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Nuclear Instruments and Methods in Physics Research A 559 (2006) 414–416
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

First test runs of a dark-matter detector with interleaved ionization electrodes and phonon sensors for surface-event rejection

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Available online 28 December 2005

Abstract

To improve surface event rejection for the SuperCDMS experiment, we have designed, fabricated and tested a new detector concept where ionization electrodes are interleaved with phonon sensors on both sides of the detector. This i-(interleaved)-ZIP concept has electrical fields tangential to all detector surfaces. A surface event will produce an ionization signal in one charge read out channel, whereas an event within the bulk of the crystal will cause a signal in both charge read out channels. In addition, the symmetric phonon channels on both sides of the crystal, two semicircles on one side for x and two on the other for y, allow three-dimensional reconstruction of event locations through time delays and relative energy collection between the four phonon channels. Preliminary results from a 100 g Si prototype are presented.

PACS: 14.80.Ly; 95.35.+d

Keywords: Cold dark matter; Surface ionization detector

1. Introduction

The ability of CDMS ZIP-style detectors to discriminate between nuclear and electron recoils with very high accuracy is the main reason for the impressive recent results from the CDMS II collaboration [1,2]. This discrimination ability comes from measuring the ratio of ionization to phonon signals (the 'yield', for each event) and from using the pulse rise time produced by athermal phonons to veto surface electron-recoil events. For SuperCDMS [3], the proposed larger mass experiment following CDMS-II, we have begun testing a new iZIP detector design which could provide even higher surface event rejection.

2. The iZIP detector concept

Fig. 1 shows a symmetric design with phonon sensors and ionization electrodes on both sides of the detector. This configuration allows three-dimensional reconstruction of each event. Fig. 2 shows more details for one of the phonon sensors. There is a 1 mm spacing between all ionization bias electrodes and the phonon sensors. The phonon sensors serve as the ground electrode for the ionization measurements.

Fig. 3 shows a finite element method calculation for the electric field pattern with the top (bottom) electrode at

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doi:10.1016/j.nima.2005.12.026

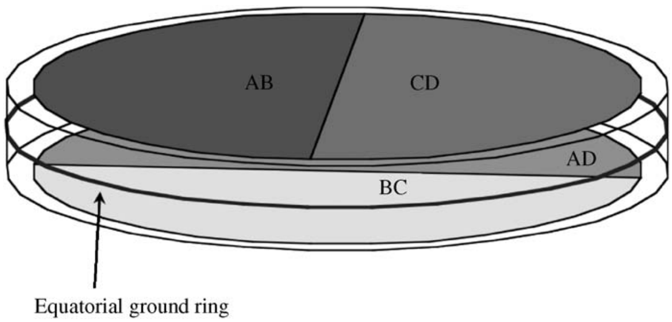

Fig. 1. Schematic of the iZIP (interleaved Z-dependent Ionization and Phonon) detector concept. The metallized equatorial ring defines the ground potential around the perimeter of the detector substrate. The four phonon sensors are arranged to allow the reconstruction of the particle event position in all three spatial coordinates by relative timing and energy collection. The ionization bias electrode (Q_{top}) on the top surface is interleaved with the two phonon channels (labeled AB & CD on the top surface) and the bottom electrode (Q_{bottom}) is interleaved with the two phonon channels (labeled AD & BC) on the bottom surface.

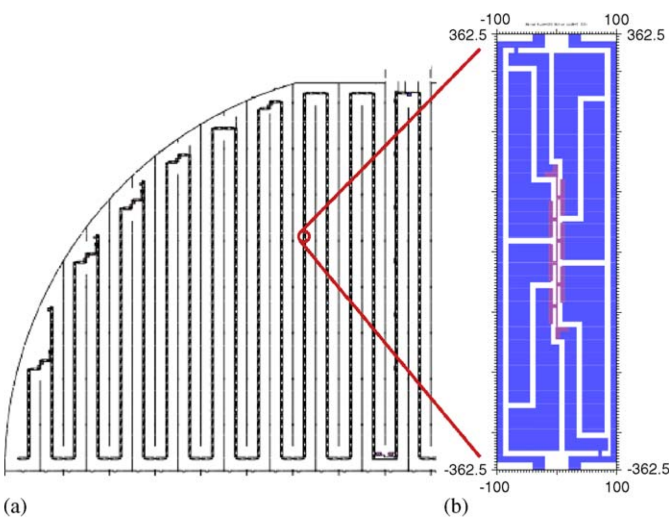

Fig. 2. (a) Design layout for one of the photolithographically patterned phonon sensors on the 76 mm diameter substrate. The phonon sensors are contained within a 200 μm wide 'ribbon' that snakes inbetween the interleaving 20 μm wide ionization rails. (b) Zoom-up showing one of the QET [2] elements comprising the phonon sensor. Eight Al athermal phonon collection fins are connected to a 1 μm wide W TES. Superconducting Al rails encompass the QET and supply the voltage bias for all 1246 QETs connected electrically in parallel for each phonon sensor.

+3 V (−3 V) with the chosen design parameters. The capacitance between the electrodes and ground is estimated to be 60 pF. This design is based on a surface rejection technique invented by Luke [4] to improve the spectra from ionization diode detectors.

3. First test results

Recently we have operated the first iZIP at the UC Berkeley Test Facility. These first results are prior to ion-implantation of the W TESs whose $T_c \sim 140$ mK. Thus, the

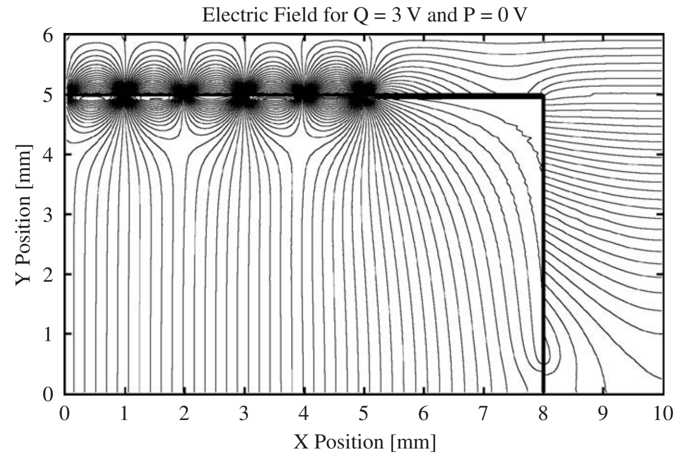

Fig. 3. Calculated electric-field distribution expected for the iZIP electrode configuration with only one quadrant in cross-section shown. Note that the equatorial ground ring maximizes the utility of the surface-ionization scheme to shield the outer perimeter of the detector substrate.

phonon response is expected to be non-optimal. In addition, one phonon channel ('CD' in Fig. 1) has an electrical short. However, both phonon sensors on the other side ('AD' and 'BC') were well matched and allowed us to make an estimate of the phonon energy.

We obtained a large calibration data set with a ^{60}Co gamma source. The trigger was formed using the two good phonon channels on the bottom of the detector. Fig. 4 shows the top-surface ionization signal height versus the bottom-surface ionization signal height. The band of events near the midline correspond to bulk events. A cut can be made to remove surface events using radial lines on either side of the central band.

As shown in Fig. 5, after using this surface cut and a χ^2 cut for the charge signals, we obtain the charge versus recoil energy for (a) ^{60}Co events and for (b) ^{252}Cf neutron and gamma source. The nuclear recoil band is clearly visible. An approximate energy scale was obtained using the known charge amplifier feedback capacitance. The fiducial volume efficiency of the cuts chosen is 74% for both data sets.

4. Conclusions

In summary, the first Si iZIP detector has demonstrated the principle of surface-event rejection using interleaved ionization electrodes and phonon sensors. We expect full demonstrations soon that will characterize the rejection factors in detail for Si and for Ge iZIP detectors. If successful, 1 in. thick by 3 in. diameter iZIPs can form the base design for SuperCDMS.

Acknowledgements

This work is supported by the National Science Foundation (NSF) under Grant no. AST-9978911, by the

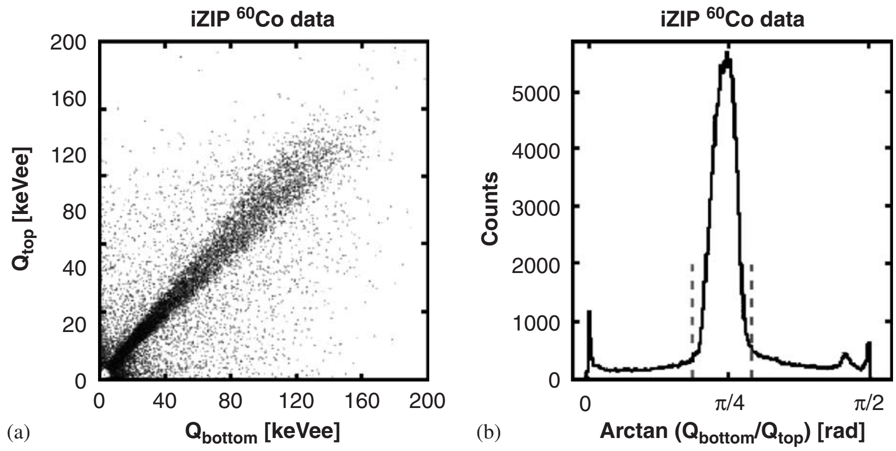

Fig. 4. (a) Ionization signal from the top-surface (Q_{top}) ionization electrode plotted against the bottom-surface electrode (Q_{bottom}) for a ^{60}Co external source without any analysis cuts. The energy calibration is approximate and given in units of keV electron equivalent. Bulk events within the crystal produce equal (but opposite polarity) charge pulses in both ionization channels, whereas events near one surface (within ~700 μm, see Fig. 3) will only generate events in one of the ionization channels. (b) A histogram in radial angle of (a) showing the response of the ionization channels for the almost uniform irradiation of the 1 cm thick Si substrate. The cut used in subsequent analysis to reject surface events is shown by the (dashed) vertical lines.

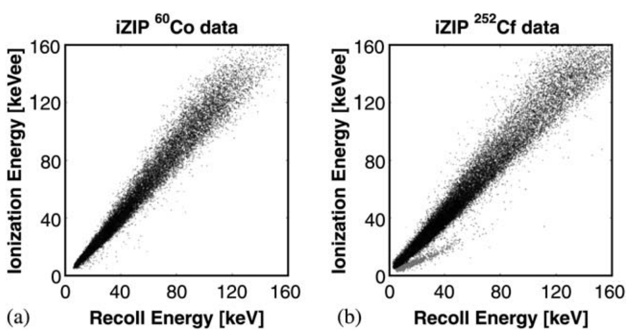

Fig. 5. Preliminary results showing coincident ionization and phonon signals ($|Q_{top}| + |Q_{bottom}|$ vs $P_{AD} + P_{BC}$) for (a) ^{60}Co source calibration producing only gamma events, (b) ^{252}Cf source calibration producing both electron and nuclear recoil events. The nuclear recoil events are clearly identified as the events in the lower band with a relatively reduced ionization yield of ~30%. The energy calibrations shown are only approximate. Some analysis cuts have already been performed on the raw events, as described in the text.

Department of Energy under contract DE-FG03-90ER40569. These iZIP detectors are fabricated in the Stanford Nanofabrication Facility (which is a member of the National Nanofabrication Infrastructure Network sponsored by NSF under Grant ECS-0335765). In addition, seed funding for SuperCDMS detector development has been provided at Stanford by the KIPAC Enterprise Fund, the Dean of Research, and a Center for Integrated Systems Internal Grant.

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