Comparative Studies of CdZnTe, CdMnTe, and CdZnTeSe Materials for Room-Temperature Nuclear Detection Applications

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***Abstract*–Cadmium telluride (CdTe) and its ternary and quaternary compounds have found applications in the development of X-ray and gamma-ray detectors used in nuclear detection and medical imaging applications. Example of these detectors include CdZnTe (CZT), CdMnTe (CMT), and CdZnTeSe (CZTS). These nuclear detectors can operate at room temperature without cryogenic cooling. This paper presents comparative studies of these semiconductor material. The properties studied include detector resistivity, Te inclusions, grain boundary networks, mobility/lifetime of the charge carriers, and energy resolution. The effects of passivation with chemicals such as KOH and NH_4F, are also presented. X-ray photoelectron spectroscopy (XPS) studies showed increase in the quantity of TeO_2 on surfaces of these materials after passivation in KOH and NH_4F. While CZT detector has wide commercial availability, it has more Te inclusions and grain boundary network compared to CZTS. CMT and CZTS have better crystal uniformity than CZT. The comparatively low presence of Te inclusions and grain boundary network in CZTS gives it a higher crystal growth yield for detector-grade material.**

I. Introduction

Cadmium Telluride (CdTe) and its ternary and quaternary compounds have applications in the development of X-ray and gamma-ray detectors used in medical imaging and nuclear detection applications at room temperature [1]–[7]. Typical CdTe ternary compound semiconductors include Cadmium Zinc Telluride (CdZnTe or CZT) and Cadmium Manganese Telluride (CdMnTe or CMT). The most recent quaternary compound of CdTe that has shown great promise in radiation detection is Cadmium Zinc Telluride Selenide (CdMnTeSe or CZTS). The major advantage of these detectors is the ability to operate at room temperature without cryogenic cooling. This enables them to be fabricated into portable nuclear detection devices that can be used at seaports and border security, and at nuclear facilities to monitor radiation levels. Among these detectors, CZT has received a lot of efforts and funding in research and development (R&D) compared to CMT and CZTS. CZT has been developed into commercial radiation detection devices by several companies. Some of these companies include Kromek Group PLC [8], Redlen Technologies [9], FLIR Systems [10], Eurorad [11], and H3D [12]. There are ongoing R&D efforts aimed at improving the performances of these detectors. In this paper, we focus on comparative studies of CZT, CMT, and CZTS semiconductor materials that we have separately worked in the past several years. The comparisons are on individual detector experiments. The properties studied include detector resistivity, Te inclusions, grain boundary networks, mobility/lifetime of the charge carriers, and energy resolution.

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II. Detector Fabrication and Experiments

Planar detectors are often used in characterizing the properties of CdTe-based materials. The fabrication involves four major steps: wafer cutting, mechanical polishing, chemical etching and air-drying, and deposition of electrical contacts. The wafer is cut to desired dimension using a special cutting machine equipped with a fine diamond wire and water pump that provides cooling and lubrication. This is followed by mechanical polishing. The polishing is aimed at removing surface defects and residues. Silicon-carbide abrasive papers of several grades ranging from 600-grit to 1200-grit papers are successively used in the first step of the mechanical polishing process. The second step involved polishing the wafers further on multi-tex pads to produce mirror-shine surfaces using alumina (Al_2O_3) powder in decreasing steps from 3.0 μm to 0.1 μm sizes. The surfaces of the wafers could be further smoothened using chemical etching to remove fine residual damages caused by the mechanical polishing process [13]. This process involves dipping the wafer in a 1% to 2% solution of bromine methanol. The sample is then dried using compressed air. Some studies do not involve chemical etching.

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To perform detector testing, electrical contacts are deposited on opposite sides of the wafer and the contact-wafer interface is allowed to stabilize for a desired period which could range from hours to days. The electroless contact deposition technique is widely used due to its simplicity, and it is known to produce a strong chemical bonding between the metal contact and the semiconductor wafer [12]. Other contact deposition techniques include thermal evaporation and sputtering. Examples of contact materials are gold, carbon, and aluminum.

Current-voltage (I-V) characterization experiment is made to determine the detector resistivity and the contact type. After establishing that the sample has high resistivity, in the order of 10^8 Ω-cm and above, the detector is tested using a sealed nuclear radiation source. An example I-V measurement setup is shown in Fig. 1. A schematic diagram of the setup for detector testing is shown in Fig. 2.

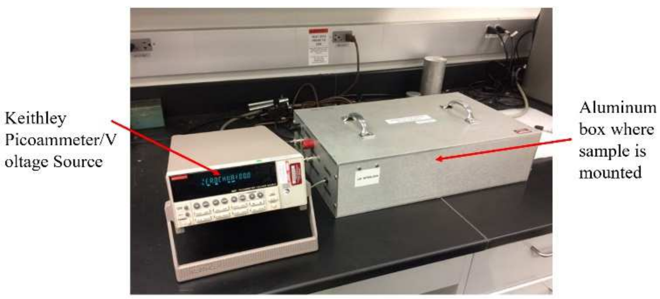

Fig. 1. An example I-V measurement setup consisting of voltage source, pico-ammeter, and sample box.

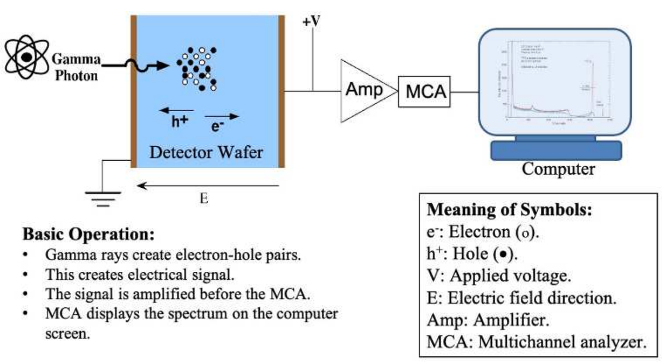

Fig. 2. Basic operation of CdTe-based detectors and setup for measuring performance. A pre-amplifier is often used to amplify the signal from the detector before the amplifier.

III. Results and Conclusion

X-ray photoelectron spectroscopy (XPS) studies showed increase in the quantity of TeO_2 on surfaces of these materials after passivation in KOH and NH_4F solutions [13],[14]. The energy resolution of CZTS planar detector was found to improve significantly after passivation in NH_4F solution [5]. CZT detector has wide commercial availability, however, it has more Te inclusions and grain boundary networks compared to CZTS. CMT and CZTS has better crystal uniformity than CZT. The comparatively low presence of Te inclusions and grain boundary network in CZTS gives it a higher crystal growth yield for detector-grade material.

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