Fabrication and Characterization of CdZnTeSe Nuclear Detectors

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***Abstract*–Cadmium zinc telluride selenide (CdZnTeSe) is emerging as a promising semiconductor material for low-cost production of nuclear and radiological detection systems capable of operating at room temperature. This paper presents studies of the fabrication process and detector response for gamma-ray detectors produced from high-quality CdZnTeSe crystals grown by the traveler heater method (THM). The resistivity of the CdZnTeSe is on the order of 10^{10} Ω-cm. The electron mobility-lifetime (μτ) product characterizing the charge-transport properties is on the order of 10^{-3} cm^2/V. Energy resolutions as good as 6.5% FWHM for the 59.5-keV gamma-peak of ^{241}Am were recorded for planar detectors with gold contacts.**

I. Introduction

NUCLEAR radiation detectors that are fabricated from ternary and quaternary compounds of cadmium telluride (CdTe) have the advantage of operating at room temperature (i.e., without cryogenic cooling) [1]–[7]. One of the most extensively researched CdTe-based semiconductor compound is cadmium zinc telluride (CdZnTe), which is commercially available from several vendors [8]–[11]. CdZnTe is however prone to defects caused by Te inclusions, network of subgrain boundaries, and compositional nonuniformity [12]–[14]. These defects are unevenly distributed in the detector matrix, and they limit the movement of charge carriers. This results in the degradation of detector energy resolution. Cadmium zinc telluride selenide (CdZnTeSe or CZTS) is emerging as a promising material for producing high-resolution detectors. The introduction of Se into the cadmium zinc telluride (CdZnTe) matrix in the growth process has led to increased compositional uniformity, less Te inclusions, and absence of a subgrain boundary network, thereby resulting in large high-quality crystal yields with less defects [15–19]. The large high-quality crystal yields of CZTS growth would give more detector-grade wafers per ingot grown and hence should lower the cost of high-resolution detectors. This paper presents the fabrication and characterization of CZTS planar detectors.

The CZTS semiconductor used in this experiment was grown by the traveling heater method (THM). The growth process is described in detail by Roy et al. [18]. The material composition is $Cd_{1-x}Zn_xTe_{1-y}Se_y$ where x = 0.1 and y = 0.02. Predetermined stoichiometric amounts of 6N-purity CdZnTe and CdSe were used in the synthesis. A conically tipped quartz ampoule, coated with carbon, was used for the THM growth. The CZTS was doped with indium.

II. Experiment

Detector wafers were cut from the as-grown ingot of CZTS using a diamond-impregnated wire saw. Several wafers were cut, polished and tested for high electrical resistivity. In this experiment, we fabricated a CZTS detector from a wafer of size 5.9 x 6.0 x 1.6 mm^3. The wafer was successively polished with 800-grit, 1000-grit and 1200-grit carbide abrasive papers. The surfaces of the wafer were further smoothened by polishing on MultiTex pads with alumina powder. Alumina powder of sizes 3.0 µm to 0.1 µm were successively used. The wafer was then rinsed in distilled water followed by drying using compressed nitrogen gas. Gold electrical contacts were deposited on the two opposite 5.9 mm x 6.0 mm sides of the wafer by an electroless deposition technique. In this technique, gold chloride ($AuCl_3$) solution was pipetted on each surface and left to react with the surface, and then the excess $AuCl_3$ solution was removed through absorption by a felt paper.

Current-voltage (I-V) measurements were made using a customized box made from aluminum sheets and equipped with Keithley Picoammeter/Voltage Source model 6487. The detector was tested using a sealed ^{241}Am un-collimated nuclear radiation source. The CZTS detector was placed in a sample holder equipped with pogo-pin made by eV Products (now Kromek). This special sample holder is made of brass, and it has a beryllium window on which the ^{241}Am radiation source was placed. The signal from the detector is displayed in a computer after passing through a preamplifier, an amplifier, and a multichannel analyzer.

III. Results

The I-V plot of the CZTS detector is shown in Fig. 1. The resistivity was 1.4 x 10^{10} Ω-cm. This high electrical resistivity

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is an important factor in room-temperature semiconductor detectors. High resistance is needed to reduce the leakage current and noise. Low noise translates to a better energy resolution. The surface current is often a major contributor to the electronic noise in CdTe-based detectors [7], [20]. The passivation of CZTS in ammonium fluoride (NH_4F) solution was reported to reduce the surface current and allow for improved detector resolution [7].

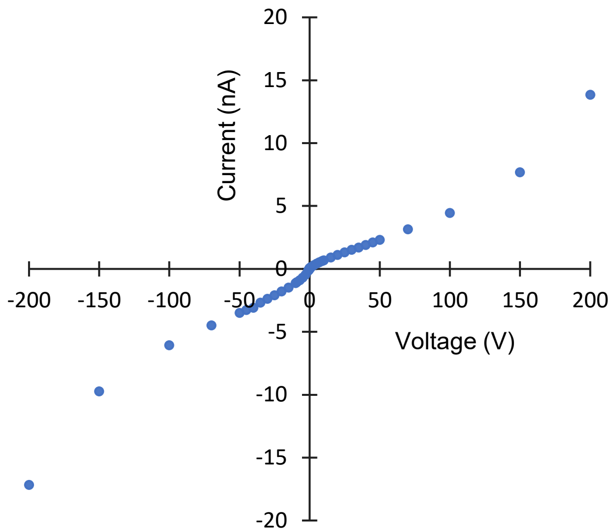

Fig. 1. Current-voltage plot of the CZTS detector. Wafer size: 5.9 x 6.0 x 1.6 mm^3. Resistivity: 1.4 x 10^{10} Ω-cm.

The response of the planar CZTS detector to the 59.5-keV gamma line of ^{241}Am is shown in Fig. 2. The energy resolution measured as full-width-at-half-maximum (FWHM) for the 59.5-keV peak is 6.5%. An energy resolution of ~0.9% FWHM was reported for the 662-keV gamma of ^{137}Cs at 1800 V with a 5 x 5 x 12.3 mm^3 Frisch grid CZTS detector [18].

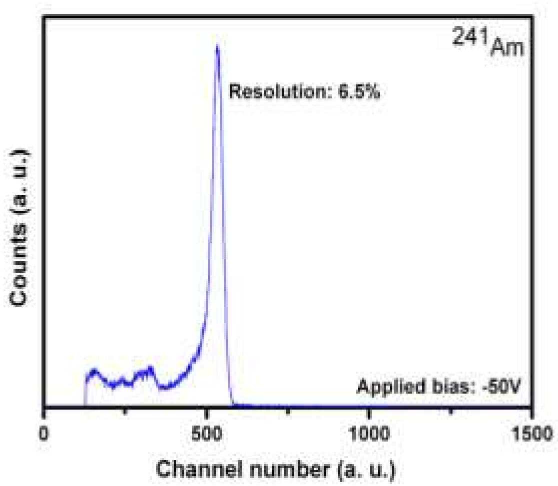

Fig. 2. Response of the CZTS detector to the 59.5-keV gamma line of ^{241}Am at -50 V. Energy resolution: 6.5% FWHM.

The electron mobility-lifetime (μτ) product characterizing the charge-transport properties is on the order of 10^{-3} cm^2/V. This was measured by recording the charge collection at various applied voltages and fitting to the Hecht equation.

IV. Summary

The fabrication and characterization of a planar CZTS detector has been presented. An electrical resistivity of 1.4 x 10^{10} Ω-cm was measured from the I-V plot of a CZTS wafer with electroless-deposited gold contacts. The measured detector resolution for the 59.5-keV gamma of ^{241}Am was 6.5% FWHM. An electron mobility-lifetime product of 10^{-3} cm^2/V was recorded for the detector. CZTS detectors have shown promise in reducing the cost of room-temperature CdTe-based nuclear detectors due to their high compositional uniformity, less Te inclusions, and absence of a subgrain boundary network. Future research efforts will be aimed at optimizing the fabrication of CZTS Frisch grid detectors. Better energy resolutions are expected by optimizing the detection fabrication techniques, particularly the contact deposition and surface passivation processes.

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