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Comparison of 5 and 10 mm thick HgI_2 pixelated γ-ray spectrometers

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Abstract

HgI_2 detectors fabricated with pixelated anodes were tested as potential room temperature spectrometers. Spectra were obtained with 5 and 10 mm thick devices, and their results were compared. The 5 mm thick devices showed some effect of the anode weighting potential, while the 10 mm thick devices showed the effects of charge diffusion/sharing and electron trapping. A resolution near 1.4% FWHM using a ^{137}Cs source was achieved after correcting for the interaction depth within the detector. The resolution from individual depths was as low as approximately 1.1% FWHM.

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Keywords: Mercuric iodide; Room temperature; Compound semiconductor; γ-ray detectors

1. Introduction

Mercuric iodide (HgI_2) crystals are being investigated as a potential γ-ray spectrometer that can operate at room temperature. However, like most compound semiconductor γ-ray spectrometer materials, HgI_2 suffers from poor charge transport characteristics. Despite the fact that HgI_2 has a wide band gap, high average atomic number, and a high density, the crystals suffer from low electron and hole mobility, significant hole trapping, and material non-uniformity. For these reasons, HgI_2 spectrometers have been limited to a thickness less than 3 mm. To improve the spectroscopic performance of thicker HgI_2 detectors, one must reduce the depth dependence of the generated pulse from a γ-ray interaction event common to these materials.

The use of single-polarity charge sensing was implemented in order to overcome the severe hole trapping present in wide band gap semiconductor detectors, including HgI_2. The introduction of pixelated anodes to CdZnTe [1,2] and HgI_2 [3] showed that the resolution of wide band gap semiconductor detectors can be dramatically improved compared to standard planar electrode configuration. By simultaneously measuring the signal from the planar cathode and anode pixels, the interaction depth [4] can be obtained by calculating the ratio of the induced charge on each electrode.

In this paper, we present and compare spectroscopic results from 5 and 10 mm thick HgI_2 detectors. Both raw and depth-corrected spectra

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are presented, along with a comparison of the peak position as a function of depth of interaction.

2. Detector description and setup

The anode pixel configuration used in this work is shown in Fig. 1. The four small pixels are surrounded on all sides by a large anode plate. The area of each pixel is $\sim 1\,mm^2$ and is comprised of palladium. When the cathode is negatively biased, electrons moving toward the anode surface induce charge on the pixels. The induced charge on a pixel is determined mainly by the movement and collection of electrons underneath each pixel. The signal produced by the anode pixel is only slightly dependent upon the distance traveled by the electrons, and is not significantly affected by hole movement.

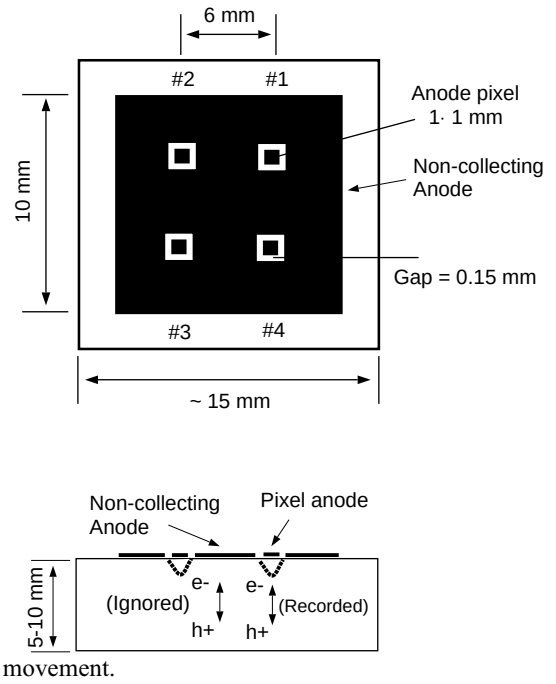

Fig. 1. Top: view of the HgI_2 anode configuration. Bottom: cross-sectional view of the crystal. The lines under the pixels represent the region of the detector where the majority of the induced charge on the anode is produced.

The detector electrodes are connected to Amp-Tek [5] A250 charge-sensitive preamplifiers, which are connected to standard NIM shaping amplifiers for pulse shaping and amplification purposes. The signals are fed into peak-hold circuitry to hold the peak of the shaped pulse for a sufficiently long time before the ADC samples the pulse amplitude. The signals are analyzed by programs produced using LabVIEW™ and Matlab® software.

3. Results

3.1. 5 mm thick detectors

The majority of the data from 5 to 6 mm thick detectors have been described previously [6]. These detectors had resolutions near 2.1% FWHM at 662 keV after correcting for the interaction depth. Interaction depth is broken up into 20 thin strips known as the "depth index." For example, a depth index of 1 would indicate events near the anode surface, while a depth index of 20 indicates events near the cathode surface. The resolution obtained at individual depth indices reached 1.6% FWHM (Fig. 2). The resolution of the spectra was independent of the depth index; however, spectral

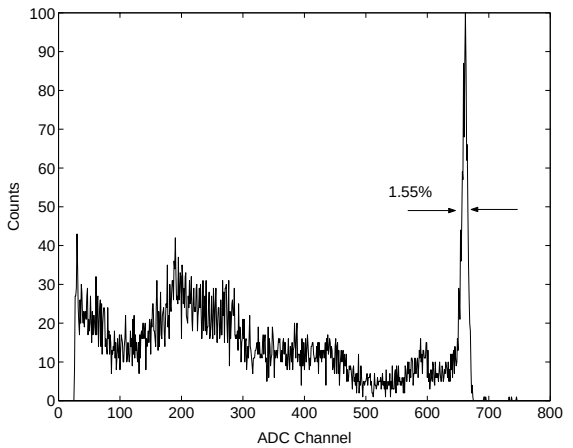

Fig. 2. ^{137}Cs spectrum collected over 22 h from an individual depth of a 5.9 mm thick detector (Pixel #2) biased at −1500 V and using a shaping time of 4 μs. The resolution of the 662 keV γ-ray was 1.55%. The events selected here are from interactions near the middle of the detector.

resolution from events near the electrodes (anode or cathode) degraded to 2.3–3.7% FWHM. Poor resolution near the anode was expected because, in this region, the induced charge (weighting potential) has a steep slope. Thus, the recorded pulse can be highly dependent on the interaction depth near the anode and on the induced charge produced by the small amount of hole movement present in these detectors. For events near the cathode, the degradation in energy resolution was due to electron trapping, charge sharing between the anode pixel and the non-collecting anode, and material non-uniformity effects.

3.2. 10 mm thick detectors

Fig. 3 is an example spectrum collected over the same time frame as the 5 mm devices. The resolution of the spectrum was approximately 3% FWHM at 662 keV prior to correcting for interaction depth, and improved to 1.4% FWHM after depth correction. Resolutions as low as 1.0–1.1% FWHM can be observed when analyzing the spectra from individual depths (Fig. 4). The lack of dependence on hole movement and the dependence of peak position on interaction depth were also seen in the 10 mm detector.

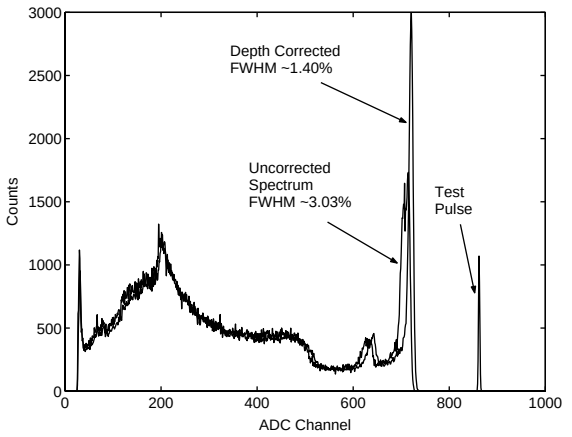

Fig. 3. ^{137}Cs spectrum collected over 22 h from a 10 mm thick detector (Pixel #2) biased at –2500 V and using a shaping time of 8 μs. The electronic noise of the system was approximately 2.8 keV. This value was consistent for all pixels tested.

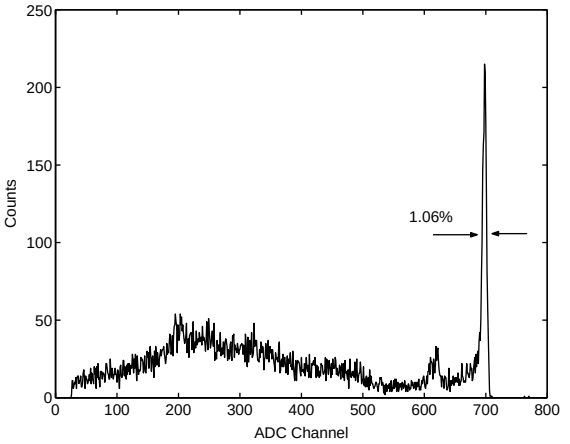

Fig. 4. ^{137}Cs spectrum collected over 22 h from an individual depth of a 10 mm thick detector (Pixel #2) biased at –2500 V and using a shaping time of 4 μs. The resolution of the 662 keV γ-ray was 1.06%. The depth index of this spectra was 10, which corresponds to γ-ray interactions from the middle of the detector (i.e., 5 mm from the cathode or anode surface).

4. Discussion

It is important to note that differences in the weighting potential, electron trapping, and charge sharing between anode pixels can have a significant effect on the spectra between 5 and 10 mm thick HgI_2 detectors. For thinner pixelated detectors, there will be a larger dependence on depth as electrons traverse the detector. This is shown in Fig. 5. The slope of the weighting potential throughout the majority of the thickness of the detector is slightly larger for 5 mm detectors. The non-zero slope in the bulk of the detector causes the induced signal to have a slight depth dependence This results in a variation of photopeak position as a function of interaction depth. This effect can be seen when comparing peak position data with expected results (Fig. 6).

When comparing the peak position as a function of depth index between 5 and 10 mm thick detectors, a number of features can be distinguished. The 5 mm peak positions tended to lie below the expected curve for nearly all depth indices. This indicates that there was a more severe depth dependence on the induced charge than what was expected. The assumptions on weighting

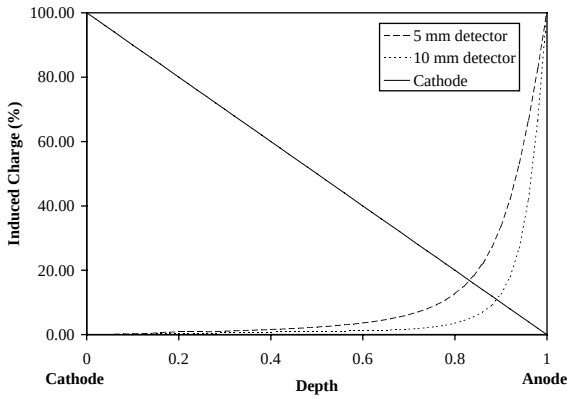

Fig. 5. Weighting potential versus normalized depth for 5 and 10 mm thick HgI_2 pixelated anodes. The weighting potential for the planar cathode is also presented for reference.

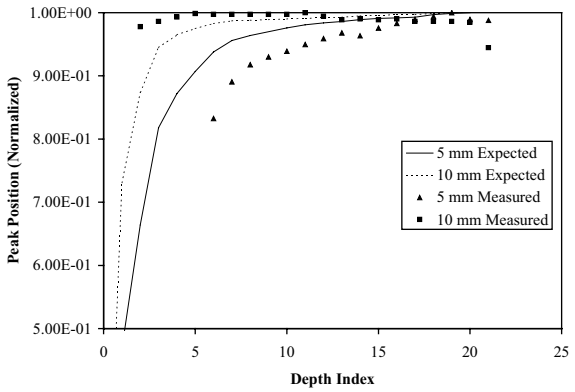

Fig. 6. Normalized peak position as a function of depth index.

potential (such as material uniformity) may not be entirely correct in this case [7]. A more severe depth dependence would adversely affect the overall resolution even with depth correction. Despite its advantages, depth correction cannot overcome the finite difference in the weighting potential within an individual depth (or voxel) itself.

The number of depths that contained a clear photopeak was larger for 10 mm thick detector as a result of the weighting potential While the 10 mm measurements agree quite well with expectations, the measured data tends to be slightly higher for events near the anode (depth index 3–7) and slightly lower than expected for events near the cathode (depth index 15–20). The slightly higher induced charge could be due to a small amount of hole movement within the detector. The decrease in induced charge from γ-ray events near the cathode could be due to electron trapping and charge sharing.

5. Conclusion

HgI_2 detectors of 5–10 mm thickness with pixelated anodes have been tested as potential room temperature γ-ray spectrometers. Since hole collection is unnecessary, relatively low electric fields and short shaping times were used. By using pixelated anodes and depth sensing and correction techniques, the resolution of individual pixels can be less than 2% FWHM when using a ^{137}Cs source. These detectors show no significant polarization effects resulting in the degradation of resolution. However, the 10 mm results showed the effects of charge trapping and charge sharing that degraded the signal from events near the cathode. If these effects can be reduced, the detector performance (resolution and photopeak efficiency) should improve.

Acknowledgements

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References

[1] H.H. Barrett, Phys. Rev. Lett. 75 (1995) 156.
[2] Z. He, W. Li, G.F. Knoll, D.K. Wehe, J. Berry, C.M. Stahle, Nucl. Instr. and Meth. A 422 (1999) 173.
[3] Z. He, R.D. Vigil, Nucl. Instr. and Meth. A 492 (2002) 387.
[4] Z. He, G.F. Knoll, D.K. Wehe, R. Rojeski, C.H. Mastrangelo, M. Hammig, C. Barrett, A. Uritani, Nucl. Instr. and Meth. A 380 (1996) 228.
[5] Amptek, Inc., 6 Angelo Drive, Bedford, MA 01730, USA.
[6] J.E. Baciak, Z. He, R.P. DeVito, IEEE Trans. Nucl. Sci. NS-49 (3) (2002) 1264.
[7] Z. He, Nucl. Instr. and Meth. A 365 (1995) 572.