SNOWMASS2021 - LETTER OF INTEREST

EFFECTS OF ENERGY ACCUMULATION AND AVALANCHE -LIKE RELEASES IN MATERIALS AND LOW ENERGY THRESHOLD DETECTORS

Topical Group(s):

- IF1: Quantum Sensors
- IF2: Photon Detectors
- IF3: Solid State Detectors and Tracking
- IF8: Noble Elements
- IF9: Cross Cutting and Systems Integration

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Abstract:

Similarities are often present in low-energy background spectra of ultrasensitive detectors for dark matter particles or CEvNS low energy neutrinos. The energies in these backgrounds are above thermal noise, and self- shielding prevents low energy electrons or gammas to penetrate; low-angle Compton scattering or low-energy Beta impurities would provide a flat background spectrum at low energies, while background event rates have been observed to increase toward low energies. This leads to the question of what underlying mechanism gives rise to such background shapes. We hypothesize the scenario in which low level energy accumulates over time and then manifests in an avalanche which releases this energy in the material. This is potentially an example of self-organized criticality, but the process lacks universal scaling, so each material requires studying the involved excitations and interactions. This mechanism for low-energy noise is cross-cutting, affecting a variety of detector types including noble-elements and solid-state detectors, photon and quantum sensors. As a result, several distinct fields could benefit from investigations of these dynamics which could lead to suppression strategies. We predict significant sensitivity improvements and new possibilities to study SOC-like dynamic in Superconducting Nanowire Single Photon Detectors (SNSPDs).

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Proposed avenue of study

Superconducting Nanowire Single Photon Detectors (SNSPDs) demonstrate remarkable progress in recent years- currently they are among the fastest photon counters (~10 picosecond timing), have low energy detection threshold (10 μm wavelength photon detection) and have low dark count rates. At the same time microscopic model of operation of these detectors remains unclear.

When a SNSPD detector is waiting for an event (photon producing energetic quasi-particles in nanowire with superconducting current), no dissipation or energy production takes place in the detector material, so SOC-type dynamic should be absent or strongly suppressed. This opens the possibility to introduce some low energy influx into materials (at frequencies below superconducting gap) to study both appearance of SOC dynamics, density of sub-gap states and effects of populating these states on energy sensitivity and dark counts of these detectors.

While there has been tremendous work building SNSPD arrays with improved energy sensitivity of individual detectors, no attempts have been done so far to detect hot phonons with these detectors. Also, while most of the materials used for SNSPDs have low carrier concentrations, and thus the electron concentrations in thin films of these materials can be manipulated by strong electric field, no such experiments have been done in this direction either. This situation is partially due to the lack of understanding of the processes in SNSPDs. But studying of effects of hot phonons (produced by particles bombarding the SNSPD's substrates) and effects of in-situ changing electron concentration by electrostatic field can provide new clues for understand microscopic processes in the detector.

LLNL is interested in detection of hot phonons as this can lead to new techniques for CEvNS detection as well as for light dark matter particles detection. Suppression of superconductivity by strong electrostatic fields can be used to push photon detection threshold to longer wavelength, which is of interest to LLNL in connection with searches for axion dark matter.

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References.

Self-organized criticality- general ideas are in these papers; as in materials avalanche relaxation can be due to formation of "excitation clusters", universal scaling of SOC model may be absent, as stability of different clusters depends on microscopic interactions/ microscopic structure of clusters and is not universal function of the cluster size.

Per Bak, Cho Tang, and Kurt Weisenfeld, "Self-Organized Criticality: An Explanation of 1/f Noise", Phys. Rev. A, 38, pp. 364-374, (1988).

Per Back and Can Chen, "Self-organized criticality", Scientific American, Vol. 264, pp. 46-53, (1991).

SNSPD: while there are many papers on operation principles of superconducting nanowire detectors, recent reviews make impression that unified picture is still absent

Itamar Holzman, Yachin Ivry, "Superconducting Nanowires for Single-Photon Detection: Progress, Challenges, and Opportunities", Advanced Quantum Technologies, Vol. 2 issue3-4(2019), https://doi.org/10.1002/qute.201800058

Field-effect in superconductors

L. J. Li, E. C. T. O'Farrell, K. P. Loh, G. Eda, B. Özyilmaz & A. H. Castro Neto, "Controlling many-body states by the electric-field effect in a two-dimensional material", *Nature* **volume 529**, pages185–189(2016).

G De Simoni, F Paolucci, P Solinas, E Strambini, et al., "Metallic supercurrent field-effect transistor", *Nature Nanotechnology* **volume 13**, pages802–805(2018)

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