Ar Flow-Rate Effect for Low-Resistivity Al/Ti/Al Ohmic Contact to n-ZnO Thin Films

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***Abstract*— The Ar flow rate effect on the electrical and optical properties of the sputtered Al-doped ZnO thins films were investigated. It was shown that a strong X-ray peak from (002) and (004) planes is dominant, suggesting that most grains have *c*-axis perpendicular to the substrate surface. The (002)-ZnO and (004)-ZnO peaks were measured at $2\theta = 34.12^0$, and 71.85^0, respectively. It was also found that the growth rate of the Al-doped ZnO thin films increases when the sputtering power is increased. The transmittance of these film are strongly dependent on the sputtering power with the maximum transmittance of 92% was obtained at the sputtering power of 150 W and 50 sccm of Ar flow rate. The resistivity of the films is decreases as the Ar flow rate is increased. The lowest resistivity of 9.74×10^{-4} Ω.cm was obtained at the films with Ar flow rate of 80 sccm. The mobility increases with the Ar flow rate increases. The carrier concentration also indicates the same pattern as the mobility. The transmittance of Al-doped ZnO thin films is also strongly dependent on the Ar flow rate. It was also observed the variation of contact resistivity of Al/Ti/Al to Al-doped n-ZnO thin films. The specific contact resistivity ρ_c of 1.8×10^{-5} Ω.cm^2 was obtained at 150 nm-thick Al.**

Keywords— Al-doped ZnO thin films, Ar flow rate, X-ray peak of ZnO, resistivity, carrier concentration, mobility, transmittance, ohmic contact, specific contact resistivity of Al/Ti/Al.

I. INTRODUCTION

In recent years, the sputtered Al-doped ZnO/n-Si thin films has wide attractive applications for solar cells and other optoelectronic devices [1][2][3] because of their good electrical and optical properties, wide band gap of 3.3 eV, and large exciton binding energy of 60 meV at room temperature. [4]To obtain a high quality of ZnO thin films, the understanding of the growth condition effect on the material properties and for possible applications is still needed. For high performance solar cells applications, it is important to control not only the resistivity and transparency but also the contact resistance.

There have been research efforts into reducing the resistivity of ZnO. Most efforts involve in doping Al into ZnO thin films. Many articles report on the study of Al dopant on properties of the ZnO thin film like resistivity, mobility, carrier concentration, transmittance, optical band gap, structural, and surface morphology (see for instance Refs. [5][6][7]). The Al dopant acts as donor to improve the electrical conductivity and most suitable for substituting at the Zn site in the ZnO lattice because the Al^{3+} dopant have been addressed as affecting the carrier concentration, when it occupies. One of the main problems in creating high quality ZnO thin films are the difficulty of making good electrical conductivity and high transparency. Therefore, more studies on the electrical and optical properties of Al-doped ZnO thin films are needed.

ZnO is usually prepared by evaporation, metalorganic chemical vapor deposition, and molecular beam epitaxy and sputtering. In this study, in order to grow films with high electrical conductivity and transparent, the sputtering technique is employed. This technique offers a high purity, homogeneities, rough surface, nanostructured features of thin film, and low cost. [8] Meanwhile, the substrates are injured by plasma damage during the sputtering process. The ionic bombardment energy during the sputtering process may influence the quality of the films. Therefore, in this study, we investigated the Ar flow rate effect on the electrical and optical properties of Al-doped ZnO thin films and study of Ti/Al Ohmic contact to n-ZnO thin films.

II. EXPERIMENTAL

In this work, Al doped ZnO thins films were grown on glass substrate using Tri-Axis Semicore rf sputtering system. A 3 inch diameter, 99.99% purity Al-doped (5%) ZnO target from Semiconductor Wafer Inc. was fitted to one of the rf cathodes. The distance between the target surface and the substrates was kept at ~10 cm. The substrate was heated at deposition temperature of 400° C. The sputtering power was varied between 50 W and 200 W. During deposition, the Ar flow rate was 30 sccm, 50 sccm, 60 sccm, 70 sccm and 80 sccm, respectively. At a base pressure of 10^{-6} mbar, Ti/Al metal electrode was deposited on n-type ZnO thin films by Leybold e-beam evaporator which a 99.999% pure as metal source. Finally, the Al metal electrode was evaporated on Ti/Al/n-ZnO by thermal evaporator (Model: Ulvac Kiko VPC-061).

The crystallinity of the ZnO films was evaluated through an X-ray diffractometer (Bruker D8 Discover) using Cu K_α radiation (λ = 1.5406 Å) at a rating of 40 kV, and 20 mA. The Ellipsometer from Rudolf Research (AutoEL) was used to measure the optical thickness of the ZnO films. The Shimadzu Solidspec 3700 DUV spectrophotometer was used for optical transmittance measurements, with wavelength ranges between 200 nm and 1500 nm. To evaluate electrical properties of the films, Lakeshore 7704A Hall measurement system was used. The current-voltage (*I-V*) characteristics of the contacts were acquired at room temperature using a Keithley 617 Picoammeter source unit. Resistance measuared by a digital oscilloscopes (TBS1000 series from Tektronik).

III. RESULT AND DISCUSSION

In order to fully exploit ZnO as a solar cell layer, besides improving the quality of the electrical properties, study of surface morphology on ZnO thin films is very important. In this study, we measured structural of the films by X-rays diffraction (XRD) method and is shown in Fig 1 (a). The film was sputtered on glass substrate. The substrate temperature and Ar flow rate were kept at 400^0 C, and 50 sccm, respectively. The sputtering power was varied between 50 W and 200 W. The chamber was initially vacuum pumped to a pressure below 2×10^{-6} Torr.

It was shown that a strong X-ray peak from (002) and (004) planes is dominant, suggesting that most grains have c-axis perpendicular to the substrate surface**.** The (002)-ZnO and (004)-ZnO peaks were measured at $2\theta = 34.12^0$, and 71.85^0, respectively. This result is in agreement with joint committee on powder diffraction standards no. 00-005-0664 (inset Fig 1a). [9]The growth rate of the Al-doped ZnO films and transmittance grew on glass substrate at 400° C and in a 50 sccm Ar flow rate as a function of the sputtering power, as shown in figure 1(b).

As can be seen, the growth rate of the Al-doped ZnO thin films increases nearly linearly from 1.0 to 5.4 nm/min when the sputtering power increases from 50 to 200 W. This may due to the electrons and argon ions through increasing the kinetic energy in which enhanced the sputtering yield. The dependence of the transmittance on the sputtering power was also evaluated. As the sputtering power increases from 50 to 150 W, the transmittance at 480 nm increases firstly from 83% to 92% and then decreases to 80%. It is clear that the transmittance of the film is depending greatly on the sputtering power. The maximum transmittance of 92% was obtained at the sputtering power of 150 W.

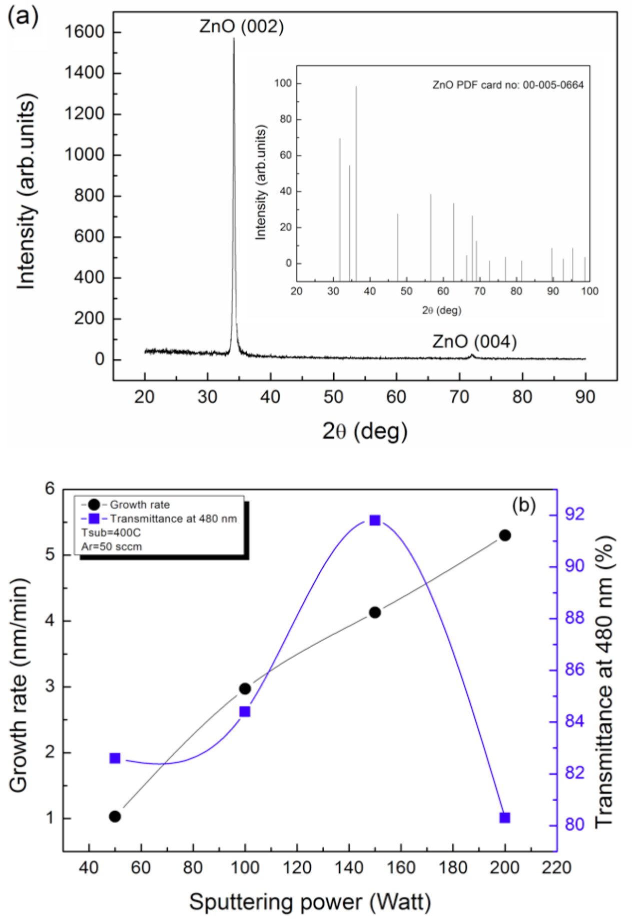

Fig. 1 (a). X-rays diffraction spectra of sputtered Al-doped ZnO thin films on glass substrate at T_{sub} = 400° C , P = 200 W, S_{Ar} = 50 sccm, (b). Effect of sputtering power on the growth rate and transmittance at 480 nm.

To further study the ionic bombardment energy during the sputtering process, the effects of adjusting Ar gas flow rate were then investigated. The optimum sputtering power and substrate heating conditions at a constant Ar flow of 50 sccm were determined in the previous data to be 150 W and 400° C, respectively. Since the Ar flow rate affects the deposition rate, the deposition time was varied in order to keep a roughly constant thickness of approximately 100 nm for each sample.

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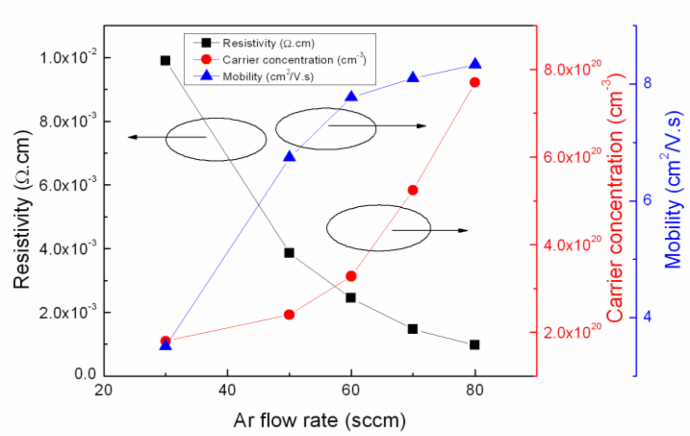

Fig. 2 Ar flow rate effect on the electrical properties of Al doped ZnO film on glass substrate at P=150 W, T_{sub} = 400° C, and d = ~ 100 nm

To further study of deposition parameters in the experiments on the electrical properties of Al-doped ZnO thin films, the resistivity, carrier concentration and mobility at various Ar flow rate was measured and is show in figure 2. Our results indicate that the resistivity of the films is decreases as the Ar flow rate is increased. The lowest resistivity of 9.74 x 10^{-4} Ω.cm was obtained at the films with Ar flow rate of 80 sccm. The mobility increases with the Ar flow rate increases. The carrier concentration also indicates the same pattern as the mobility.

IV. CONCLUSION

U In summary, we have investigated the influenced Ar flow rate on the electrical and optical properties of Al-doped ZnO thin films on glass substrate by rf sputtering. This study shows that the resistivity, carrier concentration, mobility and optical transmittance of Al-doped ZnO thin films strongly depend on the Ar flow rate. This method enabled the control of the quality of the films for transparent conducting oxide in solar cells and displays applications. We also fabricated and then observed the physical mechanism of metal thickness effect on the electrical properties of the Ohmic contact Ti/Al to n-ZnO thin films. Our result is essential for obtaining high electrical properties in highly transparent ZnO thin films based-solar cells.

ACKNOWLEDGMENTS

The authors are grateful to the Norwegian Research Centre for Solar Cell Technology, and the Centre for Environment-friendly Energy Research co-sponsored by the Norwegian Research Council, and industry partners in Norway for financial support under project number 193829, and postdoctoral research scheme of Universiti Tun Hussein Onn Malaysia, respectively.

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