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Detector Development for the Next Phases of the Cryogenic Dark Matter Search: Results from 1 Inch Ge and Si Detectors

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Abstract The Cryogenic Dark Matter Search (CDMS) experiment is searching for Weakly Interacting Massive Particles (WIMPs) using detectors with the ability to discriminate between candidate (nuclear recoil) and background (electron recoil) events by measuring both phonon and ionization signals from recoils in the detector crystals. As CDMS scales up to greater WIMP sensitivity, it is necessary to increase the detector mass and further improve background discrimination. CDMS is engaged in ongoing fabrication and development of new detector designs in order to meet these criteria for the proposed SuperCDMS experiment. Thicker detector prototypes have been produced with new photolithographic masks. These masks have greater surface coverage of the quasi particle trap and transition edge sensor system to provide

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superior athermal phonon collection. Results from continuing laboratory tests are presented which already indicate improvement in discrimination parameters.

Keywords SuperCDMS · Dark matter

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1 Introduction

The Cryogenic Dark Matter Search (CDMS) experiment [1] uses semi-conductor crystals of silicon and germanium to detect and discriminate between nuclear and electron recoil events. Weakly interacting massive particles (WIMPs) would produce nuclear recoils while the dominant backgrounds are due to electron recoils arising from residual radioactivity and cosmic rays. This recoil discrimination is achieved in the following way. First, we determine each event's ionization yield, that is the ratio of the ionization and the recoil signal measured. Electron recoil events (e.g. from photon interactions) produce a higher ionization yield than nuclear recoil events, allowing for a rejection of photons from the nuclear recoil signal of better than 10,000 to 1. However, near surface electron recoil events show incomplete charge collection and can thus leak into the signal region. The timing and energy distribution of the phonon signal provide a means to remove these surface events. As a rare event search looking for a signal of less than one event per 10 days per kg detector, the SuperCDMS experiment [2] needs to increase detector mass and decrease background leakage to remain background free at larger masses.

2 SuperCDMS Detectors

SuperCDMS detectors are similar to CDMS II detectors with phonon sensors patterned on one face and ionization electrodes on the other. To achieve SuperCDMS performance criteria, we are implementing three main detector modifications. Increasing the thickness of the cylindrical detectors from 1 cm to 1 inch will improve background rejection by decreasing the surface to volume ratio in the detector as well as increase sensitivity per detector (e.g., with associated benefits per channel count and total experiment thermal budget). Modifying the phonon sensor, to optimize the coverage area of the aluminum phonon-collecting fins for better collection efficiency, and decreasing the amount of passive aluminum on the surface will improve signal to noise and surface event discrimination (see Fig. 1). Finally, adding hydrogen passivation of our amorphous silicon layer decreases charge back diffusion, the primary ionization loss mechanism of surface events.

3 Results

During recent tests with a 1 inch thick silicon detector, we studied the bulk ionization collection as a function of electric field strength. For this test, four collimated ^{241}Am

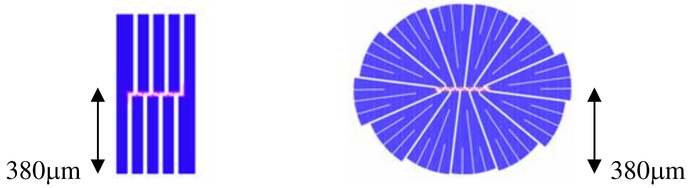

Fig. 1 (Color online) The phonon collection system of the current CDMS II detector (*left*) and that with our modified design (*right*), drawn to the same scale. For a full schematic of the CDMS II detector refer to [3]. SuperCDMS detectors will use the modified phonon collection system. For each quadrant, approximately 800 individual units (right above) are connected in parallel and read out by a SQUID based amplifier, similar to the CDMS II detectors

sources were located near the detector, two on the ionization side and two on the phonon side. 60 keV gammas from the ^{241}Am, interacting in the bulk of the detector, were used to study the ionization collection. We note that the bulk ionization collection with field for this 1 inch thick silicon detector is consistent with our CDMS II 1 cm thick silicon detectors [4].

Discrimination amongst electron-recoil events, surface events, and neutron events based on ionization yield was recently studied with a 1 inch thick germanium detector. This detector was tested during two successive runs where there was a ^{109}Cd source shining through eight collimated holes first onto the ionization side of the detector and then on the phonon side. The ^{109}Cd source produces low energy photons at 22 and 25 keV along with electrons at 62.5 and 84 keV. The electrons emerge from the source with a continuum of energies and are detected as surface events. Initial analysis of these data show excellent ionization yield rejection between electron and nuclear recoil events as well as between ionization side surface events and nuclear recoil events (see Fig. 2). As already seen in CDMS II detectors [5], ionization yield based rejection of phonon side surface from nuclear recoil events is not as good as for ionization side surface events. The origin of this detector-face asymmetry is still under investigation. One possibility is amorphous silicon damage from the phonon side iron ion-implantation of the TESs.

Previous experience from CDMS I indicates an improvement in yield based discrimination for surface events with hydrogen passivation [5, 6]. For surface events, the combination of the polarity of the bias and the event side determines the sign of the dominant carrier that produces the ionization signal. Initial tests were made with a 1 inch thick silicon detector with 20% hydrogenated amorphous silicon layer that increases the barrier height for holes between the crystal and the ionization electrode. The increased barrier reduces ionization back diffusion of surface events which would otherwise be trapped in the nearby electrode rather than drifting through the bulk and contributing to the signal. Studies were done with the 14, 18, and 21 keV X-ray lines from collimated ^{241}Am sources, which are low enough energy to produce surface events in the silicon detector. We used the fraction of low ionization yield events from the X-ray lines as an indicator of ionization yield rejection of the surface events. Even with the hydrogenated amorphous silicon we still see an asymmetry between ionization yield surface event rejection for events occurring on the ionization

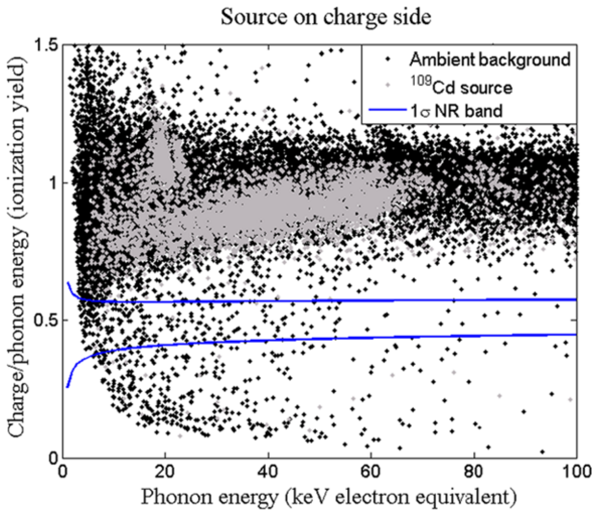

Fig. 2 (Color online) Ionization yield versus phonon energy. *Black points* indicate bulk electron recoil events while the *gray points* indicate events from the ^{109}Cd on the detector's ionization side. The *curves* outline the nuclear recoil band as determined from a dataset with a neutron source

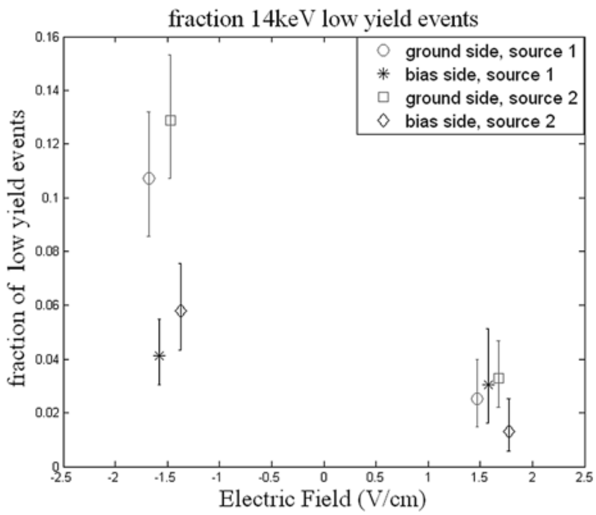

Fig. 3 The fraction of low yield 14 keV events from 4 ^{241}Am sources for negative and positive electric fields. Two of these sources were above the ground side of the detector while the other two were on the bias side

and phonon sides of the detector with a negative bias voltage. We do not see this asymmetry for positive biases, in fact, the fraction of low yield events seems to give better yield rejection at positive bias then negative bias for surface events on both detector faces (see Fig. 3).

While initial tests of a silicon detector with hydrogenated amorphous silicon show promising results of improving yield based rejection for surface events, there is also surface event / nuclear recoil event discrimination power in the phonon timing and partition, which has been demonstrated in CDMS II [1]. Initial timing analysis has been done with a 1 inch thick germanium detector exposed to a ^{109}Cd source demonstrating continued discrimination power with timing in 1 inch thick detectors (see Fig. 4).

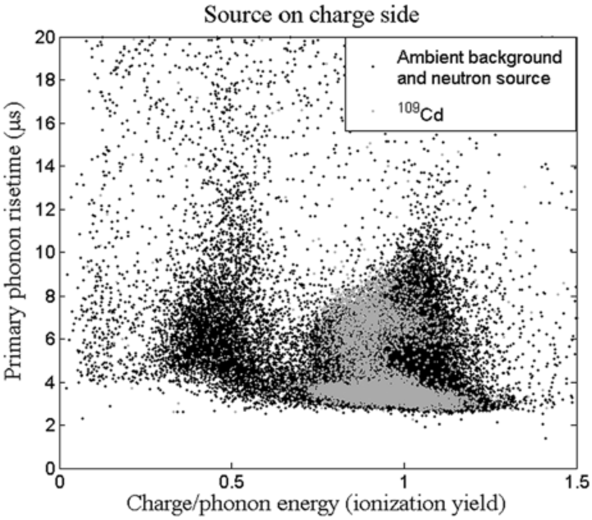

Fig. 4 Phonon risetime versus ionization yield. *Black points* with yield ∼ 1 indicate bulk electron recoil events, *black points* with yield ∼ 0.5 indicate neutron events, and the *gray points* indicate events from ^{109}Cd on the detector's ionization side

Based on our initial testing with 1 inch thick detectors, there is evidence for powerful z-dependent discrimination of surface events from a division of phonon energy between the four independent quadrants of our detectors. Early findings suggest that we may be able to take advantage of this phonon partition quantity to identify surface versus bulk events as well as distinguish between surface events on either side of the detector. There is ongoing work to further investigate this discrimination.

4 Conclusions

Initial studies of silicon and germanium 1 inch thick detectors show that we are achieving comparable or better performance in several discrimination parameters relative to our CDMS II detector design and demonstrate substantial progress towards our detector goals for SuperCDMS. Additionally, there is further effort in tuning fabrication parameters, like the percentage of hydrogen passivation, and advanced analysis techniques.

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