Simultaneous detection of phonon and light in Sapphire scintillation detector for rare event search experiments

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Introduction

Cryogenic scintillation detectors are good candidates for detection of rare events such as Low Mass Dark Matter (LMDM) [1] and Coherent Elastic Neutrino Nucleus Scattering (CEνNS) [2]. Particle identification using electron recoils and nuclear recoils can be done by the simultaneous measurement of phonon and scintillation light produced in the detector. A 100 g Sapphire detector has been fabricated and tested at the Texas A&M University, USA for the detection of rare events [3]. The detector shows a baseline resolution of $\sim$18 eV. Even considering a 5σ conservative value of this resolution ($\sim$ 90 eV), the detector would be an excellent candidate for low mass dark matter and CEνNS searches. The Sapphire detector produces a small amount of light (only $\sim$1% of the deposited energy) [4] whose detection is quite challenging. A phonon-mediated Si detector of 100 g is used to amplify the scintillation light from Sapphire. The Si detector can be operated at high voltage mode (HV) with bias voltage applied upto 240 V. The threshold of the Si detector can be improved exploiting the Neganov-Trofimov-Luke (NTL) [5, 6] gain by applying high voltage bias across the detector. In this work we show the results of the collected light from the Sapphire detector paired with the Si detector which is operated at three different voltages. An expected linearity of amplified light with the applied voltages in the Si detector is observed.

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Experimental setup

The detector assembly consisting of the Sapphire and the Si detector is placed inside dilution fridge to operate at cryogenic temperature ($\sim$50 mk). Both the detectors are 76 mm in diameter. Sapphire and Si detector are 4 mm and 10 mm in thickness respectively. Schematic of the detector setup shown in Fig. 1(a). The detectors are equipped with Transition-Edge-Sensors (TES) for phonon signal readout. Nearly 1000 sensors are divided into 4 independent channels named as A, B, C and D. 6 keV X-rays from ^{55}Fe source is used to calibrate the Si detector. A ^{241}Am source is shined on the Sapphire detector with 60 keV gammas to calibrate the detector. The scintillation light produced by the 60 keV gammas in the Sapphire detector are collected by the Si detector using coincidence techniques.

Analysis and result

With the help of Data Acquisition System (DAQ), raw data is stored that contains pulse information in terms of voltage and time for each event. A machine learning algorithm called Anomaly Detection (AD) technique [7, 8] is used to improve the data quality by retaining only good pulses. AD tries to differentiate the events on the basis of their similarity/dissimilarity with other events. In this work, we have used a combination of two algorithms to cluster our data, t-SNE and DB-

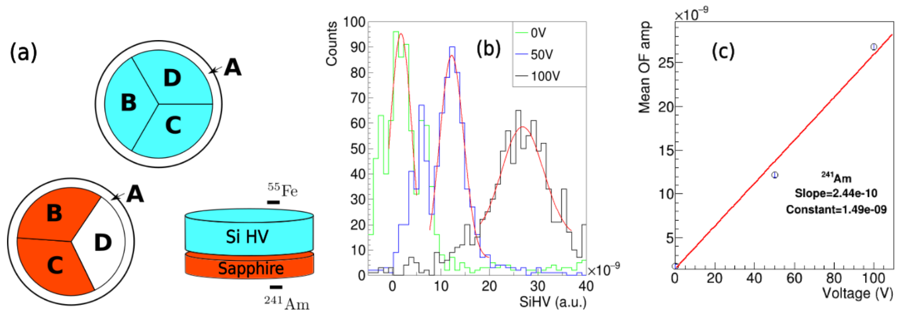

FIG. 1: (a) Schematic of the detector setup where readout channels for Sapphire (B, C) and Si detector (B, C, D) are highlighted. (b) The light output of 60 keV events from Sapphire detector using ^{241}Am source is amplified in Si HV. (c) The linearity of the amplified light as a function of voltages is observed.

SCAN. We are able to group our data to different clusters which corresponds to saturated pulses, good pulses, piled up pulses, ringing traces, and noise. Good pulses are filtered out for further analysis. We have used Optimal filter (OF) algorithm [9] to extract energy information from the raw traces. The amplitude measured in the OF method is directly proportional to the energy of the pulses. The OF amplitude distribution can be then calibrated using known energy sources.

60 keV gammas falling on the Sapphire will produce phonons and light signals simultaneously. The phonons are absorbed by the phonon sensors in Sapphire. The scintillation photons of ∼600 eV (1% of 60 keV gammas) will hit the Si detector and will create phonon signal and get collected by the sensors. The amplification of the phonon signal or the light in Si detector is observed through coincidence events with the Sapphire. A linear correlation between the events in Sapphire and Si with different voltages is observed. Figure 1(b) shows the projected distribution of the 60 keV events from the Sapphire in Si detector for 0 V, 50 V and 100 V. This demonstrate the amplification of the light at different voltages which is expected to be linear with the applied voltages. To show the linear relationship we have plotted the mean of the projected event distribution with the respective voltages. The Fig. 1(c) shows the linearity of the amplified light output in Si detector.

Conclusion

We demonstrate the simultanous phonon and light measurement using 100 g Sapphire detector. Application of higher voltages (> 100 V) improve the signal to noise ratio which will provide light detection below < 10 eV as well as the particle identification. In future work, we will show the light detection efficiency of the detector setup. The detector will be suitable for the "India based coherent neutrino scattering experiment at Apsara-U, Mumbai."

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