Characterization of Multi-element CZT arrays

L. Cirignano^a, K. S. Shah^{*a}, P. Bennett^a, L. Li^b, F. Lu^b, J. Buturlia^c, W. Yao^d, G. Wright^d, and R. B. James^d,

^aRadiation Monitoring Devices, Inc., 44 Hunt Street, Watertown, Massachusetts, USA 02472

^bYinnel Tech Inc., South Bend, IN 46619

^cThermo Electron Tecomet, Wilmington, MA 01887

^dSandia National Laboratories, Livermore, CA 94550

The submitted manuscript has been authored by a contractor of the United States Government under contract. Accordingly the United States Government retains a non-exclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for United States Government purposes.

ABSTRACT

We report on device fabrication and testing of CZT grown by the Modified Vertical Bridgman (MVB) method. Several samples of single-crystal MVB grown CZT were obtained from Yinnel Tech. Both single element devices and 2-dimensional arrays were fabricated. Resistivity and electron mobility-lifetime product were measured, and pulse height spectra were recorded for various isotopic sources. Arrays 5 mm thick and an array 1.13-cm thick were evaluated.

Keywords: CZT arrays, Modified Vertical Bridgman CZT, Gamma-ray detectors

1. INTRODUCTION

CZT has found applications in industrial, astrophysical, and medical x-ray imaging¹⁻⁴ because of its high density (6.2 g/cm³), wide bandgap (1.5 – 2.2 eV) and availability in relatively large sizes (> 1 cm³). Single carrier devices⁵⁻⁷ mitigate the effects of hole trapping enabling the development of detector arrays which have high efficiency and good energy resolution at energies of interest in medical imaging (e.g. 140 keV). To date, the majority of CZT which has been applied to x-ray and gamma ray detection has been grown by High Pressure Bridgman and, more recently, by Modified Horizontal Bridgman techniques⁸. Recently CZT grown by the Modified Vertical Bridgman (MVB) method has become available for evaluation as x- and gamma ray detectors. This material has been reported to show exceptionally high electron transport with mobility-lifetime products ($\mu\tau_e$) up to 10⁻² cm²/V. With such a large value for $\mu\tau_e$, drift lengths exceeding several centimeters are achievable at reasonable electric fields. This suggests the possibility of fabricating thick (> 1 cm) detector arrays with enhanced detection efficiency at energies of interest in applications such as positron emission tomography (PET) and x-ray astronomy.

2. EVALUATION OF MODIFIED VERTICAL BRIDGMAN CZT

2.1 Device fabrication

We received several samples of MVB CZT grown at Yinnel Tech Inc. Initially we fabricated single element planar devices for resistivity, charge collection, and spectroscopic evaluation. Both single element planar devices and arrays were fabricated as follows. First, samples were polished with 1-micron grit to remove surface contamination. Next, the samples were thoroughly cleaned with alconox and water followed by cleaning with methanol in an ultrasonic cleaner. The samples were then etched in a 10% bromine/90% methanol solution. Gold contacts were then applied by thermal evaporation. For array fabrication metal masks were used to define the pixel pattern (2mm pitch, (1.7 mm)² pixel). Figure 1 shows a photograph of two arrays which were fabricated and tested.

2.2 Device characterization

All of the Yinnel CZT pulse height measurements were recorded with an ac-coupled Cremat preamplifier, Canberra 2025 AFT Research Amplifier, and an Oxford PCA card in a portable computer.

* Correspondence: Email: lcirignano@rmdinc.com, Telephone: (617) 926-1167

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

RECEIVED
OCT 10 2000
OSTI

2.2.1 Electron mobility-lifetime product

Electron mobility-lifetime products were evaluated for several samples. Measurements were carried out by placing a device in a pressure-contact test jig with an ^{241}Am alpha particle source within 2 mm of the cathode. Alpha particle spectra were collected over a range of bias voltages. The alpha particle peak position versus bias voltage was plotted and the single carrier Hecht equation was fit to the data to obtain a value for $\mu\tau_e$. Values obtained ranged between 3 and $6 \times 10^{-3} \text{ cm}^2/\text{V}$. Figure 2 shows a plot of charge collection efficiency versus bias voltage for a planar CZT device.

Figure 1. Photograph of two arrays (5 mm and 11.3 mm thick) which were fabricated and tested. The pitch is 2 mm and the pixel size is $(1.7 \text{ mm})^2$ for each array.

2.2.2. Electrical resistivity

Current versus voltage curves were recorded for a single element device and pixels of arrays with an automated system. From the $I(V)$ curves and device geometry, resistivity values were calculated. The range of resistivity was found to be between 1.7 and $3.6 \times 10^{10} \Omega\text{cm}$. The lowest resistivity value was obtained from a sample with an area of 1.23 cm^2 and full

Figure 2. Plot of charge collection efficiency versus bias voltage for a single element CZT device with dimension 10.9 mm x 12.1 mm x 4.6 mm (thick). The line is a plot of the single carrier Hecht equation.

gold contacts. The larger values were inferred from leakage current values at operating bias voltages and pixel geometry.

2.2.3. Pulse Height Spectra

Pulse height spectra were recorded for planar devices and for the arrays. A test jig, which placed a ground ring around the

Figure 3. Pulse height spectra obtained with a planar CZT device with dimensions $1.32 \text{ cm}^2 \times 0.46 \text{ cm}$.

pixel of interest, was used to test the arrays. One pixel at a time was measured. Figure 3 shows pulse height spectra for ^{109}Cd , ^{241}Am , and ^{57}Co obtained with a planar detector with dimensions $1.32 \text{ cm}^2 \times 0.46 \text{ cm}$.

Notice that the 22 keV peak is approximately Gaussian while the peaks at higher energy exhibit hole tailing. Figure 4 shows a ^{22}Na spectrum for the same device. In this spectrum, the relatively small number of counts in the full energy peak is due to a combination of two effects. First, hole tailing is prominent since at 511 keV the interactions occur throughout the volume of the device. Second, at this energy the predominant interaction is Compton scattering.

Figure 5 shows a plot of ^{57}Co spectra for a 4×4 array of the 5 mm thick array. The standard deviation in 122 keV peak position is less than 0.5%. Note that the relative peak heights of the various pixels do not accurately reflect relative efficiencies since the pixels were not exposed to a constant photon flux.

Figure 4. ^{22}Na spectrum for a single-element CZT detector.

Figure 5. ^{57}Co spectra for a 4 x 4 array of the 5 mm thick array. The standard deviation in 122 keV peak position is less than 0.5%.

Pulse height spectra were also recorded for irradiation with a collimated ^{57}Co source. The irradiation spot size at the CZT cathode was less than 1.4 mm in diameter. Figure 6 shows spectra comparing collimated versus flood field irradiation of a pixel with ^{57}Co . Many low amplitude counts and counts in the tail region of the 122 keV peak are due to interactions which occur in the inter-pixel region⁹.

Because the CZT has relatively high values for $\mu\tau_e$, it was interesting to fabricate a thick array from this material. We fabricated an array with a thickness of 11.3 mm as shown on the right in figure 2. Figure 7 shows ^{57}Co spectra obtained with this array. Spectra were recorded with a shaping time of 2 μs and at bias voltages of 1000, 2000, and 2500 Volts. Spectra were also recorded with a collimated source but were very similar to the flood field spectra. Figure 8 shows a ^{22}Na spectrum obtained with the same pixel of the thick array.

The value of $\mu\tau_e$ for the material from which the 11.3 mm thick array was fabricated was measured to be $3.7 \times 10^{-3} \text{ cm}^2/\text{V}$. At 2500 volts the electron drift length is greater than 8 cm. Based on this value of drift length, electron trapping should be negligible. It is not clear why the ^{57}Co spectrum at 2500 V for the thick array is significantly worse than spectra from the 5-mm thick array.

Figure 6. Collimated and uncollimated ^{57}Co spectra for a pixel of the 5 mm thick array. The FWHM of the 122 keV peak of the collimated and flood field spectra are 6.7% and 7.4% respectively.

Figure 7. ^{57}Co spectra obtained for a pixel of the 11.3 mm thick array. The time constant of the shaping amplifier was 2 μs .

Figure 8. ^{22}Na spectrum obtained with a pixel of the thick array. The bias voltage was 2500 V and the shaping time was 2 μs .

3. CONCLUSIONS

Based on the small number of samples which we evaluated, the Modified Vertical Bridgman CZT grown at Yinnel Tech Inc. shows promise for fabricating arrays. The charge transport of the electrons was measured to be relatively high ($3.7\text{--}6.0 \times 10^{-3} \text{ cm}^2/\text{V}$) and the resistivity is adequate for spectroscopic devices ($1.7\text{--}3.6 \times 10^{10} \text{ }\Omega\text{cm}$). The average energy resolution of the 5 mm thick array (over a 4×4 pixel area) was approximately 8.8 % and the standard deviation in 122 keV peak position was 0.5 %. The thick (11.3 mm) array did not exhibit as good as expected spectra based on the measured electron mobility-lifetime product.

ACKNOWLEDGEMENTS

Radiation Monitoring Devices, Inc. gratefully acknowledges the support of the United States Department of Commerce through the Small Business Initiative Research Grant process for portions of the work carried out here.

The co-authors from Sandia National Laboratories received support from the U.S. Department of Energy under contract number: DE-AC04-94AL85000. Specifically, the Office of Nuclear Nonproliferation is gratefully acknowledged for their financial and technical support of the Sandia portion of this work.

REFERENCES

1. D. G. Marks, H. B. Barber, H. H. Barrett, E. L. Dereniak, J. D. Eskin, K. J. Matherson, J. M. Woolfenden, E. T. Young, F. L. Augustine, W. J. Hamilton, J. E. Venzon, B. A. Apotovsky, and F. P. Doty, *A 48 x 48 CdZnTe Array with Multiplexer Readout*, IEEE Transactions on Nuclear Science, 43 (3), pp. 1253-1259, 1996.
2. D. V. Macri, K. Boykin, M. Larson, M. L. Mayer, J. M. McConnell, M. L. Ryan, T. G. Cherry, B. A. Guzik, B. A. Apotovsky, J. F. Butler, F. P. Doty, and C. L. Lingren, *Progress in Development of Large-Area, Sub-millimeter Resolution CdZnTe Strip Detectors*, Proc. SPIE, Vol. 2859, p. 29, 1996.
3. M. Mayer, D. V. Boykin, M. L. Cherry, J. F. Courville, F. P. Doty, A. Drake, T. G. Guzik, L. A. Hamel, K. Larson, J. R. Macri, M. L. McConnell, J. M. Ryan and O. Tousignant, *Performance of CdZnTe Strip Detectors as Sub-millimeter resolution Imaging Gamma Radiation Spectrometers*, Conf. Record of the 1996 IEEE Nucl. Sci. Symp. And Med. Imaging Conf., p. 803. Nov. 1996.
4. K. Iwata, B. H. Hasegawa, J. A. Heanue, P. R. Bennett, K. S. Shah, C. D. Boles, and B. E. Boser, "CdZnTe detector for combined X-Ray CT and SPECT", Nucl. Instr. and Meth. In Phys. Res. A 422 pp. 740-744 (1999).
5. H. H. Barrett, J. D. Eskin, and H. B. Barber, *Charge Transport in Arrays of Semiconductor Gamma-Ray Detectors*, Physical Review Letters, Vol. 75(1), p. 156, 1995.
6. J. D. Eskin, H. H. Barrett, H. B. Barber and J. M. Woolfenden, *The Effect of Pixel Geometry on Spatial and Spectral Resolution in a CdZnTe Imaging Array*, Conf. Record of the 1995 IEEE Nucl. Sci. Symp. And Med. Imaging Conf., pp. 544-548, Oct. 1995.
7. P. Bennett, K. S. Shah, M. Klugerman and M. R. Squillante, *High Efficiency Pixellated CdTe Detector*, Nucl. Instr. and Meth. A, Vol. 392, pp. 260-263, 1997.
8. T. Narita, P. F. Blosier, J. E. Grindlay, J. A. Jenkins, and H. W. Yao, *Development of IMARAD CZT Detectors with PIN Contacts*, Proc. SPIE, Vol. 3768, p. 55, 1999.
9. L. Cirignano, K. S. Shah, P. R. Bennett, M. Klugerman, Y. Dmitryev, M. R. Squillante, T. Narita, P. Blosier, J. Grindlay, B. H. Hasegawa, and K. Iwata, *Pixellated CdZnTe Detector for Emission/Transmission Computed Tomography*, Nucl. Instr. and Meth A 422 pp. 216-220 (1999).