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Structure and Photo-response Properties of FZO/ITO Thin Film

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ABSTRACT

The structure and photo-response properties of ZnO:Fe/ITO thin film synthesized using a pyrolysis method were studied in this work. ZnO:Fe/ITO thin film referred to as FZO/ITO was characterized using the X-ray diffraction (XRD) technique and current-voltage (I-V) measurements. The XRD analysis showed that the detected peaks at 30.23°, 35.15°, 37.36°, 45.18°, and 50.54° belonged to the ITO cubic phase. The I-V analyses showed that the sample had the saturation current, Schottky barrier, and sensitivity of 16.24 µA, 0.4771, and 0,90 µA respectively. The FZO/ITO gave a good response toward the light.

Keywords: *ZnO:Fe, FZO/ITO, photo-response, sensitivity, Schottky barrier*

1. INTRODUCTION

Trends in optoelectronics technology are increasing these days. Optoelectronics can be applied to LED, UV detectors, and solar cells. Research on solar cells keeps rising because the sun is the biggest energy source in the world. On top of that, it is free. Zinc Oxide, commonly referred to as ZnO, is one of the transition metal oxide and semiconductors with a wide direct band gap, around 3.3 eV at room temperature [1]. Moreover, this material has a high exciton binding of 60 meV which can emit UV light at room temperature. ZnO can be an n-type as well as a p-type semiconductor. However, it more commonly acts as an n-type semiconductor due to the surplus of zinc atoms or oxygen vacancies on ZnO [2].

Transition metals, i.e. Mn, Fe, Co, and Ni, have closely matched atomic radii and electronic configuration with that of Zn atom. This makes them possible to act as a dopping in the ZnO matrix [3], [4]. Doping on ZnO could lead to a significant increase in electrical conductivity and optical transmittance compared to pure ZnO thin films [5]. Moreover, the addition of Fe, particularly, could decrease the band gap energy of ZnO [6]. It can easily enter the lattice of ZnO without disturbing the crystal structure of the host. The presence of Fe ion in the ZnO matrix also contributes more charge carriers which increases the conductivity of pristine ZnO [7,8].

However, the work of Ciciliati, et.al showed that Fe doping on ZnO at more than 2% mol using a sol-gel method could lead to phase segregation [6]. In other research, doping of Fe on ZnO using a sol-gel method caused the formation of $ZnFe_2O_4$ secondary phase [9]. Other physical and chemical techniques, like hydrothermal process, electrodeposition, RF and DC magnetron sputtering, and dip coating have been conducted to synthesize Fe-doped ZnO film. However, those methods required a vacuum condition and high cost [8]. On the other hand, the pyrolysis process is feasible, low cost, and compatible with solar cell active materials deposition [10].

In this work, we synthesized Fe doped on ZnO thin film using Iron (III) chloride hexahydrate as Fe source which was very soluble in ethanol, ether, and acetone [7]. The film deposition was performed using a simple spray pyrolysis method and is based on the formation of aerosol from various precursor solution [11]. The structure properties will be studied as well as the photo-response of the thin material toward the light.

2. EXPERIMENTAL SECTION

Zinc acetate dehydrate (Merck) was taken as a precursor for ZnO film while iron (III) chloride hexahydrate (Merck) was taken as a Fe source. ITO-coated glass (1 cm x 1 cm) was employed as the substrate. Ethanol was used as the solvent and distilled water, acetone, and alcohol 96% were used for rinsing and cleansing the substrate.

The solution was prepared by mixing zinc acetate dehydrate and Iron (III) chloride hexahydrate in 30 mL of ethanol. The solution was then stirred at 180 rpm for 30 minutes at room temperature. The molarity of the precursor was set to be 0.5 M with a Fe concentration of 3%. The ITO-coated glass substrate was employed after being washed in an ultrasonic cleaner using acetone, alcohol 96%, and distilled water for 10, 5, and 5 minutes, respectively. Subsequently, the prepared precursor was sprayed onto the substrate at 450 °C for 15 seconds. The distance between the nozzle and substrate was maintained at ~4 cm. The sample was then referred to as FZO/ITO.

The structure properties of the sample were studied using the X-ray diffraction (XRD) technique. Furthermore, the photo response of the film was characterized using current-voltage (I-V) measurements. Silver paste was used as the cathode while UV lamp was used as the light source. The saturation current (I_0) was obtained by calculating the gradient of a logarithmic plot from Equation 1.

$$I_0 = \ln \frac{I e^{\frac{qV}{KT}}}{e^{\frac{qv}{KT}} - 1} \tag{1}$$

The Schottky barrier was calculated using Equation 2, where K is Boltzmann constant ($1.38\, x\, 10^{-23}$), T is absolute temperature, q is electron charge ($1.6\, x\, 10^{-19}$), A is the contact area of the Schottky barrier, A^* is Richardson constant ($\sim 32\ A/cm^2K^2$), and I_o is saturated current.

$$\emptyset_B = \frac{KT}{q} \ln\left(\frac{A^* A T^2}{I_o}\right) \tag{2}$$

The sensitivity was calculated by subtracting the bright and the dark current [12].

3. RESULTS AND DISCUSSION

The X-ray diffractogram in Figure 1 shows the structure of the ITO-coated glass substrate and FZO/ITO thin film. The peaks observed at 30.23°, 35.15°, 37.36°, 45.18°, and 50.54° are belong to ITO crystal in cubic phase (JCPDS 00-039-1058). The crystal of ZnO and/or ZnO:Fe could not be seen perhaps due to the small amount of Fe addition, similar to the research result conducted by Shinde et.al. However, the decreasing peak intensity after ZnO:Fe deposition could be suggested as the presence of ZnO and/or ZnO:Fe thin layer [5]. Furthermore, the addition of Fe as reported in previous research leads to the defect lattice of ZnO, which could be the main contributor to the decreasing peaks of ITO crystals [13, 14].

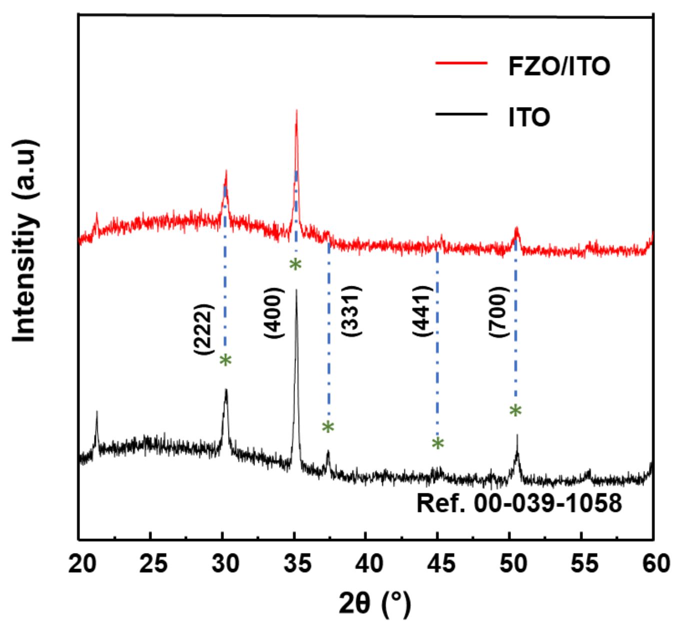

Figure 1. Diffractogram of ITO substrate and FZO/ITO

Figure 2 presents the current-voltage (I-V) characteristic of FZO/ITO from -10 V to 10 V. It could be seen that the measured current in the bright state was higher than the measured current in the dark state. This is proof that the sample gives a reaction toward light. The non-linear observed curve indicates that the Schottky barrier potential exists in the metal-semiconductor junction. The mechanism of the increasing current in the bright state can be explained as follows. The presence of UV light inducted the formation of an electron-hole pair because the energy provided by the UV lamp was higher than the band gap energy of ZnO. Hence, the electron was excited from the valence band O-2p to the conductance band Zn-3d. In this state, the O^{2-} and O^{-} atoms would be released. The defect crystal of ZnO due to Fe addition increased the carrier concentration and mobility which could have a main role as a facilitator in photoconduction properties in the sample [13]. Consequently, the carrier concentration would be increased, resulting in a higher detected current [15], which is in accordance with some previous work [6, 13, 14, 16]

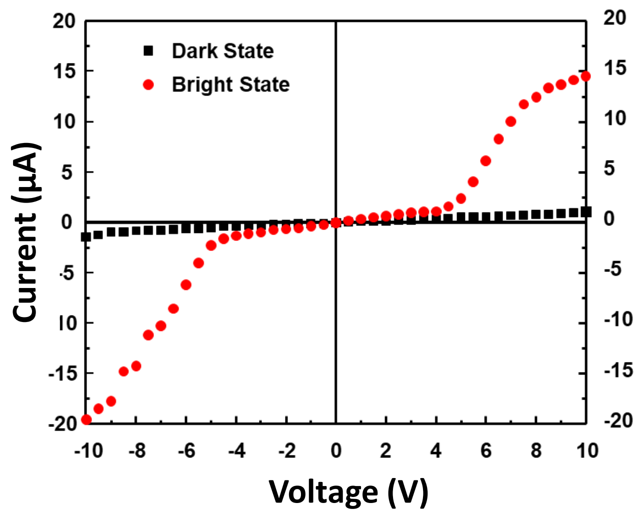

Figure 2. *The current-voltage curve of FZO/ITO*

The presented curve shows that when the voltage was increased from 0 to 4 V, the detected current was slightly increased during the bright state. The current drastically increased as the voltage was increased from ~4 to 8 V, the current drastically increased until the voltage reached 10 V. The detected current at 10 V was 14.55 µA, while the saturated current and Schottky barrier calculated from Equation 1 and 2 were 16.24 µA and 0.4771, respectively. The higher Schottky barrier caused electrons hardly to flow from the FZO thin film to the metal, resulting in the lower dark state current. The sensitivity of FZO/ITO calculated using Equation 3 was 0,90 µA. A higher sensitivity results in a better response toward light.

4. CONCLUSIONS

ZnO:Fe/ITO thin film has been synthesized using the pyrolysis method and characterized using the X-ray diffraction technique and current-voltage (I-V) measurement. XRD curve showed that the detected peaks belonged to the ITO cubic phase. The addition of ZnO:Fe layer caused the decrease in diffraction peaks. I-V analyses showed that the sample gave a good photo response toward UV light with the saturation current, Schottky barrier, and sensitivity of 16.24 µA, 0.4771, and 0,90 µA, respectively. The addition of Fe into the ZnO matrix facilitates the increase in thin film photo-response.

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