Transparent Conducting ZnO:Ga_2O_3 Thin Films Grown by r.f. Magnetron Sputtering

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Abstract

Transparent conducting ZnO:Ga_2O_3 thin films were deposited on glass substrates using rf magnetron sputtering method. The ZnO:Ga_2O_3 thin films were highly c-axis oriented normal to the substrates and had smooth surface features. The sheet resistance of the films was 2.8-6.4 Ω/□ at the growth temperature ranging from 25 to 300°C.

1. Introduction

In recent years, highly transparent conducting oxide (TCO) thin films with low resistivity have received considerable attention because of their potential applications in optoelectronics such as flat cathode ray tube, electroluminescent displays, and solar cells [1-3]. To develop the TCO offering good conductivity, visible transmittance, and more stable properties under degrading environments is one of the key factors to improve performance in the optoelectronic devices. At present, indium tin oxide (ITO) thin films are predominantly used because of their high transmittance in the visible range, high infrared reflection, and low electrical resistivity. However, alternatives are highly required, especially, for applications under degrading environments.

ZnO is II-VI semiconductor with a wide band gap of approximately 3.4 eV at room temperature and has wurtzite crystal structure [4]. It has been investigated for applications of acoustic, optic, and microelectronic devices due to good piezoelectric, photoelectric, and nonlinear optic properties. Moreover, it is nontoxic, inexpensive, chemically and thermally stable under hydrogen plasma processes. It has been reported that the group IIIB elements such as B, In, Al, and Ga served as efficient shallow donors in ZnO so as to give high conductivity without deterioration of transmission throughout the visible range. In the last decade, ZnO transparent conducting thin films have been studied using a number of deposition techniques such as rf magnetron sputtering[2], metal organic chemical vapor deposition[5], and pulsed laser deposition [6].

In this work, we have grown ZnO:Ga_2O_3 thin films on glass substrates using rf magnetron sputtering and characterized the structural and electrical properties of the films.

2. Experimentals

The ZnO:Ga_2O_3 thin films with thickness of 1 μm were prepared on glass substrates using a single Ga_2O_3 doped ZnO target with 4 inches in diameter (99.9% pure, High Purity Chemical Co.). The chamber was pumped down to 2×10^{-7} Torr using a turbo molecular pump prior to introduction of Ar gas. The total chamber pressure and the separation between the cathode and the anode varied from 3 to 20 mTorr and from 5.3 to 7.3 cm, respectively. The substrate temperature varied from 25 to 300 °C and the applied r.f. power was fixed at 100W.

Crystallographic orientation of the ZnO:Ga_2O_3 films was determined by an x-ray diffractometer (XRD) with Cu Kα radiation and surface morphologies of the films were observed using a scanning electron microscope (SEM). The sheet resistance was measured using four-point probe system.

3. Results and discussion

Figure 1 shows variation of XRD patterns of the ZnO:Ga_2O_3 films with increasing substrate temperature. Only (0002) diffraction peak could be observed in this study regardless of deposition conditions. This indicated that the films were highly c-axis oriented normal to the substrates because the c-plane is the most densely packed one in the wurtzite system. Significantly improved XRD intensities for the films were observed with increasing substrate temperatures as shown in Fig. 1. Whereas the films deposited with variations of other deposition parameters such as target-to-substrate distance and sputtering pressure did not reveal distinguishable changes in XRD intensity, in this study.

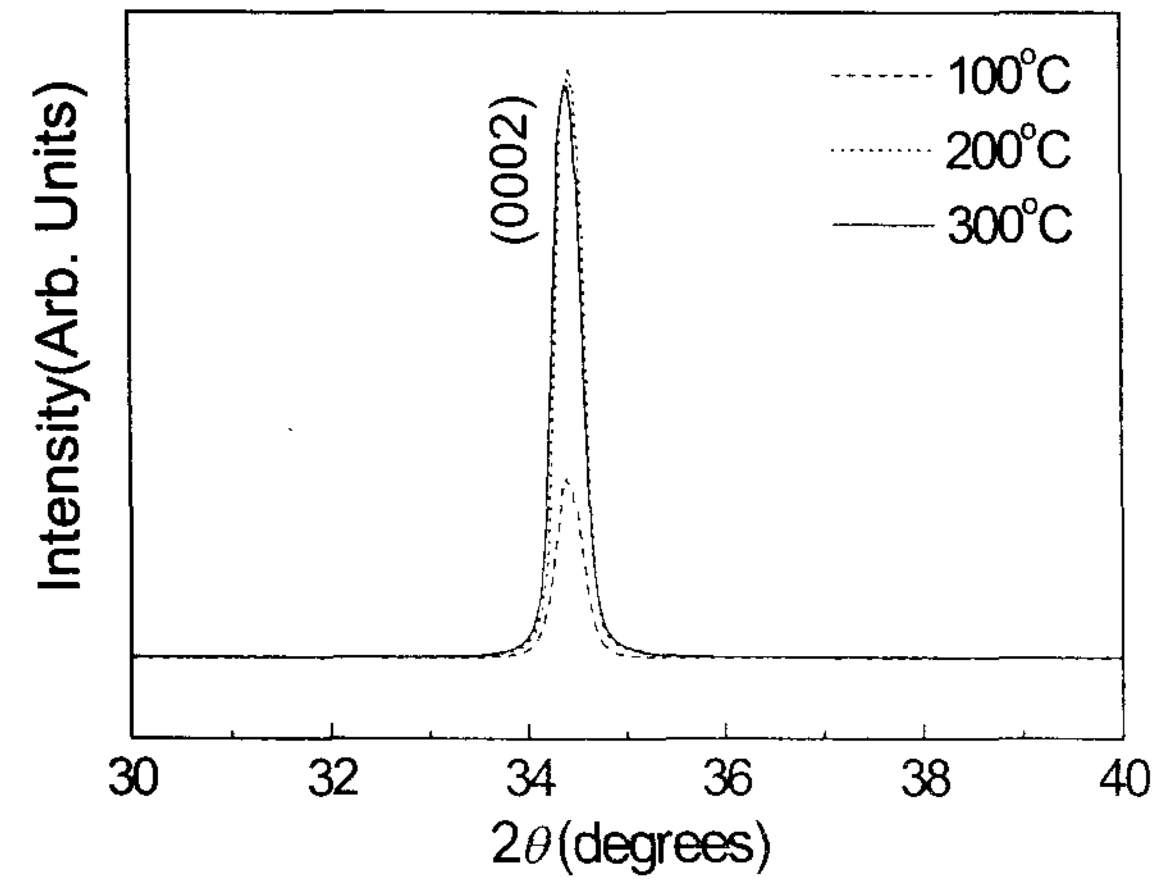

Figure 1 X-ray diffraction θ-2θ scan results of ZnO:Ga_2O_3 thin films with increasing substrate temperatures.

Surface microstructures of the films were measured as shown in Fig. 2 (a)-(c). The films deposited at a substrate temperature lower than 100 °C have somewhat rough surfaces [Fig. 2(a)]. It might be caused by low mobility of incident species on the substrate. With increasing substrate temperatures, the films exhibit smoother surface microstructure.

In case of sheet resistance, the lowest resistance was observed at the substrate temperature of 200°C although any considerable change was not observed for the films deposited with various growth conditions. The film deposited at lower substrate temperature had somewhat higher sheet resistance. The ZnO:Ga_2O_3 film with thickness of 1 µm exhibited the sheet resistance of 2.8 Ω/□ at the substrate temperature of 200°C and with the chamber pressure of 5 mTorr. The variations of sheet resistance for the films were summarized in Table 1.

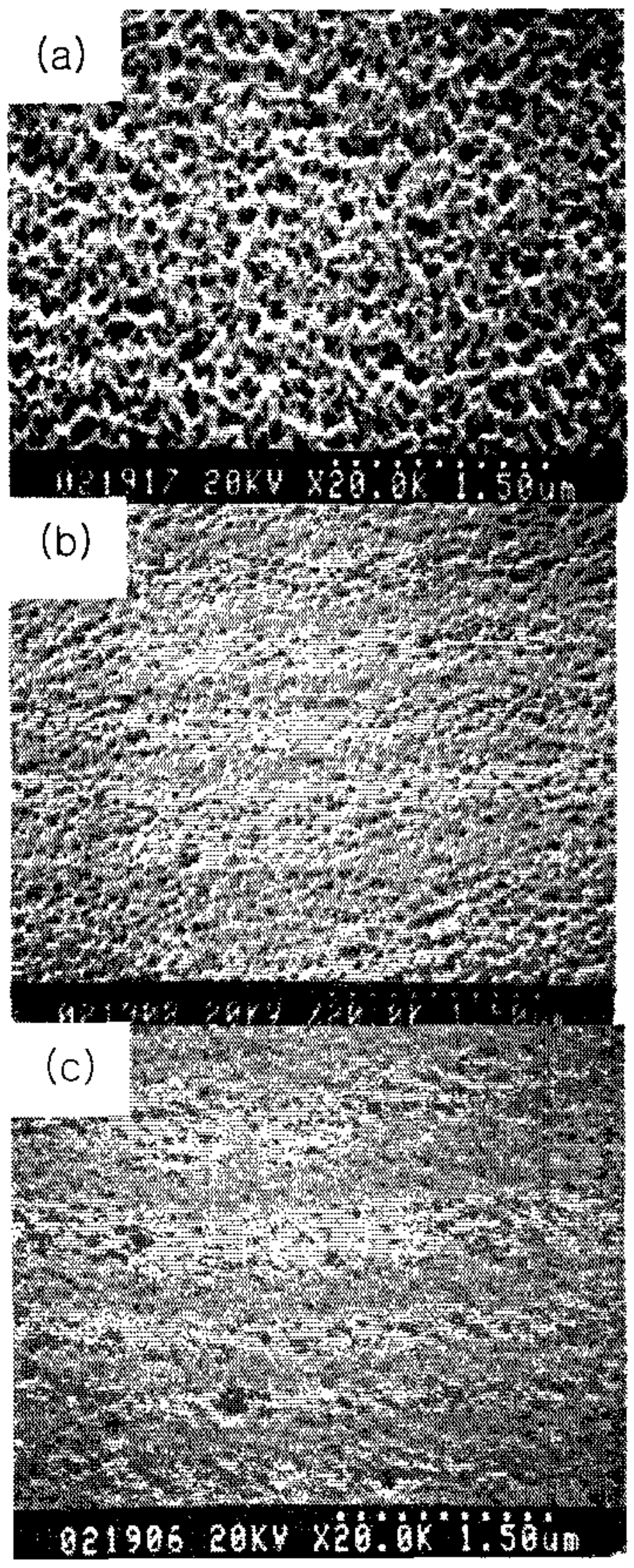

Figure 2 SEM photographs showing surface morphologies of the ZnO:Ga_2O_3 thin films deposited at the substrate temperature of (a) 100 °C, (b) 200 °C, and (c) 300 °C.

4. Summary

Highly transparent conducting polycrystalline ZnO:Ga_2O_3 thin films were deposited on glass substrates using r.f. magnetron sputtering method. The ZnO:Ga_2O_3 thin films were highly c-axis oriented normal to the substrates. The surface smoothness and the XRD intensity were improved as increasing the substrate temperature. The sheet resistance of 1 µm thick ZnO:Ga_2O_3 films was ranged from 2.8 to 6.4 Ω/□ under the experimental conditions used in the present work. The lowest resistance was observed at the substrate temperature of 200°C.

Table 1 Summary of sheet resistance variations for ZnO:Ga_2O_3 films with deposition pressure and substrate temperature (Power=100W, D_{S-T}=7.3 cm)

Deposition conditions		Sheet resistance (Ω/□)
Pressure (mTorr)	Substrate Temperature(°C)	
3	RT	6.4(±1.09)
	100	5.5(±0.59)
	200	3.3(±0.19)
	300	3.8(±0.29)
5	RT	4.1(±0.63)
	100	4.5(±0.46)
	200	2.8(±0.15)
	300	3.6(±0.21)

5. References

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