatility to satisfy the diverse constraints of both experiments without altering the process flow, all while producing highly uniform arrays. Together, these arrays comprise a total of 5784 TES detectors for AdvACT and 1536 TES detectors for SPIDER. All arrays exhibit ¿ 99% device yield with unprecedented device parameter uniformity and low-loss microwave performance. We present histograms of superconducting transition temperature, bolometer saturation power, and thermal conductance for these arrays, showing a ¡ 2% variation in transition temperature across the AdvACT HF array and a 5% spread in saturation power across the 512-TES element SPIDER array. In addition to updates on these arrays, details will be given on current process developments as we continue to improve uniformity and perform further material characterization to achieve state-of-the-art arrays applicable for 4th generation CMB experiments and beyond.

category : Fabrication & Implementation Techniques

O-64 Superconducting Ti/TiN thin films for mm wave absorption

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Superconductors based on thin films are of common issue for many applications at low temperature, mainly in the field of polarization detection. We focus on the development of polarization sensitive detectors in the range 120 to 500 GHz. In this paper, we have developed and studied superconducting thin films based on Ti/TiN bilayers in order to be integrated as electromagnetic wave absorbers in suspended silicon bolometers. These silicon bolometers are working between 50 and 100 mK. The aim is to adapt the critical temperature (Tc) in order to absorb the incident power and to reduce the heat capacity of the system at low temperature. The Tc of absorbers should be in the range of 600-800 mK. To obtain this adapted Tc, we applied the superconductivity proximity effect between the Ti and TiN layers. We have also studied the effect of thermal stress (20 - 250 °C) on the Tc and the critical magnetic field (Hc). Samples are fabricated with two different thicknesses of bilayers: Ti: 100nm/TiN: 5nm and Ti: 300nm/TiN: 5nm and are deposited by PVD technique on oxidized silicon substrates. The electrical characterization of the Tc and the Hc has been performed at low temperature. We observed that the thermal stress has an obvious influence on the critical transition temperature (Tc) behavior. To explain this influence, we performed different morphological and physical characterizations such as X-rays diffraction analysis (XRD), X-ray photoelectron spectroscopy (XPS) and secondary ion mass spectrometry (SIMS). On the basis of the results, we have suggested that the appearance of an oxidized state in the Ti/TiN films modifies the proximity effect.

Keywords: superconductors, thin films, low temperature, bilayer Ti/TiN

category : Fabrication & Implementation Techniques

O-65 Parallel plate resonators for kinetic inductance detectors

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Microwave kinetic inductance detectors (MKIDs) are superconducting devices that are lithographically patterned into microscopic resonant circuits. The resonator geometry is typically a lumped element geometry with an interdigitated capacitors and a meandered wire inductor. We report on our work to design and fabricate a parallel plate resonator, which has two parallel plate capacitors connected by a narrower trace. The trace is the sensitive element of this MKID geometry which we intend to use for optical photon detection. The main goal behind this geometry is to increase microwave readout power by making a low inductance and high capacitance, unlike the lumped element design that has high L and low C. From the parallel plate design, we expect: (1) the ability to increase sensitivity by increasing microwave drive power, (2) a concomitant significant improvement in signal-to-noise ratio due to the saturation of TLS noise resulting from high microwave drive power and (3) decreased energy resolution degradation due to geometric effects due to the more uniform current passing through the trace.

We will present results from electromagnetic simulations as well as fabricated parallel plate MKIDs. We will discuss the fabrication, which is challenging due to requiring a 10 nm thick dielectric between the two plates of the capacitor. With these results we demonstrate the feasibility of the parallel plate MKID design. We will also show that these MKIDs can be driven at readout powers at least 100 times larger than conventional lumped element designs of similar sensitivity.

category : Fabrication & Implementation Techniques

Application - CMB 1

O-66 Low Temperature Detectors For Cosmic Microwave Background Research

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The Cosmic Microwave Background (CMB) is a gift to cosmologists, providing a basic picture of how the universe began and evolved. Details of this picture, including what drove the bang of the Big Bang, may be clarified through precision measurements of the CMB. As such, enthusiasm for CMB experiment is not lacking.

More than 10 sub-orbital instruments are either observing or in active development, and satellite missions have recently been proposed in Japan, the US, and Europe. The CMB imager LiteBIRD is in fact a formal candidate under study for JAXA 's strategic large mission. Key components to all of these instruments are the arrays of low temperature detectors that populate the focal planes. In this presentation, I review the tremendous innovation in CMB detectors which has transpired in the past decade. A current state-of-the-art array consists of multi-hundreds of spatial pixels, each dual-polarization sensitive, multi-chroic, and printed on a 150 mm diameter substrate. I present a hypothetical ideal CMB imaging array, which would be sensitive over 10:1 bandwidth, fabricated on a flexible circuit to match a non-telecentric focal plane, and possess variable aperture size as a function of wavelength. Several groups are developing aspects of such a detector array, and these ideas will be presented. I will compare and contrast implementation of transition-edge-sensor (TES) bolometers with microwave kinetic inductance detectors (MKIDs) for CMB studies. Lastly, I conclude with the outlook of developing detector arrays to meet the needs of CMB Stage IV, an experiment to commence in the next decade which aims to map half of the sky to 1 microKelvin-arcminute depths by use of multiple telescopes sprinkled throughout the globe.

category : Sensor Physics & Developments

O-67 The Advanced ACTPol 27/39 GHz Array

Sara Michelle Simon[1]

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Advanced ACTPol (AdvACT) is an upgraded camera for the Atacama Cosmology Telescope that will measure the Cosmic Microwave Background in both temperature and polarization over a wide range of angular scales and five frequency bands from 27-230 GHz. AdvACT 's sensitivity, resolution, wide frequency coverage, and large sky coverage will enable it to simultaneously probe inflation at large angular scales while using small angular scale measurements to constrain the mass and number of neutrinos, dark energy, and dark matter. Measurements are currently limited by foreground contamination from galactic dust and synchrotron emission, so wide frequency coverage is required to characterize and remove these signals. AdvACT will sequentially deploy four arrays of feedhorn-coupled, polarization-sensitive multichroic pixels in its three optics tubes: one 150/230 GHz array, two 90/150 GHz arrays, and one 27/39 GHz array. The AdvACT 27/39 GHz array will consist of 75 multichroic pixels that will measure the synchrotron foregrounds, which are dominant at lower frequencies, with unprecedented sensitivity and resolution, making it singular in the field. To maximize the sensitivity of the 27/39 GHz array, the spacing between pixels was minimized to increase the number of pixels and thus the sensitivity. Light from each feedhorn is waveguide-coupled to a planar orthomode transducer that splits the radiation into two orthogonal polarizations. The signal is then sent down superconducting Nb microstrip lines, through a diplexer of quarter-wave stub filters that define the bandpasses, through a hybrid-T, and onto a transition-edge sensor (TES) bolometer. Each multichroic pixel has four TES bolometers, one for each frequency and polarization. I will present the design of the pixels and feedhorns for the AdvACT 27/39 GHz array, which will be deployed in January 2018.

category : Applications

O-68 BICEP3 performance overview and design for BICEP Array

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BICEP3 is the latest telescope in the BICEP/Keck program, deployed to the South Pole Station in 2015. It is a 550mm aperture refractive telescope observing the polarization of the cosmic microwave background at 95 GHz. BICEP3 started the second season of science observation in 2017.

This paper will show the latest BICEP3 performance, including detector spectral response, optical efficiency and telescope sensitivity. We will also present the design for our next generation telescope, BICEP Array, consisting of multiple BICEP3-like receivers spanning from 35 GHz to 270 GHz with total detector count in the tens of thousands.

category : Applications

O-69 SPT3G: A Multichroic Receiver for the South Pole Telescope

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The third-generation camera for the South Pole Telescope, SPT3G, was deployed in early 2017 to map the cosmic microwave background at 90, 150, and 220 GHz with 16,000 detectors, 10 times more than the previous-generation receiver on the SPT. The increase in detector count is made possible by lenslet-coupled trichroic polarization-sensitive pixels fabricated at Argonne National Laboratory, a new optical design with higher throughput, and new multiplexing readout electronics. The enhanced sensitivity of SPT3G will enable a diverse set of measurements on primordial B-mode polarization, gravitational lensing of the CMB, and the E-mode damping tail. The instrument is currently deployed and taking engineering observations during its first year of operation at the South Pole. Here we will summarize the scientific motivation for SPT3G and present an overview of the instrument and design considerations of its major subsystems, including detectors, optics, and readout electronics. We will also highlight the on-sky performance and status of the fully integrated camera as it begins its 4-year 2500 sq-deg survey.

category : Applications

O-70 GroundBIRD - observation of CMB polarization with a high-speed scanning and MKIDs

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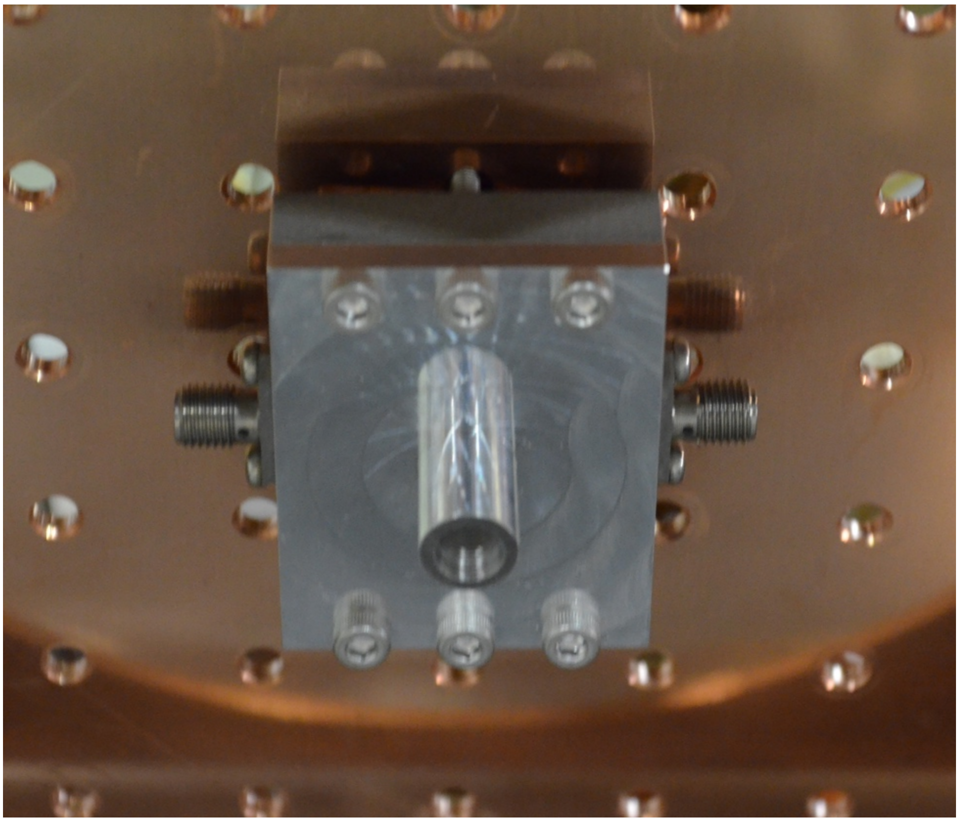
The Cosmic Microwave Background radiation (CMB) polarization contains information about of early universe. In particular, the odd-parity patterns (B-mode) at large angular scale is strong evidence for the inflationary universe. GroundBIRD is designed to detect the B-mode with high-speed rotation scan system, cold optics, and microwave kinetic inductance detectors (MKIDs). We plan to start commissioning of GroudBIRD in the Canary Islands in early 2018.

The high-speed scanning is one of the key features in our telescope. The most ground-based experiments have adopted periodic (i.e., forward and backward) swing in azimuth for their scan strategy. In this way, atmospheric fluctuation (1/f noise) degrades the sensitivity at degree scale observation because the swing scan does not achieve fast modulation to mitigate the 1/f noise effects. We employed rotation scan allowing continuous high-speed motion without any deceleration. This scan mitigates the effect of 1/f noise with multiple ranges at 6 ¡ l ¡ 300. We developed rotary joints for high-pressure helium gas and electricity lines to realize the operation of the cryocooler on a rotating table. We confirmed that cold condition can be maintained with rotation at 20 rpm. We set optical mirrors in the cryostat at 4K to reduce radiation from the mirror surfaces. We employ novel approach for blocking thermal radiations from the receiver aperture, a combination of metal mesh filters (QMC Instruments Ltd.) and radio-transparent multi-layer insulations (RT-MLI) at 300 K, 50 K, 4K, and 350 mK. We adopted a focal plane with 350 mK and 250 mK stage connected with Kevlar strings. We achieved to maintain the mirrors at 3.4 K on the optical configuration. We also achieved 0.25 K temperature for the focal plane stage with a hold time of more than 24 hours. We chose MKID for the focal plane detector array of the GroundBIRD telescope. MKID has an advantage of multiplicity with a single readout line. We plan to observe at 220 GHz (112 pixels) as one readout system and at 145 GHz (330 pixels) as six readout systems. The 220 GHz band observes thermal emission from foreground dust and the 145 GHz observes the CMB signal. In addition to that, the fast time response (order of 100 us) of MKID is suitable for our high-speed scan. 120-ch responses of MKID are measured by analog readout system at once. We developed two outputs/inputs of DAC/ADC analogue board for measurement of phase and amplitude responses. Our prototype detector has one corrugated horn and ten MKIDs at 145 GHz band (fig). We measured polarization characteristic with a rotation of half-wave plate and confirmed a couple of detectors response in directions orthogonal to each other.

In this conference, we will present our status, achievements, and prospects of the GroundBIRD experiment.



category : Applications

Application - CMB 2

O-71 Design, construction, and characterization of the 280 GHz focal plane units for the second flight of the Spider polarimeter

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We describe the construction and characterization of the 280 GHz bolometric focal plane units (FPUs) to be deployed on the second flight of the balloon-borne SPIDER instrument. These FPUs are vital to SPIDER's primary science goal of detecting or placing an upper limit on the amplitude of the primordial gravitational-wave signature in the cosmic microwave background (CMB) by constraining the B-mode contamination in the CMB from galactic dust emission. Each 280 GHz focal plane contains a 16×16 grid of corrugated silicon feedhorns coupled to an array of aluminum manganese transition-edge sensor bolometers, fabricated on 150 mm diameter substrates. In total, the three 280 GHz FPUs contain 1,530 polarization sensitive bolometers (765 spatial pixels) optimized for the low loading environment in flight and read out by time-division SQUID multiplexing. In this paper we describe the architecture of the focal planes, which includes several layers of magnetic shielding, and present cryogenic measurements characterizing their performance. The FPUs have near 90% end-to-end yield (including read-out) and an 80% band-averaged optical efficiency. We demonstrate high uniformity in device parameters, finding the mean saturation power to be 2.80 pW at 300 mK with a 5% variation across the array at one standard deviation. These focal planes will be deployed alongside the 95 and 145 GHz telescopes in the SPIDER-2 instrument, slated to fly from McMurdo Base in Antarctica in December 2018.

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Figure 1: The top author is Amanda Stevie Bergman.

category : Applications

O-72 The LiteBIRD Space Mission - Sub-Kelvin Instrument

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Inflation is the leading theory to explain the first instant of the universe. Inflation, which postulates that the universe underwent a period of rapid expansion an instant after its birth, beautifully explains cosmological observations. Recent advancements in detection technology have opened opportunities to explore primordial gravitational waves generated by the inflation through “B-mode” (divergent-free) polarization pattern embedded in the Cosmic Microwave Background anisotropies. If detected, these signals would confirm inflation, point to the correct model for inflation, and open a window to physics at ultra-high energies.

LiteBIRD is a satellite mission with a goal of detecting degree-and-large- angular-scale B-mode polarization. The LiteBIRD team is an international collaboration between Japan, the U.S., Canada, and Europe. LiteBIRD will observe at the second Lagrange point with a 500 mm diameter telescope and ∼2,000 detectors. It will survey the entire sky with ∼2 microK arcmin noise equivalent CMB temperature (150 GHz) and characterize in 15 bands from 40 to 400 GHz to measure and subtract foregrounds.

The U.S. LiteBIRD team is proposing to deliver milli-Kelvin instruments that include detectors and readout electronics.A lenslet-coupled sinuous antenna array will cover low-frequency bands (40 GHz to 235 GHz) with four frequency arrangements of triplexer pixels. Orthomode-transducer-coupled corrugated horn array will cover high-frequency bands (280 GHz to 402 GHz) with three types of single frequency detectors.

Detection will be made with Transition Edge Sensor (TES) bolometers cooled to a 100 milli-Kelvin base temperature by an adiabatic demagnetization refrigerator. The TES bolometers will be read out using digital frequency multiplexing readout with Superconducting QUantum Interference Device (SQUID) amplifiers.

Up to 78 bolometers will be multiplexed with a single SQUID amplifer. A collaborative simulation-based study is being conducted by an international team to optimize the instrument for foreground removal, including the effects of instrumental systematics. We will report on the milli-Kelvin instrument design and development plan.

category : Applications

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O-73 Measuring Reionization, Neutrino Mass, and Cosmic Inflation with BFORE

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BFORE is a NASA high-altitude ultra-long-duration balloon mission proposed to measure the cosmic microwave background (CMB) across half the sky in a single 28-day mid-latitude flight launched from Wanaka, New Zealand. With the unique access to large angular scales and high frequencies provided by the balloon platform, BFORE will significantly improve measurements of the optical depth to reionization tau, breaking parameter degeneracies needed for a measurement of neutrino mass with the CMB. The large angular scale data will enable BFORE to hunt for the large-scale gravitational wave B-mode signal, as well as the degree-scale signal, each at the r 0.01 level. The balloon platform allows BFORE to map Galactic dust foregrounds at frequencies where they dominate, in order to robustly separate them from CMB signals measured by BFORE, in addition to complementing data from ground-based telescopes. The combination of frequencies will also lead to velocity measurements for thousands of galaxy clusters, as well as probing how star-forming galaxies populate dark matter halos. The mission will be the first near-space use of TES multichroic detectors (150/217 GHz and 280/353 GHz bands) using highly-multiplexed mSQUID microwave readout, raising the technical readiness level of both technologies.

category : Applications

Fabrication & Implementation Techniques 2

O-74 Progress of Superconducting Electronics in Clean Room for Analog and Digital Superconductivity: CRAVITY

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In recent years, superconducting array detectors with quite a large number of pixels (1000) have been developed to satisfy demands for high throughput measurement or imaging capability in many applications such as astronomy, material analysis in synchrotron radiation facilities and laboratories. In order to realize such a large-scaled array, it is necessary to solve three technological difficulties: a uniform performance of all pixels, an integration of signal readout, and cryogenics. For the readout of large scale array detectors, superconducting signal processors are promising and effective to reduce the number of wires between a cryogenic temperature and a room-temperature environment. The combination of a superconducting analog detector device and a superconducting digital circuit makes the total measurement system compact and more practical.

Significant progresses in the above technological difficulties has been achieved by a facility called CRAVITY (Clean room for analog and digital superconductivity) at AIST. First of all, the uniformity of superconducting tunnel junctions(STJs) was significantly improved. For example, a 100-pixel array X-ray detectors with 100 μm-square Nb/Al STJs has a mean energy resolution (ΔE) of 6.7 eV for 400 eV X-ray [1]. The pixel-to-pixel variation is less than $\pm$ 1.0 eV. Moreover, the quality of the 1000 STJs is extremely uniform: a leakage current variation of $\pm$ 1.5 nA at 12.2 nA in the subgap region. The leakage current uniformity ensures stable biasing for the 1000 pixels simultaneously [2].

Second is the integration of superconducting detectors and signal processors. A high-resolution time-of-flight mass spectrometry (TOF-MS) was developed by combining a superconducting strip ion detector (SSID) and a single-flux-quantum (SFQ) time-to-digital converters (TDCs) [3, 4]. The signal processing with the SFQ-TDC at 4 K allows a large reduction of the number of the wirings between a future SSID array detector and a room temperature electronics. This is necessary for a practical TOF-MS system with a superconducting detector of which detection area is comparable to those of widely used microchannel plate (MCP) detectors.

The above-mentioned high-performance superconducting devices can be produced in CRAVITY. One of the unique features of CRAVITY is multilayer superconducting device fabrication based on a planarization technique using chemical mechanical polishing (CMP). In order to achieve a high productivity of complicated analog/digital superconducting devices and circuits, almost all installed process machines are fully automated. Now, the CRAVITY plays an important role as an innovation hub in the superconducting electronics research.

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Acknowledgment

The authors thank to clean room members of CRAVITY for their assistance in superconducting device fabrication.

category : Fabrication & Implementation Techniques

O-75 LC filters for FDM readout of the X-IFU TES calorimeter instrument on Athena

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The X-ray Integral Field Unit (X-IFU) will be a cryogenic X-ray spectrometer on board of the Athena space telescope (ESA, launch in 2028). A large array (4000) of Transition Edge Sensors (TES) will be read out, using a Frequency Division Multiplexing (FDM) technique. Key part of this read out circuit forms a set of chips with high quality factor superconducting resonators (LCR) where the TES, biased in its transition, forms the resistive element. The chips serve to deliver the bias power, through reactive voltage division, filter wide band noise from each TES, and sum all signals with different bias frequency to the SQUID based amplification circuit. SRON is developing this technique for many years already for bolometers and calorimeters [1, 2] and has shown that the energy resolution of calorimeters in this mode is very close to that under DC bias

Heading towards the Demonstration Model for X-IFU, we have fabricated chips for multiplexing of 40 TES pixels into one SQUID channel. We will present the fabrication and characterization results in FDM development setups for this DM. Important quality issues are fabrication yield, resonator quality (effective series resistance), cross talk, accuracy of resonance frequency distribution and packing density.

We will present results of an optimization study of these quality issues, where Finite Element Modeling (FEM) is used in aiding the design. The FEM models are being validated by direct measurements of mutual- and self inductance of representative test cases.

For the a-Si:H based capacitors and Nb-based coils, presently the component fabrication yield is about 99 % and the Q-factor at 50 mK is higher than 100.000 at 5 MHz resonance frequency.

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category : Fabrication & Implementation Techniques

O-76 The DARKNESS Array: A 10,000 Pixel PtSi MKID Array

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We have fabricated and characterized 10,000 pixel MKID arrays for the Dark-speckle Near-IR Energy-resolved Superconducting Spectrophotometer (DARKNESS). DARKNESS is a new MKID instrument designed to sit behind an adaptive optics system with the goal of directly imaging extrasolar planets in a 700-1400 nm band. The array contains 10,000 (80x125) pixels divided evenly between 5 coplanar waveguide microwave transmission lines. These MKIDs are designed with a readout band of 4-8 GHz, with 2 MHz spacing between resonators. In the past, the DARKNESS detector arrays were fabricated using titanium nitride on a silicon substrate. These arrays, however, suffered from severe non-uniformities in the TiN critical temperature, causing resonances to shift away from their designed values and lowering usable detector yield. More recently, we have instead fabricated DARKNESS arrays using platinum silicide on sapphire. Not only do these arrays have much higher uniformity than the TiN arrays, resulting in higher pixel yields, they also display improved sensitivity to photons within DARKNESS's band of operation. PtSi MKIDs also do not display the hot pixel effects seen when illuminating TiN on silicon MKIDs with photons shorter than 1 micron. Finally, the PtSi detectors have energy resolution similar to that seen in the TiN devices, but this is expected to improve as the quality factor of the resonators is increased. In the near future, we will be fabricating 20,000 pixel versions of these arrays to be used in the MKID Exoplanet Camera (MEC).

category : Fabrication & Implementation Techniques

O-77 Magnetic Calorimeter Arrays with High Sensor Inductance and Dense Wiring

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We describe prototype arrays of Magnetically-Coupled Microcalorimeters fabricated with an approach scalable to very large format arrays. The superconducting interconnections and sensor field coils have sufficiently low inductance in the wiring and sufficiently high inductance in the field coils in each pixel, to enable arrays containing greater than 4000 sensors and 100,000 x-ray absorbers to be used in future astrophysics missions such as Lynx. We have used projection lithography to create submicron patterns (e.g. 400 nm lines and spaces) in our niobium sensor meanders and wiring, integrated with gold-erbium sensor films and gold x-ray absorbers. Our prototype devices will explore the device physics of Metallic Magnetic Calorimeters as feature sizes are reduced to nanoscale.

category : Fabrication & Implementation Techniques

Cryogenics and Components 1

O-78 CUORE, a large cryogenic system for LTDs

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In recent years, large mass cryogenic detectors have achieved excellent performances and are widely used in neutrinoless double beta decay and dark matter searches. In such types of experiments a sizable detector mass is a key issues and requires special cryogenic systems.

The Cryogenic Underground Observatory for Rare Events (CUORE) is searching for neutrinoless double beta decay in 130Te. CUORE must operate a ton-scale array of 988 TeO2 cryogenic detectors at 10 mK providing exceptionally low background and low vibration conditions. In order to meet this unprecedented challenge, the CUORE detector array is cooled down by a multistage cryogen-free cryostat. The base temperature is delivered by a custom made 3He-4He dilution refrigerator. Strict material selection and cleaning procedures are applied to all the structures facing the detector. Seven tons of low-temperature lead shielding protect the inner cubic meter scale experimental volume from the residual background contamination of the cryostat. Vibration-induced noise is minimized by means of special suspensions that mechanically decouple the detector from the cryostat. In 2017 the CUORE cryostat successfully cooled down the ton-scale detector at 7mK, delivering an uniform and constant base temperature over few months. In this talk the CUORE cryogenic setup, the results of the commissioning runs and the performance of the system during the first CUORE physics run will be presented.

category : Cryogenics and Components

O-79 A continuous 100-mK helium-light cooling system for MUSCAT on the LMT

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The MUSCAT instrument is a large-format camera planned for installation on the Large Millimeter Telescope (LMT) in early 2018. MUSCAT requires continuous cooling of several large-volume stages to sub-Kelvin temperatures, with the focal plane cooled to 100 mK. Through the use of continuous sorption pumps and a miniature dilution refrigerator, the MUSCAT project can fulfil its cryogenic requirements at a fraction of the cost and space required from conventional dilution systems. Our design is a helium-light system, using a total of only 9 litres of helium-3 across several continuous cooling systems, cooling from 4 K to 100 mK. Here we describe the operation of both the continuous sorption and the miniature dilution refrigerator systems along with the overall thermal design and budgeting of MUSCAT to enable this large-format camera to be compatible with our proposed compact continuous cooler. MUSCAT will represent the first deployment of this new technology in a science-grade instrument and will prove the concept as a viable option for future large-scale experiments such as CMB-S4.

category : Cryogenics and Components

Cryogenics and Components 2

O-80 Vibration measurement and mitigation for cryogen-free dilution refrigerators

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While cryogen-free dilution refrigerators are getting more popular for operation of low temperature detectors, mechanical vibration originating from its pulse tube refrigerator can affect experiments in various ways. We present the displacement, velocity, and acceleration measurement results at different stages of a commercial dilution refrigerator in vertical and horizontal directions. The same measurements are repeated after installing mechanical filters at two different stages. The effects of the filters on the sensor waveform, energy resolution, and particle discriminations are discussed as well.

category : Cryogenics and Components

O-81 Electromagnetic Design of a Magnetically-Coupled Spatial Power Combiner

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Abstract ? The design of a two-dimensional spatial beam-combining network employing a parallel-plate superconducting waveguide with a mono-crystalline silicon dielectric is presented. This novel component employs arrays of magnetically coupled antenna elements to achieve high coupling efficiency and full sampling of the intensity distribution while avoiding diffractive losses in the multi-mode region defined by the guide. These attributes enable the structure 's use in realizing compact far-infrared spectrometers for astrophysical and instrumentation applications. If unterminated, reflections within a finite-sized spatial beam combiner can potentially lead to spurious couplings. A meta-material electromagnetic absorber is implemented to control this response in the device. This broadband termination absorbs greater than 99% of the power over the 1.7:1 operational band at angles ranging from normal to near parallel incidence. The design approach, simulations, and applications of the spatial power combiner will be presented.

category : Cryogenics and Components

O-82 A temperature dependent x-ray absorption characterization of test filters for the ATHENA mission X-IFU instrument

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The ATHENA mission, that provides the demanded capabilities to address the ESA science theme "Hot and Energetic Universe", will be equipped with an high spectral resolution energy dispersive instrument named X-ray Integral Field Unit (X-IFU).

The X-IFU detector is an array of Transition-Edge Sensor microcalorimeters that will be sensitive in the 0.2 keV - 12 keV energy range, with 2.5 eV energy resolution at 7 keV. Such a detector operates at 50 mK and thus requires a sophisticated multistage cryostat. Thermal filters will be used to close the X-rays entrance aperture in the cryostat thermal shields. These filters, highly transparent in X-rays, will attenuate the Infrared (IR) radiative heat load onto the microcalorimeters and will avoid energy resolution degradation due to photon shot noise. Polyimide and aluminum have been currently selected as suitable filter materials in order to achieve high X-ray transmission and good IR reflection, respectively. In the current design five filters are expected to be used at five different temperatures corresponding to the cryostat shields temperatures. Each filter consists of a bilayer of thin polyimide membrane (45 nm - 100 nm thick) coated with aluminum film ($\sim$ 30 nm thick).

The chemical elements (C, N, O, and Al) that make up the filters show absorption X-rays edges in the energetic range of interest of the X-IFU. The oscillations above the edges are known to be sensitive to the changes of temperatures. Since the X-IFU will have an high spectroscopic resolution, an accurate knowledge of the X-ray response of the filters is mandatory to sort out a reliable calibration plan. Here, we present the X-ray absorption characterization of test filters in the soft X-rays (40 eV - 1750 eV) range at different temperatures (80 K - 300 K) to investigate the effect of temperature on the selected materials and its impact on the calibration of the flight filters.

category : Cryogenics and Components

Application - Material analysis and others 1

O-83 Analytical Transmission Electron Microscope using a Transition Edge Sensor for X-ray Microanalysis

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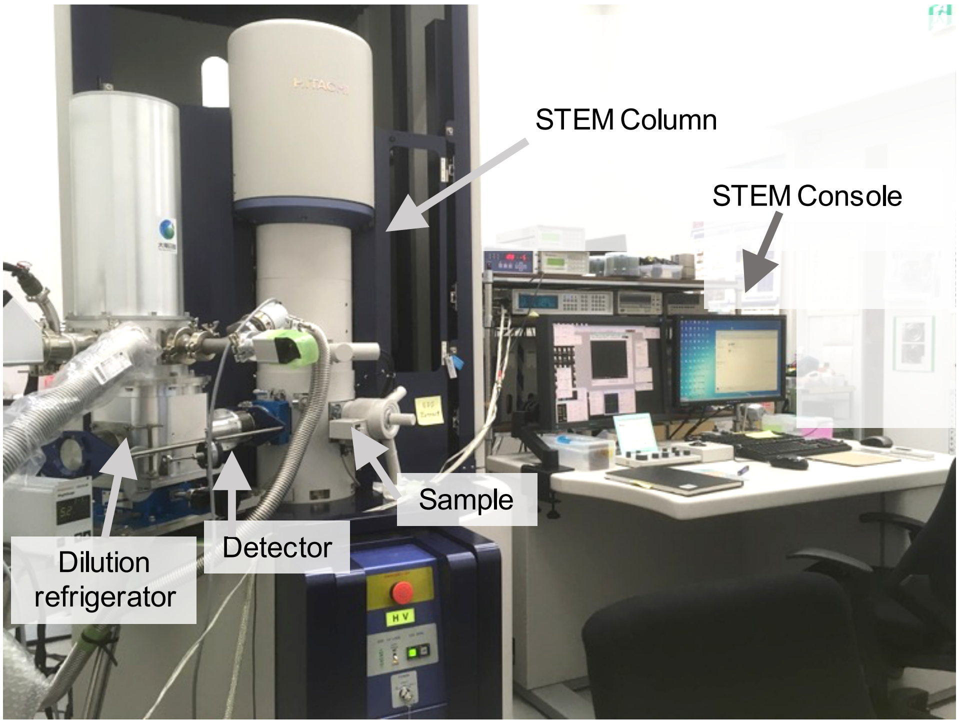
Microstructure evaluation is essentially important to develop new materials. Electron microscopes, such as scanning transmission electron microscope (STEM), plays an important role for such purpose. A function of compositional analysis in nano-scale, in addition to microstructure morphological observation, is very important for current electron microscopy analysis. In order to measure the composition in electron microscopes, x-ray spectroscopy, which is induced by the incident electron beam is now widely applied. However, accuracy and/or sensitivity of a semiconductor based x-ray detector is not sufficient for the current required level: for example, advanced heat-resistant steel contains more than 10 elements with their amount of ¡0.1% each. They have been added empirically to improve mechanical property. However, at present, we do not understand where and how these trace elements work. In order to realize precise x-ray analysis in electron microscopes, we have been trying to apply transition-edge sensor (TES) microcalorimeter. With using this detector, it is expected that most of all elements can be measured without any peak overlaps, it leads high accuracy and sensitivity. To ensure high spatial resolution, less than 1nm, we adopt the TES detector onto a STEM.

Our target specs of the developed x-ray detector are as follows: i) x-ray energy resolution: ¡10eV, ii) detecting x-ray energy range: 0.5-10keV or wider, iii) x-ray counting rate: ¿5kcps. Applying this x-ray detector with a STEM whose accelerating voltage of 200kV, we will be able to realize the elemental mapping with a spatial resolution of less than 10nm. In order to realize the specs listed above, we developed a new detector system. The developed TES-STEM system is shown in figure 1. The characteristic points of the detector are as follows: i) detector device is 64 pixel TES to increase countrate more than 5kcps, ii) multicapillary x-ray lens is applied to increase detecting solid-angle, iii) compact Liq.He free cooling system has been developed for high stability. Newly developed cooling system, based on a dilution refrigerator, can keep low temperature more than half a year, so that we can measure anytime with the same condition. By the end of 2016, we have assembled the new analytical STEM with the multipixel TES detector and succeeded to obtain x-ray spectra with high energy-resolution, less than 10eV, for the range from 0.5-15keV.

In this report, I will briefly review the recent progress of development on the analytical STEM applied with the multipixel TES detector system.



category : Applications

O-84 Ultrafast X-ray Spectroscopies using TES Microcalorimeter Sensors: Recent Table-top Demonstrations and Current Work

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This presentation on the use of Transition-Edge Sensor (TES) x-ray detectors for ultrafast materials analysis will cover three topics. First, we describe a recent successful demonstration of table-top Time-Resolved X-ray Absorption Spectroscopy (TR-XAS) using a laser plasma x-ray source to produce picosecond (ps) duration x-ray pulses and a 240 element TES array read out using time-division SQUID multiplexing for x-ray detection. This apparatus allows optical pump, x-ray probe experiments with ultrafast temporal resolution. Using TR-XAS, we studied the photoreduction of ferrioxalate, a reaction that has been the subject of a long-running debate in the literature, including contradictory x-ray measurements. Our results [1] strongly support a picture in which reduction of the central iron is complete by 100 ps and contradict a theory in which the photoreduction occurs on much longer timescales.

Second, after making a small geometrical change to our apparatus, we were able to demonstrate Time-Resolved X-ray Emission Spectroscopy (TR-XES). Using TR-XES, we studied spin cross-over in photoexcited iron tris-bipyridine and accurately measured the lifetime of the quintet state from simultaneous observations of the iron Kalpha and Kbeta features. We also determined the time resolution of our apparatus to be better than 6 ps. Better time resolution in TR-XES has only been demonstrated at two x-ray free electron lasers. These results [2] are the first laboratory-scale demonstration of ultrafast TR-XES and they were enabled by the unique combination of spectral resolution and collecting efficiency provided by TES sensors. In particular, the collecting efficiency of these devices allowed the quintet lifetime to be measured using 100-1,000 $\times$ fewer x-rays delivered to the sample than comparable work performed at a synchrotron.

Our TR-XAS and TR-XES results are the first use of TES sensors for ultrafast x-ray science. The execution of these complicated experiments has provided valuable lessons with regard to calibration, cross-talk, time stamping, and large-scale pulse processing. In the final part of the presentation, we discuss some of these lessons. We also discuss current work that includes (1) a TES spectrometer for time-resolved x-ray science at the Linac Coherent Light Source under development with SLAC and Stanford University, and (2) a significant upgrade to the table-top time-resolved x-ray apparatus located at NIST.

[1] G. C. O 'Neil et al, Journal of Physical Chemistry Letters 8, 1099 (2017)

[2] L. Miaja-Avila et al, Physical Review X 6, 031047 (2016)

category : Applications

O-85 An ultra-sensitive probe of local electronic structures using transition-edge sensor X-ray microcalorimeters at the Stanford Synchrotron Radiation Lightsource

Sang Jun Lee[1]

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Transition-edge sensor (TES) microcalorimeters provide a unique combination of good energy resolution and high efficiency, enabling a two-order-of-magnitude improvement over existing technology in sensitivity to defects, dopants, thin surface layers, and dilute solutes. We have developed an X-ray spectrometer based on an array of 240-pixel TESs using time-division multiplexed readout, and commissioned the spectrometer at the Stanford Synchrotron Radiation Lightsource (SSRL). This system is a powerful new tool to probe the local electronic structure of ultra-low concentration sites in biology, chemistry and materials science in the soft X-ray regime that are currently inaccessible due to the limited sensitivity of existing technology. We have performed a number of experiments to explore new paradigms in soft X-ray spectroscopy enabled by the TES spectrometer, achieving an extremely high sensitivity of sub-mM concentrations in aqueous/organic solvents, sub-percent sensitivity for monolayer films, and sensitivity to concentrations $< 10^{19}$/cm3 for defect and dopants. We present an introduction to our TES spectrometer and recent scientific results with dopants/defects in N-doped carbon and semiconductors, and measurements of active metal centers in bio-enzymes. We further describe our efforts towards seamless integration of the TES with X-ray science experiments in a synchrotron environment.

category : Applications

Application - Material analysis and others 2

O-86 A Search for the Decay of Metastable Th-229m with Superconducting Tunnel Junctions

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The desire to build ultra-precise nuclear clocks is currently driving the interest in accurate measurements of low-energy metastable nuclear states. The approach to embed the radioactive nucleus of interest inside the Superconducting Tunnel Junction (STJ) detector is particularly promising, because the measured decay energy does not depend on chemical effects. We have demonstrated this approach by implanting recoiling U-235m nuclei from the alpha decay of Pu-239 inside a STJ, and measuring the decay of the U-235m to the ground state. The STJ response is calibrated with an energy comb of photons from a pulsed 355 nm laser, and corrected for drift and offsets. An energy resolution of 2 eV FWHM and maximum count rates above 5000 counts/s allow calibration of the STJ to a precision of better than 10 meV. With the method proven, we began a search for the decay of metastable Th-229m, whose first excited nuclear state lies at only 7.6 $\pm$ 0.5 eV above the ground state. We show that high-resolution STJ photon detectors can reduce the uncertainty of the decay energy of U-235m by an order of magnitude, and discuss the first results from the search for the decay of Th-229m.

category : Applications

O-87 TES application to kaonic atom X-ray spectroscopy in a charged-particle beamline

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We are developing a new technique to study the strong interaction between a hadron and an atomic nucleus: high-resolution TES-based X-ray spectroscopy of hadronic atoms. A hadronic atom is a Coulomb-bound system of a nucleus, electrons, and a negatively charged hadron, such as a π^-, K^-, or anti-proton. It is formed when the negatively charged hadron beam produced at an accelerator is stopped in a target sample. The hadron is initially in a highly excited state, which then cascades by emitting electrons and X-rays. The hadron 's mass is much larger than the electron 's mass, so the atomic transitions of the hadronic atom are shifted to much higher energies than those of the corresponding standard atom. In addition, the strong interaction induces a shift and broadening of the atomic energy levels from their purely electromagnetic values. Thus, precise measurements of the X-ray-emission lines of a hadronic atom can reveal the hadron-nucleus strong interaction at zero kinetic energy.

In recent years, anti-kaonic nuclear states have been proposed and are attracting great interest as a new form of matter and a possible unique testing ground of dense nuclear matter. However, the existence of these states is still controversial, primarily due to the lack of precise enough measurements of the antikaon-nucleus strong interaction. Presently, we are preparing to measure the 3d-2p X-ray lines of kaonic helium-3 and helium-4 (6.2 keV and 6.4 keV, respectively) at the Japan Proton Accelerator Research Complex (J-PARC; Tokai, Japan). If we determined the strong-force shift in the helium 2p orbital to a precision of 0.2 eV, we could distinguish between the two leading antikaon-nucleus strong-interaction models. Semiconductor X-ray detectors have been used in previous experiments. Here, we plan to use a 240-pixel TES array of about 23 mm^2 collecting area with 4 μm thick Bi absorbers.

Our project represents the first attempt to use a TES-based X-ray spectrometer in a charged-particle beamline, and we have identified some challenges: 1) energy resolution is deteriorated by charged-particle passages; 2) a continuum background in the X-ray spectrum is generated by charged particles; 3) the science X-ray yield is expected to be very low, at 200 counts per week for the kaonic-helium-atom experiment.

Here we present the status of our project. In 2014, we performed a demonstration experiment at a pion beamline of the Paul Scherrer Institute (PSI; Villigen, Switzerland). We successfully measured the pionic-carbon 4-3 X-ray line at 6.4 keV with average energy resolution of 7 eV (FWHM). In June 2016, we tested the spectrometer under realistic experimental conditions at J-PARC K1.8BR beamline. Our two promising results were achieved energy resolution close to 6 eV and confirmation that the continuum background intensity caused by charged particles was low enough to allow observation of the dim kaonic-atom emission lines.

Finally, we describe the technical details of our scientific kaonic-atom X-ray spectroscopy campaign that is planned for early 2018.

HEATES collaboration

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category : Applications

O-88 Calorimetry of Heavy Charged Particle by superconducting transition edge sensor

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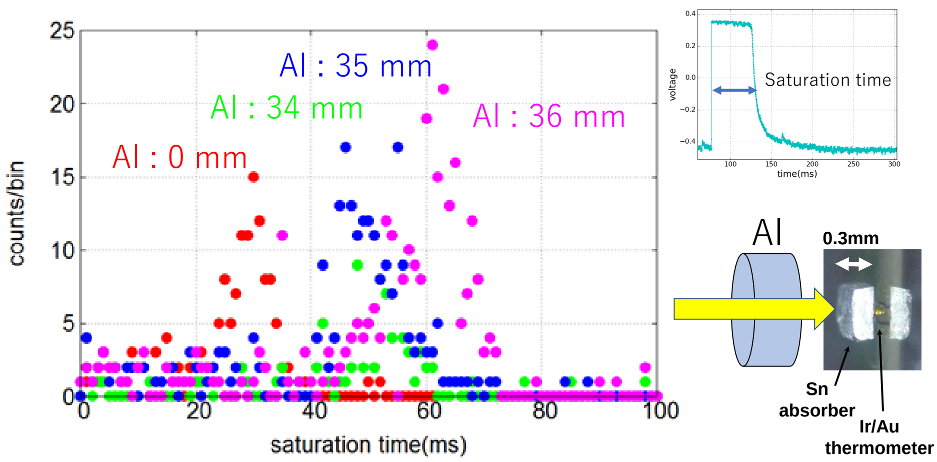
Precision measurement of the absorbed dose in heavy ion beam is required to realize the effective heavy ion cancer therapy. Calorimetry of the absorbed energy in heavy ion is very effective for minimizing of the uncertainty in dose rate measurement. Therefore we suggest the superconducting transition edge sensor (TES) for the precision heavy charged particle detector. Using the Ir/Au-TES coupled to a tin absorber, we have succeeded to detect the helium ions and the carbon ions which were injected from HIMAC (Heavy Ion Medical Accelerator in Chiba) in National Institute of Radiological Sciences. In the experiment of the helium ions beam injection (100 MeV/u), LET (Linier Energy Transfer) inside the tin absorber which is 0.3 mm thick, was adjusted by changing attenuation length of the aluminum attenuator. Although the incident signals are fully saturated because the temperature change is beyond the transition region, the saturation time of the signal is reflected the incident energy of the injected heavy ions. As a result we confirmed that the saturation time of the observed incident signal depends on the loss energy inside the tin absorber, which is calculated from the integral of LET. Based on these results, we consider that TES is the promising detector for precision calorimetry of heavy charged particle.



category : Applications

O-89 A few photon spectral imaging with photon microscope based on optical transition edge sensor

Daiji Fukuda[1], Kazuki Niwa[2], Kaori Hattori[3], Ryo Kobayashi[4], Takayuki Numata[5], Shuichiro Inoue[6]
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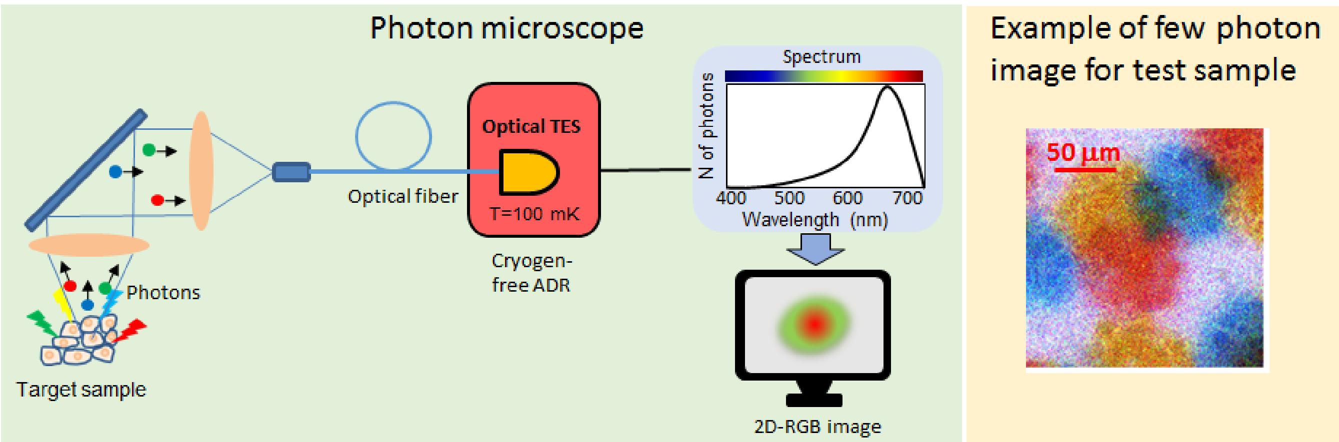
We report on the development of " a photon microscope ", which can measure single photon spectra from an object and construct two dimensional red-green-blue (RGB) and infrared images[1]. The photon microscope contains an optical system coupled to an optical fiber and a single pixel optical transition edge sensor (TES). The TES is fabricated with a Titanium-Gold bilayer embedded in an optical cavity structure to enhance detection efficiency[2]. Its effective spectral range is from the visible to the infrared (IR), up to 2800 nm, which is beyond the capabilities of other photodetectors. We have performed a demonstration of the photon microscope with a test sample of a three-color ink pattern. The test sample is illuminated by a heavily attenuated white light source from a halogen lump. The reflected photons are measured with the optical fiber coupled TES in the microscope. A spectrum of photons at each focus point on the sample is determined by measuring the energy of reflected photons from the sample with the TES. By scanning the sample, a RGB color image is constructed from the spectra. The attached figure shows an example of the obtained image for the test sample with 200 × 200 pixels, 1 μ m in the scan step and 50 ms/pixel in exposure time. The average photon number in the experiment is 20 photons/pixel, which corresponds to optical power of 0.15 fW. As shown in the figure, a high contrast RGB image was successfully obtained in the few photon regime, whereas only a black and white image could be obtained with a photon multiplier tube. This is a great advantage of the energy-dispersive TES photon detectors.

In life science research and industry, multiple biomolecules labeled with color, fluorescence, and/or chromic dye probes are observed in spectral imaging to determine the dynamic molecular mechanisms behind the biological phenomena. The results of the photon microscope show that TES is a very powerful tool for use in these spectral imaging applications.

References:
[1] K. Niwa and et al., Sci. Rep. 7, 45660; doi:10.1038/srep45660 (2017).
[2] D. Fukuda et al., Opt. Express 19, 870-875 (2011).



category : Applications

O-90 2d MMC arrays for high resolution x-ray spectroscopy

Andreas Fleischmann[1], Christian Enss[2], Loredana Gastaldo[3], Jeschua Geist[4], Daniel Hengstler[5], Sebastian Kempf[6], Mattheaus Krantz[7], Christian Schoetz[8], Tobias Gassner[9], Marc Oliver Herdrich[10], Renate Maertin[11], Thomas Stoehlker[12], Guenter Weber[13]

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The study of x-ray transition energies of highly charged ions allows for high precision tests of quantum electrodynamics (QED) in the presence of very strong electric and magnetic fields. These high precision measurements would greatly benefit from x-ray detectors characterized by high energy resolution, large dynamic range as well as high quantum efficiency over a large energy range to study precise positions and branching ratios of several atomic transitions. Low temperature metallic magnetic calorimeters (MMCs) are energy dispersive particle detectors, operated at temperatures below 50 mK, which fulfill all these requirements. MMCs use a paramagnetic temperature sensor to convert the temperature upon the absorption of a single x-ray photon into a change of magnetic flux in a SQUID.

We have developed a mobile and flexible platform to operate MMCs arrays in order to perform experiments at different facilities as the Experimental Storage Ring at GSI-Darmstadt or EBITs as the one at Max-Planck Institute for Nuclear Physics in Heidelberg. This system is based on a dry dilution refrigerator with a 40 cm long copper side arm, as extension of the mixing chamber experimental plate, suitable to locate the detectors as close as possible to the x-ray sources. The front of this long arm is equipped with an experimental platform which can host one 64-pixel array with the corresponding 8 SQUID chips, each carrying four front-end SQUIDs whose input coils are coupled to the 64 MMCs. The SQUIDs for the amplification of the front-end SQUIDs signals are located along the arm. This platform design was optimized for the use of the 2d array of the series maXs. The maXs design is flexible to be applied for detectors optimized for x-ray energies up to 20/30/200 keV, defining the name of the single designs to be maXs-20/30/200. Each array consists of 64 absorbers positioned in a square of 8*8 pixels covering a surface of 2*2 mm^2 / 4*4 mm^2 /8*8 mm^2 for maXs-20/30/200 respectively with a filling factor for the detection area of >90%. In this talk the challenges of the fabrication of the maXs arrays will be discussed and the performance achieved by these arrays will be presented.

A new large array covering 1 cm^2 has been developed to study the polarization of photon emitted in heavy ions atomic transitions which is suitable to be readout using a similar platform as for the maXs arrays. This detector chip features a 6x6 mm^2 large hole, in correspondence of the position of the Reyleigh scatterer consisting of a 20 μm thick copper foil, positioned in the center of silicon chip of about 1.7 cm^2 and surrounded by 64 pixels read out by 32 two-stage dc-SQUIDs. A first prototype of this design has been recently fabricated and preliminary tests are on-going. In this talk the design concept as well as the results from the first characterizations will be discussed.

Results obtained in proof of concept experiments will be discussed and an overview of the planned high precision measurements will be given.

category : Applications

Poster presentations

Category A : Sensor Physics & Developments

PA-1 Development of Thermal Kinetic Inductance Detectors suitable for X-ray spectroscopy

Andrea Giachero[1], Angelo Cruciani[2], Antonello D'Addabbo[3], Peter K. Day[4], Sergio Di Domizio[5], Marco Faverzani[6], Elena Ferri[7], Benno Margesin[8], Maria Martinez[9], Renato Mezzena[10], Lorenzo Minutolo[11], Angelo Nucciotti[12], Andrei Puiu[13], Marco Vignati[14]

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We report on the development of Thermal Kinetic Inductance Detectors (TKIDs) suitable to perform X-ray spectroscopy measurements. The aim is to implement MKIDs sensors working in thermal quasi-equilibrium mode to detect X-ray photons as pure calorimeters. The thermal mode is a variation on the MKID classical way of operation that has generated interest in recent years. TKIDs can offer the MKIDs inherent multiplexibility in the frequency domain, a high spatial resolution comparable with CCDs, and an energy resolution theoretically limited only by thermodynamic fluctuations across the thermal weak links.

Microresonators are built in Ti/TiN multilayer technology with the inductive part thermally coupled with a metal absorber on a suspended SiN membrane, to avoid escape of phonons from the film to the substrate. The mid-term goal is to optimize the single pixel design in term of superconducting critical temperatures, internal quality factors, kinetic inductance and spectral energy resolution. The final goal is to realize a demonstrator array for a next generation thousand pixels X-ray spectrometer.

In this contribution, the status of the project after one year of developments is reported, with detailed reference to the microresonators design and simulations, to the fabrication process, and to the obtained preliminary characterization results.

category : Sensor Physics & Developments

PA-2 Fabrication of antenna-coupled KID array for Cosmic Microwave Background detection

Qing Yang Tang[1], Peter S. Barry[2], Vasish Baungally[3], Amy Lowitz[4], Ryan McGeehan[5], Evan Mayer[6], Rong Nie[7], Ritoban Basu Thakur[8], Erik Shirokoff[9]

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Microwave Kinetic Inductance Detectors (MKIDs) have become an attractive alternative to traditional Transition Edge Sensor (TES) bolometers in the sub-mm and mm observing community due to its innate frequency multiplexing capabilities and simple lithographic processes. These advantages make MKIDs a viable option for the O(100,000) detectors needed for the upcoming Cosmic Microwave Background - Stage 4 (CMB-S4) experiment. We have fabricated dual polarization antenna-coupled MKID array in the 100GHz band optimized for CMB detection. The Al KIDs are made from evaporating Al on a high resistivity silicon substrate. The microstrip coupling the antenna and KID consists of growing Si3N4 between two layers of evaporated Nb. We present details of the fabrication process as well as a preliminary characterization of these devices with a cryogenic blackbody load.

category : Sensor Physics & Developments

PA-3 A dual polarization, 1.4 to 2.8 THz Kinetic Inductance Detector, with background limited sensitivity for future spaced-based far-infrared observatories

Juan Bueno[1], Ozan Yurduseven[2], Nuria Llombart[3], Stephen J. C. Yates[4], Vignesh Murugesan[5], Lorenza Ferrari[6], David J. Thoen[7], Andrey M. Baryshev[8], Andrea Neto[9], Jochem J. A. Baselmans[10]

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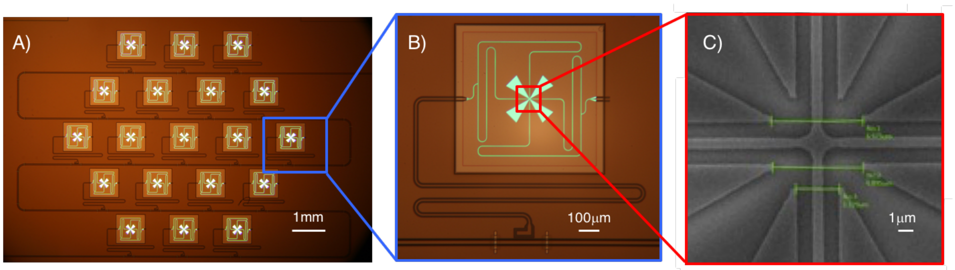
Future space based observatories for the far infrared, such as SPICA and the far infrared surveyor, will use actively cooled optics to reach the background flux of the universe. An imaging spectrometer for such an observatory requires large detector arrays that combine high optical efficiency, broad band and dual polarization radiation coupling at THz frequencies. We have developed a kinetic inductance detector (KID) coupled to a leaky lens antenna operating at a large bandwidth of 1.4 - 2.8 THz to fulfill these requirements. The device shows photon noise limited performance both in the phase and amplitude readout simultaneously, with a noise-equivalent power below 3×10^{-19} W/Hz$^{1/2}$ and good agreement between the measured and expected optical efficiency. The beam pattern and frequency response of the device are also measured, showing a good match with the simulations. The figure shows the dual polarisation leaky lens antenna coupled KID: A) Back and front illuminated optical image of a small detector array; B) Optical image of a single pixel. The bright square indicates the area of the membrane, where illumination from the chip backside brightens the image. The NbTiN section of the KID and the transmission line are fabricated on the solid substrate; C) SEM image of the centre of the antenna where the narrow Al line (1.2 – 0.8 – 1.2 μ m) can be resolved.



category : Sensor Physics & Developments

PA-4 Study on the electronic properties of Al thin-film superconducting resonators at low temperatures

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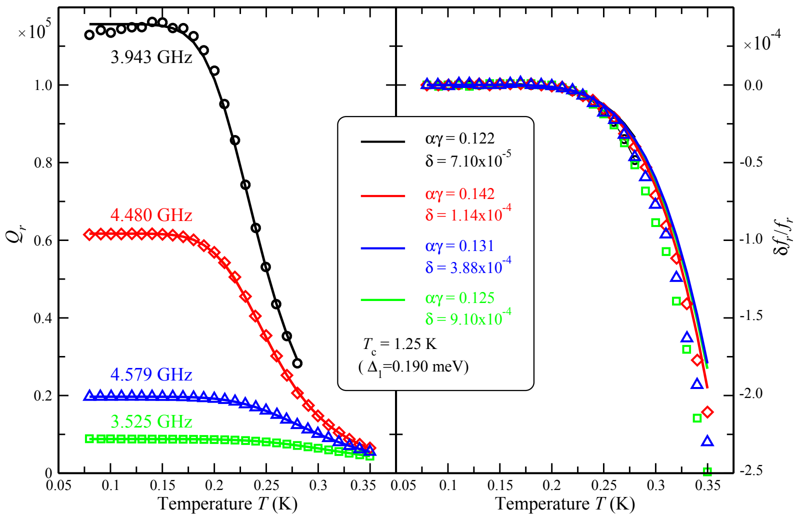
We have been studying the influence of quasiparticles in the electronic states broadened into the superconducting gap to the response of a superconducting resonator, which is a key element of the microwave kinetic inductance detector (MKID). We have derived the analytic expressions of the Mattis-Bardeen equations, which are valid for the complex conductivity, $\sigma_s = \sigma_1 + i\sigma_2$ at both the microwave frequency ($hf << 2\Delta_1$) and low temperature ($k_B T << 2\Delta_1$), using with a gap parameter which has a small imaginary part, i.e. $\Delta = \Delta_1 + i\Delta_2$, where $\Delta_2/\Delta_1 << 1$. We found that the σ_1 is dominated by the contribution of quasiparticles in the broadened states in the gap and shows saturation in decrease with decreasing temperature at low temperature. It was predicted that the conductivity quality factor defined by $Q_s = \sigma_2/\sigma_1$ saturates in increase with decreasing temperature at low temperature and reaches asymptotically Δ_1/Δ_2 at $T = 0$, since σ_2 does not strongly depend either on temperature or on the magnitude of Δ_2.

To verify the validity of the above-mentioned hypothesis, we prepared two types of Al thin-film superconducting resonators; one is made by dc magnetron sputtering and the other is made by thermal evaporation, and then the quality factor, Q_i, and resonance frequency, f_r, were measured in detail as function of temperature. The temperature dependence of the Q_i and f_r of the Al thin-film resonator made by thermal evaporation were very similar to those ever reported and well fitted by the analytic expressions of Mattis-Bardeen equations with the α and Δ as adjustable parameters, where α is a ratio of kinetic inductance to total inductance of the resonator.

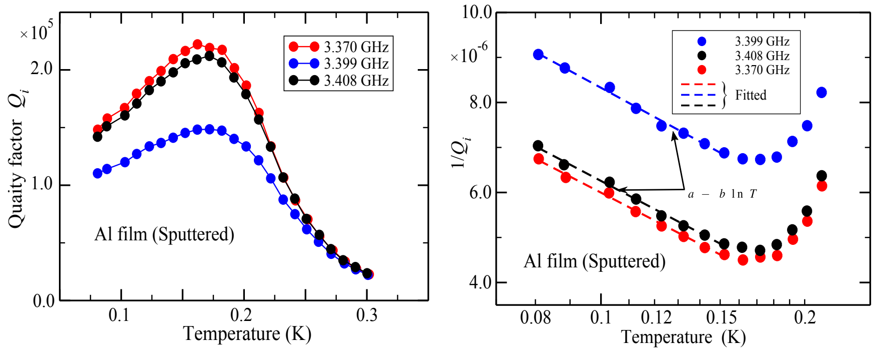
On the other hand, it was found that Q_i of Al thin-film resonator made by sputtering reaches a peak and then decreases when the temperature is lowered at well below T_c, although its f_r is very similar to those observed in the thermally evaporated Al thin-film resonators. From the plot of $1/Q_i$ as a function of temperature, it was found that $1/Q_i$ increases in proportion to $-\log(T)$ as the temperature goes down below the temperature where Q_i reaches the peak. Since it is supposed that $1/Q_i \approx \alpha(R_{res}/\omega_r L)$, where R_{res} and L are a residual resistance and inductance of the resonator at low temperature, respectively, and $\omega_r = 2\pi f_r$, it is indicated that the R_{res} has a $\log(T)$-temperature dependence, suggesting of the Kondo effect.

According to the results above mentioned, we confirmed that the electronic properties of the Al resonators at the temperature far below T_c are governed by residual quasiparticles occupying the broadened quasiparticle states at the bottom of the superconducting energy gap, not by the two level systems (TLS).

category : Sensor Physics & Developments



(a)



(b)

(a) Quality factor and fractional frequency change of the e-beam deposited Al thin-film resonator as a function of temperature
(b) Intrinsic quality factor and inverse of the intrinsic quality factor of the sputtered Al thin-film resonator as a function of temperature

PA-5 Dual-polarization LEKIDs for CMB Polarimetry

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We report on the development of dual-polarization, lumped-element kinetic inductance detectors (LEKIDs) optimized for cosmic microwave background (CMB) polarization studies. We have designed, fabricated, and tested 64-element modules where each element contains a profiled horn and two resonators sensitive to orthogonal polarizations. Therefore, there are 128 single-polarization detectors per module. The front-illuminated devices are fabricated on 160 μm thick silicon wafers, which are diced into square arrays and mounted inside the aluminum modules containing the horn arrays. The thickness of the wafer sets the distance to the backshort, which is used to optimize millimeter-wave radiation absorption. We will present the constraints and motivations behind the detector design and array architecture, and discuss solutions to problems encountered, such as methods for reducing the cross-polarization response and mitigating the effect of mechanical vibrations. We will present measured results from these arrays including responsivity, noise, and polarization selectivity. Finally, we will outline our work towards integrating a LEKID array comprised of four dual-polarization LEKID modules into the Atacama B-mode Search (ABS) instrument. This ABS project will allow us to demonstrate LEKIDs in a CMB polarimeter with on-sky measurements and test a multiplexing factor of 512.

category : Sensor Physics & Developments

PA-6 CALDER: Phonon-mediated Kinetic Inductance light detectors

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The development of large area cryogenic light detectors is one of the priorities of next generation bolometric experiments searching for neutrinoless double beta decay. The simultaneous read-out of the heat and light signals enables particle identification, provided that the energy resolution and the light collection are sufficiently high. CALDER (Cryogenic wide-Area Light Detectors with Excellent Resolution) is developing phonon-mediated silicon light detectors using KIDs, with the goal of sensing an area of 5x5 cm^2 with a resolution of 20 eV RMS. We present the latest results obtained with aluminum chips and with newly developed multilayer titanium-aluminum chips featuring a remarkable sensitivity.

http://www.roma1.infn.it/exp/calder

category : Sensor Physics & Developments

PA-7 Mitigation of cosmic ray effect on Microwave Kinetic Inductance Detectors

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One of the main issues for space borne observatories is the interaction between radiation detectors and cosmic ray particles. Approximately 90 % of the cosmic rays in space consist of protons produced by solar activity or other galactic sources. The energy spectrum of the cosmic rays has a peak at around 200 MeV with quite a broad energy distribution. Therefore, the cosmic rays can easily penetrate the satellite structure and reach the detectors. The incident particles interact with the detectors and deposit a fraction of their energy through ionization. The energy deposition in a 350 μm Sapphire / Si substrate, which is usually used for the detectors, is simulated to have a peak at around 100-200 keV. The deposited energy causes a cascade of high-energy phonons that spread inside of the detectors, trigger the detectors ’ response, and create glitches in the data stream. These glitches lead to dead time of the detectors during observation.

We investigate possible solutions to mitigate the dead time caused by cosmic ray events for Microwave Kinetic Inductance Detector (MKID) arrays. We prepared 4 types of Al-NbTiN hybrid MKID arrays: 1), 2) Arrays with a capacitive mesh of TiN on backside (T_c = 3.2 K and 0.8-1.2 K, respectively); 3) Array with SiN membrane structure and no backside TiN mesh layer; and 4) Reference array without any back side layer or membrane structure. All arrays are made on a 55 mm x 55 mm x 350 μm chip and consist of 961 MKIDs. For arrays type 1 and 2, the idea is that high-energy of phonons are down-converted efficiently in the TiN layer to phonon energies below the gap energy of aluminium, which makes them impossible to be detected by the MKIDs. For type 3, the aluminium of the MKID is on top of SiN membranes and physically isolated from the substrate.

We measured cosmic ray events with those arrays in the laboratory, where cosmic rays consist mainly of muons. Cosmic ray events were extracted from 30 minutes of data by a 2-step iterative procedure based upon the second derivative of the time ordered data of the phase response of MKIDs. As a result, the array dead time caused by cosmic rays was reduced to 80 %, 20 %, and 3 % of the dead time with respect to the reference array (4) for type 1, 2 and 3, respectively. We estimated the dead time fraction of the MKIDs arrays when operating them in an L2 or similar far-Earth orbit by simply scaling cosmic ray event rates on the arrays to the measured rate of 5 /s/cm^2 by Planck satellite at L2 orbit: they are 13 %, 4 % and 0.5 % for type 1, 2, and 3, respectively.

category : Sensor Physics & Developments

PA-8 Development of an MKIDs-Based THz Superconducting Imaging Array (TeSIA) at 0.85 THz

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Dome A, the highest point of the cold and dry Antarctic ice sheet, offers the best access to atmospheric windows at THz/FIR wavelengths on Earth. China is planning to build a 5-m THz telescope (DATE5) at Dome A. To fulfill the DATE5 's scientific objectives, we are developing a THz superconducting imaging array (TeSIA). The TeSIA, based on Aluminum MKIDs, will be operating at 0.85 THz (350-micron window) with a pixel number of 32 × 32 and back-ground limited sensitivity (NEP) of 10-16W/Hz0.5. Detailed system design and performance of TeSIA will be presented.

category : Sensor Physics & Developments

PA-9 Titanium nitride for kinetic-inductance detectors: a problematic material or an engineering opportunity?

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Titanium nitride and related materials with a large normal-state resistivity have been proposed and used for kinetic inductance detectors at various wavelengths from near-IR to millimeter. The expected advantages of these materials are manifold, e.g. a tunable critical temperature, a large kinetic inductance fraction, and better matching to the incident radiation due to the large resistivity. However, whereas even large (2 ” diameter) telescope-ready detector arrays have come into sight, the detailed behavior of TiN detectors still shows many puzzling features, at odds with the perfectly understood behavior of “ conventional ” aluminum KIDs.

In this contribution I will give an overview of the different studies that have been performed on TiN resonators. In this overview, I will emphasize the unconventional behavior of the material, and the differences with aluminum. Among these differences are a smooth detection gap edge, an increasing sensitivity with optical power, and a quality factor that does not change with loading. I will argue that these differences are unavoidably linked to the large normal-state resistivity of the material and its accompanying intrinsic electronic inhomogeneity, and that they should be fully taken into account when considering this material for detectors.

Finally, I will discuss the status of TiN for use in (sub)-mm instruments and I will argue that some of the observed unconventional behavior might in fact prove an engineering opportunity for ground-based observation.

category : Sensor Physics & Developments

PA-10 Update on TKIDs: Thermal Kinetic Inductance Detectors for X-ray imaging spectroscopy

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Thermal Kinetic Inductance Detectors (TKIDs) are MKIDs that operate as microcalorimeters by suspending their inductor and a separate photon or particle absorber on a freestanding Si3N4 membrane. They allow the kinetic inductance detector principle to be extended to detect and characterize X-rays and higher energies while retaining the unique multiplexibility MKIDs offer, promising the potential to scale up to kilo- or even mega-pixel detector arrays. We will present our recent progress with improving and optimizing our TKID prototype design and characteristics. We investigated both sub-stoichiometric TiNx and co-sputtered WSix for TKIDs and will compare their respective advantages and disadvantages in respect to detector performance and fabrication. We will also discuss our first experiments varying the TKID readout frequency in order to utilize smallest possible heat capacities to allow to further increase energy resolution in tighter energy bands.

category : Sensor Physics & Developments

PA-11 Projection of Cosmic Microwave Background anisotropy measurements for Microwave Kinetic Inductance Devices

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The Stage 4 Cosmic Microwave Background (CMB-S4) collaboration will bring together tens of telescopes, each with 1E5 low-temperature low-noise detectors, to measure the CMB with sub-nK sensitivity across decades of angular scales (1E-1 to 1E2 degrees). These measurements will enable deriving extremely precise constraints on the matter-energy budget and dynamics of the universe, and probe several interesting early universe inflationary theories. Microwave Kinetic Inductance Devices (MKIDs) are poised to allow for massively and natively multiplexed detectors arrays, improving the current multiplexing factor by over an order of magnitude, thus enabling for 1E5 detectors required for CMB-S4. In this proceeding we forecast what the status of the present generation of MKIDs implies for CMB measurements. We use various MKID noise spectra and simulate a telescope scan strategy which projects the detector noise onto the CMB sky. We then analyze the simulated CMB + MKID noise to understand how MKID properties, such as responsivity, low frequency and white noise levels, affect the various features of the CMB, such as the acoustic peaks and the damping tail. Based on this we develop a framework connecting the MKID characteristics with scan strategies, to the type of CMB signals we may probe with such detectors.

category : Sensor Physics & Developments

PA-12 AlMn LEKIDs for millimeter-wave astronomy below 100 GHz

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We report the development of manganese-doped aluminum lumped-element MKIDs (LEKIDs) with high internal quality factor, high uniformity, and tunable critical temperature for millimeter-wave astronomy below the gap of aluminum. Manganese-doped aluminum (Al-Mn) has a critical temperature that can be tuned by varying the manganese concentration. It is an attractive material for MKIDs if the internal quality factor remains sufficiently high. Manganese loses its magnetic character in lightly doped Al-Mn, and the resulting films have been shown to retain a relatively sharp density of states, with only a small broadening of the superconducting gap, as expected for non-magnetic impurities. We have fabricated and tested a prototype eight-element array of Al-Mn LEKIDs. The manganese concentration of 900 ppm results in a measured critical temperature of 694 mK. We measure a quasiparticle lifetime of 60 microseconds using light pulses from a 1550 nm light-emitting diode. The internal quality factor of this prototype array is greater than 2×10^5, which is high enough for millimeter-wave astrophysical observations. We also measure deviations of microwave surface impedance from the Mattis-Bardeen theory, suggesting that a small smearing of the gap needs to be taken into account in the theory.

category : Sensor Physics & Developments

PA-13 Antenna-coupled lumped-element kinetic inductance detectors for CMB observations

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Focal plane arrays consisting of low-noise, polarization-sensitive detectors have made possible the pioneering advances in the study of the cosmic microwave background (CMB), and have provided exquisite constraints on the origin, content and evolution of the Universe. To make further advances, the next generation of CMB experiments will require a substantial increase in the number of detectors compared to current instruments. Arrays of kinetic inductance detectors (KIDs) provide a possible path to realizing such large format arrays owing to their inherent multiplexing advantage and relative simplicity. In this proceedings, we report on the design and performance of a novel variant of the traditional KID design; the antenna-coupled lumped-element KID. This design employs a polarization-sensitive twin-slot antenna behind an anti-reflection coated hemispherical alumina lens, and incident power couples into a niobium microstrip line that guides the power into the inductive section of an aluminum KID. The optical signal then breaks Cooper pairs in the Al inductor, and modifies the resonant frequency and quality factor of the KID. We will present preliminary results from dark and optical characterization of a small seven-element prototype array and compare to the expected modeled performance, and discuss ongoing progress toward a field-ready kilo-pixel array.

category : Sensor Physics & Developments

PA-14 Coherent excited states in superconductors due to a microwave field - microscopic perspective on microwave nonlinearity

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How is the superconducting state modified by a current, i.e., when the condensate is moving? Working with superconductors in strong microwave fields (MKIDs, parametric amplifiers), we often ask ourselves this question, either explicit or unknowingly.

The answer is well known for the case of a dc current flowing in a superconducting wire. For a dc current, the Cooper pairs gain a finite momentum, which leads to the suppression of the superconducting properties of the wire. The superconducting order parameter $|\Delta|$ is reduced and the sharp BCS singularity near the gap is smeared. This effect leads to the well-known I^2 nonlinearity of the inductance. For microwave frequencies, the dc-derived I^2 nonlinearity is usually assumed, which is a reasonable approximation for some practical cases. However it does not address what happens on a microscopic level to the superconductor when exposed to a microwave field, which is, in contrast to a dc field, quantised by the microwave photon energy.

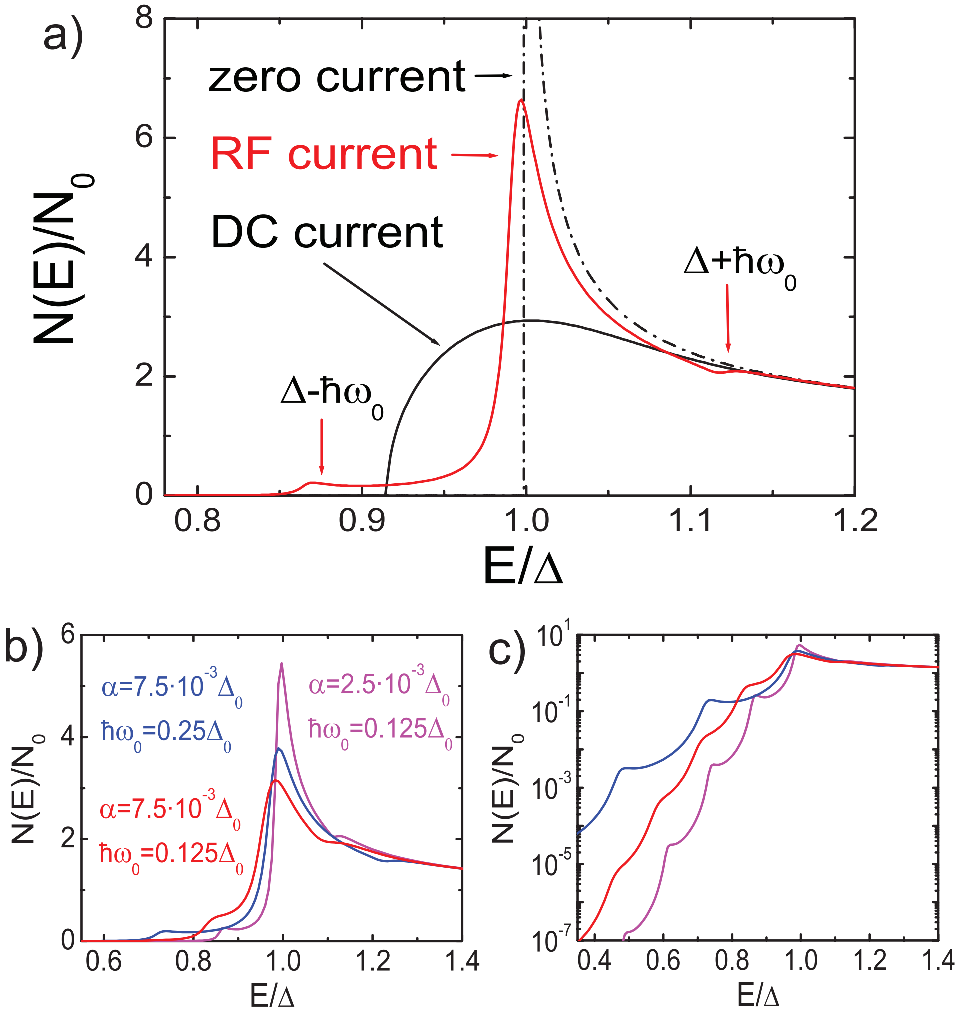
We describe theoretically the depairing effect of a microwave field with frequency ω_0 on diffusive s-wave superconductors [1]. In contrast to dc depairing, the density of states acquires, steps at multiples of the photon energy $\Delta \pm n\hbar\omega_0$. Fig. a compares the density of states as a function of energy (E) for dc and rf fields. Fig. b shows the density of states for different field strengths and microwave energies. On top of that, the density of states shows an exponential-like tail in the subgap regime (clearly seen on log-scale in Fig. c). We show that this ac depairing explains the measured frequency shift of an aluminium superconducting resonator with microwave power at low temperatures [2].

For MKIDs this shows that not only the distribution function of the resonator is affected by the microwave field [2], but also the density of states changes, which becomes apparent especially at low temperatures. The exponential tail in the density of states provides a clue what triggers the microwave absorption (leading to excess quasiparticles) at low temperatures. For parametric amplifiers this work does not only give a rigorous basis for understanding the nonlinearity, but may also lead to new functionality or exotic phenomena due to the acquired steps in the density of states of the superconductor.

[1] A. V. Semenov, I. A. Devyatov, P. J. de Visser, and T. M. Klapwijk, Phys. Rev. Lett. 117, 047002 (2016)

[2] P. J. de Visser, D. J. Goldie, P. Diener, S. Withington, J. J. A. Baselmans, and T. M. Klapwijk, Phys. Rev. Lett. 112, 047004 (2014)

category : Sensor Physics & Developments


a)
zero current
RF current
DC current
Δ+ħω0
Δ-ħω0
N(E)/N0
E/Δ
b)
α=7.5·10^-3Δ0
ħω0=0.25Δ0
α=2.5·10^-3Δ0
ħω0=0.125Δ0
α=7.5·10^-3Δ0
ħω0=0.125Δ0
N(E)/N0
E/Δ
c)
N(E)/N0
E/Δ

PA-15 Operation of a superconducting nanowire in two detection modes: KID and SPD

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We present the characterization of a superconducting nanowire that can be operated in two detection modes: i) as a kinetic inductance detector (KID) or ii) as a single-photon detector (SPD). Two superconducting nanowires developed for use as single-photon detectors (SNSPDs) are embedded as the inductive (L) component in resonant inductor/capacitor (LC) circuits coupled to a microwave transmission line. The capacitors are low loss commercial chip capacitors and limit the internal quality factor of the resonators to approximately $Q_i = 200$. The resonator quality factor, $Q_r \simeq 25$ is dominated by the coupling to the feed line and limits the detection bandwidth to on the order of 1 MHz. When operated in KID mode, the detectors are AC biased with tones at their resonant frequencies of 46 and 93 MHz. In this mode, a single photon produces a hot spot that does not turn an entire section of the line normal but only increases the kinetic inductance. The optical response of this detector, or superconducting nanowire resonator (SNR), in linear-mode to 1.3 μm photons is characterized by a noise equivalent power (NEP) of approximately 10^{-14} W/rtHz at an operating temperature of 2.8 K. At low optical loading levels, the noise is dominated by the cryogenic low noise amplifier (LNA) with a noise temperature of 4 K. The noise was characterized with a homodyne system by recording the tone and transmitted signals on an oscilloscope and mixing the results in software. When operated as an SPD in Geiger-mode, the resonators are DC biased through cryogenic bias tees and each photon produces a sharp voltage step followed by a ringdown signal at the resonant frequency of the detector which is converted to a standard pulse with an envelop detector. The internal quantum efficiency (IQE) in Geiger mode is obtained by determining the number of photons that are counted for a given LED current bias at a given device current bias and comparing that with the absorbed power estimated from the frequency shift and the excess photon noise in linear-mode.

category : Sensor Physics & Developments

PA-16 A Superconducting Phase Shifter and On-Chip Fourier Transform Spectrometer for W-Band Astronomy

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Accessible from the ground, W-Band (75-110 GHz) contains a plethora of information about star formation, galaxy evolution, and the cosmic microwave background. We present the design, fabrication, and characterization of a dual purpose superconducting microstrip circuit that facilitates the next generation of high sensitivity astronomical observations in this regime. Signal amplification is a universal need for all astronomical instruments. In phase shifter mode, our device provides the means to measure the relative phase shift between two signals propagating down two identical NbTiN microstrip lines subject to different DC bias. Measurement of the current-dependent non-linear phase shift due to non-linear kinetic inductance provides the upper limit to the achievable gain of a NbTiN kinetic inductance parametric amplifier (KIP). Compared to current transistor-based low noise amplifiers, KIPs provide significant improvements in bandwidth, dynamic range, and noise performance. Applying this new amplifier technology would greatly increase both the scanning efficiency and sensitivity of W-Band receivers. In addition, our device can also operate as an on-chip Fourier Transform Spectrometer (FTS) that provides continuous phase shift and parametric gain.

To deliver W-Band signals into our cryogenic testbed for circuit characterization, we have developed a custom high frequency waveguide feedthrough which minimizes conductive heat load on the cooling system, delivers sufficient signal power to our device under test, and avoids stray light issues that complicate free-space propagation solutions. Our feedthrough is comprised of copper circular waveguide sections, thin Mylar vacuum windows, and conical horn thermal breaks. Measurements at room temperature indicate electromagnetic losses well within our loss budget of 30 dB. We will integrate this feedthrough into our cryostat and perform full system calibration at 4 K before using it to characterize the optical response of our W-Band phase shifter and FTS circuit.

category : Sensor Physics & Developments

PA-17 A broadband antenna for on-chip integrated spectrometers at 300-900 GHz

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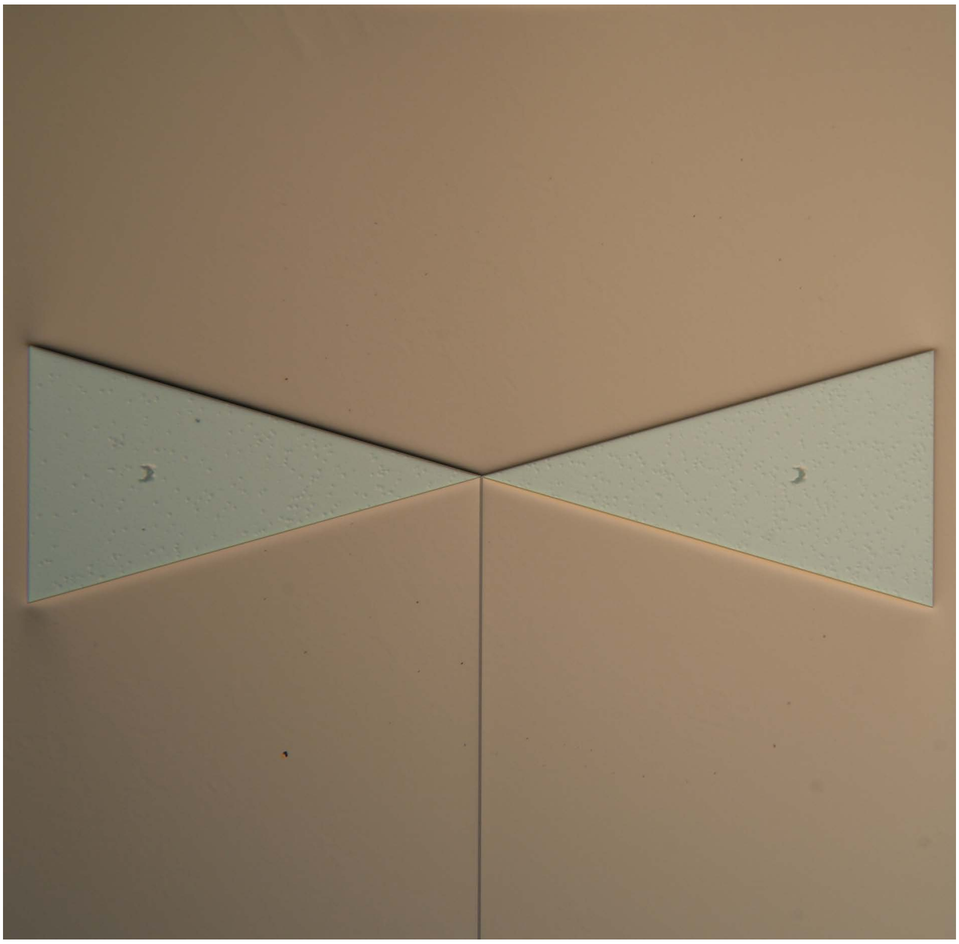
The redshift mapping of sub-mm galaxies requires broad band spectrometers. Highly integrated on-chip spectrometers based on KIDs (Kinetic Inductance Detectors) are a prime candidate for this type of experiment and different designs have been shown to work using narrow band prototypes. One of the challenges in the step from a narrow band to a broad band spectrometer is the efficient coupling of incoming radiation to the detectors over the whole frequency range.

We designed an antenna based on the leaky-wave principle with a high efficiency over a bandwidth of 300 - 900 GHz. In a spectrometer, the antenna is coupled to a superconducting transmission line (co-planar waveguide or microstrip) which is connected to an on-chip filterbank. The whole spectrometer is therefore fully integrated on a single chip. We fabricated a prototype of the antenna and characterized it using a single MKID directly coupled to the Antenna.



category : Sensor Physics & Developments

PA-18 Development of the Kinetic Inductance Detector Spectrograph (KIDSpec) prototype

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KIDSpec is a proposed medium-resolution Visible/NIR spectrograph using an array of Microwave Kinetic Inductance Detectors (MKIDs). The intrinsic energy resolution of the MKIDs (R 10-20) is used to distinguish photons from multiple orders to obtain a higher final spectral resolution (R ¿ 1000). We present the design and current build status of the KIDSpec prototype which will be used to demonstrate the order sorting capabilities of the MKIDs. The detectors are PtSi devices cooled to ¡100mK using an Adiabatic Demagnetisation Refrigerator. Using a benchtop setup with a reflective diffraction grating and a broadband light source, we illuminate the MKID pixels with light from multiple diffraction orders. An optical fibre couples the dispersed light to the detectors in the cryostat. The readout is based on a Reconfigurable Open Architecture Computing Hardware (ROACH) board. We also present numerical simulations of the spectral reconstruction capability of KIDSpec which has been simulated using Python.

category : Applications

PA-19 MoBiKID - Kinetic Inductance Detectors for upcoming B-mode satellite missions

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Our comprehension of the dawn of universe grew incredibly during last years, pointing to the existence of the cosmic inflation. The primordial B-mode polarization of the Cosmic Microwave Background (CMB) represents a unique probe to confirm this hypothesis. The detection of such small perturbations of the CMB is a challenge that will be faced in the near future by a new dedicated satellite mission.

MoBiKID is a new project, funded by INFN, to develop an array of Kinetic Inductance Detectors able to match the requirements of a next-generation experiment. The goal of the project is to reach a Noise Equivalent Power better than 5 $aW/Hz^{0.5}$. The detectors will be designed to minimize the background induced by cosmic rays, which could be the main limit to the sensitivity.

I will present the current status of detectors development and the next planned steps to reach the goal of this project.

category : Sensor Physics & Developments

PA-20 Electron-phonon coupling in Ti/TiN MKIDs multilayer microresonator

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Over the last few years there has been a growing interest toward the use of superconducting microwave microresonators operated in quasi-thermal equilibrium mode, especially applied to single particle detection. Indeed, previous devices designed and tested by our group with X-ray sources in the keV range evidenced

that several issues arise from the attempt of detection through athermal quasiparticles produced within direct strikes of X-rays in the superconductor material of the resonator.

In order to prevent issues related to quasiparticles self-recombination and to avoid exchange of athermal phonons with the substrate, our group focused on the development of thermal superconducting microresonators. In this configuration resonators composed of multilayer films of Ti/TiN sense the temperature of an absorbing material. To maximize the thermal response, low critical temperature films are

preferable. By lowering the critical temperature, though, the maximum probing power bearable by the resonators decrease abruptly because of the weakening of the electron-phonon coupling. A proper compromise has to be found in order to avoid signal to noise ratio degradation. In this contribution we report the latest measurement of the electron-phonon coupling and the latest designs of our thermal devices.

category : Sensor Physics & Developments

PA-21 Prototype high angular resolution LEKIDs for NIKA2

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The resolution of a detector is determined by the size of the effective beam resulting from the convolution of the diffraction pattern created by the instrument optics with the pixel transfer function. This resolution is expected to approach the telescope diffraction limited resolution with small pixels. The current 1 mm arrays of the NIKA2 instrument consist of 1140 lumped element kinetic inductance detector (LEKID) pixels for each polarization. In current design, an inductor size of 1.6 mm, which is equivalent to 10.4 " angular resolution when projected on the sky, is chosen to cover the full 6.5 ' field-of-view. During commissioning, the angular resolution of the instrument has been demonstrated to be very close to this designed value. To further approach the diffraction limit of the IRAM 30-m telescope (8.5 " in the 1.2 mm band), a compact Hilbert-type LEKID array is designed with a 1 mm inductor size. The array is fabricated with 20 nm thick aluminum and contains 1312 LEKIDs covering a 60 mm diameter circle on the NIKA2 focal plane, which corresponds to a field-of-view of 4.9 '. We present the design and characterization of this array, and compare it to the performance of the current NIKA2 1 mm arrays. The design could easily be expanded to cover the full field-of-view with 2400 pixels once the readout bandwidth will be doubled.

category : Sensor Physics & Developments

PA-22 Polarization filter for microstrip lumped-element kinetic inductance detectors

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Lumped Element Kinetic Inductance Detectors (LEKIDs) have a broad potential for their future use in Cosmic Microwave Background radiation (CMB) experiments. However, for these experiments, polarization sensitivity is a major requirement and LEKIDs based on meander inductors exhibit a cross polarization around 30%.

LEKIDs consist of series inductance-capacitance resonators coupled to a feed line. Coplanar waveguide (CPW), coplanar striplines (CPS) and microstrip (MS) have been tested for the feed line configuration in order to decrease coupling dispersion and avoid parasitic propagating modes. MS configuration, which consists on shield loops around each resonator and a ground plane on the bottom side of the wafer, has already shown good performance and is, for instance, the configuration integrated in NIKA 2 arrays [1].

In this work, continuous ground plane of the MS has been replaced with parallel lines in order to be used as a polarizer. Microwave simulations show that if the spacing between lines is small enough compared to the resonant frequency wavelength, it acts as an effective ground plane with no influence on the electromagnetic performance. Several devices have been fabricated in order to test the polarizer-ground plane and preliminary experiments show a mitigation of the cross polarization to 2 %.

[1] Calvo, M. et al. “ The NIKA2 instrument, a dual-band kilopixel KID array for millimetric astronomy ”, J. Low Temp. Phys, 184: 816 (2016).

category : Sensor Physics & Developments

PA-23 Dual-color antenna-coupled LEKID for next generation CMB focal planes

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We present an antenna coupled Kinetic Inductance Detector for millimeter wave astronomy. Next generation telescopes for observing the Cosmic Microwave Background are demanding in terms of number of detectors and focal plane area filling efficiency. Moreover, foreground reduction in B- Mode polarimetry requires sky observation with multiple frequency bands. In this context KIDs are promising technology because of their large multiplexing rate, while antenna coupling can provide multi-band and dual-polarization solutions in compact design.

We have developed polarization sensitive dual band pixel at 140 GHz and 160 GHz with a bandwidth of almost 10

We will present performance estimations with numerical simulation software (CST, Sonnet) and preliminary measurements of sample devices.

category : Sensor Physics & Developments

PA-24 Optimisation of an antenna-coupled LEKID for future ground-based CMB experiments

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Optical coupling to a lumped-element kinetic inductance detector (LEKID) via an antenna and transmission line structure enables compact, polarisation sensitive multichroic pixels to be realised in an architecture easily optimised for sensitivity and multiplexing performance. Here we present a robust study into the optimisation of an antenna-coupled LEKID for applications in cosmic microwave background (CMB) experiments. Future ground-based B-mode studies will require thousands of detectors performing at the photon noise limit under typical optical sky loading. We combine electrodynamics of type-I superconductors and transmission line theory to investigate the pair breaking efficiency of an optical signal coupled to a LEKID meander via a microstrip transmission line to yield the optimum length of meander required for full absorption. We then consider the performance of a LEKID under optical load, exploring the relationship between quality factor, quasiparticle lifetime and other limitations allowing for ideal detector parameters to be determined when incorporated into a large array with high multiplexing ratios. We discuss the experimental data acquired to corroborate our model and the steps required to extend this model to support to bi-layer materials with reduced band-gaps to enable detection at wavelengths beyond 3mm.

category : Sensor Physics & Developments

PA-25 Investigation of Single Crystal Niobium for Microwave Kinetic Inductance Detectors

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During last decade, Microwave Kinetic Inductance Detectors (MKIDs) have been increasingly investigated in the field of astrophysical observations. The Advanced Technology Centre (ATC) of National Astronomical Observatory of Japan is developing MKIDs for future wide field-of-view observations.

In this contribution, we present our study on MKIDs made of single crystal niobium with 150 nm of thickness. The entire fabrication of the detector is carried out in the ATC clean room. The Nb layers have been sputtered on sapphire wafer with a large 4″ target and a high speed of 1.7 nm/s. The chamber vacuum was maintained to 10^{-6} Pa and the substrates were heated up to 800 degC during the deposition.

First, the DC properties of the single crystal Nb layer (Tc, rho and RRR) have been characterized using a helium bath (T = 4.2 K). A critical temperature of 9.4 K and a resistivity of 15.8 μOhm.cm have been measured for a thickness of 150 nm. The residual resistivity ratio has reached values ranging from 40 to 80.

Then, the MKIDs made with this single crystal Nb have been characterized in a 0.1 K dilution refrigerator. An internal quality factor Qi was measured up to 10^6 and the two level system effects are found in the shift of resonance frequency with increasing temperature up to 1.9 K. The Qi reaches its maximum value under -70 dBm readout power at 800 mK. The measurement of the noise power spectral density of these MKIDs gives a low value of -95 dBc/Hz from 100 Hz to 100 kHz.

This study on MKID made of single crystal Nb has been compared to a similar device made of polycrystalline Nb in order to show the interest of using a single crystal structure material for superconducting micro-resonators.

category : Sensor Physics & Developments

PA-26 Design of Near Infrared and Visible Kinetic Inductance Detectors using MIM Capacitors

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Abstract

We are developing superconducting microwave kinetic Inductance detectors (MKIDs) to operate at near infrared and optical wavelengths for astronomy applications. In order to efficiently meet with the requirements of some astronomical applications, the KID size should be diminished typically from hundreds to a few tens of μ m. Successful titanium nitride (TiN) optical Lumped-element KID using an inductive meander with an interdigital capacitance have been developed [1]. These pixels feature, for example, a size of 130 × 130 μ m and are coupled to coplanar transmission line (CPW) to operate at around 4 GHz. For operation in the band 1-2 GHz where the readout electronics system is easier to implement, the pixel can easily reach a size of 300 × 300 μ m. In this case, the interdigital capacitance size can represent up to 90 % of the overall pixel size. We propose to replace the interdigital capacitor by a MIM (Metal-Insulator-Metal) capacitor which has the advantage of presenting a larger capacitance value within a much smaller space, which can also be adjusted by choosing dielectrics with high permittivity (ε r).

In this paper, we will present designs and simulation results of the reduced TiN-based LEKID using MIM. The pixel will occupy a space of typically 100x85 μ m which is 9 times less than a typical pixel size using the interdigital capacitor for frequency operation below 2 GHz.

[1] Meeker, S.R., Mazin, B.A., Jensen-Clem, R., Walter, A.B., Szypryt, P., Strader, M.J., and Bockstiegel, C.Design and Development Status of MKID Integral Field Spectrographs for High Contrast Imaging. Proc.

AO4ELT 4, 2015.

category : Sensor Physics & Developments

PA-27 A TiN/Ti/TiN Trilayer Lumped Element KID Array for CMB Polarimetry at 100 GHz

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Kinetic inductance detectors (KIDs) are a promising technology for astronomical observations over a wide range of wavelengths in the mm to submm regime and beyond. Simple fabrication, with as little as a single lithographic layer, and passive frequency-domain multiplexing, with readout of up to 1000 detectors on a single line with a single cold amplifier, make KIDs an attractive solution for high pixel-count detector arrays. In this presentation we describe the design, fabrication, and testing of a 20-pixel prototype array of TiN/Ti/TiN trilayer kinetic inductance detectors intended for cosmic microwave background (CMB) polarimetry in a band centered at 3 mm (100 GHz), which is an important band for CMB observations from the ground. We discuss the theoretical performance of idealized KIDs compared to idealized superconducting transition edge sensors (TESs), describe the lumped-element, integrated groundplane resonator design, and present measurements of dark performance and optical response.

category : Sensor Physics & Developments

PA-28 Ultra Low-NEP FIR LEKIDs: a Three-Pronged Approach

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Future generations of far-infrared (FIR) telescopes such as the Origins Space Telescope will need detectors with NEPs on the order of 5x10^{-20} W/sqrt(Hz) in order to be limited by astrophysical backgrounds only. FIR detectors that can robustly reach this limit have not yet been demonstrated. We present updates on three arrays of around 100 kinetic inductance detectors (KIDs) that use a variety of techniques for achieving these low NEPs. Our first arrays (presented at LTD 2015) are low-volume Al/TiN bilayer devices that reached an NEP of 2x10^{-17} W/sqrt(Hz) at 350 um and showed evidence for excess photon loading and significant 1/f noise. Our second arrays (presented at SPIE 2016) are low-volume Al-only devices and are of a similar design to the bilayer devices. These devices reached an NEP of 10^{-17} W/sqrt(Hz) at 350 um and also showed evidence of excess photon loading, but no 1/f noise. Our third array (simulations of which were presented at SPIE 2016) use phonon recycling, the process of trapping recombination phonons below the detector active area, to increase sensitivity. We present strategies to reduce the excess photon loading seen in arrays one and two, and preliminary tests on the phonon recycling arrays.

category : Sensor Physics & Developments

PA-29 Optimization of geomagnetic shielding for MKIDs mounted on rotating cryostat

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Observational confirmation of the cosmic inflation theory is one of the most important subjects in the modern cosmology. Existence of a period of exponential expansion of the space-time metric in the very early universe, inflation period, provides solutions for problems left in the standard Big Bang model of the cosmology. One of the consequences of the inflation is an emergence of the primordial gravitational waves, which imprint characteristic spiral patterns (B-modes) on the polarization map of the Cosmic Microwave Background (CMB) radiation.

GroundBIRD is a ground based CMB experiment which aims to detect the CMB B-modes polarization imprinted by the gravitational waves. One of the key features of the GroundBIRD telescope is the rotating scan in azimuth direction at 20 rpm to suppress the baseline drift of the detector response caused by 1/f atmospheric fluctuation. We employ Microwave Kinetic Impedance Detectors (MKIDs). MKID is a high sensitive superconductive direct detector. Its extremely fast time response direct detectors makes possible to realize this high-speed scan.

Shielding of MKIDs from geomagnetism is an important subject. If the detector traps magnetic field in a process of the phase transition from normal to superconducting state, the sensitivity of the detector is dramatically reduced. To solve this problem significant reduction of the magnetic field at the focal plane by using magnetic shield with high permeability is designed. Our cryostat is composed by cavity at 4 Kelvin, 40 Kelvin, and 300 Kelvin. We set magnetic shields on each cavity.

We used MS-FR made by Hitachi-material as high permeability magnetic shield. First, we measured shielding power using a cylinder of MS-FR seat with a Gaussmeter. Based on this consistency check, we estimate required shielding power using a prototype MKIDs array installed in cryostat which also has three layers of cavity and shield similes to GroundBIRD. We also estimated how time required for cooling down response to number of shield. We confirm that our strategy of magnetic shields satisfies our requirements. In order to design magnetic shield for GroundBIRD, we evaluated the shielding power by ANSYS Maxwell, which employs finite element method to simulate electromagnetic field. Dealing with thin film with high permeability or a large volume causes systematic bias in the simulation. By increasing the thickness of the shield as keeping a value multiplied by the thickness of the shield and the permeability of the shield material constant, times required for simulations are dramatically reduced. From measurement and simulation we conclude that the sensitivity of MKIDs is not affected by geomagnetism if five sheets of MS-FR set on each cavity of the cryostat. We also simulate the effect of gap between the side and top shields and the effect of rotation of the cryostat due to scanning observations.

category : Sensor Physics & Developments

PA-30 Proposal of a kinetic inductance current amplifier with coplanar waveguide input structure for magnetic flux focusing

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We propose a multiplexable kinetic inductance current amplifier which has a high-quality-factor, superconducting, lumped-element kinetic inductance resonator for readout and a short, superconducting coplanar waveguide (CPW) for input. The resonator consists of an interdigitated capacitor and a narrow strip that inductively couples to the CPW. The input current running through the central line of the CPW generates magnetic fields. These magnetic fields are focused into the CPW gaps where the inductive superconducting strip of the resonator sits. Because the kinetic inductance of the superconducting strip depends on the strength of the magnetic fields, the input current is converted to a change of the resonance frequency of the high-quality factor resonator. With appropriate geometrical parameters, and high-resistivity superconducting films, the amplifier is expected to have a low input impedance and a high current readout sensitivity. We present a preliminary analysis of the amplifier's response to an input current, and discuss its noise.

category : Sensor Physics & Developments

PA-31 Disk Resonator Format for Kinetic Inductance Detectors

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We propose disk format resonators for use as kinetic inductance detectors. Pros and cons of this design are discussed with consideration for potential detector applications. We have conducted electromagnetic simulations of the resonator geometry and will use them to discuss the disk resonator properties. We will compare several schemes for coupling these resonators to feed lines and discuss the effect of a large kinetic inductance on the design equations for the resonant frequency and coupling quality factor. Additionally, a strategy to reduce the resonator metal volume by meshing is considered and its effects on the resonator 's current distribution are shown. We find that meshing can significantly alter the resonant frequency of the disk.

category : Sensor Physics & Developments

PA-32 Design and characterization of titanium nitride subarrays of Kinetic Inductance Detectors for passive terahertz imaging

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Terahertz (THz) imaging for security applications attracts increasing interest in both research community and industrial sector. As THz radiation can be transmitted through many non-metallic materials, passive imaging camera can detect thermal radiation from room temperature objects and allow to identify the presence of concealed dangerous objects. During the last few years several passive imagers have been built utilising different types of superconducting bolometers and semiconducting detectors [1, 2]. Kinetic Inductance Detectors have an advantage of relatively simple fabrication and scalability, which makes them a technology of choice for building an imager with large number of pixels. Recently, arrays of KIDs, predominately used in astronomical instruments, were successfully utilized in THz camera built by Cardiff University [3, 4]. With Lumped Element design of KIDs (LEKIDs) based on aluminium film demonstration camera achieved quasi-video frame rate of 2 Hz and noise equivalent temperature of 0.1 K at 0.35 THz. At the same time usage of Al based chips requires sub ¡300mK cryogenic setup, which adds complexity to the overall design. On the other hand, titanium nitride (TiN) film based LEKIDs with sheet impedance of the order of 100-300 μ Ohm*cm and transition temperature (Tc) of 3.5-4 K can be operated at ¿1K bath temperature, which is easily achievable with modern compact cryogenic systems. Also varying the thickness of the TiN film, one can adjust its Tc and sheet impedance for the optimal optical coupling in LEKID configuration.

Here we report on development and characterization of a prototype subarrays based on Atomic Layer Deposition (ALD) TiN films. We present results on growth and characterization of ALD TiN films with thickness ranging from 15 to 60 nm and Tc ranging up to 3.5 K and compare the results with sputtered TiN films. We also present the results of LEKID subarray design, fabrication and optical characterization with internal black body source and 0.35 THz band pass filter.

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category : Sensor Physics & Developments

PA-33 Multilayer Readout Wiring for Transition Edge Sensor Calorimeter Arrays Using Chemical Mechanical Polishing

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We report on fabrication and evaluation of a 20 ×20 pixel array of TES (Transition Edge Sensor) microcalorimeters based on multilayer readout wiring for future X-ray astronomy missions (e.g., DIOS, Ohashi et al. 2016 SPIE). We have achieved 2.8 eV at 5.9 keV with a 4×4 pixel TES array (Akamatsu et al., 2009 AICP) and 4.4 eV at 5.9 keV with a 16×16 pixel TES array (Ezoe et al., 2009 AICP). For a larger format TES array required in future missions like DIOS,superconducting readout wiring becomes important. In the multilayer readout wiring, signal and return lines are vertically stacked via insulation layer to reduce mutual inductance between readout lines and also self inductance. It also reduces wiring space.

We thus have been developing the multilayer readout wiring TES arrays (Ezoe et al. IEEE JQE 2015, Kuromaru et al. J. Low Temp Detector 2016). However, surface roughness of the upper readout wiring on which a TES film is deposited hindered a proper super-normal transition, resulting in a large residual resistance. Therefore, we introduced chemical mechanical polishing process. In this new fabrication process, we pattern the upper and lower readout wiring made of Nb as before. Then, we put a thick SiO2 layer on the wafer (∼800 nm thick) and polish the wafer until the upper wiring is exposed to the surface. We achieved about 2.5 times better roughness than before (∼0.4 nm rms at 1 micro meter scale). We then put a TES film (Ti 100 nm/Au 20 nm) on the wafer. To minimize damage of the layer underneath TES, we lowered the inverse sputtering power and time from 150 W, 3 min to 100 W, 1 min.

We characterized RT curves of the new TES array and confirmed a proper super-normal transition at 360 mK with a small residual resistance of ∼1 mOhms. The transition temperature is near that of bulk Ti (390 mK), which is consistent with the fact that the thick Ti and thin Au make proximity effect weaker and the TES transition temperature approach that of Ti. We will proceed to complete fabrication of the 20×20 multilayer wiring TES array by depositing Au absorbers and etching the silicon substrate for membrane structures to evaluate the energy resolution of pixels in the array.

category : Sensor Physics & Developments

PA-34 An on-chip filter bank spectrometer based on Transition Edge Sensors for meteorology and climatology

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We propose a new superconducting on-chip filter bank spectrometer, based on novel few-mode ballistic Transition Edge Sensors (TES 's). This is a key enabling technology for a novel hyperspectral microwave instrument for use in satellite-based meteorology and climatology applications. The instrument is currently in its design and implementation phase. TES 's are still the leading technology in astronomy due to their reliability, low-noise and high dynamic range. A filter bank spectrometer based on TES 's has a significant advantage over similar systems based on Kinetic Inductance Detectors (KIDs), as, unlike KIDs, they can easily reach frequencies below 140GHz. Importantly TES 's will allow access to critical atmospheric temperature sounding lines in the 50-60GHz region. While demonstration of lower frequency response is the initial goal, the final satellite concept will take advantage of the wide responsivity of TES 's to allow the coverage of significant absorption features across the 50-850GHz region. Current meteorological satellite technology does not employ active cooling to sub-kelvin operating temperatures. Therefore in conjunction with industry partners we are initiating a parallel study to investigate solutions to cooling an instrument of this type in low earth orbit. This instrument will be a disruptive technology for use in improving numerical weather prediction and in constraining global climate models. Here we report on the current design and predicted performance of our instrument concept.

category : Sensor Physics & Developments

PA-35 Advanced ACTPol TES Device Parameters and Noise Performance in Three Fielded Arrays

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The Advanced ACTPol (AdvACT) upgrade to the Atacama Cosmology Telescope features arrays of aluminum manganese transition-edge sensors (TESes) optimized for ground-based observations. These arrays are central to AdvACT 's science goals, which include measuring B-mode polarization patterns in the cosmic microwave background (CMB). Tests of these arrays reveal highly responsive detectors with uniform thermal parameters across the array and thermal conductance-dominated noise at low frequencies. We report on parameters acquired from swept-sine impedance data taken on a small subset of TESes using simple and extended bolometer electrothermal models. We then compare expected noise spectral densities based on these parameters to measured noise. These tests indicate excess noise at frequencies around 100 Hz, outside of the nominal band of temporal frequencies used in CMB measurements. However, we investigate this excess in order to shed light on the mechanism of excess noise in TESes. In addition, we describe full-array noise measurements in the laboratory and in the field for two new AdvACT mid-frequency arrays, sensitive at bands centered on 90 and 150 GHz, as well as achieved noise performance during observations of the previously installed high-frequency array (150 and 230 GHz).

category : Sensor Physics & Developments

PA-36 Development of gamma-ray position-sensitive transition-edge-sensor microcalorimeters

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We are developing Transition-edge sensor (TES) microcalorimeters to detect gamma-rays up to a few MeV. The photoelectric attenuation length in the energy range is several tens of mm. Energy resolutions of such thick-absorber microcalorimeters tends to suffer from degradation due to dependence of pulse shape on gamma-ray interaction positions in the absorber. In order to avoid such a degradation of energy resolution due to the position dependence, we are proposing Position-Sensitive TESs (PoSTs) for gamma rays. We fabricated a PoST with a long lead absorber and a TES on each end of the absorber. The length, width and thickness of the absorber are 20 mm, 0.5 mm and 0.5 mm, respectively. We report on the results of gamma-ray irradiation on the device.

category : Sensor Physics & Developments

PA-37 Dark characterization and comparison of various Mo/Au based TESs

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Transition Edge Sensors (TESs) are among the best devices for radiation detection in a wide range of energies. They are very sensitive thermometers that, when coupled to suitable absorbers or antennas, exhibit excellent energy resolution for a specific energy range (microcalorimeters) or excellent signal to noise ratio (bolometers). This explains their increasingly widespread use in several instruments for fundamental and applied science.

We report here on the DC dark characterization and comparison of parameters of different TESs based on Mo/Au proximity bilayers, aimed at soft X-ray detection, with Bi absorbers. A refinement of the fabrication process has improved reproducibility and allowed fabrication of devices with Tc, G and power dissipation in the range of interest for the X-IFU instrument onboard Athena. Thanks to the achieved control of both Tc, G and Rn, we can also tune our designs towards other wavelengths of interest as new applications of TESs emerge.

TESs with two different designs and several geometries of bare sensors, with and without lateral banks, have been characterized, with critical temperatures on the order of 100 mK and normal resistances between 10 m? and 20 m?. Various sizes and thicknesses of SiN membranes have been used to control the thermal link of the bilayer to the thermal bath. First TESs with a few microns of electrodeposited Bi have also been characterized. A good understanding of the thermal conductance, capacitance and noise levels of our devices has been achieved through IVs, Z(w) and noise measurements. For all the tested devices, G scales perfectly with the radiant area of the TES-membrane system irrespective of the membrane size. Detailed analysis of key parameters like logarithmic sensitivities, effective time constants, capacitance and excess noise has also been performed as a function of bath temperature and TES operation point for these bare devices.

A reasonable understanding of TES performances through complex model fitting of our data is also the starting point for further optimizations. We show that even for simple devices without absorber, banks or metal structures, two thermal block models are not in general enough to reproduce the experimental data.

category : Sensor Physics & Developments

PA-38 Twin-slot antenna coupled superconducting Ti transition edge sensor at 350 GHz

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Superconducting transition edge sensors (TES) based on a Ti microbridge on Si substrate have demonstrated a very low noise equivalent power. Their effective response time, however, is in the order of microseconds due to its relatively high transition temperature of 400 mK, making it difficult to read out the signal of a large Ti TES array with a SQUID-based multiplexer. We have reported on a free-standing membrane supported superconducting Ti TES with an effective response time of 5 μ s. In order to further increase the effective response time, we etch the supported SiN membrane before KOH wet etching, and then the Ti TES microbridge is suspended only by the left four legs after removing the silicon substrate. The current-voltage (I-V) curves are measured at different bath temperatures before and after KOH wet etching. The thermal conductance is reduced to 500 pW/K from 9000 pW/K. The effective response time measured with a light emitting diode (LED) is about 100 μ s, about 20 times larger. In addition, we have studied the optical noise equivalent power (NEP) with a cryogenic blackbody in combination with metal-mesh filters to define the radiation bandwidth. The obtained optical NEP is 6x10^{-16} W/$Hz^{0.5}$ at a bath temperature of 350 mK. The achieved optical sensitivity is suitable for ground-based astronomical applications.

category : Sensor Physics & Developments

PA-39 Magnetic Sensitivity of AlMn TESes and Shielding Considerations for Next Generation CMB Surveys

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In the next decade, new ground-based Cosmic Microwave Background (CMB) experiments such as Simons Observatory (SO), CCAT-prime, and CMB-S4 will increase the number of detectors observing the CMB by an order of magnitude or more, dramatically improving our understanding of cosmology and astrophysics. These efforts will likely deploy receivers utilizing large arrays of (tens of thousands) transition edge sensor (TES) bolometers coupled to Superconducting Quantum Interference Device (SQUID)-based readout systems. It is well known that superconducting devices such as TESes and SQUIDs are sensitive to magnetic fields. Understanding the magnetic field sensitivity of TESes is particularly important for upcoming CMB surveys because changes in the TES responsivity could mimic faint CMB signals. The effects of magnetic fields on the superconducting transition of these devices are not easily predicted due to the lack of a complete physical model of the TES transition. This motivates direct measurements of the magnetic sensitivity of these devices to inform magnetic shielding requirements for upcoming CMB surveys. AlMn TESes are becoming widely used due to their simple single layer film manufacturing process yielding highly uniform arrays over large detector wafers, and will likely be used for upcoming experiments such as SO and CCAT-prime. We present measurements of the critical temperature versus applied magnetic field, which may be the first of this type for AlMn TESes, on devices varying in both geometry and manganese concentration, including ACTPol, Advanced ACT (AdvACT), and POLARBEAR bolometers, using four-lead measurements. We discuss the observed effects of externally applied magnetic fields on detector parameters and their implications. We also compare measurements of magnetic sensitivity for time division multiplexing SQUIDs used in AdvACT to that of frequency division multiplexing microwave rf-SQUIDs currently under consideration for use in SO and CCAT-prime. We discuss the implications of our measurements on the magnetic shielding required for upcoming CMB experiments, which may field hundreds of thousands of TESes and SQUIDs in order to map the CMB to near-fundamental limits.

category : Sensor Physics & Developments

PA-40 Study of Dissipative Losses in AC-Biased Mo/Au Bilayer Transition-Edge Sensors

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We are developing a kilo-pixel array of transition-edge sensor (TES) microcalorimeters for the X-Ray Integral Field Unit of the future European X-Ray Observatory Athena. Recent measurements of AC-biased Mo/Au bilayer TESs imply a dissipative loss at the TES. These measurements are made using a resonant circuit in the frequency range of 1-5 MHz. In this paper, we present the results of our measurements and discuss the cause of the AC losses. The AC bias currents used in these measurements are so low that under DC-bias, with the same nominal Joule power heating, the TESs would remain in the superconducting state. However under AC bias there is loss at MHz frequencies, which is frequency dependent and can be non-negligible even when biasing within the TES transition. The dissipation behaves as a series resistance within the TES, and therefore alters the transition shape, lowering the steepness of the transition, particularly low in the transition. This will affect the key properties that determine the microcalorimeter energy resolution. We measured AC losses and transition properties on various TES geometries. We looked at TESs with different sizes, TESs with different numbers of stripes, TESs with different sheet resistances, and TESs with different geometries for the contact area between the TES and the absorber. We also modeled the TES using a finite element method (FEM) and simulated the AC loss. The loss measurements on various TES devices and the FEM simulation results indicate a causal relationship between the loss and the normal metal area exposed to the self-induced magnetic field, implying that the loss is due to Eddy current heating.

category : Sensor Physics & Developments

PA-41 Development of TiAu TES X-ray calorimeters for the X-IFU on ATHENA space observatory

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SRON is developing X-ray calorimeters with a goal to meet the detector requirements for X-IFU instrument on the ATHENA space observatory. ATHENA is the second 'Large mission' of ESA's Cosmic Vision-programme and has a planned launch date in 2028. This X-ray telescope will study spectacular astrophysical phenomena near black holes and neutron stars. The X-ray Integral Field Unit (X-IFU) is one of the instruments on board to deliver spatially resolved high-resolution X-ray spectroscopy over a limited field of view.

Our calorimeters are based on a superconducting TiAu bilayer TES (transition edge sensor) with critical temperature of around 100 mK on a 1 um thick SiN membrane with gold or gold and bismuth absorbers. Quite a few devices have been successfully fabricated with a large variety of design parameters that includes:

- TESes with or without metallic bars and dots of different sizes.
- TESes with or without slots in the SiN membrane for low and high thermal conductance.
- Variety of absorbers and absorber coupling schemes.
- Variety in wiring.

We are currently characterizing these calorimeters under AC bias (1-5 MHz bias frequency) using an FDM readout, also developed at SRON. This system is a small version of what is considered as the baseline for X-IFU instrument readout and enables us to measure up to 18 devices in each run.

Characterization is done by measuring the IV curves, critical temperature, thermal conductance, noise and baseline resolution. We also measure the X-ray energy resolution using Fe-55 source at 6 keV at selected bias points. By looking at the shape and the statistics of the rise/fall time of the pulses, we are able to determine the quality of our absorber and absorber coupling. So far our best calorimeter shows a 2.9 eV baseline resolution and a 3.6 eV X-ray resolution at 6 keV. We will present all the key results and report the latest status of development of X-ray calorimeters at SRON.

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category : Sensor Physics & Developments

PA-42 The succesfull readout of the 176 TES FDM system for SAFARI

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At SRON we are developing Frequency Domain Multiplexing (FDM) for read out of large AC biased TES arrays for both the SAFARI instrument, for the far-IR SPICA mission, and XIFU instrument, for the X-ray Athena mission. In this paper we focus on the development of a FDM demonstration model for the SAFARI instrument. SAFARI is one of the focal-plane instruments for the Japanese/European far-IR SPICA mission proposed earlier this year for the ESA M5 selection. It is a high sensitive grating spectrometer with a resolving power of 300 operating in the wavelength range of 34-210 µ m. The instrument is based on four arrays with in total 3550 TES-based bolometers with noise-equivalent powers (NEP) in the range of 2?10-19 W/?Hz having background-limited sensitivity and high efficiency. In FDM the TES bolometers are AC biased and readout using in total 24 channels. Each channel contains 160 pixels of which the resonance frequencies are defined by in house developed cryogenic lithographic LC filters. To overcome the dynamic range limitations of the SQUID pre-amplifier, a special technique named baseband feedback (BBFB) is applied. FDM is based on the amplitude modulation of a carrier signal, which also provides the AC voltage bias, with the signal detected by the TES. BBFB attempts to cancel the error signal in the sum-point (located at the input coil of the SQUID), by feeding back a remodulated signal to the sum-point, and therefore improving the dynamic range of the SQUID pre-amplifier.

Previously we reported on the results of our first iteration of a prototype 160 pixel FDM system with which we performed a detailed study on the effects of electrical crosstalk. The knowledge obtained we used to develop a second generation full 176 pixel FDM experiment in which the electrical crosstalk elements are minimized. The cold part of the experiment consists of a detector chip with 176 bolometers with a design NEP of 7?10-19 W/?Hz. On either side of the bolometer chip two LC filter chips are placed of which each contain 88 carefully placed high-Q superconducting resonators with in total 176 different resonance frequencies. The pixels are read out using a single-stage SQUID. The warm electronics consist of a low-noise amplifier (LNA) and in-house developed digital board which performs; the generation of the bias carriers, the demodulation of the signal and remodulation of the feedback signal.

In the new prototype the electrical crosstalk has been drastically lowered by reducing the carrier leakage by a factor two and removing the effects of mutual inductance by careful design. The common impedance has been reduced to 4nH, including the 3nH input coil of the SQUID. By implementing screening of the input coil this has successfully been further reduced to below 1nH. Connecting the pixels in stages; a quarter, half and the full array resulted in detecting and solving remaining issues. Using this set-up we successfully simultaneously locked and read-out more than 130 pixels. In this paper we will report on the results obtain with this 176 pixel FDM experiment.

category : Sensor Physics & Developments

PA-43 Design of the EBEX-IDS Instrument and Detectors

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EBEX-IDS is a balloon-borne polarimeter designed to characterize the polarization of foregrounds and to detect the primordial gravity waves through their B-mode signature on the polarization of the cosmic microwave background (CMB). EBEX-IDS will operate 20,562 transition edge sensor (TES) bolometers spread over 7 frequency bands between 150 and 360 GHz with resolution higher than 7.2' for all bands. EBEX-IDS will use sinuous antenna multichroic pixels (SAMP) with TES bolometers which have been developed for ground-based CMB telescopes such as POLARBEAR-2, Simons Array and SPT-3G. Balloon and satellite platforms enable observations at frequencies inaccessible from the ground and with higher instantaneous sensitivity. Both advantages are due to the lower atmospheric emission. But to realize these advantages the instrument must be optimized for a significantly lower optical loading.

We introduce the instrument design of the EBEX-IDS CMB polarization balloon-borne payload to take advantage of high altitude balloon flight. We also present our work to develop and characterize low thermal conductance bolometers that are part of SAMPs to be used with the EBEX-IDS payload. We use longer and thinner bolometer legs to decrease the bolometer thermal conductance. We consequently modify the heat capacity in contact with the transition edge sensor to tune the time-constant of the detector. We finally discuss cold inductor-capacitor chips operated at 4 K to read out the detectors with frequency domain multiplexing electronics that has a multiplexing factor of 105, which is 60% larger than the highest factor used to date with this readout system.

category : Sensor Physics & Developments

PA-44 Does membrane strain impact the TES transition surface?

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Recently, we have shown that uniaxial strain can shift the transition temperature of Mo by about 0.3K/(unit strain). Additionally, we have observed small strain induced changes in critical current. The implications of this finding on practical transition edge sensor devices depend on two questions: 1) How big are the strains encountered in real world devices, and 2) how does a strain induced change in Tc or Ic impact the resistive transition surface and thus device operation?

To answer the first question we use an optical technique to measure the curvature of TES fabricated on membranes and estimate the magnitude of the strains present in such devices.

The second question, however, is more difficult to address: the transition surface of typical devices shows a significant amount of structure commonly attributed to weak-leak effects. It is conceivable that local modulation of strain and Tc may lead to substantial qualitative changes in these important details of the transition surface. Since no detailed physical model has been proposed to predict these features, we attempt to tackle this problem experimentally. To this end, we are investigating methods to systematically modulate the strain field on a membrane.

category : Sensor Physics & Developments

PA-45 Optical Characterization of the SPT-3G Focal Plane

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The third-generation South Pole Telescope camera (SPT-3G) is designed to measure the Cosmic Microwave Background (CMB) across three frequency bands (90, 150 and 220 GHz) with 16,000 transition-edge sensor (TES) bolometers. Each multichroic pixel on a detector wafer has a broadband sinuous antenna that couples power to six TESs, one for each of the three observing bands and each polarization, via lumped element filters. Ten detector wafers populate the focal plane, which is coupled to the sky via a large-aperture optical system. Here we present optical characterization of the cryogenic detectors and outline our testing set up. In particular we focus on frequency band characterization done via Fourier Transform Spectrometry, optical time constant, beam properties, and optical and polarization efficiencies of these detectors.

category : Sensor Physics & Developments

PA-46 Spectroscopic measurements of L X-rays with a TES microcalorimeter for a non-destructive assay of transuranium elements

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Because L X-rays of the energy ranging from 10 keV to 25 keV are emitted following internal conversion after the α-decay of TRU elements, spectroscopic measurement of L X-ray is one of important techniques for a non-destructive assay of transuranium (TRU) elements. High purity germanium (HPGe) semiconductor detectors have been used in spectroscopic measurement of L X-rays emitted from TRU elements so far. However, the accurate identification of L X-ray peaks is difficult due to the insufficient energy resolution of the HPGe detector. For identification of L X-ray peaks of TRU elements, the energy resolution of the detector is required to be better than 100 eV of the full width at half maximum (FWHM).

In this work, a transition-edge-sensor (TES) microcalorimeter was operated for spectroscopic measurements of L X-rays emitted from a Np-237 and Cm-244 sources. The Au absorber of 5 μm thick was deposited on the TES to provide absorption efficiency from 35 to 80 % for incident X-ray photons with the energy from 10 to 30 keV. Energy spectra of L X-rays were obtained by processing detection signal pulses with using an optimal filtering method. Typical L X-ray peaks of Pa, U and Pu elements were clearly identified in the obtained energy spectra. In peak fittings, natural line width of L X-ray emission and an impulse response of the detector was approximated by Lorentzian distribution and Gaussian distribution, respectively. The FWHM energy resolution of the TES microcalorimeter was obtained to be 32.7 eV at Pu L α1 X-ray peak of 14.28 keV with natural line width of 12.20 eV. We considered a feasibility of a non-destructive assay of TRU elements with experimental L X-ray spectra obtained by the TES microcalorimeter.

Acknowledgement

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category : Sensor Physics & Developments

PA-47 Performance of an X-ray absorber on a transition edge sensor for Athena/X-IFU

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Cryogenic calorimetric sensors using a transition edge (TES) given by a super conducting film are known as one of the promising devices for future satellite missions thanks to their major breakthrough in sensitivities. Athena is an ESA-driven X-ray observatory to be launched in 2028, with the aim of high resolution spectroscopy enabling us to explore new horizons of science themes on the hot and energetic universe. X-ray Integral Field Unit (X-IFU) is an instrument consisting a large array of the TES calorimeter designed to be offering 2.5 eV spectral resolution with a 5 " image pixel, corresponding to the pixel size of 250 μm square.

Thermal properties of the X-ray absorber coupled on a part of the TES thermometer play important roles to achieve requirements for the X-IFU. We have improved electroplating techniques for a few microns thick gold and bismuth, which can be used as heat thermalization and X-ray stopping layers in the absorber respectively. The typical resistivity of 1 micron thick gold at 4 Kelvin is 0.1 $\mu\Omega$ cm, corresponding to the residual resistance ratio of 24 which is limited by surface scattering. The bismuth films are well dense and flat with the crystalline structure. We have integrated these processes into the X-ray TES device fabrication with optimization of photolithography and demonstrated free-standing full-size absorbers with a pixel gap of a few microns, which meet requirements for the X-IFU such as high filling factor and quantum efficiency above 95 %.

We will present details of fabrication and discuss performances of X-ray absorbers based on the X-ray pulse analysis.

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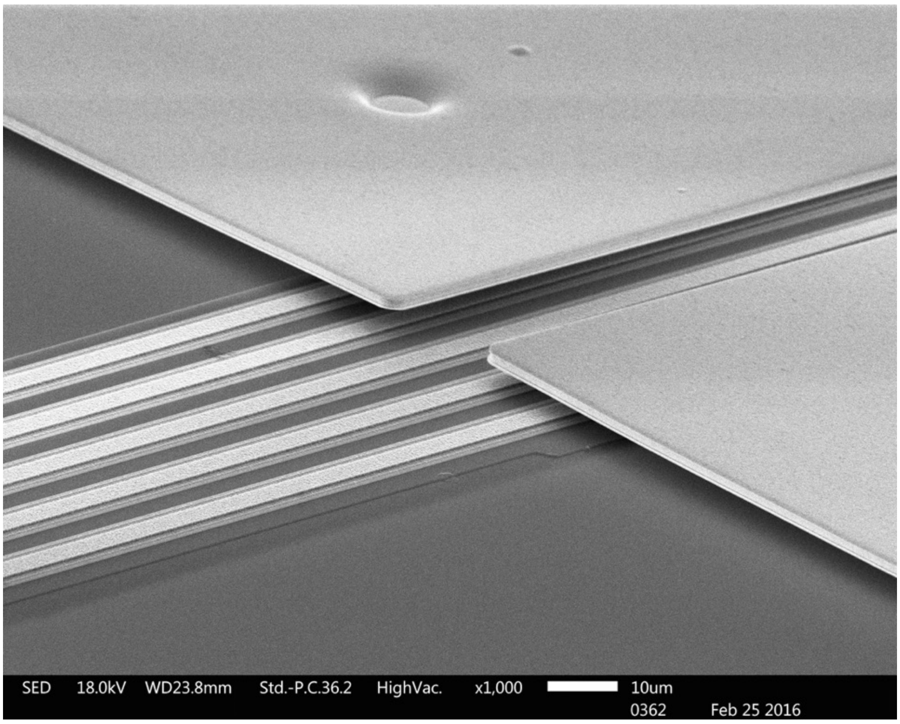

category : Sensor Physics & Developments

PA-48 Development of cryogenic single photon TES detectors for an Investigation of the VUV region.

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Deep UV energy range (10 eV-30 eV) is very interesting for astrophysics spectrometry and quantum information.

In our work we want to investigate the possibility to use cryogenic TES-microcalorimeters for single photon detection in the VUV range. Small and quick detectors should be developed in order to increase the VUV photon peaks resolution.

TES microcalorimeters are fully fabricated with photolithographic techniques in the clean room facility inside the Low Temperature Detector Laboratory of the University of Genova. The TESs are 100 nm Ir films deposited by Pulsed Laser Deposition (PLD). The absorbers are made of gold and are directly set on the TES.

The Ir TES detectors are tested in our 3He-4He dilution refrigerator Oxford Kelvinox-25, on high temperature stability cold finger whose base temperature is 50 mK. The working temperature of Ir TES is around 100 mK. The signal readout is performed by a VTT SQUID with Magnicon electronics for I-V curves. A lock-in amplifier with 4 probe measurement is used for ancillary R(T) transition measurements.

We excite the microcalorimeter with a UV pulsed laser light source, by using an optical fiber. The pulse response in time is registered. Fast microcalorimeters have been developed, realized and tested in the Low Temperature Laboratory of the University of Genoa. The latest results are shown.

category : Sensor Physics & Developments

PA-49 Mapping the TES Temperature and Current Sensitivities as a Function of Current, Magnetic Field and Temperature with IV Curve and Complex Impedance

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To resolve the spectra of the astronomical diffuse X-ray background in the 0.1-0.5 keV energy range, we need large area pixels (∼1mm2) with excellent energy resolution (1–2 eV). The energy resolution of a micro-calorimeter with a resistive thermometer is ideally $\sim 7\sqrt{}(k_B\ T^2\ C \sqrt{}(1{+}2\beta)/\alpha)$. For TES pixels with large absorbers that have relatively high heat capacity, high α and low β are needed to achieve the required energy resolution. But most work in the field has found high α to be correlated with high β and also with excess noise, with the cause of this correlation remaining not understood.

To investigate this correlation, we have been mapping the resistance R(T, I, Bext) surface of TES devices over the entire transition region, calculaing α and β from the derivatives of the IV curves.Admittance (A(f)) measurements could provide a more efficient way to map α and β that would allow characterization of a large number of devices. We are currently performing this complementary measurement to see if the results agree with those obtained from IV curves. We have also begun measuring noise spectra at promising operating points on the R(T, I, Bext) surface to determine weather excess noise is an unavoidable accompaniment of high α.

category : Sensor Physics & Developments

PA-50 Performance of an X-ray microcalorimeter with a 0.24 mm absorber and a 50 um TES bilayer

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We have been developing superconducting transition-edge sensor (TES) microcalorimeters for a variety of potential astrophysics missions, including Athena. The X-ray Integral Field Unit (X-IFU) instrument on this mission requires close-packed pixels on a 0.25 mm pitch, and high quantum efficiency between 0.2 and 12 keV. The traditional approach within our group has been to use square TES bilayers of molybdenum and gold that are between 100 and 140 microns in size, deposited on silicon nitride membranes to provide a weak thermal conductance to a 50 mK heat bath temperature. It has been shown that normal metal stripes on top of the bilayer are needed to keep the noise consistent with the spectrum expected from the electrothermal model and estimates of the near-equilibrium non-linear Johnson noise.

In this work we describe a new approach in which we use a square TES bilayer that is 50 microns in size. While the superconducting weak link effect is much stronger in this size of TES, we have found that excellent spectral performance can be achieved without the need for any normal metal stripes on top of the TES. A spectral performance of 1.58 eV at 6 keV has been achieved, the best resolution seen in any of our devices with this pixel size. The absence of normal metal stripes has lead to more uniform transition shapes, and more reliable excellent spectral performance. The smaller TES size has meant that that the thermal conductance to the heat bath, determined by the perimeter length of the TES and the membrane thickness, is lower than on previous devices, and thus has a lower count rate capability. This is an advantage for low count-rate applications where the slower speed enables easier multiplexing in the read-out, thus potentially higher multiplexing factors. In order to recover the higher count rate capabilities, a potential path exits using thicker silicon nitride membranes to increase the thermal conductance to the heat bath.

category : Sensor Physics & Developments

PA-51 Exploration of alternative Transition Edge Sensor materials for the SPT-3G experiment

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The SPT-3G focal plane targets detector saturation powers in the range of 10-20 pW, which can be achieved with Transition Edge Sensors (TES) having Tc in the range of 400-500 mK. The baseline TES material for the SPT-3G focal plane are bilayers and multi-layers using Ti and Au. In addition to the Ti/Au materials, we have also explored alternative TES materials including ion-implanted materials like Al-Mn and Mo-Cu. For Al-Mn, we have investigated fabrication techniques using either lift-off and a dry etch processing. In this work, we present some results from our studies of these alternative TES materials.

category : Sensor Physics & Developments

PA-52 Transition edge sensor (TES) array for astrophysical observations

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We present a design and fabrication process of transition edge sensor (TES) array for astrophysical observations. The fabricated prototypes contain Al TES array with transition temperature at 1.2K, in which the TES islands are supported by Si3N4 holders. The low temperature performance of the TES array is measured in a He3 sorption refrigerator, such as the resistance -temperature curve. We designed different structure for connecting TES and antenna to detect the irradiation from the optical window.

category : Sensor Physics & Developments

PA-53 Fabrication and Characterization of Al/Ti bilayer Transition Edge Sensor Bolometer Array

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We present design and development of transition edge sensor (TES) bolometer array for astrophysical observations and the low noise, low impedance and low power of superconductor quantum inference device (SQUID) make it more ideal amplifier signal condition. We have fabricated 4x4 TES bolometer array that based on Al/Ti bilayer with transition temperature at most 1.2 K the layout design is given in figure1. Our bolometers are established on Si3N4 membrane technology for the thermal link as shown in figure3(c). A TES is described, that should enable the readout of the bolometer operated at 4.2 K using a room temperature amplifier without a significant degradation in noise performance. We also focus on the voltage-biased TES, which is feasible in strong negative electrothermal feedback (ETF) for improved linearity.

Keywords: TES, SQUID, ETF.

category : Sensor Physics & Developments

PA-54 Development of a small pixel Ir-TES for optical applications

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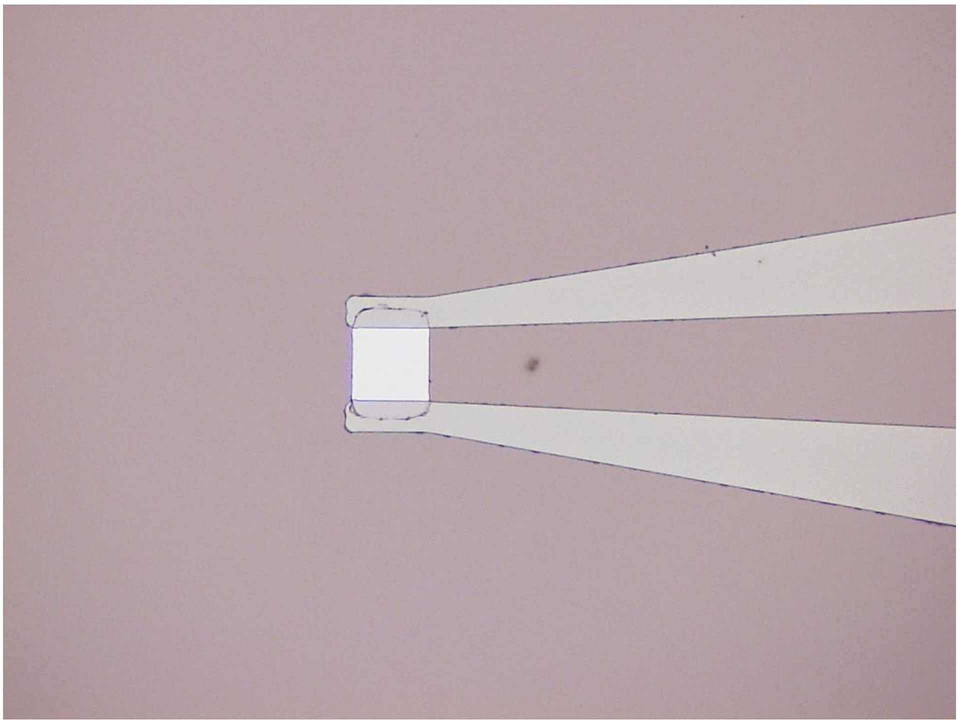
We aim to realize a single-photon detector which greatly improves its sensitivity and response speed by minimizing of the thermometer volume using a single superconducting Ir thin film. Iridium has a sharp superconducting transition at 112 mK in bulk, therefore, even if it is used as a single superconducting thin film for the thermometer of TES, excellent energy resolution is expected.

Under this concept, we fabricated 5 to 25 μ m size small pixel Ir-TES for single-photon detector. In this presentation, we will introduce the result in our first small pixel Ir-TES device (10 μ m size, 20 nm thickness, Fig.1). In the I-V characterization, two transition regions and two normal regions were observed. Resistance of each normal region was estimated at approximately 3 and 6 ohms respectively. We consider that it is because the contact area between Ir-TES and niobium electrode is wide, but this is under investigation. Also, now we plant to perform the photon irradiation experiment using this small pixel Ir-TES.



category : Sensor Physics & Developments

PA-55 Understanding and Manipulating the Thermal Conductance of SiN Membranes in Sub-Kelvin Refrigerators and Sensors

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Ultra-sensitive cryogenic detectors, like Transition-Edge Sensors (TESs), that operate at sub-Kevin temperatures are critical for understanding the structure and origins of the universe. Refrigeration to sub-Kelvin temperatures remains costly, bulky, and complex. A new refrigeration technique using Normal-Insulator-Superconductor (NIS) tunnel junctions has been developed to provide an economical, light, and compact solution to reach temperatures near 100 mK. In previous work, we demonstrated a copper platform with over 150 g of mass and 28 cm2 of area for attaching user-supplied devices cooled by NIS tunnel junction refrigerators from 291 mK to 233 mK and infer cooling to 228 mK [1]. The thermal isolation provided by micromachined SiN membranes plays an important role in a variety of devices including these tunnel junction refrigerators and TES bolometers. To improve the performance of NIS tunnel junction refrigerators and TESs, a better understanding of the SiN membranes ’ thermal conductance is desirable. The design of SiN membranes often balances the level of thermal isolation against mechanical robustness. To achieve greater thermal isolation while preserving robustness, we are exploring the impact of surface roughness and additional patterned features on the thermal conductivity of SiN membranes. We are conducting this study as a function of membrane thickness and temperature. Techniques to suppress the thermal conductivity of SiN membranes have obvious applications for TES bolometers whose Noise-Equivalent-Powers (NEPs) depend sensitively on this parameter. The base temperature of refrigerators based on NIS tunnel junctions designed to cool the phonons of a payload also depends on membrane conductance. We have demonstrated that the thermal conductance of SiN membranes can be reducing using several techniques including: (1) depositing normal metal islands on the membrane; (2) cutting holes in the membrane; (3) using meandering legs. We attempt to explain our results using contemporary theory for phonon transport [2].

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[2] T. Kuhn, Phononic Transport in Dielectric Membranes, doctoral thesis, University of Jyvaskyla (2007)

category : Sensor Physics & Developments

PA-56 A low nuclear recoil energy threshold for dark matter search with CRESST-III detectors

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The CRESST-III experiment (Cryogenic Rare Events Search with Superconducting Thermometers), located at the underground facility Laboratori Nazionali del Gran Sasso in Italy, uses scintillating $CaWO_4$ crystals as cryogenic calorimeter to search for direct dark matter interaction in detectors.

Detecting dark matter particles is one of the most exciting experimental challenges of modern astroparticle physics. A large part of the parameter space for spin-independent scattering off nuclei remains untested for dark matter particles with masses below few GeV, despite many naturally motivated theoretical models for light dark matter.

The CRESST-III detectors are designed to achieve the performance required to probe the low mass region of the parameter space with a sensitivity never reached before.

Each detector consists of a scintillating crystal of $\sim$ 25 g and a second smaller nearby cryogenic calorimeter made of Silicon-On-Sapphire for the detection of the scintillating light. Both calorimeters are equipped with Transition Edge Sensors (TES) for read-out, designed to provide thresholds of the order of 50-100 eV for the $CaWO_4$ crystals and 10-20 eV for the Silicon-On-Sapphire detectors. The double channel read-out allows event-by-event particle identification which is used for background suppression. In addition, the CRESST-III detectors are also equipped with a fully scintillating housing and instrumented holders to veto a possible background originating from surrounding surfaces. This innovative active holding system allows to suppress induced thermal signals from particle interaction in the holding material.

In this talk, new results on the performance and a complete overview of the CRESST-III detectors will be presented, emphasizing the current status and future perspectives of Phase 1 that started taking data in August 2016.

category : Sensor Physics & Developments

PA-57 Two-Dimensional Spatial Imaging of Charge Transport in Silicon at Low Temperature

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The Cryogenic Dark Matter Search (CDMS) is a direct-detection dark matter experiment which employs high-purity silicon and germanium crystals as dark matter detectors. Accurate modeling of charge transport in these materials is essential for improving our data analysis and detector design.

This experiment produces a two-dimensional image of charge density, which allows electron and hole transport in silicon and germanium to be studied in detail at sub-kelvin temperatures and in electric fields of strength between 0.5 and 6 V/cm. We have demonstrated anisotropic behavior in both electron and hole propagation, which varies as a function of temperature and applied electric field. We present these experimental results, along with Monte Carlo simulations which reproduce the observed behavior.

category : Sensor Physics & Developments

PA-58 Progress on SuperSpec

Jordan Wheeler[1], Steve Hailey-Dunsheath[2], Erik Shirokoff[3], Peter Barry[4], Charles M Bradford[5], Scott Chapman[6], George Che[7], Jason Glenn[8], Matthew Hollister[9], Attila Kovacs[10], Henry G Leduc[11], Philip Mauskopf[12], Ryan McGeehan[13], Christopher M McKenney[14], Roger O'Brient[15], Stephen Padin[16], Theodore Reck[17], Colin Ross[18], Corwin Shiu[19], Carole Tucker[20], Ross Williamson[21], Jonas Zmuidzinas[22]

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SuperSpec is an exciting new technology for millimeter and submillimeter spectroscopy. It is an on-chip spectrometer being developed for multi-object, moderate resolution (R = 100?500), large bandwidth survey spectroscopy of high-redshift galaxies for the 1 mm atmospheric window. In particular it targets the CO ladder in the redshift range of z = 0 to 4 and the [CII] 158 um line from redshift z = 5 to 9. SuperSpec employs a novel architecture in which detectors are coupled to a series of resonant filters along a single microwave feedline instead of using dispersive optics. This construction allows for the creation of a full spectrometer occupying only 10 cm squared of silicon. This is a reduction in size of several orders of magnitude when compared to standard grating spectrometers. This small profile enables the production of future multi-object spectroscopic instruments required as the millimeter-wave spectroscopy field matures.

SuperSpec receives astrophysical radiation via a lens-coupled antenna. This radiation then propagates down a microstrip transmission line where specific frequencies of radiation are picked off by proximity coupled half wavelength microstrip resonators. Careful tuning of the proximity of the resonators to the feedline dials in the desired resolving power of the SuperSpec filterbank by tuning the coupling quality factor. The half wavelength resonators are then in turn coupled to the inductive meander of kinetic inductance detectors (KIDs), which serve as the power detectors for the SuperSpec filterbank. Each SuperSpec filter bank contains hundreds of KIDs and the natural multiplexibility of these detectors allow for readout of the large numbers of required detectors. SuperSpec employs titanium nitride TiN KIDs. The unique coupling scheme employed by SuperSpec allows for the creation of incredibly low volume, high responsivity, TiN KIDs. Current inductor volumes are of order 2 cubic microns. Since responsivity is proportional to the inverse of quasiparticle-occupied volume this allows SuperSpec to reach the low NEPs required by moderate resolution spectroscopy to be photon limited from the best ground-based observing sites.

We will present the latest results from SuperSpec prototype devices and ongoing progress toward the deployment of a SuperSpec demonstration instrument covering the full 1 mm atmospheric band in Spring 2018. In particular NEPs, measured filter bank efficiency, and spectral profiles for a 50-channel filterbank prototype will be presented. This includes the results of new detector design changes. Such as, detector NEP values for newly reduced inductor volumes of 2 cubic microns from 9 cubic microns of the previous generation prototype devices. In addition we have tested capping the interdigitated capacitor of the kinetic inductance detectors with niobium to reduce the parasitic inductance in the capacitor rails. Also the optical properties of our new wide band dual slot bowtie antenna will be presented. Finally, we will report on our system end to end efficiency and total system NEP.

category : Sensor Physics & Developments

PA-59 MgB2 hot-electron bolometer mixers for sub-mm wave astronomy

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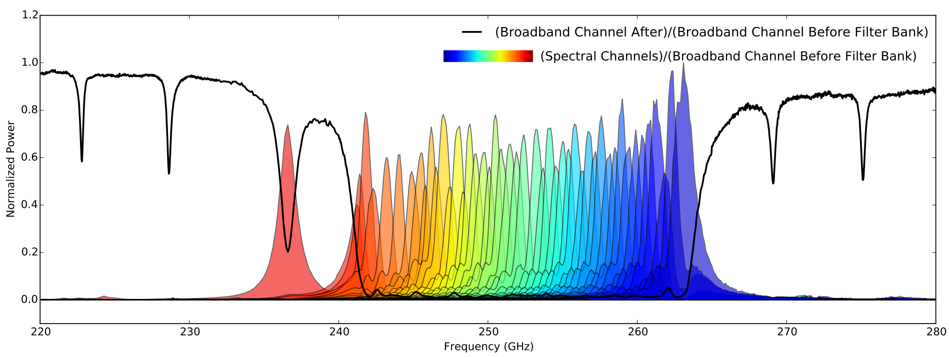
The terahertz range (0.1-10THz) of electromagnetic spectrum is of the great interest for astronomical observations due to the presence of large amount of various emission lines. The study of these lines allows for investigation of physics, chemistry and dynamics of various remote space objects. Heterodyne receivers with their high spectral resolution (106-107) are required in order to benefit from astronomical observations in THz range. For frequencies above 1THz phonon-cooled hot-electron bolometers (HEBs) are devices of the first choose for heterodyne instrument 's mixers. The currently used NbN and NbTiN HEB mixers are suffering from a relatively small noise bandwidth (NBW) of about 4GHz. It sets the limitation on study of some extra-galactic objects which Doppler-shifted emission lines could be as few GHz wide. Such wide lines could be then observed only been divided into two scans, which doubles required observation time.

We have managed to improve the bandwidth of HEB mixers without sensitivity sacrificial by using MgB2 superconducting ultrathin films grown by hybrid physical chemical vapor deposition (HPCVD) technique. Both a high Tc (short electron-phonon interaction time) and a small thickness (short phonon escape time) are crucial for large bandwidth achievement. Using this deposition method films as thin as 5-10nm with a critical temperature (Tc) above 30K were grown. A NBW of 11GHz was measured for HEBs with a Tc of 30K fabricated from an 8nm thick film, and a NBW of 13GHz was measured for HEBs with a Tc of 33K fabricated from a 5nm thick film. The DSB receiver noise temperature of such devices measured at a 5K bath temperature is about 1000K at 0.69THz and 1.69THz local oscillators (LOs). The HEBs can operate at bath temperatures up to 20-25K without significant increase of the noise temperature. The main reason for the noise temperature increase at higher temperatures is a reduction of the mixer gain, which occurs proportionally to the LO power reduction while the mixer output noise remains constant. Device current-voltage (IV) characteristics are identical when pumped with LOs from 0.69 THz to 2.56 THz, and match well with IV curves at elevated temperatures. Therefore, the effect of the THz waves on the mixer is totally thermal, due to absorption in the π conduction band of MgB2. The MgB2 HEB mixer noise temperature was found to be proportional to the device width, and we expect it to be further decreased if HEBs wider than 1 μ m would be fabricated and anti-reflection coating would be applied.

Fig. 1. The receiver noise (at 1.63 THz LO) as a function of the IF recorded at 5K, 15K, and 20K operation temperatures.

category : Sensor Physics & Developments



PA-60 Integrated SQUID/sensor designs for metallic magnetic microcalorimetry

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Metallic magnetic microcalorimeters (MMCs) achieve energy resolution performance comparable to transition-edge sensors (TESs) while relying on very different measurement physics. One consequence of MMC physics of current interest is the improved linearity of MMC pixels over a wide energy range compared to TES. We have recently completed fabrication of new low-pixel-count (14 pixels, 7 SQUIDs) MMC gamma-ray detector arrays using several exploratory integrated SQUID/sensor designs. Integration of the SQUID and sensing coil on the same chip allows optimal inductance matching and control of stray reactances. These designs use different combinations of one-layer/two-layer sensing coils and direct/flux-transformer coupling of the input circuits. All designs use the " superconducting cap " geometry to keep the magnetizing field in-plane and lower sensing coil inductance. Passive Nb:Ta alloy (Tc = 5.3 K) persistent-current shunts, described in a previous report, are used throughout the chip both for trapping persistent magnetizing currents as well as for blocking unwanted induced persistent currents. We describe the motivations, tradeoffs, and measured performance of these exploratory designs.

category : Sensor Physics & Developments

PA-61 Metallic magnetic calorimeter optimization for large-area light detectors

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We report on an optimization study for large-area light detectors using metallic magnetic calorimeters (MMCs). The detectors are to be used for light detection in simultaneous phonon-scintillation measurement for rare event search experiments.

The present detectors are composed of a 2-inch Ge wafer as an absorber and an MMC as a temperature sensor. We studied the dependence of signal amplitudes to MMC and SQUID parameters. The erbium concentration, size of meander-shaped pick-up coil, field current, SQUID input and mutual inductances were subjected to change maximizing the signal size. Measured results are compared with calculation.

category : Sensor Physics & Developments

PA-62 BRAHMS: POLARIZATION SENSITIVE BOLOMETER ARRAYS FOR THE SPICA IMAGING POLARIMETER

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We develop bolometer arrays, with pixel polarimetric capability, to be used in the polarization sensitive camera for the SPICA Space Observatory, a joint JAXA/ESA mission. The detectors are based on the resistive all silicon technology initially elaborated for the Herschel/PACS photometer. With our new design, each pixel will output total flux and fully differential polarization signals. The camera covers a 2.6 arcmin FOV simultaneously at three wavelengths (100, 200 and 350 μ m) with Nyqvist sampling. The 1334 pixels (5336 bolometers) are operated around 50 mK to achieve a sensitivity of few aW/ $\sqrt{}$ Hz. The three Stokes parameters I, Q and U are retrieved by the specific arrangement of the focal plane and a rotating half wave plate located near the Camera optical input.

category : Sensor Physics & Developments

PA-63 Wavelength dependence of intrinsic detection efficiency for NbN superconducting nanowire single-photon detector

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Superconducting nanowire single photon detectors (SNSPDs) have been demonstrated as a key-enabling technology for various applications such as quantum key distribution, space-ground laser communication and depth imaging. Nevertheless, the working mechanisms of SNSPD have not been well understood though many theoretical and experimental studies were reported in recent years. By tuning the wavelength of the incident photons, one can study the detection efficiency (DE) dependence on the bias current (Ib) for the photon energies, which provides an interesting method to probe the intrinsic detection efficiency (IDE). Renema et al first systematically studied the DE-Ib (bias current) relations at different photon energy[1] and found a linear relation between the photon energy and triggering current for NbN-based bow-tie nanodetector, where the triggering current is defined as the point leading to the detection probability of 1%. Later, similar studies were carried out on WSi [2] and MoSi [3] SNSPDs, while the nonlinear relations were reported.

In this work, we carried out the study on NbN-SNSPDs. We designed and fabricated NbN-SNSPDs with different linewidths. In our measurement polarized photons from 450 to 2000 nm were prepared using a supercontinuum laser and an acousto-optic tunable filter. By tuning the wavelength and polarization, the DE- Ib relations were obtained at various wavelengths for both parallel and perpendicular polarizations. Different with reported work on NbN detectors [1], nonlinear relations between photon energy and current were concluded. Detailed wavelength dependence of intrinsic detection efficiency and energy-current relations will be presented in our report.

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category : Sensor Physics & Developments

PA-64 A model on heat signal of crystal detector at low temperature

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We present a model to calculate heat signal shapes from low temperature bolometer attached to a crystal. It can be used to understand and predict signals of real detectors, e.g., in the AMoRE double beta decay experiment. This model is based on the elementary acoustic wave theory at low temperature, and has been developed using modern Monte Carlo techniques. Physical processes in phonon propagation, such as scattering, decay and reflection are considered. Finally, the calculated time dependence of signal is compared against real experimental data to test our model.

category : Applications

PA-65 Characteristics of IF bandwidth of NbN Superconducting Tunneling Junction Mixers

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Besides the sensitivity nearly approaching the quantum limit, the intermediate-frequency (IF) bandwidth is of particular interesting for Superconductor-insulator-superconductor (SIS) mixers for radio astronomy research. In this paper, we are going to present the characteristic of IF bandwidth of two type of NbN SIS mixers, long distributed junctions and two distributed junctions. Firstly, the relative mixers' gain are measured with 50 Ω IF load impedance for both two SIS mixers. And also the relative mixers' gain with different IF load impedance are simulated to get the optimum IF load impedance over a relative large IF bandwidth (2-15GHz). Finally, an IF matching circuit are designed and measured associating with SIS mixers, the measurement results show that the mixers gain are flatter over a large IF bandwidth than with 50 Ω IF load impedance.

category : Sensor Physics & Developments

PA-66 NTLE cryogenic light detectors with planar electrode geometry - latest results

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The Neganov-Trofimov-Luke effect (NTLE) is a promising way to improve the sensitivity of cryogenic light detectors by enhancing the thermal signal in a semiconductor. This effect in the semiconductor is caused by drifting photo-generated electron-hole pairs while under an electric field and at mK temperatures. Such cryogenic light detectors are of high importance for direct dark matter searches (such as CRESST), cryogenic neutrinoless double-beta decay searches, and experiments searching for coherent neutrino nucleus scattering (CNNS); experiments where excellent sensitivity and energy resolution are required. A novel approach to NTLE light detectors is the use of a planar electrode geometry based on very thin implanted contacts on silicon absorber crystals. The main difference to previous approaches is that the photo-generated charge carriers are drifted through the bulk of the absorber instead of being drifted across the free surfaces of the absorber, leading to an improved signal-amplification, signal-to-noise ratio, and charge collection. In this contribution we will present an update on the development of these detectors at the Technical University of Munich.

category : Sensor Physics & Developments

PA-67 Design and fabrication of mid-infrared superconducting hot-electron bolometers

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To design antennas for mid-infrared superconducting hot-electron bolometer (HEB), the surface reactance of Au thin film at cryogenic temperatures was evaluated using Fourier transform infrared spectroscopy with a sample cooling system. We fabricated mid-infrared resonator arrays that were constructed by gold thin film strips, and found that the resonant frequency was shifted to the low frequency side as the temperature was lowered. By fitting the resonant frequency to simulated results, the corrected surface reactance was established. Prototypes of a mid-infrared HEB formed by a twin-slot antenna with a niobium nitride strip were fabricated. When the HEB was biased close to the critical current under mid-infrared pulsed light (λ =4.89 μ m) irradiation, the detector output synchronized with the trigger signal was observed. The output waveforms comprised voltage pulse trains, and the full width at half maximum of the pulse was evaluated to be approximately 0.25 ns.

category : Sensor Physics & Developments

PA-68 Progress towards Photon Counting Detectors for Terahertz Astronomy

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High resolution imaging plays an important role in modern astronomy and astrophysics. ALMA or VLTI are successfully serving their high angular resolution capability in radio or optical wavelengths, respectively, while high resolution imaging technology for terahertz frequency is yet to be explored. Intensity interferometry will be a powerful method for next generation interferometric instruments, where direct detectors can be used to realize high sensitivity and wide bandwidth. We have introduced a new concept to determine the 'delay' to synthesize images with intensity interferometry by making use of the photon bunches of thermal radiation, even with the absence of electromagnetic phase information. This idea was demonstrated by observing the sun with the Nobeyama Radioheliograph, where the key to the success was to sample the signal in high speed (Ezawa et al. 2015, ISSTT 2015, W2-2)

Following this success, we are discussing to introduce a photon counting concept to intensity interferometry (PCTI; Matsuo 2012, JLTP 167, 840), aiming for high angular resolution and high sensitivity with future space terahertz interferometers. Various developments are ongoing to realize photon counting detectors in terahertz region. Considering a typical case of observing an 1 Jy source using a 10-m telescope at 1 THz with 100 GHz bandwidth, photon rate of 100 Mphotons/s is expected. Therefore the detector should respond as fast as 1 GHz, and realize NEP$< 10^{-17}\mathrm{W}/\sqrt{\mathrm{Hz}}$ (Matsuo & Ezawa 2016, JLTP 184, 718).

Our design involves SIS junctions (or STJs) to be used as photon detectors. The key to realize the required specification is to develop an SIS junction with low leakage current of 1 pA at cryogenic temperature of 0.8 K. We are fabricating small junctions with Nb/Al/AlOx/Al/Nb using CRAVITY facility at AIST to meet this requirement. Key parameters including junction area, thickness of aluminum layer, and current density are optimized. The cryogenic properties of the junctions are investigated at NAOJ, especially to ensure the low leakage current to operate them as photon counting devices.

Photoelectrons produced by the SIS junction, will be read out through cryogenic FETs and wide-bandwidth amplifiers. GaAs-JFET or Junction pHEMT are considered as candidates for the first-stage FET of the readout circuit, which show good performance under cryogenic temperatures, such as low noise and low gate leakage. Currently we are working with the prototype of each component. Various properties including NEP, spectral and time responses of the detector measured with a cryogenic calibration source, as well as the design of the detection system will be discussed in the presentation.

category : Sensor Physics & Developments

PA-69 A Graphene Based Terahertz Hot Electron Bolometer with Johnson Noise Readout

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Graphene is a very attractive material for hot electron bolometers due to its weak electron phonon coupling and small electronic heat capacity. Here we present the development of a graphene based hot electron bolometer at terahertz (THz) frequencies. The bolometer is a 2 um long and 10 um wide graphene microbridge connected to a log spiral antenna by Au contact pads. The Fourier transform spectrometer (FTS) measurement shows that the bolometer has high coupling efficiency in the frequency range from 0.3 to 1.6 THz. During the measurement, the electronic temperature of graphene is measured by means of noise thermometry. Using 300 K/77 K blackbody loads, we measure an optical noise equivalent power (NEP) of 5.7 × 10-12 W/Hz0.5 at 3 K. To understand the thermal transport inside the graphene microbridge, we also measure the bolometers with different microbridge lengths (varying from 0.6 to 8 um) at different bath temperatures. The measurements show that the thermal conductance caused by the electron diffusion to the Au contact pads is significant in our bolometers. Therefore, the bolometer performance can be further improved if the electron diffusion is eliminated (e.g., using superconducting contact pads).

category : Sensor Physics & Developments

PA-70 HIGH-PRECISION X-RAY SPECTROSCOPY OF HIGHLY-CHARGED IONS AT STORAGE RINGS USING SILICON MICROCALORIMETERS

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High precision X-ray spectroscopy of hydrogen-like heavy ions provides a sensitive test of quantum electrodynamics in very strong Coulomb fields. However, one limitation of the current accuracy of such experiments is the energy resolution of available X-ray detectors [1]. To improve this accuracy, a novel detector concept, namely the concept of microcalorimeters, is now exploited for such measurements. With this kind of detectors and affixed X-ray absorbers appropriate to the desired energy range, a relative energy resolution of about 1 per mille is obtained in the energy regime of 1 - 100 keV [2].

The application of microcalorimeters for hard X-rays, based on silicon thermistors and tin absorbers, for the determination of the 1s Lamb Shift in hydrogen-like heavy ions has been pursued by our collaborating groups for more than two decades. Two detector arrays have been successfully applied in two experiments at the Experimental Storage Ring (ESR) of the GSI Helmholtz Center for Heavy Ion Research to determine the 1s Lamb Shift of hydrogen-like lead and gold [3]. An excellent agreement with theory has been obtained.

In order to improve the statistical uncertainty and lateral sensitivity, a larger detector array with three times the active detector area in a new, cryogen-free cryostat is currently in preparation. Due to space limitations within the sidearm of the cryostat, a re-design of the detector was necessary for the next generation detector. The new detector design is a more compact version of the design of Bleile et al. [2]. In 2016 this new design was tested at the ESR storage ring of the GSI facility using a hydrogen-like Xenon and a lithium-like Uranium beam. This test was an important benchmark on the way to the larger detector array.

In this contribution, we will present the design of the new experimental setup and the results of the recent experiment. In addition to the current developments for experiments at the future FAIR facility, perspectives for other high-precision experiments, i.e. spectroscopy of inner-shell transitions, will be discussed.

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category : Sensor Physics & Developments

PA-71 Temperature Study of the DC IV curves of NbN Superconducting Nanowire Single Photon Detectors

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Superconducting nanowire single photon detectors (SNSPDs) are the leading technology for efficient high-speed-detection of single telecommunications wavelength photons. SNSPDs are attractive because they combine 100s of MHz count rates, with close to 100% detection efficiency and 10s of picoseconds of timing jitter. A range of applications and basic measurements have employed SNSPDs or are being developed to take advantage of the SNSPD 's superior performance, including: low power space-based optical communication, quantum photonic integrated circuits, and tests of quantum mechanics.

Despite the SNSPD 's attractive features and demonstrated performance, the fundamental limits to performance as well as a large number of sample and material dependent properties which strongly influence device performance are unknown or infrequently measured. For instance, the thermal boundary conductance to the substrate, which removes the heat generated in an SNSPD by an absorbed photon or proceeding detection event, has no definitive measurements, despite our understanding that it may be the determinant of maximum non-latching detector speed. Additionally, constrictions remain an important issue for SNSPDs but compared to switching currents and photon count rates, constriction factor is not typically measured.

We measured the temperature dependence of a NbN SNSPD 's current-voltage (IV) relationship in order to better understand the thermal properties of the nanowire system. As the current bias through the SNSPD is varied at 3.2 K, the nanowire IV curve shows pronounced hysteresis, switching into a voltage state when the bias exceeds the switching current (I_{sw}), but only switching back once the bias is reduced below a current less than half of I_{sw}. This lower current is known as the retrapping current (I_r) and its magnitude can be related to the thermal parameters of the system. As the system temperature was raised, I_{sw} dropped rapidly, while I_r reduced more gradually. At a crossover temperature (T^*) 9 K, the switching and retrapping currents became equal, and between T^* and T_c the IV curve of the wire was non-hysteretic.

Figure 1 shows our fit of the non-hysteretic IV curve data at 9.4 K with the Ambegoakar and Halperin model for thermal noise in an overdamped Josephson junction. The wire critical current and the normal state resistance were both used as fitting parameters. This fit suggests a temperature regime where flux flow across the wire is prominent and the available cooling power is larger than the dissipated electrical power. The critical currents used to fit the IV curves in this regime are significantly higher than the switching currents obtained using a 1 mV voltage threshold to define the switching current of the wire. A comparison between the critical current obtained by modelling the wire this way and the experimentally determined switching currents may give us insight into premature switching of the wire due to vortex motion at lower temperatures.

Lastly, the non-hysteretic regime may represent an opportunity for a fundamentally different type of device operation where the absorption of a photon modulates flux flow across the nanowire. We comment on the feasibility of detecting photons while operating in this regime.

category : Sensor Physics & Developments

PA-72 Axion search experiment by using Josephson-Junction device

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Cosmic dark matter is the main component of the universe, and its detail has not been identified. Axion is known as one of the leading candidates of cosmic dark matter. Axion was theoretically proposed by Peccei and Quinn in 1970s, to solve the so-called strong CP problem in Quantum-chromo dynamics. However, the existence of axion has not been confirmed, because it hardly interact with the ordinal matter.

We are planning a new search experiment of axion by using a unique technique which was proposed by C. Beck et al. in 2013 (Phys. Rev. Lett. 111, 231801).

They focused on the analogy between the equation of motion of axion and the equation of the phase of Josephson-Junction. In the theoretical model, a quantum interference effect will occur if the voltage corresponding to axion mass is supplied in the Josephson-Junction.They insist the existence of axion field explains some steps which were observed around 0.55 meV in the I-V curves.

However, there are some critical opinion for their model. There is a possibility that observed steps were created by the external radiation. The situation is still controversial, and a systematic study of Josephson-Junction in the low background conditions is awaited.

We are planning an new experiment to search for axion by using the same method. In our Josephson-Junction device, Nb and Al was used for the superconducting,and normal conducting material, respectively. The gap distance was set to 120 nm to maximize the probability to observe axion.

The device was produced at RIKEN, and the property was measured. The electro-magnetic shield was also designed and the was shielding power was tested by using FEM software. We need to measure extraordinarily small current, and the experimental design was determined.

In this contribution, the experimental overview and the current situation will be explained. The plan will be also shown.

category : Sensor Physics & Developments

PA-73 The DM Radio Pathfinder experiment: searching for dark matter from 500 peV to 50 neV

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In this work we describe the DM Radio Pathfinder, a dark matter search based on a superconducting lumped-element LC resonator. While WIMP searches have been conducted for several decades, very little is known about the fundamental properties of dark matter, motivating the search for a broad range of dark matter candidates. Light-field dark matter candidates, including the spin-0 axion and the spin-1 hidden photon, can be detected with coherent amplifiers. DM Radio is an experimental campaign using tunable, lumped element LC resonators and SQUID-based amplifiers to probe many orders of magnitude of hidden photon and axion mass and coupling strength. In this work, we report on progress on the detector for the DM Radio Pathfinder experiment, a liquid-helium-cooled, niobium lumped element detector. We perform *in situ* measurements to demonstrate the lumped element resonator, and measure coupling to the SQUID amplifiers and isolation from the environment.

category : Sensor Physics & Developments

PA-74 Characterization of doped silicon thermometers for cryogenic bolometers

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Doped silicon has long been used as thermometers for X-ray micro-calorimeters and in far-infrared bolometers. In the course of developing cooled semiconductor thermometers for submillimeter wave detection, typically 100 µ m ? λ ? 1.5 mm, we have investigated several phosphorus and boron ion-implanted Si (Si:P,B) thin layers with different doping densities at temperatures between 50 and 300 mK. The aim was to get sufficient understanding of thermometer behavior for optimizing the design of cryogenic detectors. The first step of this work, presented as part of this congress, is to obtain a square thermometer of 1 Mohm impedance around 50-100mK with high sensitivity to build 1 Gohm sensor (thanks to an aspect ratio around 1000). This leads to an important increase of the readout signal.

The obtained results showed that, at low supplied power, the electrical conductivity is approximated over a wide range of doping densities and temperature by the variable range hoping (VRH). However, at high supplied power, the non-Ohmic effects become dominant and the so-called "hot electron model", where the resistance is a function of the electrons temperature, provides a good fit to our data over a wide range of doping densities and temperature. These non-Ohmic effects may cause additional noise but mainly decrease the net sensitivity of the thermometers.

category : Sensor Physics & Developments

PA-75 Electromagnetic Simulations of newly designed semiconductor bolometers for submillimeter observations

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In the frame of the SPICA mission, new semiconductor bolometers have been designed for the SAFARI/POL instrument which are directly part of the HERSCHEL/PACS legacy. These detectors are cooled down to 50 mK and are sensitive to the polarization for the 100, 200 and 350 um wavelength bands. In this paper, preliminary simulations have been carried out using thin film theory to check the reliability of the first 3D simulations with a multiphysics software. The detector is broadly modelled by absorbers deposited on a silicon substrate suspended at the top of a resonant cavity (created by a reflector). This work shows that we can accurately recover the theoretical absorption curves by simulating a 3D structure within a short computation time. Then the whole bolometer structure has been designed with the two suspended interlaced silicon-spirals which support the vertical and horizontal absorbers (sensitive to the two orthogonal polarizations) of the SAFARI/POL detectors. These simulations allow to quantify the cross-polarization potentially induced by the layout of the absorbers. From this study we can conclude that cross-polarization has a really small effect on the electromagnetic absorption of the detector, which should be confirmed by forthcoming measurements.

category : Sensor Physics & Developments

PA-76 Development of a Dielectric Microcalorimeter with Quantum Ferroelectric Materials

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The dielectric constant of quantum paraelectric materials increases with temperature decreasing and holds a constant value at a temperature region of lower than tens K. Quantum paraelectric materials transit into a quantum ferroelectric phase by employing appropriate impurity doping. The dielectric constant of some kinds of the quantum ferroelectric materials has temperature dependence below 1K, and the change of the dielectric constant can be utilized as a thermosensor of microcalorimeters. The following are an operating principal of a dielectric microcalorimeter (DMC): By applying a constant DC voltage to facing surfaces across the dielectric capacitor, a change in the electric capacitance alters the amount of the electric charge stored in a dielectric capacitor. The temperature rise induced by the incident radiation is converted into electric charge proportional to the change in dielectric constant of the material. This electric charge is collected by the feedback capacitance of a conventional charge sensitive preamplifier. Because there is no DC-current through the dielectric device, the DMC has advantage of the suppression of the Johnson noise and the Joule heat generation in the device. Furthermore, the DMC is insensitive to magnetic fields. In this work, we fabricated prototype of DMC using $KTa_{(1-x)}Nb_xO_3$ (KTN) dielectric material, whose quantum ferroelectrics has been reported on “ D. Rytz et al. : Phys. Rev. B 27, 6830 (1983) ”. Geometrical dimensions of the KTN chip are surface area of 2 mm X 1 mm and 0.2 mm thick. Au electrodes of 0.1 μ m thick were deposited on the upper and lower surfaces. Electric capacitance of the KTN with x = 0.01 was found to have temperature dependence of 3 pF/K at temperatures below 1 K by electric capacitance measurement with using the 4 terminal pair method. The DMC using KTN with x=0.01 was irradiated with alpha rays emitted by a Am-241 source at a temperature of 100 mK. Although signal pulses were observed with applying a DC bias voltage of 10 V, the number of the observed pulse was extremely small. The number of the observed signal pulse was found to increase by applying an AC bias voltage with the amplitude of 10 V and the frequency of 0.01 Hz. Signal pulses corresponding to alpha particle detection were selected with analyzing the rise time constant of the signal pulses. In this presentation, we report details of sensitivity of the dielectric thermosensor and alpha ray response of the DMC using the KTN with x=0.01.

category : Sensor Physics & Developments

PA-77 Accurate Measurement of Gain Saturation of Superconductor-Insulator-Superconductor

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Superconductor-Insulator-Superconductor (SIS) tunnel junction mixers and direct detectors are very sensitive detectors in millimeter and submillimeter waves. However, they can be significantly saturated by a room temperature blackbody radiation, which results in uncertainties in calibration of radio telescopes. Astronomical observation, on the other hand, requires high fidelity in order to accurately derive physical parameters of celestial bodies. Besides efforts in improving the linearity of SIS mixers in circuit design, accurate measurement of the gain saturation up to an uncertainty of 1

Experimentally the gain saturation measurement is implemented by introducing a weak cw (continue wave) signal together with a broadband blackbody radiation into the input port of the mixer and measuring the difference of cw power at the output with switching the blackbody temperature from liquid nitrogen to room temperature. For an ideal linear mixer, the cw output power is indifferent to the broadband noise level. But in practice, a certain reduction in the cw output power can be detected when the input noise level is switched from low (liquid nitrogen) to high (room temperature). Although the principle is simple, the measurement result is found to be different with different power measurement instruments, specifically a standard spectrometer and a diode powermeter. Both of them are verified to show good linear responses to a cw source. This discrepancy is found to be dependent on the power level of the cw signal that is injected. The lower signal-to-noise level, the bigger discrepancy was found. Besides the uncertainty in measure gain saturation, the noise temperature of the mixer is also found to vary with output power level.

The above mentioned uncertainties were found to be caused by the difference in the response of power detectors between cw signal, noise-like signal and the mixture of cw and noise-like signal with small signal-to-noise ratio. Power detectors that are widely used are diode-based detectors because they are fast in response, stable, sensitive and economical. However, because they are not based on thermal effect in the measurement of signals, they may response differently to cw signals of different frequencies and between cw signals and noise-like signals. While the former one is often noticed in the calibration manual, the later one is in general not been paid attention to. In this work, we will analyze the detection error, the calibration method and an example of characterization of a SIS mixer.

category : Sensor Physics & Developments

PA-78 Study for the Operating Principle of Superconducting Strip Photon Detectors (SSPDs)

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Superconducting strip photon detectors (SSPDs) are promising single photon detectors for realizing practical quantum cryptography; their high quantum efficiencies, low timing jitters, and low dark count rates overcome those of avalanche photo diodes or other single photon detectors. Recently, some research groups have established testbeds for quantum cryptography and succeeded in field tests of quantum key distribution at a speed of sub Mbps using practical optical fibers in the length of tens of km.

However, the detecting mechanism of the SSPD is still under investigation. The most probable hypothesis is the followings: (1) an incident photon fluctuates the order parameter of a superconducting strip resulting in the nucleation of vortex-antivortex pairs; (2) vortex pairs are unbound and forced out of the strip in the perpendicular direction of bias current; (3) kinetics of vortices forms a normal band across the strip and a current pulse outputs. Conventional SSPDs utilize the current pulse as a photon detection signal and its response characteristics such as a response time of several ns regulate the quantum communication speed of sub Mbps as mentioned above.

On the other hand, the numerical simulations have shown that the time scale of kinetics of vortices is in the range of ps. Therefore, by detecting the extruded vortices instead of current pulse, we could expect the communication speed faster than several orders of magnitude of that realized by conventional SSPDs. In this study, we have directly connected a superconducting strip with single flux quantum (SFQ) circuits to capture the extruded vortices out of the strip. Since the information carriers of SFQ circuits are also vortices, not only capturing the vortices but also counting the number of them or other logical operations are possible.

category : Sensor Physics & Developments

PA-79 MOCCA: A 4k-pixel molecule camera for the position and energy resolving detection of neutral molecular fragments at the Cryogenic Storage Ring CSR

Lisa Elena Gamer[1], Steffen Allgeier[2], Klaus Blaum[3], Christian Enss[4], Andreas Fleischmann[5], Loredana Gastaldo[6], Sebastian Kempf[7], Oldrich Novotny[8], Dennis Schulz[9], Andreas Wolf[10]

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The Cryogenic Storage Ring CSR at the Max Planck Institute for Nuclear Physics in Heidelberg is designed to prepare and store molecular ions in their rotational and vibrational ground state. A key requirement for the study of electron-ion interactions within CSR is the identification of reaction products. The use of metallic magnetic calorimeters (MMCs) allows for identifying all neutral products since the deposited kinetic energy of incident particles into MMC absorbers can be used as a measure of the particle mass. To actually resolve the full reaction kinematics, a position sensitive coincident detection of multiple reaction products is necessary.

For these measurements we designed MOCCA, a 4k-pixel molecule camera based on MMCs with a detection area of 45mm $\times$ 45mm, which is segmented into 64 $\times$ 64 absorbers and read out using only 32 SQUIDs. We discuss the detector design and its microfabrication as well as its multi-hit capability, cross-talk and expected energy resolution for photons and massive particles. In addition, we present first proof-of-principle measurements with photons as well as our plans for integrating MOCCA and its 3He/4He dilution refrigerator into CSR.

category : Sensor Physics & Developments

PA-80 Tantalum STJ X-ray Detectors with an Energy Resolution Limited by Charge Statistics

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We are developing superconducting tunnel junction (STJ) detectors for high-resolution soft X-ray spectroscopy at synchrotron light sources. The sensor consists of 36- or 112-pixel arrays of Ta-Al-AlOx-Al-Ta STJs, and each pixel has an area of (208 μm)^2. When illuminated directly with a monochromatic X-ray beam at a synchrotron, the STJs have an energy resolution between ≈2 and ≈5 eV FWHM in the energy range below 1 keV, and can be operated at several 1000 counts/s per pixel. The STJ line width is much narrower than the width of X-ray fluorescence lines in the same energy range, indicating that the STJ energy resolution is higher than the natural line width of the fluorescence. In fact, at low energies the resolution is set by the statistics of charge generation and tunneling, plus an electronic noise contribution of ≈2 eV. We discuss STJ detector performance and their use in synchrotron science.

category : Sensor Physics & Developments

PA-81 Development of metallic magnetic calorimeters with critical temperature switch for AMoRE experiment

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We report the recent progress on MMC development of a critical temperature switch. A meander-shaped coil in the MMC should form a superconducting loop to measure the magnetic signal and to apply a persistent field current to magnetize the paramagnetic sensor material. In this work, a part of the superconducting loop is fabricated with another superconducting material with its transition temperature (Tc) lower than that of niobium. A persistent current can be injected in the loop while reducing the temperature from above to below Tc. A part of the loop is made of an alloy of Nb and Ta (NbTa) with its Tc between 2.7 K to 5 K. In this method, the number of MMC wirings can be reduced, and the field current injection procedure can be simplified. The MMCs with a critical temperature switch are to be used for future AMoRE detector that requires about 1000 MMC channels.

category : Sensor Physics & Developments

PA-82 Thermal modelling and experimental results on NTD heat signals for Ge macro-bolometers

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This work describes the methodology and results from a dedicated study of the heat signals from germanium Neutron Transmutations Doped (Ge-NTD) used for Ge macro-bolometers as in the EDELWEISS experiment. We show how, with a combined set of measurements with different detector configurations, we construct a coherent thermal model, including the effect of Aluminum electrodes on the heat signals. Eventually, from the set of detector configurations studied, we define a pathway at improving the energy resolution for 200 (800) gram-scale Ge bolometers down to 100 eV (RMS) which would provide great sensitivity to low-mass dark matter down to 0.5 GeV.

category : Sensor Physics & Developments

PA-83 Statistical approach to the investigation of dark counts in Superconducting Nanostrip Single Photon Detectors

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Superconducting Nanostrip Single Photon Detectors (SSPDs or SNSPDs) are typically based on thin and narrow nanowires patterned out of NbN or NbTiN superconducting films that operates at a temperature of about 2 K and biased close their critical current value. They can detect single photons in the wavelength range between visible and near infrared with unprecedented performance in terms of high detection efficiency, excellent timing jitter, free-running operation and especially very low dark count rate [1-3]. In particular, the investigation of the dark count generation phenomenon will reveal important aspects of the intrinsic mechanisms underlying the SNSPD operation and signal-to-noise in practical photon counting applications. In addition, this understanding will guide optimization of improved SNSPD device based on meandered nanostrips like, through mitigation of effects due to current crowding effects, inhomogeneities and constrictions along the nanostrips and so on [4].

We present measurements of NbN SNSPD performed in the range from 4.2K to 60 mK. At 4.2 K we characterized current bias dependence of the dark count rate using an innovative statistical approach. From the measurements, we can reconstruct the dark count rate of the detector along with its statistical distribution and compare this to mathematical models. The detector was subsequently cooled in a dilution refrigerator and measurements were performed in the range 60 - 650 mK but no dark count events were observed. A follow up optical characterization in the presence of 1550 nm laser light was performed using the same statistical approach.

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category : Sensor Physics & Developments

PA-84 Low loss submillimeter wave coplanar waveguide made of superconducting NbTiN on sapphire substrate

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Low loss submillimeter wave coplanar waveguide made of superconducting NbTiN on sapphire Recent advances in submillimeter technology have enabled on-chip superconducting components such as on-chip spectrometers, parametric amplifiers, multi-color pixels, phased array antennas, and delay lines. Many of these components, and their interconnections, require transmission lines with very low losses of the order of $\tan\delta \ll 10^{-2}$-10^{-4}, or $Q \gg 10^{2}$-10^{4}, depending on the application. In this study we measured the loss of a superconducting coplanar waveguide (CPW) using an on-chip CPW Fabry Perot (FP) interferometer. The CPW-FP is fabricated from a 100 nm thick NbTiN film, sputter deposited on a C-plane sapphire substrate, and has an equal slot width and strip width of 2 μm. To minimize the effects of coupling ends of the FP, we drive the resonator at high order modes (n = 95-100). We measure in the 360-380 GHz range Q ~13 000-16 000, setting lower limits to the intrinsic CPW losses at each resonance frequency. This shows that 100 nm NbTiN CPW lines are potential building blocks for on-chip components and devices.

category : Sensor Physics & Developments

PA-85 NTD-Ge production in the LUMINEU experiment using cryogenic detectors for Rare Events searches and other applications

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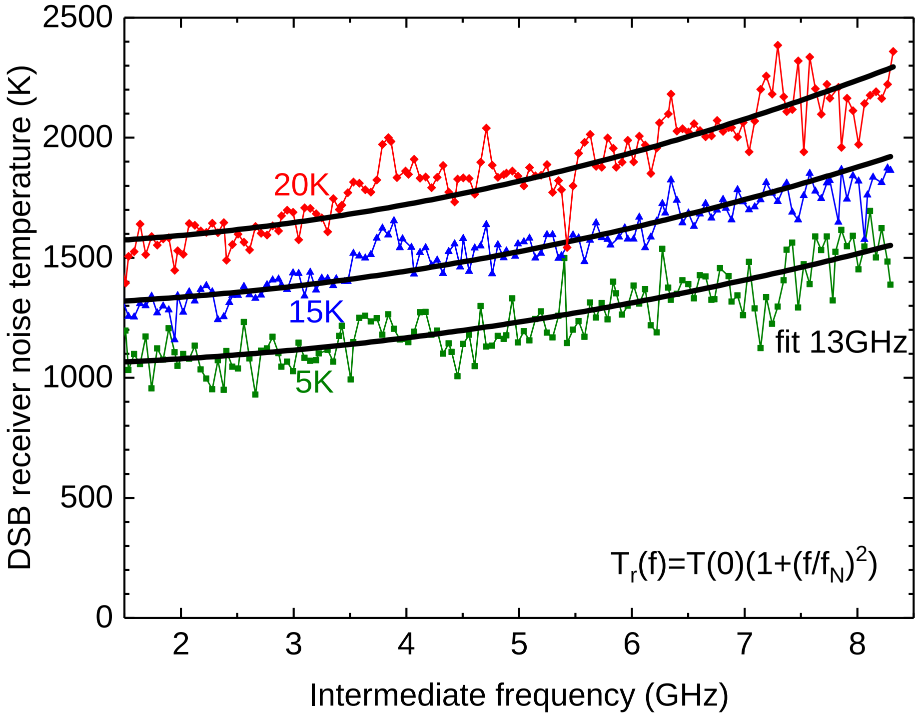
Experiments such as Cupid-Mo and Edelweiss-3 plan to use Neutron Transmutation Doped Germanium sensors (NTD) as thermistors on their detectors for Neutrinoless Double Beta Decay and light-mass-WIMP search respectively. Such a choice is motivated by their robustness, reliability, ease of use over a large range of temperature and large dynamic range in energy. To cope this future large demand on NTDs, our groups in LUMINEU started a new production line for Ge-NTDs.

In this poster, we present the synthesis of irradiation dose of the different irradiations of HPGe wafers and parameters of metallization. Some wafers have been selected on the basis of their R(T) at very low temperature and first signals obtained from LUMINEU 's detectors equipped with sensors made from these wafers. The performance in term of noise and signal to noise ratio are equivalent to the best previously available NTD sensors. This demonstrates our ability to produce performant NTD sensors for the desired range of working temperature.

category : Sensor Physics & Developments



DSB receiver noise temperature (K)
Intermediate frequency (GHz)
20K
15K
5K
fit 13GHz
$T_r(f)=T(0)(1+(f/f_N)^2)$
2500
2000
1500
1000
500
0
2
3
4
5
6
7
8

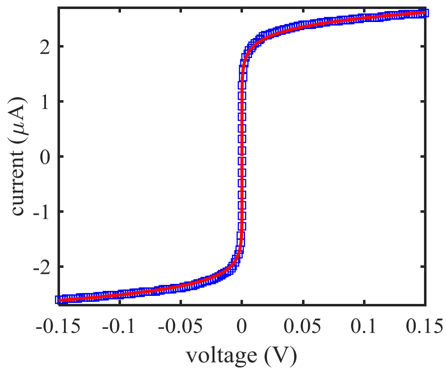


Figure 1. Non-hysteretic current-voltage (IV) curve measured for a 100 nm wide NbN SNSPD on silicon at 9.4K. A fit line based on Ambegaokar and Halperin's model of the effect of thermal noise on a resistively shunted Josephson junction is shown in red. The critical current (I_c) and normal state resistance (R_n) were used as fitting parameters, with I_c = 4.2 µA and R_n = 6 MΩ.

Category B : Readout Techniques & Signal processing

PB-1 Development of a data acquisition system for kinetic inductance detectors: wide dynamic range and high sampling rate for astronomical observation

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Microwave Kinetic Inductance Detectors (MKIDs) have a potential for a variety of applications to astronomical observation. One of these applications is observation of cosmic microwave background radiation (CMB), and the GroundBIRD telescope for CMB polarization measurement adopts MKIDs arrays as its focal plane detectors.

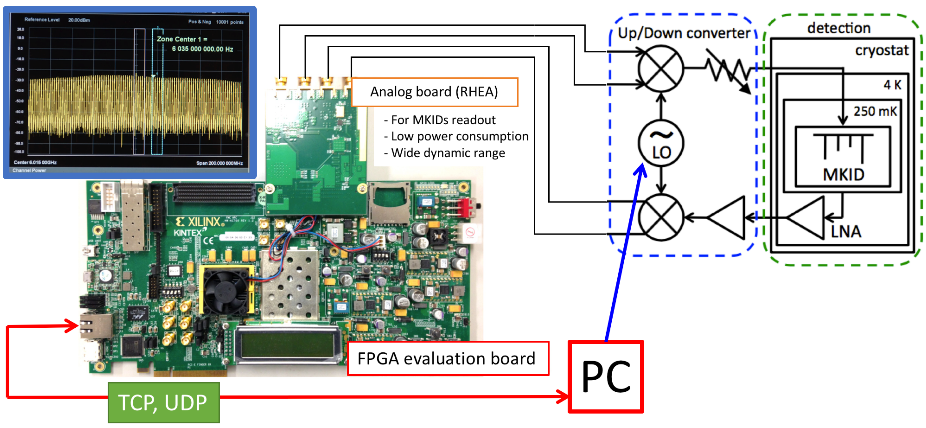
In order to achieve high sensitivity for large angular scale, the GroundBIRD telescope utilizes a novel circular scanning system employing rotary joints for gas and electricity. MKIDs well match with this high-speed scan for their prompt time responses. The observation requires high sampling rate (over 1 kSpS), wide dynamic range, and stable operation for the read-out system.

We built a data acquisition system combining a dedicated analog board and a commercially available digital board. The analog board " RHEA " has two pairs of 14-bit ADC and 16-bit DAC operating at 200 MSPS, whose high bit resolution enables wide dynamic range without losing sensitivity. RHEA also achieves low power consumption and low heat emission in comparison with a commercially available analog board, enabling stable operation at least over a month. The digital board is an evaluation board for an FPGA Xilinx KCU105, which calculates the output multi-tone wave and processes the input waves deformed by detectors to extract the signal. After the process, the data is sent to a computer via gigabit Ethernet.

In this conference, we will present the status of the development of the data acquisition system. We have already achieved 120 channel simultaneous readout using the direct down-conversion method to decode the signal. Using the functionalities of the system, a variety of software, e.g., VNA-like sweep, time-ordered data acquisition, and real-time monitoring, were developed and tested. We also performed measurements with a test array of MKIDs fabricated in RIKEN, and confirmed that the system properly works.

Although the data acquisition system was developed for the GroundBIRD experiment, it can be generally used for readout of MKIDs, in particular when the measurement requires high sampling rate and wide dynamic range. In addition, the analog board RHEA has a potential for a wide variety of applications beyond MKIDs readout.

Figure: Schematic view of the developed readout system. Output with 120 tones measured with a spectrum analyzer is included in the upper-left panel.



category : Readout Techniques & Signal processing

PB-2 In-orbit performance of the pulse shape processor of ASTRO-H SXS

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The pulse shape processor (PSP) is the onboard digital signal prcessing unit of the X-ray micro-calorimeter mission; the Soft X-ray Spectrometer (SXS) onboard the Hitomi (ASTRO-H) satellite. We have reporeted its design and expected performance in the previous LTD meetings. We present the result obtained in the orbit in this meeting.

The PSP continuously recieves the signal, which is sampled at 12.5 kHz, shaped, amplified, and digitized by the preceding analogue signal processing unit from 36 micro-calorimeter and two anti-coincidence detector channels. It is responsible for detecting X-ray pulses, deblending them if they are overlapped in time, cross-correlating them with templates to derive precise arrival time and energy based on the optimum filtering technique, and editing the telemetry for downlink. Because these calculations are resource-demanding, the CPU processing speed of the PSP determines the total throughput of the SXS. When the PSP cannot catch up with the incoming rate, it inserts dead time artificially to discard an entire event buffere once in a while.

This design was tested in the orbit during the observation of the Crab nebula, which was sufficiently bright to hit the PSP limit. Using the data, we show that the maximum processing rate exceeded the required value of 150 Hz/array, and that the dead times were properly recorded so that we can reconstruct the images, spectra, and pulse shape of the Crab pulsar and its surrounding nebula.

category : Readout Techniques & Signal processing

PB-3 Crosstalk in an FDM laboratory set-up and the Athena X-IFU science performance

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The detector of the X-ray Integral Field Unit (X-IFU) instrument onboard Athena will consist of 3840 TES pixels read out with a Frequency Domain Multiplexing system of 96 channels. At various points along the read-out chain crosstalk may arise, effectively causing offsets in photon energies measured on pixels due to signals received in neighbors. Neighboring pixels may be adjacent in space, in the case of thermal crosstalk arising on the array, or in frequency, in the case of crosstalk in the electrical circuit of the FDM readout. The impact of various crosstalk mechanisms on the instrument performance has been assessed with detailed end-to-end simulations and so far found to be accomodatable within the requirements for energy resolution degradation and throughput of high-quality events. For the crosstalk in the electrical circuit a detailed model has been developed. In this contribution we test this model against measurements made with an FDM laboratory set-up and discuss the assumption of deterministic crosstalk in the context of the weak link effect in the detectors. We show that crosstalk levels predicted by the model are conservative with respect to the observed levels.

category : Readout Techniques & Signal processing

PB-4 Evaluation and Improvement of Nb and NbN Microwave SQUID multiplexers for a gamma-ray TES with a Sn Absorber linked by Au Post

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Transition edge sensors arrays based on microwave SQUID multiplexer[1] (MW-MUX) is promising technique to realize a superconducting detector system with high energy resolution and large active area. The MW-MUX takes advantage of high-Q superconducting thin-film resonators terminated by dissipationless RF-SQUIDs. Then the signals of TESs are multiplexed into large bandwidth of low noise cryo-HEMT of a few GHz which leads to the number of multiplexing TES pixels in a cable much higher than conventional multiplexers.

We have been developing MW-MUX based on Nb or NbN quarter wave resonators optimized for gamma-ray TES consists of Ir/Au bilayers coupled to a tin bulk absorber being developed at the University of Tokyo[2]. Here, we report the evaluation of our MW-MUX system based on the first readout of single gamma-ray TES signal.

In the experiment, we readout 5 channels in a MW-MUX chip simultaneously, one of them is connected to the gamma-ray TES and the other channels are open. The input power of microwave is about -85 dBm at the feedline and the flux ramp modulation[3] of 60 kHz is applied to the SQUIDs. The intrinsic quality factors (Q_i) of MW-MUX used in this experiment are about 4×10^3 - 1×10^4 at 100 mK, although our short-ended resonator achieved $Q_i \approx 10^5$ [4]. The TES is irradiated with the gamma-ray from Co-57 positioned outside the cryostat.

The time constant of rising (τ_{rise}) and the decay (τ_{decay}) are evaluated by fitting the measured pulse to a theoretical equation. The obtained values are $\tau_{rise} = 260\ \mu s$ and $\tau_{decay} = 6.4\ ms$ those are close to the values obtained by the conventional single pixel readout system.Therefore, our multiplexer is fast enough for our gamma-ray TES. Although the readout noise (RMS) is about 11 times worse than that of the conventional readout system, reduction of 10 dB white noise is expected by optimizing the microwave power and increasing Q_i to 1×10^5.
We will discuss possible origin that degrades Q_i and show the improvement of noise under the optimized microwave power.

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Acknowledgements

The chip was fabricated in the clean room for analog-digital superconductivity (CRAVITY) in AIST. This work is partially supported by the program “ The Initiatives for Atomic Energy Basic and Generic Strategic Research ” organized by Japan Science and Technology Agency and JSPS KAKENHI Grant No. JP15H02251.

category : Readout Techniques & Signal processing

PB-5 Toward a 2000-channel Microwave SQUID Multiplexed Unit for Transition-Edge Sensor Bolometer Arrays

Bradley Jerald Dober[1], Jason Austermann[2], James Beall[3], Dan Becker[4], Douglas Bennett[5], Shannon Duff[6], Jiansong Gao[7], Jonathon Gard[8], James Hays-Wehle[9], Gene Hilton[10], Johannes Hubmayr[11], John A. B. Mates[12], Christopher McKenney[13], Joel Ullom[14], Jeff Van Lanen[15], Michael Vissers[16]

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Next-generation bolometric receivers for future millimeter-wave astrophysics experiments such as Simons Observatory and CMB-S4 will have focal planes with 50,000 Transition-Edge Sensors (TESs). Focal planes of this size require both an increase in multiplexing factor as well as a reduction in detector packaging complexity. The microwave SQUID multiplexer (uMUX) is a readout technology that has the potential to both drastically increase multiplexing factors while simplifying the detector packaging. In this talk, we will describe recent measurements at NIST of TES bolometers optimized for ground-based CMB studies using uMUX. These measurements show (1) a broad-band white noise contribution well below the intrinsic sensor noise, and (2) low-frequency readout noise compatible with proposed CMB scan strategies. These two results firmly establish the suitability of uMUX readout for future ground-based CMB studies. In addition, we will review progress made at NIST towards further optimizing the uMUX design to accommodate 2000 detector channels on a single readout line, which is achieved by decreasing the resonator bandwidth from 300 kHz to 100 kHz and the resonator frequency spacing from 6 MHz to 2 MHz. These steps will allow 2000 TES channels to fit on a single 4-8 GHz bandwidth readout card. Finally, we will highlight steps we have been taking to significantly reduce the complexity of assembling large focal planes. For example, the complexity of wiring interconnects can be eliminated by utilizing a single interface and bias wafer that is mounted to the back of the detector array. The uMUX and packaging technologies described here are expected to enable next-generation CMB experiments.

category : Readout Techniques & Signal processing

PB-6 Development of a cryogenic capacitive trans-impedance amplifier based on FD-SOI CMOS

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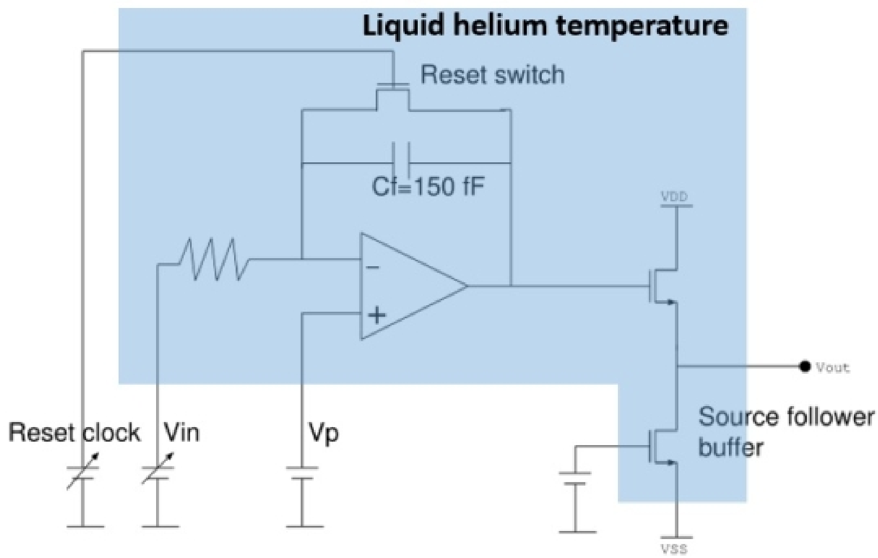
We are developing an image sensor with sensitivity to far-infrared (IR) wavelengths ranging from 30 to 200 μm for astronomical observations. Our image sensor consists of a cryogenic readout integrated circuit (ROIC) and a semiconductor detector, such as germanium which is often used for a far-IR detector. The detector must be cooled down below 2 K to reduce thermal noise; the dark current of the detector is reduced to be below 5 fA. To achieve the detector noise limit, the input leak current of the ROIC should be lower than the detector dark current. The ROIC based on MOSFETs is advantageous to achieve such very low leak current.

However, conventional bulk-MOSFETs, in particular NMOS FETs, show degradation such as the kink effect and hysteresis in drain current at cryogenic temperatures. These anomalies are caused by instability of the potential distribution in the MOSFETs under a carrier freezeout condition. In contrast, MOSFETs fabricated by a fully depleted silicon-on-insulator (FD-SOI) CMOS process show stable characteristics at cryogenic temperatures. Due to very thin Si bodies and thus full depleted ones, FD-SOI MOSFETs have no neutral region where the anomalies by carrier freezeout may happen. Thus, their I-V curves are not almost affected by the kink effect and the hysteresis.

We developed an operational amplifier (OPAMP) based on the FD-SOI CMOS and obtained its excellent performance at 4.2 K. For the far-IR image sensor, we designed a capacitive trans-impedance amplifier (CTIA) using the OPAMP and evaluated the performance of the CTIA at 4.2 K. The schematic circuit diagram to evaluate the performance of the CTIA is shown in Figure 1. We demonstrated that our CTIA works as designed and that the input leak current is $< 1.4 \times 10^{-17}$ A. Those results meet our requirements on the CTIA.



category : Readout Techniques & Signal processing

PB-7 A Second Generation Digital Readout for Large Photon Counting UVOIR MKID Arrays

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We present the development of a second generation digital readout system for photon counting MKID (Microwave Kinetic Inductance Detector) arrays, operating in the UVOIR (UV, optical, infrared) regime. Like our first generation system, the readout utilizes a two stage downconversion/channelization algorithm, and is capable of measuring photon arrival time to 1 microsecond. IQ modulation and A/D conversion are performed using custom IF and ADC/DAC boards, and the channelization algorithm is implemented using a CASPER ROACH2 board. Each complete set of readout electronics is capable of reading out 1000 pixels in a 2 GHz band between 4 and 8 GHz. Ten such units are combined to read out our 10,000 pixel DARKNESS array; this setup, combined with a 80 TB storage server, can record every photon's arrival time, energy, and absorption location for over 10^7 photon/second. At a cost of roughly 7/pixel, this system could conceivably be scaled up to read out much larger arrays.

category : Readout Techniques & Signal processing

PB-8 Series SQUID Array Amplifiers Optimized for MHz Frequency-Domain Multiplexed Detector Readout

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The CMB-S4 next-generation ground-based cosmic microwave background experimental program aims to provide definitive measurements of the early universe using telescopes with large focal plane arrays of ?100,000 detectors. In this report, we describe first results of a project to develop low-noise cryogenic amplifiers based on series SQUID arrays that are suitable for frequency domain multiplexed readout for large CMB instruments. Designs were optimized using modeling and simulation tools to meet the requirements for CMB detector readouts. Two generations of prototype series SQUID array amplifier (SSAA) designs were completed. A large number of devices from each design iteration were tested and characterized at 4 K. The new SSAA designs exhibit excellent performance characteristics. V Phi curves are very smooth indicating little or no impact of RF resonances will be seen at higher frequencies. The best-performing designs ’ transimpedance (400 V/A versus 500 V/A) and current noise (5.9 pA/Hz versus 3.7 pA/Hz) are approaching those of the benchmark series SQUID array amplifier from NIST. Two features of the new designs are of particular interest for future large-pixel-count CMB experiments: 1) input inductance has been lowered substantially (11 nH versus 150nH), which may permit a higher density of channels in frequency space, and 2) power dissipation has been lowered substantially (18 nW versus ?900 nW at typical bias) that for the first time will enable the SSAAs to be operated in close proximity to the pixels and filters at the 100mK focal plane array stage.

category : Readout Techniques & Signal processing

PB-9 SLAC Microresonator Radio Frequency (SMuRF) Electronics for read out of Frequency-Division-Multiplexed Cryogenic Sensors

Zeeshan Ahmed[1], SMuRF collaboration

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Large arrays of low-temperature sensors for various applications ranging from x-ray, gamma-ray, Cosmic Microwave Background (CMB) and mm/sub-mm imaging to particle detection increasingly rely on superconducting microresonators for high multiplexing factors. These microresonators take the form of microwave SQUIDs that couple to Transition-Edge Sensors (TES) or Microwave Kinetic Inductance Detectors (MKIDs). In principle, such arrays can be read out with vastly scalable software-defined radio using suitable FPGAs, ADCs and DACs. In this work, we share plans and show initial results for SLAC Microresonator Radio Frequency (SMuRF) electronics, a next-generation control and readout system for superconducting microresonators. SMuRF electronics are unique in their implementation of specialized algorithms for closed-loop tone tracking, which consists of fast feedback and feedforward to each resonator's excitation parameters based on transmission measurements. Closed-loop tone tracking enables improved system linearity, a significant increase in sensor count per readout line, and the possibility of overcoupled resonator designs for enhanced dynamic range. Low-bandwidth prototype electronics were used to demonstrate closed-loop tone tracking on twelve 300-kHz-wide microwave SQUID resonators, spaced at ∼6 MHz with center frequencies ∼5–6 GHz. We achieve multi-kHz tracking bandwidth and demonstrate that the noise floor of the electronics is subdominant to the noise intrinsic in the multiplexer. Finally, we present the status of the high-bandwidth SMuRF electronics for read out of ∼4,000 microwave-SQUID-coupled TES bolometers, or ∼500 fast TES x-ray calorimeters per readout line. These electronics are designed for high density and scalability to enable systems with $\sim 10^5$ or more channels.

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category : Readout Techniques & Signal processing

PB-10 Firmware Development for Microwave SQUID Multiplexer Readout

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The readout requirements for instruments based on Transition-Edge Sensors (TESs) have dramatically increased over the last decade as demand for systems with larger arrays and faster sensors has grown. Emerging systems are expected to contain many thousands of sensors and/or sensors with time constants as short as 100 us. These requirements must be satisfied while maintaining low noise and low crosstalk. A promising readout candidate for future TES arrays is the microwave SQUID multiplexer, which offers several gigahertz of readout bandwidth per pair of coaxial cables. In microwave SQUID multiplexing, sensor signals are coupled to RF-SQUIDs embedded in superconducting microwave resonators, which are probed via a common microwave feedline and read out at room temperature using GHz signals carried on coaxial cables. This form of SQUID multiplexing moves complexity from the cryogenic stages to room temperature hardware and digital signal processing firmware which must synthesize the microwave tones and process the information contained within them.

To demultiplex at room-temperature, we have implemented an FPGA-based solution using the ROACH2 hardware platform developed by the CASPER consortium. We have successfully developed a flexible firmware architecture that, with few modifications can read out implementations of microwave SQUID multiplexers optimized for bolometric, high count rate x-ray, and AC-bias TES applications. These implementations have resonator widths of 100 kHz, 2 MHz, and 30 MHz full width at half maximum respectively, with each different resonator bandwidth necessitating digital filter modifications to accommodate the differing channel counts and required sampling rates.

A gamma-ray spectrometer targeted at nuclear materials accounting applications, known as SLEDGEHAMMER, is an early adopter of microwave SQUID multiplexing and is driving our current firmware development effort. This instrument utilizes medium-bandwidth (300 kHz) resonators with 256 channels in a one gigahertz band. We have recently demonstrated undegraded readout of 128 channels using two ROACH2s and a single HEMT amplifier. We discuss how the electronics and firmware function, the challenges we encountered, and how these early results are informing our current electronics and firmware development.

category : Readout Techniques & Signal processing

PB-11 Development of Microwave Multiplexer Readout System Based on SQUIDs Directly Coupled to Resonators for TES X-ray Microcalorimeter

Yuki Nakashima[1], Fuminori Hirayama[2], Satoshi Kohjiro[3], Hirotake Yamamori[4], Shuichi Nagasawa[5], Akira Sato[6], Noriko Yamasaki[7], Kazuhisa Mitsuda[8]

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We are developing a microwave superconducting quantum interference device (SQUID) multiplexer (MW-Mux) readout system aimed to realize more than 10^4 pixels large format superconducting transition edge sensor (TES) X-ray microcalorimeter array, which is larger than that of the Athena mission (i.e., 3840 pixels planned to launch around 2028) in an order of magnitude, for future space missions such as an advanced version of DIOS (e.g., Yamada et al. in this workshop). MW-Mux is a multiplexing technique capable of reading out potentially hundreds to thousands of TES pixels in a single coaxial pair because of that three orders of magnitude larger bandwidth than those of conventional multiplexing methods (i.e., TDM, CDM and FDM) with several MHz bandwidths. It consists of a number of superconducting resonators in the GHz range, each employing a unique resonance frequency, terminated by either an inductance magnetically coupled to dissipationless rf-SQUID (conventional work) or SQUID itself (this work). Each SQUID acts as a flux-variable inductor responding to the magnetic flux threading the SQUID loop in a flux-quantum Φ_0 ($= 2.07 \times 10^{-15}$ Wb) cycle. The advantage of our SQUID directly coupled to resonators is the simple design even when the number of pixel becomes quite large. It is because, in our direct-coupled SQUIDs, all pixels with different resonance frequencies can adopt SQUIDs with the same shape, structure, and dimensions, while it is not the case for magnetically coupled SQUIDs.

The developed MW-Mux readout system consists of the MW-Mux optimized for our TES X-ray microcalorimeter, the input circuit on chip connecting to that microcalorimeter and the readout electronics. To optimize a MW-Mux for our TES X-ray microcalorimeter under the condition of applying flux ramp modulation for a linearization purpose, we made an investigation into required MW-Mux bandwidth by numerical and spice simulations. In our case, that was required larger than 3 MHz to satisfy sufficient energy resolution of our TES X-ray microcalorimeter whose signal rise and fall time constants were respectively 5 to 20 and 60 μs. Then, the 16-channel MW-Mux with larger bandwidth than 3 MHz was designed and fabricated based on three Nb electrode layers with SiO_2 insulation layers stacked on Si substrate. Moreover, we experimentally confirmed that all 16 resonances and SQUID responses to the input signal agreed with the designed ones, and the bandwidths of those resonances were all over 3 MHz. We have also been developing the input circuit including a microwave filter and some of dumping inductors, which are used to control the TES signal rise time constant, on the purpose of read the TES signals out using this system.

In this presentation, we report optimized designs of our developed MW-Mux readout system for our TES X-ray microcalorimeter, experimental result of that performances and brief introduction of TES X-ray microcalorimeter features using that system.

category : Readout Techniques & Signal processing

PB-12 Investigation of SIS up-converter for use in multi-pixel receivers

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In radio astronomy, there is a strong interest in large-scale multi-pixel heterodyne receivers, which enable wide field-of-view observations with high spectral resolutions. So far, multi-pixel heterodyne receivers have been developed by several institutes, up to a maximum pixel number of 64. This number of pixels was achieved by " SuperCam ", which explored astrophysically important emission and absorption lines within the 850 micron atmospheric window. Further increase of the pixel number to as many as 1000 is now being considered. In this case, a key problem is the total power consumption of a large number of cryogenic low noise amplifiers (LNAs). Given that a typical LNA consumes a few milliwatts of power, refrigerators with several watts of cooling capacity at the 4-K stage are necessary to cool down thousands of pixels. This is clearly impractical. To overcome this issue, we propose the use of a frequency division multiplexing (FDM) technique to reduce the number of amplifiers at 4 K. The intermediate frequency (IF) outputs of the different SIS mixers used for each of the different pixels could be up-converted by a local oscillator (LO) signal composed of different frequency tones, a so-called frequency comb signal. The frequency difference between 2 LO tones should be larger than the IF bandwidth at the SIS mixer IF output. Doing this, several SIS mixer IF bandwidths could be allocated in a larger IF bandwidth, as a FDM signal, which could be amplified at once with current wideband IF amplifiers. One of the key components to implement this concept is the up-converter, which should have a gain larger than unity to prevent degradation of the receiver performance due to extra losses before amplification in the LNA. For this reason, we consider SIS mixers with conversion gains greater than unity due to quantum effects are good candidates for this purpose. For the currently on-going feasibility study, we have calculated the up-conversion characteristics of SIS mixers based on the quantum mixing theory developed by Tucker. Analytical results show that it is necessary to select LO frequencies larger than the voltage scale of the dc nonlinearity of the SIS junction in order to obtain positive conversion gains. First preliminary experimental results using Nb/AlOx/Nb SIS junctions showed a possible gain in an SIS up-converter at the LO frequency of 85 GHz.

category : Readout Techniques & Signal processing

PB-13 Active tuning of the resonance frequencies of LC bandpass filters for frequency domain multiplexed readout of TES detector arrays

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Efficient use of the available frequency space for frequency domain multiplexing (FDM) is essential for space-based TES detector applications such as the X-IFU instrument on the Athena X-ray telescope. For cross talk reasons there exists a lower limit on the distance between neighbouring pixels in frequency space, so that accurate control of the resonance frequency helps to use the available frequency space. Independently, from the point of view of efficient sinusoidal bias voltage generation, placing the frequencies on a grid with a fixed spacing helps to avoid the effects of nonlinearity on the detector performance. Inevitable tolerances in the lithographic production of LC bandpass filters, and margins in the design of stray inductances limit the the relative accuracy of the resonance frequencies to a few times 10^{-3}.

In this paper we will propose a new method which uses the active SQUID readout electronics at room temperature to further fine tune the resonance frequencies of the LC filters beyond the manufacturing limitations. The results of an experimental demonstration, in which resonance frequencies of 1 - 5 MHz will be changed over a range of few kHz, will be shown.

category : Readout Techniques & Signal processing

PB-14 Development of semi-rigid superconducting coaxial cables with normal-conductor-clad center conductor

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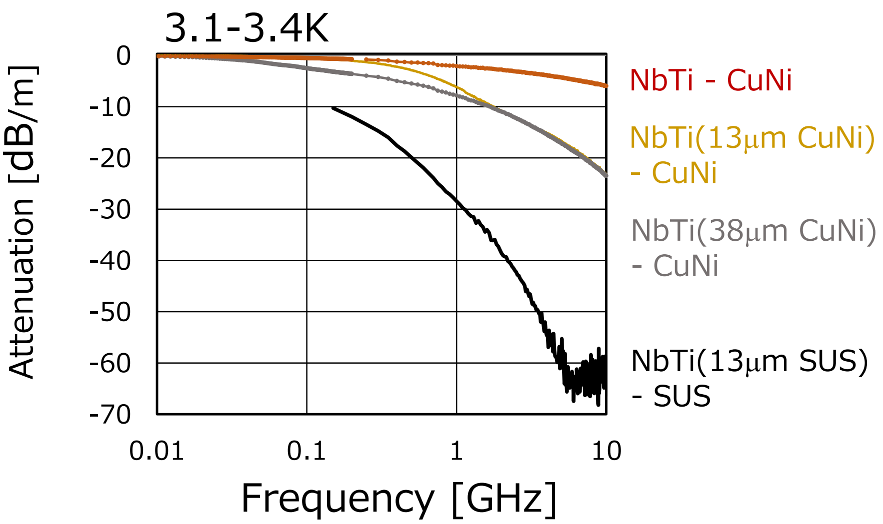
[1]Kurume University, [2]Department of Materials Systems Engineering, National Colleges of Technology, Kurume College , [3]COAX CO., LTD.

Semi-rigid coaxial cables with seamless metal materials as the outer electrical conductors can often been used for the readout of low temperature detectors realizing low noise measurements. Moreover thin semi-rigid coaxial cables employing superconductors, such as niobium-titanium (NbTi) at both center and outer conductors, enable very small attenuation as well as small heat penetration into the cryogenic stages thanks to their almost zero electrical resistivity and extreme low thermal conductivity.

We developed low-pass-filter-type semi-rigid coaxial cables with an outer diameter of 0.86 mm adopting bilayer structure in the center conductor with a diameter of 0.20 mm, i.e., the inner superconductor and surficial normal conductor. By this configuration, high frequency noise component is expected to attenuate in the normal conductor with high electrical resistivity when it is thicker than the skin depth. We made and evaluated semi-rigid coaxial cable, the center conductor of which consists of superconducting NbTi and surficial cupro-nickel (CuNi) clad with different thickness from zero to 38 μm, and observed that cutoff frequency goes higher as the clad becomes thinner. In order to promote filtering performance, we have chosen more electrically resistive alloy, stainless-steel (SUS304) as the clad material. The semi-rigid cable with SUS304/NbTi center and SUS304 outer conductor was made by the conventional drawing method. Thermal conductance and high frequency performance were measured. Thermal conductance was reasonably low as expected from each material. However, attenuation of this SUS304/NbTi center - SUS304 outer semi-rigid cable was very large and attenuation and cutoff frequency cannot be controlled as could be done in CuNi clad case.

We think martensitic transformation might occurred during drawing treatment of commercial SUS304/NbTi wire, and observed large attenuation was caused by the magnetization surrounding the center conductor. Precise investigation is being performed.



category : Readout Techniques & Signal processing

PB-15 Superconducting multilayer high density flexible PCB for very high thermal resistance interconnection

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Lot of ultra-sensitive detectors, such as IR and X-ray detectors, or detectors for searching of dark matter or gravitational waves, operate at deep cryogenic temperatures. Similarly, the number of space detectors requiring very low temperature operation increases, and these detectors are increasingly segmented (large number of readout channels). This causes ever greater difficulties in extracting the signals from the detector (typical temperatures from 50 mK to 300 mK) and interconnecting them with the readout electronics, placed at a higher temperature.

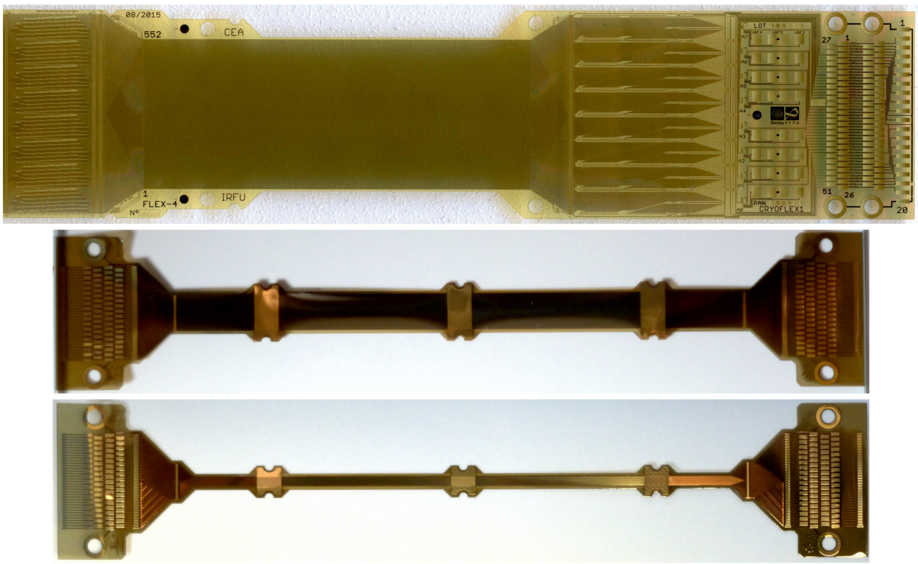
Indeed, each electrical link constitutes a connection generating thermal leaks. When the number of interconnections multiplies, the thermal leaks increase until it becomes impossible to cool the detector because the power supplied by the cryo-refrigerator is insufficient, and this is all the more so as the temperature to be generated is low. For example, space cryogenerators can evacuate only a few microwatts at 50 mK, and in conventional Cu or Manganin technology thermal leaks generated by electrical links quickly exceed this value, limiting the number of reading paths to a few hundred at most. It is therefore a very strong constraint to the increase in the number of channels of the detectors.

For this reason we have carried out a development to produce high-density flexible PCB (17 µ m to 34 µ m depth) with superconducting tracks (15 µ m wide spaced by 15 µ m), because superconductors are excellent thermal insulators. They combine the advantages of niobium as superconductors (critical temperature around 9 K) and polyimide as dielectric, which has an intrinsically low thermal conductivity (1.17x10-4 W/K/cm) and remains flexible even at very low temperatures.

After the very first validation samples, we have successively developed two products, both in the context of the X spatial spectro-imagery. The first product is monolayer, includes 552 tracks, 15 µ m wide spaced by 15 µ m, and receives 24 integrated circuits glued and wire-bonded directly on the flexible PCB. The second product is multilayer, with one tracks layer between two shielding layers interconnected by microvias, includes 37 tracks and can be interconnected at both ends either by wire-bonding or by connectors. We present the first results of our harnesses ; the measurements include, among others, the critical temperature of the superconducting tracks and the critical current density.

The presented technology exhibits good yields and is, to our knowledge, a world-first. It has also a great potential for many other applications at K- and mK-temperatures, such as some implementations of quantum cryptography or quantum computing, and superconducting electronics in general.

category : Readout Techniques & Signal processing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PB-16 Acquisition System of Nobeyama MKID Camera

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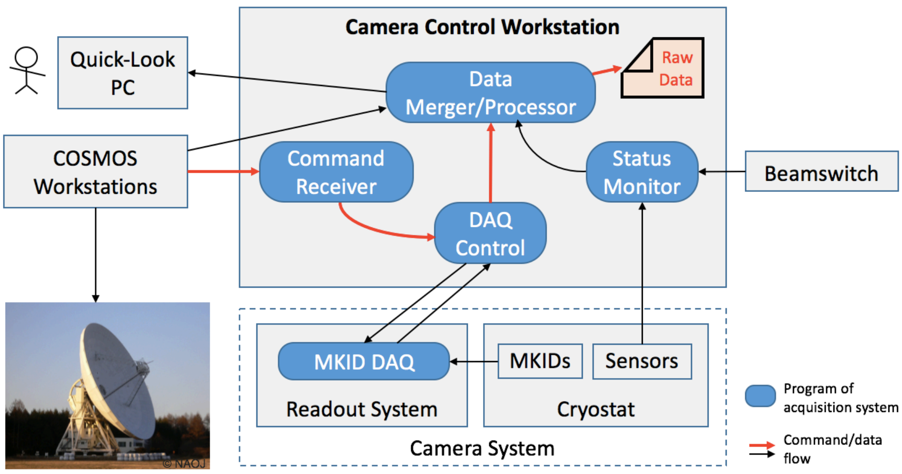
We are developing a superconducting camera based on microwave kinetic inductance detectors (MKIDs) to observe 100/150-GHz bands with the Nobeyama 45 m telescope. An acquisition system for the camera has been designed to operate the MKIDs with the telescope. This system is required to connect the telescope control system (COSMOS) to the readout system of the MKIDs (MKID DAQ) which employs the frequency-sweeping probe scheme. The acquisition system is also required to record the reference signal of the beam switching for the demodulation by the analysis pipeline in order to suppress the sky fluctuation. The system has to be able to merge and save all data acquired both by the camera and by the telescope, including the cryostat temperature and pressure and the telescope pointing. In addition, the system is desired to provide quick-look data that observers would check. A collection of software which implements these functions and works as a TCP/IP server on a workstation was developed. The server accepts commands and observation scripts from COSMOS, and then issue commands to MKID DAQ to configure and start data acquisition. We checked the demodulation algorithm of beam switching by observing celestial continuum sources with a receiver of the Nobeyama 45 m telescope. We also made a test operation of the MKID camera on the Nobeyama 45 m telescope and obtained successful scan signals of the atmosphere and of the Moon.



category : Readout Techniques & Signal processing

PB-17 Frequency Domain Multiplexing Readout with a Self-Trigger System for Kinetic Inductance Detector Pulse Signals

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We present development of a frequency-domain multiplexing readout of Kinetic Inductance Detectors (KIDs) for pulse signals with a self-trigger system. The KIDs consist of an array of superconducting resonators that have different resonant frequencies individually, allowing us to readout multiple channels in the frequency domain with a single wire using a microwave frequency comb. The energy deposited to the resonators break Cooper pairs, changing the kinetic inductance and, hence, the amplitude and the phase of the probing microwaves. For some applications such as X-ray detection, the deposited energy is detected as a pulse signal shaped by the time constants of the quasi-particle lifetime, the resonator quality factor and the ballistic phonon lifetime in the substrate, that range from micro-seconds to milliseconds. A readout system commonly used converts the frequency domain data to the time domain data. For the short pulse signals, the data rate may exceed the data transfer bandwidth, as the short time constant pulses require us to have a high sampling rate. In order to overcome the circumstances, we have developed a KID readout system that contains a self-trigger system to extract relevant signal data, and reduces the total data rate with a commercial off-the-shelf FPGA board. We have demonstrated that the system can readout pulse signals of 15 resonators simultaneously with about 10 Hz event rate by irradiating alpha particles from Am-241 to the silicon substrate on whose surface niobium KID resonators are formed.

category : Readout Techniques & Signal processing

PB-18 Design and Assembly of SPT-3G Cold Readout Hardware

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The SPT-3G receiver on the South Pole Telescope was commissioned at the South Pole during the 2016-2017 austral season to study polarization of the Cosmic Microwave Background. In increasing the number of detectors by a factor of 10 to 16,000, the design of the cryogenic wiring was constrained by the need for low thermal conductance and the need for low inductance imposed by the increased multiplexing factor and bandwidth of the frequency-domain readout electronics. Our cold readout system consists of aluminum inductive capacitive resonators at 300mK connected to 4K SQUIDs by 10 micron thick Niobium-Titanium broadside coupled striplines. Here, we present a general overview of the cold readout electronics for the SPT-3G receiver, including new applications of ultrasonic soldering for low resistance Niobium-Titianium connections, performance of the Niobium-Titanium striplines, and characterization of the cold readout chain.

category : Readout Techniques & Signal processing

PB-19 Automated Measurements for the Characterization of SQUID-Based Time-Division Multiplexing Chips

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SQUID-based time-division multiplexing (TDM) is a mature and widely implemented technology for the readout of transition edge sensors. We describe a suite of automated measurements and software algorithms that have been developed for detailed TDM chip characterization as well as high throughput screening. We show how these techniques may be used to probe the physics of TDM and in particular, the latest generation of multiplexers (TDM+), which implement feedback switching for reduction in distant pixel crosstalk. We present data from a variety of recent measurements.

category : Readout Techniques & Signal processing

PB-20 Development of cross-talk suppression algorithm for MKID readout

Kyungmin Lee[1], Jihoon Choi[2], Makoto Hattori[3], Masashi Hazumi[4], Hikaru Ishitsuka[5], Kenichi Karatsu[6], Kenji Kiuchi[7], Ryo Koyano[8], Hiroki Kutsuma[9], Jose Alberto Rubino Martin[10], Satoru Mima[11], Makoto Minowa[12], Makoto Nagai[13], Taketo Nagasaki[14], Masato Naruse[15], Shugo Oguri[16], Chiko Otani[17], Rafael Rebolo[18], Ricardo T. Genova Santos[19], Yutaro Sekimoto[20], Munehisa Semoto[21], Junya Suzuki[22], Tohru Taino[23], Osamu Tajima[24], Nozomu Tomita[25], Tomohisa Uchida[26], Eunil Won[27], Mitsuhiro Yoshida[28]

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The Cosmic Microwave Background Radiation (CMB) is a robust evidence of the expanding Universe. It is observed as homogeneous and isotropic microwave from the sky. To explain its features, the Inflation model is employed. The model predicts very weak polarized pattern, B-mode, which is an imprint of the primordial gravitational waves generated by the early inflation. The GroundBIRD telescope is under construction at present, aiming to achieve the sensitivity on the tensor-to-scalar ratio down to 0.01. One of the key elements in this experiment is the Microwave Kinetic Inductance Detector (MKID) as the photon sensor of the system.

We have developed a readout system for the MKID. The system is consisted of three parts: Digital part (KC705+RHEA analog board), analog part for up and down-conversions, and a computer for the control and the data acquisition. KC705 is a commercially available evaluation board for Xilinx Kintex 7 Field Programmable Gate Array (FPGA). RHEA board is an analog board which contains a digital to analog converter (DAC) and an analog to digital converter(ADC). The FPGA receives frequencies from the computer, and synthesizes In-phase/Quadratic-phase (I/Q) signals as carriers for each frequency with Direct Digital Synthesizer (DDS) blocks. The I/Q signals are combined to a single signal, frequency comb, and converted to analog signal by the DAC. This signal is upconverted to RF (6 GHz), the resonant frequencies of MKIDs, by frequency mixers, and its amplitude and phase are changed while passing through the MKID. This signal is down-converted, and the ADC receives the modified signal. The FPGA channelize the signal by mixing it with the reference I/Q signals from DDS.

The channelized data is downsampled to remove the cross-talks, sinusoidal waves at the frequencies of intervals between the frequency of the target channel and those of other channels. The cross-talks are not eliminated and leave leakages when the frequency intervals are arbitrary values instead of the divisors of sampling frequency of the ADC. The leakage degrades the accuracy of the readout, and becomes more significant when the sampling rate of the readout is higher and the frequency intervals between the channels are small. We applied the Hanning window function to solve this problem. It makes the boundaries of the downsampling window to be zero, and removes the leakage effectively.

We will discuss the leakage problem; how does it degrade the accuracy and the sensitivity, and the effect of the window function. It will become more important for the future applications which need faster sampling and higher order multiplexing.

Figure 1. The leakage with respect to the frequency interval between the MKID resonances. The leakage is higher for smaller frequency intervals. The minimum interval is determined by this. The leakage is on the order of 10^{-4} and suppressed to 10^{-8} with the Hanning window.

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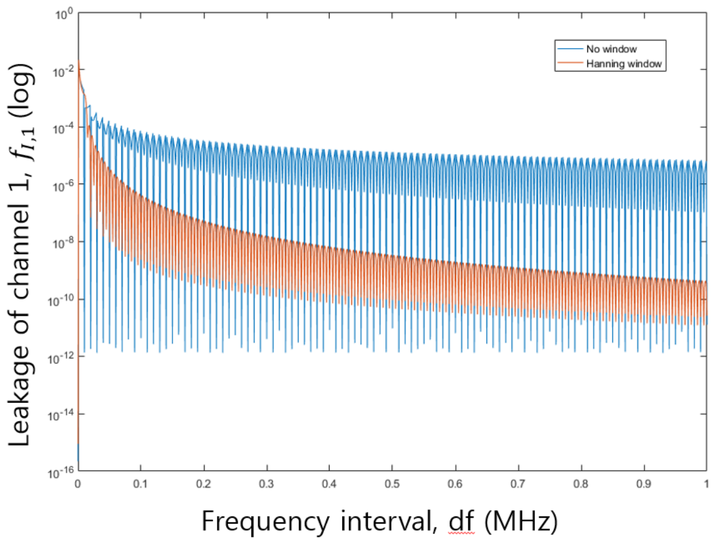

No window
Hanning window
Leakage of channel 1, $f_{I,1}$ (log)
Frequency interval, df (MHz)

PB-21 Evaluating and Understanding Crosstalk in Microwave SQUID Multiplexers

Douglas A. Bennett[1], Dan Becker[2], Joseph W. Fowler[3], Johnathon D. Gard[4], James P. Hays-Wehle[5], Gene C. Hilton[6], John A. B. Mates[7], Carl D. Reintsema[8], Daniel R. Schmidt[9], Daniel S. Swetz[10], Leila R. Vale[11], Joel N. Ullom[12]

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Electrical crosstalk is an important property of multiplexed readout systems for low temperature detector arrays, particularly as array sizes and event rates grow. Microwave SQUID multiplexing shows significant promise to increase achievable array sizes. The lack of feedback in microwave SQUID multiplexers eliminates one of the major crosstalk mechanisms observed in conventional SQUID multiplexing, while the use of flux ramp modulation produces crosstalk of an unusual character. Crosstalk mitigation in this emerging readout architecture needs to be optimized in the context of limited resources in both physical and frequency space. To properly evaluate the levels of crosstalk, the dominant mechanisms need to be understood and experimentally characterized. We describe the nature of the crosstalk observed in our most recent generation of microwave SQUID multiplexers, present crosstalk measurements taken as part of a working TES gamma-ray spectrometer, and compare these results to theoretical estimates.

category : Readout Techniques & Signal processing

PB-22 Error Correcting Codes for code-division multiplexed TES detectors

Charles James Titus[1], Saptarshi Chaudhuri[2], Hsiao-Mei Cho[3], Carl Dawson[4], W. Bertrand Doriese[5], Joe W. Fowler[6], Gene C. Hilton[7], Kent D. Irwin[8], Stephen Kuenstner[9], Dale Li[10], Kelsey Morgan[11], Carl Reintsema[12], Dan Swetz[13], Joel Ullom[14], Betty Young[15]

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Transition Edge Sensors (TES) have proven to be highly sensitive and versatile X-ray spectrometers. Upcoming missions, including Athena X-IFU, will rely on highly multiplexed focal planes where more than 32 TES pixels are read out using a single SQUID amplifier channel. As multiplexing factors increase, error correcting codes can provide redundancy to failure of one or more SQUID readout devices. We have developed an error correction algorithm for code division multiplexed TES signals that is both scalable and easily implemented in hardware. We will present this algorithm for error correction, as well as the result of laboratory tests to assess algorithm performance at recovering TES channels after a SQUID failure.

category : Readout Techniques & Signal processing

PB-23 SQUID Characterization for Next Generation Digital Frequency Domain Multiplexing

Maximiliano Silva-Feaver[1], Kam Arnold[2]

[1]Department of Physics, University of California San Diego, [2]University of California San Dieog

Transition edge sensor (TES) bolometer arrays are the highest sensitivity cameras employed for millimeter wave applications and are currently operating in the photon noise limited regime. In this regime larger arrays leads to overall higher array sensitivity. One factor limiting array size is cost of readout in terms of thermal loading, cryogenic complexity, and component cost. Multiplexing is employed to reduce these constraints but currently deployed arrays have only demonstrated multiplexing factors of O(100). One avenue to increase multiplexing factors is to extend the frequency range for the Digital Frequency Domain Multiplexing (DfMux) scheme currently used in CMB experiments such as POLARBEAR-2, and SPT-3G. This readout multiplexing system uses SQUID amplifiers as the first-stage amplifying element; We present a characterization of SQUID amplifiers as a function of amplifier and multiplexing circuit design. We present results from tests on 8-turn NIST SQUID Series Arrays (SSAs) currently used by the POLARBEAR collaboration and on a newer version of SSA 's which have gradiometric input coils which are under consideration for PB2-C, Simons Observatory, and the LiteBIRD satellite projects.

category : Readout Techniques & Signal processing

PB-24 Combined operation of two TESs for front-end signal processing and amplification

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Conventionally, TES is used as an independent device although TES arrays are employed for some applications. In the past, we demonstrated a parallel bias scheme with some weak link between neighboring TESs. This principle ensures a coupling of two TESs could make it possible to coordinate two TESs operation as an active circuit. We have used a simulation code based on a two-fluid model for the investigation of such a combined operation of two TES electrically coupled each other. Of course, in some condition the TESs become unstable. However, we could find a operating condition and the electrical circuit that enables a stable operation. Based on such an idea, we are trying to investigate a TES circuit mostly for low-energy photon applications. A simple bridge circuit with two TESs showed a current gain of 3.

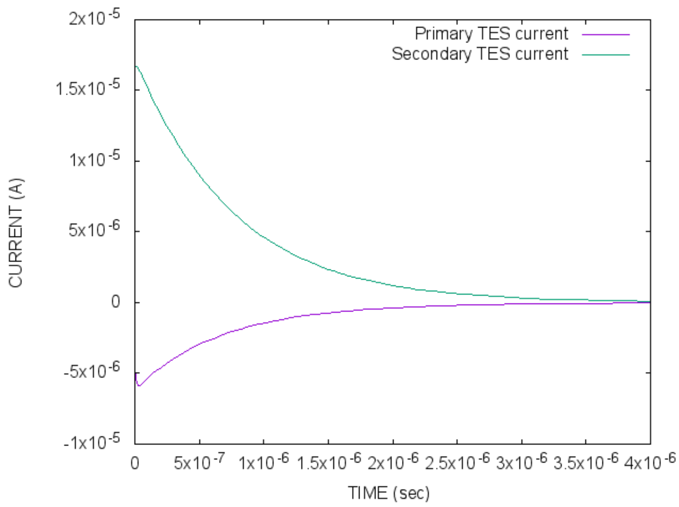

Fig.1 Primary TES current and secondary TES current.

category : Readout Techniques & Signal processing

PB-25 Framework for Analyzing Events at High Rates in TES Microcalorimeters

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At very high event rates, the exquisite energy resolving power of transition edge sensors is not easily retained due to detector nonlinearity, short averaging duration per event, and heightened sensitivity to lab environmental conditions. After a number of false starts, we have achieved some success processing TES current pulses from x-ray excitation rates previously unanalyzable. In particular, we demonstrate 4.5 eV resolution FWHM at 6 keV in a detector with a 1.2 ms decay time constant at a Poisson event rate of 497 /s with 53% pulse utilization. We present our approach involving continuous system calibration and change-point detection.

In lieu of simple detector models valid to the level of precision of our devices, we develop empirical calibration models considerably more elaborate than needed for analysis of isolated events. The effort is focused on event efficiency both in building such models and, from ongoing calibration data, detecting spectrometer perturbations and adjusting the model. The approach relies on an unvarying spectrum of calibration events, and a device state space that is effectively single-dimensional (current or temperature) following a brief inductance-induced two-dimensional state space (current and temperature). Continuous monitoring enables updating of calibration parameters for continuous change in conditions and replacement of those parameters for discontinuous change.

This analysis approach is intended for use in TES spectrometers deployed at intense x-ray light sources such as synchrotrons and free electron lasers. For example, a TES spectrometer is under development for LCLS-II, targeting an initial excitation repetition rate of 10 kHz.

category : Readout Techniques & Signal processing

PB-26 Thermal conductance and high frequency properties of cryogenic normal or superconucting semi-rigid coaxial cables in a range of 1 and 8 K

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Recently, the sizes of superconducting array detectors have been enlarging rapidly for practical applications. The thermal conductance of wires should be reduced with keeping their transmission performance, because the superconducting large-scaled arrays need a large number of wires for those operations, which leads to increasing the heat flow from a room temperature environment through the wires.

The semi-rigid cable is a kind of coaxial cable with seamless outer electrical conductor surrounding center one through insulator. This configuration generally enables low noise measurements compared to twisted pairs or coaxial using braided wires as outer conductors. Users can bend semi-rigid cables to match their own experimental apparatus. In order to develop a semi-rigid cable exhibiting small thermal conductance and high frequency transmission performance simultaneously, we evaluated the dependence of thermal conductance between about 1 and 8 K and transmission characteristics at 3 K on the outer diameter of wires and materials of center and outer electrical conductors. The outer diameter was changed from 0.86 to 1.19 mm. The electrical conductors were made of alloys, such as beryllium-copper (BeCu), brass, stainless-steel (SUS304), phosphor-bronze (PB), cupro-nickel (CuNi), and niobium-titanium (NbTi). Thermal conductance of a commercial miniature coaxial cable with braided wires for the outer electrical conductor was also examined for a comparison. The transmission performance of semi-rigid cables with normal conductor was improved by plating silver with a thickness of about 3 μm on the CuNi or SUS304 center conductors. The thermal conductance after the plating was significantly increased .

The superconducting NbTi semi-rigid cable had the smallest thermal conductance of all below 3 K along with very small attenuation up to 5 GHz. The NbTi calbes will play an important role for superconducting scientific instruments.

category : Readout Techniques & Signal processing

PB-27 High count-rate study of TES X-ray microcalorimeters with two different Tc's

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We have developed transition-edge sensor (TES) microcalorimeter arrays with high count-rate capability and high energy resolution to carry out imaging spectroscopy observations of X-rays from various astronomical sources and also the Sun. We have studied the energy resolution and throughput (fraction of processed pulses) dependency on countrate for microcalorimeters with two different transition temperatures (Tc). Devices with both transition temperatures were fabricated within a single microcalorimeter array directly on top of a solid substrate where the thermal conductance of the microcalorimeter is dependent upon the thermal boundary resistance between the TES sensor and the dielectric substrate beneath. Because the thermal boundary resistance is highly temperature dependent, the two types of device with different Tc's had very different thermal decay times, approximately one order of magnitude different. In our earlier report, we achieved energy resolutions of 1.6 eV and 2.3 eV at 6 keV from lower and higher Tc devices, respectively, using a standard analysis method based on the optimal filtering in a low flux limit. We measured the same devices at elevated X-ray fluxes ranging from 50 Hz to 1000 Hz per pixel. In high flux limit, however, the standard optimal filtering scheme nearly breaks down because of too frequent X-ray pile-ups. To achieve highest possible energy resolution for a fixed throughput, we have developed an analysis scheme based on the so-called event grade method. Using the new analysis scheme, we achieved 5.0 eV FWHM with 96% throughput for 6 keV X-rays of 1025 Hz per pixel with the higher Tc device, and 5.8 eV FWHM with 97% throughput with the lower Tc device at 722 Hz.

category : Readout Techniques & Signal processing

PB-28 Toward large FOV high-resolution x-ray imaging spectrometers: microwave multiplexed readout of 32 TES microcalorimeters

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We performed a small-scale demonstration at GSFC of high-resolution x-ray TES microcalorimeters read out using a microwave SQUID multiplexer. This work is part of our effort to develop detector and readout technologies for future space based x-ray instruments such as the microcalorimeter spectrometer envisaged for Lynx, a large mission concept under development for the Astro 2020 Decadal Survey. In this paper we describe our experiment, including details of a recently designed, microwave-optimized low-temperature setup that is thermally anchored to the 50 mK stage of our laboratory ADR. Using a ROACH2 FPGA at room temperature, we simultaneously read out 32 pixels of a GSFC-built detector array via a NIST-built multiplexer chip with Nb coplanar waveguide resonators coupled to RF SQUIDs. The resonators are spaced 6 MHz apart (at 5.9 GHz) and have quality factors of 15,000. Using flux-ramp modulation frequencies of 160 kHz we have achieved spectral resolutions of ¡ 3 eV FWHM on each pixel at 6 keV. We will present the measured system-level noise and maximum slew rates, and briefly describe the implications for future detector and readout design.

category : Readout Techniques & Signal processing

PB-29 A high-throughput automated test system for dc parametric evaluation and quality assurance of TDM and CDM SQUID multiplexers

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The successful realization and broad deployment of TES based detector systems has led to significant demand for time-division and code-division SQUID multiplexers (TDM and CDM) as essential components of the cryogenic readout chain. TDM and CDM circuits are produced by the Boulder Microfabrication Facility in large quantities and multiple varieties to meet the needs of various bolometric and calorimetric applications. In most cases the basic functionality of these devices must be verified before they are passed along to internal or external collaborators for integration into scientific instruments. Until recently, these measurements were made by hand in a slow and arduous process that created a bottleneck in our supply and delivery chain. Over the past year, the instrumentation and methodology of the measurements has been completely revamped resulting in vastly improved throughput and enhanced data products. We present a full description of the measurement system including results from the application of the test process to flux-activated switch style multiplexers. The utility of this approach for identifying fabrication trends, yield indicators, and common failure modes will be demonstrated.

category : Readout Techniques & Signal processing

PB-30 Cryotron Switches for Current-Summed Code-Division Multiplexing in TES Arrays

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Next-generation applications of TES arrays in x-ray astrophysics and materials analysis will require instrument designs with 105 to 106 pixels. These large arrays provide an increased collection area and enable higher count rates resulting in improved imaging resolution, reduced measurement integration time, and expanded capability towards high-flux x-ray sources. To scale arrays by several orders of magnitude beyond the current state-of-the-art, device readout techniques will need to be significantly improved. Up to now, several multiplexing strategies, including time-division (TDM) and frequency-division multiplexing (FDM), have been developed and successfully integrated with TES arrays. In TDM, individual TESs within a column are read out successively. Consequently, the effective sampling rate is reduced, resulting in an aliased noise penalty. FDM avoids this pitfall but relies on physically large LC circuitry and potentially suffers sensor resolution degradation from the use of ac sensor biases.

Current-summed code-division multiplexing (I-CDM) [1] is an alternative to TDM and FDM that, in many ways, combines the attractive features of both. In I-CDM, signals from all TESs in a column are coupled to a common readout SQUID with controllable polarity. Suitable polarity modulation creates an orthogonal basis set that can be used to distinguish signals from different sensors. I-CDM avoids noise aliasing, can be physically compact, and is compatible with dc bias. Because switching control currents are implemented on a row by row basis and device readout on a column by column basis, wiring schemes are readily scalable. High performance double-pole, double-throw switches are a critical requirement for I-CDM. Recently, NIST has developed cryotron switches for a variety of applications, including I-CDM [2]. A cryotron switch consists of a signal element switched between superconducting (closed) and normal (open) states by a separate magnetic coil. These switches surpassed available measurement bandwidth, yielding switching times faster than 200 ns. Device currents up to 900 uA were switched using 2 mA of control current. A notable attraction of I-CDM with cryotron switches is the possibility of in-focal plane multiplexing of TES detectors where the readout circuitry is located underneath suspended, overhanging absorbers. We present recent experimental efforts to improve cryotron performance by increasing maximum device currents while reducing control currents. In addition, we describe ongoing efforts to model and design I-CDM circuitry.

[1] K. Irwin et al, Journal of Low Temperature Physics, 167, 588-594 (2012)

[2] P. Lowell et al, Applied Physics Letters, 109, 142601 (2016)

category : Readout Techniques & Signal processing

PB-31 Measurements of Improved TDM and Prototype TDM+ Multiplexing Circuits

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The successful deployment of detector systems based on Transition Edge Sensors (TESs) at facilities around the world has led to demand for larger TES detector systems such as the Athena X-IFU and the proposed Lynx X-ray microcalorimeter array. Effective readout of these large sensor arrays motivates improved multiplexers with large multiplexing factors. To meet the energy resolution requirements, these multiplexers must combine low levels of readout noise with low levels of cross talk.

To maximize the multiplexing factor in Time Division Multiplexing (TDM) SQUID circuits, it is desirable that the row time be as short as possible. Rapid switching between rows requires large analog bandwidth and small amplitude, fast decaying switching transients. We describe recent work to understand and minimize these transients so as to achieve 160 ns row times in large format multiplexing measurements while achieving a total readout noise level of 0.19 μ Φ 0/ √ Hz .

Distant pixel cross-talk via a shared SQUID feedback line is another issue in existing TDM circuits. In these architectures, a feedback line is shared between the 1st stage SQUID readout amplifiers of every pixel in an array column. While the amplifiers can be turned off by setting the SQUID bias to zero, the feedback line remains inductively coupled to the unbiased SQUID, resulting in cross-talk between ‘ on ’ pixels and ‘ off ’ pixels. Previous TDM designs have sought to reduce this source of cross-talk by canceling the feedback signal applied to ‘ off ’ SQUIDs using a dummy squid coupled in the opposite direction. However, this geometric mitigation strategy cannot completely eliminate coupling due to the variable inductance of the Josephson Junctions in SQUIDs.

The TDM+ architecture seeks to eliminate this source of cross talk by using superconducting switches to bypass the feedback coils not in use. In this presentation, we show measurements of the first prototypes of this new generation of multiplexers and compare these results with TDM circuits currently being produced at NIST.

category : Readout Techniques & Signal processing

PB-32 Intrinsic losses and noise of high-Q lithographic MHz LC resonators for frequency division multiplexing

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We are developing the frequency division multiplexing (FDM) read-out for the superconducting transition-edge sensors arrays of the X-IFU instrument on board of Athena and of the SAFARI instrument on board of SPICA.

An essential component of the FDM is the array of narrow band superconducting resonators, each consisting of lithographically made inductors and capacitors. In the standard FDM configuration, the LC resonators are connected in series with the input coil of a low noise two-stage SQUID amplifier. In this work we have modified the electrical scheme to decouple the SQUID amplifier from the LC filters in order to measure their intrinsic properties. We report on the intrinsic losses and on the noise of high-Q superconducting LC resonators, with resonant frequencies ranging between 1 and 5 MHz, measured at temperature from 70 to 500 mK.

category : Readout Techniques & Signal processing

Category C : Fabrication & Implementation Techniques

PC-1 Microfabrication Developments for future Instruments using KID Detectors

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The NIKA2 instrument, operating at the 30 meters telescope of the IRAM, demonstrates that the aluminum LEKID technology is a state of the art solution for detectors dedicated to millimeter wave astronomy. Following this path, several instrumental projects envisage today the use of the LEKID technology. For covering the full 60 GHz ? 600 GHz band, of interest for CMB-oriented experiments, we are exploring new materials and solutions. Bi-layers or tri-layers of titanium and aluminum are used to address the 60 GHz ? 100 GHz range. Tantalum and vanadium are tested with aluminum to optimize the responsivity in the high end of the band. We present our latest results on such multilayers and materials. Furthermore, we will present an update on our development of silicon optical lenses, to reduce the high frequency photons absorption. In order to minimize the boundary reflections at the silicon, we introduce the thermal-compression process to add anti-reflection layers on curved surfaces.

category : Fabrication & Implementation Techniques

PC-2 Electrical contacts on germanium at cryogenic temperatures (¡ 300 mK)

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Germanium electrical resistivity shows a strong dependency on temperature below   300 mK. The material is thus suitable to fabricate accurate and reliable cryogenic temperature sensors and has been successfully used to build high-resolution energy-dispersive microcalorimeter detectors.

The electrical contacts used in a germanium detector to measure its resistance have to show an ohmic behaviour, since a strong rectifying effect can alter the measurements accuracy. Ion implantation or metal diffusion into germanium are commonly employed in order to obtain ohmic contact, but these techniques generally imply heat treatments at high temperatures.

Within an effort to develop planar processes to build arrays of germanium cryogenic microcalorimeters, we have experimented with two techniques to fabricate electrical contacts on germanium that do not require high temperature processes. The first one is based on a surface localized high doping of germanium by Gas Immersion Laser Doping (GILD), the second one consists of an indium deposition followed by a mild heat treatment. We fabricated GILD and indium electrical contacts on a set of p-type compensated Neutron Transmutation Doped (NTD) germanium samples and performed an electrical characterization at temperatures between 30 mK and 300 mK. Here, we show the comparison between the two contacts fabrication techniques, reporting the data measured at different temperatures and germanium doping levels.

category : Fabrication & Implementation Techniques

PC-3 Hierarchical sinuous phased array for increased mapping speed of multichroic focal planes

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We present the design, fabrication and performance of a hierarchical sinuous-antenna phased array coupled to transition-edge-sensor (TES) bolometers for measurements of the cosmic microwave background (CMB). To efficiently cover a broader range of frequencies, many CMB experiments have begun to deploy multichroic pixels. For a given cryogenic and optical design, the pixel size that optimizes the mapping speed is frequency-dependent and increases with wavelength. If a multichroic pixel is the same size at all frequencies, then the mapping speed will be optimal in at most one frequency band. To achieve optimal mapping speed at all frequencies, a pixel size that varies with frequency is needed. This can be accomplished by creating phased arrays from neighboring pixels, where the size of each phased array is chosen independently for each frequency band. As the array unit, we choose a lenslet-coupled sinuous antenna on account of its wide bandwidth, dual polarization and constant beam waist. We find that the array factor tends to compensate for beam non-idealities, so that the sinuous antenna can be substantially undersized relative to the single-element case; this frees up valuable focal-plane area for bolometers, bandpass filters, summing networks, readout circuitry, etc. An additional benefit of a hierarchical phased array is the reduced readout requirement: since the low frequencies are arrayed to increase their mapping speeds, the detector count scales approximately logarithmically with the number of frequency bands. Here we present measurements from a prototype device, in which hierarchical triangular arrays are used at 90, 150 and 220 GHz to keep the effective pixel size and, therefore, the beam width roughly constant across the entire frequency range. The fabrication process is described, and the utility of hierarchical phased arrays is discussed in the context of upcoming CMB experiments.

category : Fabrication & Implementation Techniques

PC-4 Design and fabrication techniques used to optimize MKID arrays for BLAST-TNG

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We report on the layout and fabrication techniques developed for the focal planes of the Balloon-borne Large Angular Scale Telescope (BLAST-TNG), scheduled to be the first balloon payload to utilize arrays of microwave kinetic inductance detectors (MKIDs). Implementation of $\sim$ 3000 resonators in the presence of readout constraints set by limitations in power, cryogenic cabling, and electronic bandwidth of a balloon mission required an improved understanding of the sources of frequency scatter in TiN/Ti multilayer films and ultimately the development of a stepper compliant tiling scheme. This scheme allows thousands of unique pixels to be laid out in a semi-automated manner using a small number of reticles with minimal lithographic uncertainty. We detail the layout approach and show its efficacy through dedicated test structures that map out the intrinsic TiN/Ti multilayer transition temperature variations as well as lithographic uncertainties which contribute to frequency scatter. We find that percent-level wafer-scale variations exist. However since the frequency scatter is less than 10^{-3} on the size scale of near neighbor pixels, careful engineering allows low instances of frequency collisions. With this knowledge, we designed the 3,244 superconducting resonators of BLAST-TNG to be read out using five ROACH2-based readout modules, which each have 500 MHz of readout bandwidth. A balance between single pixel sensitivity, which in our pixel architecture scales as 1/Q, and high multiplexed density was considered. Ultimately our material choice and tiling scheme enables 85% of the detectors to be separated by more than 5 linewidths from its nearest neighbors, when operated from a 275 mK bath. Based on these results, we make performance predictions for future arrays fabricated on 150 mm wafers to acheive $\sim 10^4 - 10^5$ pixel counts for next-generation astronomical focal planes.

category : Fabrication & Implementation Techniques

PC-5 Low-T_c superconducting TES for a Cuore UPgrade with Particle IDentification (CUPID)

Raul Hennings-Yeomans[1]

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We present measurements of the T_c suppression in superconducting Iridium films, in the range of ∼18-100 mK. We demonstrate a simple and effective way to suppress T_c of superconducting Iridium, through the proximity effect, by using Ir/Au and Ir/Pt bilayers as well as Au/Ir/Au trilayers. We study T_c suppression of Ir/Au and Ir/Pt as a function of Iridium deposition temperature between 100-600 °C. We also present results of T_c suppression on Iridium by deposition at room temperature in Au/Ir/Au trilayers and Ir/Pt bilayers. Measurements of the relative impedance between the Ir/Pt bilayers and Au/Ir/Au trilayers fabricated at room temperature show factor of ∼10 higher in the Ir/Pt case. These new, room temperature-deposited films, could play a key role in the development of scalable superconducting transition edge sensors that require low-T_c films to minimize heat-capacity and maximize energy resolution, while keeping high-yield fabrication methods. This work was done in the context of R&D for a future bolometric experiment in search for neutrinoless double beta decay called CUPID (Cuore UPgrade with Particle IDentification).

category : Fabrication & Implementation Techniques

PC-6 Commercialization of micro-fabrication of antenna-coupled Transition Edge Sensor bolometer detectors for studies of the Cosmic Microwave Background

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We report on the development of commercially fabricated multi-chroic antenna coupled Transition Edge Sensor (TES) bolometer arrays for Cosmic Microwave Background (CMB) polarimetry experiments. CMB polarimetry experiments have deployed instruments in stages. Stage-II experiments deployed with O(1,000) detectors that reported successful detection of B-mode (divergent free) polarization pattern in the CMB. Stage-III experiments have recently started observing with O(10,000) detectors with wider frequency coverage.

A concept for a Stage-IV experiment, CMB-S4, is emerging to make a definitive measurement of CMB polarization from the ground with O(500,000) detectors. The orders of magnitude increase in detector count for CMB-S4 requires a new approach in detector fabrication to increase fabrication throughput. We report on collaborative efforts with two commercial micro-fabrication foundries to fabricate antenna coupled TES bolometer detectors.

The detector design is based on the sinuous antenna coupled dichroic detector from the POLARBEAR-2 experiment. The TES bolometers showed the expected I-V response and the RF performance agrees with simulation. We will discuss the motivation, design consideration, fabrication processes, test results, and how industrial detector fabrication could be a path to fabricate hundreds of detector wafers for future CMB polarimetry experiments.

category : Fabrication & Implementation Techniques

PC-7 The POLARBEAR-2 and Simons Array Focal Plane Fabrication Status

Benjamin Westbrook[1]

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We present on the status of POLARBEAR-2 and Simons Array detector fabrication. The Simons Array is an array of three Cosmic Microwave Background (CMB) polarization sensitive telescopes located at the POLARBEAR (PB) site in Northern Chile. As the successor PB experiment each telescope and receiver combination is named as PB-2A, PB-2B, and PB-2C. PB-2A and -2B will have identical receivers operating at 90 and 150 GHz while PB2-C will house a receiver operating at 220 and 270 GHz. Each receiver will have 1,897 polarization sensitive pixels with 2 transition edge sensor (TES) bolometers per band and polarization (for a total of 7,588 TES bolometers per telescope). We have produced 7 candidate wafers for PB2-A wafers which are undergoing detailed characterization prior to deployment in the Fall of 2017. Characterization from a witness pixel co-fabricated with these wafers indicates that these wafers meet our original specifications for the PB2-A receiver. Production of the PB-2B focal plane is ongoing and is expected to be completed by the end of 2017 for deployment in summer of 2018. Initial designs and prototype devices have already been fabricated for PB2-C which will also deploy in 2018.

category : Fabrication & Implementation Techniques

PC-8 Development of dual-polarization sensitive KIDs for CMB measurements

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KIDs are very sensitive millimeter wave detector suitable for CMB measurements. Some group already reported that the sensitivities of their detectors are limited by photon noise under the loading power comparable to the typical ground based CMB experiment. Once the detector achieved photon noise limited sensitivity, increasing the number of detectors is the straightforward way to improve the measurement sensitivity. KIDs are promising detector to develop a large number of detector arrays thanks to the intrinsic capability of frequency division multiplexing.

Very characteristic polarization patterns called " B-modes " on the CMB anisotropy map are a next biggest target of CMB experiments. The polarization sensitive antennas and millimeter wave circuit to transmit an energy absorbed at antennas to KIDs are required to measure the B-modes. We designed the horn coupled dual-polarization sensitive KIDs array. And fabricated a first prototype of our detector.

Each pixel of our detector consists of KIDs part and millimeter wave circuit part. Each part is evaluated separately. A Hybrid Nb-Al KIDs structure is employed to improve the responsivity. The quality factor of our detector required to be greater than 50,000 and our fabricated KIDs already satisfied it. And responsivity of our device is also reasonable level. The characteristics of the millimeter wave circuit components are measured using the test device. In this conference, we will report the status of our development.

category : Fabrication & Implementation Techniques

PC-9 TiN-Al MKID Polarimeter Arrays Optimized for Balloon-borne Submillimeter Imaging on BLAST-TNG

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Microwave Kinetic Inductance Detectors (MKIDs) have held promise as the focal plane sensing elements in large-format imaging arrays for over a decade and have found application in several ground-based instruments. In this presentation, we discuss the first implementation of MKIDs for a balloon-borne instrument. We have built three, large-format MKID arrays for the Balloon-borne Large-Aperture Submillimeter Telescope ? The Next Generation (BLAST-TNG), which is scheduled for Antarctic launch in December 2017. Each monolithic 100mm diameter array is sensitive to a different waveband centered at 250 micron, 350 micron, or 500 micron; and a each microwave feedline addresses between 466 and 938 resonators depending on the array. Designing for space-like low photon loads, polarization-sensitivity, different frequency bands, and 275 mK operation all pose unique challenges. We address these challenges by employing feedhorn-coupled, dual-polarization sensitive pixels fabricated from TiN/Ti multilayers that combine high responsivity, high uniformity, low loss, and a tunable superconducting Tc. Here, we present the detailed design and fabrication of these arrays, which includes an optimized quarter wavelength silicon backshort realized by use of a silicon on insulator (SOI) wafer; aluminum patching of the TiN/Ti absorbing inductor to increase response and tune the effective optical coupling impedance; and a semi-automated layout scheme to make a stepper-compliant lithography process that tiles identical stepper images across the array and then trims them individually to minimize their frequency scatter. This results in high quality, easily reconfigurable, and uniform arrays of MKIDs. We show measurements that demonstrate high pixel yield, ¿ 98% polarization isolation, and a noise equivalent power (NEP) limited by photon noise at the expected in-flight photon load.

category : Fabrication & Implementation Techniques

PC-10 A calibration target for cm-range instruments.

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High precision measurements in radio astronomy require a good knowledge of noise properties of the receiver in use.

For this purpose we are working on the design, fabrication and test of a pyramidal dry cold load to characterize receivers in the 4-20 GHz frequency range. At this frequencies, receivers make use of low noise amplifiers with typical noise temperature below 5 K. From simulations and experience the overall receiver noise temperature doesn 't exceed 10-15 K, therefore, to be able to measure a similar noise level with a 5% accuracy, we need to design a target with a brightness temperature uncertainty smaller than 0.1 K.

The main aim of this work is to test the performances and characterize the noise properties of SKA Band 5 receiver (4.6-15.3 GHz) and NextBASS prototype receiver (6-20 GHz), both under development.

I will present the analysis conducted to design the load to meet the required thermal and electromagnetic specifications.

category : Fabrication & Implementation Techniques

PC-11 Design and Fabrication of Multichroic Feedhorn-Coupled MKID Arrays

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Utilizing the advantageous combination of a high optical efficiency feedhorn-coupled architecture and the easy readout scheme with high multiplexing factors from microwave kinetic inductance detectors (MKIDs), we developed a novel hybrid design: feedhorn-coupled polarization-sensitive MKID arrays. The incoming radiation is coupled from feedhorns to planar orthomode transducers (OMTs). Each polarization is read out by an MKID. The prototype MKID array contains 23 multichroic polarization-sensitive pixels resulting in 92 MKIDs which are coupled to only one feedline. We designed the dual frequency bands to be 125-170 GHz and 190-280 GHz for simultaneous observation of polarization from both the cosmic microwave background (CMB) and Galactic dust emission. These OMT-coulpled MKID arrays are fabricated on ultra-high purity (UHP) silicon substrates to achieve high internal quality factors with thin membranes under each OMT for high optical efficiency. We start with a bonded silicon-on-insulator (SOI) wafer, which is a composed of 5 microns of UHP silicon, 500 nanometer silicon dioxide, and a 350 micron silicon handle wafer. Aluminum is used for the sensing region of the resonators, in which Cooper pair breaking alters the kinetic inductance of the film. All other microwave elements are made of niobium films and silicon nitride as the dielectric material. Prototype all-niobium resonators reach internal quality factors of 400,000 in dark conditions, and the coupling quality factors are 30,000-100,000. In this paper, we present the design and fabrication of prototype arrays as well as some preliminary results.

category : Fabrication & Implementation Techniques

PC-12 Fabrication and Characterization of (100) Silicon Membranes for a Multi-beam Superconducting Heterodyne Receiver

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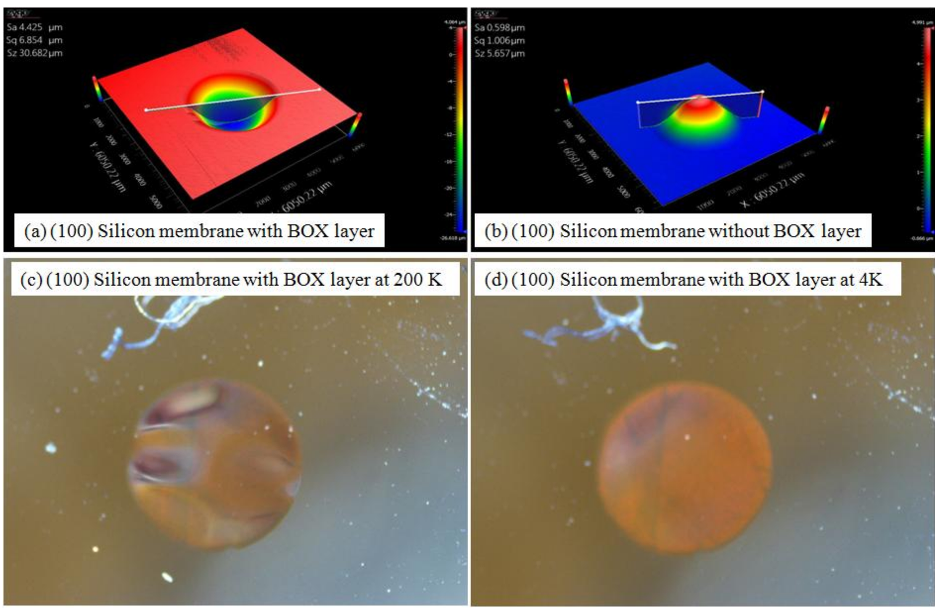
Narrow field of view (FOV) is one of the significant limitations of a radio telescope for large area surveys. Aiming to extend the FOV of the radio telescopes, we started to develop multi-beam superconducting heterodyne receiver which is highly compact and can accommodate more pixels than before. The concept for the multi-beam superconducting heterodyne receiver is implementing planar orthomode transducers (OMTs) and Superconductor-Insulator-Superconductor (SIS) circuits into an integrated circuit (IC). The fabrication of membranes is one of the most important techniques for these ICs, because the planar OMTs and wave probes that couples local oscillator power in the IC are fabricated on the membranes. As a prestudy before the IC fabrication, we fabricated (100) silicon membranes of 3 mm in diameter on the surface of silicon on insulator (SOI) substrates, and the characteristics of the membranes were investigated.

Two pieces of 15 mm square SOI substrates were used for the membrane fabrication. The SOI substrates consist of a 6 μm thick (100) silicon device layer on a 1 μm thick buried oxide (BOX) layer of amorphous SiO2 followed by a 400 μm thick (100) silicon handle layer. The handle layer of one SOI substrate was etched using deep reactive ion etching process with the BOX layer remained together with the device membrane. The BOX layer of the other SOI substrate, however, was removed using C4F8 based plasma etching after the handle layer etching. Both (100) silicon membranes are 3 mm in diameter.

The surfaces of both (100) silicon membranes were observed at room temperature using the scanning white light interferometer system. Figure (a) and (b) show the 3 dimensional profiles of the (100) silicon membranes with BOX layer and without BOX layer, respectively. We found that the degrees of curving of the membrane caused by stress are pronounced. The (100) silicon membranes with BOX layer and without BOX layer have the arc-like deformation with maximum height of 30.7 μm and 5.7 μm, respectively. It shows the (100) silicon membranes of SOI substrates are effectively flattened by etching BOX layers under the (100) silicon device layers.

Both (100) silicon membranes were cooled from room temperature to 4 K by the Gifford-McMahon refrigerator to inspect how the deformation may change at low temperature. The surfaces of the (100) silicon membranes were observed using the optical microscopy. Both (100) silicon membranes survived at 4 K. The deformation of both (100) silicon membranes were observed to become more significant near 200 K as shown figure (c). However the wrinkles of both (100) silicon membranes disappeared below about 180 K as shown figure (d). This phenomenon indicates the deformation of the (100) silicon membranes at low temperature depends on the properties of the (100) silicon of the device layers and independent of BOX layers under the (100) silicon membranes.



category : Fabrication & Implementation Techniques

PC-13 Investigating the Effect of Fabrication Processes and Material Properties to the Large Transition Edge Sensor Array Performance for the South Pole Telescope 3G Experiment

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The cosmic microwave background (CMB) is remnant radiation from the early universe that provides a wealth of information leading to many breakthroughs in our theory of cosmology. Current and future CMB experiments aim to measure the CMB polarization precisely with the goal of exploring inflation physics and neutrino mass. In order to precisely measure the CMB polarization, especially the parity violating B-mode polarization pattern, a focal plane with approximately 2690 pixels (6 transition-edge sensor (TES) bolometers per pixel) has been designed and fabricated. The focal plane contains 10 wafers of detector arrays and it has been installed in the South Pole Telescope at the end of 2016 for the latest generation of CMB experiment (SPT-3G). In order to further improve the detector performance, it is critical to understand the effect of fabrication process and material properties to such a large TES detector array. In this work, we will discuss how the properties of the detector key components, i. e. the dielectric layer, the microstrip in-line filters, the TES film configurations and the thermal links of the TES bolometers can be extracted and investigated basing on the full detector array testing results.

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category : Fabrication & Implementation Techniques

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PC-14 Fabrication of Flexible Superconducting Wiring with High Current Carrying Capacity Indium Interconnects

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The X-ray Integral Field Unit (X-IFU) is a cryogenic spectrometer for the Advanced Telescope for High Energy Astrophysics (ATHENA). ATHENA is a planned next generation space-based X-ray observatory with capabilities that surpass the spectral resolution of prior missions. Proposed device designs contain up to 3840 transition edge sensors (TES), each acting as an individual pixel on the detector, presenting a unique challenge for wiring 8000 superconducting leads to the remaining parts of the instrument. In prototypes, the edges of the focal plane on the instrument hosted aluminum wire bonding pads; however, indium ‘ bumps ’ deposited on molybdenum nitride (MoN) can instead be used as an array of superconducting interconnects. We investigated bumped MoN:In structures with different process cleans and layer thicknesses. Measurements of the resistive transitions showed variation of transition temperature TC as a function of bias and generally differed from the expected bulk TC of In (3.4 K). Observed resistance of the In bump structures at temperatures below the MoN transition also depended on the varied parameters. For our proposed X-IFU geometry (10 microns of In mated to a 1 micron In pad), we measured a TC of 3.1 K at a bias current of 3 mA and a normal resistance of 0.55 m Ω per interconnect. Along with characterizing In interconnects, the design and fabrication of flexible superconducting niobium (Nb) microstrip atop flexible polyimide was also investigated. We present a process for combining In bumps with Nb on polyimide to enable high density wiring for the ATHENA X-IFU focal plane.

category : Fabrication & Implementation Techniques

PC-15 Growth and Post Treatment of AlMn Film for X-ray Microcalorimeter Based on Transition Edge Sensor

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Magnetically doped superconducting films are promising materials for transition edge sensors because it reduces the complexity in the design and fabrication of the sensors. We report our recent progress in the DC magnetron sputtering growth of AlMn superconducting films. We investigated the influence of various film-growth and post-treatment conditions on the superconducting properties of the AlMn films. We found that the power of DC magnetron sputtering and the temperature of heat treatment are crucial parameters for obtaining high quality films.

category : Fabrication & Implementation Techniques

PC-16 Tuning SPT-3G transition-edge-sensor electrical properties with a trilayer Au-Ti-Au thin-film stack

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The allowed electrical properties of the transition-edge-sensors in the South Pole Telescope's third generation receiver (a CMB polarimeter, installed at the South Pole this January of 2017) are constrained by several different physical considerations. These considerations include various sources of noise, detector stability, impedance matching to electronics, detector saturation power, cryostat base temperature, and fabrication repeatability. Here we discuss tuning the transition temperature and normal resistance of our gold-titanium-gold tri-layer sensors to satisfy the aforementioned criteria by varying the relative thicknesses of the tri-layer stack.

category : Fabrication & Implementation Techniques

PC-17 Fabrication of Absorbers with Dry Film Photoresist for Gamma Ray Spectroscopy with Metallic Magnetic Calorimeters

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We are developing metallic magnetic calorimeters (MMCs) for high resolution gamma-ray spectroscopy for non-destructive assay of nuclear materials. Absorbers for these higher-energy photons can require substantial thickness ?100 um to achieve adequate stopping power. We have previously reported successful electroforming of gold absorbers for these devices using a sacrificial Cu layer as the mask for the posts and Az125nXT photoresist to pattern the tops. In this report, we describe a new absorber fabrication process using dry film photoresist for both posts and tops. As with the copper process, the dry-film process is completely compatible with the STARCryo “ Delta 1000 ” SQUID microfabrication process, enabling future commercial deployment of our integrated SQUID/sensor detector designs. The dry film approach produces well-defined absorbers with fewer and much-simpler process steps and improved yield (100% to date). Absorber adhesion is excellent, with 100% survival to date against vigorous ultrasound and repeated rapid immersion in liquid nitrogen. Using this approach we have completed fabrication of 14-pixel arrays of integrated SQUID/sensor MMCs with attached absorbers. At present the absorber thickness is limited to ¡ 50 um with the dry-film approach. Process development is ongoing to increase the maximum thickness by layering the film. In this report we describe the post-“ Delta 1000 ” fabrication steps used to complete the new MMC devices and initial performance results.

category : Fabrication & Implementation Techniques

PC-18 Fabrication of ultrasensitive transition edge sensor bolometric detectors for HIRMES

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The high resolution mid-infrared spectrometer (HIRMES) is a high resolving power (R 100,000) instrument operating in the 25-122 micron spectral range and will fly on board the Stratospheric Observatory for Far-Infrared Astronomy (SOFIA) in 2019. Central to HIRMES are its two transition edge sensor (TES) bolometric cameras, an 8x16 detector high resolution array and a 64x16 detector low resolution array. Both types of detectors consist of Mo/Au TES fabricated on leg-isolated Si membranes. Whereas the high resolution detectors, with NEP 2 aW/rt(Hz), are fabricated on 0.45 micron Si substrates, the low resolution detectors, with NEP 10 aW/rt(Hz), are fabricated on 1.45 micron Si. Here we discuss the similarities and differences in the fabrication methodologies used to realize the two types of detectors.

category : Fabrication & Implementation Techniques

PC-19 Absorber Materials for the transition edge sensor bolometric detectors on HIRMES

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The high resolution mid-infrared spectrometer (HIRMES) is a high resolving power (R 100,000) instrument operating in the 25-122 micron spectral range and has two absorber-coupled transition edge sensor (TES) bolometric detector cameras. The detector pixels on one camera, the high resolution detector array, will be optically coupled to a quarter-wave backshort. Consequently, in order to achieve high optical efficiency, the absorber-coupled detector pixels need to be flat to within lambda/10. We have developed novel NbTiN low stress coatings and have demonstrated that the 1.4 mm x 1.7 mm optically active region on the 450 nm thick Si high resolution detector pixels is flat to within 5 microns, and these coatings have the required optical impedance across HIRMES operating band. Furthermore, these coatings have a superconducting transition temperature 10 K, which allows them to simultaneously act as high pass filters. This attribute makes these coatings especially attractive for ultrasensitive absorber-coupled bolometric detector applications, because it decreases optical loading from out-of-band radiation.

category : Fabrication & Implementation Techniques

PC-20 Flexible Cryogenic Microwave Wiring for the MKID Exoplanet Camera

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We present the microwave and thermal properties of custom made flexible cryogenic microwave cabling for the MKID Exoplanet Camera (MEC) on the Subaru Telescope. MEC cools a 20,000 pixel MKID array to 100 mK and requires 10 microwave feedlines (20 connections) with signals from 4–8 GHz. Between 300 K and 4 K we use the Rogers Corp. LCP dielectric film Ultralam with 1/4 oz Cu cladding to make a 10 trace stripline flexible cable. The ends have G3PO push-on coax connectors. The input side has an integrated 30 dB Pi attenuator at the 4 K end. Between 4 K and 100 mK we use superconducting 53% Nb - 47% Ti alloy laminated onto DuPont's Kapton/epoxy dielectric film Nikaflex to make a 10 trace microstrip flexible cable. The ends are glued with silver epoxy to a copper transition board with G3PO connectors. Our newest design uses 10 micron thick Nb-47Ti and a 76 micron dielectric stackup. The thermal load on the 100 mK stage, assuming thermalization at an intermediate 800 mK stage such as in a two stage ADR, is about 0.7 uW-cm and is dominated by the dielectric.

category : Fabrication & Implementation Techniques

PC-21 TiNx KIDs for the second phase of CALDER

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The goal of the CALDER (Cryogenic wide-Area Light Detectors with Excellent Resolution) project is the development of light detectors with large active area and noise energy resolution smaller than 20 eV RMS using phonon-mediated Kinetic Inductance Detectors (KIDs).

Background suppression plays a key role for experiments searching for rare events, like neutrinoless double beta decay and dark matter interactions. Next generation experiments based on the technology of cryogenic calorimeters can improve the background rejection exploiting the different light emission of different particles. CALDER is focussed on the development of sensitive light detectors that can be easily scaled up to?1000 devices without increasing the heat load for the cryogenic apparatus.

The ?rst phase of the project allow us to reach a baseline resolution of 80 eV using 60 nm Al device. To increase the energy resolution of our detectors we are considering to use sub-stoichiometric TiN (TiNx) as an alternative material and we are optimizing its deposition by means of DC-magnetron reactive sputtering. We used a 4-point scheme to measure the critical temperature from the IV curves, putting the sample in an Oxford HELIOX cryostat. First results show that the critical temperature changes consistently with the nitrogen content, as determined by changing the composition of the sputtering gas. Furthermore a first KID prototype was designed, entirely made of TiNx, paying attention to impedance match of the feedline to the external electrical connection.

category : Fabrication & Implementation Techniques

PC-22 Fabrication of a uniform large scale array of X-ray microcalorimeters for the X-IFU instrument on Athena

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Future spaced-based imaging X-ray spectrometers, such as the X-IFU (X-ray Integral Field Unit) instrument on ESA ’s Athena mission, will be based on large format arrays consisting of more than 3800 Transition Edge Sensor (TES) microcalorimeters. We present an optimized lithographic fabrication route that enables the realization of such large format arrays of microcalorimeters. We improved on process steps concerning the X-ray absorber, the stripline wiring system and the silicon grid support structure.

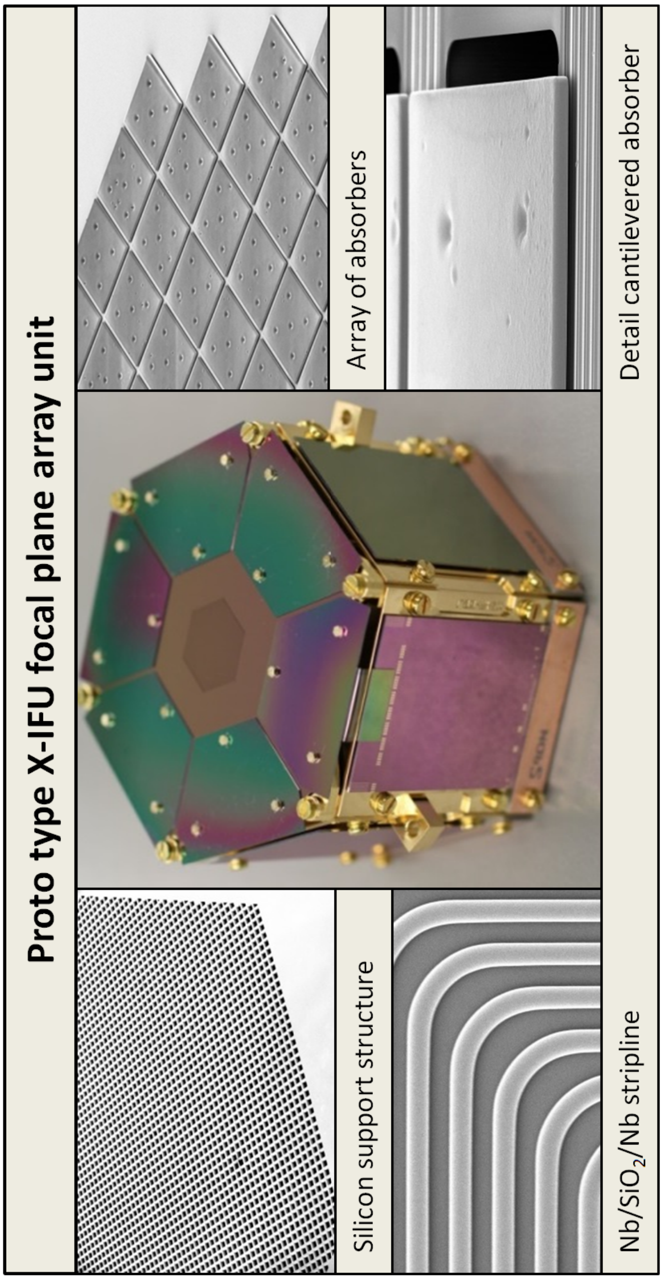
We have developed an electroplating process for the fabrication of free standing cantilevered X-ray, which leads to a uniform absorber film thicknesses over the large array. The thickness uniformity obtained across the array is better than 5% for Au/Bi absorbers with thicknesses of 2/7 μ m.

We developed and fabricated high density Nb/SiO2/Nb striplines to wire a 4000 pixel array with yield of more than 98%. We designed a fan-out scheme for the stripline wiring system that allows the study on the integrity of the wiring in the array area of the large format array.

We report on the optimization of the deep reactive ion etching step to form the silicon grid structure, which allows the production of uniform silicon grids accommodating an array of 4000 TES pixels.

Acknowledgement: ESA CTP contract ITT AO/1-7947/14/NL/BW

category : Fabrication & Implementation Techniques


Proto type X-IFU focal plane array unit
Array of absorbers
Detail cantilevered absorber
Silicon support structure
Nb/SiO_2/Nb stripline

PC-23 Fabrication of the arrays of detectors deployed with the SPT-3G receiver

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The South Pole Telescope third-generation (SPT-3G) receiver was installed during the austral summer of 2016-7. It is designed to measure the Cosmic Microwave Background (CMB) across three frequency bands centered at 95 GHz, 150 GHz and 220 GHz. The SPT-3G receiver is composed of ten modules of 271 pixels each. Each pixel features a broad-band sinuous antenna coupled to a niobium microstrip transmission line. In-line filters define the desired band-passes before the millimeter-wavelength signal captured by the antenna is coupled to the six individual Ti/Au based transition edge sensors (TESs) located within each of the pixels in the arrays. In total, the SPT-3G receiver is composed of 16000 detectors, which are readout using a 64x frequency domain multiplexing (fMux) scheme. Here, we present the process employed in the fabrication of the arrays of detectors currently installed in the SPT-3G receiver. In addition, we discuss changes being implemented for the fabrication of a second set of detectors with improved yield and fine-tuned performance. These new set of detectors will be installed at the end of 2017 for the second observation season of the SPT-3G receiver.

category : Fabrication & Implementation Techniques

PC-24 Impact of electrical contacts design and materials on the stability of titanium film superconducting transition shape

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The South Pole Telescope's SPT-3G camera,currently deployed, utilizes (Ti/Au)- based Transition Edge Sensors (TES). One of the key requirements for these sensors was reproducibility and long-term stability of the superconducting transitions. Here we will discuss the impact of electrical contacts design and materials on the superconducting transition shape of Ti-based TESs. Using SEM, AFM and DIC optical microscopy we observed the presence of unexpected defects of morphological nature on the titanium surface and their evolution in time in proximity to Nb contacts. Furthermore, we found direct correlation between the variations of the morphology and the superconducting transition characteristics. Model experiments with different diffusion barriers between TES and Nb leads were performed to clarify the origin of this problem. We have demonstrated that the reproducibility of superconducting transition can be significantly improved by preventing diffusion processes in the TES-leads contact areas.

Acknowledgments : This work was supported in part by the Office of Science and the Office of Basic Energy Sciences of the US Department of Energy under Contract DE-AC02- 06CH11357; by the National Science Foundation (NSF) under Grant ANT- 0638937; by the NSF Physics Frontiers Center under Grant PHY-1125897; by The Kavli Foundation; by the Gordon and Betty Moore Foundation; and by the NSF under Grants AST- 0956135 and AST-1402161. Use of the Center for Nanoscale Materials, an Office of Science user facility, was supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

category : Fabrication & Implementation Techniques

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PC-25 Microfabrication of transition-edge sensor arrays of microcalorimeters with Ho-163 for direct neutrino mass measurements with HOLMES

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Measuring the neutrino mass is one of the major challenges in today's particle physics and astrophysics. There are several methods to determine the neutrino mass: cosmological observations, neutrinoless double beta decay and beta or electron capture spectrum end-point study. The latter is currently the only one capable of providing a model independent measurement of the absolute scale of neutrino mass.

The HOLMES experiment will provide an important step forward in direct neutrino mass measurements with a calorimetric approach as an alternative to spectrometry. In such approach the beta source is embedded in the detector and the energy emitted in the decay is entirely measured by the detector, except for the fraction taken away by the neutrino. HOLMES plans to deploy a large array of transition-edge sensor (TES) microcalorimeters with implanted Ho163 nuclei. The detectors will be Mo/Cu TES on a solid Si3N4 membrane and a gold absorber. While good progress has been made in optimizing single pixel design and fabrication to achieve the target resolution, a major challenge is the fabrication of arrays of such microcalorimeters with the required amount of Ho163 nuclei embedded in the gold absorber. Fabrication needs to be compatible with ion implantation, while preserving detectors performance. Specifically, the gold absorbers will need to be fabricated in more than one step, before and after ion implantation, in order to fully embed the isotope.

In this contribution we describe the multi-step microfabrication process implemented to produce the final detector arrays for HOLMES, its challenges and our progress in assessing the feasibility of each step. One crucial part of such process is the ability to perform deposition of gold simultaneous to the Ho163 implantation in the detectors absorber. We describe the UHV target chamber, with integrated gold deposition system, we have built to achieve this goal and the first fabrication tests on prototype arrays, prior to integration with the ion implanter.

category : Fabrication & Implementation Techniques

PC-26 Characterizing Atomic Layer Deposition Titanium Nitride Kinetic Inductance Detectors

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Kinetic Inductance Detectors (KIDs) offer simple fabrication and low cost multiplexing, and are a compelling candidate for future astronomical instruments, which require arrays containing thousands of detecting elements. One of the main obstacles that needs to be overcome when scaling to large-format arrays is tight control of uniformity and repeatability of detector performance across entire wafer. Hence in this work, a novel deposition method - Atomic Layer Deposition (ALD) is implemented. We outline preliminary results of single-layer lumped-element Titanium Nitride (TiN) resonators coupled to a coplanar waveguide feedline. We demonstrate the effect on the critical temperature variation with thickness, wafer-scale uniformity, and present detailed modelled fits to frequency and internal quality factor as a function of temperature. In particular, we demonstrate that films grown by ALD enables us to achieve thin films with good repeatability with internal Q factors approaching 10^6. We also discuss the measured frequency noise of these devices and will present preliminary results of the optical responsivity of these films when coupled to a microstrip fed mm-wavelength antenna.

category : Fabrication & Implementation Techniques

Category D : Cryogenics and Components

PD-1 Metamaterial Achromatic Half-Wave Plates for Cosmic Microwave Background Observation

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The Advanced ACTPol instrument on the Atacama Cosmology Telescope is one of the latest generation of ground based Cosmic Microwave Background (CMB) experiments, and incorporates new detector and optical technologies to make improved measurements of the polarization of the CMB. One of the major issues facing ground based CMB measurements is noise introduced by the turbulent, unpolarized atmosphere. The constant fluctuations of the air in the beam of the telescope show up in the data as low frequency noise. To mitigate this effect, ACT will deploy continuously rotating, ambient-temperature half-wave plates (HWPs) to modulate the incident polarization. The HWPs are made from metamaterial silicon. A custom 3-axis dicing saw was used to machine subwavelength features into the silicon. Breaking 90 degree rotation symmetry in the features induces birefringence in the metamaterial, and allows a HWP to be made. The HWPs use a 3-stack Pancharatnam geometry with three layers of metamaterial antireflection (AR) coating. Three such HWPs have been made for act; two for the 90/150 GHz band, and one for the 150/220 GHz band. These HWPs have a number of advantages over the standard sapphire HWPs. With a tunable birefringence, these plates can be made thinner, reducing the thermal loading on the telescope. The metamaterial AR coating is birefringent, allowing better reflection mitigation than a standard AR coating. This supporting technology will have significant implications for the requirements on detectors, superconducting readout, and ability to make large angular scale CMB measruements from the ground. Here, laboratory data from these HWPs will be presented, including the reflection, polarization modulation efficiency, and thermal loading. This will be compared with numeric simulations for the HWPs and preliminary data from field observations.

category : Cryogenics and Components

PD-2 Development of a cylindrical magnetic refrigerant with polycrystaline $GdLiF_4$ for Adiabatic Demagnetization Refrigerator

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Adiabatic Demagnetization Refrigerator (ADR) is one of the most promising tool for realizing 0.1 K. The lowest temperature and holding time are determined by the magnetic characters of refrigerant materials, starting temperature of demagnetizing, strength of the magnetic field and thermal inflow to the refrigerant. Because recent mechanical cooler, like pulse-tube cooler, can easily achieve a thermal bath with 2.7- K, designing as a cryogen-free system with ADRs is a big advantage.

We have designed double refrigerant ADR with a superconducting magnet, chrome potassium alum (CPA) and polycrystalline $GdLiF_4$ in order to prepare a 0.1 K stage, on which we operate TES x-ray microcalorimeters on 0.1 K stage. To reduce the thermal inflow from 2.7 K of the thermal bath by pulse-tube cooler to CPA, we are developing the cylindrical polycrystalline $GdLiF_4$ for utilizing as a thermal buffer between CPA and magnet. $GdLiF_4$ has been investigated as magnetic material by Numazawa. $GdLiF_4$ has larger entropy change at ¿ 2T than that of a typical magnetic refrigerant GGG. This cylindrical $GdLiF_4$ cut the radiation to CPA and 5μW of thermal inflow in our cooling system. And we estimate that $GdLiF_4$ can keep about 17 hours on 0.5 K.

The $GdLiF_4$ polycrystalline sample was prepared by one axis-pressing powders of GdF_3 and LiF with 0.4 g binder in 50 ± 5 kPa, molded it and calcinating it for 10 hours in 973 K in Ar atmosphere and sinking it to graphite powder for avoiding reduction reaction by oxygen and evaporation of LiF. In the case that calcinating temperature is 1073 K for 1.5 hours, LiF is evaporated locally and porous are formed. The optimal calcinating temperature and holding time depend on the shape and size.

We measured magnetization with MPMS, specific heat capacity with PPMS, crystal structure by XRD, and uniformity by SEM to evaluate our samples. Though we detect existence of GdF_3, $Gd_4O_3F_6$ and Gd_2O_3, magnetic moment was well consistent with Brillouin function. Our samples were also well consistent to Gd^{3+} characters between 2-10K. GdF_3, $Gd_4O_3F_6$ were identified by XRD, but other evaluation did not detect them. Small λ-type peak appears at 3.8 K due to the Gd_2O_3 inclusion, of which abundance ratio was partially several percent on entropy compared with $GdLiF_4$. We think these contaminants exist locally on samples.

We are preparing for fabricating cylindrical structure of 10 cm length, 43mmϕ and 3mm thickness with gel casting method. In the gel casting method, we press slurry with high-pressure water and mold it. It is useful for this method to fabricate large and unique shapes. We report the status of the development.

category : Cryogenics and Components

PD-3 Development of a half-wave plate based polarization modulator unit for LiteBIRD

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We report our development of a half-wave plate (HWP) based polarization modulator unit (PMU) for a cosmic microwave background (CMB) polarization experiment. Inflationary signal appears at a large angular scale on the sky and this large spatially fluctuating signal tends to appear as a long-time scale fluctuating signal in time domain after scanning by a telescope. This requires for the end-to-end low temperature instruments including detector system to achieve typical stability in time below 0.1 Hz or less.

An increasing interest toward the physics of early universe drives rapid progress in low temperature detector and its surrounding technologies. A HWP based PMU modulates the incident polarized signal in a telescope. This enables to up-convert an incident polarization signal frequency above typical detector $1/f$ knee, and thus we achieve a required stability at the signal band effectively. In addition to achieve the stability, a single polarization sensitive detector can operate as an independent polarimeter. There is no need for differencing between the orthogonally polarized detectors, and correspondingly it does not require a high precision matching of the detector properties, e.g. beam, gain and bandpass, in the detector pair.

LiteBIRD is a candidate of JAXA strategic large satellite projects and currently in Phase-A1 within the JAXA/ISAS program. The baseline mission design of LiteBIRD is to employ a kilo-pixel transition edge sensor (TES) bolometer array with a HWP based PMU. A current development goal is to demonstrate the feasibility, i.e. experimental demonstration of a continuously rotating 450 mm diameter HWP operating at about 1 Hz below 10 K.

In this presentation, we report our design of PMU for LiteBRD and the experiment demonstration of our prototype. We develop a Pancharatnam half-wave plate using a sapphire crystal that covers from 40 to 235 GHz bands. We employ a superconducting magnetic bearing to support the continuous rotation of the HWP at below 10 K to minimize the heat dissipation. We discuss the requirement of the PMU and impact using HWP which can relax some of the requirements to TES specifications. We also address the potential systematics and its mitigation that is introduced with use of PMU.

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category : Cryogenics and Components

PD-4 The CUORE cryostat

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The Cryogenic Underground Observatory for Rare Events (CUORE) is an experiment searching for neutrinoless double beta decay in ^{130}Te. CUORE must operate an ton-scale array of 988 TeO_2 bolometers at ∼10 mK providing exceptionally low background and low vibration conditions. In order to meet this unprecedented challenge, the CUORE detector array is cooled down by a multistage cryogen-free cryostat unique of its kind. Due to the large mass, a custom made precooling system brings the whole cryostat to a temperature of 35 K using LHe vapours. Later the Inner Vacuum Chamber (IVC) is cooled down to 4K by five Pulse Tubes (PTs). Finally the base temperature is delivered by a custom designed continuous-cycle ^{3}He/^{4}He dilution refrigerator. Strict material selection and cleaning procedures are applied to all the structures facing the detector. Seven tonnes of low-temperature lead shielding protect the inner cubic meter scale experimental volume from the residual background contamination of the cryostat. Special suspensions mechanically decouple the detector from the cryostat. Vibration-induced thermal noise on the bolometers is minimized by means of a dedicated software that optimizes and control the working frequencies and phases of the five PTs. The cooling power, the total mass and the experimental volume make the CUORE cryostat the biggest and most powerful dilution cryostat in the world.

CUORE is currently in its final detector commissioning phase at the Laboratori Nazionali del Gran Sasso. The CUORE cryostat successfully cooled down the ton-scale detector at ∼7 mK, delivering an uniform and constant base temperature. This result marks a fundamental milestone in low temperature detectors techniques, opening the path for future ton-scale bolometric experiments searching for rare events.

category : Cryogenics and Components

PD-5 Stacked Wafer Gradient Index Silicon Optics with Integral Antireflection Layers

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A wide range of applications in astronomy from tens of GHz to THz frequencies, on the ground and in space, would benefit from silicon optics because silicon's high refractive index and low loss make it an ideal optical material at these frequencies. It is even possible to use silicon for ambient temperature vacuum windows. Silicon's large refractive index, however, necessitates antireflection coating. Moreover, multilayer antireflection treatments are necessary for wide spectral bandwidths, with wider bandwidths requiring more layers. To this end, we are developing multilayer coatings for silicon by bonding together wafers individually patterned with deep reactive ion etching (DRIE).

While a standard approach to antireflection coating is to deposit or laminate dielectric layers of appropriate refractive index, it is difficult (but not impossible) to find low loss dielectrics with the correct refractive index and other properties to match silicon well, especially if more than one layer is required, operation up to THz frequencies is desired, and/or the optic will be used cryogenically. Textured surfaces are an attractive alternative to dielectric antireflection coatings. For millimeter wavelengths, multi-layer antireflection textures with up to 4:1 bandwidths have been cut successfully into silicon lens surfaces with a dicing saw, but this technique becomes unusable at frequencies of 300 GHz and higher given the saw dimensions. Laser machining is being explored but demonstrations are not yet available. DRIE works well on flat surfaces (and has been demonstrated for narrowband windows to THz frequencies), but there are limits to the depth and aspect ratio of the features it can create. Furthermore etching has not been adapted to large, curved optics.

We are pursuing a hybrid approach to this problem: construct a silicon optic by stacking flat patterned wafers. The starting point is a multilayer optical design incorporating both an axial gradient in the refractive index for antireflection and a radial index gradient for focusing. For each optical layer, a hole or post pattern is used to achieve the required effective index of refraction. Using a novel multilayer etching procedure, several layers of the optical structure are fabricated on a flat wafer. Several individually patterned wafers are stacked and bonded together to produce the completed optic. This approach can thus address the aspect ratio limitations of DRIE, and it obviates etching on curved surfaces.

We present our results to date, which include measurements at 210-330 GHz (and 75-115 GHz) of single-layer and double-layer coatings before and after wafer-bonding. These measurements indicate the basic technique is sound. We will also report on explorations of the maximum etchable hole aspect ratio, which will define the minimum and maximum refractive index that can be used for gradient index lens and antireflection designs. We are also beginning to design 4- and 6-layer structures. Our near-term goal is to produce a 10-cm lens with a 6-layer coating providing 5.5:1 bandwidth from 85 to 420 GHz, eventually scaling up to 15-cm, 30-cm, and larger elements.

category : Cryogenics and Components

PD-6 Superconducting Flex Cables for CMB Detector Readouts

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Next-generation instruments for astrophysical surveys will have large focal plane arrays of detectors with 100,000 or more superconducting pixels and thousands or tens of thousands of low-noise cryogenic amplifiers. High-frequency, high-density superconducting flex cables are needed to read out these arrays using frequency domain multiplexing. We describe a process we have developed for the fabrication of robust superconducting flex cables to meet these requirements and to simplify cryogenic system integration. The flex circuits are fabricated using superconducting NbTi traces (Tc 9 K) sandwiched between a 6-μ m thick polyimide base layer and a 6-μ m thick top layer on a 100-mm diameter Si wafer. The NbTi superconducting traces are sputter deposited onto the base polyimide and patterned using a lift-off process, and transition to wire bond pads patterned directly on the Si wafer to improve wire bond reliability. After applying the top polyimide layer, the Si under the traces is removed using a deep reactive ion etch process, leaving just the thin polyimide/superconductor/polyimide flex with a total thickness of 12.4 μ m. We discuss preliminary test and characterization measurements carried out at 4 K and future development plans.

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category : Cryogenics and Components

PD-7 Improved Automated Control System for ADR Cryostats

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We have developed an improved control system for ADR cryostats. The LabVIEW-based ACS3 ADR Control Software enables fully automated ADR cryostat operation in conjunction with a STAR Cryoelectronics MC-20 Magnet Controller and PA-10 Power Amplifier, and a Lake Shore 372 Resistance Bridge and 218 Temperature Monitor. The application allows the user to monitor up to ten thermometers, and automatically or manually regenerate the ADR, automatically or manually operate the ADR heat switch, regulate the ADR temperature (using local or remote control), and log all ADR temperatures and cryostat data for further processing or diagnostic purposes. Dual configurable graphical displays can be used to plot versus time any of the ten thermometer values, the superconducting magnet parameters (e.g., voltage, current), cryostat pressure, or compressor parameters. The application monitors key system temperatures and magnet parameters in real time. If temperature or magnet thresholds are exceeded due to a loss of cooling or a magnet quench, or there is a power outage, the system is automatically shut down to reduce the risk of damage to the ADR or cryostat. We report recent results for temperature control stability and temperature regulation range.

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category : Cryogenics and Components

PD-8 Compact 0.8 K Helium-4 Sorption Cooler

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Cryocooler is one of the crucial component for cryogenic detectors, where the cooling power limits the detector performance, such as pixel numbers or operation speed. Our goal is to realize photon counting terahertz interferometry (PCTI; Matsuo 2012, JLTP 167, 840) by implementing fast terahertz detectors, which count incoming photons of 100 Mphoton/s. Readout electronics as fast as 1 GHz is required, which causes relatively high heat dissipation of 100 μW. Furthermore, we aim to realize a multi-pixel array of these detectors, which requires higher cooling power.

Niobium based devices are preferred for terahertz detectors, such as superconducting tunnel junctions, since their energy gap stays within the terahertz frequency range. By cooling niobium device to less than 0.8 K, the quasiparticle density reduces and the device behaves as an ideal superconductor. We are developing a compact 0.8 K ^{4}He sorption cooler which can operate continuously with base temperature of 4 K. ^{4}He sorption cooler provides relatively high cooling capacity and simple operation as demonstrated by Lau et al. 2006 (Cryogenics 46, 809), where the orifice size is one of the key parameter to achieve appropriate cooling temperature and power. Our new design aims to realize the required cooling power with minimum physical size. Altering two sorption coolers will make continuous operation possible when the 0.8 K hold time is designed to be longer than the fridge-cycle time.

Prototype sorption cooler using 4 ℓ (STP) of ^{4}He was fabricated in order to evaluate the optimum amount of activated charcoal, which dominates the physical size of the cooler. The relation between cool down temperature and heat load was evaluated with an orifice of 1 mm in diameter. With no heat load, the hold time was about 5 hours, whereas the fridge-cycle time was about 30 minutes. Even with 400 μW heat load, the hold time was more than 2 hours, which is still much longer than the fridge-cycle time. Then we designed another sorption cooler with 2 ℓ (STP) of ^{4}He, and the fridge-cycle time becomes even shorter. Altering operation of two coolers can provide continuous 0.8 K cooling under heat load of 400 μW. Experimental results of the compact sorption coolers, and the ultimate design of the compact sorption cooler will be discussed in the presentation.

category : Cryogenics and Components

PD-9 Improvements of our TES microcalorimeter operation system with a compact adiabatic demagnetization refrigerator cryostat

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We are developing a TES microcalorimeter operation system using a compact adiabatic demagnetization refrigerator (ADR) of our own making, keeping ground application and future missions in mind. Our ADR cryostat is composed of an FAA salt pill fabricated in-house, a superconducting magnet with a passive magnetic shield around it, and a mechanical heat switch, with a liquid helium tank as a heat sink. In LTD16, we reported the energy resolution of 3.8 ± 0.2 eV (FWHM), when the detector was operated at 80 mK. Among the noise terms, the readout noise had the largest contribution ($\sim$ 3.0 eV). It turned out that the noise level of the SQUID we were using became gradually higher below 3 kHz, while the signal-to-noise ratio of the TES microcalorimeter was the highest at around a few 100 Hz. Thus, we evaluated the noise level of SQUIDs in our cryostat and adopted a gradiometer-type SQUID developed by ISAS/JAXA for TES microcalorimeter operation. When it was operated in our cryostat, the noise level was about 14 pA/$sqrt$Hz in the 1–10 kHz range, and 26 pA/$sqrt$Hz at 100 Hz. An advantage of this SQUID is that the heat dissipation is low, and hence, it can be operated at the detector stage. We also improved the SQUID drive circuit, and removed noise of certain frequencies other than 60 Hz and its harmonics. We are now evaluating the TES microcalorimeter performance using the new SQUID and the improved circuit. In the poster, we will present the results.

category : Cryogenics and Components

PD-10 Large Angle Optical Access in a sub-Kelvin Cryostat for the Development of a Beam Steering Antenna

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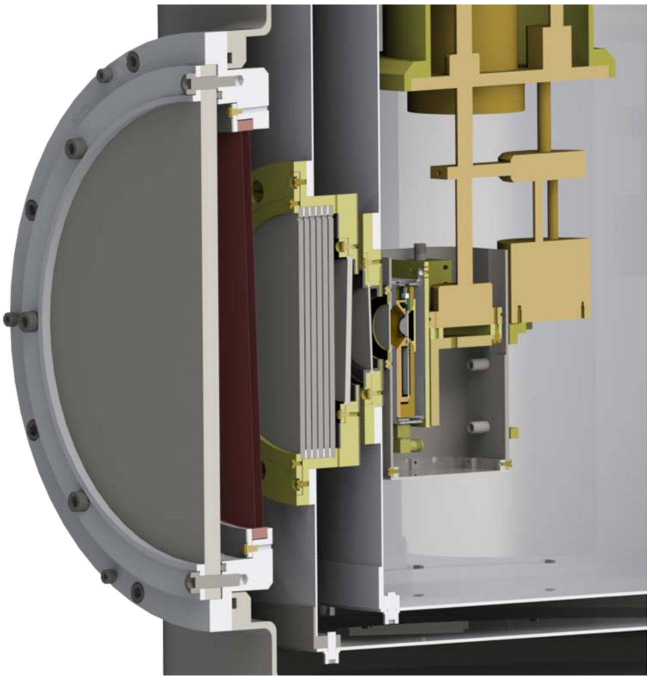
Imaging arrays of antenna coupled MKIDs (Microwave Kinetic Inductance Detectors) use antennas with fast beams in order to increase the pixel density for a given throughput of the telescope optics, therefore reducing the size of the array and the cryostat optics. The beam width of these antennas at −10 dB taper is in the order of ±20°, which makes measurements of the antennas full beam pattern, including side lobes, challenging to implement. However, these measurements are necessary to fully understand the performance of the imaging array. As the operation of hybrid MKIDs also requires temperatures of $T < 270$ mK, a low-temperature setup with optical access to an external hot source at extremely large opening angles is needed.

We present the design of a cryostat based on a He-7 sorption cooler in a dry pulse-tube system with a total opening angle of $\theta = 75.6°$ transparent up to $f_c \approx 950$ GHz. The cryostat was succesfully tested, reaching a loaded base temperature of $T_b = 264$ mK with a holdtime of $t_h > 24$ h for a single recharge of the sorption cooler.



category : Cryogenics and Components

PD-11 Feasibility Study for an IR-LED Based Calibration System for SuperCDMS Detectors

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The Super Cryogenic Dark Matter Search (SuperCDMS) is one of the leading experiments in the direct search for the Weakly Interacting Massive Particles (WIMPs) at the low mass scale (below 10 GeV/c2). The experiment operates cryogenic germanium detectors at a few tens of mK in a well-shielded environment, measuring both phonon and charge signals to identify elastic scatters of WIMPs off atomic nuclei. The experiment now is in transition to the new location at SNOLAB near Sudbury, Canada, and the plan is to lower the energy threshold of the detectors down to a few tens of eV by reducing the noise in the readout circuit and improving the design of the TES based phonon sensors. Traditionally radioactive sources are used to calibrate the energy scale and to check the detector stability. However, in most cases, it takes a long time to accumulate enough events to identify peaks in the energy spectrum. Moreover, gammas at low energy as would be desired for the lower threshold detectors cannot penetrate the cryostat. In this poster, I am presenting a study investigating the possibility of using pulsed infrared LEDs (1650 nm) as alternative calibration sources.

category : Cryogenics and Components

PD-12 A cryogenic detector characterisation facility in the shallow underground laboratory at the Technical University of Munich

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The Physics Department of the Technical University of Munich operates a shallow underground detector laboratory (overburden 15 m.w.e.) featuring approximately 180m^2 of laboratory space at the campus in Garching, Germany.

One of the main applications of this laboratory is the development and characterisation of cryogenic detectors in the framework of the CRESST-III experiment and next-generation cryogenic neutrinoless double beta decay experiments. To this end, a dedicated 3He/4He dilution refrigerator (Oxford Kelvinox 100) is operated. The experimental setup is instrumented with a 4-channel SQUID readout system together with a readout system for NTD sensors, enabling the operation of a wide range of cryogenic detectors. The experimental setup, furthermore, features a CRESST compatible data acquisition system as well as an active muon veto system. Passive shielding against external radiation is provided by 10-15 cm of lead completely surrounding the cryostat dewar.

The laboratory has also recently (2016) been extended to include a 25m^2 cleanroom (class ISO 7) which will be used for the fabrication and assembly of cryogenic detectors for the CRESST-III experiment. In this contribution, we will present the current status of the shallow underground laboratory, and of the experimental setup.

category : Cryogenics and Components

PD-13 Concept Design of High Frequency Telescope for LiteBIRD

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LiteBIRD is a satellite mission which is planned to be lunched by JAXA in middle of 2020's for verification of inflation at the beginning of the universe via the B-mode polarization of the cosmic microwave background. The precise measurement of the B-mode signal with the sensitivity of σr < 0.001 requires the removal of contaminating polarized emissions, mainly from synchrotron and thermal dust. In order to separate these foreground emissions, the observations of the broad frequency spectrum of them are necessary. For the purpose of the broadband and wide filed observations of the all sky, LiteBIRD receives frequency bands of 40 - 402 GHz with two telescopes, which are the low frequency telescope (LFT) and the high frequency telescope (HFT).

The HFT consists of a continuous-rotating half wave plate, two silicon lenses and focal plane detectors. In order to suppress thermal emissions from the optical elements, all components are cooled down to less than 5 Kelvin. Superconducting detectors at the focal plane operate at 100 mK for extremely low-noise detection.

The baseline design of the HFT has an aperture diameter of 200 mm for 280 - 402 GHz.

The optical design has been optimized to the field-of-view of 10 deg $\times$ 10 deg. The mechanical structure and thermal design has been studied to derive requirements and specifications of the components. A possibility to an expanded option of the HFT with an aperture diameter of 300 mm for 166 - 402 GHz is discussed.

category : Cryogenics and Components

PD-14 CUTE - A low noise facility for testing cryogenic dark matter detectors

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CUTE is a new cryogenic facility for testing cryogenic dark matter detectors. It is under construction at SNOLAB, a laboratory for particle research located 2 km underground near Sudbury (Ontario, Canada). Close to the future SuperCDMS experiment, this facility will be used to validate the detector towers before installation in the main experiment. Being in a low background environment, the CUTE facility has a sensitivity competitive with other dark matter experiment and will be able to produce several advanced results in the search for low-mass WIMPS.

We report the design choices made to control the local background around the detectors and the mechanical architecture in order to limit the vibrations transmission. The low temperature required to operate the cryogenic detector is obtained by an advanced pulse-tube based dilution refrigerator from CyroConcept (France). The so-called ‘ Ultra Quiet Technique ? UQT, reduces the vibration transmission by using an original gas-coupled thermal link between the 2-stages pulse tube and the cryostat. In order to install the cryostat into a shielding water tank, we have developed an advanced suspension system which de-couples the cryostat from his environment with a low stiffness support, making a mechanical low-pass filter below 2 Hz for the vertical attenuation.

category : Cryogenics and Components

PD-15 Optimization of detector arrays and the cryogenic platform for the ECHo experiment

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The Electron Capture in ^{163}Ho experiment ECHo aims to probe the electron neutrino mass on a sub-eV level via the analysis of the calorimetrically measured high statistics electron capture spectrum of ^{163}Ho. For this, metallic magnetic calorimeter arrays (MMC) will be used, which are operated at millikelvin temperatures. The performance achieved by first prototypes of MMC detectors show that an energy resolution of ΔE_{FWHM} ¡ 5 eV and a signal rise time of τ_{r} ¡ 1 μs can be reached. These values, obtained with single channel read out, fulfill the requirements for the first phase of ECHo, ECHo-1k. The challenge is to keep the same performance using the multiplexed read out. We present the current status of the new design for the detector arrays to be used in ECHo-1k. This array design allows for parallel read out as well as for multiplexed read out. We discuss results obtained during the first characterization of these detectors. The first phase of ECHo will be performed in a new dedicated cryostat. The future plans for mounting read out cables and the design for the installation of the array on the experimental platform will be shown. Finally we discuss the present status of the ECHo-1k experimental set-up and present first results obtained with the new arrays operated in the new cryostat.

category : Cryogenics and Components

PD-16 Impact of a cryogenic half-wave plate polarization modulator on the detector array sensitivity of the POLARBEAR-2 CMB experiment

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Polarization modulation using a continuously-rotating half-wave plate (HWP) is a promising technique to mitigate the impact of low-frequency noise and systematic error on the performance of Cosmic Microwave Background (CMB) polarization experiments. However, thermal emission from an ambient-temperature HWP adds significant optical loading onto the focal plane and thus decreases detector sensitivity to the CMB signal. Therefore, we present the design and testing of a cryogenic HWP (CHWP) for implementation on POLARBEAR-2 (PB-2), an upcoming CMB camera consisting of 7,588 Transition Edge Sensor (TES) bolometers observing at 95 and 150 GHz via dichroic, dual-polarized pixels. The CHWP is comprised of a broadband Pancharatnam sapphire stack on a superconducting magnetic bearing. It will operate at 50 K, 460 mm diameter, and 2 Hz continuous rotation, modulating the Stokes Q/U sky signal input to all 1,897 pixels at 8 Hz simultaneously. We discuss CHWP performance from the perspective of detector sensitivity, with an emphasis on photon noise, bolometer thermal carrier noise, and instrument mapping speed.

category : Cryogenics and Components

PD-17 International Development of Detector Cooling System Down to 50 mK in Space without Cryogens

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Low temperature detectors with supreme sensitivity are often expected to be cutting-edge instruments for space-astronomy missions. The Athena mission has been selected by European Space Agency (ESA) , as a large X-ray observatory launched in 2028 to implement the Hot and Energetic Universe. One of its instrument is X-IFU, a cryogenic X-ray spectrometer based on a large array of TES microcalorimeter with 3840 pixels and 2.5 eV energy resolution. There also several proposed missions like infrared mission SPICA, cosmic microwave background (CMB) polarization mission Core+/LiteBIRD to be operated below 100 mK.

ESA called a Core Technology Program (CTP) for design, development, assembling, and functional verification of a detector cooling chain including cryostat and coolers down to 50 mK . The goal of this“ CC-CTP ”(Cooling Chain CTP) is to develop a feasible cryogenic chain in space without exhausting cryogen and/or operating fluid to achieve ¿5 years working life. It requires a technical jump from Plank and Astro-H. CNES (Centre National d ’Etudes Spatiales) and X-IFU pre consortium members for cryogenic system, ALAT (Air Liquid Advanced Technologies), CEA(Commissariat a l ’Energie Atomic et aux Energies Alternatives), INTA(Instituto Nacional de Tecnica Aeroespacial), JAXA (Japan Aerospace eXploration Agency), SRON (SRON Netherlands Institute for Space Research) and RAL (Rutherford Appleton Laboratory) , participate in this project.

As a first step of CC-CTP, CNES, CEA, and JAXA is fabricating and testing a cryostat with a combination of 4K Joule-Thomson (JT), 2K JT, pre-coolers and sub-K coolers, an adiabatic demagnetization refrigerator (ADR) as sub-K cooler. Test campaign at CEA premise with Japanese 4K/2K JT and French sub-K coolers to obtain the cooling power as a function of interface temperatures, power consumption etc., has started from 2017 April. We will present these activities , as a key technology for future applications of low temperature detectors.

category : Cryogenics and Components

PD-18 Experimental study and modeling of cryogenic detectors decoupling within dry cryostat

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The dry cryostat technology is based on pulse tube cryo-coolers and offers a good alternative to wet dilution cryostats. However, the main drawback is the production of vibrations from the pulse tube. These vibrations can be transmitted to the cryogenic detectors mounted in the cryostat and cause extra-noises dramatically affecting their performances. A solution to mitigate the impact of these vibrations is to mount the detectors on a suspended tower.

For this purpose, vibrations in a dry cryostat were modelled and preliminary prototypes were investigated in the scope of detectors R&D for the EDELWEISS-III experiment.

First results and future prospects are discussed in this presentation.

category : Cryogenics and Components

PD-19 A 300 mK Testbed for Rapid Characterization of Microwave SQUID Multiplexing Circuits

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A significant challenge in the development of arrays of low-temperature detectors has been the development of simple, low-power, multiplexed readout schemes. This challenge has been heightened as demand grows for arrays of tens of thousands of pixels and large arrays of high-speed pixels. To meet this demand, a new multiplexing method, microwave SQUID multiplexing, has been developed that is capable of providing the bandwidth necessary for large arrays of fast TESs. These multiplexers consist of RF-SQUIDs coupled to superconducting microwave resonators, which are probed via a common microwave feedline and read out at room temperature using GHz signals carried on coaxial cables.

For both the development of microwave SQUID circuits and quality assurance before circuits are integrated into instruments, we need a high-throughput testbed for characterization and testing. This will allow us to rapidly screen devices and develop useful statistics describing them. Because the microwave properties of our lithographically-patterned niobium resonators change substantially above 500 mK, any characterization testbed must reach temperatures below this critical value to provide relevant data.

We have therefore assembled a testbed for measurement of microwave SQUIDs consisting of a helium-3 sorption refrigerator, backed by a pumped helium-4 stage, in a compact liquid helium dip probe. The probe enables us to cool microwave devices to 300 mK in roughly three hours. This system will substantially accelerate our ability to test and characterize microwave SQUID multiplexing circuits. In addition to describing the probe, we show representative microwave SQUID test data, including the dependence of resonator frequency locations and quality factors on temperature.

category : Cryogenics and Components

PD-20 A micro-vibration acoustic attenuator for low temperature detectors.

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Most of the low temperature detectors are nowadays operated in dilution or adiabatic demagnetization refrigerator are based on pulse tube cryocoolers. The main disadvantage of a cryogeen-free cooler is the potential high level of mechanical vibrations at the warm and cold interfaces that could affect the sensitivity of low temperature instruments.

We describe the performance of a very simple acoustic attenuation system used to eliminate the pulse-tube-induced low frequency noise of the superconducting transition-edge sensors under development for the instruments of the next generation of infra-red and X-ray space observatories. The attenuator consists of a multi-stage passive mass-spring system designed to reduce the level of micro-vibration at the detector site for all the six rotational and translational modes. Attenuation of more than 60dB in the noise equivalent power of TES bolometers has been demonstrated with a two-stage acoustic isolator.

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category : Cryogenics and Components

PD-21 Magnetic field shielding for a Rydberg-atom single-photon detector: basic approach and measurements

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The Rydberg-atom single-photon detector developed by the CARRACK group in Kyoto is expected to be one of the most sensitive methods to search for dark matter axions[1]. In order for the detector to be successful enough, it is essential to shield a microwave-detection cavity and the following selective field ionization (SFI) region from the high magnetic field inevitably present closely to convert axions to microwave photons. It is because without the magnetic field, the energy level structure of the relevant Rydberg atoms becomes simpler and thus easier to handle theoretically and also experimentally. Moreover, the effect of motional Stark effect can be reduced by the magnetic field shielding for an Rydberg atomic beam with its velocity of around 300 m/s suitable for the sensitive photon detection.

We developed an efficient way to shield the magnetic field of 7 T maximum for the axion-photon conversion situated very closely from the microwave-photon detection region. Basic approach to this is firstly to reduce the magnetic field to less than 0.1 T at the photon detection region by using a superconducting cancellation coils and then to cover the region with Nb metals in which the magnetic field is below the lower critical field B_{c1} of Nb. By reducing the magnetic field below the lower critical field of the type II superconductor Nb, it is possible to utilize efficiently the perfect diamagnetic (Meissner) effect for the shielding.

Here we report our basic approach to the subject and its related measurements for the magnetic field shielding in the Rydberg-atom single-photon detector. Specifically we analyzed in detail the effect of the demagnetizing factor in the shape of the Nb metals on reducing the magnetic field below B_{c1} of Nb. We also studied the effect of additional Nb metal rings and commercially available NbTi/Nb/Cu multilayer-alloy sheets placed above the Nb metal cover. [1] R. Bradley, S. Matsuki et al., Rev. Mod. Phys. 75(2003)777.

category : Cryogenics and Components

PD-22 Design of magnetic shielding and field coils for a TES X-ray microcalorimeter test platform

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The performance of transition-edge sensors (TES) and their SQUID multiplexed read-outs are very sensitive to the ambient magnetic field and fluctuations that can arise due to fluctuating magnetic fields outside of the focal plane assembly. In order to run ground experiments on thousands of X-ray TES microcalorimeters within a low ambient and uniform magnetic field (¡ 1 uGauss, with a uniformity ¡ 0.1 uGauss) we need a very low field to be trapped into out superconducting magnetic shields. In addition, we require very stringent magnetic field shielding factors, ideally less than a part in 10?5 for field components normal to the surface of the thin-film TES sensors and read-out amplifiers. This level of shielding is highly beneficial in enabling the detectors and read-out to be immune to external field variations that can arise due to, for instance, fluctuations in the fields from the adiabatic demagnetization refrigerator, as well to be immune to AC fluctuations in the external fields.

We have designed a sub-kelvin test platform to reach these specifications. For this purpose, we modeled a new design for the shielding consisting of a series of different mu-metal and superconducting shields, including a niobium shield at 50 mK, a cryoperm (A4K) shield at 3 K and a mu-metal shield at 300 K. Our study included comparisons of different shield geometries and material thicknesses, which is presented. The status of measurements that confirm these models will also be presented.

It is often desirable to be able to apply a DC magnetic field across an array to help optimize the performance of the TESs. We have studied a number of different field -coil designs, and the impact of the different shield geometries, in order to reach the required field uniformity. The uniformity desired for the TES array is less than one part in 1000 across a 15 mm array. The variation in fields seen by the read-out SQUID electronics has also been considered, and has been designed to be kept sufficiently low to avoid having such fields affect to the read-out performance.

category : Cryogenics and Components

Category E : Applications

PE-1 A Review of Packaging and Integration Techniques for Large Superconducting Detector Arrays for Cosmic Microwave Background Observations

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The cosmic microwave background (CMB) continues to reveal new aspects of the large scale universe. For example, current projects are searching for evidence of primordial gravitational waves, for signatures sensitive to the sum of the neutrino masses, and for further understanding of the formation and growth of large structures under the influence of gravity in the accelerating universe. Technologies for ground-based and balloon-borne instruments measuring the polarization of the CMB have been well established and advanced in the last decade. Experience from the current generation of CMB projects indicates that the integration of the cryogenic detector array package, including its multiplexing and readout elements, is critical to the performance of the CMB instrument. The next generation of instruments needed to fully explore the potential of the CMB will require many more detectors than have currently been deployed. As the number of detectors per focal plane scales up, improvements and new technologies for large array packaging will be required. In this proceedings, we review the integration of Transition-Edge Sensors with readout components and optical coupling structures for the current array package assembly processes of multiple telescopes. We present the concept from Advanced ACTPol for the assembly of large bolometer arrays, and compare to the successes from other CMB projects. We will summarize the possible improvements and limitations anticipated in driving towards large numbers of even higher density detector arrays, keeping in mind the need for faster production rates while maintaining good performance and high yield.

category : Applications

PE-2 Polarization Sensitive Microwave Detectors for a Satellite CMB Mission

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The detailed characterization of the intensity and polarization of the Cosmic Microwave Background (CMB) radiation provides a powerful tool to constrain the properties of the early Universe. The polarization induced by a stochastic gravitational wave background in this epoch produces a distinctive and measurable signature of primordial inflationary processes. Here we report on the status and development of polarization-sensitive detectors for a satellite CMB polarization mission and their application in ground based instrument settings. The sensor architecture features an antenna-coupled detector with an integrated orthomode transducer (OMT), on-chip band defining filters, and features to control spurious radiometric coupling. The detectors are based on a Transition-Edge Sensor (TES) design and the superconducting circuitry is defined via thin film coatings on a single-crystal silicon substrate. The sensor design is readily scalable in both frequency coverage, 30-300 GHz, and in number of detectors.

category : Applications

PE-3 Advanced ACTPol 27/39 GHz Detector Array Calibration with Fourier Transform Spectroscopy: Foreground Removal in CMB Maps

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Advanced ACTPol (AdvACT) is an upgrade to the Atacama Cosmology Telescope that offers a unique combination of sensitivity, resolution, spectral channels, and sky coverage for mapping the polarization of the Cosmic Microwave Background (CMB). Detection of?B-mode polarization in the CMB could provide the first measurements of?quantum gravity, determine the energy scale of inflation,?constrain dark matter, and allow us to measure the sum of the neutrino masses.?To obtain a precise?measurement of the primordial B-mode power spectrum, polarized?galactic?foreground emission from synchrotron radiation and dust?must be?characterized and?removed with high accuracy. Accurate subtraction of this foreground emission is contingent upon precise knowledge of the spectral responses of the AdvACT detectors over AdvACT 's five frequency bands, which requires state of the art calibration. A Fourier Transform Spectrometer (FTS) is an interferometer?with a known source?that can be used to measure the spectral responses of the AdvACT detectors. Polarizers within the FTS split orthogonal polarizations and allow us probe the detectors 'full polarized responses, and a set of coupling optics couple the FTS beam to the detectors housed in a cryostat.?The?FTS used to perform detector calibration?for?ACTPol achieved 2-GHz accuracy on the 150 GHz band centers, but this accuracy must be improved?by?at least a factor of 4 to obtain?sufficient polarization measurements for foreground cleaning. A new FTS with larger etendue is required to calibrate the low-frequency channels of AdvACT and to enable?fast?calibration of the full focal plane.?To improve the?calibration accuracy in the low frequency range, the transmission and polarization properties of all optical elements in the new FTS and coupling optics must be precisely characterized. I will present optical measurements of the AdvACT low frequency 27/39 GHz detector bands obtained using the new FTS, and?an overview of the design, characterization, and implementation of the new FTS technology.

category : Applications

PE-4 SPIDER: CMB polarimetry from the edge of space

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SPIDER is a powerful balloon-borne instrument to map the polarization of the millimeter-wave sky at large angular scales. SPIDER targets the B-mode signature of primordial gravitational waves in the cosmic microwave background (CMB), with a focus on mapping a large sky area with high fidelity at multiple frequencies. SPIDER's first long-duration balloon flight in January 2015 deployed a total of 2400 antenna-coupled TESs at 94 GHz and 145 GHz. I will review the design and in-flight performance of the SPIDER instrument, as well as the current status of science analysis and technology developments toward SPIDER 's second flight in 2018. I will also discuss the optimization of the TESs and receivers to take full advantage of a space-like observing platform, including the characterization of the response of these detectors to particle radiation encountered in space.

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Figure 2: The top author is Jeffrey P. Filippini.

category : Applications

PE-5 Advanced ACTPol Low Frequency Array: Readout and Characterization of Prototype 27 and 39 GHz Transition Edge Sensors

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Advanced ACTPol (AdvACT) is a third generation polarization sensitive upgrade to the Atacama Cosmology Telescope (ACT). AdvACT expands on the ACT Polarimeter's mid frequency (MF, 90/150 GHz) transition edge sensor (TES) bolometer arrays and adds both high frequency (HF, 220/270 GHz) and low frequency (LF, 27/39 GHz) multichroic arrays. The addition of the high and low frequency detectors allows for the removal of synchrotron and spinning dust emission at the low frequencies and foreground emission from galactic dust and dusty star forming galaxies at the high frequencies. The increased spectral coverage of AdvACT will enable improvements in a wide range of science, such as improving constraints on dark energy, the sum of the neutrino masses, inflationary parameters and potentially the energy scale of inflation. The HF array was deployed for the 2016 season and two MF arrays are being deployed for the 2017 season. The LF array will be the final AdvACT array, with deployment planned for the 2018 season. Prior to fabrication of the final LF detector array we designed and characterized prototype TES bolometers. Detector geometries in these prototypes are varied in order to inform and optimize the bolometer designs for the LF array, which requires significantly lower noise levels and saturation powers than the higher frequency detectors. Here we present the design and characterization of the first LF prototype detectors for AdvACT, including measurements of the saturation power, critical temperature, thermal conductance, time constants and noise properties. We also describe the modifications to the time-division SQUID readout architecture compared to the MF and HF arrays.

category : Applications

PE-6 POLARBEAR-2: Development of a receiver system for CMB measurements

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POLARBEAR-2 is a newly developed receiver system for improving the measurement of Cosmic Microwave Background (CMB) polarization, in particular odd-parity pattern called B-mode, to achieve both the detection of degree-scale inflationary signatures and the precise measurement of gravitational lensing effects induced by the cosmological large-scale structure observed in sub-degree angular scales. This receiver system is planned to be installed on the Simons Array experiment in the Atacama desert in Chile. The 365mm-diameter focal plane of the receiver is cooled to 0.27 K by a three-stage Helium sorption refrigerator and will have 7600 dichroic super-conducting transition-edge sensor (TES) bolometers with the broadband antennas. We plan to start deploying the first POLARBEAR-2 receiver, which is sensitive to 90 and 150 GHz, in Chile in 2017. The expected array sensitivity of POLARBEAR-2 is 4.1 $\mu\mathrm{K}\sqrt{s}$. The initial Simons Array sensitivity with three-year observation using the first POLARBEAR-2 receiver is expected to achieve significantly better sensitivities on the measurement of the inflationary B-mode (sigma(r: tensor-to-scalar ratio)=0.01) and the gravitational lensing B-mode (resulting in 90 meV (1-sigma) for the sum of neutrino mass) than the current limits. Before the deployment in Chile, we are performing the end-to-end tests of the first receiver in our laboratory to characterize the integrated performances of the instruments with the observation quality optics, readout hardware, detectors, and cryogenics, using various types of calibration equipment. In this talk, we report the current status of the end-to-end test and initial characterization results of the integrated receiver.

category : Applications

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PE-7 LiteBIRD: a satellite for the study of B-mode polarization and inflation from cosmic microwave background radiation detection

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LiteBIRD is a candidate for JAXA 's strategic large mission to map the polarization of the cosmic microwave background (CMB) radiation over the full sky at large angular scales with unprecedented precision. It is currently in the stage of concept design (Phase-A) at ISAS/JAXA. A global joint study group has been formed with researchers from Japan, U.S., Canada and Europe. We plan a launch in mid 2020 's with a H3 rocket of JAXA for three-year observations at a Lagrangian point L2. Cosmological inflation is the leading hypothesis to resolve the problems in the Big Bang theory. It predicts that primordial gravitational waves were created during the inflationary era, which then imprinted large-scale curl patterns in the CMB polarization map, called the B-modes. Measurements of the CMB B-mode signals are known as the best probe to detect the primordial gravitational waves. The scientific objective of LiteBIRD is to test well-motivated inflation models that satisfy single-field slow-roll conditions and lie in the large-field regime. The power of the B-mode is proportional to the cosmological parameter tensor-to-scalar, r. The requirement for LiteBIRD is to measure r with the precision of $\delta r < 0.001$, which will offer us a crucial test of cosmic inflation. The required angular coverage is $2 \geq \ell \geq 200$, where ℓ is the multipole moment. LiteBIRD is also expected to produce various scientific results in cosmology and astronomy. The design and operation of the LiteBIRD system are driven by the requirements mentioned above. A 3-year full sky survey will be carried out for 15 frequency bands between 40 and 400 GHz to achieve the total sensitivity of 2.5 μK ' with a typical angular resolution of $\sim$30 ' at 150 GHz. The key components of the mission payload include a half-wave plate system for polarization signal modulation, a low-frequency telescope with two reflective mirrors with an aperture of $\sim$40 cm, a high-frequency refractive telescope with an aperture of $\sim$20 cm, an array of polarization-sensitive multi-chroic TES bolometers read out with high multiplexing factors in the frequency domain, and the cryogenic system to provide the 100 mK base temperature.

category : Applications

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PE-8 The POLARBEAR and Simons Array Cosmic Microwave Background Experiments

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The POLARBEAR and Simons Array Cosmic Microwave Background experiments are pathfinders in both science and low-temperature detector development. POLARBEAR-1 has used a 1,274 detector antenna-coupled TES array to make a 5 sigma detection of gravitational lensing of the polarized CMB, set an upper limit of 3.9 nG on a primordial magnetic field, and set an upper limit on cosmic birefringence of 93 nG equivalent magnetic field. We will present new results from an analysis of the first two years of POLARBEAR observations which increase the significance of the the gravitational lensing detection.

POLARBEAR-1 has observed the BICEP/KECK patch using a continuously rotating half-wave plate during the third and fourth years of observations. This data set will be used to measure degree angular scales to constrain inflation, and we will present the status of the analysis.

We will also present the development of the three POLARBEAR-2 receivers which will be installed in the Simons Array. The POLARBEAR-2 receivers will each have focal-plane arrays with two-band Sinuous-Antenna-Coupled TES bolometers. Two of the receivers will have 95 and 150 GHz bands and one will have 220 and 280 GHz bands. Each receiver will have 7,588 bolometers, and the Simons Array will have a total of 22,764 detectors. The detectors will be readout with a 40x Frequency-Domain Multiplexer (FDM). We will report on the construction status of the experiment and give science forecasts for an inflation search and a measurement of the sum of neutrino masses and the effective number of relativistic species in the early universe.

category : Applications

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PE-9 Simons Observatory: Next Generation Telescopes Featuring Large Detector Arrays for Observations of the Cosmic Microwave Background

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The Simons Observatory is a next generation observatory comprised of large and small telescopes optimized to make precise measurements of the comic microwave background (CMB) over frequencies spanning 30-300 GHz. These data will be used to detect or place stringent limits on gravitational waves from inflation, new light relativistic species, neutrino properties, and to make many other astrophysical and cosmological measurements. The SO instrument will pave the way for CMB-S4 which will field hundreds of thousands of CMB detectors across multiple plaftorms. Here we present an overview of the SO large and small telescopes, the cryogenic receivers, cold optical elements, and our plan for fielding and reading out tens of thousands of multichroic, superconducting detectors on the SO large and small telescopes.

category : Applications

PE-10 Design and Performance of the SPT3G First-year Focal Plane

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During the austral summer of 2016-7, the third-generation camera, SPT3G, was installed on the South Pole Telescope, increasing the number of detectors in the focal plane by an order of magnitude relative to the previous generation. Designed to map polarization of the Cosmic Microwave Background, SPT3G utilizes ten 6 ”-hexagonal modules of detectors, each with 271 trichroic and polarization-sensitive pixels coupled to the sky using broadband sinuous antennae and hemispherical alumina lenslets. Each pixel contains six transition-edge-sensor (TES) bolometers, which are read out using 64x frequency-domain multiplexing (fMUX). Here we will discuss design and assembly of the detector modules, as well as the layout of the first-year focal plane. We ’ll also discuss early performance characterization of the full array, including yield and detector properties across the array: TES properties of transition temperature, normal resistance, saturation powers, and loopgain, and readout properties such as stray resistance and stability.

category : Applications

PE-11 Design, Characterization, and Assembly of the POLARBEAR-2A Cryogenic Readout System

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The Simons Array (SA) is a Cosmic Microwave Background (CMB) experiment comprised of three telescopes that aims to characterize the B-mode polarization signal from inflationary gravitational waves and gravitational lensing by large scale structure. The first Simons Array instrument, POLARBEAR-2A (PB-2A) will have 7,600 polarization sensitive Transition Edge Sensor (TES) bolometers mutliplexed and read out by 300 mK channel defining aluminum LC filters and 4 K SQUID amplifiers. This represents a factor of 6 increase in detector count compared to its predecessor, POLARBEAR-1 (PB-1). The improved array sensitivity that comes with an increased number of detectors is accompanied by the challenge of improving the thermal performance of the readout system. To this end, we have expanded our carrier frequency range from 1 MHz to 4.5 MHz and increased our multiplexing factor from eight to forty. The higher multiplexing factor allows us to increase the detector count without dramatically increasing the thermal load on the detector stage. This also imposes stringent constraints on stray impedances in the biasing circuit since these can cause bolometer nonlinearity and crosstalk between readout channels. We use a NbTi broadside coupled stripline to minimize thermal loading and stray impedance in the wiring between SQUIDs and LC filters. Here we describe the details of the design, assembly, and characterization of the readout system in the PB-2A receiver and a dark test cryostat.

category : Applications

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PE-12 T_C tuning of Titanium thin films for CMB detectors on the SWIPE/LSPE experiment

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Cosmic microwave background (CMB) B-mode polarization detection is a major challenge in modern cosmology, which future experiments are going to undertake either from the ground, on balloons or on satellites. Among these, the SWIPE/LSPE balloon-borne experiment aims at searching for B-modes exploiting the re-ionization peak at large angular scales. Detectors in SWIPE are Transition Edge Sensor (TES) spider-web bolometers, with required $T_C \simeq 500\,\mathrm{mK}$. We found evidence that temperature control during deposition and post annealing of Titanium thin films allows the tuning of critical temperature. Titanium is a Type I superconductor with $T_C \simeq 380\,\mathrm{mK}$. In this paper we present a systematic study done on thermal treated Titanium films, showing that higher T_C can be achieved, in a range suitable for SWIPE.

category : Applications

PE-13 Development of a Massive, Highly Multiplexible, Phonon-Mediated Particle Detector using Kinetic Inductance Detectors

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We present a status update on the development of an phonon-mediated particle detector using Kinetic Inductance Detectors (KIDs). The design is intended for $\mathcal{O}(1)$ kg substrate, using tens to hundreds of KIDs on a single readout line, to image athermal phonon distribution.

The fine-scale position information provided by the highly multiplexed KIDs, combined with their excellent energy sensitivity, will provide competitive energy resolution and threshold below 1 keV, as well as precise, robust position reconstruction. The primary goal is to use the fine-scale position information to make significant gains in defining the substrate's fiducial volume, excluding surfaces and edges that are subject to higher backgrounds and, in the case of joint detection of ionization production, incomplete ionization collection. In rare-event searches, mis-reconstruction of the surface event positions and/or incomplete ionization collection can be the dominant background.

Prior work successfully demonstrated the concept on a 20 mm $\times$ 22 mm $\times$ 1 mm Si substrate with 20 KIDs (Moore et. al. APL 2012) but met substantial challenges with feedline quality when scaling up to larger substrate. We were able to overcome it with new feedline design combined with thicker films, resulting in robust feedline characteristics. We have also developed a new KID design based on improved simulation, and the end product shows much higher current density uniformity and negligible crosstalk. We will report on the design, fabrication, and performance of demonstration devices on 76 mm $\times$ 1 mm Si substrate, with 40, 80, 140, 256 Nb KIDs, for assessing resonance placement accuracy, and with 40 Al KIDs to demonstrate responsivity, noise performance, and particle detection with energy and position reconstruction.

category : Applications

PE-14 A NaI-based cryogenic scintillating calorimeter: status and results from the first COSINUS prototype detectors

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The COSINUS (Cryogenic Observatory for SIgnals seen in Next-generation Underground Searches) project aims to provide a model independent cross-check of the long-standing DAMA/LIBRA claim on the observation of dark matter by using the same target material, but in a different experimental approach.

Operating undoped sodium iodide (NaI) scintillating crystals as low temperature scintillating calorimeters has the distinguished advantage of providing a lower energy threshold for nuclear recoil events as expected from dark matter particle interactions combined with particle discrimination. Infact, the dual read-out of phonon and light allows us to provide background rejection on an event-by-event basis, a unique feature in comparison to other NaI-based dark matter searches.

In this talk we will discuss in detail the COSINUS detector concept and present the results and performance parameters from our first prototype measurements.

category : Applications

PE-15 The DM Radio: Searching for Ultra-Light-Field Dark Matter

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The Dark Matter Radio (DM Radio) is a sensitive search for sub-eV axion and hidden photon dark matter over a wide mass range. While Weakly Interacting Massive Particles (WIMPs) have been the primary focus of direct detection for several decades, there has been growing interest in searching for ultra-light-field candidates such as the hidden photon (spin 1 boson) and axion (spin 0 boson). DM Radio uses a superconducting, tunable lumped-element LC resonator with SQUID-based readout. The DM Radio Pathfinder is now in operation, and the DM Radio program has been funded for Stage 2, in which it will set important new limits on hidden photon and axion dark matter. In this talk, I will discuss the motivation, detection strategy, status, and prospects for the DM Radio experiment and show the dark matter phase space that DM Radio will search over the next several years.

category : Applications

PE-16 Directional sensitivity in single-electron resolution phonon-mediated detectors

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A large body of astrophysical observations indicate that around 85 percent of the matter in the universe is not made of recognized standard model particles. Understanding the nature of this so-called dark matter is of fundamental importance to cosmology, astrophysics, and high energy particle physics. We present a method for using solid state detectors with directional sensitivity to dark matter interactions to detect low-mass Weakly Interacting Massive Particles (WIMPs), the main dark matter candidate, originating from galactic sources. In spite of a plethora of literature for high-mass WIMP detectors with directional sensitivity, there is no available technique to cover WIMPs in the mass range ¡1 GeV/c^2. We make the reasonable assumption that single electron-hole pair creation is caused by defect formation, which is in sharp contrast to the well-established, but physically incorrect, Lindhard model at energies below about 100 eV. We examine commonly used semiconductor material response to these low-mass WIMP interactions using numerical simulations of classical interatomic potentials in these materials. These simulations, backed up by more precise density functional theory simulations and experiments, predict an angular dependence in the defect formation energy threshold that varies by around 20 eV from minimum to maximum. Experiments such as the Cryogenic Dark Matter Search (CDMS) and the Mitchell Institute Neutrino Experiment at Reactor (MINER) are actively developing detectors to reach the resolutions necessary to observe this effect. Once these detectors are calibrated at these low recoil energies, we argue that the anisotropy in defect formation in single-electron resolution semiconductor detectors allows for very effective directional sensitivity to dark matter signals for masses below 1 GeV/c^2.

category : Applications

PE-17 Solid xenon bolometers for anti-correlation studies

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Cryogenic liquid xenon detectors have become a popular technology in the search for rare events, such as dark matter interactions and neutrinoless double beta decay. The power of the liquid xenon detector technology is in the combination of the ionization and scintillation signals, resulting in particle discrimination and improved energy resolution over the ionization-only signal. The improved energy resolution results from a strong microscopic anti-correlation phenomenon that has not been described from first principles. Solid xenon bolometers, under development at Drexel University, would offer an opportunity to study scintillation, ionization, and phonon signals simultaneously. This additional energy channel may offer the final piece of the puzzle in understanding the microscopic anti-correlation phenomenon in detector energy response.

category : Applications

PE-18 The MINER Experiment: Coherent Neutrino-Nucleus Scattering Measurement With Cryogenic Semiconductor Detectors

Andrew Jastram[1]

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The proposed Mitchell Institute Neutrino Experiment at Reactor (MINER) experiment at the Nuclear Science Center at Texas A/&M University will search for coherent elastic neutrino-nucleus scattering within close proximity (about 2 m) of a 1 MW TRIGA nuclear reactor core using low threshold, cryogenic germanium and silicon detectors. Given the Standard Model cross section of the scattering process and the proposed experimental proximity to the reactor, as many as 5?20 events/kg/day are expected. We discuss the status of preliminary measurements to characterize the main backgrounds for the proposed experiment. Both in situ measurements at the experimental site and simulations using the MCNP and GEANT4 codes are described. A strategy for monitoring backgrounds during data taking is briefly discussed.

category : Applications

PE-19 A Systematic Study of the Theoretical Calorimetric Electron Capture Spectrum

Katrina E. Koehler[1], Mark P. Croce[2], Christopher J. Fontes[3], Michael W. Rabin[4], Michael A. Famiano[5], Thomas W. Gorczyca[6]

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A high statistics, high resolution calorimetric spectrum of electron capture in ^{163}Ho yields the neutrino mass provided the degree of fidelity in the atomic description high enough. By systematically assessing the contributions from increasingly detailed descriptions of the atomic theory, it is possible to determine the statistical requirements for experimentally measuring each contribution. Given a theoretical description of high enough fidelity, additional components will be unmeasurable even in the high-statistics regime of a neutrino mass measurement, indicating the level to which a theoretical model must be calculated. We will show this systematic assessment for the calorimetric electron capture spectrum of ^{163}Ho.

category : Applications

PE-20 Updates on the Transition Edge Sensors and multiplexed readout for HOLMES

andrei puiu[1], Dan Becker[2], Douglas Bennet[3], Valentina Ceriale[4], Matteo De Gerone[5], Marco Faverzani[6], Elena Ferri[7], joseph fowler[8], john gard[9], andrea giachero[10], james hays-wehle[11], gene hilton[12], biasotti michele[13], john mates[14], angelo nucciotti[15], angiola orlando[16], gianluigi pessina[17], dan schmidt[18], dan swetz[19], joel ullom[20], bradley alpert[21], carl reintsema[22]

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Measuring the neutrino mass is one the most compelling issues in particle physics. HOLMES is an experiment for a direct measurement of neutrino mass. HOLMES will perform a precise measurement of the end point of the Electron Capture decay spectrum of 163 Ho in order to extract information on neutrino

mass with a sensitivity as low as 1 eV.

HOLMES, in its final configuration will deploy a 1000 pixel array of low temperature microcalorimeters: each calorimeter is made of an absorber, where the Ho atoms will be implanted, coupled to a Transition Edge Sensor thermometer.

The detectors will be kept at the working temperature of 70 mK in a dilution refrigerator. In order to easily read out the 1000 detectors array of HOLMES, a multiplexing system is necessary: the choice is to couple the Transition Edge Sensors to a multiplexed rf-SQUID. The rf-SQUIDs are operated in flux ramp modulation

for linearisation purpouses. The rf-SQUID is then coupled to a superconducting quarter wavelength LC resonator in the GHz range, from which the modulated signal is finally recovered using the homodyne technique.

In this contribution we outline the progress made towards the final configuration of HOLMES regarding both the performances of the TES detectors and the characteristics of the multiplexing system. We reached the target time and energy resolution and we are about to finalise the detector array design before starting to

implant Ho in the absorbers. By the end of 2017 we plan to start measuring the first 64 detectors array with implanted 163 Ho. From this first measurements crucial information will be extracted, such as the importance of shake-up and shake-off second order processes, which need to be taken into account in the calculation of

the theoretical spectral shape used for the evaluation of the neutrino mass. With 64 active detectors, a two month long exposure time will allow us to set a limit of 7 eV on the neutrino mass.

category : Applications

PE-21 ^{193}Pt Electron Capture Spectra with Microcalorimeters

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A neutrino mass can be extracted from a high statistics, high resolution calorimetric spectrum of electron capture in ^{163}Ho. In order to understand the resolution degradation seen in embedded sources as measured by microcalorimeter Transition Edge Sensors, a platinum absorber with embedded ^{193}Pt was created by irradiating a ^{192}Pt-enriched platinum foil in the 6-MW MIT reactor. This absorber provides the opportunity to determine the sample preparation and deposition contributions to resolution degradation. Additionally, the ^{193}Pt electron capture spectrum provides another independent check on the theoretical calculation for the electron capture spectrum, which has thus far been compared only to ^{163}Ho. Experimental and theoretical spectra from this ^{193}Pt-in-Pt absorber are presented and discussed.

category : Applications

PE-22 Data processing and analysis for AMoRE-Pilot

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AMoRE (Advanced Mo-based Rare process Experiment) is an international collaboration searching for neutrinoless double beta decay (0 ν β β) of 100Mo by using 40Ca100MoO4 scintillating crystals equipped with metallic magnetic calorimeters (MMCs) operating at millikelvin temperatures. AMoRE utilizes the phonon (heat) ? photon (scintillation light) simultaneous-measurement technique to achieve excellent particle discrimination, thus reducing alpha background events. The pilot phase of the experiment has been running in the 700-m-deep Yangyang underground laboratory in Korea, with about 1.5 kg of 40Ca100MoO4 scintillating crystals at temperatures as low as 10 mK. We present the techniques used for the data analysis of the AMoRE-Pilot experiment. These include optimal signal filtering to maximize the signal-to-noise ratio and coincidence analysis to reject muon backgrounds.

category : Applications

PE-23 Characterisation of CRESST-III target crystals in the shallow underground laboratory at the Technical University of Munich

Michael Willers[1], Xavier Defay[2], Nahuel Ferreiro[3], Angelina Kinast[4], Jean-Come Lanfranchi[5], Alexander Langenkamper[6], Erik Lindner[7], Michele Mancuso[8], Elizabeth Mondragon[9], Andrea Munster[10], Tobias Ortmann[11], Walter Potzel[12], Stefan Schonert[13], Raimund Strauss[14], Andreas Ulrich[15], Stephan Wawoczny[16]

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The Technical University of Munich (TUM) produces scintillating CaWO4 target crystals with high radiopurity for the direct dark matter search experiment CRESST-III (Cryogenic Rare Event Search with Superconducting Thermometers). The full production process from the raw materials to the final target crystals is performed in-house at TUM.

Phase 2 of the CRESST-III experiment plans an increment of the target mass, therefore, the growth of several CaWO4 ingots (raw crystals used to produce the target crystals) is required. To ensure the high radiopurity of the produced crystals, TUM is investigating new diagnostic techniques that enable a fast feedback to the production process. One of the investigated methods is the measurement of the internal alpha-contamination of CaWO4 crystals operated as scintillating cryogenic detectors. In order to avoid the time-consuming production of W-TES (transition-edge sensors) on the crystals and underground

operation, we study the readout of the alpha-induced phonon signal with the TES based active holding scheme of CRESST and by means of NTD thermistors in the shallow underground laboratory at TUM.

In this contribution we will present first results on the radiopurity of TUM-grown CaWO4 crystals investigated by these new methods.

category : Applications

PE-24 Quantum-limited scan strategies: Optimizing resonant axion and hidden photon dark matter detection

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Tunable electromagnetic resonators read out with a sensitive amplifier provide a promising approach for probing axion and hidden photon dark matter over a large mass range. For example, DM Radio is a search using a tunable, lumped-element superconducting resonator read out by a SQUID which will scan for axion and hidden photon dark matter over frequencies between 100 Hz and 100 MHz (masses between 0.5 peV and 500 neV). In this work, we discuss the optimization of scanning resonant searches in the broader context of impedance matching and amplifier noise matching. We show that an optimized scan strategy uses a resonant circuit which is not noise-matched to the amplifier. We explain this result in terms of measurement backaction, which results in a tradeoff between the on-resonance signal-to-noise and the bandwidth over which appreciable sensitivity may be obtained. We also determine the optimal time allocation over resonant frequency scan steps. With these results in hand, we derive a quantum limit on the sensitivity of scanning resonant searches. We show, contrary to previous results, that there is a gain in sensitivity for resonator quality factors above one million and that the bandwidth set by virialization does not fundamentally set an optimal Q for a search. We also show that a scanning resonant search is superior to a purely broadband search at all frequencies at which a resonator can be made. We present progress toward a fundamental limit on all electromagnetic searches (regardless of pole structure) based on criteria similar to the Bode-Fano limit. We discuss the implications of these results for resonant searches, in particular, for DM Radio. The application of an optimized scan strategy may lead to a reduction in scan time, especially at the lower frequencies, where it promises a few orders of magnitude improvement.

category : Applications

PE-25 TES-based light detectors for the CRESST direct dark matter search

Johannes F. Rothe[1]

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The CRESST (Cryogenic Rare Event Search with Superconducting Thermometers) experiment uses TES-based cryogenic detectors, namely scintillating CaWO4 crystals and silicon-on-sapphire (SOS) light detectors, to search for dark matter interactions with the phonon-light technique. The ?40mm SOS plates of the most recent data taking phase typically reached absolute baseline energy resolutions of σ = 4-7 eV. This is the best performance reported for cryogenic light detectors of this size. First results of further improved light detectors developed for the ongoing low-threshold CRESST-III experiment and new developments for large-area visible light detectors are presented.

category : Applications

PE-26 Development of Lumped Element Kinetic Inductance Detectors for Light Dark Matter Searches using Liquid Helium

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We have developed the superconducting detector LEKIDs (Lumped Element Kinetic Inductance Detectors) for a dark matter search using liquid He. It has been supposed that the dark matter is composed of Weakly Interacting Massive Particles (WIMPs). Direct searches for the WIMPs have been conducted using Xe, Ge, Si and NaI as targets. These experiments have sensitivities for WIMP mass down to about 10 GeV/c^2. In 2013, W. Guo and D. N. McKinsey proposed to use liquid He as a target to obtain a sensitivity beyond 10 GeV/c^2 in WIMP mass. Recoiled helium atoms produce scintillation light photons with the wavelength of 80 nm (16 eV in energy). Those photons can be detected with the superconducting detector LEKID surrounding the target liquid He. The LEKIDs offer us a frequency domain multiplexing readout that reduces the number of readout cables, decreasing the heat load from the outside. In this work, we present the overview concept of the dark matter detector using liquid He and the current status of the development of LEKIDs.

The LEKIDs are fabricated with photolithographic techniques in clean rooms: CRAVITY in AIST and another at KEK. We use Nb or NbN for superconducting materials. For the proper operation of LEKIDs, its resonant frequencies should be as close as designed ones. We have found that the over-etching of the substrate surface during the fabrication affects the resonant frequencies and AlN etching stopper underneath the electrode relaxes this problem. We will discuss in detail this improvement as well as other several topics.

category : Applications

PE-27 Current Status of the Detector Developement for the CRESST Dark Matter search

Marc Wuestrich[1],
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The cryogenic dark matter experiment CRESST aims at the direct detection of dark matter via elastic scattering off nuclei in scintillating $CaWO_4$ crystals. Operated as cryogenic calorimeters, the required sensitivity is achieved reading them out with transition edge sensors (TES). This combination provides excellent energy resolution and allows the CRESST experiment to achieve one of the lowest detection thresholds in the field. Particle identification is achieved by the simultaneous measurement of phonon and scintillation signal. By exploiting the reduced scintillation output of nuclear recoils in $CaWO_4$, the dominant β/γ-backgrounds are vetoed efficiently on a event-by event level.

To probe the low mass parameter space of dark matter, a new generation of detectors was developed to be deployed in the CRESST setup at LNGS Gran Sasso. By significantly reducing the mass of the target crystals and by using improved TES structures, the currently used detector modules (CRESST-III (Phase 1)) aim to lower the threshold of the phonon channel below ~ 100 eV and of the light channel below ~ 20 eV. Furthermore, a new detector housing and holding concept was developed which establishes a measurement environment able to identify background originating from surrounding surfaces. The poster will give a review of the currently achieved detector performance within CRESST-III (Phase 1) and an overview of the ongoing R&D efforts to improve the currently achieved detector performance.

category : Applications

PE-28 163Ho distillation and implantation for Holmes experiment

Giovanni Gallucci[1]

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HOLMES is an experiment to directly measure the neutrino mass with a calorimetric approach. The calorimetric technique eliminates several systematic uncertainties usually present in spectrom- eters where the external source and the decays to excited states affect the measurement. 163Ho is chosen as source for its very low Q-value (2.8 keV), the proximity of the end-point to resonance M1 and its half life (4570y). These features are optimal to reach simultaneously a good activity to have sufficient statistics in the end-point and a small quantity of 163Ho embedded in the de- tector to not alter significantly its heat capacity. 163Ho will be produced with neutron irradiation of enriched 162Er2O3 at the Institute Laue-Langevin (Grenoble, France), and chemical separated at Paul Scherrer Institute (Villigen, Switzerland). It will arrive at INFN laboratory of Genova in oxide form (Ho2O3) with traces of others Ho isotopes and contaminants not removeable using chemical methods. In particular the metastable 166mHo has a beta decay with half life of about 1200y which can induce background below 5 keV. The removal of these contaminants is critical for Holmes so a dedicated system is being set up by our group from the Genova INFN section. The system is designed to achieve an optimal mass separation for 163Ho and consists of two main components: an evaproation chamber and an ion implanter. In the evaporation chamber Holmium will be reduced in metallic form, using the reaction 2Y+Ho2O3 $\rightarrow$ Y2O3+2Ho and used to produce a metallic target for the ion implanter source. The ion implanter consists of five main components. A Penning sputter ion source, an acceleration section, a magnetic/electrostatic mass analyzer, a magnetic scanning stage and a focusing electrostatic triplet. In this contribution we describe the procedures, under continuous refinement, for the Holmium evaporation process, the metallic target production and the status of the ion implanter.

category : Applications

PE-29 A low-energy electron detector from photoionization process with Rydberg atoms at low temperature to search for dark matter axions

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The axion, originally invoked to recover from a serious defect of QCD theory on the CP (Time reversal) invariance in the strong interactions, so-called “strong CP problem”, is one of the most plausible candidates of dark matter particles. It is usual to search for axions by firstly converting axions into photons in a high magnetic field and then the photons are detected with a photon detector in a high-Q resonant cavity [1,2]. In this scheme, we can search for axions in a very limited range of its mass in one run, although the detection efficiency is increased due to the effect of high-Q cavity.

We recently proposed to apply the direct photoionization process with Rydberg atoms to search for axions over a wide range of its mass simultaneously without degrading the sensitivity at low temperature[3]: In this new scheme, axion-converted microwave photons are absorbed to highly excited Rydberg atoms, thereby ionized directly in a metal container instead of a resonant high-Q cavity. Then the electrons from this photoionization process are guided to outside the container and accelerated and detected with an electron detector.

Since the final states in the photoionization process distribute continuously, microwave frequencies of photons absorbed and detected in this process are also continuous, thus enabling us to search for axions in a wide range of its mass simultaneously. It should also be mentioned that by changing the initially prepared state of the Rydberg atoms and/or by varying the electric field strength applied to the Rydberg atoms, it is possible to know the mass of axions once some definite signals of axions are observed.

In order to realize such scheme actually for axion search, it is essential to develop a sensitive low-energy electron detector from the direct photoionization process at low temperature. We studied possible configuration of the detector system in which electrons produced over a wide spatial region in a metal container are collected and transported to a scintillation detector while keeping the temperature of the container and detector system low enough (less than 100 mK) to avoid increasing the background from blackbody radiations.

Here we present an electron detector system, which fulfills the above requirement by fully designing the whole system with an ion and an optical simulation calculations. Some results of the obtained performance of the detector system are also presented and discussed.

References:

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category : Applications

PE-30 Sensitivity of TES Microcalorimeter Arrays for Solar-Axion Line Emission

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Axion is a hypothetical elementary particle proposed to solve the strong CP problem in QCD. It is suggested that the sun is a strong axion emitter through Primakoff effect, and that the emission has an energy spectrum with a shape of a blackbody spectrum with k$T \sim 1.3$ keV, reflecting the photon temperature at the center pf the sun. Moriyama (1995) first suggested that monochromatic lines will be also emitted by M1 transition of nuclei. He also suggested that such axion lines could be detected by using a proper conversion material at the Earth. Several experiments have been done so far, however, the upper limit is still high compared to estimations basing on axion models. In this paper, we will investigate methods to detect solar-axion line emission using TES microcalorimeter arrays and estimate the sensitivities. We consider that by using TES array of a size discussed for future X-ray astronomy mission, such as Athena X-IFU, we can reach a meaningful sensitivity.

category : Applications

PE-31 Status of the AMoRE experiment searching for neutrinoless double beta decay using low-temperature detectors

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The goal of the Advanced Mo-based Rare process Experiment (AMoRE) is to search for neutrinoless double beta decay of ^{100}Mo using low-temperature detectors consisting of Mo-based scintillating crystals read out via metallic magnetic calorimeters (MMCs). Simultaneous measurements of heat and light signals are performed at millikelvin temperatures, which are reached using a dilution refrigerator. The AMoRE-Pilot experiment, using five ^{100}Mo-enriched, ^{48}Ca-depleted calcium molybdate crystals with a total mass of about 1.5 kg, has been running in the 700-m-deep Yangyang underground Laboratory as the pilot phase of the AMoRE project. Several setup improvements through different runs allowed us to achieve high energy resolution and efficient particle discrimination. The current status of the AMoRE experiment, as well as the plans for the next, higher-scale, experimental stages, will be presented.

category : Applications

PE-32 Development of patchable light detectors for the AMoRE project

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We describe light detector development to be used for AMoRE neutrinoless double beta decay experiment. The light detectors used in the present stage of the project is composed of a Ge wafer as an absorber for scintillation light and an MMC sensor to read the temperature change by the light absorption. Each MMC sensor is tested individually and assembled with an absorber wafer. In this patchable design of light detectors, it is relatively easy to replace the absorber material with better phononic properties. We investigate the absorber dependence of the light signals employing Ge, Si and Si-on-sapphire wafers. Moreover, the phonon collector films are heat treated in various conditions to make an efficient heat transfer to the MMC sensor from the wafer.

category : Applications

PE-33 Signal stabilization study for AMoRE detectors

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AMoRE (Advanced Mo-based Rare process Experiment) is an international project to search for neutrinoless double beta decay (0 ν β β) of 100Mo. The project employs simultaneous phonon-scintillation detection from scintillating crystals containing 100Mo elements based on MMC readouts. As the heat capacities of a crystal absorber and an MMC sensor varies with temperature together with MMC sensitivity, signal amplitudes may drift over a long time constant as the base temperature fluctuates. This effect degrades the energy resolution of the calorimetric detection at low temperatures. By installing a Joule heater on the detector to periodically inject controlled amount of heat, we can produce reference signals that can be used for gain stabilization. We present the characterization of Joule heaters for future AMoRE runs, and test results using a molybdate crystal.

category : Applications

PE-34 Development of phonon and photon detectors for rare events searches using scintillating crystals

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The use of scintillating crystals in cryogenic experiments searching for rare events as neutrinoless double beta decay or the interaction of a Dark Matter particle allows for an efficient background reduction thanks to particle discrimination. We have developed phonon and photon detectors based on metallic magnetic calorimeters (MMCs) for the simultaneous measurement of heat and light generated upon the interaction of a particle in a scintillating crystal. The aimed values for the energy resolution and signal rise-time expected for the phonon detector are $\Delta E_{\rm FWHM} < 100$ eV and $\tau < 200\mu$s while for the photon detector we expect $\Delta E_{\rm FWHM} < 10$ eV and $< 10\mu$s. The achievement of these time and energy resolutions will pave the way for a more selective particle discrimination which is of utmost importance for next generation experiments searching for neutrinoless double beta decays and dark matter direct detection aiming for target material of the order of 1 ton.

We present the concepts for the development of the P2 detector, a combined photon and phonon detector, which is fabricated on a 3" Si or Ge wafer. We discuss the challenges to fabricate the P2 detector, in particular the segmented temperature sensor for the photon detector and the decoupling of the two readout channels. We present the results obtained with the first experimental characterizations.

category : Applications

PE-35 Fabrication and characterization of MMCs with enclosed ^{163}Ho

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The Electron Capture in ^{163}Ho experiment ECHo aims to probe the electron neutrino mass on a sub-eV level via the analysis of the calorimetrically measured electron capture spectrum of ^{163}Ho. For this, metallic magnetic calorimeters (MMC) operated at temperatures in the mK range will be used. The first prototypes of MMC detector arrays with embedded ^{163}Ho showed so far an excellent performance, with an energy resolution of ΔE_{FWHM} ¡ 5 eV and a signal rise time of τ ¡ 1 μ??. We present the current status of the detector developments for ECHo-1k, the first phase of the experiment characterized by a source activity of 1 kBq and an expected sensitivity on the neutrino mass below 10 eV.

We discuss the optimization of the design and fabrication of the ECHo-1k detector arrays including their single channel to multiplexed readout, and the necessary not standard fabrication processes to prepare the detector for the ion implantation of ^{163}Ho. For this, the RISIKO facility at Mainz University underwent several modifications to improve the reliability and the efficiency of the different steps as resonant laser ionization, mass separation and implantation in the array. We also present simulations and experimental studies concerning the implantation process itself.

We discuss the results of measurements of the expected additional heat capacity of the detector due to the implantation of ^{163}Ho, which is a crucial parameter for the detector performance.

category : Applications

PE-36 The ν-cleus experiment: Gram-scale cryogenic calorimeters for a rapid discovery of coherent neutrino scattering.

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We investigate new gram-scale cryogenic detectors, 1-2 orders of magnitude smaller in size than previous devices. These are expected to reach unprecedentedly low energy thresholds, in the 10 eV-regime and below. This technology allows new approaches in rare-event searches, including the search for MeV-scale dark matter, detection of solar neutrinos and a rapid discovery of coherent neutrino-nucleus scattering (CNNS) at a nuclear reactor. We show a simple scaling law for the energy threshold of cryogenic calorimeters, allowing to extrapolate the performance of existing devices to smaller sizes. Results from a measurement with a 0.5 g sapphire detector are presented. This prototype reached a threshold of 20 eV, one order of magnitude lower than previous results with massive calorimeters. We discuss an experiment, called ν-cleus, which enables a 5-σ discovery of CNNS within about 2 weeks of measuring time at 40 m distance from a power reactor. In a second stage, this experiment enables precision measurements of the CNNS cross-section and spectral shape for new physics beyond the Standard Model.

category : Applications

PE-37 Trigger study on AMoRE-pilot detector

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Advanced Mo-based Rare process Experiment (AMoRE) is a search for neutrinoless double beta decay of Mo-100 at millikelvin temperatures using metallic magnetic calorimeters (MMCs). The crystal based detectors that are used for the experiment have a high energy resolution and a low baseline fluctuation, as well as a low background level that is acquired by installing the detectors in the underground laboratory. Therefore, the detector setup used for AMoRE experiment can also be used for a low energy dark matter search experiment given that a crystal with suitable nuclear mass number is used. As the recoil energy of matter-dark matter collision is thought to be very low, a method to effectively trigger low energy events is required. In this presentation, we discuss the triggering method and the energy threshold of the AMoRE-pilot detector with 40Ca100MoO4 crystals.

category : Applications

PE-38 Directionality study of phonon-scintillation signals from a zinc tungstate crystal

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Direct dark matter searches for weakly interacting massive particles (WIMPs) are confronted by a firm background from coherent neutrino-nucleus scatterings. Introduction of directional dependence of detector response can be one of the possibilities for WIMP searches to break the neutrino background floor. We report a directionality study of phonon and scintillation signals from a zinc tungstate crystal at low temperature. The simultaneous detection of the heat and light signals with MMC readouts is realized for alphas and low-energy gammas incident in different directions. We present the progress on directional dependence study of the phonon and scintillation signals in comparison with a room temperature PMT measurement.

category : Applications

PE-39 Development of Aluminum LEKIDs for Balloon-Borne Far-IR Spectroscopy

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We are developing lumped-element kinetic inductance detectors (LEKIDs) designed to achieve background-limited sensitivity for far-infrared (FIR) spectroscopy on a stratospheric balloon. The Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE) will study the evolution of dusty galaxies with observations of the [CII] 158μm fine-structure transition at $z = 0.5 - 1.5$, both through direct observations of individual luminous infrared galaxies, and in blind surveys using the technique of line intensity mapping. The spectrometer will require large format (∼1600 detectors) arrays of dual-polarization sensitive detectors with a targeted NEP of $\sim 4 \times 10^{-18}$ $\mathrm{W\,Hz^{-0.5}}$.

We are developing low-volume LEKIDs fabricated with a single layer of aluminum (20nm thick) patterned on a crystalline silicon wafer, with resonance frequencies of $100 - 250$ MHz. The inductor is a single meander with a linewidth of 0.7μm, patterned in a grid to absorb optical power in both polarizations. The meander is coupled to a circular waveguide, fed by a profiled feedhorn. A backshort is produced by backside etching, then depositing gold. Initial testing of a small array prototype has demonstrated good yield, and an NEP of $\sim 2 \times 10^{-17}$ $\mathrm{W\,Hz^{-0.5}}$. We will present our ongoing characterization of prototype arrays, and discuss the prospects for achieving our targeted NEP and scaling up to large format arrays.

category : Applications

PE-40 The Mexico-UK Sub-millimetre Camera for Astronomy

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The Mexico-UK Sub-millimetre Camera for Astronomy (MUSCAT) is a large format camera scheduled for installation on the Large Millimetre Telescope (LMT) in 2018. MUSCAT will employ a horn coupled LEKID architecture incorporating a novel meta-material anti-reflection layer to provide a low cost, background limited focal plane operating at 1.1mm that fills the field of view of the telescope. The easily accessible focal plane will be continuously cooled to 100mK with a novel closed cycle miniature dilution refrigerator and is fed with fully baffled reflective optics providing a platform that can be used to demonstrate a range of detector technologies such as on-chip spectrometers and multi-chroic polarisation sensitive pixels. The MUSCAT project will demonstrate the science capability of such an instrument on the LMT through two relatively short science programmes to provide high resolution follow up surveys of galactic and extra-galactics sources previously observed with the Herschel space observatory. In this presentation we will provide and overview of the detector architecture and the overall instrument design as well as updating on progress and scheduled installation on the LMT.

category : Applications

PE-41 Second-generation design of Micro-Spec: a medium-resolution, submillimeter-wavelength spectrometer-on-a-chip

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Micro-Spec (μ-Spec) is a direct-detection spectrometer which integrates all the components of a diffraction-grating spectrometer onto a $\sim$ 10-cm^2 chip through the use of superconducting microstrip transmission lines on a single-crystal silicon substrate. The second generation of μ-Spec is being designed to operate with a spectral resolution of 512 in the submillimeter (500-1000 μm, 300-600 GHz) wavelength range, a band of interest for several spectroscopic applications in astrophysics and Earth science. High-altitude balloon missions will provide the first testbed to demonstrate the μ-Spec technology in a space-like environment and also an economically viable venue for multiple observation campaigns. This work reports on the current status of the instrument design and will provide a brief overview of each instrument subsystem. Particular emphasis will be given to the design of the spectrometer 's two-dimensional diffractive region, through which the light of different wavelengths is focused on the kinetic inductance detectors along the focal plane. An optimization process is employed to generate geometrical configurations of the diffractive region that satisfy specific requirements on spectrometer size, operating spectral range and performance. An optical design optimized for balloon missions will be presented in terms of geometric layout, spectral purity and efficiency.

category : Applications

PE-42 CCAT-prime: An Extreme Field-of-View Submillimeter Telescope on Cerro Chajnantor

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CCAT-prime is a six meter aperture off-axis submillimeter telescope that will be located at 5600m elevation on Cerro Chajnantor in Chile with operations beginning in 2021. The science priorities for CCAT-prime span from cosmology and inflation in the first fraction of a second after the Big Bang to probing the epoch of reionization and galactic ecology studies of the dynamic interstellar medium. Advances in all these areas are enabled by the combination of the large field-of-view (FOV) and accessible atmospheric windows between 200 microns and 3 millimeter wavelengths. We are developing: broadband superconducting detector technologies optimized to measure the cosmic microwave background (CMB) and Sunyaev-Zel 'dovich (SZ) effects and modest resolution spectroscopic imagers to measure fine structure line emission from ionized carbon ([CII] 158 micron) during reionization. In addition, heterodyne spectrometers will be built to measure galactic emission lines. The crossed-Dragone optics design provides an eight degree diameter FOV, enabling CCAT-prime to host a next generation CMB instrument with as many as $\sim 10^5$ superconducting detectors for a " Stage-IV "-scale CMB survey and many more detectors at sub-millimeter wavelengths. Here we present a brief overview of the project and describe the superconducting detector, readout, and instrument technologies that are being developed and studied for CMB/SZ and [CII] intensity mapping observations.

category : Applications

PE-43 On-Sky Performance of MUSTANG-2: the Multiplexed SQUID TES Array at Ninety GHz

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We present the array performance and astronomical images from early science results from MUSTANG-2, a 90 GHz feedhorn-coupled, microwave SQUID-multiplexed TES bolometer array operating on the Robert C. Byrd Green Bank Telescope (GBT). MUSTANG-2 was installed on the GBT on December 2, 2016 and immediately began commissioning efforts, followed by science observations. The feedhorn and waveguide-probe-coupled detector technology is a mature technology, which has been used on instruments such as the South Pole Telescope, the Atacama Cosmology Telescope, and the Atacama B-mode Search telescope. The microwave SQUID multiplexer-based readout system developed for MUSTANG-2 currently reads out 66 detectors with a single coaxial cable and will eventually allow thousands of detectors to be multiplexed. This microwave SQUID multiplexer combines the proven abilities of millimeter wave TES detectors with the multiplexing capabilities of KIDs with no degradation in noise performance of the detectors. Each multiplexing device is read out using warm electronics consisting of a commercially available ROACH board, a DAC/ADC card, and an Intermediate Frequency mixer circuit. The hardware was originally developed by the Collaboration for Astronomy Signal Processing and Electronic Research (CASPER) group, whose primary goal is to develop scalable FPGA-based hardware with the flexibility to be used in a wide range of radio signal processing applications. MUSTANG-2 is the first on-sky instrument to use microwave SQUID multiplexing and is available as a shared-risk/PI instrument on the GBT. In MUSTANG-2's first season 7 separate proposals were awarded a total of 230 hours of telescope time.

category : Applications

PE-44 The KIDS project

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The aim of Kinetic Inductance Detectors for Space (KIDS) experiment is the optimization of KIDs for low-energy photons (IR to mm-waves). Future space missions devoted to the cosmology of the early universe, to molecular and plasma astrophysics and to the observation of the earth and its atmosphere can benefit significantly from the availability of ultra-sensitive detectors like KIDs.

The goal of the project is the development and characterization of two KIDs array, completed by their corrugated feedhorns, test-bed cryogenic setup and custom readout electronics.

The first prototype will be an Al LEKID resonators, sensitive to the total power, and coupled directly to the exit aperture of the corrugated feedhorns. The second prototype will be an OMT at the output of each feedhorn, with the outputs of the two OMTs feeding two independent Al LEKIDs on the wafer. Corrugated, dual-profile feed horn antennas and waveguide ortho-mode transducers (OMTs) represent, nowadays, the best devices to couple microwave signals.

An important problem of KIDs in space is their sensitivity to cosmic rays (CR). CR crossing the Si wafer produce ioniziation, this is converted into phonon, producing large glitches in the detected signals. One possible solution is a phonon-absorbing superconductor layer deposited on a face of the wafer, which reduces very significantly the propagation and energy of phonons towards the resonators. Another possible solution is micromaching of silicon wafer, this technique could be used to minimize silicon volume below the resonator.

category : Applications

PE-45 The performance of the Athena X-ray Integral Field Unit at very high count rates

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The Athena X-ray Integral Field Unit (X-IFU) will operate at 90 mK a matrix of 3840 Transition-Edge Sensor pixels providing spatially resolved high resolution spectroscopy (2.5 eV FWHM up to 7 keV) between 0.2 and 12 keV. During the observation of very bright X-ray sources, the X-IFU detectors will receive high photon rates going up to several tens of counts per second per pixel and hundreds per readout channel, well above the normal operating mode of the instrument. In this contribution, we investigate through detailed End-to-End simulations the performance achieved by the X-IFU up to Crab-like fluxes. Special care is notably taken to model and characterize pulse processing limitations assuming different reconstruction methods, readout-chain saturation effects, as well as the non-Gaussian degradation of the energy redistribution from crosstalk at the focal plane level (both thermal and electrical). Overall we show that more than 50 % throughput at 1 Crab in the 5 to 8 keV band can be achieved with better than 10 eV average resolution with the inclusion of a Beryllium filter, enabling breakthrough science in the field of bright sources, as illustrated by the simulation of representative science cases.

category : Applications

PE-46 The Design of Whiskers, the Lynx X-ray Microcalorimeter

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Lynx is an x-ray telescope, one of four large satellite mission concepts currently being studied by NASA to be the next flagship mission after WFIRST. One of Lynx 's three instruments is an imaging spectrometer named Whiskers, an x-ray microcalorimeter behind an X-ray optic with an angular resolution of 0.5 arc-seconds and approximately 3 m2 of area at 1 keV. Whiskers will provide unparalleled diagnostics of distant extended structures and in particular will allow the detailed study of the role of cosmic feedback in the evolution of the Universe.

We discuss the design of the baseline configuration and a number of options for increasing the capabilities to maximize the scientific return of the Lynx observatory. We discuss the design of Whiskers, including transition-edge sensors (TES) versus metallic magnetic calorimeters (MMC), pixel layout, and readout options relative to the four key instrument requirements: energy resolution, energy range, pixel size, and count-rate. Each option is assessed in terms of read-out complexity, cryogenic cooling requirements, technical readiness of the approach, and ultimate mass, power, and cost of the instrument. In particular we will discuss the use of microwave SQUIDs, HEMT amplifiers, and parametric amplifiers for the read-out.

The baseline configuration utilizes a central 5 arc-minute region consisting multi-absorber devices known as "hydras". In each hydra the temperature sensor being read out (TES or MMC) is attached to up to twenty-five 1 arc-second absorbers (pixels), 50 microns in size. Discrimination between absorbers from an x-ray event is possible because the different thermal links to each absorber cause characteristic pulse shapes that can be discriminated. We will also discuss the possibility of having additional enhancements to the baseline configuration. These include: (1) a sub-region of the array with pixel sizes as small as 0.5 arc-seconds to provide better angular resolution; (2) a sub-region with energy resolution as good as 0.3 eV for energies up 1 keV, allowing the measurement of turbulence in winds of individual galaxies; and (3) a field-of-view extension that could be as large as 20 arc-minutes using 5 arc-second pixels, optimized for low-energy X-rays to 2 keV with an energy resolution of approximately 1 eV, allowing the study of velocities of winds in the outer regions of groups of galaxies.

category : Applications

PE-47 The Demonstration model of the Cryogenic AntiCoincidence detector for the ATHENA X-IFU

Michele Biasotti[1], Andrea Argan[2], Valentina Ceriale[3], Dario Corsini[4], Matteo D'Andrea[5], Matteo De Gerone[6], Flavio Gatti[7], Simone Lotti[8], Claudio Macculi[9], Gabriele Minervini[10], Guido Torrioli[11], Luigi Piro[12]

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The present path toward the X-IFU Flight Model (FM) foresees, as first step, a Demonstration Model (DM) necessary to solve for technological critical aspects before the mission adoption (2020). This path is also applied to the Cryogenic AntiCoincidence (CryoAC) detector, whose planning is to deliver its DM to the Focal Plane Assembly team (SRON), for a subsequent integration with the TES array, by end 2017.

The CryoAC DM is constituted by one single pixel as representative model of the CryoAC Flight Model. It is a microcalorimeter based on 96 parallel connected iridium/gold TES, in which the silicon substrate is used also as absorber. The silicon substrate has been etched, in order to control the thermal conductance, obtaining a free-standing pixel connected to the thermal bath with silicon beams.

The main aspects to be solved for the CryoAC DM are: verification of the suspended silicon absorber at cold; operation at 50mK bath temperature; energy threshold of 20 keV.

In this paper, we present the CryoAC DM development status, and we will show its complete design with also the study of silicon beam thermal conductance at low temperature. The first prototype will be presented and a preliminary device characterization, including transition and load curves will be reported.

category : Applications

PE-48 Detector Calibration of the Micro-X Sounding Rocket Telescope

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Micro-X is a sounding rocket borne X-ray telescope that uses a Transition Edge Sensor microcalorimeter array to provide superior energy resolution. Micro-X is a versatile instrument with plans to observe the Puppis A supernova remnant during its first flight, as well as future observations of the Milky Way to search for X-ray signals from decaying dark matter. Commissioning and functionality testing are complete and the thermal performance of the system has been validated. We are currently evaluating the detector performance in the flight cryostat with the flight multiplexing electronics. Operating in this setup has allowed us to characterize sources of detector and readout noise, as well as to implement mitigation techniques to improve performance in anticipation of the upcoming flight. We present an overview of important noise considerations in addition to updating the latest detector performance.

category : Applications

PE-49 Multi-parameter gain drift correction of X-ray micro-calorimeters for the X-ray Integral Field Unit

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With its array of 3840 Transition Edge Sensors (TESs), the X-Ray Integral Field Unit (X-IFU) onboard *Athena* (2028) will provide spatially resolved high-resolution spectroscopy (2.5eV FWHM up to 7keV) from 0.2 to 12keV, with an absolute energy scale accuracy of 0.4eV. Slight changes in the TES operating environment can cause significant variations in its energy response function, which may result in systematic errors in the absolute energy scale. We plan to monitor such changes via onboard X-ray calibration sources and correct the energy scale accordingly using a linear or quadratic interpolation of gain curves obtained during ground calibration. However, this may not be sufficient to meet the 0.4eV accuracy required for the X-IFU. In this contribution, we introduce a new two-parameter gain correction technique, based on the pulse-height estimate of a calibration line and the baseline value of the pulses. From simulated gain functions, we show that this technique can accurately correct gain drifts over the instrument bandpass despite significant deviations in heat sink temperature, bias voltage, thermal radiation loading and linear amplifier gain. We also address potential optimizations of the onboard calibration source and compare the performance of this new technique with those previously used.

category : Applications

PE-50 Development of Multi-temperature Calibrator for the TES Bolometer Camera: System Design

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We developed a simple add-on, cryogen-free, and low power consumption calibrator for a new Transition Edge Sensor (TES) bolometer camera for the ASTE 10-m telescope. To accurately correct for the non-linearity and atmospheric extinction, we designed a motor-driven rotating filter wheel system installed in front of the cryostat window. This calibrator is required to cover the loading power under various atmospheric conditions, corresponding to precipitable water vapor (pwv) of 0.5–4 mm. For this range of pwv, we imitated 10–150 K blackbody using the 300 K semi-transparent filters. Bolometers in the cryostat were optically-coupled to the low temperature stage (4 K) inside the cryostat by spherical mirrors. In addition, moderately absorbing polystyrene plates were placed in between a spherical mirror and the cryostat window. Various combinations of filters result in eight different temperature, and simulate the atmospheric emission under various weather conditions at the ASTE site.

category : Applications

PE-51 Pyramid-type Antireflective Structures on Silicon Lenses for Millimeter-wave Observations

Tom Nitta[1], Yutaro Sekimoto[2], Kazufusa Noda[3], Takashi Hasebe[4], Shigeyuki Sekiguchi[5], Hiroshi Matsuo[6], Makoto Nagai[7], Agnes Dominjon[8], Wenlei Shan[9], Yosuke Murayama[10], Shogo Hattori[11], Masato Naruse[12], Nario Kuno[13], Naomasa Nakai[14]

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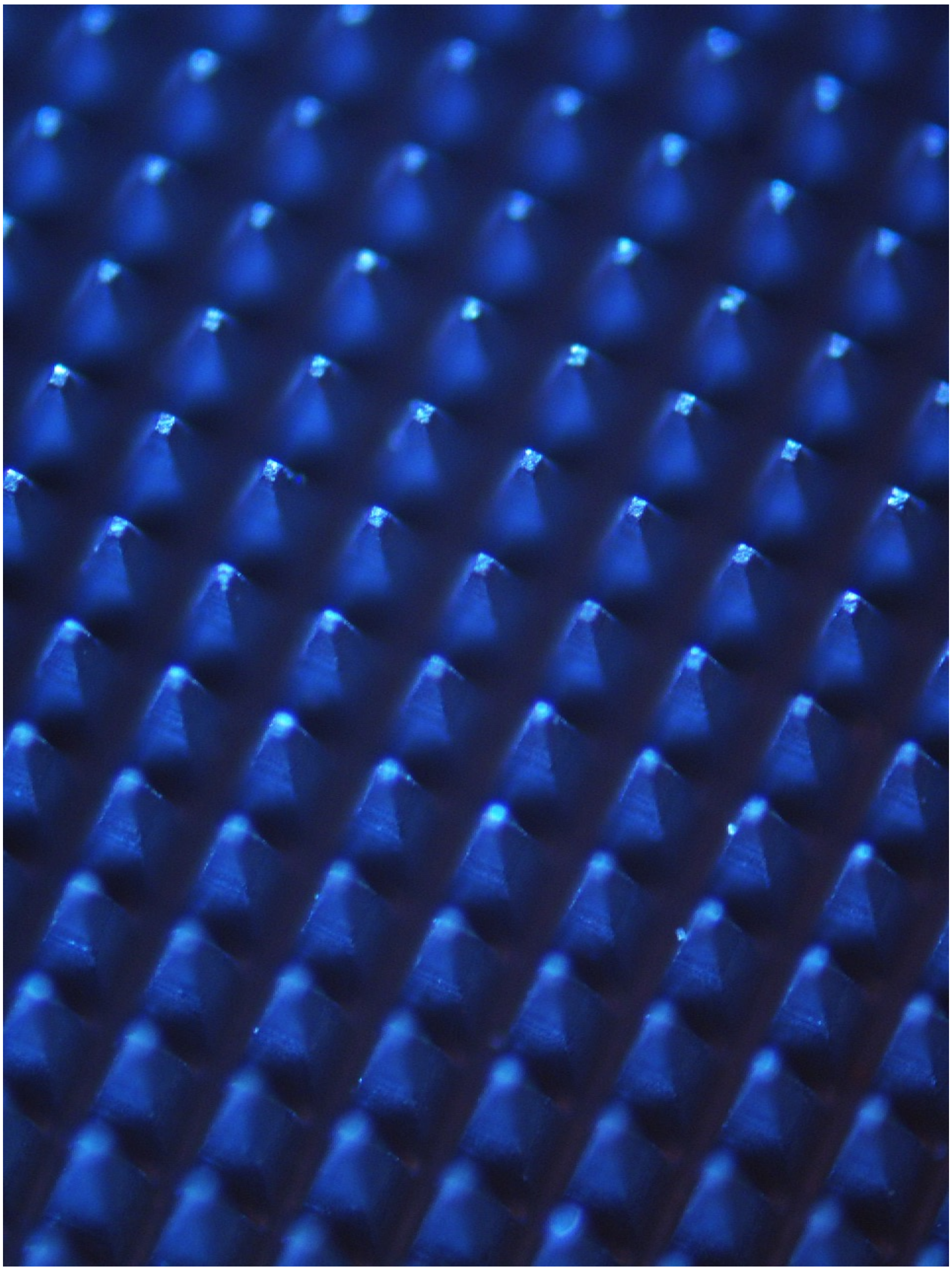
We are developing a 100-GHz band superconducting camera with microwave kinetic inductance detectors (MKID) for the Nobeyama 45-m telescope. A cold optics of the camera is based on a refractive-type optics and is composed of a cold baffle, a cold stop, IR blocking filters and two silicon lenses with 300-mm-diameter at 4 K and 154-mm-diameter at 1 K. A columnar crystal silicon manufactured by Mitsubishi Materials Electronic Chemicals Co., Ltd. is a promising material for large-diameter lenses because it is available up to 100 cm $\times$ 100 cm base material. The refractive index and the dielectric loss tangent in the sub-millimeter frequencies were measured to be ~ 3.42 and $1 - 5 \times 10^{-4}$, respectively, at around 30 K.

For a silicon lens, almost 30% reflection loss is caused at the lens surface. To reduce this reflection loss, a pyramid-type antireflective subwavelength structure was designed. The structure, which has 600-μm-depth and 265-μm-period, was simulated using an electromagnetic field simulator (Ansoft HFSS) in order to obtain the reflectance. The simulated result shows that the reflectance from 140 to 335 GHz is less than 9%. This structure was fabricated on both sides of a 100 mm diameter plane-convex lens with a 150 mm radius of curvature. A metal bonded V-shaped dicing blade and a homemade three-axis machine were used for the fabrication. The reflectance of the pyramid-type structures on the silicon lens was measured by vector network analyzer. The measured result from 110 to 170 GHz was -8 to -17 dB.

category : Applications



PE-52 The Cryogenic AntiCoincidence detector for ATHENA X-IFU: characterization of the last generation single pixel prototype (AC-S8).

Matteo D'Andrea[1], Claudio Macculi[2], Andrea Argan[3], Simone Lotti[4], Gabriele Minervini[5], Luigi Piro[6], Michele Biasotti[7], Dario Corsini[8], Flavio Gatti[9], Guido Torrioli[10]

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The Advanced Telescope for High ENergy Astrophysics (ATHENA) is the second large-class mission selected in ESA Cosmic Vision 2015-2025, with a launch foreseen in 2028 towards an L2 orbit. One of the two instruments that will alternately operate at the focal plane is the X-ray Integral Field Unit (X-IFU). The X-IFU is a cryogenic spectrometer based on a large array of Transition Edge Sensor (TES) microcalorimeters, which will operate at a base temperature of 50 mK, providing spatially resolved high-resolution spectroscopy (2.5 eV at 6 keV) over a 5 arcmin diameter FoV.

The X-IFU sensitivity is highly degraded by the particle background expected in L2 orbit, which is induced by primary proton (of both galactic and solar origin) and secondary electrons. To efficiently veto these particles and enable the observation of faint and diffuse X-ray sources, the X-IFU incorporates a TES-based Cryogenic Anticoincidence detector (CryoAC), placed less than 1 mm below the main array.

The baseline CryoAC design foresees 4 identical pixels, each one having an active area of 1.2 cm^2, a bandpass of 20 keV - 750 keV and a separated readout chain. Each pixel is made of a suspended Silicon absorber (500 μm thick) sensed by a network of a hundred Ir:Au TESes. The TESes are uniformly distributed over the absorber surface and connected in parallel to each other. This design takes advantage of the athermal pulse to be used as fast anticoincidence trigger: the higher the athermal phonons collection efficiency, the better is the detector response.

Here we will report the characterization measurements performed on the last generation CryoAC single pixel prototype, namely AC-S8. This sample, 1 cm^2 area, incorporates 65 Ir TESes connected to an additional network of Aluminum fingers. We will focus on the role of these Aluminum collector fins, investigating the efficiency improvement in the athermal phonons collection.

category : Applications

PE-53 The Cryogenic AntiCoincidence detector for ATHENA X-IFU: improvement of the test setup towards the Demonstration Model

Matteo D'Andrea[1], Claudio Macculi[2], Andrea Argan[3], Simone Lotti[4], Gabriele Minervini[5], Luigi Piro[6], Michele Biasotti[7], Dario Corsini[8], Flavio Gatti[9], Guido Torrioli[10], Angela Volpe[11]

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The X-IFU sensitivity is highly degraded by the particle background expected in L2 orbit, which is induced by primary proton (of both galactic and solar origin) and secondary electrons. To efficiently veto these particles and enable the observation of faint and diffuse X-ray sources, the X-IFU incorporates a TES-based Cryogenic Anticoincidence detector (CryoAC), placed less than 1 mm below the main array.

The CryoAC development schedule foresees by the end of 2017 the delivery of a Demonstration Model (DM) to the X-IFU Focal Plane Assembly development team. The DM is a single-pixel detector based on Silicon suspended absorber, which will address the final design of the CryoAC. It will verify some representative requirements at single-pixel level, in particular the detector operation with a 50 mK thermal bath and the threshold energy at 20 keV.

Before the delivery, test and characterization activities of the CryoAC DM prototype will be performed in the cryogenic system at INAF/IAPS. To improve the quality of these measurements, the test facility has been recently upgraded inserting a magnetic shielding system at the 2.5 K stage of the cryostat.

Here we will describe this cryogenic magnetic shielding system and the preliminary measurements carried out to test its performances. Furthermore, we will report the study of the noise environment, focusing on the impact of the Pulse Tube Cooler operations on the detector noise spectra.

category : Applications

PE-54 Optical Response of TES Bolometer Arrays for SAFARI

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We report on the optical testing of ultra-sensitive prototype horn-coupled bolmeter arrays for SAFARI, the grating spectrometer on board the proposed SPICA satellite. SAFARI's four bolometer arrays, coupled with a diffraction grating and Martin-Puplett Fourier Transform Spectrometer (FTS), will make spectroscopic observations of the cold, dusty Universe over the wavelength range $34--230$ μm.

Each of SAFARI's prototype bolometers consists of a Ti/Au transition edge sensor (TES), with a transition temperature close to 100 mK, and a tantalum absorber on a thermally-isolated silicon nitride membrane. The nitride membrane sits behind a few-moded feedhorn and in front of a hemispherical backshort. SAFARI requires extremely sensitive detectors ($NEP < 2 \times 10^{-19}$ W/$\sqrt{\text{Hz}}$), with correspondingly low saturation powers, to take advantage of SPICA's 6-K cooled optics.

We have measured the optical efficiency of prototype detectors for SAFARI's short-wave band ($34--60$ μm) and used an external FTS to explore the effects of non-linearity and saturation on their spectral response. We present our latest measurements of the optical response of prototype arrays, compare them with simulations, and discuss them in terms of the instrument performance.

category : Applications

PE-55 Vector Beam Pattern Measurements of a large field of view Microwave Kinetic Inductance Detector camera at 350GHz

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We present vector beam pattern measurements of a large field of view Microwave Kinetic Inductance Detector camera at 350GHz. The angular and position dependent optical response of a receiver, its beam pattern, is given by the E-field of the detected radiation and as such is a vector with both amplitude and phase. Amplitude only measurements, even if taken in multiple optical planes, will be an incomplete description of the optical response. As such they will miss subtle phase errors and so not describe how a full instrument will operate in its final scientific operation configuration on sky. With the phase information the full E-field is described, allowing the beam to be numerically propagated in either direction to investigate the optics or optical coupling between components. This allows testing at sub-component level or in the near field of the full instrument, which can then be used to determine and understand the final deployed far field on sky performance. The power of this technique is widely recognised and as such the phase and amplitude measurements are now standard procedure in phase sensitive heterodyne instruments, such as used in ALMA. However, vector beam pattern measurements have only recently been shown to be possible with direct, power sensitive, detector arrays: the lack of an intrinsic phase response, high pixel count and low detector speed make it more difficult. Additionally, with large field of view cameras the optics become more complex so making this technique more relevant. Measurements are presented from a large field of view camera with an array of 880 lens-antenna coupled Kinetic Inductance Detectors. The vector beam patterns are measured using a dual optical source modulation scheme, using multiplexing electronics allowing around 400 pixels to be simultaneously characterized. Properties across the field of view are investigated, including defocus and Gaussian beam coupling, that would not otherwise be available from an amplitude only beam pattern. An added advantage of the technique is that standing waves off the source can be corrected for, important for single frequency. Finally, the dual source modulation scheme means the dynamic range for a given modulation depth is the square of that given by a single source amplitude only measurement. This has opened up much weaker features on the beam pattern for investigation, placing a limit on the residual in-detector-chip stray light.

category : Applications

PE-56 PICTURE-C: A Balloon-borne Optical MKID Camera

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We present PICTURE-C, a NASA-funded mission to fly optical MKIDs on a balloon to observe circumstellar debris disks of three nearby systems in scattered optical light in 2019. UC Santa Barbara is developing the 10,000 pixel MKID array, cryostat, and readout electronics. The PtSi MKIDs will be optimized for 600nm with a 20% bandpass, and will be read out with five feedlines by ten ROACH2 and custom ADC/DAC boards. The balloon will launch from Fort Sumner NM and fly for 24 hours, carrying the MKIDs for one night at an altitude of 40 km. The Wallops Arc-Second Pointing system on the gondola will support a 0.6 meter primary mirror and the MKID cryostat, as well as deformable mirrors for wavefront correction and a Vector Vortex Coronagraph to suppress the on-axis starlight.

category : Applications

PE-57 Development of Multi-temperature Calibrator for the TES Bolometer Camera: Deployment at ASTE

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Extensive large-scale sky survey in the millimeter/submillimeter bands with multi color continuum camera is indispensable for efficiently estimating the redshift of submillimeter galaxies, studying the internal structure of hot plasma in clusters of galaxies using the Sunyaev-Zel'dovich effect, and constraining physical properties of the dust in star-forming regions and the spectral index of the initial submillimeter afterglow of gamma ray bursts (GRBs). In order for these sensitive scientific observations, reduction of the measurement error induced by the calibration, such as the non-linearity correction and atmospheric extinction correction, plays an important role. Therefore, we developed and deployed a simple add-on multi temperature calibrator for our multicolor Transition Edge Sensor (TES) bolometer camera for the ASTE (Atacama Submillimeter Telescope Experiment) aimed for simultaneous observation at observing frequencies of 270 GHz and 350 GHz. To cover the power loading level from the atmospheric emission corresponding to precipitable water vapor (pwv) of 0.5 mm to 4 mm, the calibrator consists of spherical mirrors to show the low temperature stages of the cryostat and filters with moderate opacity to mimic the eight temperature cold blackbodies. The loading powers introduced by each filter were self-calibrated by measuring the load curves of the TES bolometers when a filter was placed in front of the cryostat window. Each science observation was preceded by the calibration process, which measures the response of the TES bolometers to the atmosphere and filters of various opacity. Then the responsivities of TES bolometers were derived to convert its output signal to the loading power and correct for the non-linearity inherent in its response. Furthermore, the loading power falling on the TES bolometers from atmospheric emission measured at various pwv were in good correlation with the pwv measured with the line of sight radiometer. Which enables the atmospheric extinction correction by fast and sensitive bolometers compared to the available radiometers with the modest sampling speed.

category : Applications

PE-58 Super DIOS: future X-ray spectroscopic mission to search for dark baryons

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We present an updated program of the future Japanese X-ray satellite mission DIOS (Diffuse Intergalactic Oxygen Surveyor), called as Super DIOS. The goal of the mission is to search for dark baryons in the form of warm-hot intergalactic medium (WHIM) with high-resolution X-ray spectroscopy. The mission will detect redshifted emission lines from OVII, OVIII and other ions, leading to an overall understanding of the physical nature and spatial distribution of dark baryons as a function of cosmological time scale. Original DIOS was planned as a small satellite mission which would be launched in early 2020's with Epsilon rocket of JAXA. Because of the new start of the program of XARM, we will re-design the DIOS mission and propose it to be launched around 2030 as a larger satellite.

We are starting conceptual design of the satellite and on-board instruments, which should give us original science in the era of 2030's. Major change will be an improved angular resolution of the X-ray telescope. Super DIOS will have 10 arcsecond resolution, which is an improvement by a factor of about 20 over DIOS. With this resolution, most of the contaminating X-ray sources will be separated and the level of diffuse X-ray background will be much reduced after subtraction of point sources. This will give us higher sensitivity to map out the WHIM in emission. We will keep the field of view to be 30 arcmin or larger, which is along the technical extension of the X-ray telescopes employed for XMM-Newton. Effective area will be around 1000 cm^2.

Harder technical challenge will be a new TES microcalorimeter with a pixel number of a few tens of thousands. Super DIOS will have about 10 times more pixels than Athena, and a new readout technique such as microwave mulplexing would be necessary for such an instrument. The mission will clearly map out the filamentary structure of the universe from redshift 0.3 to present. We are carrying out a simulation study to see how much Super DIOS can constrain the chemical and structural evolution of the universe, in collaboration with theory groups. Furthermore, to analyze a plenty of plasma spectra automatically, a plasma diagnosis method using data-driven feature extraction is being studied.

We will report the status of our study of Super DIOS, including conceptual design of the satellite with its basic parameters. We also mention possible international collaboration for this program.

category : Applications

PE-59 Design and optimization of multi-pixel transition-edge sensors for X-ray astronomy applications

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Multi-pixel transition-edge sensors (TESs), commonly referred to as ‘ hydras ’, are a type of position sensitive microcalorimeter that enables very large format arrays to be designed without commensurate increase in the number of readout channels and associated wiring. In the hydra design, a single TES is coupled to discrete absorbers via varied thermal links. The links act as low pass thermal filters that are tuned to give a different characteristic pulse shape for x-ray photons absorbed in each of the hydra sub pixels. The pre-equilibration signal, such as the pulse rise-time, is then used to determine in which pixel the photon was absorbed. The energy of the photon E is determined using a digital optimal filter, pre-calibrated for each absorber element.

We are developing hydras with up to 25-pixels per TES for proposed future x-ray astronomy applications such as ‘ Lynx ’, a large mission concept under study by NASA for the Astro-2020 Decadal Survey. The proposed Lynx concept for the ‘ Whiskers ’ instrument combines a sub-arcsecond x-ray optic with a micro-calorimeter spectrometer incorporating 100,000-pixel TES array, with spectral resolution better than 5 eV full-width-at-half-maximum (FWHM) in the energy band 0.2-10 keV.

In this contribution we report on the experimental results from hydras consisting of up to 20 pixels per TES. We discuss the design trade-offs between energy resolution, position discrimination and number of pixels and investigate future design optimizations specifically targeted at meeting the readout technology considered for Lynx. We have fabricated and tested hydras with 9 pixels per TES that have demonstrated ¡Δ EFWHM¿ of 2.23 ± 0.14 eV at 1.5 keV and 2.42 ± 0.29 eV at 6 keV. The 4.5 μ m Au absorbers are on a 65 μ m pitch and are connected to a 35 × 35 μ m TES via 480 nm thick Au strips of different lengths. We extended these designs to develop the first prototype 20-pixel hydras. These designs utilize a hierarchical structure using trunks and branches that make it easier to design and lay out, but require more complex position discrimination algorithms. We present results on the first design iteration consisting of 5 clusters of 4 absorbers, where each cluster was individu-ally coupled to the TES. The measured spectral resolution at 5.4 keV showed ¡Δ EFWHM¿ =3.39 ± 0.18 eV for all 20 pixels. For both of these hydra designs we explore different position discrimination algorithms for optimized position determination down to energies of a few 100 eV. Measurements are compared to simulations using a finite-element model that qualitatively reproduce the measured pulse shapes and is used to investigate the role of detector non-linearity with energy on the position sensitivity.

category : Applications

PE-60 Resolve instrument on X-ray Astronomy Recovery Mission (XARM)

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The X-ray Astronomy Recovery Mission (XARM) is a recovery mission of ASTRO-H/Hitomi, which is expected to be launched in Japanese Financial Year of 2020 at the earliest. The Resolve instrument on XARM consists of an array of 6×6 silicon-thermistor microcalorimeters cooled down to 50 mK and a high-throughput X-ray mirror assembly with focal length of 5.6 m. Hitomi was launched into orbit in February 2016, and observed several celestial objects including the Perseus cluster and the Crab pulsar, although the operation of Hitomi was terminated in April 2016 due to the break-up of spacecraft. Soft X-ray Spectrometer (SXS) on Hitomi demonstrated high resolution X-ray spectroscopy of ∼5 eV (FWHM) in orbit for most of pixels. The Resolve instrument is in principle a remake of Hitomi SXS and Soft X-ray Telescope, several design changes are planned based on the lessons learned of Hitomi. For example, the vibration isolation system for cryocoolers to have launch lock, and adding baffle for possible optical light leak by micrometeoroids and orbital debris, are investigated. In addition, the gate vale of liquid helium dewar was kept closed for Hitomi, one of the largest concern is change of detector performance after the gate valve open due to electro-magnetic interference or optical light leak. We report the developing status of the Resolve instrument and summarize possible design changes.

category : Applications

PE-61 Noise performance of SuperSpec: an on-chip, TiN KID based mm-wave spectrometer

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SuperSpec is a compact on-chip spectrometer for mm and sub-mm wave observations of high redshift dusty galaxies. With moderate resolution (R=100-500) and large bandwidth (1.8:1), this detector 's small size and highly multiplexed readout will enable the construction of powerful multi-beam spectrometers.

The detector employs a filter bank architecture, consisting of lithographically patterned niobium superconducting microstrip mm-wave resonators. The power admitted by each resonator is detected by a lumped element titanium nitride (TiN) kinetic inductance detector (KID) with resonant frequencies from 100-200 MHz.

We present the characterization of the KID noise performance. The low frequency noise intrinsic to the resonators will be critical to the design of future instruments in a range of applications. We present measurements of detector noise for prototype devices and compare to a multi-component model as a function of temperature and power.

category : Sensor Physics & Developments

PE-62 Characterization Tests of Thermal Filters for the ATHENA mission X-IFU Low Temperature Detector

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The X-Ray Integral Field Unit (X-IFU) is one of the two detectors of the ATHENA astrophysics space mission approved by ESA in the Cosmic Vision Science Program (launch scheduled in 2028). The X-IFU consists of a large array of TES micro-calorimeters that will operate at ∼50 mK inside a sophisticated cryostat. A set of thin filters, highly transparent to the X-rays focused by the telescope, will be mounted on the dewar and the focal plane assembly thermal/EMI/mechanical shields. These are designed to attenuate the IR radiative load avoiding energy resolution degradation due to photon shot noise, to attenuate EM interference onto the detector and the read-out electronics, and to protect the detector from contamination.

The adoption of ATHENA by ESA is expected at the beginning of 2020; by that time the thermal filter design has to be consolidated, and the Technology Readiness Level 5 must be demonstrated for the selected technology. Here, we present the current filter design based on aluminum/polyimide thin bilayer membranes supported by stainless steel meshes. We describe the filter samples developed/procured so far, and present preliminary results from the ongoing characterization tests.

Keywords: ATHENA mission, X-IFU, X-ray microcalorimeters, thermal filters.

category : Applications

PE-63 MetroBeta: Beta Spectrometry with Metallic Magnetic Calorimeters in the Framework of the European Program of Ionizing Radiation Metrology

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MetroBeta is a European project aiming at the improvement of the knowledge of the shapes of beta spectra, both in terms of theoretical calculation and measurement. It is part of a common European program of ionizing radiation metrology. In this context, metallic magnetic calorimeters (MMCs) are being developed for the precise measurement of the shapes of beta spectra. MMCs with the beta emitter embedded in the absorber have in the past proven to be among the best beta spectrometers, in particular for low energy beta transitions.

New MMC designs have been optimized for five different absorber heat capacities, enabling the measurement of beta spectra with Q values ranging from few tens of keV up to 1 MeV. In parallel, a new detector module has been designed. One of the improvements compared to the previously used setups is a thermal decoupling between the MMC and SQUID chips. This feature was added since the power dissipation in the shunt resistors of the SQUID often prevented the MMCs to be cooled below 20 mK.

Four spectra from pure beta emitters will be measured within the project: Sm-151 ($Q = 76.3$ keV), C-14 ($Q = 156.5$ keV), Tc-99 ($Q = 293.8$ keV) and Cl-36 ($Q = 709.5$ keV). Intense research and development work is devoted to the fabrication of high quality sources from each of the nuclides and their integration with the MMC absorbers. This is required because in the past it has been observed that the spectra measured with sources composed of a salt can be considerably distorted due to the loss of a fraction of the beta energy in the salt which is then not fully converted to heat. Both (electro-) chemical and physical processes are being studied that can help to avoid this problem. Another study concerns the composition of the absorbers. For low energy spectra, simple gold or silver absorbers can be used. However, spectra with Q values higher than 500 keV will be distorted by the escape of Bremsstrahlung from the absorber. Monte Carlo simulations were performed to study the influence of the absorber material and the usefulness of composite absorbers to minimize this source of spectrum distortion.

The status of the developments within the project and first measured spectra will be presented.

category : Applications

PE-64 Development of high energy resolution and high throughput SEM-EDS analyzer utilizing 100-pixel superconducting-tunnel-junction array toward nanometer scale elemental mapping

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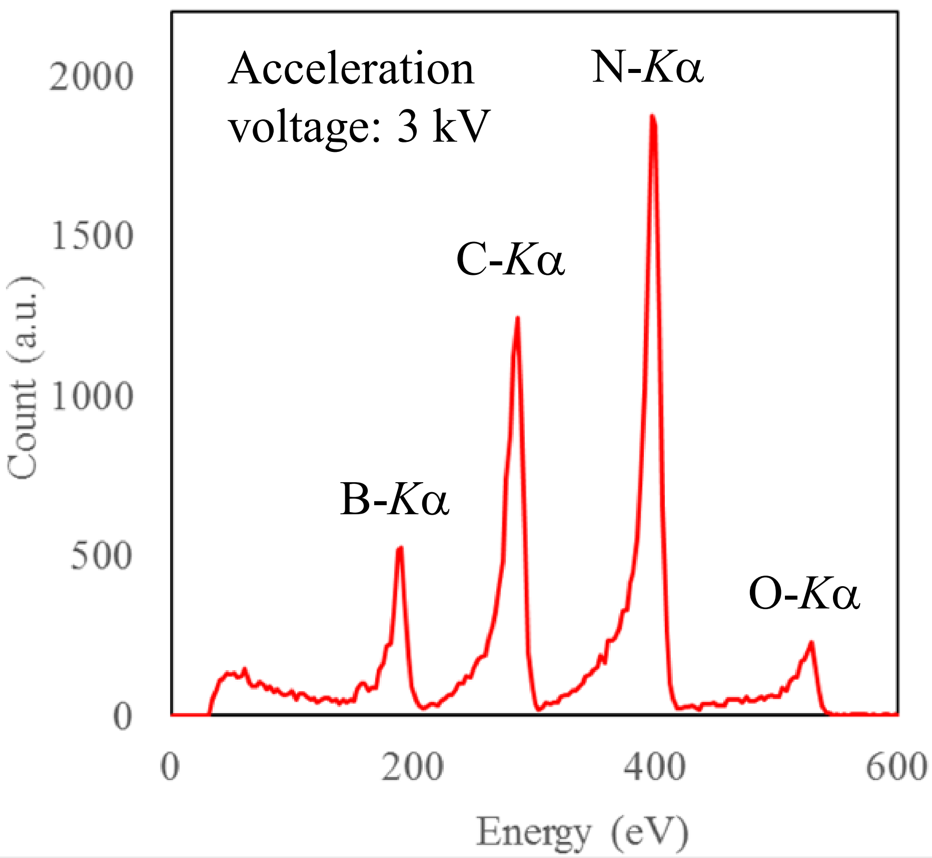
An energy-dispersive X-ray spectroscopy (EDS) analyzer combined with a scanning electron microscope (SEM) is suitable to obtain spatial and quantitative information on the elemental composition of a sample non-destructively. In order to achieve nanometer scale resolution of the elemental analysis, it is necessary to operate a SEM at lower accelerating voltage less than 1 keV, because electron ranges and interaction volumes in samples become significantly small (¡ several 10 nm) at accelerating voltage of 1 keV. However, in the above condition, the material analysis by using energy-dispersive X-ray detectors such as silicon drift detectors (SDDs) or Si(Li) detectors in the conventional EDS analyzers is quit difficult, because characteristic X-ray from samples are only soft X-ray less than 1 keV and the energy-resolving power of conventional energy-dispersive X-ray detectors is insufficient to clearly resolve such soft X-rays.

In contrast, energy-dispersive X-ray detectors based on array of superconducting-tunnel-junctions (STJs) have simultaneously exhibited excellent energy resolution, relatively large detection area, and high counting rate capability for soft X-rays less than 1 keV. Our X-ray detector using 100-pixel Nb/Al/AlOx/Al/Nb STJs with 100 μ m square has already exhibited a maximum energy resolution of about 4 eV for monochromatic 400 eV X-rays, large detection area of 1 mm^2, and a maximum counting rate of several 100 kcps, simultaneously. The STJ array was fabricated in the Clean Room for Analog & digital superconductiVITY (CRAVITY). We have been developing an EDS analyzer equipped 100-pixel Nb/Al STJ array soft X-ray detector to perform the elemental analysis with nanometer scale resolution.

In this work, as a first step we have developed a typically SEM with a tungsten filament utilizing the STJ array as an EDS system, which is abbreviate as SC-SEM hereafter, in order to demonstrate the throughput and the energy resolution of the STJ array in the EDS analyzer. To improve a collection efficiency of the characteristic X-rays, a polycapillary collimating X-ray lens was installed in the analyzer. An X-ray spectrum acquired by using the SC-SEM for pure BN is displayed in Fig. 1. Separate B-Kα (188 eV), C-Kα (277 eV), N-Kα (393 eV), and O-Kα (525 eV) peaks were clearly observed. Its counting rate performance for the N-Kα line was 9.4 cps/nA, which performance was almost the same as that of electron microprobe analyzer (EPMA), which use wavelength-dispersive X-ray spectrometers (WDS) as X-ray detectors. By replacing collimating X-ray lens for a focusing X-ray lens, the counting rate is expected to be increased more than 600 times. The counting rate of the improved SC-SEM is almost equal to that of conventional X-ray spectroscopy analyzers employing SSDs. The energy resolution of the SC-SEM was 10 eV for N-Kα. The energy resolution of the SC-SEM was 7 times higher than that of the SDD, and was almost equal to that of the WDS. These results indicate that the improved SC-SEM can realize both the high throughputs of SDDs and the high energy resolution of WDSs.

category : Applications


Acceleration voltage: 3 kV
N-Kα
C-Kα
B-Kα
O-Kα
2000
1500
1000
500
0
Count (a.u.)
0
200
400
600
Energy (eV)

PE-65 An X-ray TES detector head assembly for a STEM-EDS system and its performance

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?An energy-dispersive X-ray spectroscopy (EDS) on a scanning transmission electron microscope (STEM) is a useful tool for material analysis, biotechnology, and other researches.

Conventional semiconductor-based EDS system is sometimes insufficient to resolve emission lines at closely adjacent energies. ?Transition Edge Sensor (TES) X-ray microcalorimeter is a promising solution to overcome this problem. ?However, the low maximum counting rate of this type of detector is a significant limitation when we adopt TES-based EDS for material analysis. ?We thus set the requirement of a maximum counting rate at 5 kcps for our STEM-EDS. ?We also set an energy resolution of FWHM < 10 eV, and an energy band of 0.5 - 15 keV as requirements.

In order to satisfy the counting rate requirement, we adopted an 8×8 format 64 pixel TES array (Muramatsu et al., 2016). We read the signals from 64-pixel using parallel 64 signal chains with SQUID array amplifier (SAA). We decided to mount both the TES microcalorimeter array and 64 SAAs on the detector head at the 100 mK cryogenic state.

?In this paper, we present the design, integration, and performance of the detector head assembly. ?The size and shape of the detector head is strongly constrained by the geometry of STEM and the 100 mK refrigerator. We adopted a shape consisting of a rod of 12 mm ?$\times$ 12 mm $\times$ 10 cm and a 3 cm cube connected at the bottom rod. ?The detector-head body of the mentioned shape was machined from a copper block. The 64-pixel TES array is mounted on the top of rod, while the SAAs are mounted on four surfaces of the cubic part. ?Connectors to room-temperature electronics are also mounted on the cube surface. ?SAAs and connectors are first mounted on a superconducting sapphire circuit board and then mounted on detector-head body. Both the SAA chips and the connectors are connected to the circuit board using superconducting flip-chip-bonding technology. ?The TES and circuit boards are connected with superconducting electrodes assembled on the surface of the rod and cube (Sakai et al. 2012). ?We experienced some problems in flip-chip bonding and the yield rate was 99.3 % at 50 mK. ?Installing the detector head on the STEM-EDS, we confirmed the energy resolution of about 9 eV at Au Lα at a counting rate of 150 cps/pixel. In the paper we will show more details of performance tests.

category : Applications

PE-66 Superconducting microcalorimeters absolutely calibrated?for x-ray spectroscopy

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Databases of fundamental parameters for x-ray analysis include fluorescence line energies and relative intensities, as well as line shape information including line widths and asymmetries. Although these parameters are often considered well-established, this is not uniformly true. The fluorescence line energies of some elements come from measurements made 40 to 60 years ago. Data on the lower-energy lines, such as the M lines of the heavier elements, are incomplete. Measurements of fundamental parameters can be time consuming and challenging to calibrate reliably. The US National Institute of Standards and Technology (NIST) is exploring a new program to improve the situation.

At the heart of this new?program are arrays of superconducting microcalorimeters, Transition-Edge Sensors (TESs). A TES is an energy-resolving detector, which operates at its?superconducting transition temperature. Energy resolutions of 1 eV at 1500 eV and 2 eV at 5900 eV have been demonstrated, and arrays of hundreds of TESs currently operate with 3 to 4 eV resolution at 5900 eV. Unlike a wavelength-dispersive spectrometer, the TES can cover a very broad energy range all at once. This ability offers the potential for rapid characterization of multiple emission lines.

We present results from metrological-quality data taken with an array of 100 TESs to study the positions and shapes of the L-line emission from the lanthanide elements neodymium, samarium, terbium,?and holmium. Employing the well-characterized K lines of some 3d?transition metals as our calibration reference standards, we find that the TESs can be calibrated to absolute accuracy of approximately 0.2 eV for use in the estimation of unknown line energies, a level of accuracy already better in some cases than existing published uncertainties. We also discuss the general problem of absolute calibration of TESs, which is relevant to tabletop, synchrotron, and astronomical uses of these devices.

category : Applications

PE-67 TES X-Ray Spectrometer for LCLS-II

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SLAC National Accelerator Laboratory, as part of the U.S. Department of Energy Office of Science, is scheduled to complete upgrades to its Linac Coherent Light Source (LCLS) in 2020. The new LCLS (called LCLS-II) will be the world 's highest average brightness soft x-ray source (10,000 times brighter than LCLS): a free electron laser (FEL) capable of up to one million pulses of x-ray photons per second. With such high x-ray intensities and precise timing resolution, LCLS-II will open the door to new studies of the ultra-fast and the ultra-small. One of the four first-light detectors for LCLS-II will be a fast soft x-ray (250-1000 eV) superconducting transition-edge sensor (TES) spectrometer for LCLS-II designed for x-ray repetition rates of 10 kHz to 100 kHz. This spectrometer will provide an unprecedented combination of spectral resolution and efficiency to the FEL community. The initial array will have 256 pixels, with upgrades planned to 2,000 and 10,000 pixels (and upgrade paths toward megapixels), an initial solid angle of 6 milli-steradians towards nearly 2 pi steradians, energy resolution of 1 eV with an upgrade planned to 0.5 eV, and a photon efficiency of up to 90% for Cu L. These TES arrays will be multiplexed using microwave SQUIDs. We present an overview of this instrument.

category : Applications

PE-68 Recent advances in broadband, ultrahigh resolution spectroscopy of particle induced x-rays using TES microcalorimeter arrays

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We discuss the latest developments in wide energy range, energy dispersive X-ray emission spectroscopy in the particle induced mode (PIXE) using high-energy resolution superconducting transition-edge sensor arrays. This technique offers great promise in elemental analysis of many types of samples, especially in the difficult cases where tens to hundreds of different elements with nearly overlapping emission lines have to be identified down to trace concentrations [1]. Spectroscopy of several complex multi-element samples in the energy range 1 - 10 keV is presented. Some of the samples have trace amount of impurities not detectable with standard silicon drift detectors (SDD). The ability to distinguish the chemical environment of an element was also demonstrated by measuring the intensity differences and chemical shifts of the characteristics X-ray peaks of titanium compounds. We also assess the detection limits of the new technique and demonstrate a case study of fly ash with overlapping Ti, V, Ba, and Ce peaks, where minimum detection limits of V, Ba, and Ce were decreased by factor of 620, 400, and 680, respectively, compared to the SDD detector [2]. Possible applications for TES-PIXE are also discussed.

[1] M. R. J. Palosaari, M. Kayhko, K. M. Kinnunen, M. Laitinen, J. Julin, J. Malm, T. Sajavaara, W. B. Doriese, J. Fowler, C. Reintsema, D. Swetz, D. Schmidt, J. N. Ullom, and I. J. Maasilta, Phys. Rev. Applied 6, 024002 (2016).

[2] M. Kayhko, M.R.J. Palosaari, M. Laitinen, K. Arstila, I.J. Maasilta, J.W. Fowler, W.B. Doriese, J.N. Ullom, T. Sajavaara, Nucl. Instrum. Methods Phys. Res. B, in press (2017).

category : Applications

PE-69 Microcalorimeters for Nuclear Material Analysis

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The capabilities of low-temperature microcalorimeters are enabling new possibilities in nuclear material analysis. We present our recent work to develop superconducting transition-edge sensor microcalorimeters and analytical techniques for decay energy, x-ray, and gamma-ray spectroscopy of nuclear materials. Decay energy spectroscopy, in which a radioactive sample is embedded within a microcalorimeter absorber, is an emerging technique for determining the isotopic composition of trace-level samples. For each alpha-decaying nuclide, a single peak at its unique total nuclear decay energy (Q value) is measured. For beta-decaying nuclides, where the neutrino or antineutrino will escape the absorber, a continuous spectrum ending at the Q value is measured. We are developing sensors and methods to enable decay energy spectroscopy of a broad range of samples from pure certified reference materials to nuclear detonation debris. We have demonstrated that microcalorimeter x-ray emission spectroscopy has the resolution to measure subtle effects of chemical bonding and nondestructively determine chemical speciation in nuclear materials, and are now evaluating potential applications. Measurements over the past several years with a time-division multiplexed 256-pixel microcalorimeter gamma ray spectrometer have demonstrated the advantages of improved energy resolution over high-purity germanium detectors. The order-of-magnitude improvement in energy resolution enables more precise and accurate nondestructive measurement of plutonium isotopic composition, an important goal for nuclear safeguards. High-bandwidth microwave frequency-division multiplexing will soon enable high-throughput microcalorimeter gamma spectrometers suitable for deployment in operational nuclear facilities. We discuss the latest developments in these three analytical techniques, and present recent results.

category : Applications

PE-70 Application of Calorimetric Low-Temperature Detectors for the Investigation of Nuclear Charge Distributions of Fission Fragments

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Calorimetric Low-Temperature Detectors (CLTDs) for heavy-ion detection have demonstrated to achieve an excellent relative FWHM 1-5 × 10-3 and negligible pulse height defect in a wide range of ions and energies from 20 to 700 MeV. After successful application in accelerator mass spectrometry and stopping power measurements [1,2], these detectors were recently applied for the investigation of nuclear charge distributions of fission fragments produced by thermal neutron induced fission, as precise fission fragment yield data are of great interest for better understanding of the fission process and in applied fields.

The experiment was performed at the high neutron flux reactor ILL, Grenoble at the LOHENGRIN mass spectrometer which filters fission fragments with respect to a specific mass, kinetic energy and ionic charge but not to the nuclear charge. For the nuclear charge separation, we exploit the nuclear charge dependent energy loss of fission fragments passing through a degrader foil. With the CLTDs, we measure residual energies of the fragments after spectrometer separation and passage through a stack of SiN foils as a novel type of degrader material. Compared to the conventional ionization-mediated detectors, the concept of CLTDs provides better or comparable energy resolution but no pulse-height defect, both being very important for such measurements. The present CLTD array with an active area of 15x15mm2 consists of 25 independent detector pixels made of sapphire crystals with aluminum transition-edge-sensors (TES) operated at 1.5K. The windowless 4He bath cryostat containing the CLTD array was coupled to the LOHENGRIN. Variation of absorber thickness was achieved by a remotely controlled sample changer operated inside the cryostat, close to the CLTD array.

Using three fissile targets of 235U, 239Pu and 241Pu, the quality of nuclear-charge separation was studied for selected masses in the region 82 ? A ? 139 as a function of degrader thickness and fission-fragment kinetic energies. For the light fragment group, the Z resolution attained matches historically best values achieved with Parylene-C absorbers and ionization chambers, while for mass symmetry and heavy mass region substantial improvement was observed with the new set-up. We have gained first LOHENGRIN data on the isotopic yields in the light-mass group, 89 ? A ? 109 for 241Pu fission. Towards mass symmetry, known Z-yield data were supplemented in the range A = 110 to 112 for 241Pu, and A = 111 to 113 for 239Pu. Extended data sets were cumulated for the masses A = 92 and 96 for 235U (and 241Pu) due to special interests in the precise yields of these isotopes for studies on the reactor anti-neutrino spectrum [3]. Furthermore, an attempt was made to extend isotopic yield measurements to the heavy-mass region, 128 ? A ? 139 to study odd-even staggering, which was hardly accessible until now. Preliminary data will be presented for the various parts of the investigations.

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[2] A. Echler et al., J. Low Temp. Phys. 176, 1033 (2014)

[3] A. A. Sonzogni et al., Phys. Rev. C 91, 011301(R) (2015)

category : Applications

PE-71 Development of total decay energy spectrometry of alpha emitters using Metallic Magnetic Calorimeters

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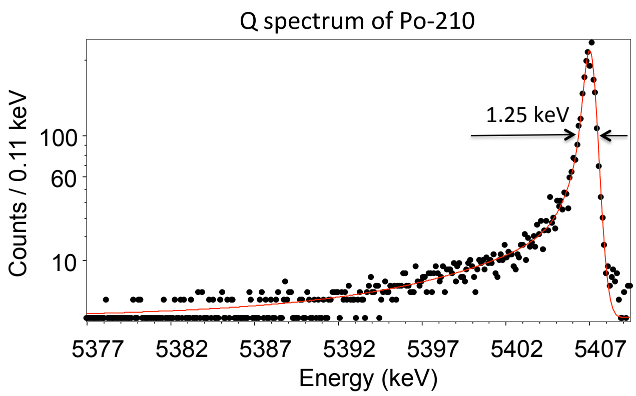
Total decay energy spectrometry (Q spectrometry) with cryogenic detectors is a promising technique for radionuclide analysis of alpha emitters. It consists of embedding the radioactive sample in the detector absorber and measuring all of the energy from the emitted particles, and the nuclear recoil. Compared with alpha spectrometry, it has the advantage of simpler energy spectra, since each radionuclide produces a single peak at its Q-value energy, and the Q-values for different radionuclides tend to differ by more than a few tens of keV from each other, making them readily identifiable. Moreover, Q spectrometry is independent of the emission probabilities of the emitted particles.

We are developing Metallic Magnetic Calorimeters (MMCs) for Q spectrometry, and applying this technique to the largest number of radionuclides, noting that some are not compatible with this technique due to high-energy gamma-rays (which would require large absorbers) or due to extremely short or long half-lives. However, MMCs can use large and thick gold absorbers to provide significant detection efficiency for gamma-rays below 100 keV. Based on Monte Carlo simulations of the absorber detection efficiency and based on numerical calculations of the expected energy resolution, a feasibility study has identified the radionuclides compatible with a low photon escape probability and an FWHM energy resolution of 1 keV using MMCs.

Furthermore, the first MMCs have been optimized and tested. The thermal coupling between the absorber and the sensor was adjusted in order to obtain a rise time and a pulse height that respect the slew rate of the SQUID electronics. Large pulse heights of 18 Φ 0 were successfully measured. The total decay energy spectrum of a Po-210 source spontaneously deposited on silver and embedded in a silver absorber has been measured. The spectrum shows a FWHM energy resolution of 1.25 keV at 5.4 MeV with a Gaussian broadening at the half maximum of 0.9 keV. The baseline FWHM energy resolution is 0.2 keV, consistent with the resolution obtained on low energy L X-rays in the spectrum at 14 keV. Details of this development and the results of the measurements with MMCs will be presented.



category : Applications

PE-72 Spectroscopic Measurement of X-rays and γ-rays Emitted by Neptunium Sample Irradiated in the Experimental Fast Reactor Joyo using a TES microcalorimeter

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Nuclide analysis methods are roughly divided into two categories: non-destructive inspection using direct measurements of γ-rays or neutrons emitted by samples, and destructive inspection using chemical analysis technique. The destructive inspection is more accurate but less rapidity due to its complicated procedure compared to the non-destructive inspection. In other words, the non-destructive inspection applying γ-ray spectroscopy achieve rapid analysis. However, it is difficult to γ-ray spectroscopy using conventional radiation detectors with insufficient energy resolution such as scintillation detectors or high-purity Germanium detectors makes it difficult to identify nuclides since the energies of photons emitted by transuranium elements such as Plutonium and Americium are close to each other. In order to maintain an effective nuclear safeguards, establishment of non-destructive inspection of the nuclide elements like the spent fuel with high efficiency and more accuracy is necessary. These demands lead us to the precision gamma-ray spectroscopy using superconducting transition edge sensor (TES) with ultra-high energy resolution.

To demonstrate the precision measurement of nuclear material sample using a TES microcalorimeter, spectroscopic measurements of X-rays and γ-rays emitted by neptunium (Np) samples were performed. We measured two types of Np samples: ^{237}Np irradiated by neutron in the experimental fast reactor Joyo and a non-iradiated ^{237}Np. The obtained results are shown in fig.1 (see the attachment). In the energy spectrum obtained from the measurement of non-irradiated Np sample, several energy peaks of γ-rays and characteristic X-rays emitted by the elements of ^{237}Np and ^{233}Pa daughter of ^{237}Np are observed. On the other hand, energy peaks of γ-rays and characteristic X-rays emitted by the elements of ^{238}Pu and ^{137}Cs are observed as well as energy peaks derived from ^{237}Np in the energy spectrum obtained from the measurement of irradiated Np sample. ^{238}Pu is created from the ^{237}Np(n, $gamma$)^{238}Np $\rightarrow$ ^{238}Pu + β reaction. ^{137}Cs is one of long-lived fission product created by nuclear fission.

From these results, we consider that γ-ray spectrometer using a TES microcalorimeter can be applied to the advanced non-destructed inspection of the nuclide material.

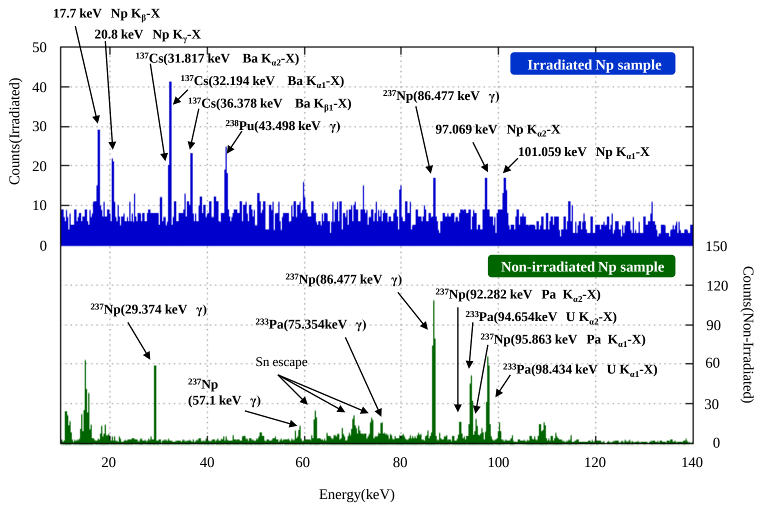

Fig.1 Energy spectrum of X-rays and γ-rays emitted by an irradiated Np sample (upper) and a non-irradiated Np sample (lower).

category : Applications

PE-73 Application of photon number resolving transition edge sensors for the metrology of quantum dot based light sources

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Light emitting devices based on semiconductor quantum dots (QD) are considered as promising candidates for future photonic technologies. They will pave the way for applications in the fields of quantum information, quantum computation and quantum metrology. Photon number resolving (PNR) detectors are very attractive optical characterization tools for such quantum devices as they provide direct access to the photon number distribution and the photon statistics, which allows one to gain detailed knowledge about the quantum optical properties of QD-based quantum light sources.

In this work, we report on setting up and calibrating of a detection system based on fiber-coupled Tungsten transition-edge sensors (W-TESs) [1]. The stand-alone system comprises two W-TESs read out by two 2-stage-SQUID current sensors, which are operated in a compact detector unit integrated in an adiabatic demagnetization refrigerator with a base temperature of 100 mK. Fast low-noise analog amplifiers and digitizers are used for signal acquisition. The detection efficiency of the single-mode fiber-coupled detector system in the relevant wavelength Range (850 -950 nm) is determined to be larger than 81%. As a first application in QD-metrology, we employ this detector to evaluate the performance of different types of QD-based light sources. For instance, we determine the photon number distribution of single-QD sources emitting triggered single-photon and twin-photon states [2].

This first application of photon number resolving detectors in the field of QD-based quantum metrology opens up new routes towards applications of quantum light sources in quantum information, quantum-enhanced sensing and quantum metrology.

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[2] Heindel, T. et al. A bright triggered twin-photon source in the solid state. Nat. Commun. 8, 14870 doi: 10.1038/ncomms14870 (2017)

category : Applications

PE-74 Total efficiency calibration of a metallic magnetic calorimeter detector for photon spectrometry below 100 keV.

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L X-ray and gamma emission intensities are fundamental parameters for the quantitative assay of radioactive material by photon spectrometry. However, they are not very well known or even unknown for many actinides below 100 keV. Due to the numerous L X-ray emissions within a narrow energy range, their separation is not possible using HPGe detectors. To complete the knowledge of photon emissions of actinides and improve their quantification, an ultra-high resolution spectrometer is needed. Therefore CEA-LNHB developed a Metallic Magnetic Calorimeter (MMC) spectrometer with 4 pixels employing silver-gold bilayer absorbers to obtain a constant efficiency below 25 keV and an energy resolution about 30 eV.

Absolute determination of L X-ray emission intensities necessitates a good knowledge and accurate calibration of detection efficiency. To cover the energy range below 100 keV, measurements of many standard sources are needed. However, cooling down the detector with the source for each radionuclide would be time consuming and expensive. So, we have combined Monte Carlo simulations of the efficiency curve with sampling efficiency at various energies by measuring only one standard source. In this work we will show and discuss about the total efficiency calibration of the MMC by combining Monte-Carlo simulation (using PENELOPE 2014) with the measurement of a reference source of Am-241, one of the best-known radionuclides for photons of low energies. In addition an algorithm based on the extended dead time has been created to determine the live time required for total efficiency calibration. We have successfully measured the total efficiency, through the intensities of L-X-ray groups and gamma emission below 100 keV (Np L α L β L γ L η & L ι and gamma emission at 26, 33, 43, and 59 keV).

The accuracy of the Monte Carlo simulations strongly depends on the uncertainties of the simulated geometry. Dimensional measurements are not precise enough to ensure precise simulations. Therefore the geometry in the MC simulations (thickness and position of the individual absorbers with respect to the collimator, source position) was established in an iterative way, adapting the results of the initial simulation to the measured intensities of the reference source. This corrected geometry will be used in future, for measurements of emission intensities for different source dimensions and source-detector distances simply by applying efficiency correction by Monte Carlo simulations.

category : Applications

PE-75 Calibration of Ge and Si Ionization Yield using Phonon Detectors with Luke-Neganov Amplification

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The SuperCDMS collaboration is currently planning to do a calibration of the ionization yield and nuclear recoil energy scale of Ge and Si crystals to 100 eVnr. These measurements will be performed using cryogenic phonon detectors biased at 100V using Luke-Neganov amplification. Two phases of calibration are planned. First, a small-scale detector (1 cm x 1 cm x 1 mm) will be calibrated at the Triangle Universities Nuclear Laboratory (TUNL) using a monoenergetic neutron beam of 40 keV. In a second phase, a full-scale SuperCDMS SNOLAB HV prototype detector will be calibrated using a 2.5 MeV DD (deuterium-deuterium) neutron generator and a custom-built backing detector array at the Northwestern EXperimental Underground Site at Fermilab (NEXUS@FNAL). In this poster we discuss the simulation and optimization of the calibration campaign, and give an update on the testing of the small-scale detectors in preparation for the TUNL campaign.

category : Applications

PE-76 A high-resolution x-ray spectrometer for a kaon mass measurement

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The ASPE!CT consortium (Adaptable Spectrometer Enabled by Cryogenic Technology) is currently constructing a generalised cryogenic platform for cryogenic detector work which will be able to accommodate a wide range of sensors. The cryogenics system is based on a small mechanical cooler with a further adiabatic demagnetisation stage and will work with cryogenic detectors at sub-Kelvin temperatures. The commercial aim of the consortium is to produce a compact, user-friendly device with an emphasis on reliability and portability which can easily be transported for specialised on-site work, such as beam-lines or telescope facilities. The cryogenic detector platform will accommodate a specially developed cryogenic sensor, either a metallic magnetic calorimeter or a magnetic penetration-depth thermometer. The detectors will be designed to work in various temperatures regions with an emphasis on optimising the various detector resolutions for specific temperatures. One resolution target is of about 10 eV at the energies range typically created in kaonic atoms experiments (soft x-ray energies). A following step will see the introduction of continuous, high-power, sub-Kelvin cooling which will bring the cryogenic basis for a high resolution spectrometer system to the market. The scientific goal of the project will produce an experimental set-up optimised for kaon-mass measurements performing high-resolution x-ray spectroscopy on a beam line provided foreseeably by the J-PARC (Tokai, Japan) or DA Φ NE (Frascati, Italy)

category : Applications

PE-77 Development of hard X-ray TES microcalorimeters using microwave multiplexing for synchrotron science

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Transition edge sensor (TES) spectrometers offer great potential for applications in hard X-ray science including chemically sensitive X-ray microscopy at scanning nanoprobes, dilute sample XAFS, energy-dispersive diffraction, and Compton scattering. The Advanced Photon Source at Argonne National Laboratory is the premier hard X-ray facility in the US and is embarking on a major facility upgrade (APS-U). As part of the upgrade, nine new beamlines will be constructed. Three of these nine flagship beamlines would greatly benefit from hard X-ray TES spectrometers (i.e., In-situ Nanoprobe, Ptychoprobe, Polarization Modulation Spectroscopy). To meet the needs of the APS-U, there are two critical development needs for hard X-ray TESs: 1.) improvements in thick absorber performance and 2.) improvements in count rate throughput. We describe results of a small-scale TES array with absorbers made of gold and gold with electroplated or evaporated bismuth to study the influence of film properties on the low energy tails in energy spectra. Finally, we present results on the use of a new readout technology for TESs, developed at NIST, based on the use of superconducting microwave resonators in combination with SQUID amplifiers. In particular, we describe results of its performance when used to read out hard X-ray TESs.

category : Applications

PE-78 Low-Energy X-ray Spectroscopy down to 50 eV using a TES microcalorimeter

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An energy dispersive spectroscopy (EDS) combined with electron microscope is widely used to analyze the elements contained in a sample because an EDS can detect X-rays in a wide energy range of typically 0.15 to 20 keV with a single detector. However the energy resolution of conventional silicon based detector is limited to 100 to 200 eV FWHM. A TES (Transition edge sensor) microcalorimeter is a new type of EDS with a high energy resolution (¡ 10 eV). The TES enables detecting small peaks generated by minor elements which are buried underneath tails of large peaks of major elements for Si detectors. The peak separation ability is important especially when we analyze elements using X-ray peaks under 1 keV because the K lines of light elements and L lines of transition metal and M lines of heavy metals are closely packed. However, ability to detect such low energy lines are often limited with the entrance window and optical blocking filters of the cryogenic system, even though the noise level of the detector is much below the X-ray energy.

In this paper, we report the results of the X-ray detection experiments for lines blow 1 keV with our TES system. The energy resolution of our TES is 7 eV for Al-K line. We used the metal samples (Mg, Al, Si) excited by electron bombardment to create low energy lines.

We detected not only K and L emission lines of those elements but also bound-free emission which is caused by valence band to L shell transitions of electrons.　The upper cut-off energies of the emission appear at 49.6eV、69.1eV、93.8 eV, respectively for Mg, Al, Si.

We will discuss the consistency between the L to K line intensity ratios of the three elements and the X-ray transmission of the entrance window and blocking filters.

category : Applications

PE-79 Using a TES microcalorimeter spectrometer as a novel probe of heterogeneous quantum materials

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Despite more than 30 years of intense research, the physical mechanism that causes high-temperature superconductivity remains a mystery. ?One intriguing property of high-temperature superconductors that may be a source of insight into the pairing mechanism is the presence of spatial variations in the charge density. Progress understanding these variations has been limited, in part, by a lack of instrumentation that can readily observe these variations. X-rays that undergo resonant scattering from the correlated electrons can be used to observe charge density variations, but work to date has struggled to detect the small scattered x-ray signal above a large incoherent x-ray background from fluorescence. ?Recently, the NIST Quantum Sensors Group has pioneered a new x-ray spectrometer based on arrays of superconducting TES microcalorimeters that have the sensitivity to separate the scattered signal from the background of fluoresced photons. ?

The QSG, working with researchers at the University of Illinois - Urbana Champaign and Argonne National Laboratory, have installed a TES spectrometer at the Advanced Photon Source beamline 29. The instrument achieves energy resolution as good as 1. 0 eV below 1 keV. Here, we present the first resonant scattering measurements with this instrument from a cooled high-temperature superconducting crystal of La2-xBaxCuO4 (x=0.125). We demonstrate the detection of the charge density wave (CDW) that arises from the correlated electrons as a function of beam energy and sample angle. Using the exquisite resolution of the TES detector, we are able to separate the CDW signal from the fluorescent background. We also present a measurement of the d-d excitation that resides 2 eV below the (002) Bragg scattering peak. Finally, we will compare the capability of TES spectrometers to multi-channel plate area detectors and grating spectrometers and show that the TES provides roughly 2 orders of magnitude increase in sensitivity. The increased sensitivity of the TES spectrometer will allow researchers to probe broad classes of correlated electronic material systems for the first time.

category : Applications

PE-80 TES x-ray detectors for high efficiency spectroscopy of hemoglobin and other proteins

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Many fundamental questions about metal-centered proteins, including hemoglobin and photosystem-II, can in principle be addressed with X-ray spectroscopy, but they remain unsolved because of the low efficiency of presently available x-ray spectrometers. TES x-ray spectrometer arrays offer a unique combination of large active area and good energy resolution, enabling a powerful new probe of these bioinorganic complexes. We present preliminary results from a 240-pixel Transition-Edge-Sensor (TES) array that we have deployed at the Stanford Synchrotron Radiation Lightsource (SSRL). For the first time, this spectrometer makes it possible to apply x-ray spectroscopy techniques, including partial fluorescence yield x-ray absorption spectroscopy (PFY-XAS) and resonant inelastic x-ray scattering (RIXS), to the transition metal L edges in dilute proteins. In this poster, we demonstrate our ability to measure ultra-dilute samples and present preliminary data on hemoglobin that have direct relevance to a long-standing debate about the nature of the iron-oxygen bond.

category : Applications

PE-81 Development of Polycapillary Optics for STEM?TES?EDS

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Scanning transmission electron microscope (STEM) allows direct observation of the nanoscale structure with a high spatial resolution. An energy dispersive spectrometer (EDS) performed on a STEM plays an important role in a wide range of science. A Si (Li) semiconductor detector (SSD) is used for detecting X-rays in a typical energy dispersive spectroscopy (EDS). An insufficient energy resolution of SSD results in peak overlaps of closely adjacent peaks and hinders high accuracy analysis. A superconducting transition edge sensor (TES) microcalorimeter system has been developed for improving the energy resolution of an EDS performed on STEM. The objective lens of the STEM generates a strong magnetic field in the specimen chamber, which makes it difficult to operate the TES microcalorimeter without degrading the energy resolution. Therefore, the TES microcalorimeter has been placed outside the STEM column. To increase the effective detection solid angle, we employed polycapillary optics. The X-ray transmission characteristics of the polycapillary optics such as a focal spot size and an intensity gain depend on geometrical arrangements of the optics and the X-ray energy. The counting rate of the single-pixel TES microcalorimeter was 300 cps when using the polycapillary optics. However, a counting rate of 300 cps is insufficient for practical STEM operation. To achieve the counting rate larger than 5000 cps, we are now conducting development of a 64-pixel array TES microcalorimeter.

In this work, the X-ray transmission characteristics of the polycapillary optics were evaluated by analyzing results of energy spectrum measurements of X-rays transmitted by the polycapillary optics installed in the STEM. Then we made a simulation model that reproduces experimental results. Polycapillary optics for a 64-pixel array TES microcalorimeter was designed with using the simulation model for evaluating X-ray transmission characteristics. We performed energy spectrum measurements of X-rays transmitted by the fabricated polycapillary optics for a 64-pixel array TES microcalorimeter.

category : Applications

PE-82 Development of MMC gamma detectors for precise measurements of uranium isotopes

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Precise gamma-ray energies and branching ratios from nuclear decays are important for non-destructive assay in nuclear safeguards. We are developing high energy resolution gamma detectors using metallic magnetic calorimeters (MMCs) to measure and improve nuclear decay properties of uranium isotopes. We have shown that our MMC gamma detectors have good linearity and reproducibility, which makes them suitable for safeguards applications. We discuss the performance of MMC gamma detectors, and present initial measurements from a mixed-isotope uranium source.

category : Applications

PE-83 Compact measurement system to study scintillation and phononic properties of scintillating crystals at low temperatures

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A metallic magnetic calorimeter (MMC) is one of the most sensitive detector technologies used in low temperature detectors (LTDs). On the other hand, the study on absorber crystals is another important subject in the application of LTDs to rare event search experiments such as neutrinoless double beta decay searches. We developed a compact heat and light detection system to investigate various crystals using MMC sensors. The heat measurement channel is designed for a cubic crystal in a standard dimension of 1 x 1 x 1 cm3. A Ge wafer in 15 x 15 x 0.5 mm3 is used for the absorber of the light detection. We will report recent results with the compact measurement system for scintillating crystals of CaMoO4 and Na2Mo2O7.

category : Applications

PE-84 Transition-edge-sensor microcalorimeters for mass spectrometric identification of neutral molecules

Shinji Okada[1], Toshiyuki Azuma[2], Douglas Alan Bennett[3], William Bertrand Doriese[4], Joseph W. Fowler[5], Tadashi Hashimoto[6], Ryota Hayakawa[7], James Hays-Wehle[8], Gene Hilton[9], Yuto Ichinohe[10], Yoshitaka Ishisaki[11], Susumu Kuma[12], Toshio Nakano[13], Yuji Nakano[14], Hirofumi Noda[15], Galen C. O'Neil[16], Carl D. Reintsema[17], Daniel R. Schmidt[18], Daniel S. Swetz[19], Hideyuki Tatsuno[20], Shutaro Ueda[21], Joel N. Ullom[22], Shinya Yamada[23]

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To explore the quantum collision dynamics of the stored molecular ions by the merging experiments with a beam of the neutral atoms, we are developing a new technique of mass spectroscopy for the neutral molecular fragments from the collisions using an array of superconducting transition-edge-sensor (TES) microcalorimeters at a brand-new cryogenic electrostatic ion storage ring in RIKEN (Wako, Japan).

In the cosmic space, more than 100 kinds of various molecules exist despite low temperature and low density which is disadvantageous environment to the molecule formations. It remains still unknown how to be generated even for the simple molecules. We have recently developed a cryogenic low-temperature ion storage ring to reproduce such chemical reactions at a temperature of outer space. A molecular ion beam with a vibration-rotation energy (temperature) of 4 Kelvin is stored in this storage ring; and we conduct experiments by an interflow collision with neutral molecular beam having the same direction and velocity as the stored ion beam, where low-energy collisions at the center-of-mass system are realized.

It is important to identify the products by measuring those molecule masses after the collision to study the reaction mechanism. In the case of neutral fragments, however, it is difficult to apply the ordinary mass spectrometry without ionization for the neutral fragments. In our storage ring, the neutral products after the collision have almost the same velocity as initial ions / neutral molecules; thus mass identification can be realized by a measurement of the translational energy. However, the energy resolution of Micro Channel Plate (MCP) detector commonly utilized so far is not enough to identify the mass of molecular fragments.

We aim a direct detection of neutral molecules and molecular fragments (less than 15 keV) generated after the chemical reactions reproduced using an array of TES microcalorimeters developed by NIST. By a measurement of the kinetic energy, we perform the mass spectrometric identification of those neutral fragments and aim comprehensive understanding of the chemical reactions from the initial to final stages.

TES is operated at the superconducting critical temperature of less than 100 mK; thus we usually install radiation shields in front of the TES sensors to avoid infrared background from heat radiation which deteriorates the energy resolution. Unlike x-rays, the low energy molecules (10 keV) easily stop at the radiation shields even for 100-nm-thick aluminum sheet; thus we need to remove the radiation shield window. One of key issue towards this TES application is how to operate TES system against the radiation background although our storage ring is at 4 K. We just started the study at RIKEN from this spring.

In this presentation we will give an overview of this project and the recent progress.

category : Applications

PE-85 New frontier in TES application: X-ray spectroscopy of hadronic-atoms at Japan Proton Accelerator Research Complex (J-PARC)

Ryota Hayakawa[1], HEATES collaboration[2]

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We are opening up new frontiers in TES application: X-ray spectroscopy of kaonic-helium atoms at Japan Proton Accelerator Research Complex (J-PARC). We will deduce 2p shifts and 2p width in kaonic helium-3 and helium-4, by measuring 6 keV X-rays from those transitions from 3d to 2p. Our ultimate goal is to clarify the role of the strange quark and its composites in the equation of state of a neutron star.

This project is not only the first attempt to apply TESs to a hadron-beam experiment but also improving the technical readiness levels (TRL) of TESs for future satellite missions equipped with TESs such as ATHENA and (super) DIOS. These missions will challenge to detect the X-rays from the warm-hot intergalactic medium (WHIM) to understand large-scale structure on a cosmic time scale. However, X-ray emission from WHIM is quite weak, so undistinguished with a classical semiconductor detector from other background sources. Therefore, it is necessary to utilize the sensor which has good energy resolution. Knowing the TES performance under the influence of charged particles gives another important input to future space calorimetry missions.

In October 2014, we performed the first experiment at the Paul Scherrer Institute (PSI) in Switzerland using pion beam. We succeeded to measuring 6 keV X-rays emitted from pionic-carbon with an energy resolution of 7eV (Tatsuno et al. 2015, Okada et al. and Hashimoto et al. ?2016). In June 2016, we performed a short commissioning experiment at J-PARC to optimize the shield thickness to stop K- beam in the target sample. In this test, a lithium block was placed at the final focus of the K- beam instead of liquid helium target. After optimizing degrader thickness for K- beam condition, we installed the TES spectrometer to the beamline and evaluated in-beam performance of the TESs under realistic background conditions by observing X-rays from 55 Fe radioactive source. Our TES spectrometer achieved energy resolution of 6.7eV FWHM at 6keV for the on-beam resolution and 5eV for the off-beam resolution. From these tests, we learned the background in the X-rays spectrum induced by charged particles were mostly consistent with the simulation by Geant4. During beam on, bath temperature was slightly worsen and the background events increased. The temperature stability was restored to be about 5 uKrms by optimizing the shielding configuration.

Liquid helium-3 and helium-4 to create Kaonic 3He and 4He will be used for the scientific campaign in early 2018. Microphonics from vacuum pumps could be an additional concern because they are connected mechanically to the TES system to maximize effective solid angle. We confirmed that the bath-temperature fluctuation was about 5u Krms under the same condition as the real test setup. Thus we are ready to compile our TES application when beam time is allocated to our mission.

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category : Applications

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