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Investigation of the Properties of Al-doped ZnO Thin Films with Sputtering Pressure Deposition by RF Magnetron Sputtering

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Abstract. The aluminum doped ZnO thin films were prepared on quartz glass substrates by RF magnetron sputtering at room temperature with varying sputtering pressure. As the sputtering pressure increased, the crystallinity of AZO thin films improved and the surface crystallite size increased. The optimized AZO thin film obtained at the sputtering pressure of 1 Pa exhibited the lowest resistivity of 8.6×10(^-3) Ω·cm and an average transmittance of 74.15% in the wavelength range of 400 to 1000 nm.

Introduction

Zinc oxide (ZnO) has the potential to be applied in the area of liquid crystal display, plasma display panel, organic electroluminescence, and solar cells, due to its wide band gap (3.4 eV) and large exciton binding energy (60 meV), which lead to efficient exciton UV emission at room temperature [1, 2]. The properties of ZnO highly rely on dopants, post-deposition treatments, and deposition parameters. For example, these properties can be enhanced by doping with the following elements: Li, Mg, Al, Cu, W, etc. [3].

Aluminum (Al) has three valence electrons per atom. The ionic radius of Al^{3+} and Zn^{2+} are 0.053 nm and 0.074 nm, respectively. Thus it is theoretically possible for Al^{3+} to substitute Zn^{2+} in ZnO, which can contribute one extra electrons to one dopant atom. The aims of the present study are to increase the amount of information already in existence on ZnO by preparing thin films of Al doped ZnO on quartz glass using radio frequency magnetron sputtering (RF magnetron sputtering) and to study their structural, optical and optical properties. In this work, the Al doped ZnO (AZO) thin film was deposited on quartz glass substrates by RF magnetron sputtering. And the effects of the sputtering pressure on the structural, morphological, electrical and optical properties of the thin films have been investigated.

Experimental Details

The Aluminum doped Zinc oxide (AZO) thin films were deposited on quartz glass substrates by the radio frequency magnetron sputtering method at room temperature. The quartz glass substrates were cleaned with semiconductor cleaning fluid and deionized water in an ultrasound bath for 1 h and dried with compressed nitrogen gas. The ceramic target was sintered from ZnO (99.99% in purity) and Al_2O_3 (99.99% in purity) at a high temperature with the molar ratio of Zn: Al=97.5:2.5, with a diameter of 90 mm. Pure Ar (99.99% in purity) gas was used as this experiment's working gas. The working pressure was maintained at 250 W and total flow (Ar) was set at 30 sccm during deposition. The distance between the target and the substrate was 70 mm. The deposition sputtering pressure of the layer was kept at 0.6, 0.8, 1.0, 1.2 and 1.4 Pa for 60 min throughout the deposition, while labeled as samples 1#, 2#, 3#, 4# and 5#, respectively.

The analyses of the films were completed using X-ray diffraction (XRD, D8Advance), scanning

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electron microscope (SEM, FEI, Quan TA-200F), and UV-VIS spectrophotometer (Perkin Elmer Lambda 750).

Results and Discussion

XRD patterns of all thin film samples are shown in Fig. 1. The observed peak positions were correlated to the peaks of hexagonal ZnO with the ICDS card number 00-036-1451. It can be seen that all the AZO thin films samples have an obvious (002) diffraction peak, no other diffraction peaks, from other impurity phases, were found, implying a hexagonal structure. To varying degrees, the relative intensity of (002) peak changed with the sputtering pressure increasing. The (002) peak intensity is minimum while the sputtering pressure is 0.6 Pa, and the pressure is 0.8 Pa the (002) peak intensity is maximum. On the one hand, at very low sputtering pressures (lower than 0.80 Pa) the particles when arriving at the substrate surface do not have enough energy (and therefore have low mobility), resulting in more irregular crystalline lattice formation [4]. On the other hand, the increase in the sputtering pressure above 0.80 Pa and concomitant reduction in the energy of the sputtered particles leads to a decrease in the intensity of diffraction peak [4].

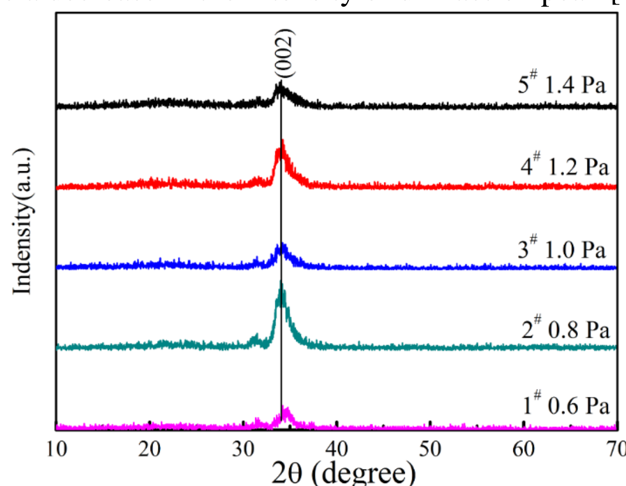

Figure 1. X-ray diffraction (XRD) patterns of AZO thin films deposited at different sputtering pressure

Fig. 2 displays the typical SEM images of AZO thin films deposited at various sputtering pressure. Fig. 2 (a) shows that $1^{\#}$ sample (0.6 Pa) thin film exhibited tiny particles and that the particles were evenly distributed on the surface. The films' surfaces show heavily island- shaped and flaky-shaped nanocrystals on the substrate for Fig. 3 (b, c, d).

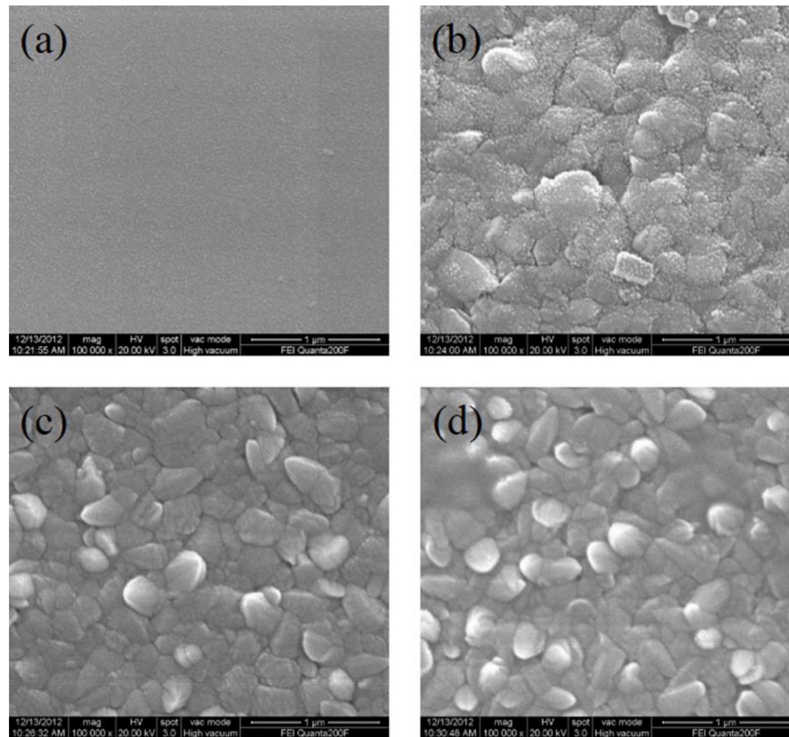

Figure 2. The SEM images of AZO thin films with varying sputtering pressure, (a): 0.6 Pa, (b): 0.8 Pa, (c): 1.0 Pa, (d): 1.2 Pa

The optical transmittance spectra of AZO thin film samples, shown in Fig. 3, indicate that the films were transparent in the range of 300-1000 nm. All samples obtained an average optical transmittance in the region from 400 nm to 1000 nm of above 80%. In the range of 450-600 nm, the transmittance of all samples decreased with the sputtering pressure changed. The main reason is the film surface changed coarser which increased the light diffuse reflection. The result is consistent with the film surface SEM image.

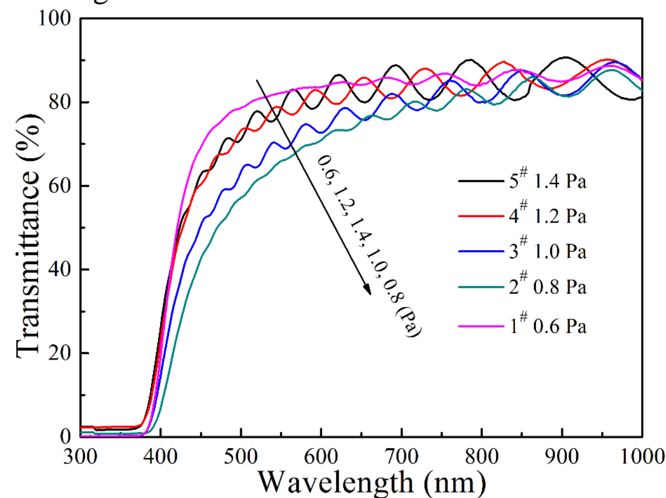

Figure 3. Optical transmittance spectrum of AZO thin films deposited at different sputtering pressure

Fig.4 shown the resistivity of AZO thin films measured by the four-probe resistivity tester. The resistivity decreased from 2.1×10^{-2} Ω•cm to 8.6×10^{-3} Ω•cm with the increase of sputtering pressure from 0.6 Pa to 1.0 Pa. The conductivity of AZO thin films was mainly dependent on the carrier concentration and carrier mobility. This could be attributed to the sputtering particle energy decreased while the particle reached the substrate surface, which led to the carrier mobility increased and the AZO film resistivity decreased.

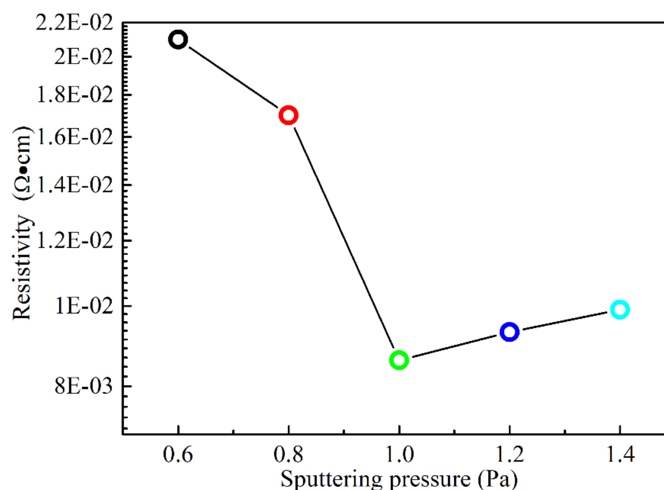

Figure 4. Electrical properties of AZO thin films deposited at different sputtering pressure

Conclusion

The aluminum-doped ZnO thin films were prepared on quartz glass substrates by RF magnetron sputtering at room temperature with varying sputtering pressure. As the sputtering pressure increased, the crystallinity of AZO thin films improved and the surface crystallite size increased. The optimized AZO thin film obtained at the sputtering pressure of 1 Pa exhibited the lowest resistivity of 8.6×10^{-3} Ω·cm and an average transmittance of 74.15% in the wavelength range of 400 to 1000 nm.

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