Large Volume HgI_2 Gamma-Ray Spectrometers

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Abstract. This paper demonstrates the enhanced capability of single polarity charge sensing, the 3-dimensional position sensing technique, developed at the University of Michigan and previously successfully demonstrated on CdZnTe detectors, to improve the spectroscopic performance of HgI_2 and to extend its range for spectrometry to an unprecedented thickness of 10 mm. Energy resolutions of close to 1% FWHM at 662 keV gamma-ray energy were obtained from individual depth locations underneath pixel anodes, and 1.4-2.0% FWHM energy resolutions from 5 out of 6 tested pixel anodes on two 10 mm thick detectors.

Introduction

HgI_2 has properties of high atomic number (Z=80-53), high density (ρ= 6.3 g/cm^3), wide band-gap (2.13 eV) and high bulk resistance (10^{12}-10^{13} Ω). These properties make it a very attractive material for efficient gamma-ray detectors capable of room-temperature operation. However, problems of charge trapping, material non-uniformity and temporary change of its properties result in poor spectral performance and limited thickness (not more than 3 mm) of a conventional detector using planar-electrodes.

The 3-dimensional position-sensitive single-polarity charge sensing technique developed at the University of Michigan [1] should be able to eliminate the problem of trapping of holes, to correct for the trapping of electrons, and to mitigate the material non-uniformity to the scale of the position resolution (~1 mm in 3-dimensions) of the detector system. Figure 1 illustrates the principle of the 3-dimensional position sensing technique. A two dimensional array of anode pixels is fabricated on the anode surface and all pixels are biased at the same voltage potential. A large number of electron-hole pairs proportional to gamma-ray energy deposition are generated from the gamma-ray interaction. The electrons move towards the anode and are collected by one of the pixel anode directly located above the location of gamma-ray interaction. The induced signal E' on the pixel anode is dominated by the number of electrons collected, and has a slight dependence on the depth of interaction as shown in the left-bottom of Figure 1. The lateral position (x, y) of the gamma-ray interaction is identified from the location of the pixel anode, and the depth (z) of interaction can be obtained from the ratio of the cathode signal to the signal of the pixel anode [2]. The actual energy deposition E_0 can then be deduced from the signal of the pixel anode E' and the depth (z) of interaction.

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Because of the promising results obtained on 5 mm thick HgI_2 spectrometers [3,4], the 3-dimensional position-sensitive single polarity charge sensing technique has been applied to 10 mm thick detectors. Several prototype detectors have been fabricated by Constellation Technology Corporation [5], each detector has four pixel anodes with dimensions about 1×1 mm surrounded by a large anode [3]. Signals from each pixel anode and the cathode are readout using Amptek A250 preamplifiers and shaped using standard Canberra 243 amplifiers. A sample prototype HgI_2 detector with dimensions of 1×1×1 cm is shown in Figure 2.

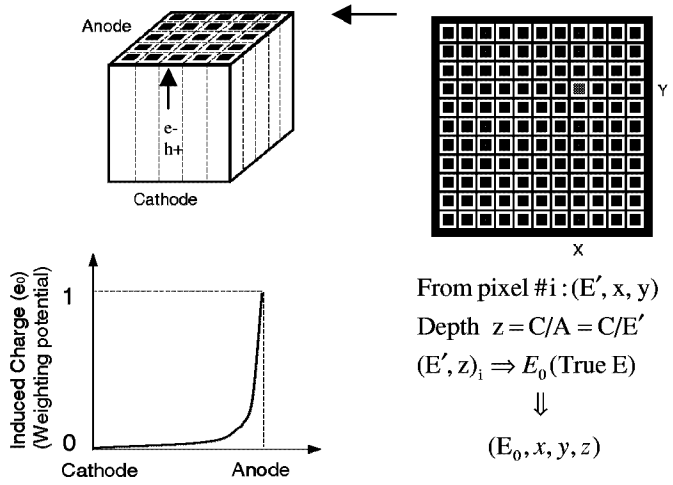

FIGURE 1. Illustration of the 3-dimensional position-sensitive technique.

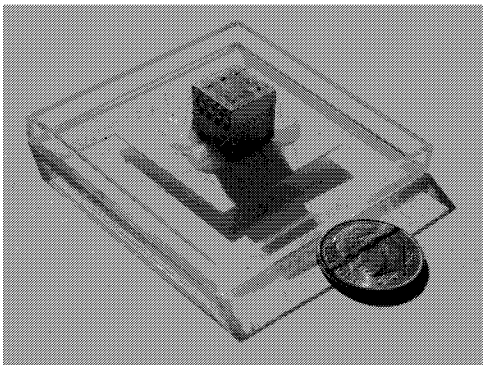

FIGURE 2. A sample 3-dimensional position-sensitive prototype HgI_2 gamma-ray spectrometer.

Detector performance

Six pixel anodes, three on each 10 mm thick HgI_2 detector, were tested. Energy spectra of 662 keV gamma rays obtained at three different interaction depths from

pixel anode #2 of detector #93203N92 are shown in Figure 3. The cathode was biased at –2500 V. The shaping times on the pixel anode and the cathode were 16 and 8 μs respectively. A 10 μCi ^{137}Cs source was located a few cm from the cathode surface. It can be seen that close to 1.1% FWHM energy resolution was achieved in the middle region between the cathode and the anode underneath pixel #2, and the mercury K X-ray escape peaks can be clearly identified due to the small volume of each voxel contributing to each energy spectrum.

It should also be noticed that the Compton continuums are quite flat down to about 20 keV region as predicted by Monte-Carlo simulations. This agreement between the observed and simulated spectra supports that all detection volume underneath the corresponding pixel anode is active. This is a distinctive feature compared with some of previous published results based on other techniques [6,7], in which sharp rising continuums are common towards the lower energy region of the spectra. If only a fraction of the detector volume contributes to the photopeak efficiency, and the other part records signals at lower amplitudes than the true energy deposition in the detector, a rising continuum towards the lower energy region would appear from the convolution of the incident gamma-ray spectrum with the detector response.

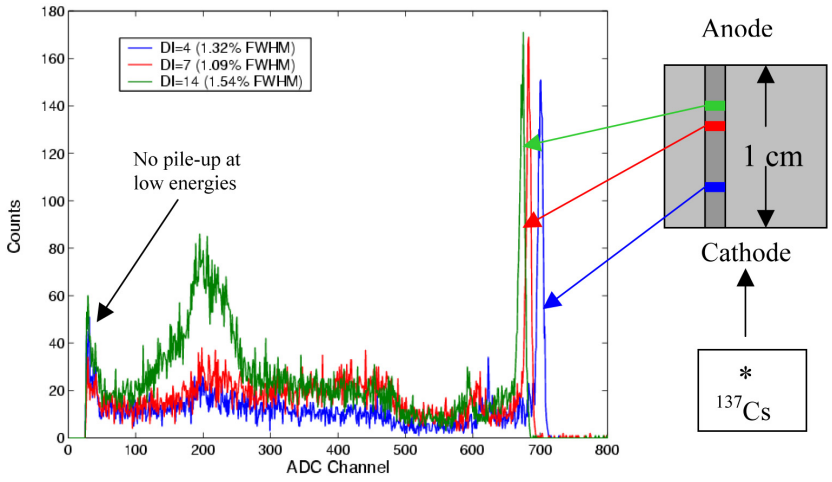

FIGURE 3. Energy spectra of ^{137}Cs at three gamma-ray interaction depths underneath pixel #2 obtained from detector #93203N92.

A digital depth correction method was employed to align the photo-peaks at different interaction depths so that the pulses corresponding to the same energy deposition appear at the same ADC channel. This technique can correct for the variation of electron trapping at various depth locations, and therefore mitigate the problems of material non-uniformity. Energy spectra from all events recorded on pixel #2 of detector #93203N91 are shown in Figure 4. The cathode bias was also –2500 V. The anode and cathode shaping times were both 8 μs in this case. If we only take

advantage of single polarity charge sensing technique based on the small pixel effect, an energy resolution of about 3% FWHM is obtained. After applying the depth correction, the energy resolution is improved to 1.4% FWHM. This result demonstrates that the 3-dimensional position sensing technique is superior to the simple single polarity charge sensing technique using the small pixel effect. Notice that the spectra shown in Figure 4 were obtained from a different detector than that shown in Figure 3, so that representative spectra from both tested detectors are reviewed.

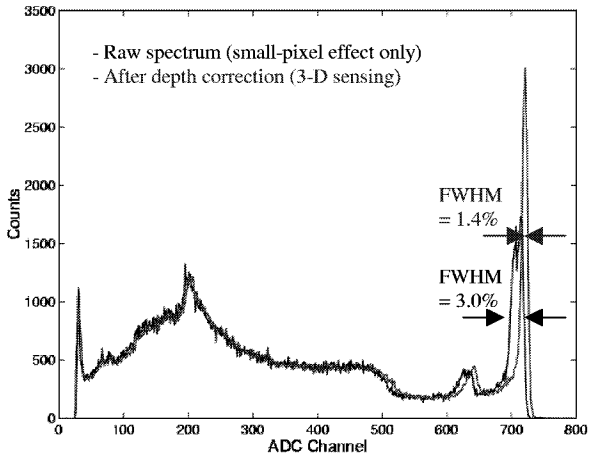

FIGURE 4. Energy spectra of ^{137}Cs from all depths underneath pixel #2 obtained from detector #93203N91. Both the raw and depth corrected spectra are shown in comparison.

Conclusions

After depth correction, 5 out of 6 tested pixel anodes on two detectors showed energy resolutions at 662 keV gamma-ray energy in the range between 1.4% to 2% FWHM. These results clearly demonstrate that 3-dimensional position sensitive single polarity charge sensing technique is promising on HgI_2 gamma-ray spectrometers with thickness of 1 cm. All tests were performed at a very low cathode bias of –2500V due to the breakdown in the circuitry at higher voltages. Efforts are underway to increase the bias voltage in our test setup so that detector performance at higher bias voltages can be studied.

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