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Section A

1-D position sensitive single carrier semiconductor detectors

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Abstract

A single polarity charge sensing method has been studied using coplanar electrodes on 5 mm cubes of CdZnTe γ-ray detectors. This method can ameliorate the hole trapping problem of room-temperature semiconductor detectors. Our experimental results confirm that the energy resolution is dramatically improved compared with that obtained using the conventional readout method, but is still about an order of magnitude worse than the theoretical limit. A method to obtain the γ-ray interaction depth between the cathode and the anode is presented here. This technique could be used to correct for the electron trapping as a function of distance from the coplanar electrodes. Experimental results showed that a position resolution of about 0.9 mm FWHM at 122 keV can be obtained. These results will be of interest in the design of higher performance room-temperature semiconductor γ-ray detectors.

1. Introduction

Room-temperature semiconductor γ-ray detectors having high atomic numbers and wide band gaps have long been under development. Among those, HgI_2 [1,2], CdTe [3] and CdZnTe [4] detectors have shown the most promise. Important progress on detector performance has been achieved through improving the material quality [4,5] and applying different signal processing methods [6,7]. Nevertheless, the energy resolution achieved using conventional planar electrodes is still far from the theoretical expectation. Charge trapping [4] and polarization [8] effects are the dominant problems which have limited the energy resolution. Recently, Luke [9,10] employed a method analogous to the Frisch grids [11] commonly employed in gas ion chambers, but using parallel coplanar strip electrodes. The strip electrodes on Luke's device were connected to give two sets of inter-digital grid electrodes. When charge carriers move within the bulk material of the detector, they induce an equal amount of charges on both electrodes except when they are within a very short distance from the coplanar electrodes. By reading the difference signal between these two sets of electrodes, a net signal is only induced when the charge carriers are moving in close proximity to the coplanar electrodes. When electron-hole pairs are generated by γ-ray interaction with the detector material, only one type of charge carriers (electron or hole) will move towards the coplanar electrodes. As a result, single polarity charge sensing can be obtained. For commonly used semiconductor detectors, signals from electrons are chosen so that the hole trapping problem can be eliminated. Using this approach, Luke found a significant improvement in the energy resolution of a 5 mm cube CdZnTe detector. Following Luke's work, He [12] derived the analytical approximation of the electric field distribution within semiconductor detectors for more generalized configurations of coplanar strip electrodes.

In this work, we propose a method to make a semiconductor detector with coplanar electrodes position sensitive to the γ-ray interaction depth between the cathode and coplanar anodes. This technique will provide an important capability for room-temperature semiconductor detectors in γ-ray astronomy, medical imaging and other industrial applications. Furthermore, since the energy spectra can be obtained as a function of the interaction depth, electron trapping can be monitored at different distances from the anode. This would provide a more accurate correction for electron trapping than the linear compensation method [10].

2. Principle

The basic structure of coplanar strip electrodes used by Luke [9] is shown schematically in Fig. 1, where V_d is the detector bias voltage, V_g is the grid bias voltage and P is the spatial period of the strip electrodes. Since electron sensing is preferred, a negative detector bias voltage was used so that electrons move towards the coplanar anodes. The associated electronics are shown schematically in Fig. 2. The

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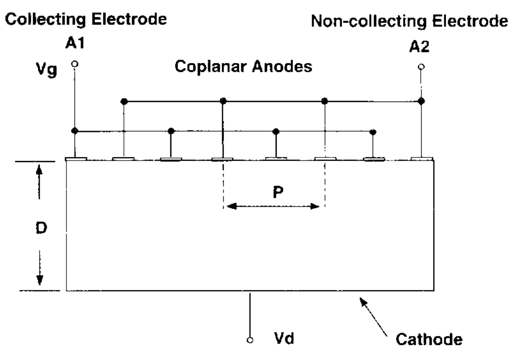

Fig. 1. End-on view of the coplanar strip electrodes.

induced signals on the two coplanar electrodes are read out using two AC-coupled conventional charge sensitive preamplifiers. The signal subtraction circuit consists of only one operational amplifier and four resistors, one of them can be adjusted in order to change the relative gain of the two signal channels. From the Ramo–Shockley theorem [13,14] and previous analysis [10,12], the induced charge on the collecting anode as a function of time is illustrated in Fig. 3a. For simplicity, it was assumed that there is no electron or hole trapping. One can see that the relative amplitudes of the signal induced by the electron motion are 0.5, 0.75 and 1.0 when the γ-ray interaction locations are at the anode, middle of detector, and the cathode, respectively. Since the electron induced pulse has a much faster rise time than that of the holes, the pulse amplitude (out2) due solely to the electron motion can be measured by using a shaping amplifier with a shaping time constant which is long compared to the rise time of electron component, but short compared to that induced by hole motion. On the other hand, the pulse amplitude (out1) of the subtraction circuit is always proportional to the number of electrons that reach the coplanar electrodes. Therefore, the ratio of the two output amplitudes out2/out1 should be linearly proportional to the distance of the γ-ray interaction from the anodes. In practice, there is always some hole signal mixed in with the electron component, and the number of electrons arriving at the coplanar anodes decreases non-linearly as the interaction distance increases from the anodes. Therefore, the ratio value as a function of interaction depth will show some non-linear effect. However, this ratio value will increase monotonically as the distance increases from the coplanar anodes.

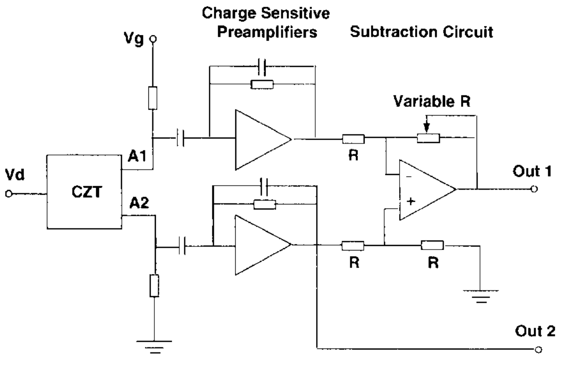

Fig. 2. Schematic diagram of the electronic circuit.

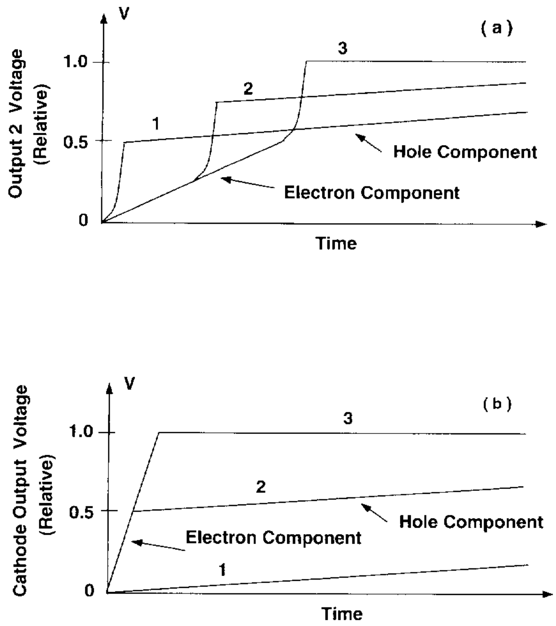

Fig. 3. Pulse shape induced on (a) the collecting electrode and (b) the cathode from interactions (1) near the coplanar anodes, (2) at the detector mid-plane, and (3) near the cathode.

The induced charge on the cathode as a function of time is illustrated in Fig. 3b. Using the same principle suggested above, position sensing can also be achieved by dividing the signal obtained from a preamplifier AC coupled to the cathode and shaped using a short shaping time constant by that from the coplanar electrodes.

3. Results at 122 keV

The technique suggested above has been tested using a 5 mm cube spectrometer grade CdZnTe detector (No. 720109Co). The crystal and the electrodes were manufactured and processed by DIGIRAD. The experimental setup is schematically shown in Fig. 4a. Three slots in the 2 cm thick Pb collimator have the same width of 0.5 mm and are separated by 1 mm thick Pb, and served to provide narrow beams of γ-rays at fixed depths. The center to center distance of neighboring γ-ray beams was thus 1.5 mm. Fig. 4b plots the counts as a function of observed signal ratio for the 3 beam irradiation. Note that the adjacent peaks are roughly equal separated along the ratio axis, although a non-linear effect is evident. A position resolution of about 0.9 mm was obtained, without correction for the width of the slots. During the measurements, the detector bias

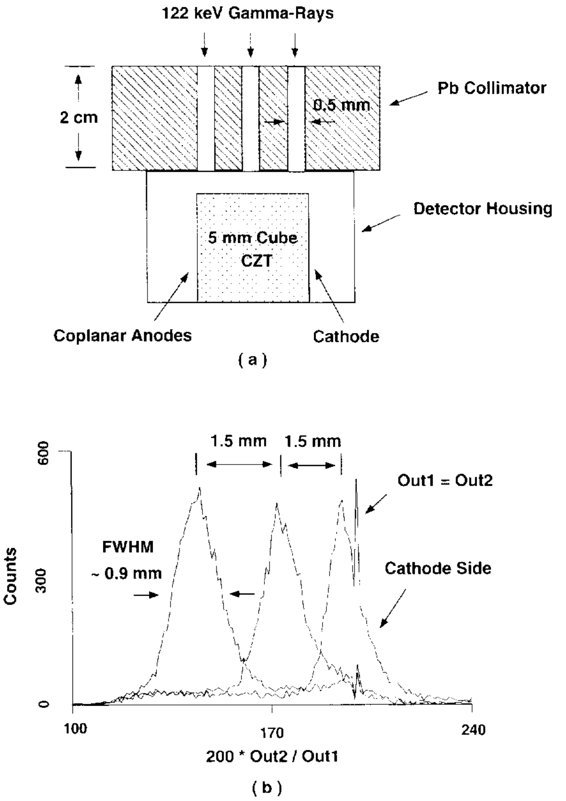

Fig. 4. Position sensitivity measurement. (a) Side view of the experiment. (b) Counts versus output ratio.

was −700 V and the grid bias was +15 V. Both shaping time-constants for the collecting electrode signal and the coplanar electrodes signal were 2 μs. Since the rise time of the hole component is about 10 μs, the 2 μs shaping time is still short for hole signals.

In another experiment, the ^{57}Co source was located about 1 cm above the top of the detector to provide a uniform incident γ-ray field between the cathode and the anodes. The energy spectra as a function of ratio value is plotted in Fig. 5a. The photo-peak amplitude of 122 keV γ-rays as a function of the ratio, which is approximately proportional to the interaction distance from the anode, is shown in contrast in Fig. 5b. The gains of the collecting electrode and coplanar electrodes signals were set equal so that no electron trapping correction was made. The energy resolution decreased from ~ 24% to ~ 11% FWHM when the γ-ray interaction position moved from the coplanar electrodes to the cathode. One can also see that the amplitude decreased slowly as the distance from the anode increased in the central part of the detector, and changes more rapidly when it approaches either end. It deviates from the exponential decrease expected for uniform electron trapping within the detector volume. This indicates that other factors, in addition to the electron trapping, affect the amplitude of the signals. Further investigation is ongoing.

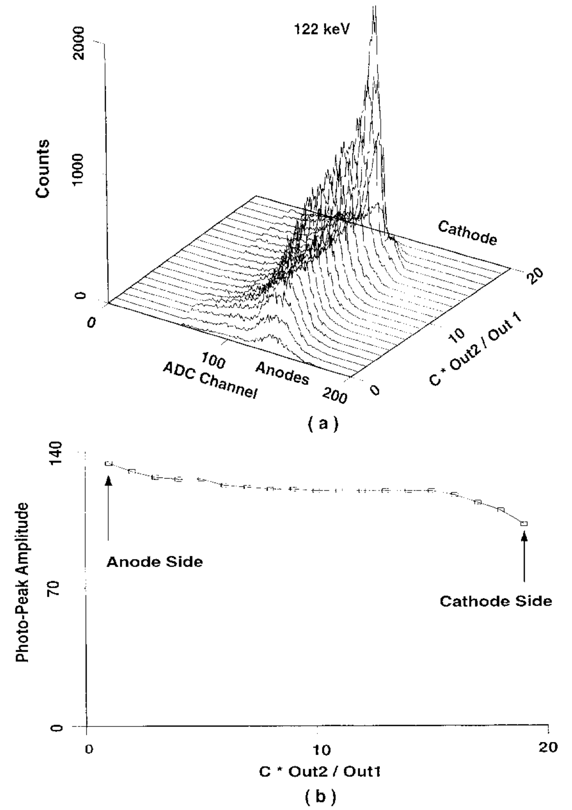

Fig. 5. Energy spectra and photo-peak amplitude vs. interaction distance at 122 keV.

4. Results at 662 keV

Experiments were also carried out using a different 5 mm cube CdZnTe detector (No. 710008T) with electrodes patterned by DIGIRAD. This CdZnTe crystal was obtained from eV Products. The energy spectrum obtained using the coplanar electrodes is compared with that using the conventional planar method from 662 keV γ-rays in Fig. 6. Note that the energy resolution is dramatically improved using the coplanar electrodes readout. The shaping time constant in both cases was 2 μs. The relative gain between the collecting and the non-collecting electrode signals was set to be equal by adjusting the resistance of the potentiometer in the subtraction circuit. Therefore, we did not compensate for electron trapping during this measurement. From Fig. 6, one can see that the energy resolution would be further improved if the shoulders at both sides of the photo-peak could be reduced.

In order to investigate the origination of the shoulders, we obtained energy spectra at different γ-ray interaction depths between the anodes and the cathode. Instead of using the ratio of the signals from the collecting electrode and the coplanar electrodes, we read out the electron motion signal from the cathode, and then divided by the signal obtained from

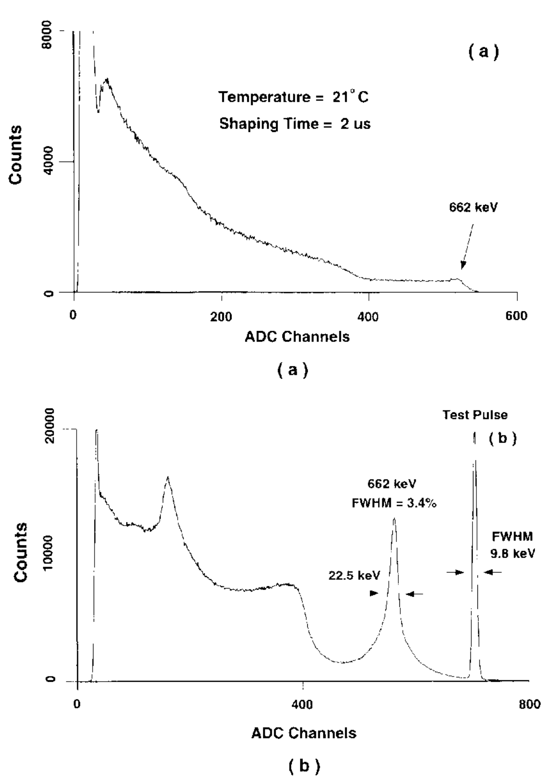

Fig. 6. Comparison of (a) conventional and (b) coplanar electrodes readout.

the coplanar anodes. The disadvantage of this method is that it requires three charge sensitive pre-amplifiers, instead of the two needed by Luke's original circuit. But we chose this technique because the position sensitivity is less affected by the non-symmetric electrode pattern on the coplanar anodes, and may yield better resolution due to the lower noise from the cathode compared to the collecting anode.

The energy spectra at 662 keV as a function of interaction depth is plotted in Fig. 7. It is evident that the peaks were broadened by those γ-ray events which interacted in the detector half close to the anodes. Excellent energy resolution was obtained from the events near the cathode. When we grouped the energy spectra with a finer ratio step, an energy resolution approaching 2% FWHM was obtained near the cathode. Near the anode, the photo-peak amplitude could not even be obtained due to the degraded energy resolution.

5. Summary

We confirmed that the significant improvement on the energy resolution can be achieved using the coplanar electrodes readout technique suggested by Luke [9]. The position sensing technique presented in this paper will provide an important capability for room-temperature semiconductor detectors, and will be a useful tool for investigating factors that affect the performance of these detectors. Comparison of the two position sensing techniques, which use signals from the collecting electrode and the cathode, is ongoing. The mechanisms which deteriorate the energy resolution when the γ-rays interact close to the anode need further investigation.

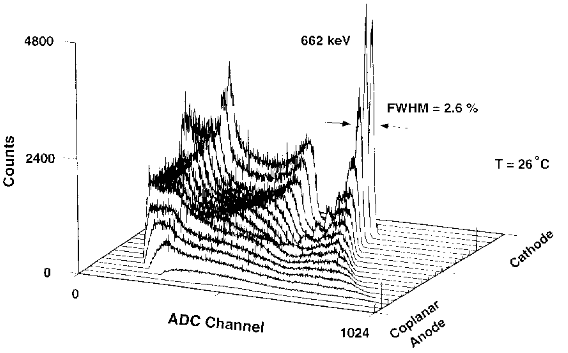

Fig. 7. Energy spectra vs. interaction distance at 662 keV.

Since no γ-ray event was lost during the processing, the detection efficiency of a coplanar electrode detector is the same as that of a conventional planar detector having the same volume.

Acknowledgements

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References

[1] D. Ortendahl et al., IEEE Trans. Nucl. Sci. NS-29 (1982) 784.
[2] B.E. Patt et al., IEEE Trans. Nucl. Sci. NS-33 (1986) 523.
[3] E. Raiskin and J.F. Butler, IEEE Trans. Nucl. Sci. NS-35 (1988) 81.
[4] J.F. Butler et al., IEEE Trans. Nucl. Sci. NS-39 (1992) 605.
[5] L.V.D. Berg, Nucl. Instr. and Meth. A 322 (1992) 453.
[6] L.T. Jones and P.B. Woollam, Nucl. Instr. and Meth. 124 (1975) 591.
[7] M. Richter and P. Siffert, Nucl. Instr. and Meth. A 322 (1992) 529.
[8] V. Gerrisch, Nucl. Instr. and Meth. A 322 (1992) 402.
[9] P.N. Luke, Appl. Phys. Lett. 65 (1994) 2884.
[10] P.N. Luke, IEEE Trans. Nucl. Sci. NS-42 (1995) 207.
[11] O. Frisch, British Atomic Energy Report BR-49 (1994).
[12] Zhong He, Nucl. Instr. and Meth. A 365 (1995) 572.
[13] S. Ramo, Proc. IRE 27 (1939) 584.
[14] W. Shockley, J. Appl. Phys. 9 (1938) 635.