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Study of CdZnTeSe Gamma-Ray Detector under Various Bias Voltage

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Abstract

Cadmium zinc telluride selenide (CdZnTeSe) is a new semiconductor material for gamma-ray detection and spectroscopy applications at room temperature. It has very high crystal quality compared to similar materials such as cadmium telluride and cadmium zinc telluride. The consistency of peak position in radiation detection devices is important to practical applications. In this paper, we have characterized a CdZnTeSe planar detector for bias voltages in the range of -20 V to -200 V and amplifier shaping time of 2, 3 and 6 µs. The peak position of the 59.6-keV gamma line of ^{241}Am becomes more stable as the absolute value of the applied voltage increases. The best energy resolution of 8.5% was obtained for the 59.6-keV gamma peak at -160 V bias voltage and 3-µs shaping time. The energy resolution was relatively stable in the -120 V to -200 V range for a 6-µs shaping time.

Keywords

CdZnTeSe, Energy Resolution, Energy-Peak Stability, Gamma-Ray Spectroscopy, Nuclear Detectors

1. Introduction

Cadmium zinc telluride selenide (CdZnTeSe or CZTS) has shown great promise as a semiconductor material for fabricating cheaper gamma-ray detection and spectroscopy devices for applications at room temperature (i.e., without cryogenic cooling), compared to similar materials like cadmium telluride (CdTe) and cadmium zinc telluride (CdZnTe of CZT) [1]-[4]. This advantage comes from the high crystal uniformity of CZTS compared to CdTe and CZT [2],[3]. A material with higher crystal uniformity and lesser defects will give more detector-grade wafers per volume of the as-grown ingot. Presently, CdTe and CZT have applications in gamma-ray spectroscopy, medical imaging, nuclear and radiological threat detection, and astrophysics. CZTS has the potential of reducing the cost of fabricating devices that could be used in these applications.

The stability of peak position and energy resolution in radiation detection devices are important for practical applications in radiation detection, spectroscopy, and imaging. Pérez *et al.* [5] studied the stability of CZT coplanar detectors over a period of four months. Shifts of about 0.5% in the photopeak positions were observed for the 662-keV gamma line of ^{137}Cs with the detectors maintained at a temperature of 22.5 ± 1.0 °C and electronic experimental parameters kept fixed [5]. Similar results were obtained for the 356-keV peak of ^{133}Ba and 1173-keV peak of ^{60}Co [5]. Degradation of energy resolution over time was observed, and fluctuations in the energy resolutions of the 356-keV peak of ^{133}Ba and 1173-keV peak of ^{60}Co were higher than that of the ^{137}Cs 662-keV peak [5]. It was concluded that increases in bias voltage and operating temperature led to a significant increase in noise, which had a greater effect on the low-energy peaks due to the smaller signal-to-noise ratio [5].

Egarievwe *et al.* [6] studied the detection and electrical properties of CZT at elevated temperatures, where the energy resolution of the 31-keV peak of ^{133}Ba was observed to be 16%, 18%, 28% and 38% at 24, 30, 40 and 50 °C respectively. The 31-keV peak position varied within 3 keV at 70 °C at an applied bias of 60 V. For bias voltages from 20 to 100 V, the fluctuation in the energy resolution was between 15% and 18% at 25 °C and between 22% and 38% at 50 °C. Studies involving cooling were carried out by Chun *et al.* [7] where an improvement of about 2% was recorded for the energy resolution from 30 °C to -40 °C for the 122-keV and 136-keV peaks of ^{57}Co. Mæhlum *et al.* [8] studied 5x5 CZT detector modules under variations of temperature (20 – 40 °C) and humidity (relative humidity 10% – 70%), where they recorded an average photopeak variation of ±1 keV for the 122-keV peak of ^{57}Co over a period of 248 days. In this paper, we present results on the study of the stability of the energy-peak position for a CdZnTeSe planar detector over an operating voltage range of 20 – 200 V. We also report on peak position changes based on the amplifier shaping time.

2. Experiments

A planar detector of size 4.65 x 7.00 x 2.70 mm^3 was fabricated from as-grown CZTS crystal. The $Cd_{1-x}Zn_xTe_{1-y}Se_y$ crystal, with x = 0.1 and y = 0.04, was grown by the traveler heater method [9]. The CZTS wafer was cut from the ingot using a diamond impregnated wire was. It was then polished using an 800-grit silicon carbide paper. This was followed by successively polishing with 100-grit and 1200-grit silicon carbide papers. Subsequent polishing on MultiTex pads with varying sizes (3.0 – 0.1 µm) of alumina powder was made to smoothen the wafer surfaces. After polishing, the wafer was rinsed with distilled water and dried with compressed air. Gold contacts were deposited on the two opposite

4.65 x 7.00 mm^2 sides of the wafer using the electroless deposition method.

Current-voltage (I-V) measurements were made prior to detector testing to determine the resistivity of the CZTS material. A special aluminum box equipped with Keithley Picoammeter and Voltage Source (model number 6487) was used in the I-V measurements to ensure that the CZTS wafer has high resistivity. After establishing a high resistivity on the order of 10^{10} Ω-cm, the wafer was mounted in a customized sample holder made by eV Products (now Kromek). The cylindrical-shaped sample holder is made of brass, and it has a beryllium window for placing a sealed radiation source. The holder is connected to a high voltage supply and a pre-amplifier that is connected to a multichannel analyzer (MCA) and amplifier. The MCA is connected to a computer that has software for recording the energy spectrum of radiation sources. An ^{241}Am radiation source was used in this experiment. Various applied bias voltages in the range of 20 – 200 V were used. The coarse gain of the amplifier was kept at 500, and measurements were made at 2, 3 and 6 μs shaping time.

3. Results

The current-voltage characteristics of the CZTS detector in the -200 to 200 V range are shown in **Figure 1**. The resistivity determined from the I-V curve is on the order of 10^{10} Ω-cm.

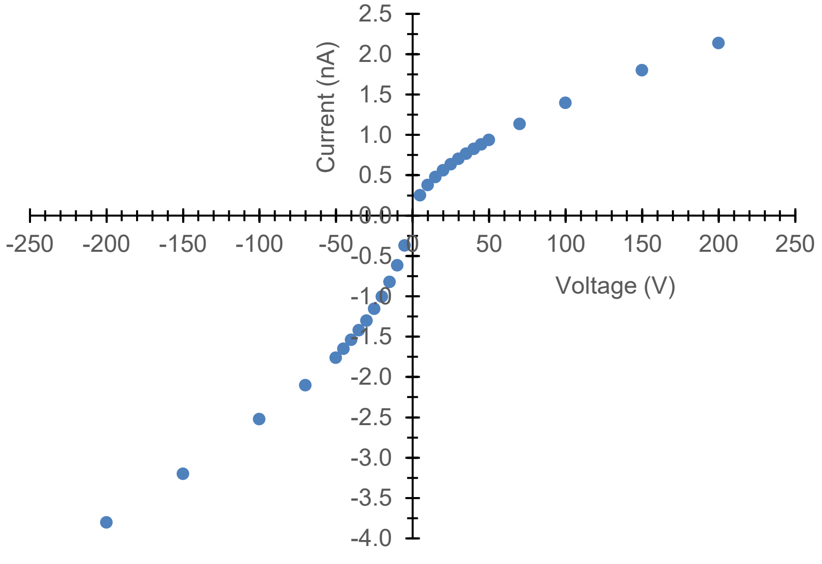

Figure 1. The current-voltage characteristics of the CZTS detector in the -200 to 200 V range. Extracted from the same dataset in [4].

The best detector responses to an ^{241}Am sealed radiation source for shaping time of 2 μs, 3 μs and 6 μs are shown in **Figure 2**. The energy resolution is reported as the full-width-at-half-maximum (FWHM) of the 59.6-keV photopeak. The best energy resolution of 8.5% was at an applied bias of -160 V and shaping time of 3 μs.

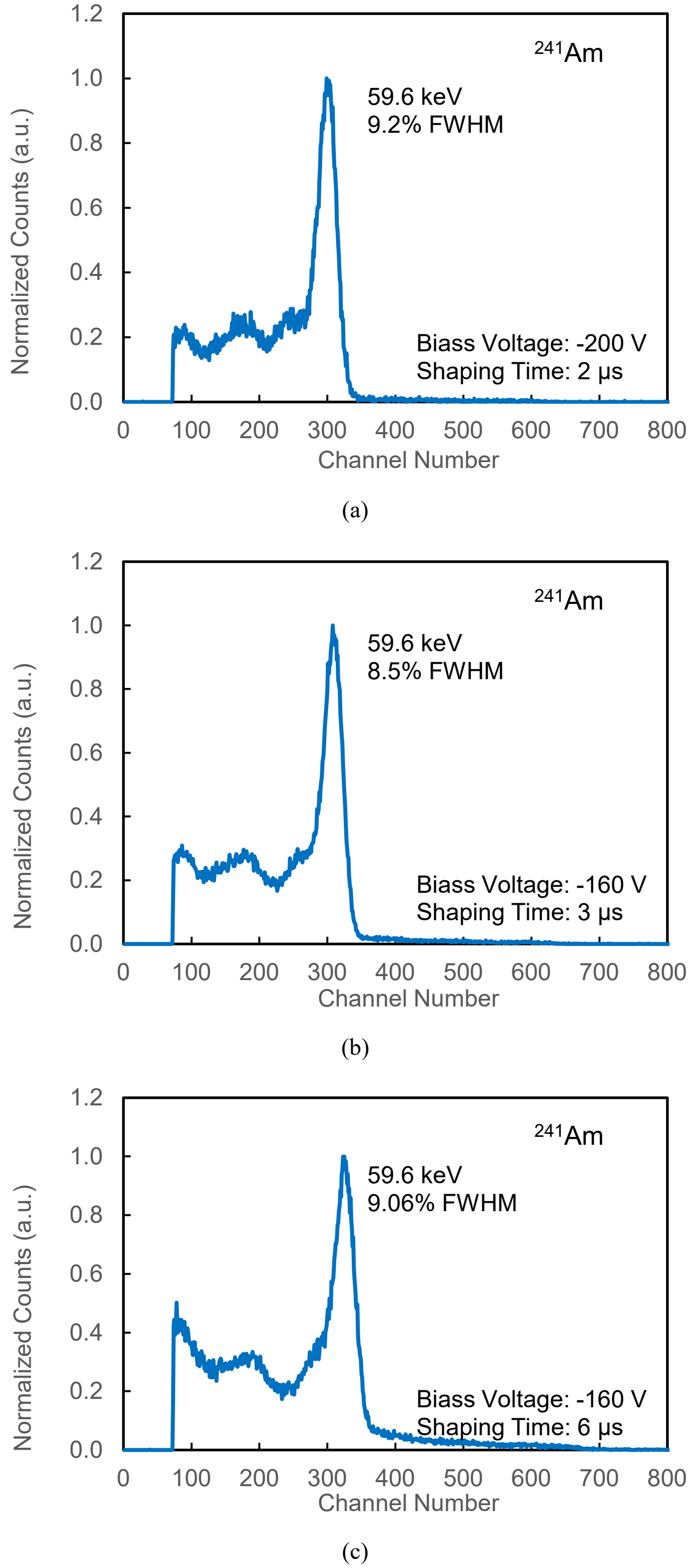

Figure 2. CZTS detector response to ^{241}Am at an applied bias of -160 V and shaping time of (a) 2 μs, (b) 3 μs and (c) 6 μs.

The energy resolution for various applied bias voltages and shaping times are shown in **Table 1**. The variation in energy resolution, computed as the difference between the maximum and minimum resolutions, is minimum for the 6-μs shaping time, and it is 1.7%. The variations are 2.5% for 3-μs shaping time and 3.6% for 2 μs. The peak positions for the 59.6-keV gamma line of ^{241}Am at various applied negative bias voltages and shaping times are shown in **Figure 3**.

Table 1. Energy resolution for the 59.6-keV gamma line of ^{241}Am at various applied bias voltages and shaping times.

Applied Bias (V)	Channel Number			Energy Resolution (FWHM)[a]		
	2-μs Shaping Time	3-μs Shaping Time	6-μs Shaping Time	2-μs Shaping Time	3-μs Shaping Time	6-μs Shaping Time
-20	128	146	169	-	-	-
-35	177	204	229	-	-	-
-65	239	265	283	-	-	-
-100	270	290	307	12.80%	11.00%	10.80%
-120	279	298	315	11.00%	9.70%	9.60%
-140	283	304	318	10.30%	9.90%	9.20%
-160	293	307	322	9.90%	8.50%	9.06%
-180	295	309	326	9.70%	8.60%	9.10%
-200	298	310	332	9.20%	8.70%	9.30%

a. For applied bias voltages of -20, -35 and -65 V, the energy resolution was not obtained by the software that came with the detection measurement system.

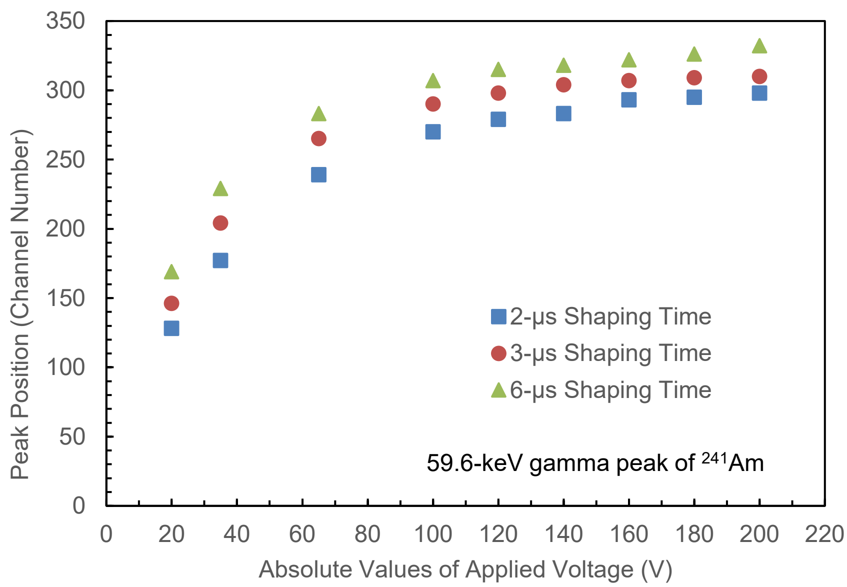

Figure 3. Peak position for the 59.6-keV gamma line of ^{241}Am at various applied negative bias voltages and shaping times. Note: Negative bias is an indication of the polarity, and the voltages shown in graph are absolute values.

The voltages shown in **Figure 3** are absolute values. The ^{241}Am spectra shown in **Figure 2** is for negative applied bias voltages, where the negative sign is an indication of the direction of current flow. The peak position becomes more stable as the absolute values of the applied bias voltage increases, and then begin to flatten at about 100 V. The resolution at various applied negative bias voltages and shaping time are shown in **Figure 4**.

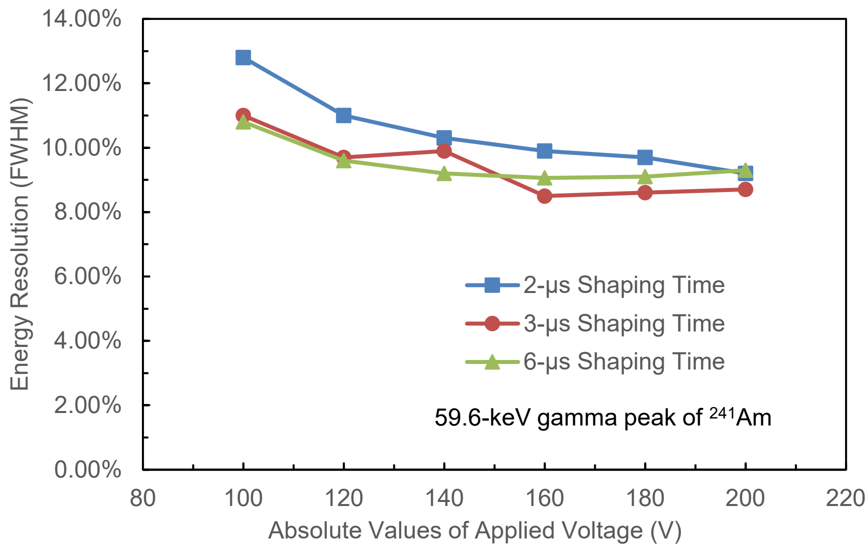

Figure 4. Energy resolution for the 59.6-keV gamma line of ^{241}Am at various applied negative bias voltages and shaping times.

4. Conclusions

The high crystal uniformity of CZTS and near absence of Te inclusions and grain boundary networks have given it great advantage in reducing the cost of semiconductor nuclear detection devices that can operate at room temperature without cryogenic cooling. An energy resolution of 0.9% for the 662-keV gamma line of ^{137}Cs was recorded at 1800 V applied bias for a Frisch-grid detector fabricated from a recent CZTS crystal grown by THM [3]. We have characterized a CZTS planar detector over an operating negative bias voltage range of -20 V to -200 V and amplifier shaping time of 2, 3 and 6 μs. The peak position of the 59.6-keV gamma line of ^{241}Am becomes more stable as the magnitude of the applied voltage increases. The energy resolution varied between 8.5% and 12.8%. The energy resolution was observed to be relatively stable in the -120 V to -200 V range at 6-μs shaping time. The variation in peak position began to decrease significantly for bias voltages over approximately -100 V. Our future work will include the study of the peak position and energy resolution over time.

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