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Effect of controlled operating pressure on physical optical and electrical properties of AZO thin film by DC magnetron sputtering technique

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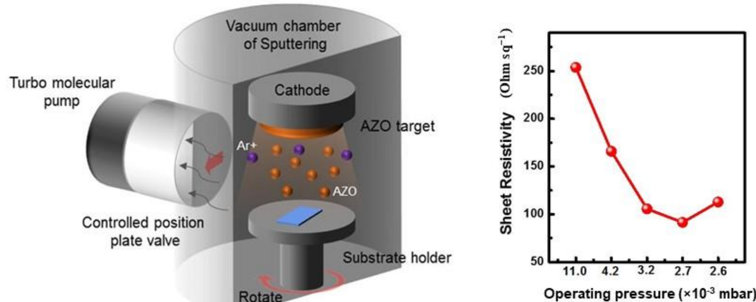
Abstract

The study aimed to research the controlled operating pressure in the range of $1.10 \times 10^{-2} - 2.60 \times 10^{-3}$ mbar with the adjustment position of plate valve (40 – 100%) using DC pulsed magnetron sputtering system. The AZO films were prepared onto n-type silicon (100) and glass slide substrates. A comparison, all samples were assigned 400 nm of AZO film thickness and then the prepared AZO films were investigated by field-emission scanning electron microscope (FE-SEM) for surface morphologies, X-ray diffraction (XRD) for crystallinity, UV-Vis-NIR spectrophotometry for optical property, Four-point probe and Hall effect instrument for electrical properties, respectively. The results from FE-SEM image showed that the AZO film was columnar structure. The XRD patterns of AZO films demonstrated the crystal growth direction which preferred AZO growth was indicated the (polycrystalline) hexagonal wurtzite structure. For the optical property, the transmittance (%T) clearly showed transparent film, indicating good average value which was 81.54 – 83.28% in visible region (380 to 780 nm of wavelength). Furthermore, the sheet resistivity, high mobility and carrier concentration displayed 91.48 Ohm sq^{-1}, 3.40 $cm^2 Vs^{-1}$ and 7.00×10^{20} cm^{-3}, respectively. These results were decided that the position of plate valve of 85% with operating pressure of 2.70×10^{-3} mbar was the optimal condition. Finally, the excellent electrical and good optical properties of AZO film is mainly applied in several application for optoelectronic device and solar cell.



Position of plate valve	40%	50%	70%	85%	100%
Operating pressure (mbar)	11.00×10^{-3}	4.20×10^{-3}	3.20×10^{-3}	2.70×10^{-3}	2.60×10^{-3}

Keywords: AZO film; Bulk concentration; DC magnetron sputtering

Introduction

Transparent conductive oxides (TCO) are electrically conductive materials base on metallic oxides in their optical transmission. TCO films have low resistivity at $10^{-3} – 10^{-4}$ Ωcm and high transmittance in the visible region of 80%. With a varied properties TCO are widely used in optoelectronic devices, i.e., liquid crystal displays, solar cells, flat-screen monitor, optical window and photovoltaic cells [1, 2]. Indium tin oxide (ITO) and fluorine-doped tin oxide (FTO) are the most popular materials, used for the production of TCO films as transparent electrodes. However, ITO has expensive cost and FTO has a difficult fabrication in Fluorine-dope. So, Aluminum-doped zinc oxide (AZO, ZnO:Al) thin films are alternative material due to the low cost, nontoxic and easy to fabricate. Also, its high conductivity and good transparency, leaded alternative material to the other ZnO-based TCO materials [3, 4] . Previously, there are various techniques for AZO thin films preparation such as thermal evaporation, chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), sol-gel, pulsed laser deposition (PLD), RF-magnetron sputtering and pulse DC magnetron sputtering [5 – 7]. Magnetron reactive sputtering using AZO alloy target has an advantage in high film deposition rate without the emission of toxic gas and be able to produce on a large-scale area deposition. In this case, the DC pulsed magnetron sputtering mode was selected due to the lower cost of plasma generator. Mostly, a various deposition parameters have been affected the properties of AZO films [8 – 11], i.e., plasma source, operating pressure and sputtering power. This work, focused on the operating pressure, which is crucial parameter affecting to energy per atom during the deposition. Therefore, the effects of the different operating pressure were studied by adjusting position of plate valve between the vacuum chamber and turbo molecular pump.

Materials and Methods

The AZO thin films were prepared on n-type silicon (100) and glass slide substrates by DC pulsed magnetron sputtering system. The glass slides were chemically cleaned by acetone, 2-propanol and deionized water for 15 min for all step in an ultrasonic bath. Afterward, the substrates were dried with nitrogen gas flow and heated using hot plate at 90 °C for 5 min. The sputtering target was a 3-inch ZnO-Al (2 wt%, Kurt Lesker) and a flow rate of high purity argon (99.999%) was fixed. Before the deposition, the base pressure in chamber was 8×10^{-6} mbar and then the operating pressure was varied by adjusting the position of plate valve in the range of 40 – 100% (operating pressure in the range of 1.10×10^{-2} – 2.70×10^{-3} mbar) during deposition. Firstly, the AZO target was pre-sputtered for 3 min and then the substrates were deposited with a rotation at 10 revolutions per min (rpm). Secondly, AZO film was initially coated for 28 min with the applied power at 100 W, displays the operated voltage of 315 V, operated current of 0.30 A, frequency of 50 kHz and pulse wide of 2.50 µs. Finally, all samples were deposited on silicon substrates for crystal structure and morphology analysis, as determined by XRD (CuKα radiation, KTTRAXIII, Rigaku) and FE-SEM (SU8030), respectively. The optical transmission of the prepared AZO films on glass slide substrates was characterized using a UV-Vis-NIR spectrophotometer (Cary 7000, Agilent) in the wavelength of 200 − 2,000 nm. The electrical properties, which was sheet resistivity by the samples were measured towards glass slide substrates, was investigated by four-point probe (JANDEL; Made in England). In addition, carrier concentration and mobility were also measured using hall-effect at room temperature (a Ecopia HMS-3000 system).

Results and Discussion

Fig. 1 (a) shows the deposition rate of AZO film from the varied position of plate value of 40 – 100% for 30 min. It was found that when operating pressure was decreased, the deposition rate directly reduced from 13.34 – 10.54 nm min^{-1}. The results demonstrated the less amount of argon gas in chamber along with the increasing of sputtered argon ion from the AZO target. The cross-sectional FE-SEM images of AZO films were presented in Fig. 1 (b). The AZO film

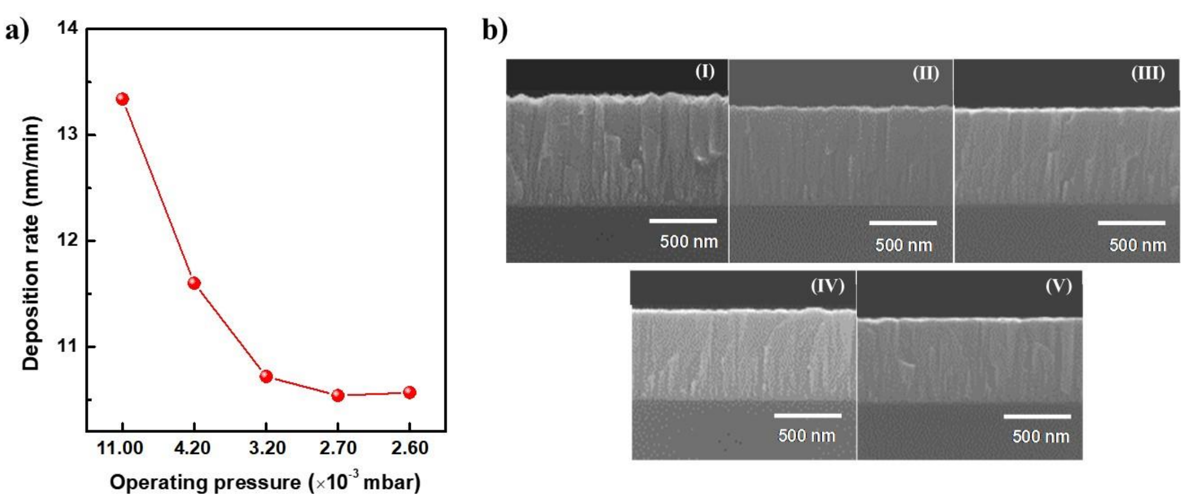


Fig. 1 (a) The deposition rate of AZO films (b) The cross-sectional FE-SEM images of AZO thin films with respect to different operating pressure which the deposition time was fixed at 30 min during deposition.

thickness is shown in Fig. 1 (b) (I)-(V) which was 380, 330, 305, 300, and 299 nm, at the operating pressure of 1.10×10^{-2}, 4.20×10^{-3}, 3.20×10^{-3}, 2.70×10^{-3} and 2.60×10^{-3}, respectively. It was found that the low operating pressure led to the decrease of AZO film thickness. Then, the AZO film thickness of all operating pressure was calculated to find the deposition rate as shown in Fig. 1 (b). After that, the AZO film thickness was fixed at 400 nm at the different operating pressure as shown in Fig. 2.

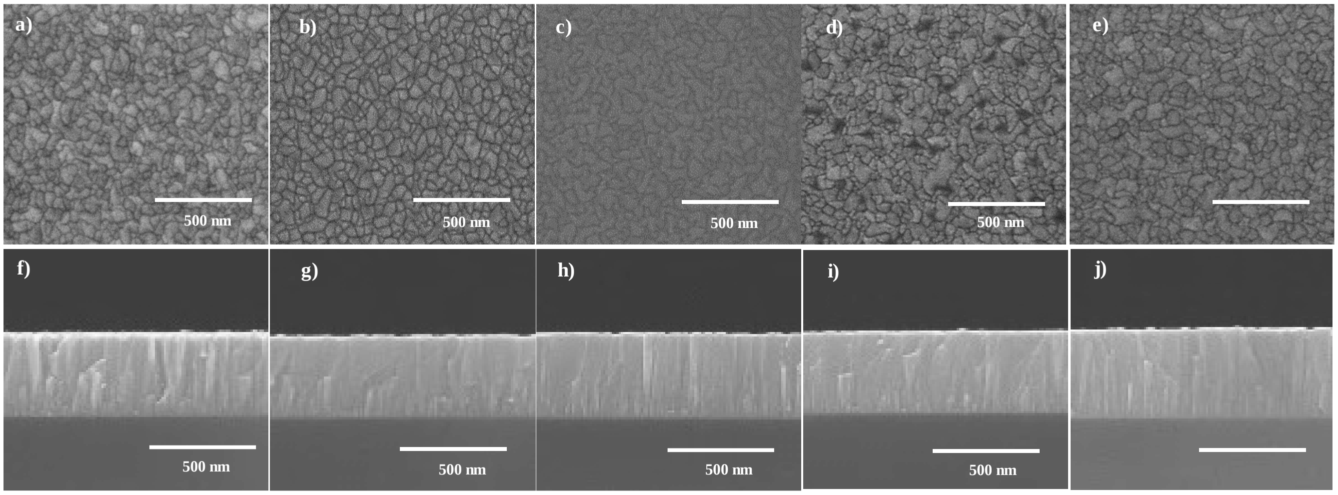


Fig. 2 Surface and cross section of FE-SEM images of AZO thin films depositing on silicon substrates at different pressure at (a), (f**)** 1.10×10^{-2} mbar, (b), (g**)** 4.20×10^{-3} mbar, (c), (h**)** 3.20×10^{-3} mbar, (d), (i**)** 2.70×10^{-3} mbar, and (e), (j**)** 2.60×10^{-3} mbar.

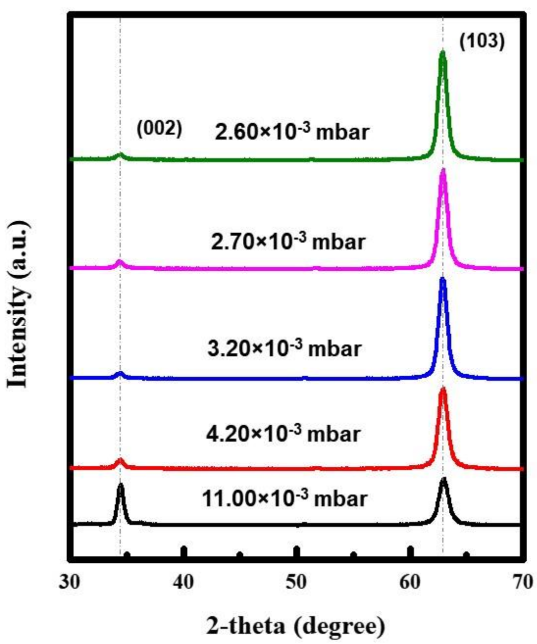


Fig. 3 XRD patterns of the AZO thin films were deposited on Silicon substrates with various operation pressure at 400 of thickness.

Fig. 3 shows the XRD patterns of the samples were deposited on silicon substrates with the different operation pressure at 400 nm thickness of films. These results were demonstrated the crystal growth direction at two peaks, which were associated with (002) and (103) planes. It was determined to be zinc oxide with hexagonal wurtzite structure (data of zinc oxide SCPDS no. 36–1451). The XRD pattern shown the most prominent (102) peak at high operating pressure of 1.10×10^{-2} mbar with a plate valve position of 40 %. Furthermore, when operating pressure is decreased to 2.60×10^{-3} mbar along with the plate valve position of 55 – 100%, the higher intensity (103) peak was presented. From results, the incorporation of Al as dopant in lattice of ZnO cause the bigger ionic radius of Zn^{2+} [9].

Fig. 5 shows the sheet resistivity, carrier concentration and mobility of the AZO films at the same thickness. Our results indicated that AZO thin films could be improved the electrical properties by decreasing the operating pressure with adjustment plate valve position, leading to the lowest resistivity and sheet resistivity at 2.42×10^{-3} Ohm·cm and 91.48 Ohm sq^{-1}, respectively., at the operating pressure of 2.70×10^{-3} mbar, which related to highest conductivity of AZO films. The carrier concentration and mobility were increased when decreasing of operating pressure. These results demonstrated that operating power at 100 W could provide higher resistivity as observed by previous work [8]. The operating pressure of 2.70 × 10^{-3} mbar is optimal condition, indicating the excellent electrical properties.

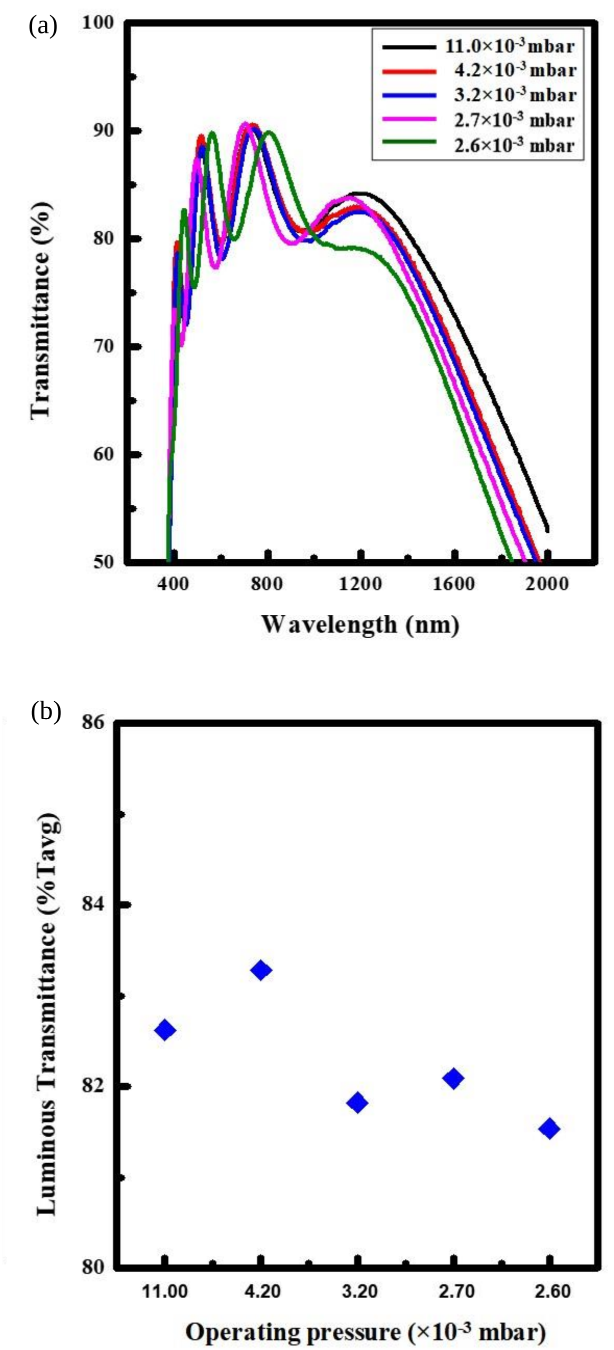


Fig. 4 (a) UV-visible light transmittance (b) Luminous transmittance of the AZO thin films were deposited on glass substrates with various operation pressure at 400 of thickness.

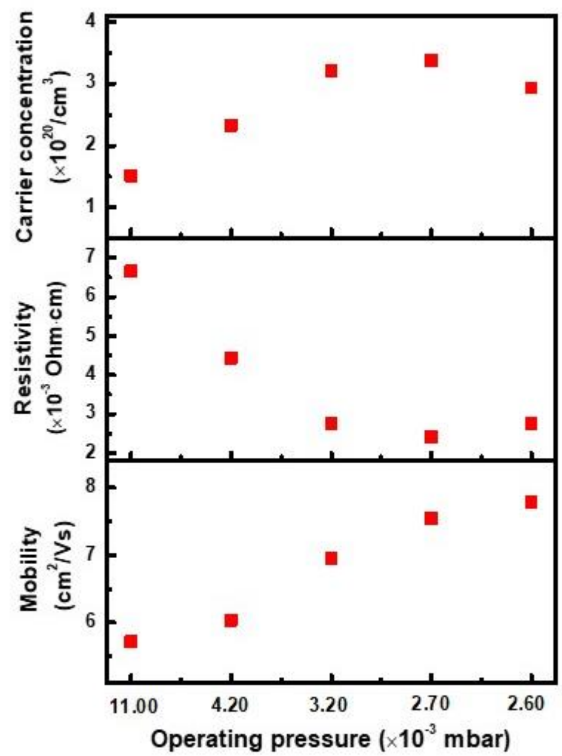


Fig. 5 Carrier concentration, resistivity and mobility of the AZO films at 400 nm thick of films.

Conclusion

We successfully prepared the AZO thin films using DC pulsed magnetron sputtering system. The adjustment of the operating pressure, physical morphologies of the prepared AZO films have been directly affected the deposition rate and thickness of films. It was found that the operating pressure effect on morphologies and crystallinity of films. The optical property demonstrated the average transmittance of 81.54 – 83.28% in UV visible range for all conditions. Finally, the prepared AZO thin films could improve the conductivity of the electrical properties, indicating the excellent conductivity with low resistivity of 91.48 Ohm sq^{-1} by controlling operating pressure. Thus, it could be concluded that the operating pressure of 2.70 × 10^{-3} mbar is the optimal condition of the prepared AZO film.

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