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Study on the electrical and optical properties of ITO and AZO thin film by oxygen gas flow rate

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Abstract Transparent conductive oxide (TCO) thin films such as tin doped indium oxide (ITO), zinc doped indium oxide (IZO) and Al doped zinc oxide (AZO) have been widely used as transparent electrode for display. ITO and AZO thin films for display was prepared by the facing targets sputtering (FTS) system. The FTS method is called a plasma-free sputter method because the substrate is located apart from plasma. This system can deposit the thin film with low bombardment by high energetic particles in plasma such as γ-electrons, negative ions and reflected Ar atoms. ITO and AZO thin films were deposited on glass substrate at room temperature with oxygen gas flow rate and input power. And the electrical, structural and optical properties of the thin films were investigated. As a result, the resistivity of ITO, AZO thin film is 6×10^{-4} Ω cm, 1×10^{-3} Ω cm, respectively. And the optical transmittance of as-deposited thin films is over 80% at visible range.

Keywords AZO · ITO · FTS · TCO

1 Introduction

TCO is receiving great attention in liquid crystal display (LCD), plasma displays (PDP) and organic light-emitting devices (OLEDs), solar cells, optoelectronics, low-emissivity windows and flexible displays. TCO thin films such as indium oxide, tin oxide, and zinc oxide have been widely used [1–3]. In particular, tin-doped indium oxide (ITO) thin films have been extensively studied for application in flat panel display devices because ITO thin films have a low resistivity, high transmittance, and chemical stability. However, ITO has several disadvantages including toxicity, high price and instability in hydrogen plasma. Recently, for those reasons, Al doped ZnO (AZO) thin films are attracting much more attention than the ITO because they have a better resistivity, higher transmittance, non-toxicity and lower cost than the ITO [4]. In generally, TCO thin films were prepared by many methods as spray pyrolysis [5, 6], pulsed laser deposition [7, 8], chemical vapor deposition [9, 10], sol–gel [11] and sputtering method [12, 13]. Especially the preparation of TCO thin films is requested in applications for flexible display devices at low temperature processing. Therefore, it is necessary to study TCO thin films deposited on substrate at room temperature due to their weak thermal resistance. It is for this reason that ITO and AZO thin films were deposited by FTS system at room temperature. FTS system, a system which consists of facing the two targets and the substrate located apart from the center of facing the two targets. So the energetic particles are restricted by magnetic force within plasma. Therefore FTS system contributes to suppression of high energy particle bombardment to the substrate. Accordingly, we can apply to FTS system to deposit high quality thin films at room temperature. We studied that electrical, optical and crystallographic properties of the ITO and AZO thin films were prepared by FTS system, which compared the ITO with AZO thin films under different sputtering conditions at room temperature.

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2 Experimental

ITO and AZO thin films were deposited on glass by FTS system at room temperature. FTS system, applied to this experiment, consists of facing the two targets and the substrate located off the center of facing the two targets shown in Fig. 1.

ITO and AZO thin films were deposited on glass (corning 2948) using a ITO target (SnO_2 10 wt.%, 5 N, 4 in. diameter), Al doped ZnO target (Al_2O_3 2 wt.%, 5 N, 4 in. diameter) and zinc oxide target (5 N, 4 in. diameter) by FTS system.

Before the deposition, the glass substrate was ultrasonically cleaned in deionized water-isopropyl alcohol and subsequently dried in flowing N_2 gas. The sputtering was performed in O_2 and Ar atmosphere at a work pressure 0.1 Pa. More detail sputtering conditions are shown in Table 1.

We measured the thickness of as-deposited thin films by Alpha-step and transmittance by UV–VIS spectrometer (HP). The electrical characteristics (resistivity, carrier concentration and mobility), structural characteristics of prepared ITO and AZO thin films were measured by Hall Effect Measurement (EGK) and XRD thin film attachment (Rigaku), respectively.

3 Results and discussion

Figure 2 shows the deposition rate of ITO and AZO thin films as a function of the oxygen gas rate and the increasing of input power. As shown in Fig. 2(a) and (b), the deposition rate of ITO and AZO thin films is increasing by input power. Increasing the power induces more sputtered species and these rapidly grow with high energy. As the species having high energy has high surface mobility, they contribute to the thin film growth on the substrate.

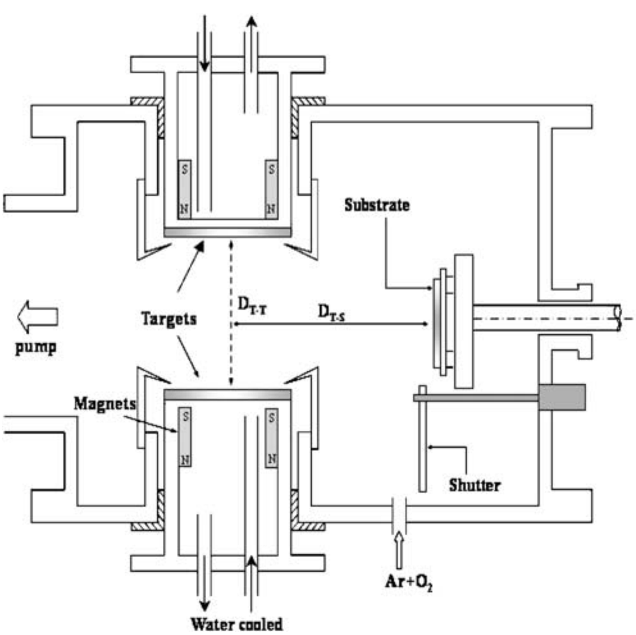


Fig. 1 Diagram of facing targets sputtering system

Table 1 Sputtering condition.

Deposition parameter	Conditions	
Targets	ITO–ITO(SnO_2 10 wt.% 5 N)	ZnO:Al(Al_2O_3 2 wt.%)–Zn(5 N)
Substrate	Glass (corning 2948)	
Substrate temperature	RT	
Bass pressure (Pa)	9×10^{-4}	
Working pressure (Pa)	0.1	
Ar: O_2 Gas flow ratio	0.1, 0.2, 0.3, 0.4	
Input power (W)	100, 200, 300	100, 150, 200

And, it was also found that the deposition rate of ITO and AZO thin films was reduced by increasing the oxygen gas flow rate. The cause of this result is that the sputter yield of oxygen gas is smaller than that of the argon gas.

Figures 3 and 4 show the X-ray diffraction patterns of as-deposited ITO and AZO thin films with oxygen gas rate and input power. In case of ITO, no peak was found in the all conditions. It seemed that as-deposited ITO thin films had insufficient energy for crystallization. In case of AZO, excluding the condition that oxygen gas rate was 0.1, (002) direction peaks were found in all the thin films and *c*-axis preferential orientation could be identified on the films.

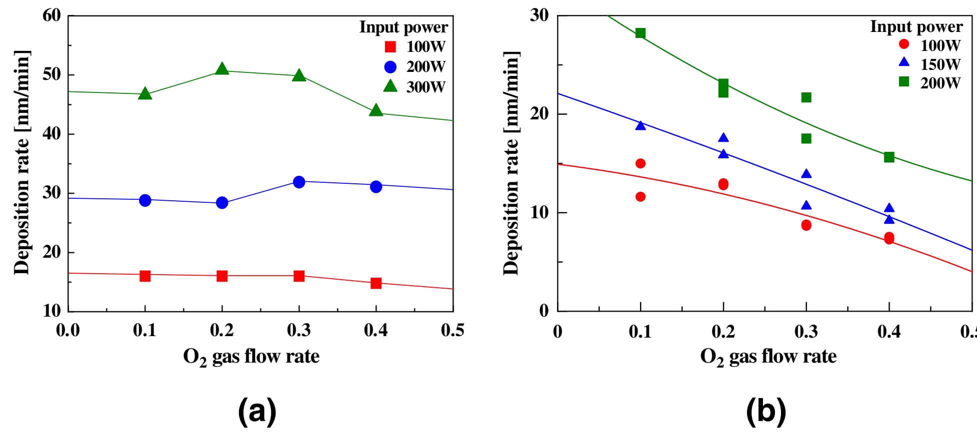
Figure 5 shows the resistivity of as-deposited ITO and AZO thin films with oxygen gas rate and input power. The ITO and AZO thin films showed the lowest resistivity at 0.2 of oxygen gas rate and the resistivity was increased with increasing oxygen gas rate. This result can be considered that the improvement of crystallization defect, caused by decreasing oxygen void with increasing oxygen gas rate, results in increasing electron mobility and resistivity is reduced. However, it is thought that excessively injected oxygen atom rather than acted as a carrier trap resulting in reduced electron mobility and increased resistivity [14]. It was found that the variation of resistivity was not large to the increasing sputter power.

Figures 6 and 7 show the transmittance in the visible range (400–800 nm) of as-deposited ITO and AZO thin films with oxygen gas rate and input power, respectively. Both thin films showed not less than 80% of transmittance at 0.2 of oxygen gas rate and showed low transmittance at 0.1 of oxygen gas rate. The cause was seemed that transmittance was reduced due to insufficient oxygen supply.

4 Conclusions

ITO and AZO thin films were prepared with the use of FTS system in various sputtering conditions. As-deposited thin

Fig. 2 Deposition rate of ITO (**a**) and AZO (**b**) thin films



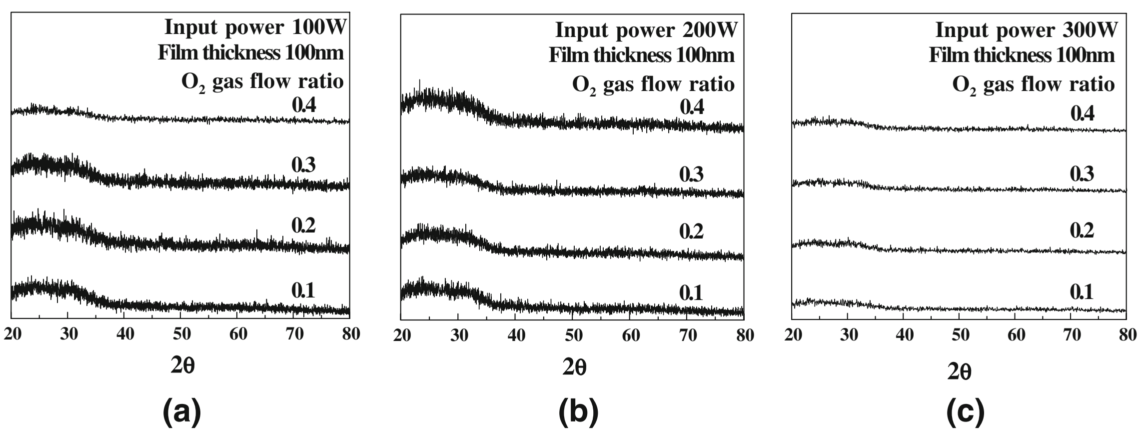


Fig. 3 XRD patterns of ITO, 100 W (**a**), 200 W (**b**) and 300 W (**c**) as O_2 gas flow rate

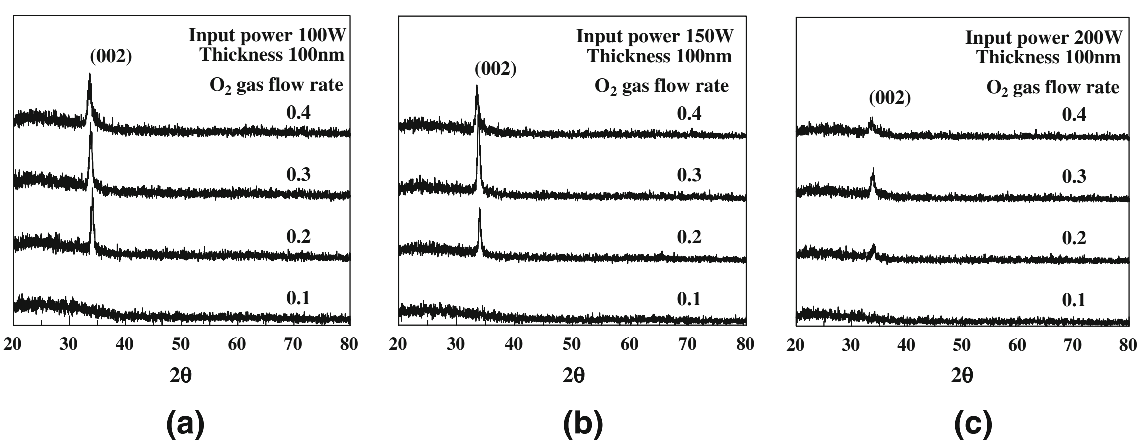


Fig. 4 XRD patterns of AZO, 100 W (**a**), 150 W (**b**) and 200 W (**c**) as O_2 gas flow rate

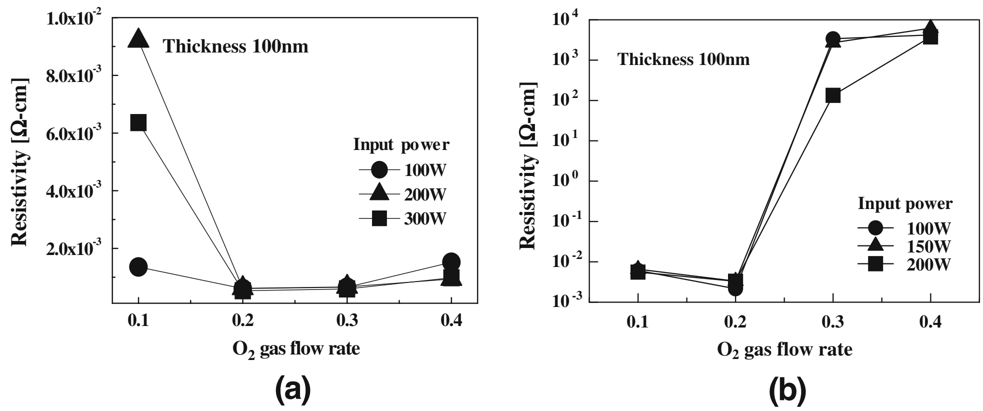


Fig. 5 Electrical properties of ITO (**a**) and AZO (**b**) thin films

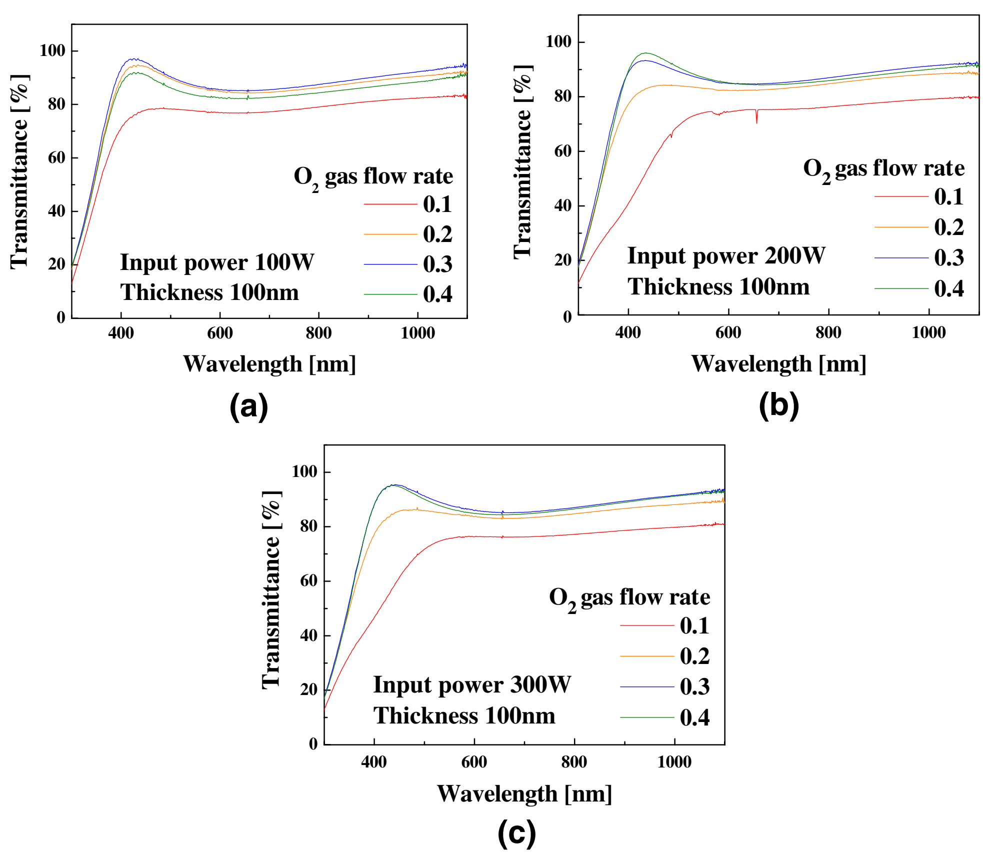


Fig. 6 Optical properties of ITO 100 W (**a**), 200 W (**b**) and 300 W (**c**) as O_2 gas flow rate

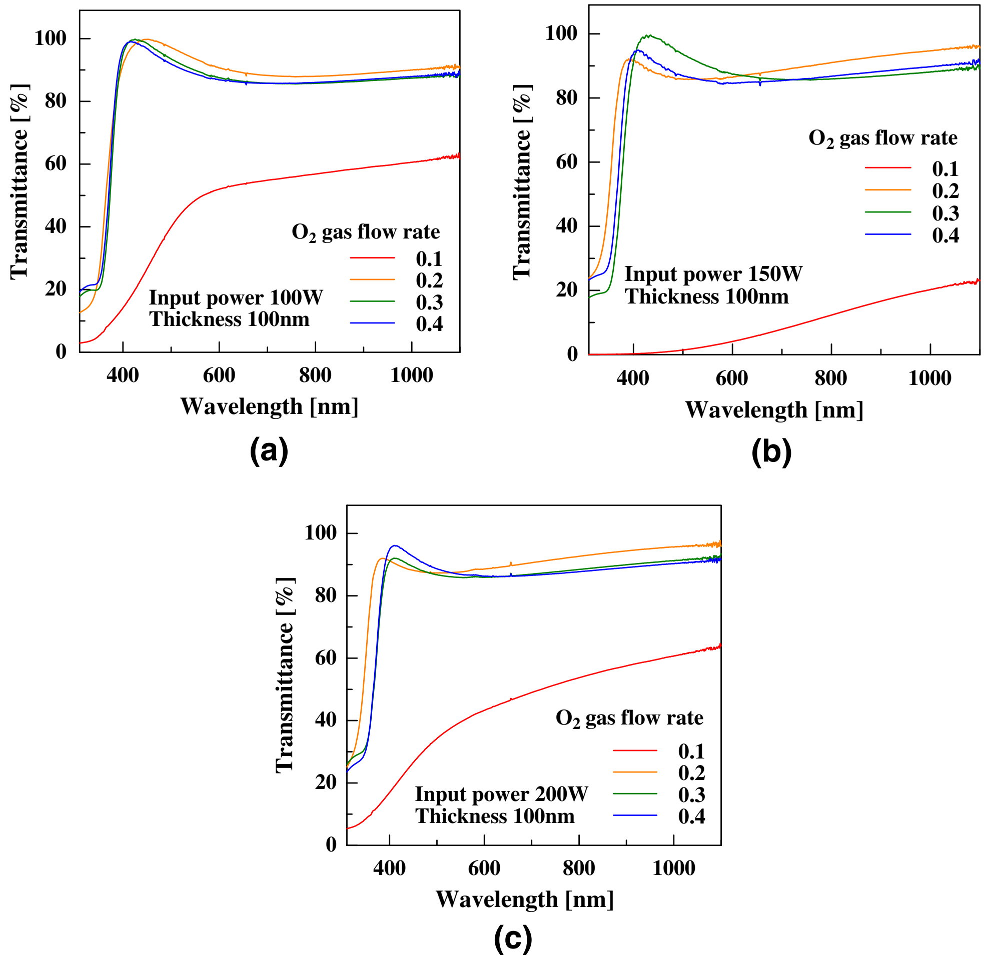


Fig. 7 Optical properties of AZO 100 W (**a**), 150 W (**b**) and 200 W (**c**) as O_2 gas flow rate

films showed fairly sensitive property change to oxygen gas rate and no large variation were identified to input power. Also, the ITO and AZO thin films prepared at the room temperature showed 6×10^{-4} and 1×10^{-3} Ω cm of resistivity at 0.2 of oxygen gas rate, respectively.

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