Single-charge-carrier-type sensing with an insulated Frisch ring CdZnTe semiconductor radiation detector

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Performance optimization of an insulated Frisch ring design was investigated for a 3×3×6 mm CdZnTe planar semiconductor detector. The Frisch ring was composed of copper and was insulated from the detector surface with Teflon. Optimization variables included the Frisch ring length and the bias voltage. Optimized overall device performance was found using a 5 mm long Frisch ring extending from the cathode toward the anode, leaving a 1 mm separation between the Frisch ring and the anode. The best energy resolution observed was 1.7% full width at half maximum at 662 keV with the ring extending 4 mm from the cathode toward the anode. © *2004 American Institute of Physics.* [DOI: 10.1063/1.1668332]

CdZnTe has shown potential as a room-temperature semiconductor radiation detector, but the effect of severe "hole" trapping inhibits the ability to efficiently collect the total charge. Conventional planar geometry radiation detectors require efficient charge collection of both electrons and holes to produce good energy resolution; hence, hole trapping poses a serious problem for CdZnTe radiation spectrometers. Single-charge-carrier device designs alleviate many of the problems caused by hole trapping. Such "electron-only" devices rely mostly on the transport of electrons to induce a signal and, by negating the deleterious effects of hole trapping, give improved energy resolution.

Frisch-grid-based designs have become a popular choice for semiconductor single-carrier radiation detectors.[1–5] The Frisch grid is a conductive screen structure originally fashioned for gas-filled ion chambers and is usually located near the anode.[6] Generally, a potential is applied to the device such that negative charges (electrons) drift through the grid toward the anode. A signal is induced at the anode by the charge motion between the grid and the anode, whereas the Frisch grid screens out the induced signal from slow moving positive ions drifting toward the cathode. Placing the grid near the anode ensures that the origin of induced signal is from those electrons that drifted from the detector volume into the measurement region, thereby causing the signal to form mainly from electron motion.

Several methods of creating a Frisch-grid effect without an embedded grid have been studied in semiconductor detectors.[1–5] Methods showing promise include "coplanar" and "small-pixel-effect" devices.[1–3] A simple method of achieving single-carrier performance was demonstrated with side contacts acting as the Frisch grid.[4,5,7] Unfortunately, all of the aforementioned designs suffer from problems, which include leakage current between the anode and grid, processing difficulties, or electric-field distortions.

The noncontacting Frisch ring detector eliminates grid-to-anode leakage current while still achieving single-carrier performance.[7] The design utilizes a bar-shaped detector inserted into a conductive ring, which also allows for an insulator filling between the Frisch ring and the detector body.[7] The conductive ring, when connected into the circuit between the anode and the cathode, confines the largest change in the weighting potential near the anode while effectively screening induction from charge motion in the region extending from the ring edge to the cathode. The applied voltage need only drift electrons toward the anode, hence a variety of biasing schemes can be used, which include connecting the ring directly to the cathode. Figure 1 displays the Frisch ring device and its components. Charge induction on the anode

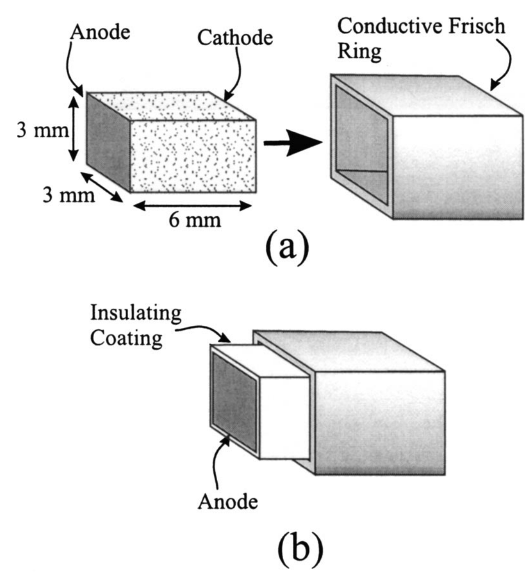

FIG. 1. A bar-shaped detector placed inside a conductive ring. (a) The CdZnTe device is completely separate from the noncontacting Frisch ring, and can be (b) inserted into the ring after a Teflon insulating coating has been applied.

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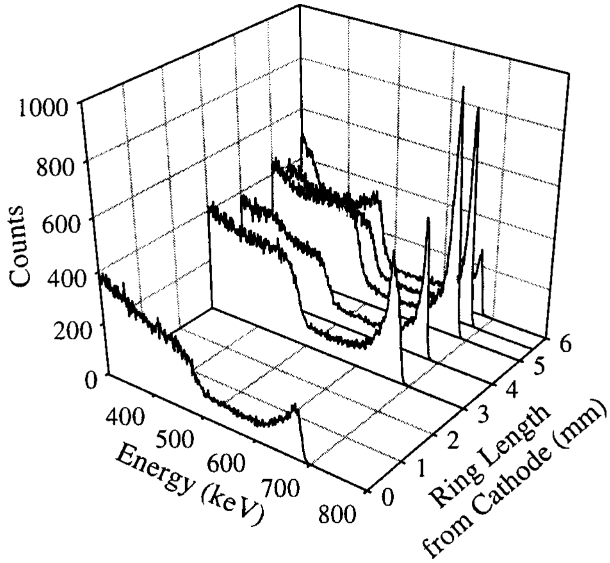

FIG. 2. ^{137}Cs spectra from a $3\times3\times6$ mm Frisch ring detector at 900 V bias. The ring length was varied from 3 mm to full length of the device.

occurs mainly in the gap region (measurement region) between the anode and the Frisch ring. One variation of the Frisch ring device was demonstrated elsewhere with promising results.[8] Here, the authors demonstrate the ability for such a device to be tuned to achieve optimum performance.

A $3\times3\times6$ mm CdZnTe crystal, acquired from Saint Gobain in Newbury, Ohio, was hand polished and etched briefly with a 2% bromine/methanol solution. Electroless gold contacts were applied to the ends, thereby composing the anode and cathode contacts. Afterward, the side surfaces were polished further to reduce the side-surface leakage current. The side surfaces of the device were then covered with Teflon tape. The insulation reduces the side-surface leakage current and eliminates the contact leakage current from the ring, both of which can degrade energy resolution. Copper tape was wrapped around the device on top of the Teflon so that one side of the tape was flush with the cathode. Hence, the copper formed the conductive Frisch ring around the device. The length of the copper ring was varied in the experiment from 3 mm to 6 mm, thereby decreasing the gap between the anode and the ring in measurable increments. A small tab of copper bent over the edge connected the Frisch grid and cathode, thereby allowing the same voltage to be applied to both. The detector was placed in a holding apparatus that pressed the cathode against a Be window. With the cathode grounded, a pogo pin was used to apply voltage to the anode. The detector was irradiated with a ^{137}Cs source located 5 mm from the cathode. The induced signal was measured from the anode connected to an eV Products 550 preamplifier. Six spectral sets of 10 min duration were acquired at 100 V intervals ranging from 500 V to 1000 V. The length of the ring was changed in small increments, which defined each spectral set. Overall, spectra were acquired with ring lengths of 6, 5.5, 5, 4, and 3 mm, and with no ring at all.

Figure 2 shows the performance of the detector as a function of ring length. The gap between the Frisch ring edge and the anode is the ring length subtracted from the CdZnTe bar length. The spectral features changed dramatically, including energy resolution, photofraction, peak-to-Compton

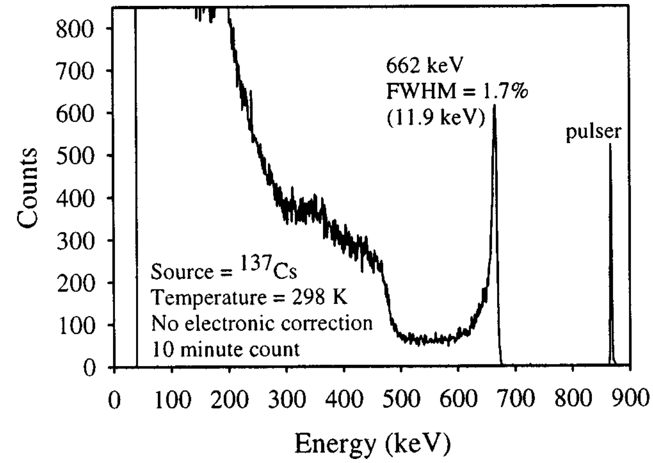

FIG. 3. ^{137}Cs spectra from a $3\times3\times6$ mm CdZnTe detector with a 4 mm insulated Frisch ring at 800 V bias.

ratio, and peak-to-valley ratio. From Fig. 2, the tallest peak was observed with a ring length of 5 mm. Varying the ring length greater than or less than 5 mm reduced the photofraction. All spectra show improved performance over the device with no ring, except for a ring length of 6 mm. It should be observed that a dramatic improvement in the device performance occurred by moving the Frisch ring edge only 0.5 mm back from the anode. Note also that device performance for no Frisch ring and the 6 mm long Frisch ring are comparable (6 mm corresponding to a ring length extending the entire length of the CdZnTe bar).

Higher electric fields could be applied to the device with the insulated Frisch ring installed than without. In most cases, up to 1200 V could be applied to the device with little increase in noise. Operation at 1200 V or above without the grid resulted in significant electronic noise.

Some notable performance instabilities were observed. In some instances, a satellite peak appeared in the spectra. Also, some performance degradation over time was observed when biases above 800 V were applied for long periods of time. However, upon refabrication of the electroless gold contacts, the instabilities were practically eliminated, indicating that the contact fabrication process is vital to optimal performance.

The device performed exceptionally well, with the best

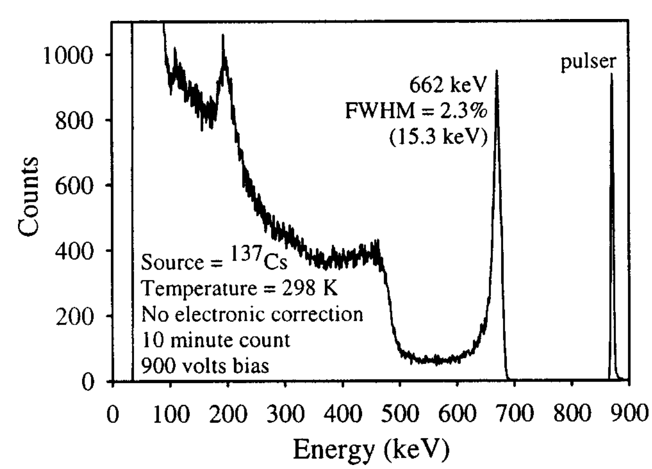

FIG. 4. ^{137}Cs spectra from a $3\times3\times6$ mm CdZnTe detector with a 5 mm insulated Frisch ring at 900 V bias.

observed energy resolution being 1.7% full width at half maximum (FWHM) at 662 keV using a 4 mm long Frisch ring and a bias of 800 V (see Fig. 3). However, the highest peak-to-valley ratio (15.8) and the most efficient photofraction (≈6%) were observed with a 5 mm long Frisch ring (see Fig. 4), which yielded an energy resolution of 2.3% FWHM at 662 keV.

The insulated Frisch ring design improves the spectroscopic performance of a planar CdZnTe bar detector without complicated electronics or cryogenic cooling. Results recently reported elsewhere corroborate the findings in the present work.[9] In the present case, the Frisch ring device was observed to have the best performance with the ring edge placed 1 mm back from the anode, whereas the highest resolution at 662 keV (1.7% FWHM) was observed with the Frisch ring edge placed 2 mm back from the anode, constituting an optimal energy resolution for such a device. Vast improvements are achieved in resolution, peak-to-Compton ratio, and peak-to-valley ratio over the simple planar device. Furthermore, the simplicity of design allows for inexpensive processing, a clear advantage over other single-carrier designs.

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