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Experimental characterization of space charge in IZIP detectors

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Abstract Interleaved ionization electrode geometries offer the possibility of efficient rejection of near-surface events. The CDMS collaboration has recently implemented this interleaved approach for the charge and phonon readout for our germanium detectors. During a recent engineering run, the detectors were found to lose ionization stability quickly. This paper summarizes studies done in order to determine the underlying cause of the instability, as well as possible running modes that maintain stability without unacceptable loss of livetime. Additionally, results are shown for the new version IZIP mask which attempts to improve the overall stability of the detectors.

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1 Introduction

The Cryogenic Dark Matter Search [1,2] (CDMS) collaboration employs instrumented germanium crystals which allow simultaneous measurement of both the phonon and ionization signals from particle collisions. The ratio of energy between these two channels provides event by event discrimination for electron and nuclear recoils in the target material. In previous phases of this experiment, near-surface events were the primary background. For these events, the hot charge carriers near the surface are able to back diffuse into the electrode, lowering the collected charge signal and causing electron recoils to mimic nuclear recoils. As a solution to this near-surface event problem, we have implemented an interleaved electrode

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design (IZIP)[3]. By biasing the ionization electrode and grounding the phonon rail, the detector has very large lateral fields near the surface while maintaining a smaller uniform field across the bulk of the detector. In this setup, the charges produced by near surface events will be transported laterally along the surface of the detector so that all charges are collected on a single side while events in the bulk are collected on both sides. This design allows a clear definition of the fiducial volume and rejection of the near-surface background events.

During an engineering run in Soudan, the IZIP detectors showed an unexpected instability in both ionization yield and longitudinal ionization partition. Such effects had been noticed at surface test facilities, but were attributed to the large radiation environment which produces significant space charge in the large crystals (630g). In Soudan's low background environment, the stability of the ionization signals did not scale with the event rate as was expected. Many recent studies have focused on this issue. These include Monte Carlo simulations of charge trapping in the detector[4], as well as efforts to improve crystal screening procedures[5], both of which are published in these proceedings.

2 Experimental Setup

The IZIP is a 3 inch diameter by 1 inch thick cylindrical crystal. It is instrumented with interleaved ionization rails and TES lines for athermal phonon collection on both faces. We report here on two versions of the electrode design: v4 with $8\mu m$ wide electrodes and v5 with $40\mu m$. In standard configuration, the IZIP detectors are biased with the ionization rails on side 1 at +2V and the rails on side 2 at -2V while the phonon bias lines are kept at ground. The detectors were exposed to a 40 Hz source of Ba-133. At the start of any dataset, the detector is flashed with 940 nm light. This light is above the energy of the bandgap and acts to clear the space charge and effectively reset the detector.

Two important derived quantities used as a measure of the charge discrimination properties of the detectors are ionization yield and ionization partition. The ionization yield is the ratio of total collected charge energy to the recoil phonon energy. The yield is normalized so that electron recoils have a value of 1, while nuclear recoils have a value roughly a third of that. The partition (eq. 1) is useful to describe the surface and fiducial (bulk) portions of the crystal and provides the most powerful rejection of near-surface events.

$$Partition = \frac{Q_1 - Q_2}{Q_1 + Q_2} \tag{1}$$

where Q_1 is the total charge collected on the top surface electrodes and Q_2 is the total charge collected on the bottom surface. A partition value of ± 1 corresponds to collection solely on one surface. For an ideal crystal, a partition value of 0 means equal collection on both sides of the crystal which corresponds to events in the fiducial volume (bulk) of the crystal. The spread seen in the bulk partition values is due to charge trapping in the crystal.

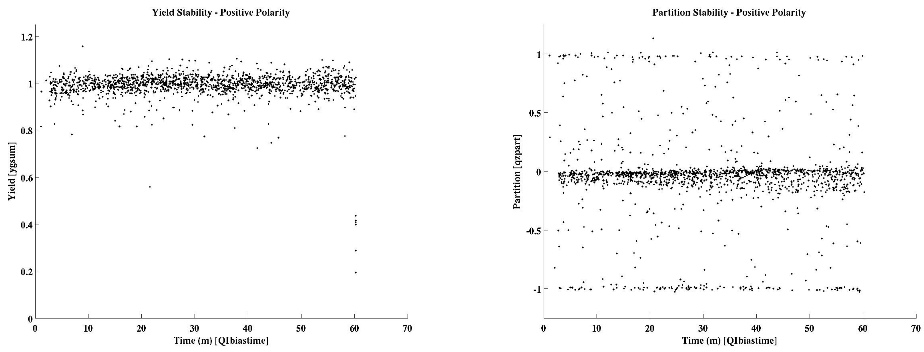

Fig. 1 The figure on the left shows the ionization yield for G48. The figure on the right shows the charge partition. G48, the most stable detector tested, showed little yield instability in an hour period. Only on inspection of the z partition can instability be seen.

3 Results

3.1 Charge Buildup

This paper discusses the ionization stability for both G47 and G48 (v4), as well as a new mask detector, G41 (v5). Each of the detectors was put through the same basic study. First, the detector was biased for an hour (2 hours for G41) at which point it was grounded for a half hour. After flashing the detectors, this same process was repeated for the opposite polarity.

Due to crystal quality and fabrication, each crystal shows unique stability characteristics. G48 was the most stable detector tested in the recent CDMS engineering run (figure 1). Over the hour bias period, there is no significant decay in the ionization yield, but we begin to see a small increase in trapping evidenced by spread in the bulk partition. While this is a small effect, it leads to a time dependance of the overall discrimination ability of the detector which would make any analysis more difficult. By comparison, the worst detector (G47 - see figure 2) loses stability in less than 15 minutes, clearly evident in both yield and partition. After this time it loses discrimination ability of both recoil type and near-surface events as the bands begin to overlap.

The charge instability is most likely due to a decrease in the overall fields due to the buildup of charges. This effect is demonstrated in the grounded data. Following the long bias period, the polarity of the pulses immediately reverses when grounded (see figure 3 - left). This reversal is true for both events near the crystal surface as well as in the bulk of the crystal. For this to be true in both regions, the residual field in the crystal must maintain the same basic structure that it had while biased though opposite in direction. This is consistent with charge buildup near the ionization electrodes. When biased, these trapped charges shield the electrodes and decrease the overall field of the crystal leading to increased trapping. Additionally, the assymetry in the polarity of events in the bulk of the crystal appears to decay in a timescale of minutes. Similar studies were done with the new

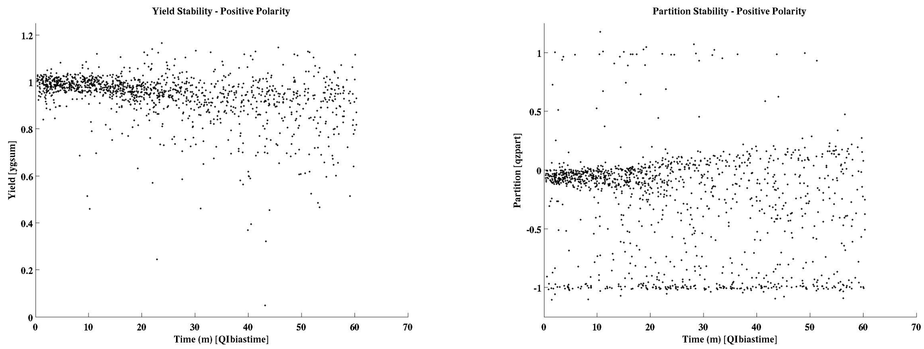

Fig. 2 The figure on the left shows the ionization yield for G47. The figure on the right shows the charge partition. Within 15 minutes, both quantities have decayed significantly which corresponds to a loss of discrimination capability.

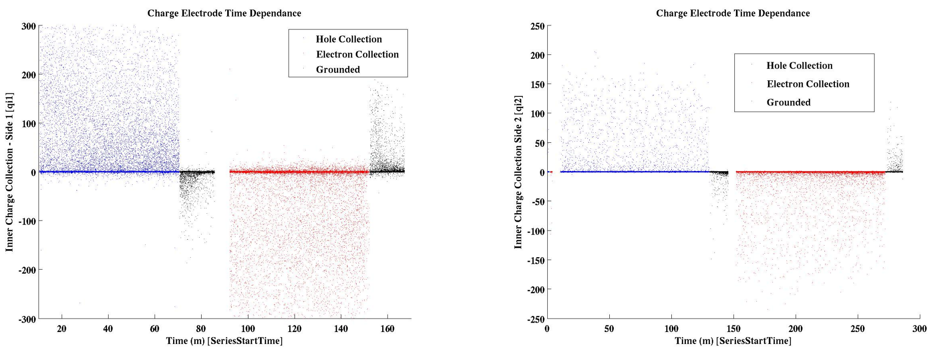

Fig. 3 The figure on the left shows the amplitude for events from a single ionization electrode from G47. The grounded events show a distinct decrease in amplitude over time. This corresponds to the dissapation of the charge buildup near the electrodes. The figure on the right shows the amplitudes for a new style IZIP.

mask pattern (G41). Figure 3 (right) shows the amplitude of the charge pulses from this new style detector. We no longer see the large population of nonzero pulses that decays with time. It appears that the wider ionization electrodes helps to prevent the buildup of charges and subsequent counterfield. The new style detector has yet to be tested in a low radiation environment, but appears to address one of the sources of instability.

3.2 Solutions

From these studies, we cannot leave the detectors biased for long periods of time as done previously. However, preliminary studies at a surface test facilty have

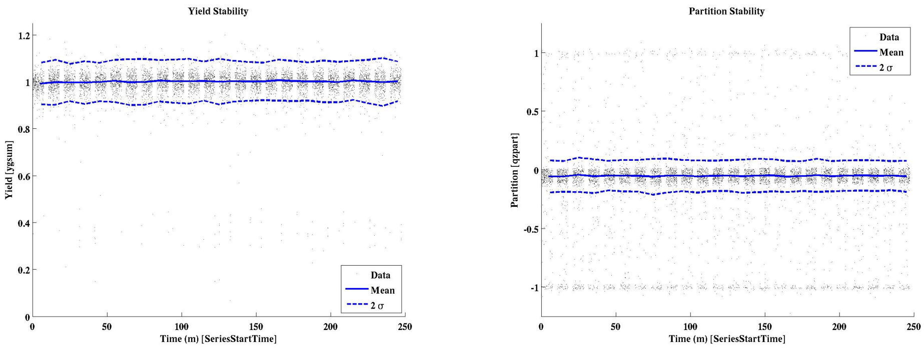

Fig. 4 The ionization yield and partition for G47 with the grounding scheme implemented. There appears to be no degradation during the entire 4 hour bias period.

found two simple running methods that can allow the detector to run for long periods with only modest loss in livetime. First, as suggested by the decay in bulk events seen in figure 3, grounding the detector for short periods of time can help to clear out the charge buildup. We biased G47 in the standard configuration for 7.5 minutes, then grounded the detector for 2.5 minutes. This cycle was repeated for a four hour period during which there is no significant decay in either yield or partition (figure 4).

Beyond simply grounding the detector, reversing the polarity of the crystal may also help to maintain stability. Figure 5 shows the ionization stability for G47 when the detector bias polarity was flipped following each 2.5 minute grounding period. We see the partition value oscillate slightly because the charge carriers are collected on changing sides, but the overall affect is to maintain the stability of the detector over the same period. Either simply grounding the detector or flipping the polarity along with grounding both appear to preserve the high discrimination of the G47, the most unstable detector, while maintaining 75% livetime. For more stable detectors, such as G48, the corresponding loss will likely be signficantly smaller.

In addition to adjusting the detector running mode, we also implemented a new ionization electrode design. A likely culprit for the charge buildup was the narrow ($8\mu m$) electrodes of the IZIP v4. A smaller surface area makes it difficult for the charge carriers to tunnel into the electrode and over time the charges begin to pileup. In order to address this issue, the IZIP v5 ($40\mu m$) was developed. Following a similar approach for the v4 detectors, G41 (v5) was biased for 2 hours, then grounded. The polarity of the surface pulses still reverse immediately upon grounding, but pulses from events in the bulk do not. Further studies must be done in order to better understand these effects, but it appears that trapped charges near the ionization electrodes are one cause of the ionization instability that can be mitigated by increasing the electrode width.

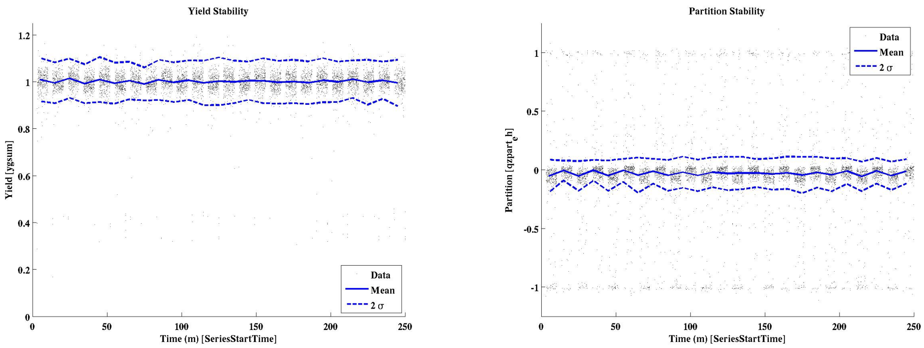

Fig. 5 The ionization yield and partition for G47 with the polarity flipping scheme implemented. Again, there appears to be no degradation during the entire 4 hour period.

4 Conclusion

While the charge instability remains a challenge in implementing the IZIP detectors, we have made significant progess in addressing this issue. A new mask with $40\mu m$ ionization rails helps to reduce the charge trapping under the electrode. Additionally, studies at the UC Berkeley surface test facility have identified possible running modes for the previous design. By grounding frequently or reversing bias polarity, we are able to maintain sufficient charge stability with only a modest loss in detector livetime. We will be testing these biasing schemes in a low background environment with the 15 detectors that we plan to deploy to Soudan in October 2011.

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