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Optical and electrical properties of aluminum zinc oxide (AZO) nanostructured thin film deposited on polycarbonate substrate

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ABSTRACT

Transparent polymer materials, due to their unique properties, such as light weight, optical transparency, and electrical and mechanical properties, have become very attractive as a replacement for inorganic glass substrates in a wide range of optoelectronic applications. In this research, aluminum zinc oxide nanostructured thin film was deposited on polycarbonate polymer substrates using a magnetron sputtering technique. The structure, morphology, and surface composition of the thin film were investigated by X-ray diffraction and field emission scanning electron microscopy. The optical and electrical properties of the thin film were investigated by UV–VIS-NIR spectrophotometer, ellipsometer, and four point probe method. The X-ray diffraction pattern showed that the aluminum zinc oxide thin film had a polycrystalline structure. The optical and electrical results indicated that the refractive index, band gap, and sheet resistance of the aluminum zinc oxide thin film were 1.8, 3.2 eV, and 265 Ω/sq, respectively.

1. Introduction

Transparent conductive oxide (TCO) thin films have been used extensively as a transparent electrode in optoelectronic devices such as flat panel displays, light-emitting diodes, and thin-film solar cells [1,2]. In addition, TCO thin films have been used in aircraft windshields in order to prevent surface icing [3]. Most of TCO thin films are based on indium oxide (In_2O_3), zinc oxide (ZnO), tin oxide (SnO_2), and their mixed compounds such as indium tin oxide (ITO), aluminum zinc oxide (AZO), etc. Among these materials, ITO is the most favorable TCO due to its electro-optical properties. However, ITO use is limited because of its high price and toxicity. ZnO has attracted much attention as a replacement for ITO because of desirable properties such as high transmittance, non-toxicity, and lower cost. ZnO is a natural *n*-type semiconductor material. Due to its wide direct band gap (3.3 eV), its transmittance in the visible region is extremely high [4–6]. ZnO thin films are also highly resistive. In contrast, doped ZnO such as AZO can increase the conductivity by several orders of magnitude [7–12].

AZO thin film immobilized on rigid glass substrates has been widely studied because of its excellent electro-optical properties. Nowadays, there is increasing interest in replacing conventional glass substrates with flexible substrates such as plastic polymers in optoelectronic devices. As it is well known, glass is very heavy, brittle, and easily deformed, especially when used for certain purposes, such as smart cards, electronic maps, and flat panel displays, where flexibility and light weight are needed. Therefore, transparent conducting films deposited on flexible polymer substrates could overcome these problems. In addition, transparent conducting films must be deposited on polymer substrates at low temperature because of the weak thermal stability of polymer materials [13,14]. Many techniques have been developed for the deposition of AZO thin films such as electron beam evaporation, chemical vapor deposition (CVD), spray pyrolysis, the sol–gel process, metal organic chemical vapor deposition (MOCVD), pulsed laser deposition (PLD), and magnetron sputtering [15,16]. Sputtering is a desirable technology for immobilizing films on polymer substrates since it permits deposition at low temperatures, leading to smooth films with good surface uniformity [15,16]. In this work, transparent conducting AZO thin film (200 nm thickness) was deposited on polycarbonate polymer substrates by magnetron sputtering. The structural and electro-optical property of the AZO thin film was investigated.

2. Experimental

Nanostructured AZO thin film was prepared on polycarbonate (PC) substrates by means of a DC magnetron sputtering method (MSS160 model, High vacuum Technology Center, ACECR-Sharif University Branch, IRAN). The deposition rate and the thickness

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Table 1
AZO thin film preparation condition.

Target	Power (W/cm^2)	Thickness (nm)	Sputtering gas	Base pressure	Work pressure
ZnO/Al_2O_3 (98/2 wt.%)	2	200	Ar	1.5×10^{-5} mbar	2×10^{-2} mbar

of the growing film were measured by the use of a quartz-crystal sensor, which was placed near the substrate. The AZO thin film preparation conditions in the sputtering method are indicated in Table 1.

It is necessary to mention, that before coating, the PC substrates were ultrasonically cleaned in a 1% neutral detergent solution and then plasma etched according to the specifications in Table 2. Plasma surface treatment was applied to improve the adhesion of the deposited AZO thin film onto the PC substrates.

The structure and morphology of the thin film was determined using a Bruker X-ray diffractometer (D8ADVANCE, Germany, Ni-filter, Cu K_α radiation $\lambda = 1.5406$ Å) and field emission scanning electron microscopy (FE-SEM, Hitachi S4160, Cold Field Emission, voltage 20 kV). The transmittance spectrum, refractive index and extinction coefficient of the AZO thin film was obtained using UV–VIS-NIR spectrophotometer (Shimadzu UV-3100) and ellipsometry method (Horiba). The sheet resistance of the AZO thin film was obtained using a four point probe method.

3. Results and discussion

The XRD pattern of the AZO thin film is shown in Fig. 1. The XRD pattern exhibits a strong 2θ peak at 34.53°, corresponding to the (0 0 2) peak of AZO. A *c*-axis (0 0 2) diffraction peak was observed in the AZO thin film [9,17]. AZO thin film with a high *c*-axis orientated crystalline structure along the (0 0 2) plane can reduce electrical resistivity due to an increase in the carriers mobility caused by a reduction in the probability of the carriers scattering at the grain boundary [18]. Al_2O_3 or other related phases are not detected in the XRD pattern. It confirms that the Al atoms may fill the zinc sites or incorporate interstitially in the lattice [19].

Fig. 2 shows an FE-SEM image of the AZO thin film. The film was quite homogeneous and no cracks or peeling were found. It may be seen, that the average grain size of the AZO thin film is 50 nm.

AFM was used to characterize the surface roughness of the AZO thin film. Fig. 3 shows an AFM image of the AZO thin film. The root mean square roughness value (R_{rms}) of the AZO is 11.15 nm. The thin film surface roughness plays an important role in optical applications [20]. High surface roughness causes light scattering and the transmission decrees. In addition, surface roughness is an important factor in thin film conductivity. Some authors have pointed out lower ITO transmittance and higher resistivity due to a rougher surface on the polymer that scatters more electrons and photons [21]. Zhang et al. [22] reported the root mean square roughness value of

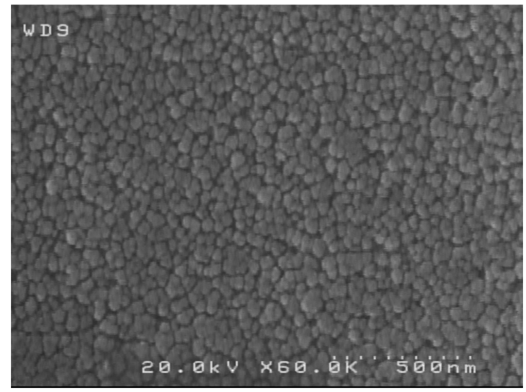

Fig. 2. FE-SEM image of the AZO thin film.

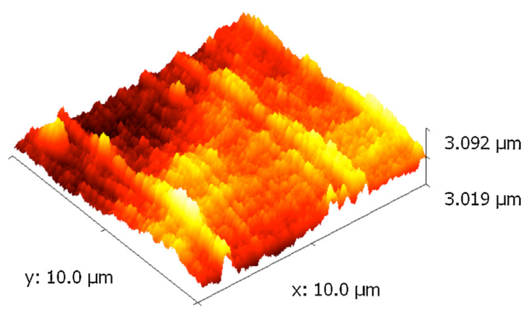

Fig. 3. AFM image of the AZO thin film.

the AZO deposited on PET substrate as 13.56 nm which is close to their result.

Fig. 4 shows the transmittance spectrum of the AZO thin film. It is clear that the AZO thin film is transparent in the visible spectrum. The average transmittance in the visible spectrum is 85%.

The optical constants (thickness, refractive index n, and absorption coefficient *k*) are very important parameters for optical applications. Figs. 5 and 6 show the refractive index and extinction coefficient (*k*) of the AZO thin film measured by the ellipsometer in various wavelengths. It can be seen that the refractive index of the AZO thin film is 1.8 at 550 nm.

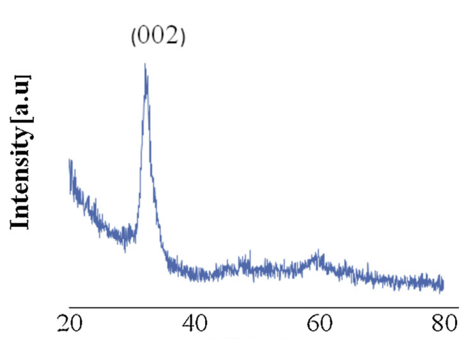

Fig. 1. XRD pattern of the AZO thin film.

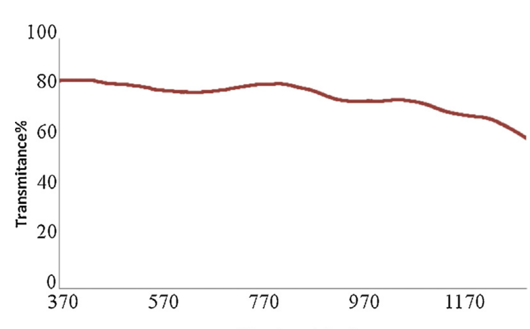

Fig. 4. Transmittance spectrum of the AZO thin film.