Critical temperature tuning of Titanium thin films for CMB detectors on the SWIPE/LSPE experiment

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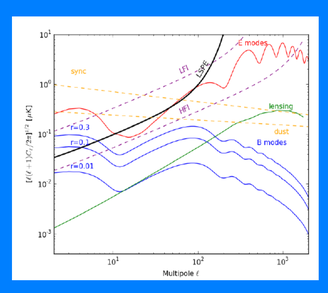
ABSTRACT

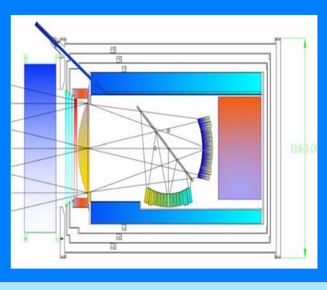
Cosmic microwave background (CMB) B-mode polarization detection is a major challenge in modern cosmology, which future experiments are going to undertake either from the ground, on balloons or on satellites. Among these, the SWIPE/LSPE balloon-borne experiment aims at searching for B-modes exploiting the re-ionization peak at large angular scales. Detectors in SWIPE are Transition Edge Sensor (TES) spider-web bolometers, requiring T_C > 500 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 ≈ 390 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.

The SWIPE/LSPE experiment

The **Large Scale Polarization Explorer**[1] **(LSPE)**:

- is a mixed ground/balloon-borne mission aimed at measuring the CMB **B-mode** polarization at large angular scales.
- will improve the limit on the tensor-to-scalar ratio down to $r = 0.03$ at 99.7% CL.
- will be launched from Longyearbyen (Svalbard Islands) in December 2018, for a 15 days-long circumpolar flight during the polar night (40 km of altitude, ≈ -80 °C).
- is composed of two instruments: STRIP (installed on ground at Tenerife) and **SWIPE** (on board).





Upper left: power spectrum of CMB polarization (E-modes and B-modes), foregrounds (synchrotron and interstellar dust) and spurious B-modes due to gravitational lensing. In black is reported the sensitivity limit of LSPE.

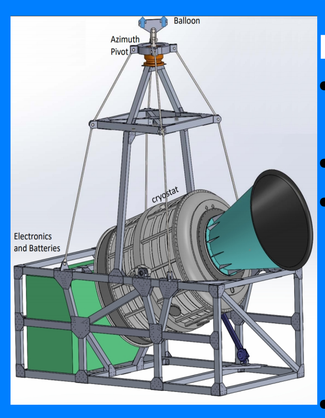
Upper right: sketch of the gondola of SWIPE/LSPE.

Lower left: sketch of the cryostat of SWIPE/LSPE, hosting the rotating HWP, the beam splitter and the two focal planes cooled at 300 mK.

Lower middle: table with the main (theoretical) parameters for the TESs to be used on SWIPE.

Lower right: one of the multimode horns to be mounted on the focal plane. The dismounted backshort shows the housing for the spiderweb TES.

Frequency (GHz)	140	220	240
N_{modes}	12	30	34
NEP_{ph} (W/√Hz)	6.4×10^{-17}	5.5×10^{-17}	11.5×10^{-17}
NEP_{th} (W/√Hz)	4.0×10^{-17}	3.2×10^{-17}	5.5×10^{-17}
P_{opt} (pW)	11	5	20
P_{sat} (pW)	28	15	50
G (pW/K)	220	120	400



The **Short Wavelength Instrument for the Polarization Explorer**[2] **(SWIPE)**:

- is composed of two focal planes with 326 **spiderweb TES bolometers** cooled at 300 mK.
- exploits multi-mode horns to convoy radiation.
- detectors are Titanium Transition Edge Sensors with the requirement of T_C > 500 mK, due to the increased optical power collected by the multi-mode horns (see Table[3]), since at equilibrium:

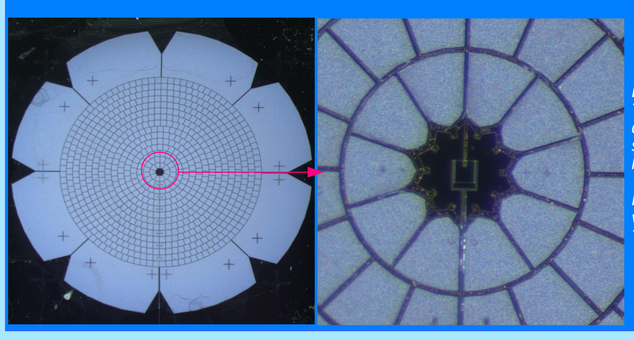
$$T_{eq} = T_{bath} + (P_{opt} + P_{Joule})/G$$

- readout is achieved by means of a 16-channel **FDM**, putting a superconducting LC filter in series with each TES. FDM chains are hosted on custom PCBs on the focal planes.
- hot electronics provides comb generation, demodulation and data reduction.

Transition Edge Sensors

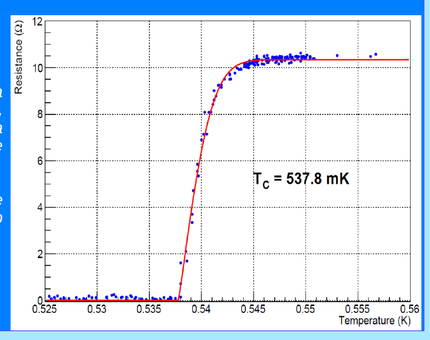
TES bolometers for SWIPE are fabricated at INFN Genova facilities[4]:

- the spiderweb structure of the SiN absorber reduces the energy release from cosmic rays.
- fabrication requires several steps (resist coating, optical lithography, e-gun and sputtering deposition, ICP-RIE etching, chip release and cleaning).
- the Titanium film is deposited in a temperature-monitored environment to maintain its T_C above 500 mK, as required.



Left: transition of a Titanium film, deposited with a substrate temperature lower than 80 °C.

Right: microscope view of a spiderweb TES chip.

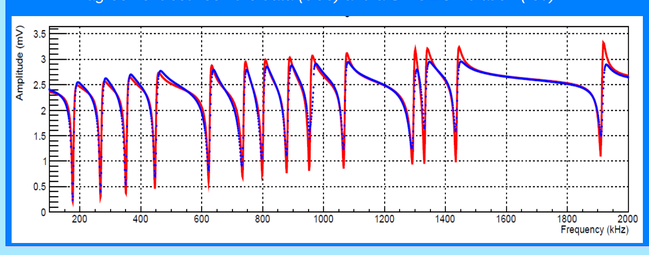


TES detectors readout

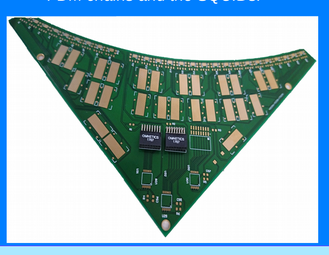
Readout electronics based on frequency domain multiplexing is being designed, realized and tested at INFN Pisa[5]:

- superconducting LC filters are fabricated at NEST-CNRnano[6] facilities in Pisa, using optical lithography and Niobium sputtering deposition.
- testing of the FDM chain is performed at INFN Pisa facilities, including the readout with SQUIDs and hot electronics.
- first results prove that we can pack 16 resonances in the range 200 kHz ÷ 2 MHz and that inter-channel crosstalk is below 0.3% level[7].

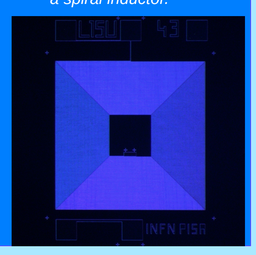
Readout of a test PCB with superconducting LC filters, showing the agreement between the data (blue) and a SPICE simulation (red).



PCB prototype for housing the FDM chains and the SQUIDs.



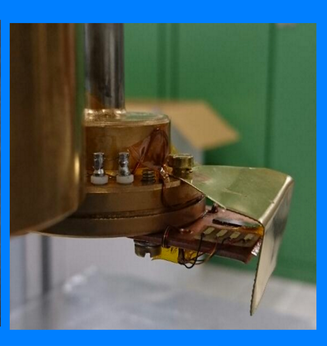
Microscope view of a spiral inductor.



Titanium T_C tuning

Titanium thin film deposition

- SiN – SiO_2 – Si clean substrate.
- substrate temperature during process less than 80 °C.
- 65 nm of Titanium deposited in 90 s using an electron gun (INFN Genova facilities).

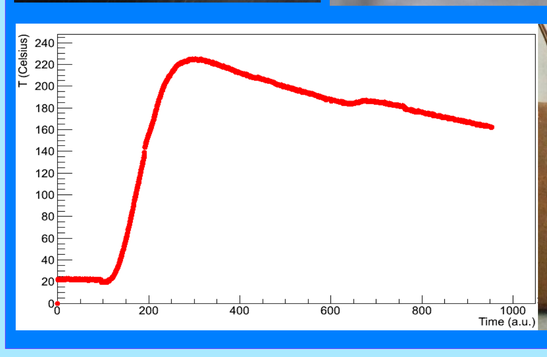


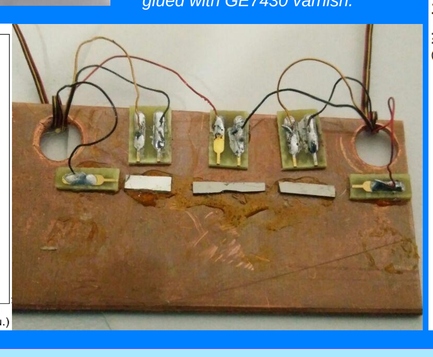
Upper left: samples after Ti deposition.

Upper right: test plate attached to the 3He cold head.

Lower left: time trend of the oven temperature during annealing.

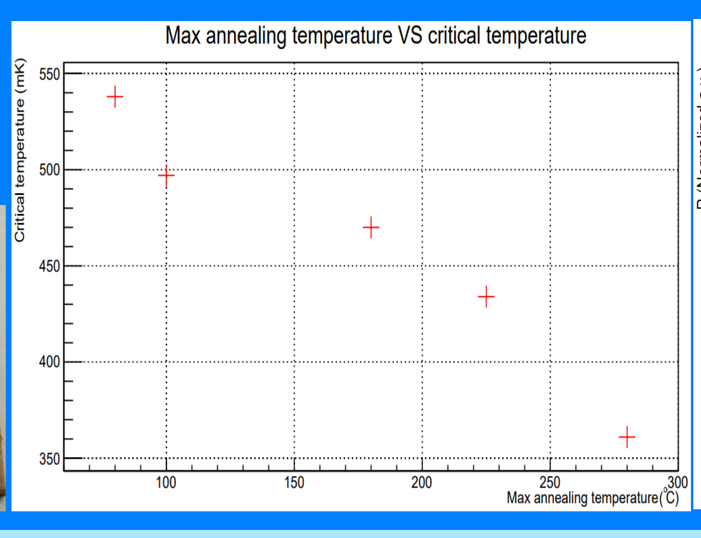
Lower right: one of the Cu plates used for testing. The Ti strips were glued with GE7430 varnish.

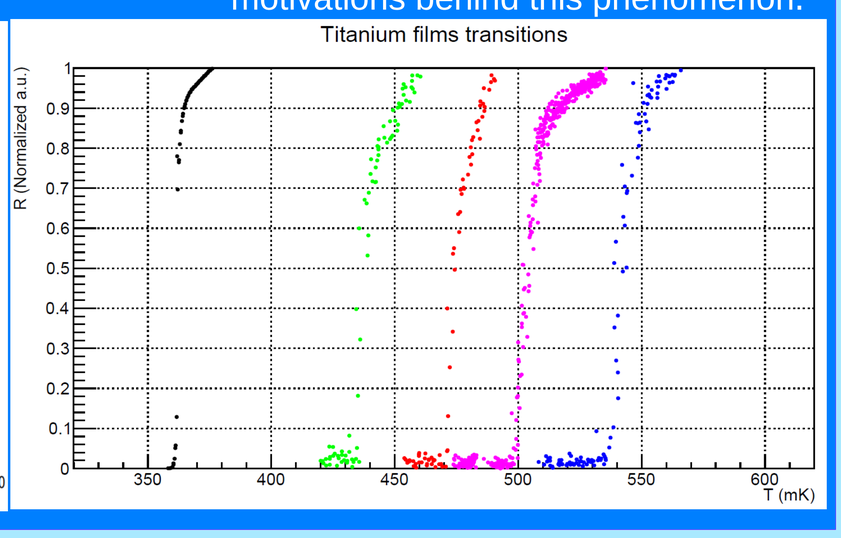




Post annealing treatment

- annealing performed in an oven with Argon atmosphere to avoid Titanium oxidation (INFN Genova facilities).
- each sample is thermally treated with a different maximum temperature in the range 80 °C ÷ 270 °C.
- the entire annealing process requires 6-8 hours, including warming and slow cooling.
- Samples are cut to strips and measured in a 3He-4He sorption cooler down to ≈ 300 mK (INFN Pisa facilities). Results are reported below.





Conclusions

- Titanium T_C decreases with the increase of annealing temperature.
- a dedicated thermal process allows to set a particular T_C.
- it is possible produce TES bolometers with a T_C suitable for LSPE.
- further investigations are in progress to understand the crystallographic motivations behind this phenomenon.

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REFERENCES

[1]Aiola, S. *et al.*, (LSPE Collaboration) "The Large-Scale Polarization Explorer", arXiv:1208.0281, (2012);
[2]de Bernardis, P. *et al.*, "SWIPE: a bolometric polarimeter for the Large-Scale Polarization Explorer", Proc. SPIE 8452, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VI, 84523F (2012);
[3]Gualtieri R. *et al.*, "Multi-mode TES Bolometer Optimization for the LSPE-SWIPE Instrument", J. Low Temp. Phys., (2015);
[4]Biasotti, M. *et al.*, "Fabrication and Test of Large Area Spider-Web Bolometers for CMB Measurements", J. Low Temp. Phys. (2015) 1–5;
[5]Vaccaro D. *et al.*, "The FDM readout system for the TES bolometers of the SWIPE instrument on the balloon-borne LSPE experiment", Proc. SPIE 9914, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy VIII, 99143C;
[6]National Enterprise for nanoScience and nanoTechnology, Scuola Normale Superiore, Piazza San Silvestro 12, 56127 Pisa, Italy;
[7]Vaccaro D.*et al.*, International Superconducting Electronics Conference 2017, *proceedings in preparation*.