A Polycrystalline CdZnTe Film and Its X-ray Response Characteristics for Digital Radiography

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The $Cd_{1-x}Zn_xTe$ film was produced by thermal evaporation for the flat-panel X-ray detector. The crystal structure and the surface morphology of polycrystalline $Cd_{1-x}Zn_xTe$ film were examined using XRD and SEM, respectively. The leakage current and X-ray sensitivity of the fabricated films were measured to analyze the X-ray response characteristic of Zn in a polycrystalline CdZnTe thin film. The leakage current and the output charge density of $Cd_{0.7}Zn_{0.3}Te$ thin film were measured to 0.3 1 nA/cm^2 and 260 pC/cm^2 at an applied voltage of 2.5 V/㎛, respectively. Experimental results showed that the increase of Zn doping rates in $Cd_{1-x}Zn_xTe$ detectors reduced the leakage current and improved the X-ray sensitivity significantly. The leakage current was drastically diminished by the formation of thin parylene layer in the $Cd_{0.7}Zn_{0.3}Te$ detector.

Keywords : CdZnTe detectors, Digital radiography, Leakage current, X-ray sensitivity, Parylene layer

1. INTRODUCTION

In recent years, a flat-panel digital imaging detectors have been developed and examined for digital radiography application[1-3]. In general, the direct detection type, in which a-Se(amorphous Se) is most commonly used as a conversion layer, provides an excellent spatial resolution because of its simple conversion process. However, it suffers from low X-ray sensitivity because it has a low X-ray stopping power and high generation energy of about 50 eV per electron hole pair. Moreover, a-Se has disadvantages, such as the breakdown of the TFT array and a extremely high voltage of above 10 V/㎛, namely several kV, for collecting electric charges.

Accordingly, a new approaches to overcoming these problems have been carried out to investigate new conversion materials[4]. Candidate materials are lead iodide (PbI_2), mercury iodide (HgI_2), thallium bromide (TlBr), and Cadmium telluride (CdTe). These materials have an inherently high stopping power, an excellent carrier transport property, and relatively wide band gap energy[4]. Among these, Cd(Zn)Te film has sufficient stopping power for use as an X-ray converter, and it is more stable, both mechanically and chemically, than other high-gain materials.

Specifically, the resistivity is greatly increased by doping Zn in CdTe film[5]. This high resistivity is due to the wide band gap of this ternary semiconductor which results in low leakage currents and, consequently, low noise characteristics. $Cd_{1-x}Zn_xTe$ detector is a potentially interesting material for digital radiography[6-8] because it has high stopping power, high mass density (5.8g/cm^3) and an effective atomic number Z of 49.9 (Cd0.9:48, Zn0.1:30, Te:52). This would allow a decrease in detector thickness and, consequently, good spatial resolution.

In this paper, the leakage currents and X-ray sensitivity of polycrystalline $Cd_{1-x}Zn_xTe$ detectors are measured as a function of an applied voltage to investigate X-ray response characteristics for digital radiography. Experimental results showed that the increase of Zn doping rates in the $Cd_{1-x}Zn_xTe$ detector sufficiently suppressed the leakage current and improved the signal to noise ratio significantly. The parylene polymer was utilized as a protection layer to prevent the breakdown of evaporated CdZnTe film due to high electric field.

2. EXPERIMENTAL

2.1 X-ray diffraction of Fabrication of CdZnTe thin film

The starting materials were prepared by mixing

CdTe(99.999%) and Zn(99.999%) in a stoichimetric ratio of x = 0, 0.15, 0.25, 0.30. Prior to $Cd_{1-x}Zn_xTe$ deposition, the ITO glass (2× 5 cm^2) was washed by aceton and, then methane, followed by a DI water rinse and, finally blown dry in N_2. The polycrystalline Cd(Zn)Te films were produced on an indium-tin-oxide (ITO) coated glass substrate by thermal evaporation. Cd(Zn)Te films were deposited at room temperature, and the deposited film thickness was 20 ㎛ and 200 ㎛. The Au layer with an area of 1.5× 1.5 cm^2 was evaporated as a upper electrode. The parylene polymer film was deposited on Cd(Zn)Te film by PDS2060(SCS, USA) for preventing the hole injection from the top electrode to $Cd_{1-x}Zn_xTe$ layer. The deposition rate of the polyparaxylene film was 5 μm/hr and the film thickness was approximately 2 ㎛, 5 ㎛, and 10 ㎛.

X-ray diffraction was carried out to investigate the crystal structure of the $Cd_{1-x}Zn_xTe$ film using XRD(RAD-3C, Rigaku, Japan)[9]. Scanning Electron Microscopy (JSM 820, Japan) was used to examine the surface morphology of thick $Cd_{0.7}Zn_{0.3}Te$ film and the cross section region consisting of parylene layer/CdZnTe/ITO.

2.2 Electrical measurement

I-V characteristics of $Cd_{1-x}Zn_xTe$ film were measured to investigate the electrical properties. Leakage currents flowing in CdZnTe film were measured at dark state after applying electric field. The experimental setup for measuring the leakage currents consisted of a DC power supplier (Protek 3033B, USA) for applying a high voltage, and an electrometer (Keithley 428, USA) for measuring a small dark current.

The measurement of X-ray sensitivity is similar to that of leakage current except for x-ray exposure. The x-ray generator used in this study was a Shimadzu TR-500-125. Irradiation conditions for signal acquisition were 70 kVp, 100 mA, and 0.03 s, respectively. Al layers were also used as x-ray absorber to control the x-ray dosage to evaluate the linearity of X-ray detector. An exposure dosage was also monitored using an Ion Chamber 2060 (Radical Cooperation, USA) during experiment. Pb collimator was used to control the extent of x-ray exposure on the fabricated CdZnTe detector.

3. RESULTS AND DISCUSSION

3.1 X-ray Diffraction pattern and Morphology

Figure 1 shows the XRD patterns of polycrystalline and $Cd_{1-x}Zn_xTe$ (x = 0, 0.15, 0.25, 0.3) as a function of a diffraction angle of 2θ . As shown in Fig. 1, a strong peak was observed at around 24° in thermally evaporated CdTe thin film. As Zn was progressively substituted with Cd in the CdTe, the peaks increased at 40 and 46 degrees, whereas the peak at 24 degrees was relatively decreased.

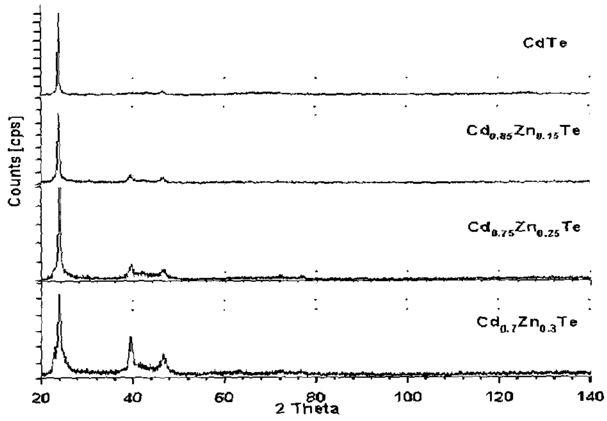
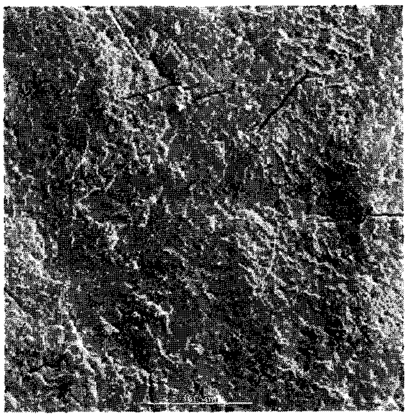
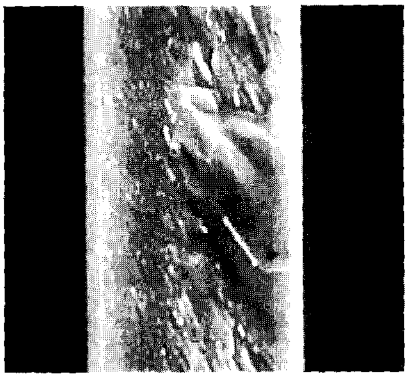


Fig. 1. X-ray diffraction patterns of $Cd_{1-x}Zn_xTe$ film.

Figure 2 shows the SEM image of fabricated 200 μm $Cd_{0.7}Zn_{0.3}Te$ detector sample. Fig. 2(a) illustrates the upper surface of $Cd_{0.7}Zn_{0.3}Te$ film due to a high voltage. Fig. 2(b) illustrates the cross sectional view of fabricated $Cd_{0.7}Zn_{0.3}Te$ with the structure of polymer/CdZnTe/ITO.



(a) upper surface region



(b) cross-sectional region

Fig. 2. SEM photographs of fabricated $Cd_{0.7}Zn_{0.3}Te$ detector: (a) The upper surface of the CdZnTe; (b) the cross-section picture of polymer/CdZnTe/ITO.

3.2 Leakage current

Figure 3 shows the leakage current of $Cd_{1-x}Zn_xTe$ films as a function of applied voltage. Leakage currents were effectively decreased by the substitution of Zn atoms in the CdZnTe film. In applied voltage of 2.5 V/μm, leakage currents were 4.3 nA/cm^2 for CdTe and 0.31 nA/cm^2 for $Cd_{0.7}Zn_{0.3}Te$, respectively. These results show that the introduction of Zn in the CdTe induces an increase of the energy band gap due to an upward shift of the conduction band edge[12]. The wider band gap increases the resistivity and then decreases the leakage current of CdZnTe film.

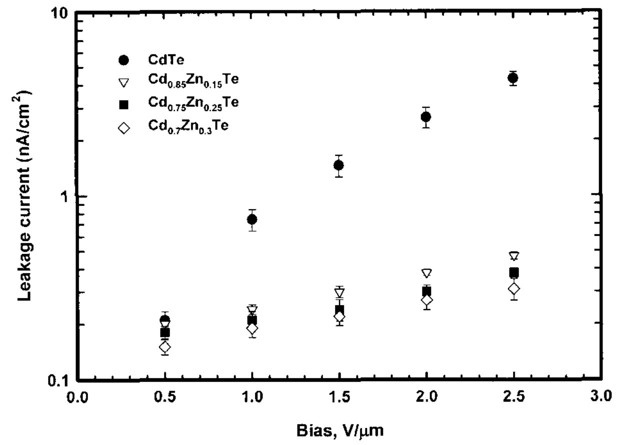
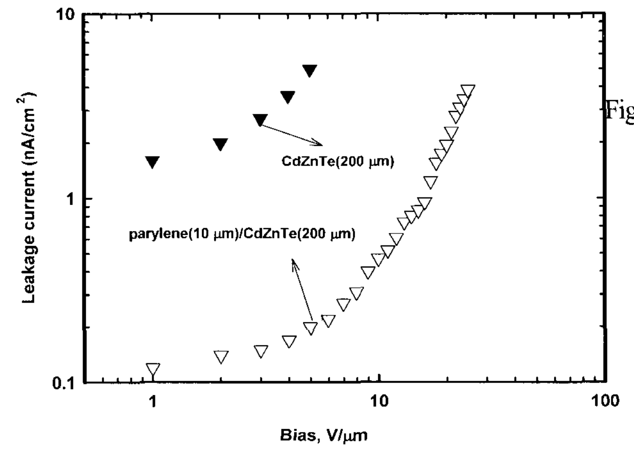


Fig. 3. Leakage currents for $Cd_{1-x}Zn_xTe$ film as a function of applied voltage.

Figure 4 shows the leakage currents of a $Cd_{0.7}Zn_{0.3}Te$ film with and without parylene layer as a function of applied bias voltage.



Figure

Fig. 4. Leakage currents for CdZnTe with and without parylene layer as a function of applied bias.

The measured leakage current of $Cd_{0.7}Zn_{0.3}Te$ film with polymer layer was found to be below 0.2 nA/cm^2 at 5 V/μm, whereas that of $Cd_{0.7}Zn_{0.3}Te$ film without polymer layer were observed above 5 nA/cm^2. This result means that the $Cd_{0.7}Zn_{0.3}Te$ detector with a parylene polymer layer can give higher x-ray sensitivity than that without a parylene polymer, since it allows a higher electric field. It is supposed that a parylene polymer layer acts as voltage reducer in Au/Polymer/CdZnTe/ITO structures.

3.3 X-ray sensitivity

Figure 5 shows the signal to noise ratio of $Cd_{1-x}Zn_xTe$ (x = 0, 0.15, 0.25, 0.3) film as a function of applied voltage. Experimental results show that the increase of Zn doping rates in $Cd_{1-x}Zn_xTe$ film sufficiently suppresses a leakage current and improves the signal to noise ratio significantly. The $Cd_{0.7}Zn_{0.3}Te$ film having a leakage current of 0.31 nA/cm^2 and an output charge density of 260 pC/cm^2 shows the highest value, of 4.65 at an applied voltage of 2.5 V/μm, among all samples.

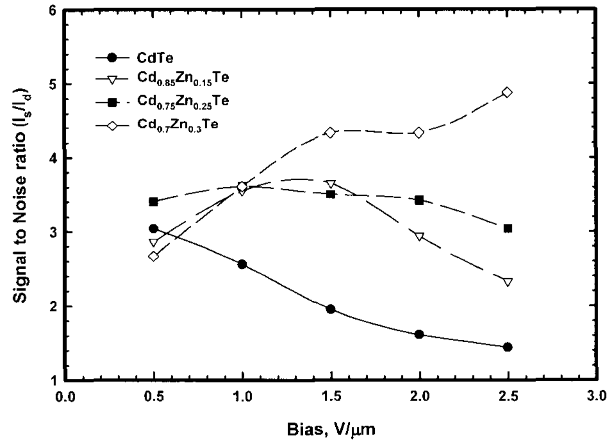


Fig. 5. X-ray sensitivity for $Cd_{1-x}Zn_xTe$ film as a function of applied voltage.

Figure 6 shows the measured X-ray sensitivity of the 200 μm thick $Cd_{0.7}Zn_{0.3}Te$ detector with a various thickness of parylene layers. The x-ray sensitivity of $Cd_{0.7}Zn_{0.3}Te$ detector with a parylene layers is increased compared to that without a parylene layer. As shown in Fig. 6, the x-ray sensitivity of $Cd_{0.7}Zn_{0.3}Te$ detector with parylene layers of 2 μm exhibited relatively a high value of 80 at 10 V/μm. It is supposed that the parylene layer between $Cd_{0.7}Zn_{0.3}Te$ film and top Au electrode gives the prevention of breakdown of an evaporated $Cd_{0.7}Zn_{0.3}Te$ film and suppress the increase of leakage current flowing inside $Cd_{0.7}Zn_{0.3}Te$ film. Therefore, the fabricated $Cd_{0.7}Zn_{0.3}Te$ detector with 2 μm parylene layer could enhance the X-ray sensitivity significantly. The observed breakdown voltages for $Cd_{0.7}Zn_{0.3}Te$ detectors without polymer layer were 6 V/㎛. The breakdown of 200 ㎛ thick a-Se based X-ray detector with parylene layer were also observed at 18 V/㎛ for 2 ㎛, at 23 V/㎛ for 5 ㎛, and at 26 V/㎛ for 10 ㎛, respectively.

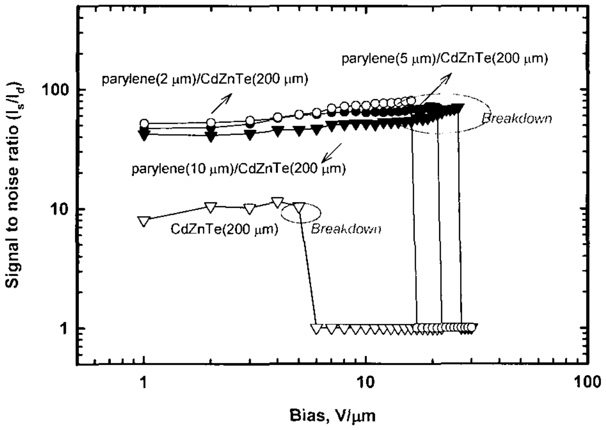


Fig. 6. X-ray sensitivity for $Cd_{0.7}Zn_{0.3}Te$ based X-ray detector as a function of applied bias.

4. CONCLUSION

A polycrystalline $Cd_{1-x}Zn_xTe$ thin film for digital radiography is produced by thermal evaporation. The crystal structure and the morphology of the fabricated Cd/Zn/Te film were examined using XRD and SEM. From measurements, it was verified that the increase of Zn injection rates in $Cd_{1-x}Zn_xTe$ film sufficiently suppresses a leakage current and improves X-ray sensitivity significantly. The $Cd_{0.7}Zn_{0.3}Te$ film with a leakage current of 0.37 nA/cm^2 and an output charge density of 260 pC/cm^2 showed the highest SNR, at 4.66, among all $Cd_{1-x}Zn_xTe$ thin film(200 ㎛). The measured leakage current of $Cd_{0.7}Zn_{0.3}Te$ film with polymer layer was found to be below 0.2 nA/cm^2 at 5 V/㎛, whereas that of $Cd_{0.7}Zn_{0.3}Te$ film without polymer layer was observed above 5 nA/cm^2. The breakdown of 200 ㎛ thick a-Se based X-ray detector with parylene layer were also observed at 18 V/㎛ for 2 ㎛, at 23 V/㎛ for 5 ㎛, and at 26 V/㎛ for 10 ㎛, respectively.

Our experimental result offers the potential capability for research and evaluation of digital X-ray image detectors using $Cd_{1-x}Zn_xTe$ thin film.

ACKNOWLEDGEMENT

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