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Improvement Of FTO/ZnO Schottky Diodes Working Profile Using Magnesium Doping For Conventional Radiology Detector

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Abstract:
The Schottky barrier diode formed from FTO substrate and ZnO semiconductor has the potential to be used as a conventional radiology X-ray detector. The addition of magnesium as a semiconductor dopant has been proven to enhance the detector's performance in the mid-range energy X-ray. The improvement is also supported by UV-Vis spectroscopy results, which show an increase in the energy band gap of 0.04 eV. With a firing voltage of 0.17 V, the detector becomes more responsive, and the stability of the current response is also observed.
***Key Word**: ZnO; magnesium; FTO; schottky barier diode; X-ray; conventional radiology.*

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I. Introduction

Thin film materials are a key element in technological advancements in the fields of optoelectronic, photonic, and magnetic devices. The study of thin films has directly or indirectly advanced many new research fields in solid-state physics and chemistry based on the unique characteristic phenomena of the film's thickness, geometry, and structure. Processing materials into thin films allows for easy integration into various types of devices [1-2]. These thin-film devices are designed with exceptional mechanical deformation capabilities, sensitivity to multifunctional responses, and intelligent control capabilities, but they are physically fragile, so sometimes they require dopant materials as reinforcement [2].

The fabrication of thin films is inseparable from the deposition process, where the thin film layers are created and stored onto substrate materials that can be made from various substances. The thin film layers also possess many different characteristics that are utilized to modify or enhance several performance elements of the substrate [3]. DC sputtering, as one of the physical vapor deposition techniques, is renowned as an excellent method for metal deposition, but it has not yet been widely used for composite materials. The advantage of DC sputtering is the simplicity of the equipment. (tidak memerlukan sistem frekuensi radio). This technique has not been widely applied except for DC sputtering with a zinc (Zn) target under an oxygen (O2) atmosphere. ZnO targets have recently been investigated in DC sputtering deposition experiments, with ZnO deposited on silicon substrates. (Si). Interesting results were obtained showing that excess oxygen was incorporated into the deposited film to form stoichiometric ZnO based on X-ray diffraction and energy-dispersive X-ray spectroscopy [3-4].

Naturally, ZnO thin films have a fairly good ability to interact with X-rays, so their development potential is very wide. Previous research conducted involved a zinc oxide detector (thin film) with a thickness of 3 µm paired with general X-ray radiography, which had a sensitivity of 25 nC/Gy with a dose rate of 1.532 Gy/s [5]. Meanwhile, other research shows higher performance when zinc oxide is doped with magnesium. Under the conditions of a thickness of 0.3 µm and a dose rate of 100mGy/s, the sensitivity increased to 3.03 µC/mGy [6]. With all the studiess that have been conducted, this research will investigate the role of magnesium as a dopant in ZnO thin films with the aim of enhancing its potential use as a detector in conventional radiology.

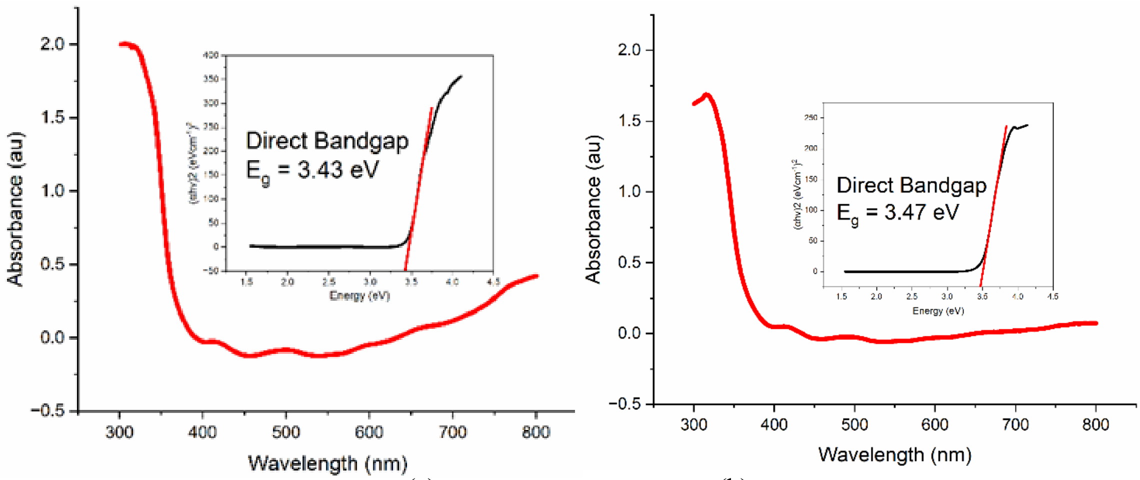
II. Material And Methods

Target Material Fabrication: The preparation of the target material in the form of Mg-doped ZnO begins with mixing 2.195 grams of zinc acetate dihydrate (Merck 1.08802) and 0.22 grams of magnesium acetate tetrahydrate (Merck 1.05819) into 20 ml of methanol [7] to obtain an impurity ratio of 1% (0.99:0.01) [8]. The solution was stirred using a magnetic stirrer for 30 minutes at an internal temperature of 70 °C and a rotation speed of 300 rpm. After stirring, the solution was left at room temperature in a closed container for 24 hours. Then, the solution was evaporated using a furnace at 250 °C for 6 hours. After the evaporation process, the solution turned into (Mg)ZnO powder. The (Mg)ZnO powder was then poured into a metal dies and compacted using a press machine with a strength of 6 metric tons for 2 hours, so that the (Mg)ZnO compact could be used as a target material.

Fabrication of (Mg)ZnO Thin Film with *DC magnetron Sputtering* method: First, the substrate preparation is carried out by cutting the FTO glass to a size of 1 x 1.25 cm. An area of 1 x 0.25 cm is arranged in such a way that it is covered with aluminum foil to prevent film material from growing, which will be used as a metal contact pad on the anode electrode side. Before being used as a substrate, the FTO glass is washed using an ultrasonic cleaner with ethanol as the cleaning medium for 20 minutes to remove contaminants. The deposition process of (Mg)ZnO on the FTO substrate uses the DC magnetron sputtering method at room temperature 30 °C, plasma power 40 watts, and a deposition time of 60 minutes.

III. Result And Discussion

The difference in energy band gaps in the material must be compatible with the type of energy spectrum that will be captured. In this study, if the energy gap is too large, many electrons will not have enough energy to flow into the metal substrate. Conversely, if the energy gap is too small, the energy from the electrons will be too high and will be converted into heat, making the overall performance of the thin film inefficient [9]. Using UV-Vis spectroscopy, the energy band gap can be observed from the absorbance graph. The energy band gap is represented by the slope of the graph. For the ZnO film, the energy band gap is measured at 3.43 eV (**Fig. 1.** (a)), while the (Mg)ZnO film has an energy band gap of 3.47 eV. (**Fig. 1.** (b)).



(a) (b)

Figure 1. Thin film energy bandgap (a)ZnO (b)(Mg)ZnO

This difference shows the role of magnesium working in the film. Magnesium, which has 2 valence electrons, tends to lose its electrons. Automatically, the state in the semiconductor field with excess electrons makes it n-type. Although this excess of electrons is not significant because the amount of magnesium dopant is only 1%, its presence is important for enhancing the overall performance of the film.

The metal-semiconductor contact or junction plays a very important role in the observation process of this research, including the I-V interaction. The interaction between the metal and n-type semiconductor generates an electric voltage with forward bias as shown in Figure 2. Schottky diodes have the advantage of a lower firing voltage compared to p-n junction diodes, allowing their use in very high-frequency applications [10]. The interaction of the FTO metal field with the semiconductor field only requires a firing voltage of 0.17 volts for both observed Schottky diodes (**Fig. 2.**). Although they have the same ignition point, there is a difference at the polynomial point where magnesium doping plays its role. Although at the end point of the observation, the undoped semiconductor has a superior peak, at the polynomial point, the film with magnesium dopant is observed to be better. This condition indicates that magnesium dopants play a role in triggering specific characteristics that need to be observed further. These results indicate that both films have been successfully fabricated as Schottky diodes.

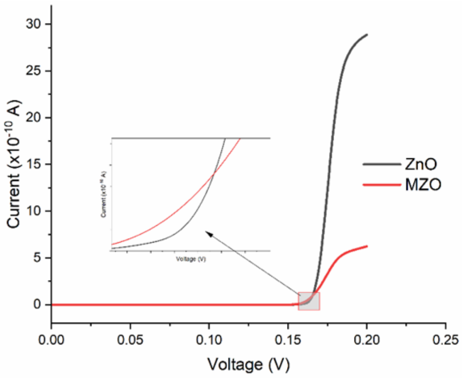


Figure 2. I-V respons of FTO/ZnO and FTO/(Mg)ZnO schottky barier diode

The baseline response of the detector over its entire operating time, measured from the zero deviation to the interval point, is referred to as stability. Zero drift refers to the change in the detector's output response over the entire working period when no radiation is detected. In other words, this event is a change in the detector's baseline over a certain period of time [11]. During the observation conducted by irradiating 50 kV X-rays from conventional radiography, the reaction showed to be quite stable. (**Fig. 3.**).

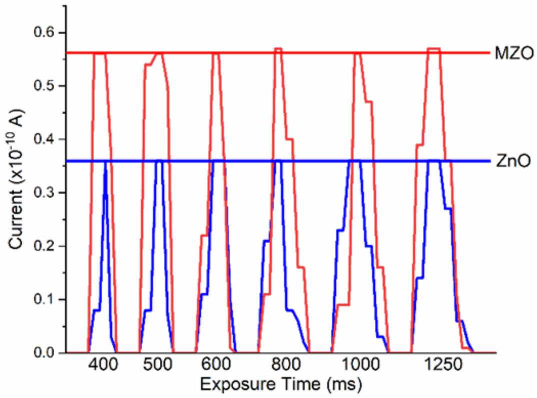


Figure 3. Current respons stability

In all test sessions, it was observed that the current deviation was at a relatively stable reading point, where the film without magnesium doping was at a current reading point of 0.36 x 10^{-10} A, while the film with magnesium doping was at 0.56 x 10^{-10} A. It was also observed that the film remained stable during irradiation with the same tube voltage. (**Fig. 4.**). This stability indicates that the film can operate stably at the same dose rate, although the Schottky barrier diode form has a weakness to performance degradation due to temperature rise during repeated interactions [10-12]. When the tube voltage is increased, the film response shows a corresponding increase in current deviation as shown in figure 4. However, the response of the two films has different patterns. The film with magnesium doping has a higher current deviation when irradiated with tube voltages between 50 – 65 kV. At a tube voltage of 70 kV, the undoped film suddenly responds with a larger current.

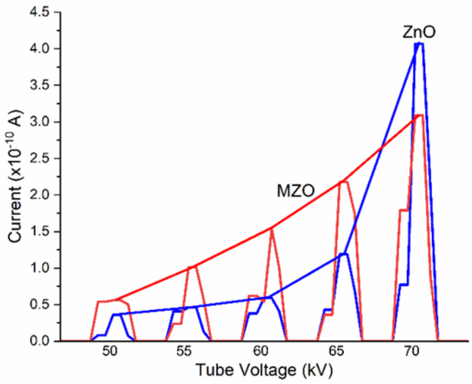
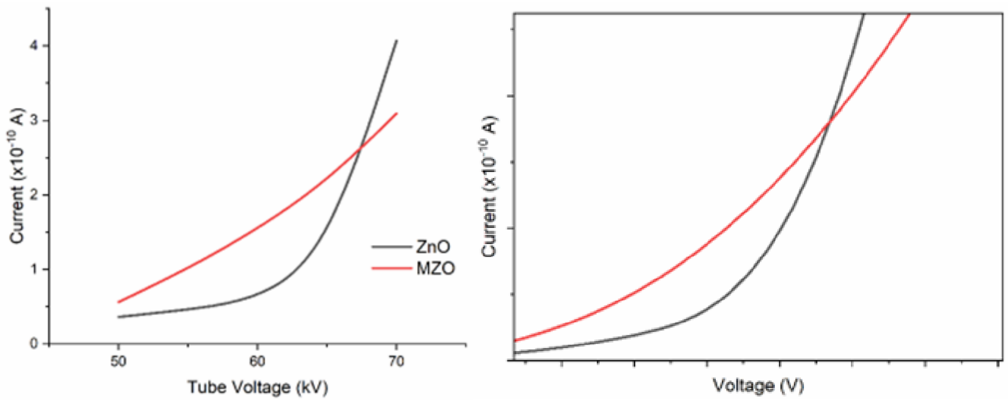


Figure 4. Current respons of detector in various X-ray energy

When X-rays penetrate the semiconductor, there will be an interaction between the X-ray electrons and the semiconductor, causing a number of energy interactions. Therefore, the sensitivity of the semiconductor part is closely related to the overall X-ray absorption efficiency by the detector [12]. This event indicates a special characteristic between both. When examined more closely, this pattern resembles the pattern in the polynomial area during the I-V test. More clearly, see figure 5, where the patterns of both graphs appear coherent. Although the film with the dopant is superior, this advantage only lasts at the irradiation energy from the medium voltage tube (around 50 – 65 kV).



(a) (b)

Figure 5. *Graph of (a)current respon of detector (b)polynomial point of I-V*

IV. Conclusion

The Schottky diode, constructed with the interaction between metal and semiconductor, has proven to function as an X-ray detector in conventional radiography both in this study and in several other studiess. In this study, the performance of the ZnO semiconductor reinforced with 1% magnesium dopant showed quite good performance where the Schottky diode only required a turn-on voltage of 0.17 V to activate the barrier feature of the Schottky diode in forward bias. The overall capability of the film can be considered for use as a direct X-ray detector in conventional radiology. Compared to undoped magnesium, doped films have quite an advantage, especially in the medium tube voltage range. The fact that the peak current response graph is coherent with the I-V graph on the polynomial side increasing the belief that this film has great potential to be used as a direct detector for conventional radiology X-rays.

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