Performance Improvement of CdZnTe Detectors Using Modified Two-Terminal Electrode Geometry

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ABSTRACT

Recently, much has appeared in the literature concerning methods to improve the resolution and photopeak efficiency of CdZnTe radiation detectors operating at or around ambient temperature. These methods generally involve either the use of modified electrode structures (e.g. coplanar grids, three-terminal devices) or pulse processing techniques, both of which add complexity, and hence cost, to the production and operation of such devices. In this paper, we will report on results obtained with a simpler, modified two-terminal device.

The detector structure combines a planar anode with an extended surface cathode, and relies on a standard, single channel preamplifier/shaping amplifier system. The results obtained demonstrate that the charge collection efficiency of the device, as shown by the Peak-to-Valley (P/V) ratio, is significantly improved when compared to the standard planar geometry, especially at higher (>200 keV) photon energies.

1. INTRODUCTION

Compound semi-conductor-based, room-temperature-operation, radiation detectors have been used for many years with varying degrees of success. Recently, CdZnTe has become the material of choice for many applications, including Nuclear Medical imaging, non-destructive testing and nuclear safeguards and non-proliferation measurements.[1] However, CdZnTe, in common with all of the other materials (e.g. GaAs, PbI_2, TlBr etc.) that have been used, exhibits charge collection problems that may limit its use in spectroscopic applications. These problems arise from the fact that the mobility-lifetime product ($\mu\tau$) of the "holes" is significantly lower, by up to 2 orders of magnitude, than that for the electrons. The disparity between the collection times of the electrons and holes results in an increase in the low energy tailing that increases with photon energy.

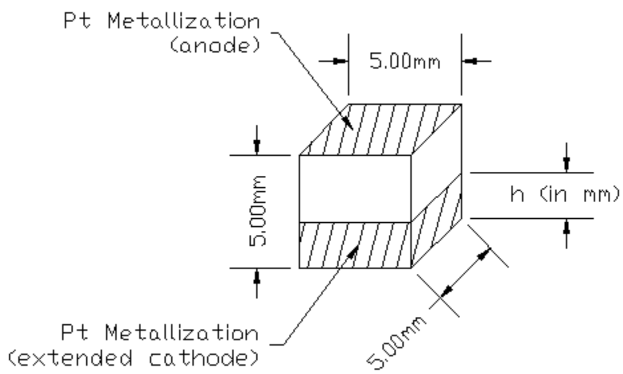
Various methods have been proposed over the last few years to mitigate this problem. These include electronic correction methods of different types, modification of the CdZnTe material properties and the use of contact structures to make use of the electron collection only. The most recent work has focused heavily on the development and production of Co-Planar Grid-type devices (modified Frisch grids) and these efforts have yielded significant improvements.[2,3,4,5] However, these devices require extensive processing and preparation, in addition to a relatively complex mounting scheme and readout electronics. They are also primarily aimed at the >500 mm^3 volume range and are not readily amenable to smaller detector volumes. Finally, the processing cost and material requirements result in a higher selling price than can be justified in many cases.

Other methods include the use of the quasi-hemispherical geometry, which yields excellent spectroscopic performance but again has certain limitations, mainly resulting from the highly non-linear field close to the small anode.[6] Recently, a 3-terminal device (Spectrum Plus from Digirad Corporation) was shown that offered excellent energy resolution but has certain limitations in the areas of efficiency.[7] Finally, work has been performed in various institutes and commercial companies with a view to producing PIN-type devices, rather than the more common MSM-type.[8] These efforts have yielded detectors that offer excellent spectroscopic performance but a limited area or active volume, thus reducing their potential uses in the field to high rate or long count time applications.

We began a limited program last year to investigate the possibilities of producing a relatively small volume detector (125-250 mm^3) that would offer the improved charge collection and hence reduced tailing and better energy resolution. Further, the design chosen offers a fully active detector volume and excellent long-term stability.

2. DETECTOR DESIGN AND FABRICATION

The study started with the basic premise that the device structure had to offer a modified internal field that would allow the greater probability of electron transport in the device to dominate the charge collection process. Building on the concept of the quasi-hemispherical devices, a design that maintained a full-area anode and an extended cathode was chosen. This was realized by allowing the cathode metallization to extend a certain distance up the sides of the cubic detector blank (5x5x5 mm^3) chosen for the experiment (figure 1). This electrode configuration is referred to by eV PRODUCTS as CAPture^{TM} technology and will be referred to by this name in this paper.



The resulting electric field distribution and electrostatic potentials are shown in figure 2.

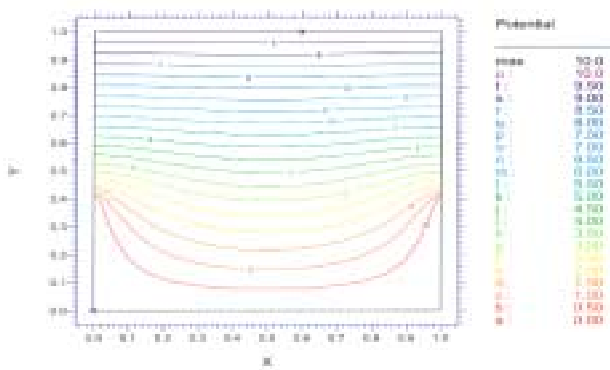


Figure 2a: Electrostatic Potential map of the CAPture^{TM} technology detector

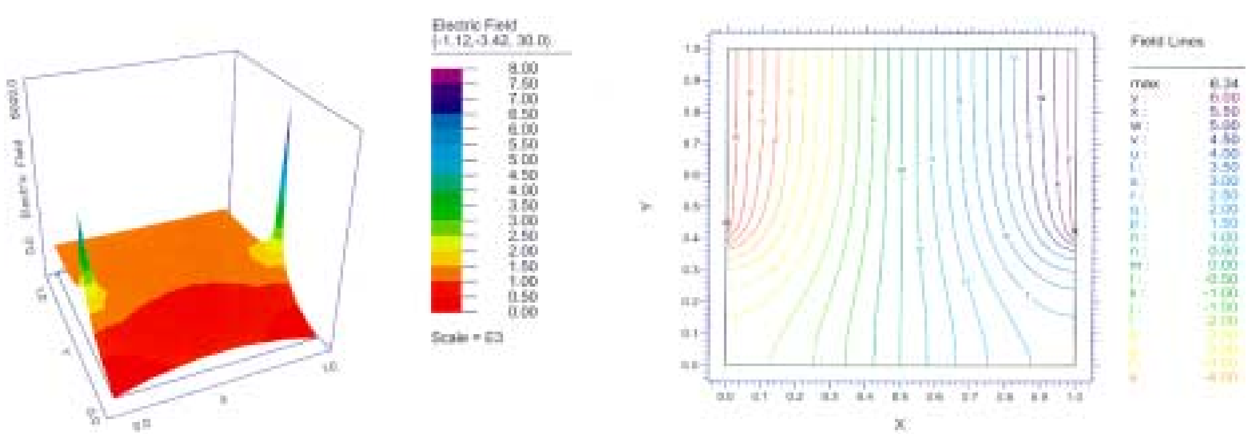


Figure 2b and 2c: Electric Field topographical map and field line distribution

The internal field is modified in such a way that there is a low field region corresponding to the volume defined by the dimensions of the cathode extension, with the linear, higher field region starting above the extended cathode. This field structure will result in a predominantly electron-only device, at least for interactions taking place in the low field region. Carriers generated in this region will have to traverse the low field, with the holes migrating towards the cathode and the electrons towards the anode. As the lifetime for the electrons is ~10 times longer than for the holes, the electrons have a high probability of traversing the low field region and arriving in the high field region. Once in the high field, the electrons will induce charge in the normal manner on the anode. In contrast, the holes, due to their low mobility and short lifetime, will induce only negligible charge on the cathode. This model indicates that, by varying the length of the cathode extension and the total detector height, a detector can be tailored to function optimally at a given energy. We chose to work with 5x5x5 mm^3 detectors for this program, with a cathode extension of 1 or 2 mm height, and all results given below will be on that dimension. The results in figure 2 were obtained using a 2 mm height cathode extension.

The detector blanks used in the experiment were selected from various ingots grown using the High Pressure Bridgman technique and in different furnaces of both the original and the newer designs, and were characterized as standard planar detectors. The planar contacts were then removed using a standard Br-MeOH solution and the areas that were not to be metallized were then masked off using tape. The prepared blank was then placed in the Perkin Elmer 4400 sputtering and platinum electrodes of approximately 500 nm thickness was applied. The detectors were then removed from the machine and cleaned using standard techniques. No surface passivation of the uncontacted areas was applied, in order to identify potential surface issues (scratches, edge chips, etc.) that may cause problems when the detector is placed under bias

3. DETECTOR PERFORMANCE

The detectors fabricated using the standard process described above were tested in a standard spectroscopy set-up, comprising an eV-550 preamplifier and an Aptec MCA/high voltage supply and shaping amplifier. All planar detectors were tested using 1000 V bias and 0.5 μs shaping times in order to obtain a standard classification of the material grade used. No detectors of less then Discriminator grade (as defined by eV PRODUCTS standard specification) were used, and all detectors were fabricated from single crystal material, although no effort was made to exclude twins.

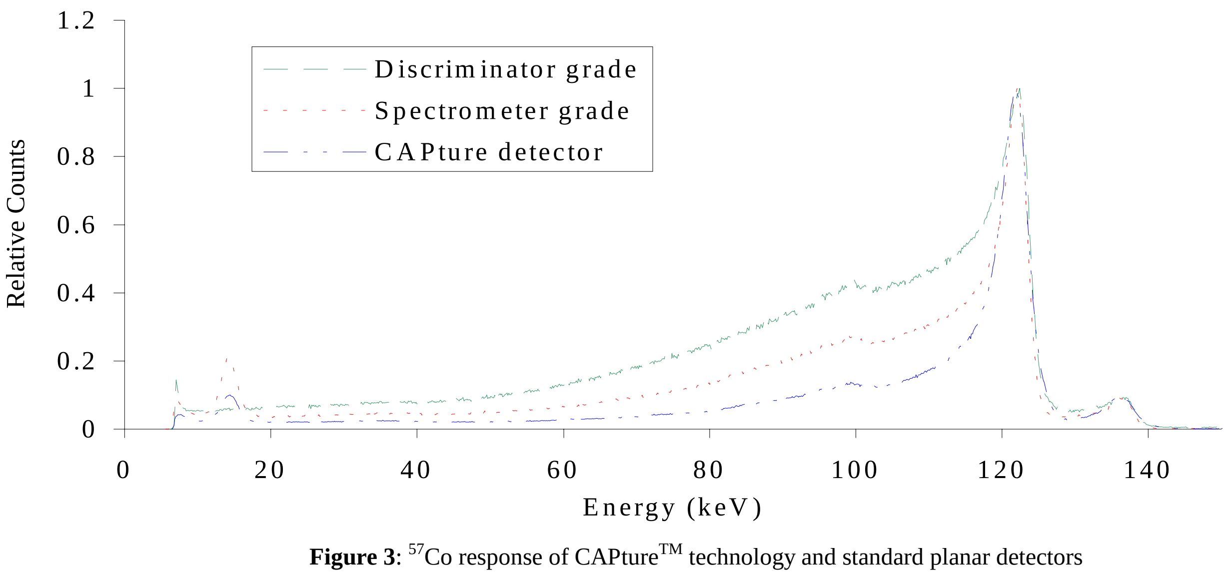


Figure 3: ^{57}Co response of CAPture^{TM} technology and standard planar detectors

Subsequent to the re-processing, the detectors were tested again using the original bias voltage, but, in order to determine the effect of the new contact geometry, various shaping times were used. It was found that a short (0.25μs) shaping time gave the best combination of improved energy resolution and lower tailing so this value was used in all subsequent measurements. Figure 3 shows the performance achieved with one of the original detectors fabricated in this study. The cathode extension in this case is ~1mm. For comparison purposes, the spectrum obtained from a Spectrometer grade detector of identical size is also shown. It should be noted that the performance obtained with this planar detector is seen in only a very small percentage of planar detectors. All spectra were individually energy calibrated and normalized to the 122 keV peak counts to provide a clearer comparison.

Several features are apparent in the spectra and deserve comment. Firstly, it is plain that the original planar, Discriminator grade, detector exhibits significant low-energy tailing associated with incomplete hole collection due to trapping. However, after reprocessing into a CAPture™ technology detector, the spectrum shows a significant improvement in this regard. It can also be seen that the Cd and Te escape peaks are approximately the same size in all detectors, indicating the effective detection volume is comparable. Finally, it should be noted that the Full Width Half Maximum (FWHM) resolution value for both the Spectrometer grade detector and the modified detector are very similar but the Full Width Tenth Maximum (FWTM) value is significantly better for the new design. This can be interpreted as indicating that even in the Spectrometer grade device there is still some evidence of incomplete hole collection.

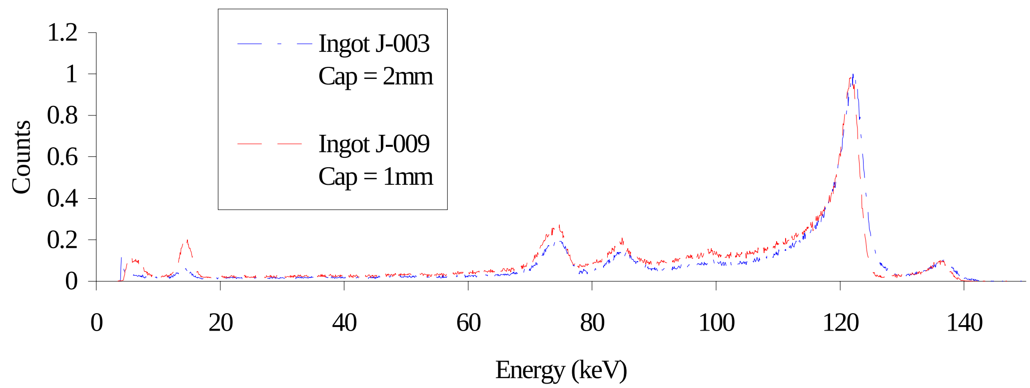


Figure 4: ^{57}Co response of CAPture technology detectors with different cap sizes

Figure 4 illustrates the difference in performance with 2 different lengths of cathode extension, 1mm and 2 mm. In this case, both spectra were individually calibrated for energy but the live time was fixed to 60 seconds. Also, a 1mm-diameter lead collimator was used, in order to reduce the low energy tailing associated with off-axis events that can occur in an open field irradiation condition. The x-ray fluorescence peaks can be clearly seen in both spectra. The resulting spectra illustrate that the longer cathode extension results in improved collection efficiency, as evidenced by the higher photopeak and reduced low energy tailing. It is also apparent that the detection efficiency for the 14.4 keV x-ray is reduced. This may be explained by the fact that all of these events generate carriers very close to the cathode, and hence in the weak field region. Although the lifetime of the electrons is relatively long, there is still a high probability of recombination and trapping in this region and hence no charge induction on the anode resulting from the interaction.

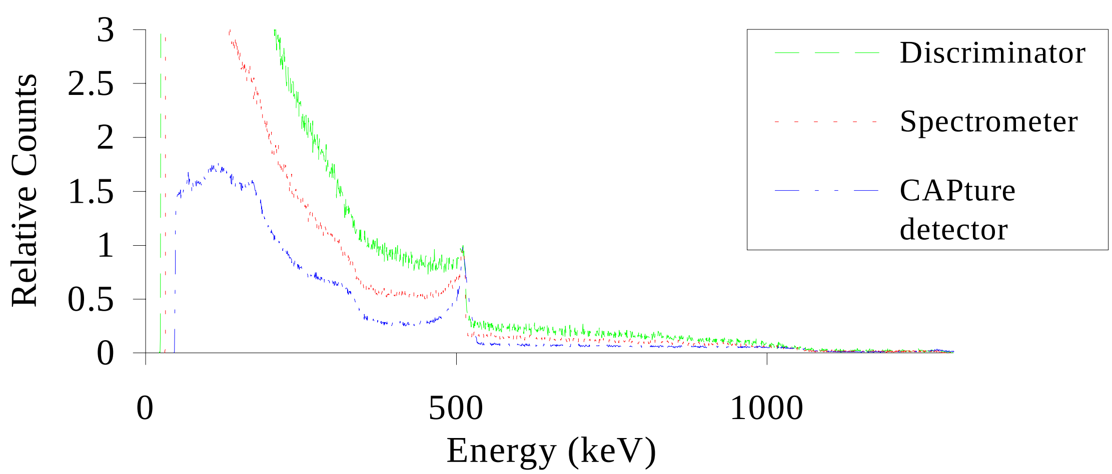


Figure 5: Response of CAPture™ technology and planar detectors to higher energy photons.

Figure 5 illustrates the response of one of the new CAPture^{TM} technology devices at higher energies (511 keV from ^{22}Na.) Once again, it is clear that the low energy tailing is reduced, although due to the much longer mean free path length of the higher energy photons in the CdZnTe, and the resultant generation of carriers in the high field region, there is significant low energy tailing visible.

4. CONCLUSIONS

It has been shown that the modified contact geometry embodied in the CAPture^{TM} technology results in an improved spectral response of the CdZnTe detectors. Various sizes of cathode extensions have been investigated and the performance characteristics measured. We have found that for a 5x5x5mm^3 device, 2mm cathode extensions provide the best compromise for all commonly used isotopes. Energy resolutions (FWHM) with these detectors of <3keV @59.5 keV, <5 keV @ 122.1 keV and <13 keV @ 662 keV have been obtained with commensurate reductions in low energy tailing.

Further work to more accurately model the internal field will be undertaken in the near future, along with work on various different sizes in an attempt to develop the largest possible detector using this technique. Additional tests will be performed using fine collimators to investigate the effect of the corners on the spectral shape, and also to attempt to improve further the performance by identifying possible deleterious effects associated with twin boundaries and/or internal structures in the material.

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