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Polycrystalline CdZnTe Thick Films for Low Energy X-ray: System Evaluation

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***Abstract*—The X-ray response of polycrystalline-CdZnTe was measured by signal-to-noise (S/N) analysis. The CdZnTe material has optimal properties in a solid-state X-ray detector, and much research has focused on single crystal CdZnTe with a small-sized, silicon readout device. However, it would be difficult to apply CdTe or CdZnTe single crystal to large area, flat panel detectors, such as those used for radiography and mammography. As an alternative of single crystal CdZnTe, we have grown thick, polycrystalline CdZnTe films of high resistivity (> 5×10^9 Ohm cm) using the thermal evaporation method on carbon substrate. A high signal-to-noise value has a direct impact on the performance of CdZnTe X-ray detectors. Important image parameters, such as dynamic range and detective quantum efficiency, rely on the signal and noise characteristics of the system. In this paper, we analyzed the properties of the X-ray detector and obtained images of the X-ray detector using the data acquisition system. The X-ray detector used the Cd1-xZnxTe (x=0.04), which used carbon substrate and gold as the electrode. The detector design is planar and 32 mm x 10 mm in size, and it has a 1.75mm x 1mm pixel electrode size and a detector thickness of 150 µm.**

I. Introduction

X-RAY detectors have been examined for various medical applications, such as panoramic dental imaging, fluoroscopy, computed tomography, mammography, and non-destructive testing. Two types of detector architectures have been developed; one of these involves indirect detection, while the other involves direct detection. In direct detection, absorbed X-ray photons are directly converted to electron-hole pairs in a conversion layer, and are then collected as electric charges on storage capacitors. High gain materials include lead iodide (PbI_2), mercury iodide (HgI_2), thallium bromide (TIBr), cadmium telluride (CdTe), and cadmium zinc telluride (CdZnTe).

These materials have an inherently high stopping power, an excellent carrier transport property, and relatively wide-band gap energy. Among the materials mentioned, CdZnTe is the most stable, both mechanically and chemically.

As is commonly known, single-crystal CdZnTe detectors are difficult to apply to large-area, flat-panel X-ray detectors. Thus, we conducted a feasibility study for an X-ray panel detector with a polycrystalline CdZnTe film as the X-ray converter [1].

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In this paper, we focused on the X-ray response of the single-crystal and polycrystalline CdZnTe films for a large-area X-ray detector. We deposited thick CdZnTe films by using a thermal evaporation method on carbon substrate and conducted a charge-sensitive pre-amplifier readout circuit using a Burr-Brown ACF2101 low-noise current to voltage conversion amplifier. The X-ray source used 65kVp with a tube current of 7.5mA and an exposure time of 0.6 sec.

II. Materials and Methods

A. Polycrystalline CdZnTe setup(ohmic)

We deposited thick CdZnTe films by using a thermal evaporation method on carbon substrate. High zinc composition CdZnTe compounds have low leakage current due to a wide energy gap, but have poor charge collection efficiency due to low electron mobility. Thus, in this experiment, we fixed the Zn composition at 4%.

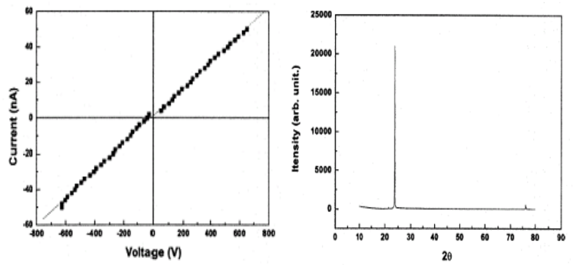
Cd1-XZnXTe (X=0.04) and CdZnTe:Cl (Cl=100ppm) polycrystalline materials were synthesized from high purity Cd, Zn, and Te using a fused quartz tube under 10^{-6} torr at 1200℃.

To prepare for the CdZnTe source, quartz tubes were rotated at a speed of 3 rev/min, and additional temperature oscillation was applied to obtain uniform Zn composition and Cl concentrations throughout the whole of the bulk material.

We specifically selected carbon substrate to increase X-ray incidence on CdZnTe thick films through a reduction of X-ray absorption. Using a thermal evaporator, the CdZnTe thick films were deposited at a rate of 50um/hour on carbon substrate at 350~400℃ and we created the thick film, with a size of 32mm x 10mm, and a pixel size of 1.75mm x 1mm by 150µm thickness. The detailed temperature profiles of the furnace and substrate heater were not described in the text.

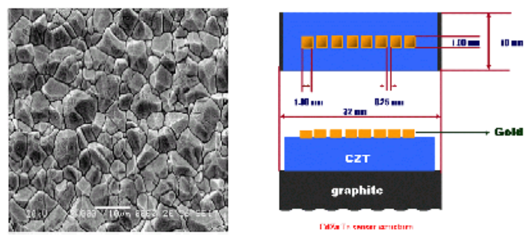
Lastly, we created an Au top electrode on CdZnTe and observed the effects of heat treatment on the resistivity of as-deposited CdZnTe thick films, Au/CdZnTe thick films were annealed at 400℃ for 24 hours in a vacuum (10^{-6} torr), and Te partial pressure and Cd partial pressure were generated using a two-zone furnace.

The I-V curve of this sample is shown in Fig. 1 (a). The resistivity of the Au/CdZnTe sample was 2×10^9 Ω·Cm. The I-V curve shows a linear line. This indicates that Ohmic contact was established. The XRD spectrum of this sample is shown in Fig. 1 (b). The result of the XRD spectrum display direction of crystallization that the (111). The SEM of this sample is shown in Fig. 2 (a). The average grain size was found to be approximately 5µm. This structure of the Ohmic contact with CdZnTe is shown in Fig. 2 (b).



(a) (b)

Fig.1. (a) Current-Voltage character of Au top electrode sample, (b) Cd1-xZnxTe(x=0.04) XRD spectrum.



(a) (b)

Fig. 2. (a) Cd1-xZnxTe(x=0.04) SEM figure, (b) Ohmic contact Cd1-xZnxTe(x=0.04) structure.

B. Polycrystalline CdZnTe Setup(Schottky)

Using a thermal evaporator, the CdZnTe thick films were deposited onto ITO- (indium tin oxide) coated glass at a temperature below 500℃.

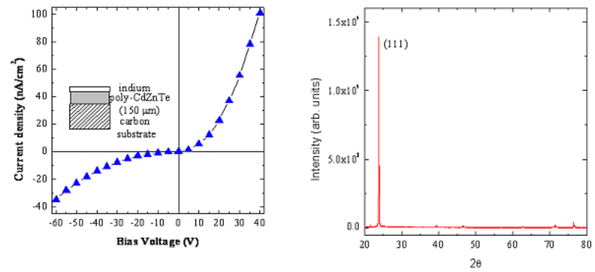
CdZnTe compounds with high zinc composition have low leakage current due to the wide energy gap, but they have poor charge collection efficiency due to the low charge carrier mobility. Additionally, by increasing the zinc content, the stopping power of the CdZnTe compounds is lowered due to the low atomic number of zinc. The use of synthesized CdZnTe compounds as source material makes it easy to control the partial pressure of each element. To obtain thick, uniform CdZnTe films in a short period of time, multiple point sources and substrate rotation were employed.

In order to analyze the structure of th films, deposited CdZnTe thick films were characterized by XRD. The XRD spectrum of this Schottky contact sample is shown in Fig. 3 (b). Surface morphology, defects, and compositions of each element were examined by SEM and XPS. The SEM of this Schottky contact sample is shown in Fig. 4 (a). The average grain size was observed to be approximately 3-4 μm.

The grain size was estimated from the Scherrer's formula, d = (kλ/βcosθ), where λ = 1.5443Å is the wavelength of the CuK2 line, β is the full width at half of the maximum of the main peak. β is Scherrer's constant, which equals approximately 1.15 for the (111) orientation in the cubic system.

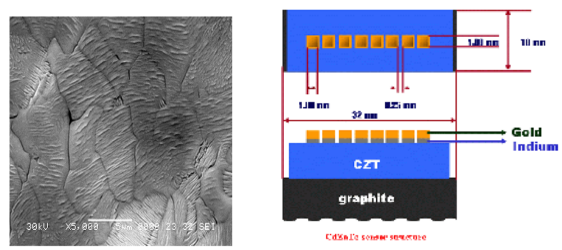
To examine the effects of heat treatment on the resistivity of polycrystalline CdZnTe thick films, as-deposited CdZnTe samples were annealed at 400℃ for 24 h in a vacuum (10^{-6} torr) and with Cd partial pressure. In order to measure the electrical properties of the CdZnTe thick films, detectors were assembled by thermal evaporation method, in which gold was deposited onto the films as front contact to 1000Å. Using the four probe method, room temperature current-voltage measurement was carried out using an electrometer (Keithley 2010) and a dc high-voltage power supply (Keithley 2410). The I-V curve of this Schottky contact sample is shown in Fig. 3 (a).

The detector module was 32mm x 10mm in size, with a 16-channel array. Each element of the array has a dimension of 1.75mm×1mm. The structure of the Schottky contact CdZnTe is shown in Fig. 4 (b).



(a) (b)

Fig. 3. (a) Current-Voltage character of Schottky contact Cd1-xZnxTe, (b) Cd1-xZnxTe XRD spectrum of Schottky contact.



(a) (b)

Fig. 4. (a) Cd1-xZnxTe SEM figure of Schottky contact, (b) Schottky contact Cd1-xZnxTe structure.

The connection of the detector material to the DAS (Data Acquisition System) conducted the FPCB module on an Al-plate due to decreased wire resistance that if it is big, current reduced in circuit. The detector module is shown in Fig. 5.

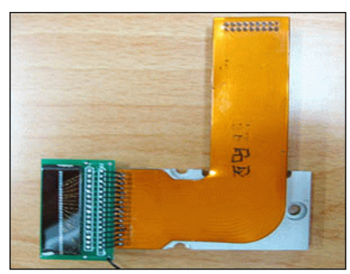


Fig.5. Polycrystalline Cd1-xZnxTe Module

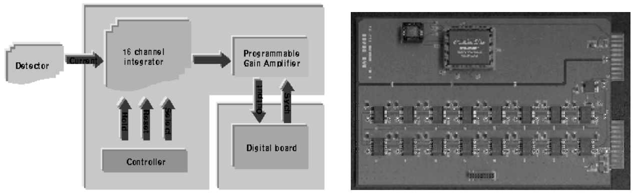
The charge collection efficiency for X-ray photons on CdZnTe detectors is dependent on both the position and direction of the irradiation. The mean free path of the carriers (electrons or holes) are depends on the products of mobility (μ) and lifetimes(τ) assuming constant electric field.

III. Experimental Condition

Ultra-low noise front-end readout electronics were used to test the single crystalline CdZnTe and the polycrystalline

CdZnTe film. The circuits were distributed into the analog board, digital board, and master board.

An analog board was manufactured in order to convert from current to voltage using the ACF2101 by Burr-Brown Co.



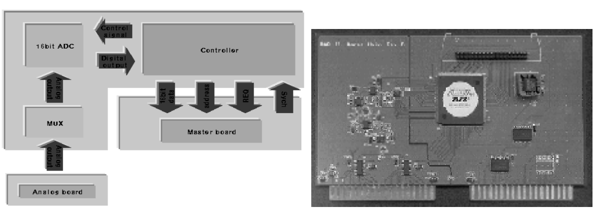
(a) (b)

Fig. 6. (a)Block diagram and (b) picture of the Analog Board

The amplifier has 90dB wide dynamic range and includes an integration capacitor, reset and hold switches, and an output multiplexer. The internal capacitor had a level of precision at 100pF. Transfer function V_{OUT} can be defined as

$$V_{OUT} = -\frac{1}{C_{INTEGRATION}} \int I_{IN} dt$$

Through a multiplexer, we developed a digital board in order to acquire the analog signals that were to be sent from the analog board and changed into digital signals through the ADS8322. This board also created an address that corresponded to each of the digital data. A diagram of this digital board is shown in Fig. 7.

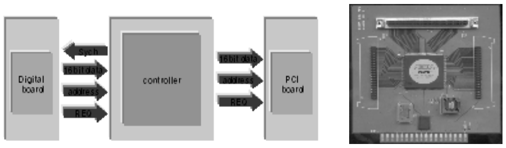


(a) (b)

Fig. 7. (a)Block diagram and (b) picture of the Digital Board.

The ADC has a 16-bit output and a 500 KHz sampling rate A/D converter with an internal 2.5V reference. Therefore, the maximum digit obtained was 65,536, as the limit of the 16-bit output is 2^{16}.

The master board was designed to transmit the 16-bit data to the PC and to have the address sent from the digital board. This board output the signal to set the synchronization signal of the digital board with that of the analog board. A diagram of this master board is shown in Fig. 8.



(a) (b)

Fig. 8. (a)Block diagram and (b) picture of the Master Board

The X-ray source used 65kVp with a tube current of 7.5mA. The exposure time was 0.3 sec. The source used 150kVp with tube current of 1mA for a continuous amount of time in order to acquire an image. The distance from the source to the detector was 20cm.

IV. Experimental Results

As shown in Fig. 9., the digital value of the photodiode, 1mm x 1mm pixel electrode size, was acquired for comparison with the polycrystalline CdZnTe. Although the dimensions of the photodiode and CdZnTe that are being tested must be the same size, the CdZnTe area was decreased by 1/17 because it generated more current leakage than the CdZnTe at the same dimensions as the photodiode. Here, the disparity of output to the difference of dimensions can be compensated for with the formula,

$$J_n = \frac{I}{A}$$

where, I is the output current of the respective detector, A is the area of several detectors, and J_n is the current density of each detector. The current-voltage characteristic of this CdZnTe sample is determined by the barrier height at the surface; the superior output of the DAS is also affected. Thus, in this study, the polycrystalline CdZnTe produced the Ohmic or Schottky contact sample that was determined from the barrier height and the analyzed X-ray response. First, experimental polycrystalline CdZnTe produced Ohmic contact using a gold electrode on the surface of CdZnTe.

The result of this Ohmic contact CdZnTe is shown in Fig. 10. The dark current of this photodiode had a digital value of almost 2~400. In contrast, because Ohmic contact CdZnTe could not block the leakage, the dark current of Ohmic contact CdZnTe was very large, with a digital value of approximately 58,000 . Consequently, this Ohmic contact CdZnTe could not take the image. Thus, the second polycrystalline CdZnTe grew indium on the surface of CdZnTe, and the gold electrode evaporated on the indium due to the formation of a blocking layer. The result of this Schottky contact CdZnTe is shown in Fig. 11.

The dark current of this Schottky contact CdZnTe is markedly reduced, to a digital value of 15000; this value is 1/4 that of Ohmic contact. However, it is still larger than the dark current of the photodiode. Although the dark current of Schottky contact CdZnTe is larger than that of the photodiode, if evolution of Schottky barrier not enough take into consideration, the dark current of this CdZnTe can be more greatly reduced through better evolution of Schottky barrier. Additionally, the signal output of the created Schottky contact CdZnTe has a digital value of approximately 25,000, and the signal output of the photodiode became saturated. In this experiment, we were able to obtain an image using the photodiode and the Schottky contact CdZnTe detector. The obtained image is shown in Fig. 12 and 13. Although both the image and the signal output of Schottky contact polycrystalline CdZnTe are worse than the image and signal output of the photodiode, their qualities are not substandard considering that the electrode area of the photodiode is larger than the electrode area of polycrystalline CdZnTe.

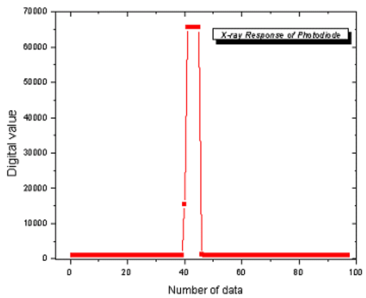


Fig. 9. Response of the photodiode

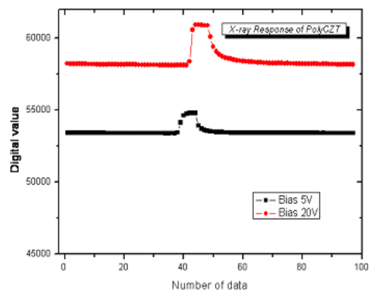


Fig. 10. Response of the ohmic contact polycrystalline CZT

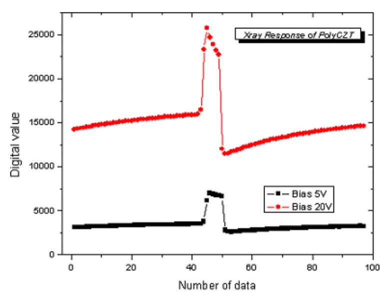


Fig. 11. Response of the schottky contact polycrystalline CZT

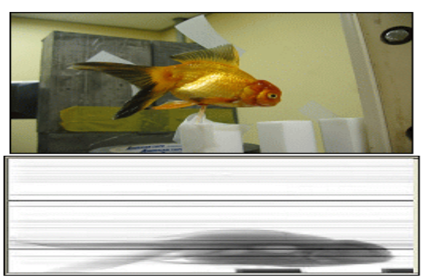


Fig. 12. Acquired image from the photodiode

Fig. 13. Acquired image from the polycrystalline CZT

V. Discussion

The small signal output and blurred image of the created Schottky contact CdZnTe can be more greatly improved by increasing the pixel electrode size and the thickness of CdZnTe after the Schottky barrier is completely made.

Through this experiment, we learned of the importance of Schottky contact in order to obtain good image. The result of this experiment showed a sufficient possibility that polycrystalline CdZnTe can be used to obtain a better image, when paper is not extant internationally that somebody used polycrystalline CdZnTe and got the image.

VI. Conclusion

We will manufacture a circuit using only another amplifier without an A/D converter in a readout circuit. In order to more significantly decrease the dark current, the Schottky barrier height must be increased. Thus, a detector will be made using an electrode composed of another material. We will also lower the experimental temperature. Additionally, the detector thickness will be raised, from up to 150μm to up to 500μm, in order to reduce the capacitance of the detector.

It appears that, structurally, the current is the vacancy of the hole that is made when the electron is moved; this indicates that a more uniform current can be obtained when the lattice structure is regular. However, the current will be distributed in diverse directions because the direction of flowing current is not uniform in polycrystalline CdZnTe, the lattice structure of which is irregular. Therefore, we will collect data related to lattice structure. In other words, it seems that a material which lattice structure is regular more thick add at output that flowed out from polycrystalline CdZnTe to the system.

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