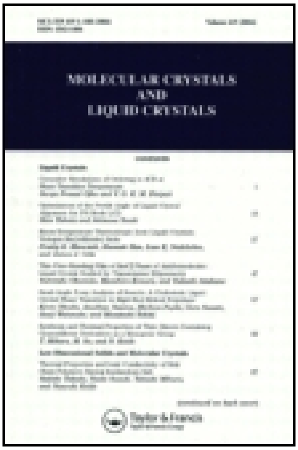

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Preparation of Indium Zinc Oxide Thin Films Deposited on Various Substrates

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The amorphous indium zinc oxide (IZO) thin films were deposited on polycarbonate (PC), polyethersulfone (PES) and glass substrates at room temperature using the facing targets sputtering (FTS). The electrical, optical, structural characteristics of IZO thin films were evaluated by a Hall Effect Measurement, an X-Ray Diffractormeter (XRD), a UV/VIS spectrometer in visible range and an atomic force microscopy (AFM), respectively. As-deposited IZO thin films exhibited the resistivity of 5.1×10^{-4}, 5.1×10^{-4}, *and* 4.9×10^{-4} *[Ω-cm] on PC, PES and glass substrates, respectively. The optical transmittance showed over 85% in the visible region, regardless of substrate type.*

Keywords: facing targets sputtering; flexible display; IZO; polymer substrate

1. INTRODUCTION

Transparent conductive oxide (TCO) thin films have been widely used in various applications, such as for transparent electrodes in flat panel displays, and in solar cells, optoelectronic devices, touch panels and IR reflectors [1,2]. Among these, tin doped indium oxide (ITO) and zinc doped indium oxide (IZO) has attracted considerable attention. Particularly, amorphous IZO film is the best candidate for high-quality transparent conducting electrodes in OLEDs and flexible displays. Generally, the rough surface morphology of TCO films should cause the degradation of the performance of OLEDs and flexible displays

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showing as dark-spots, shorter life time. In order to improve their performances, the surface morphology is required to be extremely flat [3]. On the other hand, amorphous IZO film has several advantages, such as the low resistivity, high transmittance, high etching rare and excellent surface smoothness. The high-quality IZO films can easily prepared at low temperature using the sputtering method [4,5]. Polymer substrates such as polyether sulfone (PES), polyethylene terephthalate (PET), polycarbonate (PC), polyimide (PI), polymethyl methacrylate (PMMA), polyethylene naphthalate (PEN) and polyparabanic acid (PPA) have been widely researched for certain applications such as smart cards, electronic maps, and flexible displays [6]. In order to improve their performances, flexible substrates need the thermal stability, high optical transmittance, light weight, high flexibility, and low water absorption. In this work, we prepared IZO films on glass, PC and PES substrates at room temperature using the facing targets sputtering (FTS) system. A FTS system consists of two targets facing each other and a substrate located to the side of the center line connecting the two targets. Magnetic fields are applied perpendicularly to the surface of the two targets. Therefore the FTS system can suppress the bombardment of hot particles to the substrate by using a low voltage and high current. Based on the results, the FTS system can deposit thin films without stressing them at a lower working gas pressure and low temperature [7,8]. We studied the electrical, optical, structure and crystallographic properties of IZO thin films were prepared on glass, PC and PES substrates using the FTS system.

2. EXPERIMENTAL DETAILS

We prepared IZO thin films on glass, PC and PES substrates at room temperature using the FTS system. Before film deposition, the glass substrate was cleaned by ultrasonic cleansing with distilled water for 20 min and with IPA for 20 min. It was then dried a stream of N_2 gas. The polymer (PC and PES) substrates were heated for 20 min in a conventional oven in a normal atmosphere at 70°C to remove any residual moisture adsorbed onto the surface. Figure 1 is an illustration of the FTS equipment used in the deposition process. The chamber was evacuated to 1.0×10^{-4} Pa before the film deposition began with the pressure during the process maintained at 0.1 Pa. The IZO films were deposited using identical conditions and, for each substrate, the O_2 gas flow ratio ($O_2/[O_2 + Ar]$) was adjusted from 0.01 to 0.06 to find the optimum resistivity. More details about the sputtering conditions are given in Table 1. The electrical, optical, structure and crystallographic properties of the as-deposited thin films on the glass, PC

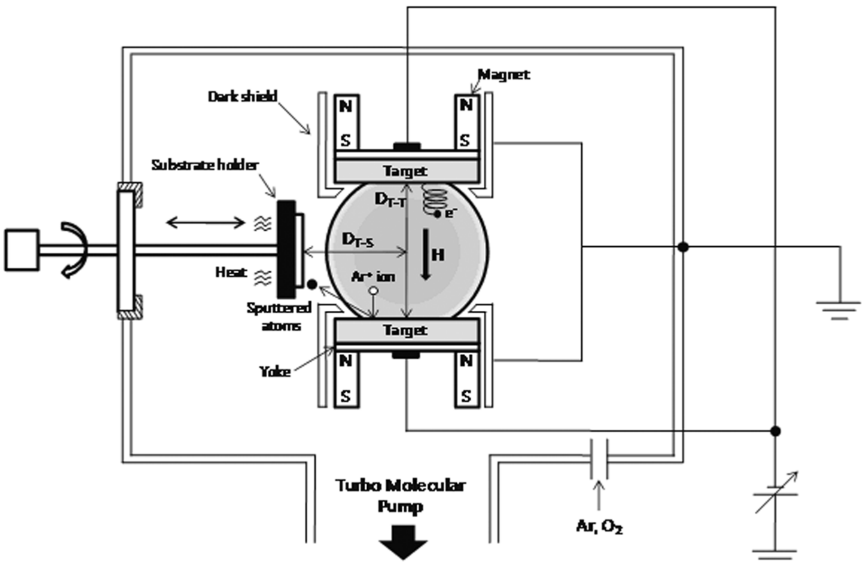

FIGURE 1 Diagram of facing targets sputtering system.

and PES substrates were evaluated using a hall effect measurement (ECOPIA), a UV/VIS spectrometer (HP) with a spectral range of 300–900 nm, an X-ray diffractometer (XRD, Rigaku), and an Atomic Force Microscopy (AFM, PSIA).

3. RESULTS AND DISCUSSION

Figures 2–4 show the changes in the carrier concentration, mobility, and resistivity of the as-deposited films with different O_2 gas flow

TABLE 1 Sputtering Conditions

Deposition parameter	Conditions		
Targets	IZO (In_2O_3 90 wt%, ZnO 10 wt%, 5 N)		
Substrate	Glass	PC (Polycarbonate)	PES (Polyethersulfon)
Base pressure	1.0×10^{-4} Pa		
Working pressure	0.1 Pa		
O_2 gas flow ratio [$O_2/(O_2 + Ar)$]	0.01–0.06		
Target-Target distance	50 mm		
Target-Substrate distance	90 mm		
Input current	0.08 A		
Film thickness	About 100 nm		

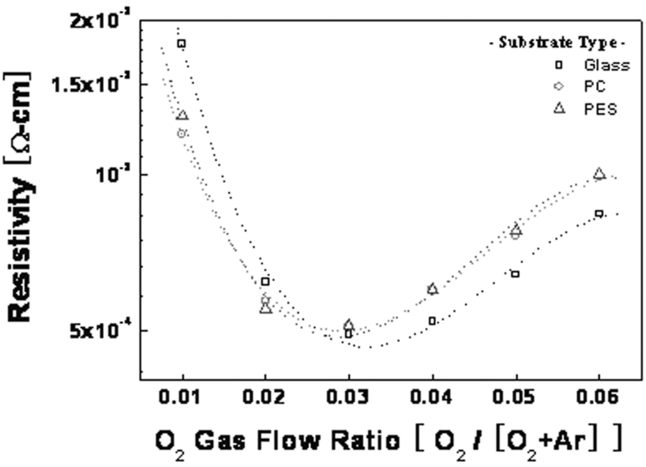

FIGURE 2 The resistivity of IZO films deposited as a function of the O_2 gas flow ratio on glass, PC and PES.

ratio for the glass, PC and PES, respectively. When the IZO thin film was prepared at an O_2 gas flow ratio of 0.03, it showed the lowest resistivity, with values of $4.9 \times 10^{-4}\,\Omega \cdot \mathrm{cm}$, $5.1 \times 10^{-4}\,\Omega \cdot \mathrm{cm}$ and $5.1 \times 10^{-4}\,\Omega \cdot \mathrm{cm}$ on the glass, PC and PES, respectively. The carrier concentrations of the as-deposited IZO films decreased on the glass,

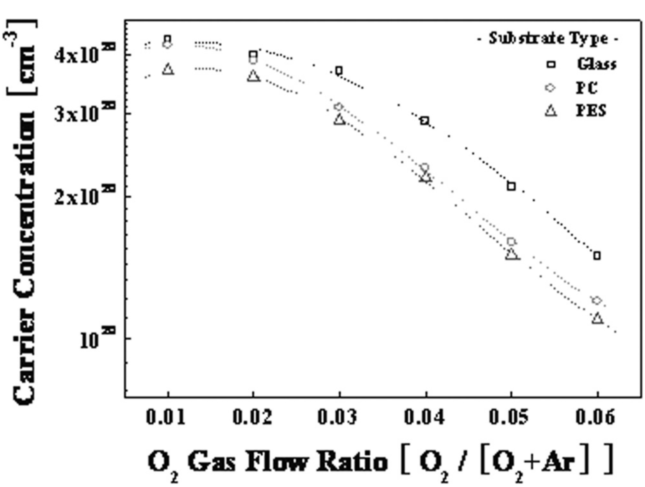

FIGURE 3 The carrier concentration of IZO films deposited as a function of the O_2 gas flow ratio on glass, PC and PES.

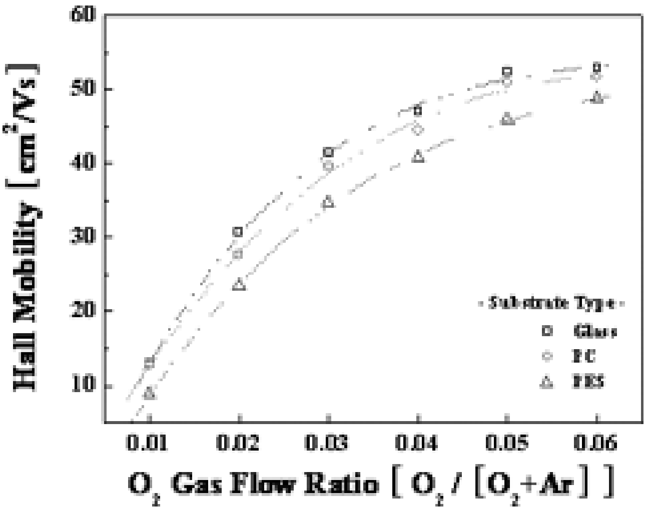

FIGURE 4 The mobility of IZO films deposited as a function of the O_2 gas flow ratio on glass, PC and PES.

PC and PES substrates with an increase in the O_2 gas flow ratio from $4.3 \times 10^{20}\,cm^{-3}$ to $1.5 \times 10^{20}\,cm^{-3}$, from $4.2 \times 10^{20}\,cm^{-3}$ to $1.2 \times 10^{20}\,cm^{-3}$, and from $3.7 \times 10^{20}\,cm^{-3}$ to $1.1 \times 10^{20}\,cm^{-3}$, respectively. The hall mobility increased when the O_2 gas flow ratio was increased. It has been reported that all the free electrons were released from oxygen vacancies in IZO film [9]. IZO films, the dominant donors are generated by oxygen vacancies which each donate two electrons if activated. So, the decrease in the carrier density with the increasing O_2 gas flow ratio should be due to the extinction of the oxygen vacancies. We also observed that the electron mobility increased with increasing the O_2 gas flow ratio, which could be explained to the decrease in the ionized scattering centers of the carrier sites such as the electrically active oxygen vacancies [10].

Figures 5(a–c) show the optical properties of the IZO thin films deposited on the glass, PC and PES substrates as a function of the O_2 gas flow ratio. These clearly show that adding a small amount of oxygen gas significantly improved the transmittance of the IZO films. Transmittance of IZO thin films showed higher than 85% could be achieved for a wavelength in the visible range at an O_2 gas flow ratio of 0.03, regardless of the substrate type. The improvement in IZO transmittance in ambient oxygen can be attributed to compensation from the oxygen vacancies in the IZO film.

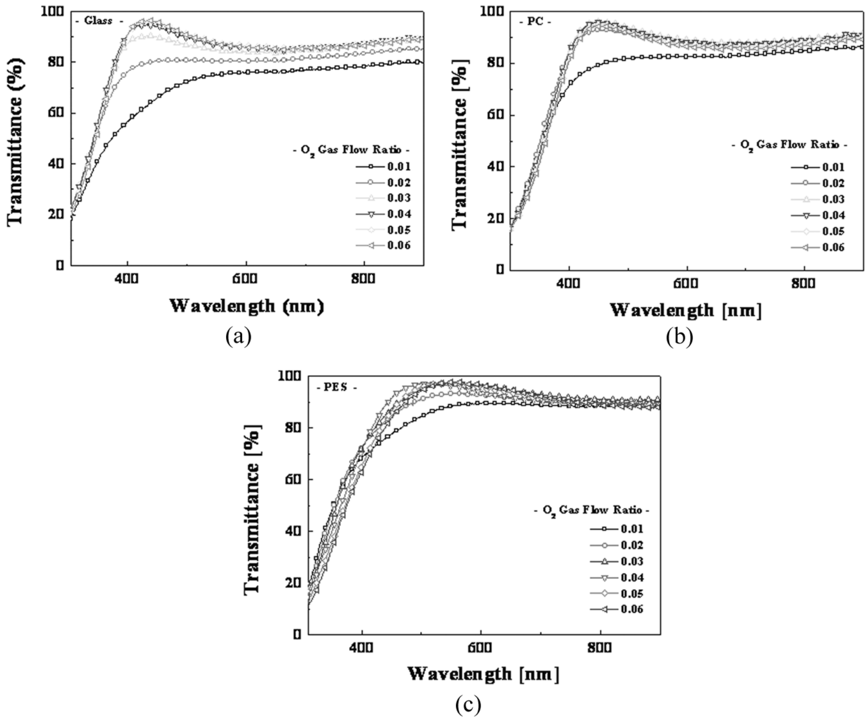

FIGURE 5 The optical properties of IZO films deposited as a function of the O_2 gas flow ratio on (a) glass, (b) PC, and (c) PES.

Figure 6 shows Plot of $(\alpha h\nu)^2$ against $h\nu$ of IZO films deposited on the glass, PC and PES substrates. The optical absorption coefficient (α) and the optical energy band gap (Eg) are related by [13]:

$$\alpha h\nu = \mathrm{C}(h\nu - \mathrm{Eg})^{1/2}$$

where h is Planck's constant, and ν is the frequency of the incident photon. C is a constant for a direct transition, and α is the optical absorption coefficient. The optical energy gap Eg can then be obtained from the intercept of $(\alpha h\nu)^2$ against $h\nu$ for direct allowed transitions [11]. The optical band gap decreased with a decrease in the carrier concentration. Changing optical band gap is explained by the Burstein-Moss shift [12]. Accordingly, the absorption edge shifts towards lower energy in the carrier concentration decrease.

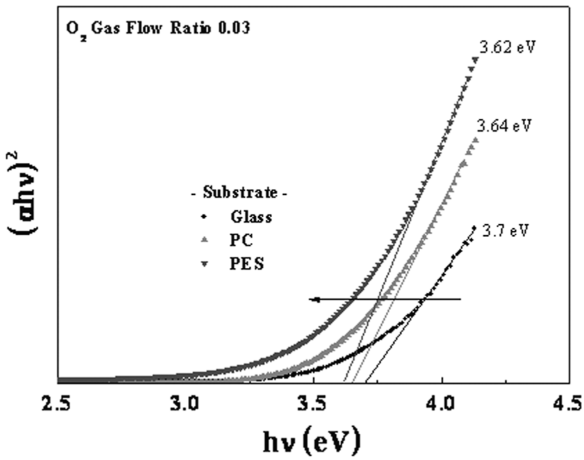

FIGURE 6 Plot of $(\alpha h\nu)^2$ against $h\nu$ of IZO films deposited on glass, PC and PES.

Figure 7 shows the XRD patterns for the IZO thin films as a function of the substrate type. The as-deposited films deposited on the glass, PC and PES substrates did not show crystalline peaks.

Figure 8 and Table 3 show AFM images and surface roughness values of the IZO film deposited on the glass, PC and PES substrates. The IZO/Glass thin film showed a root mean square roughness (Rms) of 0.496 nm, the IZO/PC thin film showed the Rms of 0.637 nm, and

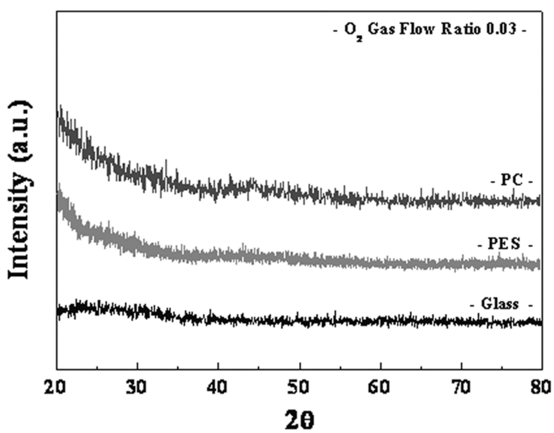

FIGURE 7 XRD patterns of IZO films deposited on glass, PC and PES.

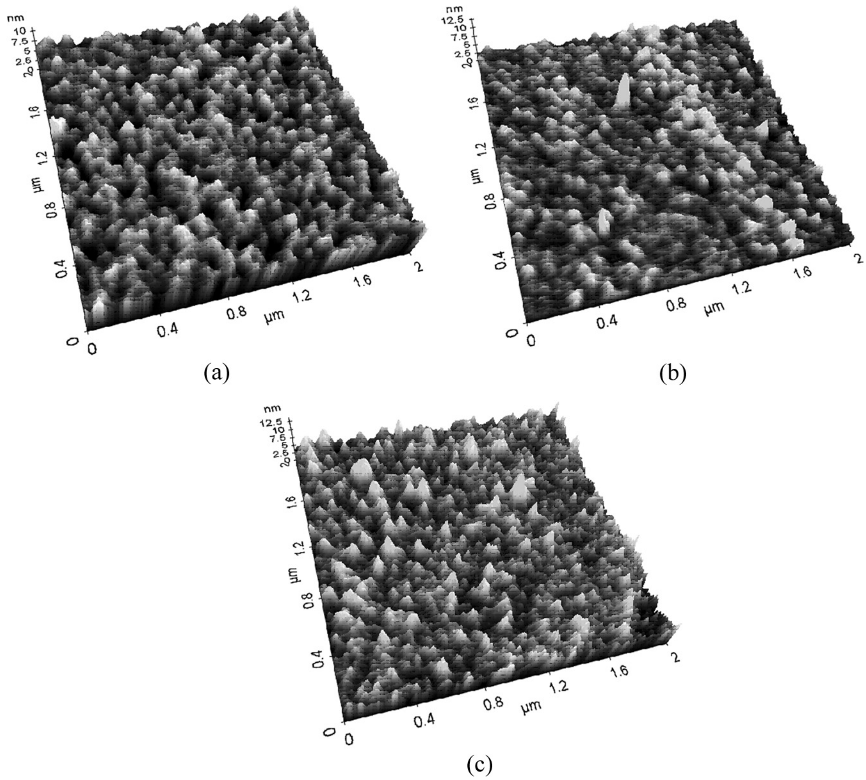

FIGURE 8 AFM images of IZO films deposited on (a) glass, (b) PC, and (c) PES at an O_2 gas flow ratio of 0.03.

the IZO/PES thin film showed the Rms of 0.891 nm, obtained when the IZO film was deposited on glass, PC and PES at the O_2 gas flow ratio of 0.03, respectively. The as-deposited film on the polymer substrates has a higher surface roughness than IZO/glass thin film. However, it is shown that the IZO films have excellent surface

TABLE 2 The Electrical Properties of IZO Films Deposited at an O_2 Gas Flow Ratio of 0.03 on Glass, PC and PES

Substrate	O_2 Gas flow ratio (O_2/[O_2 + Ar])	ρ ($\Omega \cdot$cm)	η (cm^{-3})	μ (cm^2/Vs)
Slide glass	0.03	4.9×10^{-4}	3.7×10^{20}	41.42
PC	0.03	5.1×10^{-4}	3.1×10^{20}	39.63
PES	0.03	5.1×10^{-4}	2.9×10^{20}	34.84

TABLE 3 Roughness Values of IZO Films Deposited on Glass, PC and PES

Substrate	IZO/Glass	IZO/PC	IZO/PES
Rpv	8.766	12.792	10.122
Rms	0.496	0.637	0.891

Rpv: peak to valley, Rms: Root mean square roughness.

roughness in comparison with the ITO film, regardless of the substrate type [13].

4. CONCLUSIONS

We prepared IZO thin films on the glass, PC and PES substrates using the FTS system, respectively. We observed that the as-deposited thin films showed low resistivity and high transmittance due to compensation for oxygen deficiency as the O_2 gas flow ratio of 0.03, and they showed amorphous structure. The carrier concentration of the as-deposited films had lower values on polymer substrates than the films on the glass. The lowest resistivity of $4.9 \times 10^{-4}\,\Omega \cdot cm$, $5.1 \times 10^{-4}\,\Omega \cdot cm$, and $5.1 \times 10^{-4}\,\Omega \cdot cm$ in the glass, PC and PES substrate was obtained at an O_2 gas flow ratio of 0.03. The transmittance of the as-deposited films showed over 85% in the visible range, respectively.

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