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Design and Fabrication of a CdMnTe Nuclear Radiation Detection System

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***Abstract*— Cadmium manganese telluride (CdMnTe) is one of the ternary compounds of cadmium telluride (CdTe) that has shown great potential applications in the development of X-ray and gamma-ray detectors used in medical imaging and in the detection of radiological and nuclear threats. CdMnTe nuclear detectors are capable of operating at room temperature without cryogenic cooling. The goal of this project is to design and fabricate CdMnTe detection system that can be used in laboratory experiments for characterizing detector materials and for identification of radionuclides. The engineering design objectives include a spring-based sample holder, ability to measure electrical properties of CdTe-based semiconductor nuclear detectors, and the detection of nuclear radiations. This paper presents the design of the sample holder and the fabrication of a CdMnTe detector. The current-voltage characterization experimental results showed that the CdMnTe has the high resistivity needed for CdTe-based nuclear detectors. The results also include the response of the CdMnTe detector to the 59.5-keV gamma peak of Am-241 nuclear radiation source.**

Keywords—CdMnTe nuclear detectors, gamma-rays, X-rays

I. Introduction

Cadmium Telluride (CdTe) and its ternary compounds have applications in the development of X-ray and gamma-ray detectors used in medical imaging and the detection of radiological and nuclear threats [1]–[11]. Typical CdTe ternary compound semiconductors include Cadmium Zinc Telluride (CdZnTe) and Cadmium Manganese Telluride (CdMnTe). The major advantage of CdTe, CdZnTe and CdMnTe detector is the ability to operate at room temperature without cryogenic cooling. Thus, they can be fabricated into portable nuclear detection devices that can be used at seaports and border security, and at nuclear facilities to monitor radiation levels. CdZnTe has received a lot of *research and development (R&D)* efforts compared to CdMnTe. Several companied have developed CdZnTe into commercial radiation detection devices. Some of these companies include Kromek PLC [12], Redlen Technologies [13], FLIR Systems [14], Eurorad [15], and H3D [16]. There are still R&D efforts that are aimed at improving the performances of these detectors. In this project, we focus on design and fabricate a CdMnTe nuclear detection system that could be used for experimental studies in a laboratory setting. The final goal is a system for electrical characterization, measurement of detector response to X-rays and gamma-rays, and for the identification of unknown nuclear radiation sources. The basic component of a semiconductor radiation detection system is illustrated in Fig. 1.

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II. Engineering Design Objectives

A. Ohmic Contacts

The first engineering design objective is to have ohmic contacts on opposite sides of a planer detector wafer. CdTe-based detectors have high resistivity greater than 10^8 Ω-cm to have the low leakage current, in nano-amp range, for effective operation as radiation detectors. A good ohmic contact and low leakage current are needed to get devices with effective photoconductivity [17]. Gold has been effectively used to produce ohmic contacts on CdZnTe by electroless deposition [18]. The ohmic contact will enable the effective calculation of the detector material resistivity ρ from the slope of the current-voltage (I-V) curve the following equations. The electrical resistivity of a material of length l and cross-sectional area A is

$$\rho = R\frac{A}{l} \qquad (1)$$

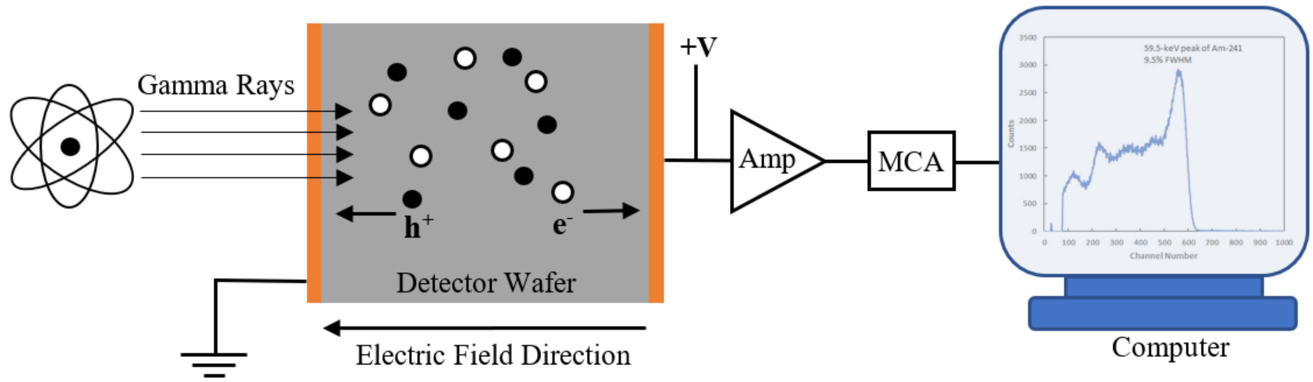

Fig. 1. An illustration of the basic component of a semiconductor radiation detection system. Not drawn to scale. V is applied voltage, e^- is electron, h^+ is hole, Amp represents a pre-amplifier and an amplifier. and MCA is multichannel analyzer.

Since $R = V/I$ and the slope of the slope of the I-V curve is *slope* $= \Delta I/\Delta V$, we have

$$\rho = \frac{A}{l}\left(\frac{1}{slope}\right) \tag{2}$$

B. Electrical Insulation and Thermal Shielding

The second design objective is to have the box that serves as sample mount and housing that is made of material which has high electrical insulation and high thermal resistance. This is important for electrical wiring and for laboratory experiments that may involve elevated temperatures. The material of choice is *Teflon*, which has been shown to have high thermal stability, low thermal conductivity, and high electrical insulator [19].

C. Spring-Based Sample Holder

The sample holder is expected to hold wafers of different dimensions. This demands special attention to the thickness of the wafer and the ability of the electrical leads to have firm contact with the electrodes without putting too much pressure that could cause damage. Thus, a spring is incorporated into the design to hold off and excessive pressure on the electrical contacts and the wafer. See Fig. 2.

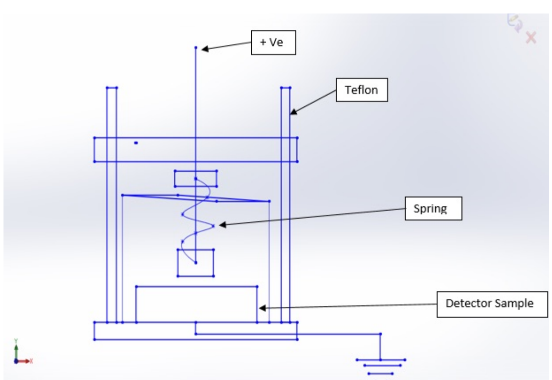

Fig. 2. A 2-dimensional view of the sample holder.

D. Engineering Standards

Several engineering standards were followed in the design and fabrication of the system. These include:

- IEEE N42.35-2016 - American National Standard for Evaluation and Performance of Radiation Detection Portal Monitors for Use in Homeland Security.
- N42.35-2016 - American National Standard for Evaluation and Performance of Radiation Detection Portal Monitors for Use in Homeland Security.
- IEEE 515-2017 - IEEE Standard for the Testing, Design, Installation, and Maintenance of Electrical Resistance Trace Heating for Industrial Applications.

III. Planner Detector Fabrication and Testing

The fabrication of the planner detector involves four major steps: wafer cutting, mechanical polishing, chemical etching and air-drying, and deposition of electrical contacts. Prior to testing the detector, the I-V characterization experiment is made to determine the detector resistivity and the contact type; in this case ohmic contact is desired as discussed in subsection IIA. 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. The determination of the resistance is important as not to damage the pre-amplifier of the radiation detection system.

A. Cutting of the Detector Wafer

Cutting the wafer to the desired dimension. This is done using a special cutting machine equipped with a fine diamond wire and water pump that provides cooling and lubrication. The dimensions of the CdMnTe wafer used in this experiment are: 6.6 mm x 3.6 mm x 2.9 mm.

B. Mechanical polishing

Polishing to remove surface defects and residues. The cutting of the detector wafer from the CdMnTe ingot causes surface defects and residues that contribute electronic noise [18], and thus degrade the energy resolution of the detection system [20]–[22]. This step of the detector fabrication starts with mechanical polishing of the wafer surfaces using silicon-carbide abrasive papers. Several grades of the abrasive papers are used. 600-grit paper is first used followed by successive polishing with higher grades up to 1200-grit abrasive paper. Next, the wafer is fine polished to produce mirror-shine surfaces using alumina (Al_2O_3) powder in decreasing steps from 3.0 µm to 0.1 µm sizes.

C. Chemical Etching and Air-Drying

The surfaces of the wafers be further smoothened via chemical etching to remove fine residual damages caused by the mechanical polishing process [18]. This is often accomplished bi dipping the wafer in a 1% to 2% solution of bromine methanol [23]–[26]. The sample is finally dried using compressed air.

It was reported that chemical etching with bromine-methanol solution could sometimes cause increased conductivity on the material surface [20], [24], 27]. The CdMnTe sample in this experiment was not chemically etched. Immediately after polishing, it was rinsed in distilled water and tried using compressed air. The sample after polishing and drying is shown in Fig. 3.

Fig. 3. CdMnTe sample after being polished with Al_2O_3. Wafer size: 6.6 mm x 3.6 mm x 2.9 mm.

D. Deposition of Electrical Contacts

The electrical contacts were deposited on the two opposite planer surfaces of the wafer using the electroless deposition method [18], [28], [29], [30]. The electroless contact deposition technique is widely used due to its simplicity, and it is known to produce a stronger chemical bonding between the metal contact and the semiconductor wafer when compared to thermal evaporation and sputtering techniques [29]. In this experiment, we deposited the gold contact by pipetting drops of gold chloride solution on the surfaces, and using the tip of a felt paper to remove the excess solution after the gold reacted with the wafer.

E. Current-Voltage Experiment

The current-voltage measurements were made using a customized box at Brookhaven National Laboratory that is equipped with a Keithley Picoammeter/Voltage Source. The electrical leads consist of a thin metal foil at the bottom and an adjustable metal pin on top. Cupper foil is placed between the pin and the CdMnTe wafer to prevent scratching the electrical contact. The I-V curve is shown in Fig. 4. The resistivity of the CdZnTe detector, calculated using Fig. 4, is 2.7 x 10^{10} Ω-cm.

F. Detector Testing

The operation of the detector is illustrated in Fig. 1. The incoming gamma rays generate electron-hole pairs (charge carriers) that results a signal that passes through a pre-amplifier, an amplifier, and a multichannel analyzer to a computer that display the spectrum of the radiation source.

In our experiment, the CdZnTe detector was mounted on a standard eV Product's sample holder made of brass, and then secured against a beryllium window. The holder is equipped with a gold-plated contact fitted with a spring. The sample holder was connected to a pre-amplifier, then to an amplifier, which is connected to a multichannel analyzer and a computer as illustrated in Fig. 1.

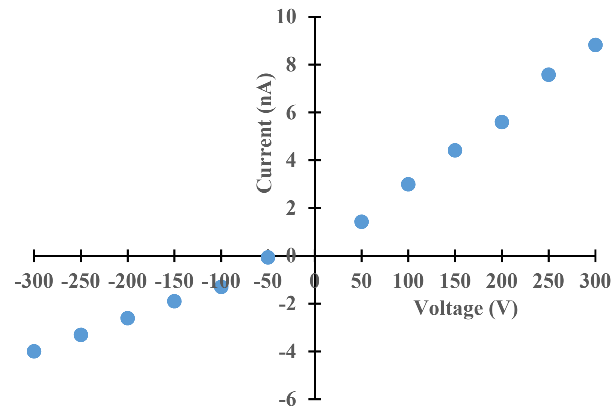

Fig. 4. The current-voltage plot for the CdMnTe sample. The resistivity was calculated to be is 2.7 x 10^{10} Ω-cm.

The test result of the detector using Am-241 radiation source is shown in Fig. 5. The energy resolution for the 59.5 keV peak measured as the full-width-at-half-maximum (FWHM) is 9.3% for an applied voltage of 130 V.

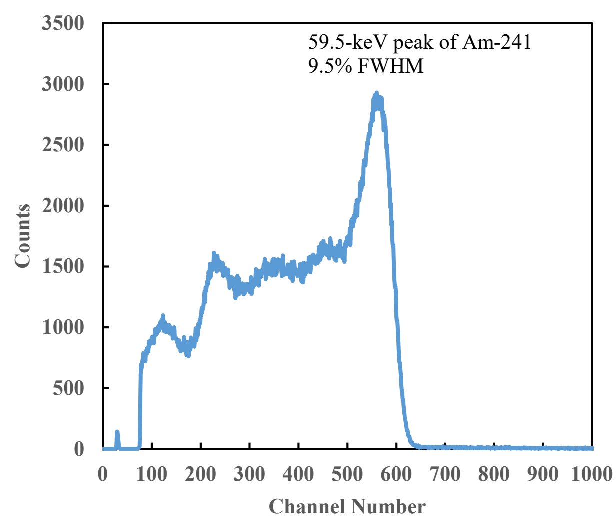

Fig. 5. The spectrum of Am-241 obtained with the CdMnTe detector. Energy resolution for the 59.5 keV peak is 9.3% FWHM for a applied voltage of 130 V

IV. Conclusions and Future Work

In this project, we designed a sample holder that can be used in laboratory experiments for characterizing CdTe-based detector materials and for identification of radionuclides. We discussed the engineering design objectives, which include a spring-based sample holder, ability to measure electrical properties of CdTe-based semiconductor nuclear detectors, and the detection of nuclear radiations. The fabricated CdMnTe detector has a resistivity of 2.7 x 10^{10} Ω-cm, which makes it suitable for detecting X-rays and gamma-rays. The test results of the detector gave and energy resolution of 9.3% FWHM for the 59.5-keV gamma peak of Am-241 nuclear radiation source. In future work, we will build the Teflon-based sample holder, test it with the CdMnTe detector, and compare the results to reported in this paper.

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