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Section A

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Study of the dead layer in germanium for the CDMS detectors

V. Mandic[a], N. Mirabolfathi[a,*], P. Meunier[a], C.L. Chang[b], L. Baudis[b], P.L. Brink[b], M.J. Attisha[c], J.-P.F. Thompson[c], R.J. Gaitskell[c], R.W. Schnee[d], B. Serfass[a], R.W. Ogburn[b], W. Rau[a], J. Filippini[a]

[a] *Cosmology Group, UC Berkeley, Berkeley, CA 94720, USA*
[b] *Department of Physics, Stanford University, Stanford, CA 94305, USA*
[c] *Department of Physics, Brown University, Providence, RI 02912, USA*
[d] *Department of Physics, Case Western Reserve University, Cleveland, OH 44106, USA*

The CDMS Collaboration

Abstract

We present new measurements on a Cryogenic Dark Matter Search (CDMS) detector with electron, neutron, and gamma sources. The measurements have been performed to investigate the dead layer of one of the CDMS Z-dependent Ionization Phonon germanium detectors. The dead layer has been studied at both charge electrodes and at different electric field intensities. We also present a method to remove the dependence of athermal phonon measurements on event position.

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Keywords: Massive bolometer; Dead layer; CDMS

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1. Introduction

The Cryogenic Dark Matter Search (CDMS) uses simultaneous measurement of ionization and phonons to directly detect Weakly Interacting Massive Particles (WIMPs), which are strong candidates for the dark matter in the universe.

The discrimination principle is based on the difference between the charge yield for nuclear recoil events (WIMPs) and electron recoil events (most of the background). For the events occurring very close to the surface of the detector, a deficit in charge collection (dead layer) degrades the efficiency of the discrimination. CDMS uses two distinct methods to overcome this problem. The first method is to improve the electrode/absorber interface by introducing a thin (~40 nm) layer of lightly doped amorphous silicon. It has been shown that this amorphous interface reduces the dead layer from 30 μm to less than 10 μm [1]. The other method utilizes the phonon signal rise time measurement. A fast down-conversion of impact phonons for an event occurring very close to a metallic layer (charge electrodes) leads to a shorter rise time for surface events [2].

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*Corresponding author. Tel.: +1-510-643-3950.
E-mail address: mirabol@cosmology.berkeley.edu (N. Mirabolfathi).

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This work is an attempt to study three important properties of ZIP detectors:

(1) The charge yield performances of each charge electrode for near-surface events.
(2) The position dependence of phonon energy measurement.
(3) The position dependence of phonon signal rise time.

2. Experimental setup

The setup consists of a Ge ZIP [3–5] detector, which is exposed to a Pb-collimated ^{109}Cd source as shown in Fig. 1. ^{109}Cd gives two major electron lines at 62 and 84 keV and low energy photons at 22 and 25 keV. The detector is mounted with the source facing the charge side (see next section) in one experiment and facing the phonon side in the succeeding one.

An important aspect of the ZIPs is the dependence of the measured phonon signal on the position of the event. This is a common property of massive athermal phonon bolometers. A solution to achieve homogeneous detector response is to correct the phonon parameters with respect to event location, i.e. to make a lookup table of correction factors for the detector. Comparing these local averages with the desired values provides the correction.

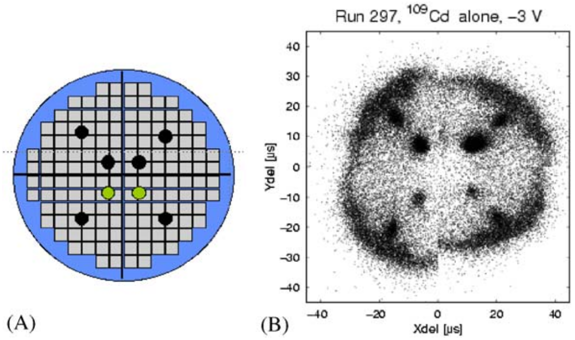

Fig. 1. (A) Phonon face of detector with eight collimator holes. Among the four inner holes, the two lower ones (lighted ones) are covered with Al foil to stop electron. (B) Reconstruction of position by relative phonon signal delay.

Data are recorded at four different charge polarities (−6, –3, +3 and +6 V). For each polarity, three different source configurations (^{109}Cd source alone, ^{109}Cd and an external ^{60}Co source, ^{109}Cd and an external ^{252}Cf source) have been used, i.e. 12 data sets per run. In order to obtain a statistically relevant number of events, large data sets ($>10^5$) were taken. We neutralize the detectors promptly after cooling down to base temperature (40 mK) by flashing with photons whose energy is slightly higher than the gap of Ge (~ 1 eV). Moreover, to avoid space-charge accumulation during the data acquisition, the detector is alternately neutralized and biased (every 3 min).

3. Result and discussion

ZIPs have cylindrical shapes ($\Phi = 76$ mm, $h = 10$ mm). One plane face of each detector is covered by a grid of aluminum–tungsten (charge side) and the other side by Transition-Edge Sensor (TES) thermometers (phonon side). The thermometer face is divided into four quadrants. Each quadrant acts like an individual athermal phonon sensor in Electro-Thermal Feeback (ETF) mode. This arrangement allows us to partially reconstruct the location of events by comparing either the time information in the four sensors (relative delay of four sensors with respect to charge signal) or their relative response amplitudes (phonon energy partition plot Fig. 2A). An example of this reconstruction is shown in Fig. 1B in which we can clearly distinguish the collimated ^{109}Cd events (eight blobs) from external source events. By carefully separating out ^{109}Cd events in this way, we are able to use bulk neutrons and photons to define nuclear recoil and electron recoil bands and correct for position-dependence without contamination from surface events with poor charge collection. We can then look at ^{109}Cd events to estimate the dead layer on both charge and phonon sides.

As described in Ref. [1], we measure the dead layer with low energy (22 keV) photons of ^{109}Cd. The results on the charge side are in good agreement with previous measurements [1]. However, on the phonon side of the detector we

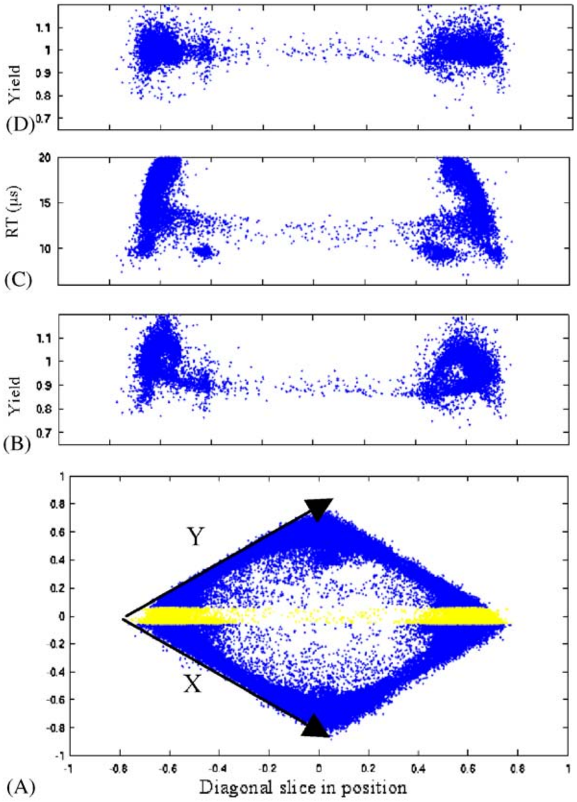

Fig. 2. All plots share the same x-axis, i.e. position based on phonon energy partition. (A) Phonon energy partition plot, showing events selected from the diagonal (light dots) for plotting in the other three subplots. (B) Charge yield, showing outer events give higher yield. (C) Rise time shows the same behavior toward the outer parts of the detector. (D) Charge yield after the correction by the method described in the text.

estimate a thicker dead layer than previously measured. A possible explanation for the asymmetry of the dead layer is the difference between the αSi and Al thicknesses on the two detector faces. This can lead to a different band structure in the interface region and consequently different blocking power against charge-carrier back-diffusion.

Fig. 2A shows a set of events selected to study the variation of the phonon signal parameters with position. The charge yield for these events is reported on the y-axis in Fig. 2B, while the x-axis indicates the distance from the center of the detector. This plot shows that the yield increases with distance from the center of the detector. The same effect is seen in phonon signal rise time (Fig. 2C).

Using the averaging method (Section 2), we attempted to correct the phonon-signal amplitude. The results of this initial correction is shown in Fig. 2D. As we see, the wide spread of the yield distribution (Fig. 2B) is reduced. We believe that we can improve the correction and further reduce the width of the yield distribution. In order to study the surface-event rejection performance on both plane faces of our detector, we have used the same method to correct the phonon rise time. Fig. 3 shows preliminary results of this correction. We can clearly distinguish three populations which are neutrons (yield ~ 0.3, long rise time) electrons (0.3 < yield < 1, short rise time) and bulk gammas (yield ~ 1). The plots suggest that it is possible to

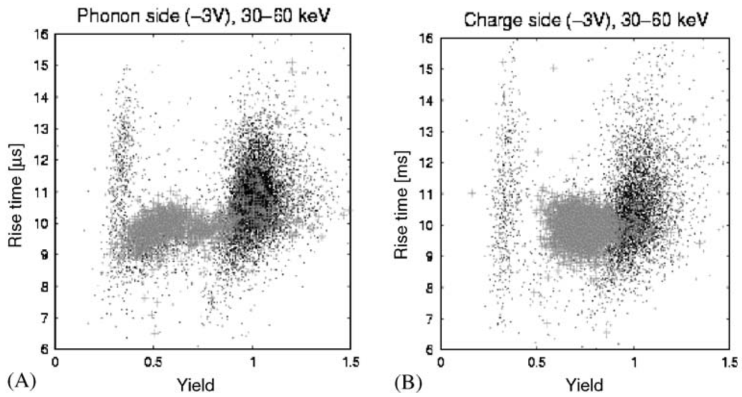

Fig. 3. Plots of yield versus phonon risetime. All events have energy between 30 and 60 keV. The high lighted events are in the blob regions, which are mostly surface events on the (A) phonon side and (B) charge side of detector.

use the phonon risetime to reject events occurring in the dead layer. The rise-time discrimination appears better for the phonon side than for the charge side (Fig. 3).

4. Conclusion

We have compared the charge yield and phonon rise time on both charge and phonon sides of a CDMS ZIP detector. Although the thicker dead layer on the phonon side limits (in this detector) the effectiveness of surface electron rejection based only on the ionization yield, the combination of the yield and rise time should lead to an excellent event-by-event background rejection.

The preliminary results of a position correction to phonon pulse amplitude and rise time are very promising but require more investigation.

There are a couple of additional observations that are worth mentioning. We have observed that the dead layer varies with the direction of the electric field and that there is a deficit in the estimate of phonon energy for events very near the electrode. The nature of both of these effects is also being studied.

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