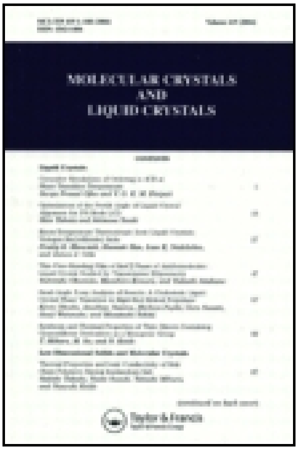

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Properties of Indium Zinc Oxide Films on Various Polymer Substrates Deposited by Low-Frequency 60 Hz Magnetron Sputtering Method

Eun Lyoung Kim [a], Sang Kooun Jung [a], Sang Ho Sohn [a], Duck Kyu Park [a], Sang Mun Lee [b], Lee Soon Park [b], Sung Ho Lee [c] & Kap Duk Song [d]

[a] Department of Physics, Kyungpook National University, Daegu, Korea

[b] Mobile Display Research Center, Kyungpook National University, Daegu, Korea

[c] Gumi Institute of Electronics Technology, Gumi, Gyeongsangbuk-do, Korea

[d] Advanced Display Manufacturing Research Center, Kyungpook National University, Daegu, Korea

Version of record first published: 22 Sep 2010

Mol. Cryst. Liq. Cryst., Vol. 470, pp. 241–250, 2007

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701495740

Properties of Indium Zinc Oxide Films on Various Polymer Substrates Deposited by Low-Frequency 60 Hz Magnetron Sputtering Method

Eun Lyoung Kim
Sang Kooun Jung
Sang Ho Sohn
Duck Kyu Park
Department of Physics, Kyungpook National University, Daegu, Korea

Sang Mun Lee
Lee Soon Park
Mobile Display Research Center, Kyungpook National University, Daegu, Korea

Sung Ho Lee
Gumi Institute of Electronics Technology, Gumi, Gyeongsangbuk-do, Korea

Kap Duk Song
Advanced Display Manufacturing Research Center, Kyungpook National University, Daegu, Korea

We introduce indium zinc oxide (IZO) thin films grown at room temperature by using a low-frequency (LF) 60 Hz magnetron sputtering system. The flexible substrates are PES, PET and PC. The optical, electrical and structural properties of IZO films on flexible substrates were investigated.

The alloy target was In_2O_3*:ZnO (90:10 wt%) with a diameter of 3 inch and thickness of 5 mm. The vacuum chamber was evacuated down to pressure* 5×10^{-6} *torr prior to deposition. The flow rates of argon gas (99.999 %) were kept at a constant value of 30 sccm by a mass flow controller(MFC). The discharges were performed by power of 300 V, 310 V, 320 V.*

This work was supported by the Regional Innovation Center (ADMRC) Program of the Ministry of Commerce, Industry and Energy of Korea.

Address correspondence to Duck Kyu Park, Department of Physics, Kyungpook National University, Sangyuk-dong, Buk-gu, Daegu 702-701, Korea (ROK). E-mail: dkpark@mail.knu.ac.kr

They have low sheet resistance of about 30 Ω/sq., high transmittance of over 85 % in the range of 400–700 nm. Also they showed good band gap of about 3.43 eV on polyethersulfone (PES) substrates, 3.50 eV on polyethylene terephthalate (PET) and 3.30 eV on polycarbonate (PC).

The experimental results imply that the films with good qualities in surface morphology, transmittance and electrical conduction can be grown by a low-frequency magnetron sputtering method an PES is the most recommendable substrate.

Keywords: indium zinc oxide; LF magnetron sputtering; optical transmittance; sheet resistance; thin film

INTRODUCTION

Several transparent conducting oxide films are an important electrode material in the construction of organic light emitting devices (OLEDs) because they show many technologically interesting properties such as high optical transmittance, good electrical conductivity and very smooth surface morphology. Also they have been the topic of many studies due to their transparency and electrical conduction, which make them useful in various applications such as solar sells, liquid crystal displays, optoelectronics etc [1,2].

These films have been deposited by various methods, such as radio frequency [RF] magnetron sputtering, direct current [DC] magnetron sputtering, pulsed laser deposition [PLD] and reactive thermal evaporation [RTE] [3,4]. In spite of the fact that the low frequency [LF] (60 Hz) plasma source has peculiar properties such as non-continuous discharge, relatively high electron temperature, and small bombarding damage, there are few experiment reports on the IZO films by the low frequency (60 Hz) magnetron sputtering [5,6]. To get s-deposited films good surface morphology, we introduced the low frequency (60 Hz) magnetron sputtering method [7,8].

We have studied that the optical and electrical properties of IZO thin films deposited on PES, PET and PC substrates by low frequency (60 Hz) magnetron sputtering system.

EXPERIMENTAL

IZO films were deposited on PES(polyethersulfone), PET(polyethylene terephthalate) and polycarbonate(PC) substrates at room temperature by the low frequency (60 Hz) magnetron sputtering system. The alloy target was In_2O_3:ZnO (90:10 wt%) with a diameter of 3 inch and thickness of 5 mm. The vacuum chamber was evacuated down to pressure

TABLE 1 The sputtering conditions of IZO thin films deposited on PES, PET and PC substrates

Sputtering parameters	Values
LF Power [V]	300, 310, 320
Base preassure [Torr]	5×10^{-6}
Working pressure [mTorr]	1.9
T-S distance [mm]	1 00
Deposition time [min]	20
Ar flow rate [SCCM]	30
Substrate temperature [°C]	RT (Room temprature)

5×10^{-6} torr prior to deposition by a rotary pump and a turbo molecular pump.

The flow rates of argon gas (99.999%) were kept at a constant value of 30 sccm (standard cc/min) by a MFC (mass flow controller). The discharges were performed under constant input power of 300 V, 310 V and 320 V. The target was pre-sputtered in an argon atmosphere of 1.9 mtorr in order to remove the surface oxide layer. The sputtering conditions of IZO thin films substrates are summarized in Table 1.

The sheet resistance of films was measured by using 4-point probe (Mitsubishi, MCP-T360) and deposition rate was determined using FE-SEM (Oxford Model, Inca Energy for JSM-6335F). The structural morphology and optical transmittance of IZO films were investigated using AFM (Digital Instrument, Nanoscope IIIa) and UV-Visible spectrophotometer (Shimadzu, UV-3150) respectively. The crystal structure and phase of the IZO films were measured using X-ray diffraction (Mx Labo). The mobility and carrier concentration were measured using Hall effect measurement system (EGK, HEM-2000).

RESULTS AND DISCUSSION

Figure 1 shows the XRD pattern of IZO films on PES, PET and PC substrates deposited by low frequency magnetron sputtering. The IZO films deposited on PES, PET and PC substrates at room temperature showed amorphous morphology. This observation suggests that the room temperature is enough to fully dissipate the particle energy in case using LF magnetron sputtering method.

Figure 2 illustrates the sheet resistance of IZO thin films deposited at 300 V, 310 V, 320 V on the various substrates. It can be see that as the voltage increases the sheet resistance decreases. All films have relatively low resistance values. The lowest resistivity showed value of about 30 ohm/sq.

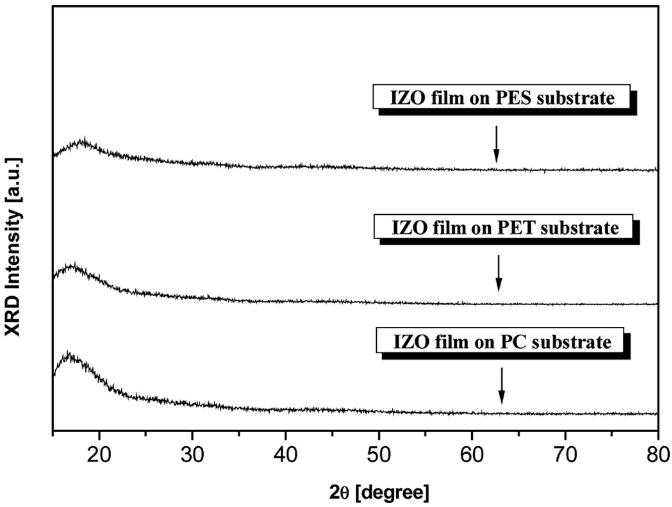

FIGURE 1 The XRD pattern of IZO films deposited at various substrate.

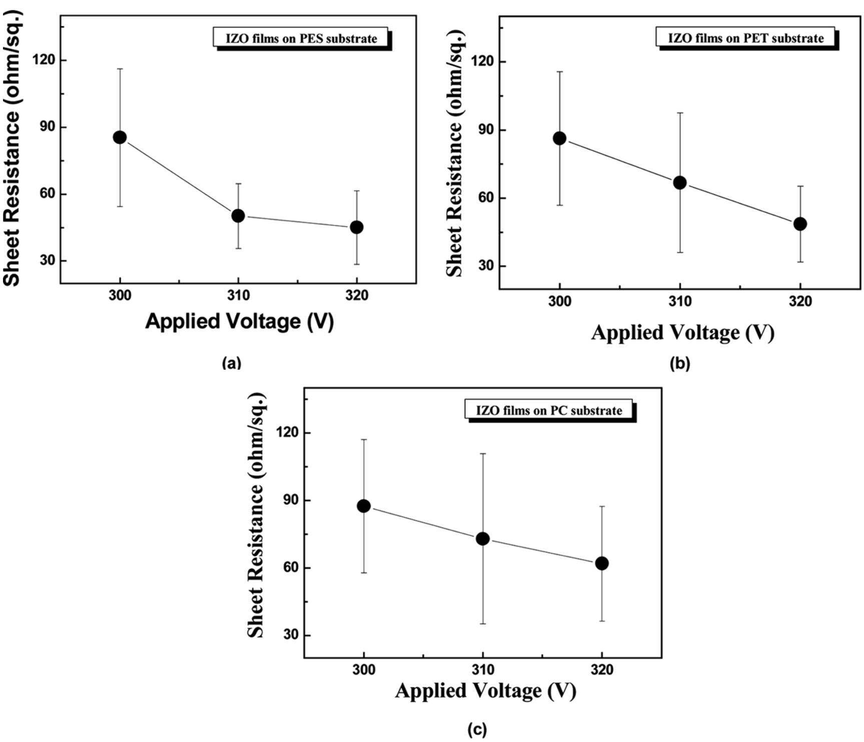

FIGURE 2 The sheet resistances of IZO thin films (a) PES and (b) PET (c) PC.

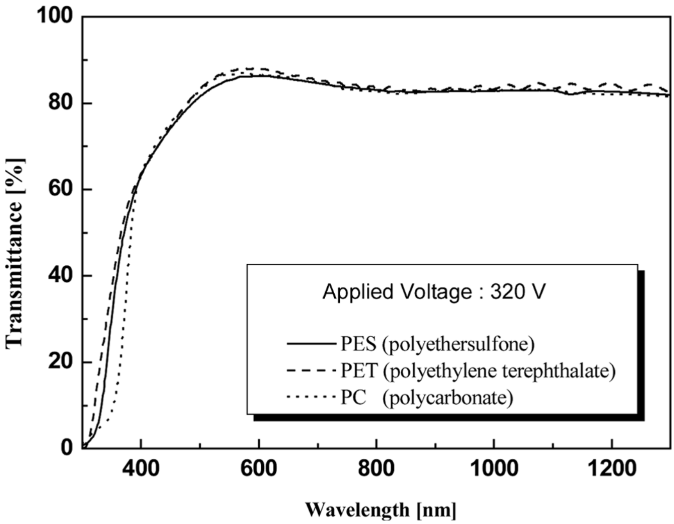

FIGURE 3 The transmittance of IZO films.

Figure 3 shows the transmittances of the IZO films. The transmittance spectra as a function of wavelength in the range 300–1300 nm are shown on different substrates at 320 V. It is observed that the optical transmittance of the IZO films between 400 and 700 nm is slightly higher on PET film than on PES and PC film. The average transmittance in the visible spectrum was over 80% no matter what kind of substrate was used.

The optical band gap (E_g) of the film could be gained by plotting α^2 vs. hv. Figure 4 shows the photon energy dependence of $(adv)^2$ for deposited IZO films. The optical band gap (E_g) of IZO thin film can be deduced from this graph. E_g is calculated using Cody' relation [9].

$$\alpha^2 = (hv - \mathrm{E_g}) \tag{1}$$

Where α is an optical absorption coefficient and hv is a photon energy. Absorption coefficients of the films in different wavelengths have been calculated from transmittance and reflection data. Extrapolations of the straight regions of plots to $\alpha = 0$ give E_g. It was observed that the direct band gap of the IZO thin films 3.43 eV for PES substrate, 3.50 eV for PET substrate and 3.30 eV for PC substrate. The band gap for PES substrate is slightly higher than one for PC substrate and lower than one for PET substrate.

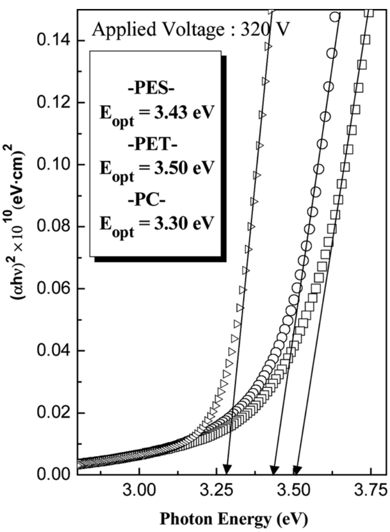

FIGURE 4 The bandgap of IZO films.

Table 2 shows the water vapor transmission rate of IZO films deposited PES, PET and PC substrates. Permeation test result was 0.9 g/m^2/days at 25°C for PES substrate, 0.1 g/m^2/days at 25°C for PET substrate and 0.2 g/m^2/days at 25°C for PC substrate.

Figure 5 show the digital images of (a) bare polymer films (b) IZO/PES (c) IZO/PET (d) IZO/PC. After deposition PET and PC films vented a lot, but PES film is almost flat. So PES substrate is more useful than other substrates.

Figure 6 shows the Hall mobility and carrier concentration of IZO films prepared at a different deposition voltage on PES, PET and PC substrates. According to the following relation [10].

$$\rho = 1/Ne\mu \tag{2}$$

TABLE 2 Water Vapor Transmission Rate

Substrates	WVTR[g/m^2/days] at 25°C
PES	0.9
PET	0.1
PC	0.2

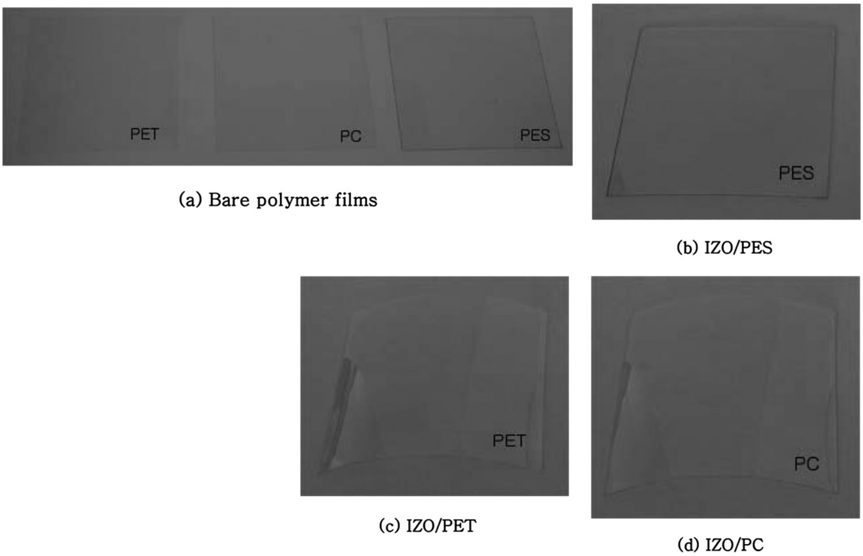

FIGURE 5 The digital images (a) bare polymer films (b) IZO/PES (c) IZO/PET (d) IZO/PC.

It was suggested that the lowest resistivity of IZO film was at 320 V due to the higher product of carrier concentration N and mobility μ, and the carrier concentration values of IZO films at a deposition time of 30 minute on PES, PET and PC substrates. At 320 V, carrier concentration is 10.2×10^{20} cm^2 and mobility is 10.3 cm^2/V sec for PES substrate, carrier concentration is 9.44×10^{20} cm^2 and mobility is 10.6 cm^2/V sec for PET substrate and carrier concentration is 10.9×10^{20} cm^2 mobility is 9.21 cm^2/V sec for PC substrate.

Figure 7 shows the thickness of IZO thin films prepared at a different deposition voltage on PES, PET and PC substrates. Thickness is related to the deposition time. The same condition only but different substrate was given thickness on the other substrate is almost same even though the substrate is different. At the applied voltage of 300 V the thickness was about 90 nm, 105 nm at 310 V and 130 nm at 320 V. As the applied voltage increases the thickness is increases.

Figure 8 shows AFM image of IZO film on PES substrate. The scan size was 5.00 μm, scan rate was 2.001 Hz, data scale was 20.00 nm and Z axis scale was 20.00 nm/div. The surface morphology of film is known to be very smooth (Ra; <1 nm, Rms; <2 nm). This can be explained by the fact the LF plasma is low processing and has energetic species.

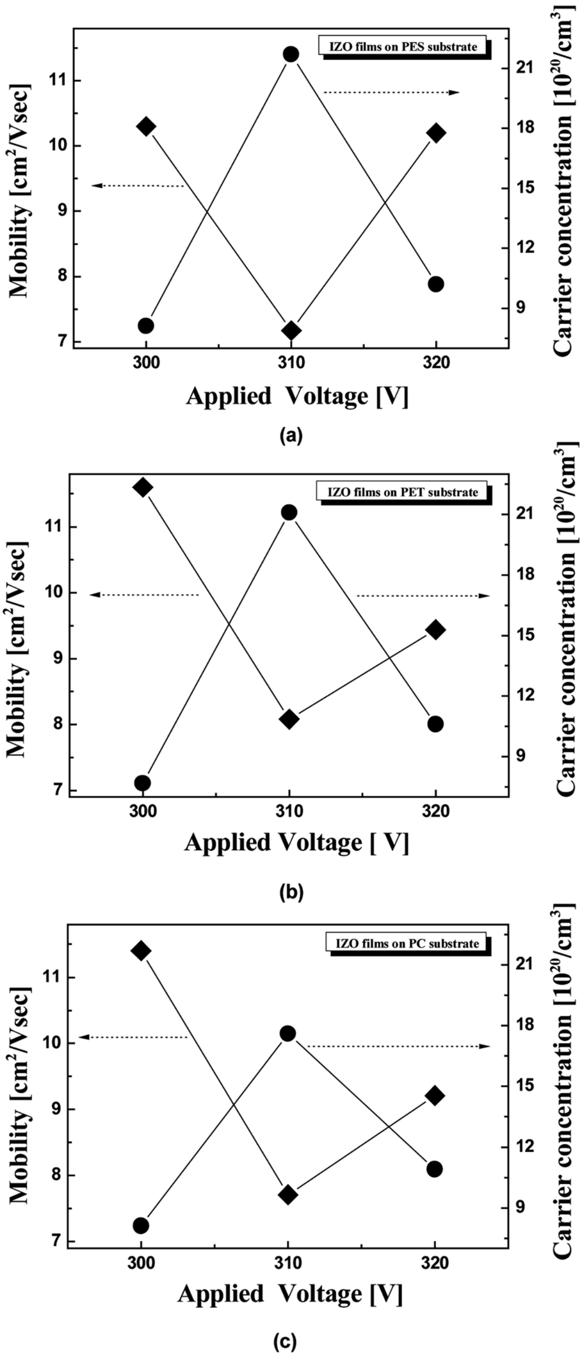

FIGURE 6 The Hall mobility and carrier concentration of IZO thin films prepared at (a) PES (b) PET and (c) PC.

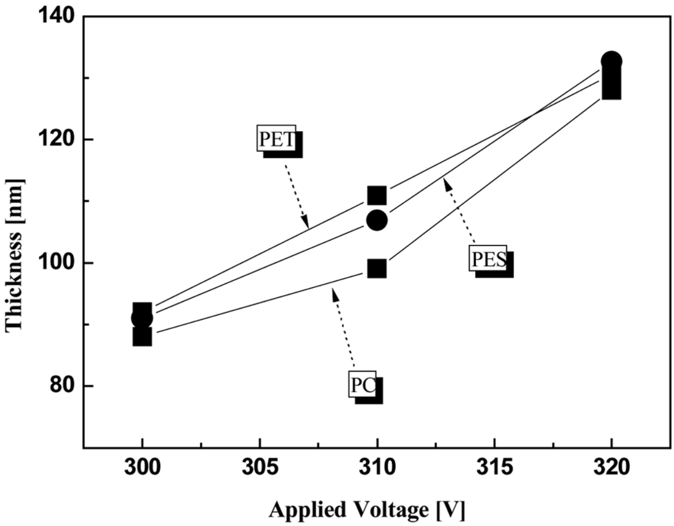

FIGURE 7 The thickness of IZO films.

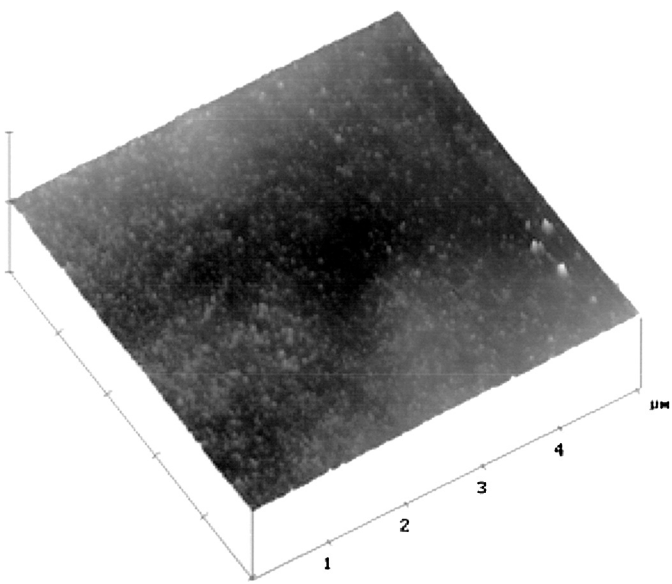

FIGURE 8 AFM image of IZO film on PES substrate.

CONCLUSIONS

We tried to find out a good way to grow high quality IZO thin films without any post treatments. For the purpose of this, we used by low frequency magnetron sputtering system to deposit IZO films at room temperature on PES, PET and PC substrates and investigated the optical, electrical and structural properties of the polymer films. The IZO films were deposited in this method, it showed very smooth surface morphology (Ra; < 1 nm, Rms; < 5 nm), high transmittance (> 84 %) and low sheet resistance (30 ohm/sq.).

We suggest that the low frequency plasma processing can be a candidate for a useful method of fabricating high quality IZO thin films on the polymer substrates at the room temperature. We will develop OLED to have better properties after those applied data in this research for new device.

REFERENCES

[1] Ishida, Y., Nakato, Y., & Tsubomura, H. (1991). *J. Appl. Phys*, *69*, 1736.
[2] Arias, A. C., Roman, L. S., Kugler, T., Toniolo, R., Meruvia, M. S., & Hummelgen, I. A. (2000). *Thin Solid Films*, *371*, 201.
[3] Tsai, S. Y., Lu, Y. M., Lu, J. J., & Hon, M. H. (2006). *Surface and Coatings Technology*, *200*, 3241.
[4] Song, Y. S., Park, J. K., Kim, T. W., & Chung, C. W. (2004). *Thin Solid Films*, *467*, 117.
[5] Kim, H. T. et al. (2003). ADMD, 7, 61.
[6] Kim, H. T. & Park, D. K. (2003). *J. Korean phys. Soc.*, *42*, S916.
[7] Lee, S. H. & Park, D. K. (2004). *J. Korean Phys. Soc.*, *44*, 950.
[8] Jung, S. K., Kim, H. T., Lee, D. L., Cho, Y., Park, L. S., Park, D. K., & Sohn, S. H. (2004). IMID'04 DIGEST.
[9] Zhang, Keran, Zhu, Furong, Huan, C. H. A., & Wee, A. T. S. (2000). *Thin Solid Film*, *376*, 255.
[10] Igasaki, Y. & Saito, H. (1991). *Thin Solid Films*, *199*, 223.