The Neganov-Trofimov-Luke effect (NTLE) [1] is a promising way to improve the sensitivity of cryogenic light detectors by enhancing the thermal signal in a semiconductor. This effect is the most important one caused by drifting photon-generated electron-hole pairs, while under an electric field and at low temperatures. Such cryogenic light detectors are of high importance for direct dark matter searches such as CRESST, [2] Neganov-Trofimov-Luke neutralino double-beta decay searches (NTDBE), and experiments searching for coherent neutrino nucleon scattering (CNOBOS), experiments where excellent sensitivity and energy resolution are required. A novel approach to NTLE light detectors is the use of a planar electrode contact geometry based on very thin implanted contacts on silicon absorber detectors. The main difference to previous approaches is that the photon-generated charge carriers are drifted through the bulk of the absorber instead of being drifted across the free surface of the absorber, leading to an improved signal-amplification, signal-to-noise ratio, and charge collection. In this contribution we present an update on the development of these detectors at the Astrophysics Physics group of the Technical University of Munich.

Neganov-Trofimov-Luke Effect

The CREST experiment (Cryogenic Rare Event Search with Superconducting Thermometers [3]) is aiming at the direct detection of a nuclear recoil induced by a WIMP (Weakly Interactive Massive Particle). It involves the detection of scintillating light as well as photon detection within a CaWO$_4$ crystal. The ratio of the two signals energies allows to determine the nature of the interaction (nuclear recoil or hadronic reaction, the latter for the background). The light signal can be detected with a second calorimeter. Only about 1% of the energy deposited in a CaWO$_4$ crystal is detected as light. The sensitivity of the light detectors must be very good for an efficient event by event background discrimination. Due to the NTLE, the threshold of low temperature light detectors based on semiconductor substrates can be significantly improved significantly by drifting the photon induced electron-hole pairs in an applied electric field which results in additional predictable heat. The gain is heat by the following equation:

$$G = 1 + \frac{e \cdot V}{\varepsilon}$$

Where $e$ is the charge of the electron, $V$ the NTLE Voltage and $\varepsilon_{\text{h-e}}$ the energy required to create an electron-hole pair. The NTLE allows us to increase the signal to noise ratio (Fig. 1).

Experiment

The detector was installed nearby an $^{57}$Fe calibration source (X-rays at 5.9 and 4.4 keV and $^{55}$Fe at 16 keV). In this paper we report on the results of the first 150 s of the 430 nm photons emited by a LED (matching the CaWO$_4$ scintillation properties). The response of the photon-signals read on the TED was recorded while varying the NTLE voltage [Fig. 3]. The 430 nm pulses together with the X-rays are visible and the amplitude of the pulses increases with the voltage applied because of the NTLE effect. The trigger signal from the LED generator allows to discriminate between LED and other events. The pulses at low energies are due to the electrons emitted by the Fe.

Conclusions

The evaluation of the thermal gain with $V_{\text{NTLE}}$ was studied providing information about the value of the ratio $T_{\text{MFE}}$. The measured gain matches well the predicted one when matching the equation of the gain providing the value of this ratio. Further experiments should be done to determine the evolution of the $\text{IT}_{\text{MFE}}$ with temperature since the red value for the transformation of the detector to the low temperature regime is not known. The fact that the thermal gain yields values matching the theory is very important because it shows a clear improvement and a better understanding of conventional NTLE detectors.

Also, for the first time an NTLE detector exhibited an energy resolution close to the theoretical limit for X-rays by a Poisson statistics. This result reveals possible because of both the excellent charge collection on the whole silicon surface of the photodetector and the independent of the diode. Notwithstanding the excellent energy resolution, the minimal peak energy achieved is still a factor 4 away from the single photon detection of 430 nm photons. Reaching such a resolution would be of great interest because it would constitute the ultimate resolution for a cryogenic light detector.

References


Results

Figure 4: a) The amplitude of the pulse is increasing with a linear behaviour for higher photon energies and a constant slope for shorter wavelength photons. This is expected from the theory and is well obtained. b) In the graph the Fe spectral peaks can be seen. The red line corresponds to the Gaussian fit. c) Evolution of the baseline for different $V_{\text{NTLE}}$ applied. d) Evolution of the linear behaviour for different $V_{\text{NTLE}}$. The black circular data correspond to the data obtained for a field detector. NTLE detector from [3].

Figure 5: This graphic shows the charge collection for both 700 nm photons (in red) and 430 nm photons (in blue) plotted against the NTLE voltage. The larger wavelength, the charge collection is maximal at a much lower $V_{\text{NTLE}}$, than for the shorter wavelength photons. This occurs due to the fact that the 700 nm photons penetrate deeper into the absorber while the 430 nm photons are absorbed close to the surface. This observation provides a better understanding of the gain that can be rewritten as $G = \frac{\varepsilon_{\text{h-e}}}{\varepsilon_{\text{h-e}}} - 1$. That is why the gain for 430 nm photons at different $V_{\text{NTLE}}$ is shown in the data points. The data presents the new fit for the gain 430 nm photons using the NTLE.

Figure 6: In this graph, the signal amplitude is shown for 430 nm photons (in blue) at 97 V, for different photon fluxes. The first 30 s, the flux is a rate of 0.3 Hz. For the next 150 s, the flux is increased to a rate of 5000 Hz. After that, the flux is back to 0.3 Hz. The LED generates illumination on the surface of the CaWO$_4$ crystal is detected as light. The pulses are visible and the amplitude of the pulses increases with the voltage applied because of the NTLE effect. The trigger signal from the LED generator allows to discriminate between LED and other events. The pulses at low energies are due to the electrons emitted by the Fe.

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