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Section A

Coplanar grid patterns and their effect on energy resolution of CdZnTe detectors

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Abstract

This paper describes diagnostic techniques using depth and radial position-sensing methods that have been applied to identify and remove the non-symmetric effect of coplanar grid electrodes. Our experimental results show that the non-symmetric effect can degrade significantly the energy resolution of single polarity charge sensing CdZnTe detectors and can be minimized by balancing the weighting potentials of coplanar anodes. The coplanar electrode design has been modified based on the knowledge gained from this study and improvements in detector performance have been achieved. © 1998 Elsevier Science B.V. All rights reserved.

1. Introduction

Semiconductors with high atomic numbers and wide band gaps, such as CdTe, CdZnTe and HgI_2, are of potential interest as γ-ray detectors operating at room-temperature and with high detection efficiency. Because of the severe charge trapping problem, detectors using conventional planar electrodes have poor spectroscopic performance. The single polarity charge sensing method based on coplanar grid electrodes [1] has shown considerable promise on CdZnTe detectors having volumes of $1\,cm^3$ or larger. However, the best energy resolution of ~ 1.8% FWHM at 662 keV γ-ray energy obtained from a cubic cm device [2] is still much worse than the prediction of 0.2–0.6% FWHM if only the statistical fluctuation of charge generation is considered. Experimental evidence showed [2] that better energy resolutions, which can be as good as ~ 1.3% FWHM at 662 keV, were obtained for interactions near the cathode surface and significant degradation in energy resolution was observed for those near the anode surface. If the crystal non-uniformity was the limiting factor, the worst energy resolution should have been obtained for interactions near the cathode side. Since the degradation of energy resolution near the anode surface cannot originate from the crystal, there are two possible factors which may contribute to this effect. The first is the non-linear region at the vicinity of anode surface [2]. The second is the the design of the coplanar anodes.

This paper describes our investigation of the causes of degradation in energy resolution near the anode side using a combination of depth and radial sensing techniques. These methods are based on the

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differences of weighting potentials of different electrode configurations. Degradation in energy resolution due to the non-symmetric effect has been identified experimentally and modifications of the anode design have been implemented. The balancing of weighting potentials of electrodes was carried out using the 3-D electrostatic design software Coulomb [3]. Our measurements on a 1 cm cube CdZnTe detector with modified anode design have shown significant improvement in detector performance over earlier designs.

2. Coplanar anode design of generation 1

On a coplanar grid single polarity charge sensing device [1], alternate strips must be connected to form two groups of coplanar anodes. The straightforward way is to use wire bonds to connect each of the strip electrodes to a common contact strip located just outside CdZnTe anode surface, or to interconnect each electrode strip with a conductor above the anode surface. In either case, tens of wires need to be connected on a detector having 1 cm square anode surface. With trends toward increasing area of the detector and smaller pitch of the coplanar grids, the wire bonding process becomes complicated and expensive for routine fabrication. In order to minimize the number of connections and ruggedize the anode structure, a design having a symmetric pattern of only two interconnected coplanar anodes was employed. A schematic drawing of the electrode pattern is shown in Fig. 1. For electron-sensitive single polarity charge sensing, the weighting potentials of the two coplanar anodes need to be identical within the linear region of the detector so that the hole contribution can be eliminated by reading out the difference signal of the coplanar anodes. Therefore, the symmetrical pattern was introduced to help in balancing the weighting potentials.

By employing the depth sensing technique introduced in a previous paper [4], the energy spectra of ^{137}Cs versus γ-ray interaction depth were obtained from a 5 mm cube CdZnTe detector [4]. The results are shown in Fig. 2. It is evident that the energy resolution is best for interactions near the cathode side and becomes very poor for interactions near the anode surface. This experiment indicates that the cause for the severe degradation of detector performance cannot come from the crystal quality, but is more likely due to the design of the coplanar anodes.

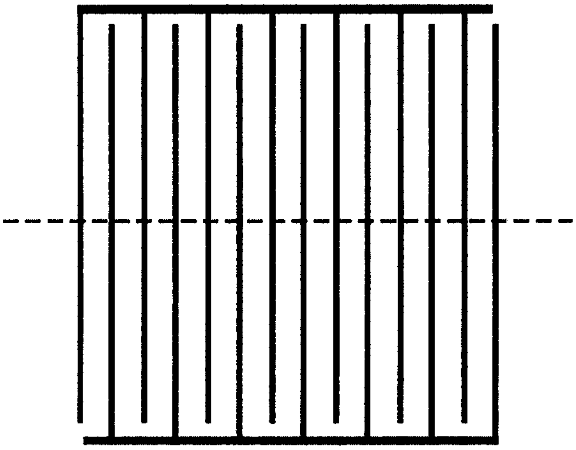


Fig. 1. Illustration of coplanar anode design of generation 1.

A 3-D electrostatic program (Coulomb) was employed to calculate the weighting potentials of the two coplanar anodes. The results showed a severe non-symmetric effect of weighting potentials, although the anode pattern looks symmetric in its geometry. As an example, the weighting potentials of two coplanar anodes of a 1 cm cube CdZnTe detector using anode design illustrated in Fig. 1 were calculated in 3-D. The results for the section shown as a dashed line in Fig. 1 and at a depth of 1 mm below the anode surface are shown in Fig. 3. For simplicity in the following discussions, we will only show the calculated weighting potentials along the same section that is perpendicular to the central coplanar grids and at a depth of 1 mm below the anode surface. Since the difference of weighting potentials between the coplanar anodes reduces as the distance from the anode surface increases, the results at 1 mm below the anode surface represent almost the worst case. If the weighting potentials can be balanced with good precision for that case, the balancing can only be better for positions further away from the anode surface.

Fig. 3 shows that the weighting potentials of coplanar anodes of generation 1 design can differ

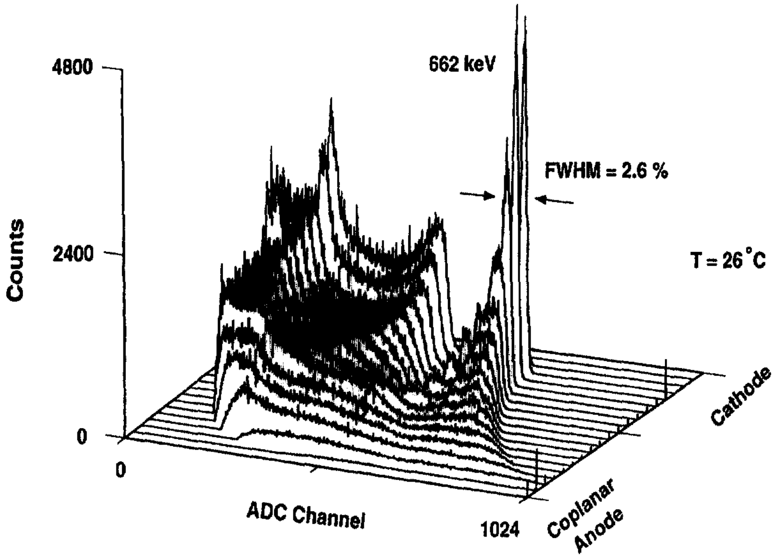


Fig. 2. Energy spectra as a function of γ-ray interaction depth [4] obtained on a 5 mm cube CdZnTe detector having coplanar anode design of generation 1.

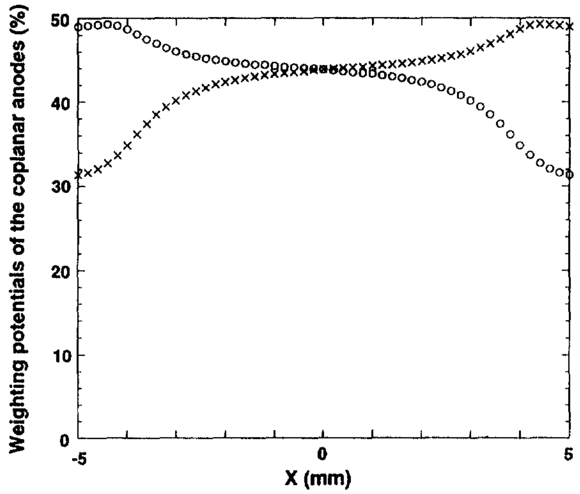


Fig. 3. Weighting potentials of the two coplanar anodes along the section shown in Fig. 1 and at a depth of 1 mm below the anode surface.

by ~ ± 20% near the anode surface. This would cause ~ 40% variation of the pulse amplitude for the same γ-ray energy. Therefore, the poor energy resolution near the anode side shown in Fig. 2 can be understood.

The key reason for the severe non-symmetric effect of the weighting potentials is that, when only two coplanar anodes are employed with self-connecting configuration shown in Fig. 1, one of the anodes must then be the outside electrode near the periphery. When the weighting potentials are calculated, 1 V is assigned to this outside electrode and 0 V to the other electrode. Therefore, the boundary conditions near the periphery of the anode surface can never be the same for the two anode electrodes. One solution to this problem is to introduce a third boundary electrode surrounding the two central coplanar anodes. This boundary electrode provides the same boundary condition, which is 0 V weighting potential, to both central anodes. This makes possible to balance the weighting potentials of the two central coplanar anodes.

3. Coplanar anode design of generation 2

The coplanar anode design of generation 1 was modified by adding a boundary electrode surrounding the central two coplanar electrodes. The schematic drawing of the generation 2 coplanar grid design is shown in Fig. 4. The weighting

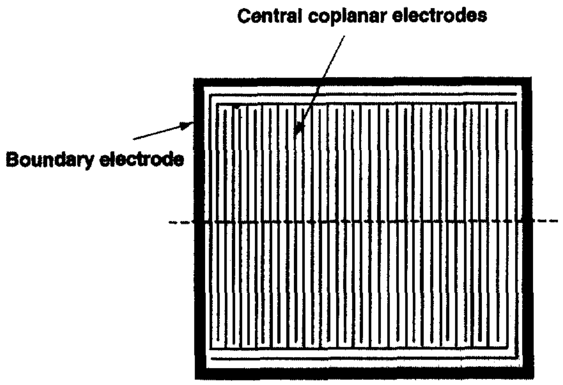


Fig. 4. Coplanar electrode design of generation 2 with the boundary electrode.

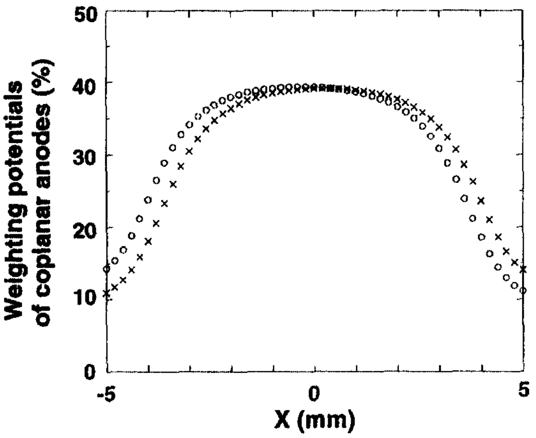


Fig. 5. Weighting potentials of coplanar anodes of generation 2 design along the section shown in Fig. 4 and at a depth of 1 mm below the anode surface.

potentials at the same location specified earlier are shown in Fig. 5. The difference in the weighting potentials is less than ~ ± 5% which is significantly smaller compared with that shown in Fig. 3.

Energy spectra of ^{137}Cs as a function of γ-ray interaction depth were obtained on a 1 cm cube CdZnTe detector using the coplanar anode design of generation 2, and the results are shown in Fig. 6. It is evident that the detector performance near the anode surface has been significantly improved by the introduction of the boundary electrode. However, the difference of a few percent of the weighting potentials of the coplanar anodes is still the major reason for the degradation of energy resolution from 1.7% to 4.7% FWHM, when the γ-ray interaction location moves from near the cathode surface to near the anode surface.

4. Radial position sensing

In order to verify our prediction that the non-symmetric effect of the coplanar anodes is still the major reason for the degradation of energy resolution near the anode surface, and not the effect of the non-linear region at the vicinity of the anode surface, we developed a radial sensing technique. The principle is based on the unique convex shape of the weighting potential of the collecting anode shown in Fig. 5, which is high in the central region and low near the periphery. Since the weighting potential of the collecting anode reaches 1.0 when electrons approach the collecting anode, the induced charge on the collecting anode is greater for those electrons that originate from positions where the weighting potential is lower. Therefore, the convex shape of the weighting potential means that when electrons drift from the same depth within the linear region of the detector and are collected by the collecting anode, the induced charge on the collecting anode is larger for electrons originating from the periphery than for those from the central region. This gives:

$$\frac{\mathrm{A1(central)}}{\mathrm{A1}-\mathrm{A2}} < \frac{\mathrm{A1(periphery)}}{\mathrm{A1}-\mathrm{A2}}, \qquad (1)$$

where A1 and A2 are the induced charges of the collecting and non-collecting anodes, respectively. It can be seen from Fig. 7 that this radial sensing method is more sensitive near the anode surface since the relative change of A1 between center and periphery compared to (A1–A2) is larger.

Energy spectra for interactions near the cathode surface and the anode surface are plotted at the top of Fig. 8. At the same interaction depth near the anode, energy spectra from increasing radial positions (1-4) were obtained using the radial sensing technique and are shown in the middle and bottom of Fig. 8. The results showed that the deviation of

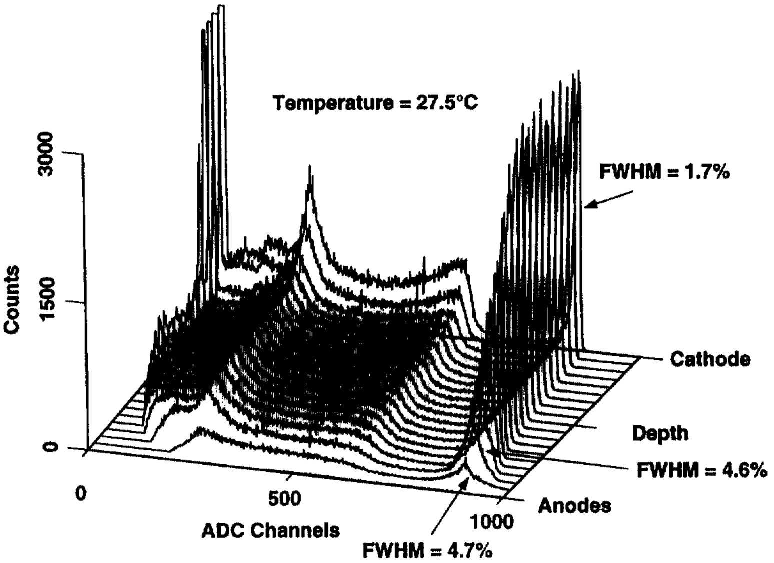


Fig. 6. Energy spectra versus γ-ray interaction depth. The detector is a 1 cm cube CdZnTe and employs coplanar anode design of generation 2.

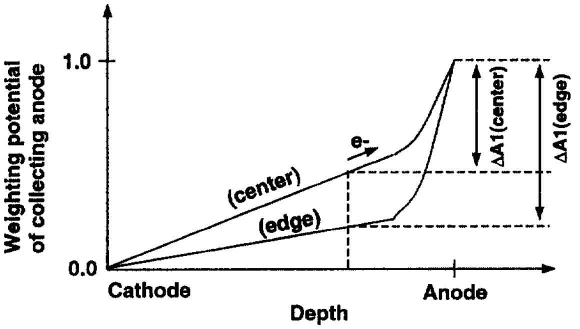


Fig. 7. Illustration of the principle of the radial sensing technique.

the centroid photopeak amplitudes from that of the spectrum for events originating from the central region of the device increases with increasing radial position. This observation of a 5–6% shift is consistent with the prediction from the calculation of the weighting potentials. This measurements also verified that the effect of the non-linear region in the vicinity of the anode cannot be the major cause of the degradation of detector performance near the anode surface because this effect should not change significantly as a function of radial position.

5. Coplanar anode design of generation 3

From the discussions of the previous section, we concluded that the non-symmetric effect of the coplanar anodes of generation 2 design still contribute significant error in the pulse amplitude. Based on the knowledge gained in these experiments, the design of the coplanar anodes of generation 2 was modified again based on extensive calculations using Coulomb. The schematic drawing of the generation 3 design is shown in Fig. 9. The strip widths of the two outermost grids and the three outermost gaps were fine tuned so that the difference of the weighting potentials was minimized. As a comparison, the difference of weighting potentials of the generation 2 and 3 designs are shown in Fig. 10. As one can see that the difference of the weighting potentials has been reduced from ~ ± 6% to less than ± 1%.

In order to verify how well our calculations worked and whether the coplanar grids can be fabricated with good precision to meet our specifications, a 1 cm cube CdZnTe crystal [5] was fabricated [6] into a coplanar grid device using the generation 3 design shown in Fig. 9. The energy spectra from ^{137}Cs were obtained for interactions

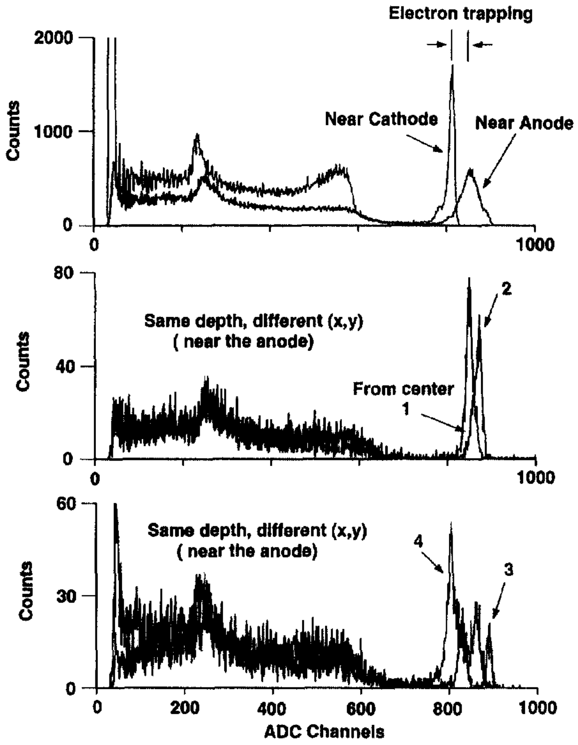


Fig. 8. Top: energy spectra versus interaction depths; Middle and bottom: energy spectra obtained from the same depth near the anode as in the upper figure, spectra # 1-4 were obtained at increasing radial locations.

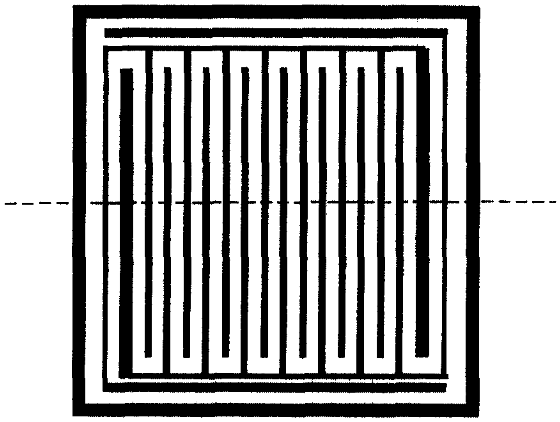


Fig. 9. Schematic drawing of the generation 3 anode design.

near the cathode and near the anode surfaces. The results are shown at the top of Fig. 11. Compared with those shown at the top of Fig. 8, the difference

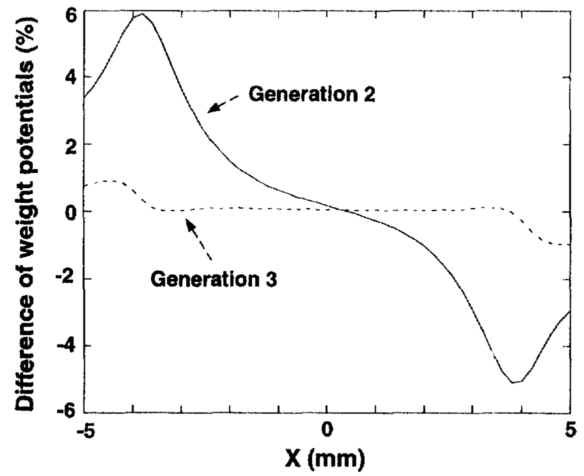
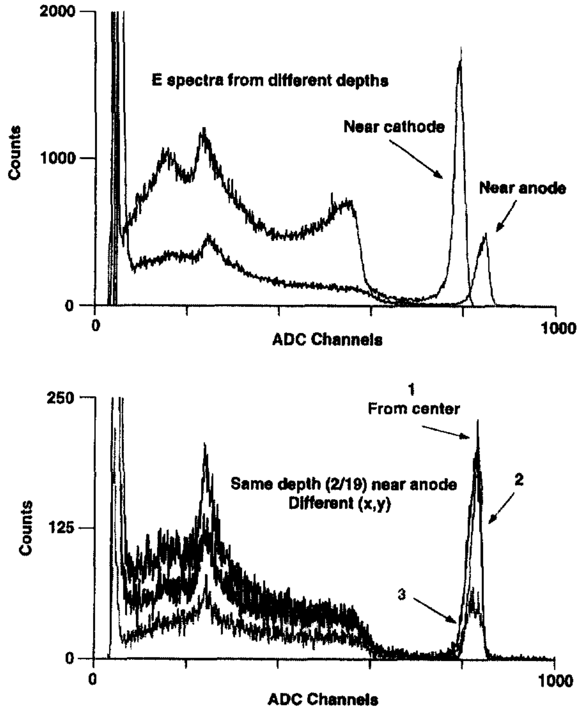


Fig. 10. The difference of weighting potentials of central coplanar anodes along the section shown as a dashed line in Fig. 9 and at a depth of 1 mm below the anode surface.



1 -> 2 -> 3 with increasing radial locations

Fig. 11. Energy spectra obtained from a 1 cm cube CdZnTe detector. The top figure shows the similarity of energy resolution obtained near the cathode and the anode surfaces. The bottom figure shows that the centroid photopeak amplitudes obtained from different radial positions near the anode surface match within 1% accuracy.

of energy resolutions obtained from near the cathode and the anode has been significantly reduced using the new anode design. This reduction has demonstrated that the detector performance is more uniform at different depths. For interactions near the anode surface, energy spectra were again obtained versus radial locations and the results are shown at the bottom of Fig. 11. The deviation of the centroid photopeak amplitudes is observed to be less than 1% for different radial positions, in good agreement with our calculations. These results not only confirmed our hypothesis about the non-symmetric effect of the coplanar anodes, but also verified the good precision of the electrode fabrication.

The energy resolutions of 3.2–4.1% FWHM at 662 keV at different depths obtained from the latest device are not as good as we expected. This is because the bias between the coplanar anodes can only reach a maximum of ~ 20 V, before excessive noise begins to overwhelm the signal. This low bias voltage is not enough to collect all the electrons and this causes incomplete charge collection. However, the results shown in Fig. 11 clearly demonstrated that the non-symmetric effect of the coplanar anodes has been significantly reduced and good detector performance should be expected if the detectors can be fabricated with better surface processing.

6. Conclusion

This paper describes the application of diagnostic techniques based on depth sensing and radial sensing methods that have helped to identify problems with the electrode design which degraded detector performance, especially near the anode surface. The non-symmetric effect of the coplanar anodes has been measured for the first time and consistent results with our calculations were obtained. The study has resulted in a revised electrode pattern that has the potential of producing much improved spectral uniformity throughout the entire detector volume.

Acknowledgements

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References

[1] P.N. Luke, IEEE Trans. Nucl. Sci. 42 (4) (1995) 207.
[2] Z. He et al., Nucl. Instr. and Meth. A 388 (1997) 180.
[3] "Coulomb", Integrated Engineering Software Inc., 46-1313 Border Place, Winnipeg, Manitoba, R3H OX4, Canada.
[4] Z. He et al., Nucl. Instr. and Meth. A 380 (1996) 228.
[5] eV Products, 375 Saxonburg Boulevard, Saxonburg, PA 16056, USA.
[6] Digirad, 7408 Trade Street, San Diego, CA 92121, USA.