A Study of the Timing Properties of $Cd_{0.9}Zn_{0.1}Te$.

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Abstract

CdZnTe has become a material of great interest in the field of X- and γ-ray imaging, and shows great promise as a highly efficient, room-temperature operation detector. However, data on the timing resolution obtainable with this material is scarce. It is known that CdZnTe, in common with all compound semi-conductors, gives pulses of varying rise-time depending on the interaction location, hence causing a broadening of the time spectrum. We therefore assembled and characterized an appropriate electronic measuring set-up and took data with 2 different sets of detectors, varying the experimental parameters such as bias voltage, threshold and temperature during the course of the experiment.

The results obtained with planar detectors of 9 mm^2 x 2 mm thick were superior to the results obtained with detectors of 25 mm^2 x 10 mm thick, even when the difference in effective bias field strength is considered. Timing resolutions of 5.3 ns and 20.9 ns (FWHM) respectively were obtained. Reducing the temperature to $0^{o}C$ reduced the resolution to 4.5 ns, thereby indicating that the performance is limited by signal-to-noise ratio considerations.

1. INTRODUCTION

Detectors fabricated from High Pressure Bridgman (HPB) grown CZT[1] have been available for several years but recent progress has broadened the potential field of application for these devices. In common with the earlier CdTe material grown by the Traveling Heater Method (THM), CZT detectors are compact, rugged devices with a high absorption efficiency for X- and γ-ray photons. There is increasing interest in the potential applications of this material in many fields, including medical imaging, industrial measurement and process control and high resolution spectroscopy for in-situ control of radioactive materials[2,3,4].

Much work has been undertaken regarding the measurement of some of the basic material parameters of CdZnTe, including mobility-lifetime ($\mu\tau$) product of both positive and negative charge carriers, bulk resistivity, trap density and charge transport properties[5]. However, very little has been reported in the literature with regard to the timing properties of CdZnTe. This value is of interest in any field where there is a requirement to perform fast coincidence measurements, for instance in TOF experiments of image reconstruction using back projection.

We assembled a system to measure the timing properties of CdZnTe, using two sets of detectors. The system assembled is similar to that used for timing resolution measurements with Ge and Si detectors[6]. One set comprised 2 small volume detectors, where the energy absorption at higher (>300 keV) takes place throughout the crystal volume equally and the photo-peak efficiency is hence very low. The other 2 were larger detectors, where the photo-peak efficiency is higher and hence the spread of rise-times greater.

2. EXPERIMENTAL SET-UP

The detectors were mounted on to BNC connectors and encapsulated in standard mounts for all the measurements. The dimensions of the small volume detectors were 3 x 3 x 2 mm^3, in a housing 12.5 mm dia. x 38 mm long and those of the large volume detectors 5 x 5 x 10mm^3, in a housing 32 mm dia. x 48 mm long. The housings were connected to the inputs of 2 eV-550 preamplifier boxes, each containing an eV-5091 hybrid preamplifier, chosen for the speed of the pulse rise and fall times (20 ns and 25 µs respectively). The input sensitivities of the preamplifiers were matched as closely as possible.

The preamplifier outputs were run into Ortec 579 Fast Filter Amplifiers, Ortec 935 Constant Fraction Discriminators (CFD's) and finally in to an Ortec 467 Time-to-Amplitude Converter (TAC) (see Figure 1). The output from one of the preamplifiers was connected separately to an Ortec 450 Research Amplifier in order to obtain an energy spectrum from the detectors and the change in peak position with varying bias voltage was measured. The bias was then set such that the maximum peak position, before breakdown, was obtained. This corresponded to a bias of 600 V in the case of the 2 mm thick detectors and 2000 V for the 10 mm units.

The time constants were chosen based on experience with HPGe detectors and were initially set at 20 ns integration and 500 ns differentiation. These values were then adjusted and modified during the course of the measurements to obtain the optimum performance. Final values are given in Table 1. The walk adjustment and delays in the CFD's were established per instructions in the EG&G/Ortec manuals. Measurements were taken using a ^{22}Na point source of low intensity (<10µCi).

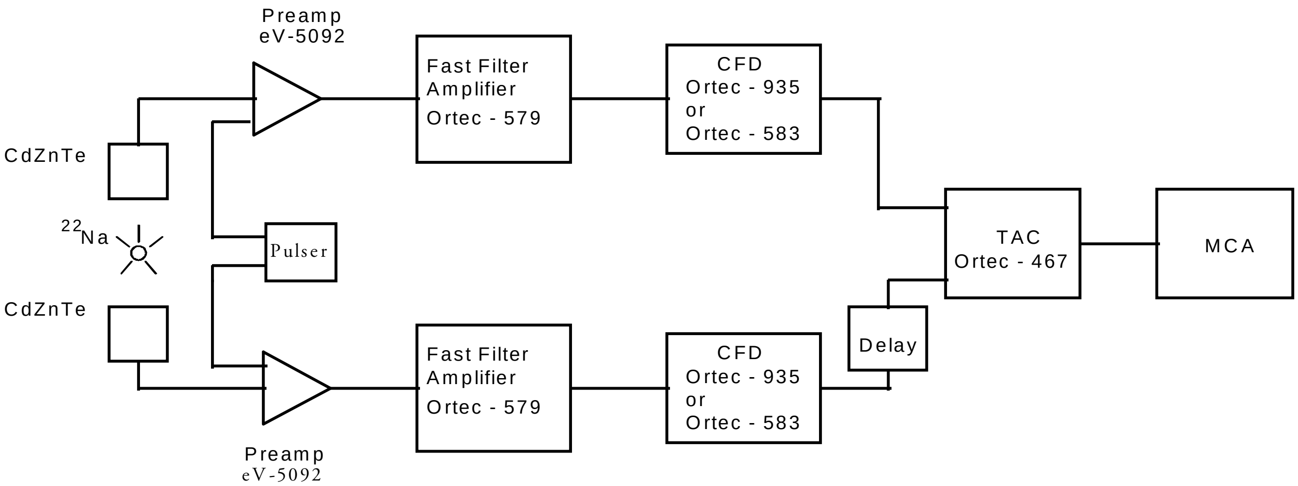

Figure 1: Block diagram of electronic set-up used for coincidence measurements

Table 1: Optimum settings for CdZnTe detectors

Detector size	Int.	Diff.	Delay
3x3x3 mm3	20 ns	20 ns	24 ns
5x5x10 mm3	50 ns	500 ns	150 ns

Finally, the threshold adjustment was calibrated, by splitting the input signal to the Fast Filter Amplifier and sending part to the 450 Research Amplifier. The output from this was directed to the Multi-Channel Analyzer (MCA), which was gated by the output from the 467 TAC, resulting in an energy spectrum that corresponded to the signal in the timing window (see Figure 2). During acquisition of the time spectrum, the same gating signal was directed to a pulse generator, which allowed for an audible tone to be generated for each coincident event, giving a simple check on the continued functioning of the system

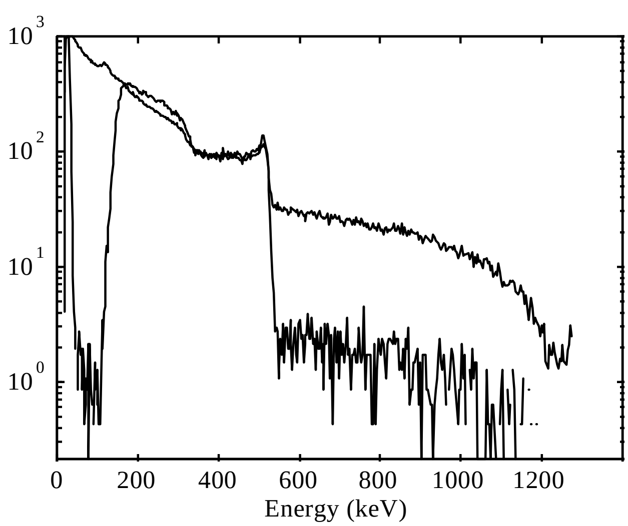

Figure 2: Full energy spectrum (top) and coincidence gated spectrum (bottom).

3. RESULTS

Data were obtained for both sets of detectors and the best results obtained at room temperature are displayed in Figure 3. The settings of the various electronic modules are also given, along with the FWHM values obtained.

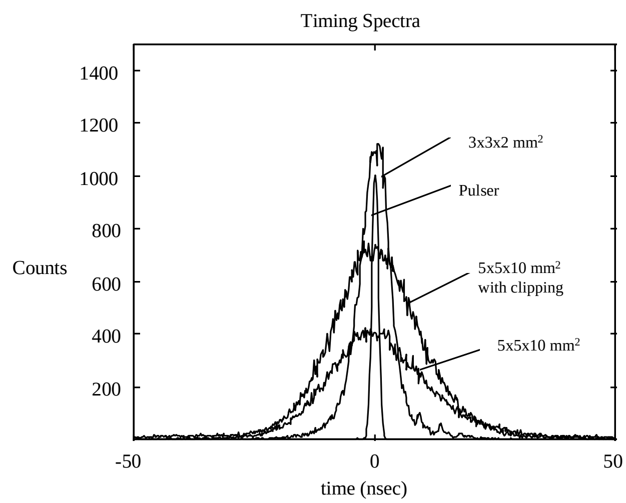

Figure 3: Timing spectra for both sets of detectors.

<u>3x3x2 mm^2</u>
FWHM = 5.3 ns
Integration time = 20 ns
Differentiation time = 20 ns
Delay in CFD =24 ns
Threshold = 300 keV

<u>5x5x10 mm^2</u>
FWHM = 20.9 ns
Integration time = 50 ns
Differentiation time = 500 ns
Delay in CFD = 150 ns
Threshold = 300 keV

<u>5x5x10 mm^2 with delay line clipping</u>
FWHM = 18.6 ns
Integration time = 20 ns
Differentiation = Out
"Clipping" Delay = 32 ns
Delay in CFD = 66 ns

The resolution can further be improved in the large volume detectors by the use of delay line clipping. This involves reducing the differentiation time to zero (from 500 ns), using a much shorted delay in the CFD (66 ns vs. 150 ns) and introducing a "clipping delay" of 32 ns. This will result in a reduction of efficiency, as more slow rise time events will be lost.

A curve showing the variation of timing resolution with threshold is shown in Figure 4. It can be easily seen that the small detectors are less sensitive at the Full Width Tenth Maximum level than the large detectors, which can be linked to the speed of charge collection in the smaller volume and the relative lack of trapping.

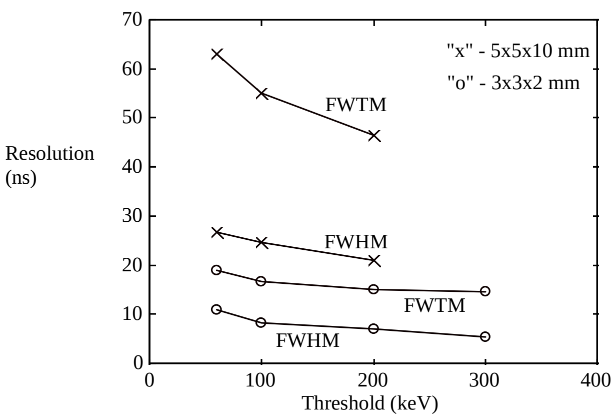

Figure 4: Resolution vs. threshold for both sets of detectors

Finally, the detectors and preamplifiers were installed in an environmental chamber and the unit was set to cool to 0^{o}C. The timing measurements were then repeated with the smaller detectors to verify the change in performance at lower temperatures. The pulser line-width was noted at both ambient and at 0^{o}C, and was seen to remain fairly constant. The best time spectrum is presented in Figure 5. The FWHM value for the detector is 4.5 ns, and for the pulser is 1.6 ns.

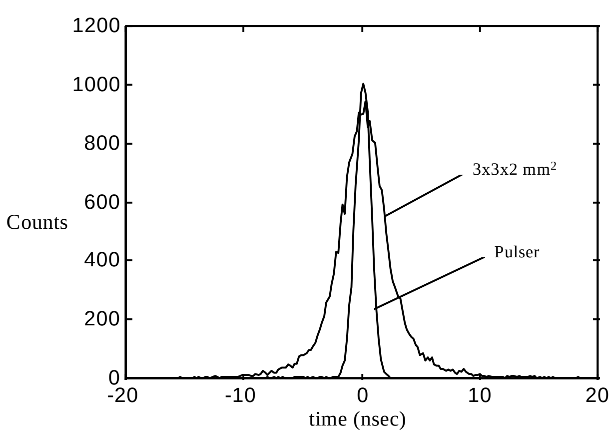

Figure 5: Time spectrum for the 3x3x2 mm^3 detectors at 0^{o}C

4. DISCUSSION

The results obtained during the course of the measurements show some interesting aspects of the behavior of compound semi-conductors. As expected, the timing resolution is best with the small detectors, where the interaction position is less critical, and is significantly worse for larger detectors. It is interesting to note that the use of Slow Rise Time rejection did not significantly improve the time resolution with the large detectors. However, it did result in the reduction of the background level beneath the peak This is due, at least in part, to the suppression of the output signal that is a combination holes and electron signal. The large difference in the $\mu\tau$ products for the charge carriers (typically $5x10^{-4}$ $cm^2.V^{-1}$ for electrons and $2\text{-}3x10^{-6}$ $cm^2.V$ for holes) results in a number of output pulses that are of much longer duration than would be the case for example in a HPGe detector, where $\mu\tau$ is similar for both polarity charge carriers.

It is also interesting to note that the time resolution improves at lower temperatures, indicating that the resolution is principally limited by the signal/noise ratio in the system.

Due to the lack of time, no attempt has been made here to measure the efficiency of the detectors under the various conditions established during the work. It is to be hoped that this work will be undertaken in the future, along with a more detailed study of the inter-dependence of the spectral performance of the detectors and their timing resolution.

5. CONCLUSION

It has been clearly demonstrated that CdZnTe, grown with current technology, can be used for fast timing studies, and that small detectors allow for measurements in the 5-10 ns FWHM range. Larger detectors are capable of providing resolution in the 18-25 ns range.

6. ACKNOWLEDGMENTS

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