High Voltage New Interface Studies

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The SuperCMDS collaboration uses advanced high voltage Neganov-Luke phonon-assisted detectors for low mass dark matter detection. The leakage current associated with high voltages limits the ultimate sensitivity reach for this large mass detector technology. Although the current leakage performance of the detectors is sufficient for SuperCDMS SNOLAB requirements, improvements are needed to reach the ultimate single electron resolution expected using this technology. We report on recent progress toward understanding the leakage in SuperCDMS-style high voltage detectors and efforts to improve our metal-semiconductor interface design.

Introduction

- This work a continuation of research presented at April 2018 American Physical Society National Conference [1].
- ~85% of matter is nonbaryonic.
- Paradigm shift to include lower mass (<10 GeV) dark matter candidates.
- SuperCDMS desires low energy threshold detectors; achievable with Neganov-Luke gain semiconductor detectors (numbers below correspond to captions).
- Using high voltage requires good understanding of contacts.
- Using contact-free geometry, we can assess the performance of the contacts with respect to leakage.
- Improved performance and different materials testable with contact-free technology.

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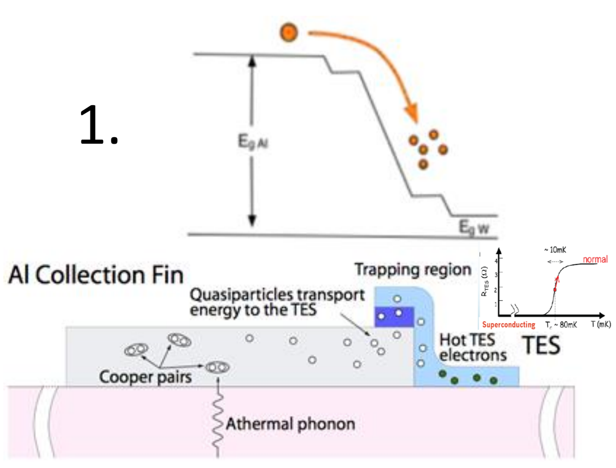

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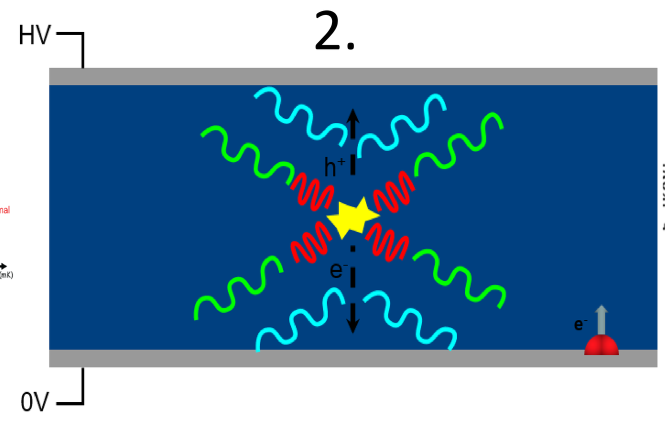

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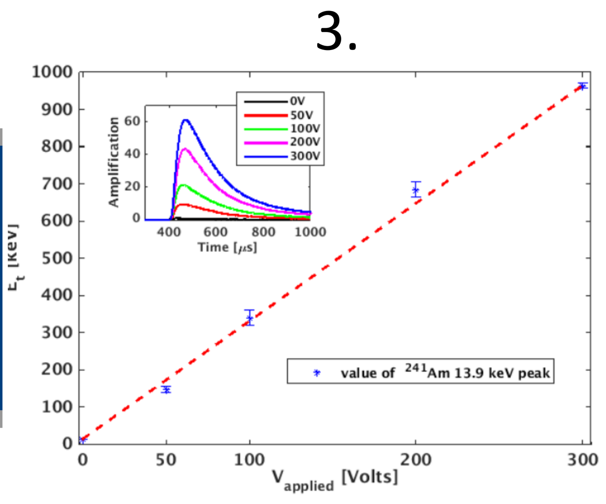

SuperCDMS Detectors and Neganov-Luke Gain

1. Schematic illustrating how athermal phonon signals are generated in Quasiparticle-assisted Electrothermal feedback Transition edge (QET) sensors. The inset shows a TES in the bias region; an increase in its temperature is read out as a sharp variation in resistance.
2. A particle generates two types of phonons – prompt phonons from the interaction itself and those due to electrons and holes accelerated across the detector that produce Luke-Neganov phonons.
3. Nuclear recoil energy as a function of applied voltage. The Luke-Neganov effect is clearly seen as an increase in the pulse amplitude, whereas the noise remains constant [2].

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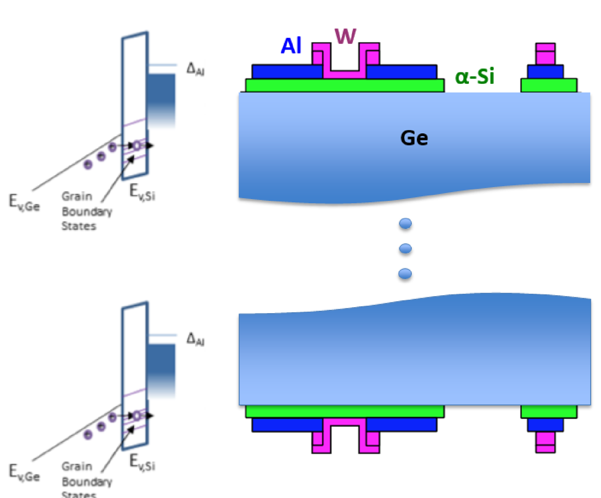

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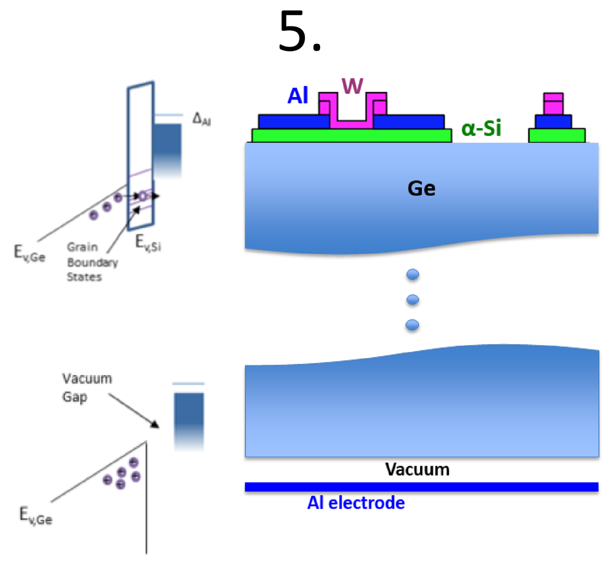

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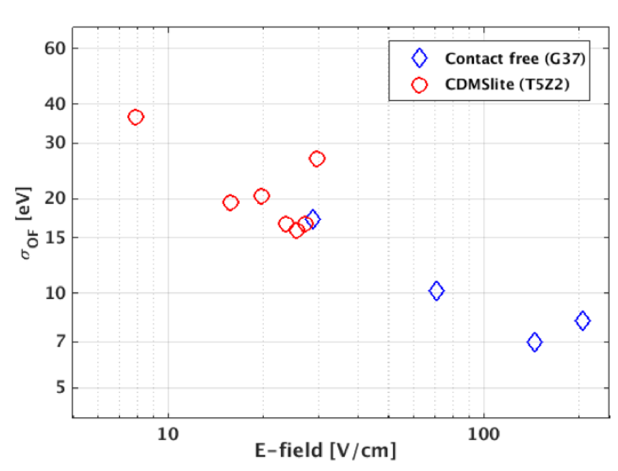
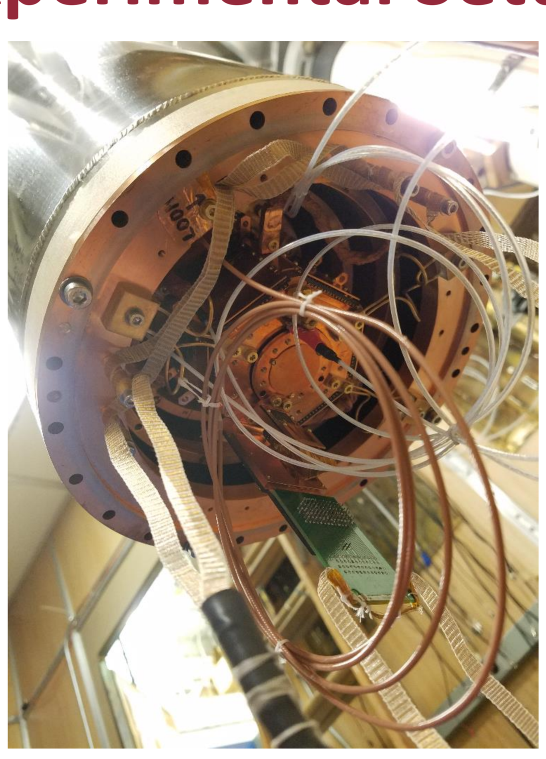


Contact-Free Geometry to Study Contact Leakage Performance

4. The difficulty in understanding contact physics with CDMS symmetric readout [2].
5. Placing an electrode with a vacuum gap on one side breaks the symmetry and by definition removes the leakage on one surface [2].
6. Plot showing how past-generation CDMSlite detectors at Soudan [3] compare to one with a contact-free design [2]. In one polarity, the detector can be run at much larger voltage bias, which significantly increases Neganov-Luke gain caused by electron-hole pairs drifting across the detector and producing phonons along the way.

Experimental Setup


1.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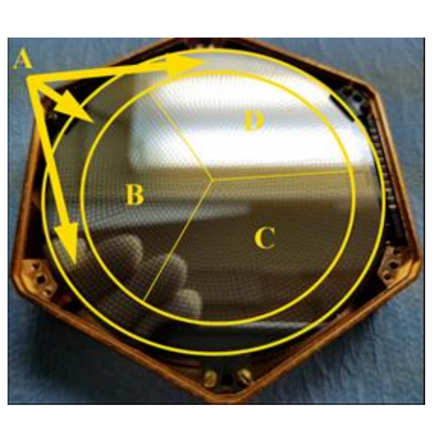

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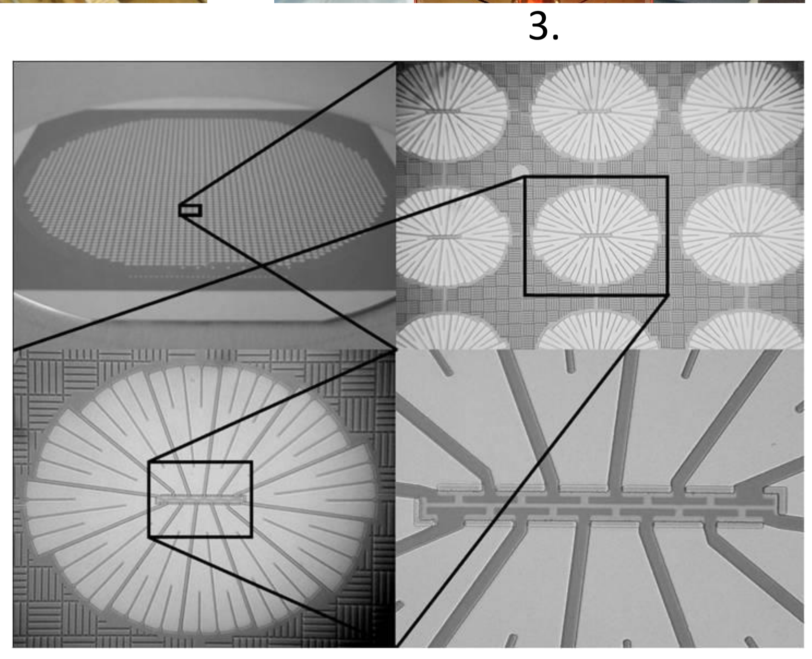
6.

1. 400 microwatt dilution refrigerator, thermal shield cans removed.
2. Underside of dilution refrigerator with cans installed showing SQUET board, readout wiring, thermometry wiring, and high-voltage line.
3. Detector tower, composed of detector housings and readout wiring, along with high-voltage line.
4. Contact-free aluminum electrode with ~300 µm uniform gap between electrode and detector surface.
5. 3 inch x 1 cm Mercedes-design Si detector S17B, with a mass of about 100 g, showing the four channels.
6. Closeup of detector QET; the bottom right image shows the TES, which is 250 µm long and 2 µm thick.

Preliminary Results from Interface Contact Studies at Texas A&M University

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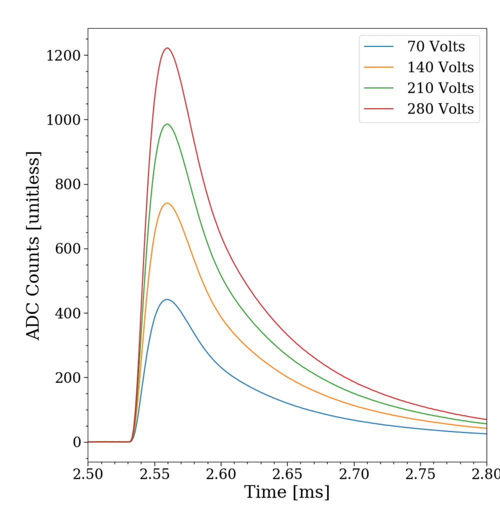

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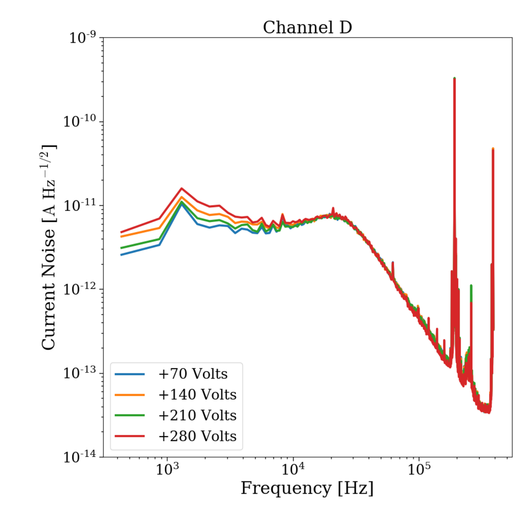

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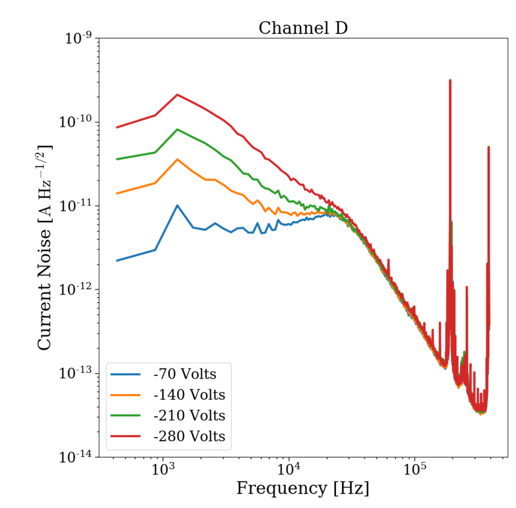
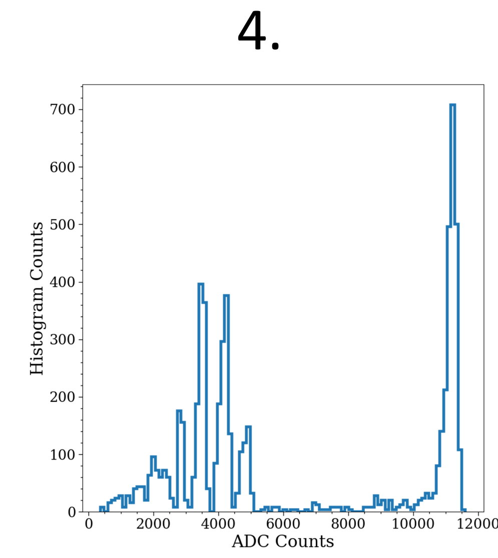


1. Plot showing how Neganov-Luke gain increases the signal traces as the voltage increases. Plot generated using a template from 13.9 keV traces scaled with respect to the detector voltages given.
2. Noise power spectral density (PSD) for positive voltages for Channel D, the channel with the Am-241 source. Due to the asymmetric nature of the contact-free design, there is very little voltage-dependent leakage current at high voltages in this polarity. Compare to the results from [2] in plot 6. on the left panel.
3. Noise power spectral density (PSD) for negative voltages for Channel D. Due to the asymmetric nature of the contact-free design, negative polarity has much higher leakage current than the positive voltages in plot 2.

4.



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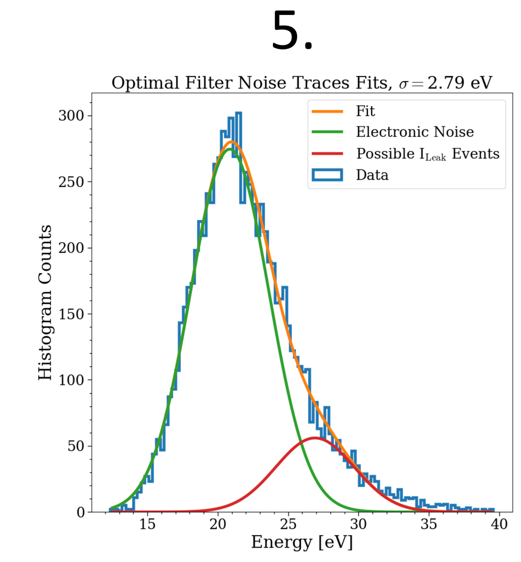

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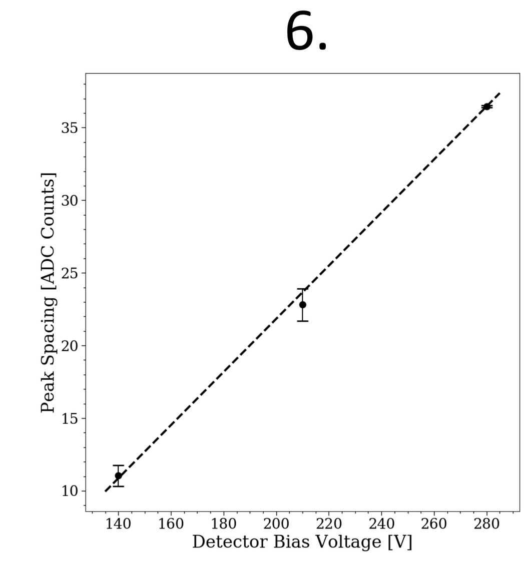
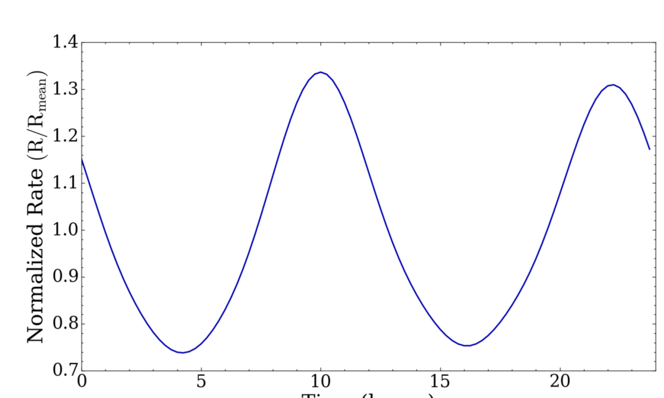


4. Am-241 events generated via an optimal filter template fit. The 13.9 keV line is used to calibrate plot 5.
5. Noise histogram generated by optimally filtering and fitting template to result, similar to Ref. [2]. Multiple-Gaussian fit generated assuming the width of each Gaussian component is the same. Preliminary resolution from this detector is also shown based on the width of each component peak scaled to the location of the 13.9 keV peak in 4. The measurement is for all of the channels summed and at -140 V detector bias.
6. Distance between the large and small peak, like those shown in 5. above, as a function of bias voltage in reverse polarity. The linear increase in the spacing as a function of applied voltage indicates that one or both peaks could be composed of real events that generate electron-hole pairs, likely the same leakage current seen at high voltages in other studies [2, 3, 4, 5]. Error bars are estimated by resampling the noise distribution and running the same fitting algorithm on the resampled data.

Possible Applications



- Detector sensitive to diurnal dark matter signal modulation. The plot at left shows the modulation for a germanium detector and for 300 MeV/c^2 dark matter. See Ref. [6].
- A related energy loss effect as described in Ref. [7]. Future publication exploring several materials pending.
- Verify defect creation models in solids to help create materials more resilient to radiation damage.
- Detectors potentially directionally-sensitive to neutrinos from the sun using the same technique as in Ref. [6].
- High-resolution neutron detectors, with possible directional sensitivity, for commercial, government, or military applications.

Future Directions

- Possibly set limits on low-mass dark matter, similar to the work in [5].
- Measure and verify defect creation models used to simulate effects discussed in Ref. [6] and [7].
- Use a higher phonon collection efficiency mask to further improve signal to noise.
- Asses other candidate electrode interfaces, such as SiO_2, α-Si, and other dielectrics.
- Identify and mitigate infrared background, as observed in Ref. [4].
- Using a low-intensity laser light source, see single electron-hole pair events as in Ref. [4].

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