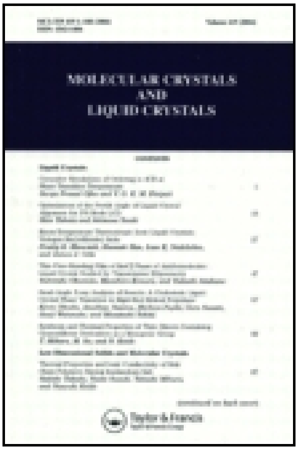

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Properties of Indium Tin Oxide on Polymer Films Deposited by Low-Frequency Magnetron Sputtering Method

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In this study, we introduce indium tin oxide (ITO) thin films grown by using low-frequency (60 Hz) magnetron sputtering method. Characteristics of the ITO thin films deposited on polyethersulfone (PES) substrates are investigated. Experiments were carried out as a function of deposition time and substrate temperature. ITO thin films on PES substrate revealed amorphous structure. The optical transmittance, the sheet resistance and the resistivity of the films decreased with the increasing deposition time. The sheet resistance and the roughness of the films increased with the increasing substrate temperature. Roughness values of ITO films on PES substrate deposited at various substrate temperatures are Ra (<2 nm), Rms (<3 nm) and Rp-v (<10 nm). The experimental results confirm that the films with good qualities in surface morphology, transmittance and electrical conduction can be grown by a low-frequency magnetron sputtering method.

Keywords: indium tin oxide; magnetron sputtering; optical transmittance; resistivity; roughness; sheet resistance; thin film

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INTRODUCTION

Indium tin oxide (ITO) films 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, organic light emitting diode, etc. [1,2] ITO films are deposited by the radio frequency magnetron sputtering, direct current magnetron sputtering, chemical vapor deposition, spray pyrolysis, pulsed laser deposition, and electron beam method [3,4].

In spite of the fact that the low frequency (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 ITO films by the low frequency (60 Hz) magnetron sputtering [5,6]. For the purpose of obtaining as-depo films with good surface morphology, we introduced the low frequency (60 Hz) magnetron sputtering method.

In this work, we studied the influence of deposition time and substrate temperature on the main properties of ITO thin films deposited on flexible, transparent substrates. We investigate the optical and electrical properties of ITO thin films deposited on PES substrate by the low frequency (60 Hz) magnetron sputtering system.

EXPERIMENTAL

ITO films were deposited on PES substrate at room temperature by the low frequency (60 Hz) magnetron sputtering system. The alloy target was In_2O_3:SnO_2 (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 by a rotary pump and a turbo molecular pump.

The flow rates of argon gas (99.999%) were kept at a constant value of 25 sccm (standard cc/min) by a MFC (mass flow controller). The discharges were performed under constant input power of 280 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 ITO thin films on PES substrate 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 ITO films were investigated using AFM (Digital Instrument, Nanoscope IIIa) and UV-Visible spectrophotometer (Shimadzu, UV-1601PC), respectively. The crystal structure and phase of the ITO films were measured using X-ray

TABLE 1 The Sputtering Conditions of ITO Thin Films Deposited on PES Substrate

Sputtering parameters	Series A	Series B
LF Power [V]	280	280
Base preassure [Torr]	5×10^{-6}	5×10^{-6}
Working pressure [mTorr]	1.9	2.2
T-S distance [mm]	100	100
Deposition time [min]	10, 15, 20, 25, 30, 35	25
Ar flow rate [SCCM]	25	30
Substrate temperature [°C]	RT (Room temperature)	RT, 60, 80, 100, 120, 140
Thickness [nm]	112, 134, 158, 170, 233, 237	≈170

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 ITO films on PES substrate deposited as a function of substrate temperature by low frequency magnetron sputtering. The ITO films deposited at substrate

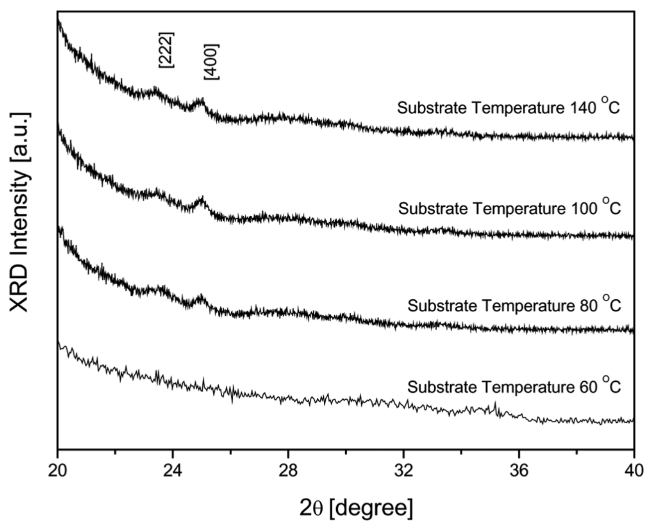

FIGURE 1 The XRD pattern of ITO films deposited at various substrate temperatures.

temperature from 60°C to 140°C were almost amorphous. This observation suggests that the substrate temperature of 60°C is enough to fully dissipate the particle energy.

Figure 2 shows the roughness value of ITO films deposited at the deposition time and the substrate temperature on PES substrate.

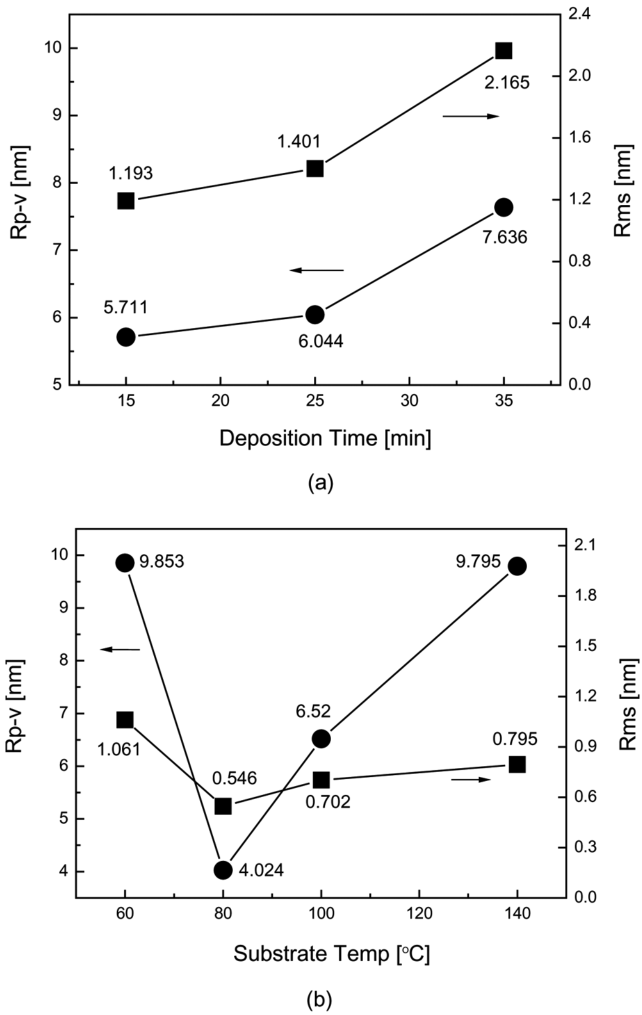

FIGURE 2 The roughness of ITO films deposited on PES at (a) deposition time of 15, 25 and 35 minutes, and (b) various substrate temperatures from RT to 140°C.

The definition of Rms is the root-mean-square value of the surface roughness profile from the centerline, peak-to-valley roughness (Rp-v = Rmax) is the vertical distance between the highest and lowest points [7,8]. The surface roughness increased with the increase of deposition time. In case of different substrate temperatures, the ITO films have a lower roughness (Rp-v) at a temperature of about 80°C relatively. The corresponding Rp-v values of the ITO films prepared with substrate temperature 60°C, 80°C, 100°C, and 140°C are 9.853 nm, 4.024 nm, 6.52, and 9.795 nm, respectively. With increasing substrate temperature from 80°C to 140°C, Rp-v values of the ITO films are increased.

Figures 3 and 4 show the sheet resistance and resistivity of ITO thin films grown by discharging under 280 V on the PES substrate. With increasing deposition time from 10 minute to 35 minute, sheet resistance is decreased. All films have relatively high resistance values, but this problem may be solved by a barrier layer of polymer substrates. But, with increasing substrate temperature from RT to 140°C, sheet resistance is increased. This resistivity showed the lowest value of about 9×10^{-4} ohm·cm.

Figure 5 shows the transmittances of the ITO films prepared by changing the deposition time and the substrate temperature. The transmittances of all films exceed about 80%, implying high optical transparency in the visible region. The In content increased and the O content decreased with the increase of the deposition time. With increasing substrate temperatures from RT to 140°C, sheet resistances are not changed.

The photon energy dependence of $(\alpha hv)^2$ for deposited ITO films and they are heated at substrate temperatures and deposition time as shown Figure 6. The optical bandgap (E_g) of ITO thin film can be deduced from this graph. E_g is calculated using Cody' relation [9].

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

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 ITO thin films increased from 3.606 to 3.83 eV with an increase in deposition substrate temperature from RT to 140°C.

Figure 7 shows the Hall mobility and carrier concentration of ITO films prepared at a different deposition time and a substrate temperature on PES substrates. According to the following relation [10],

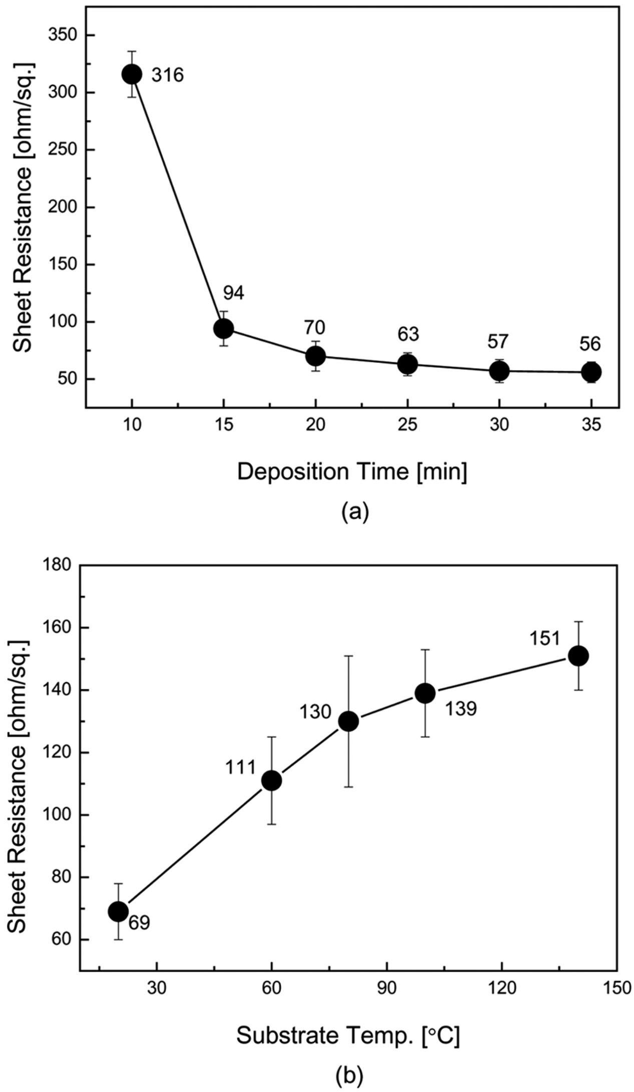

FIGURE 3 The sheet resistances of ITO thin films as a function of (a) the deposition time and (b) substrate temperature.

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

it was suggested that the lower resistivity of ITO film at 280 V was due to the higher product of carrier concentration N and mobility μ. The

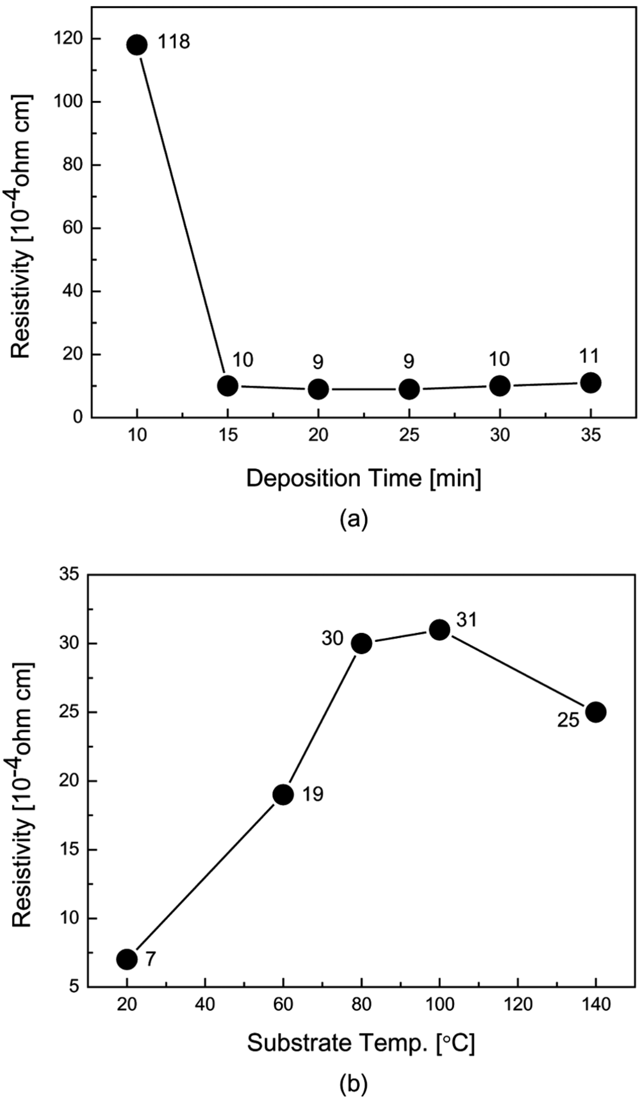

FIGURE 4 The resistivity of ITO thin films as a function of (a) the deposition time and (b) substrate temperature.

mobility and the carrier concentration values of ITO films at a deposition time of 30 minute on PES substrate are $17.3\,cm^2/Vsec$ and $3.29 \times 10^{20}/cm^3$, respectively.

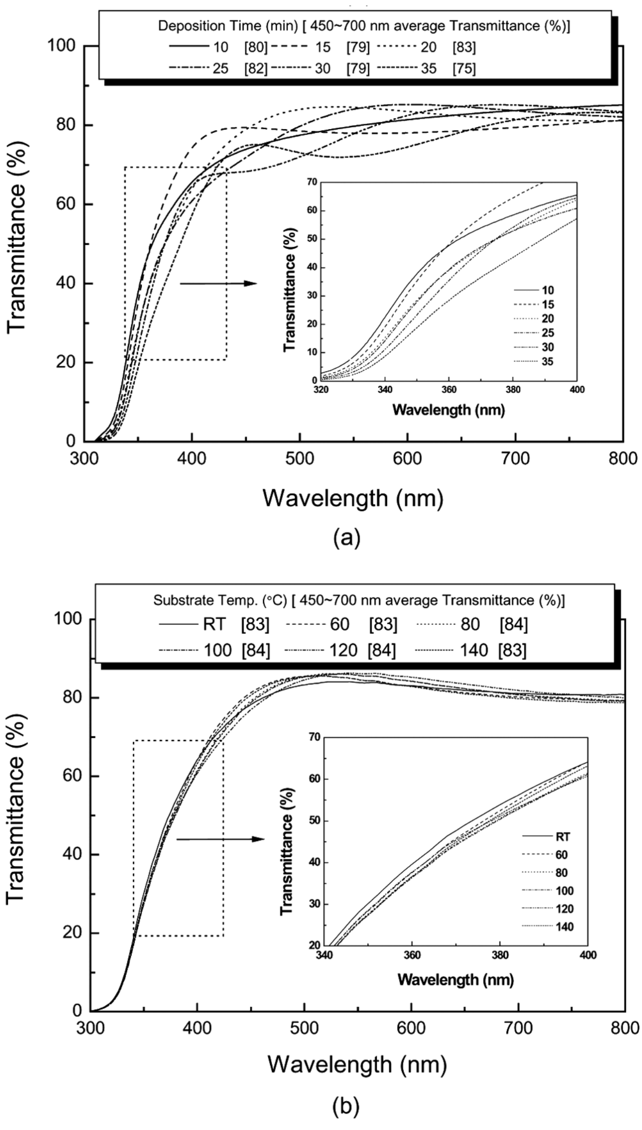

FIGURE 5 The transmittance of ITO films with (a) deposition time and (b) substrate temperature on PES substrate. Inset shows the transmittance of low wavelength.

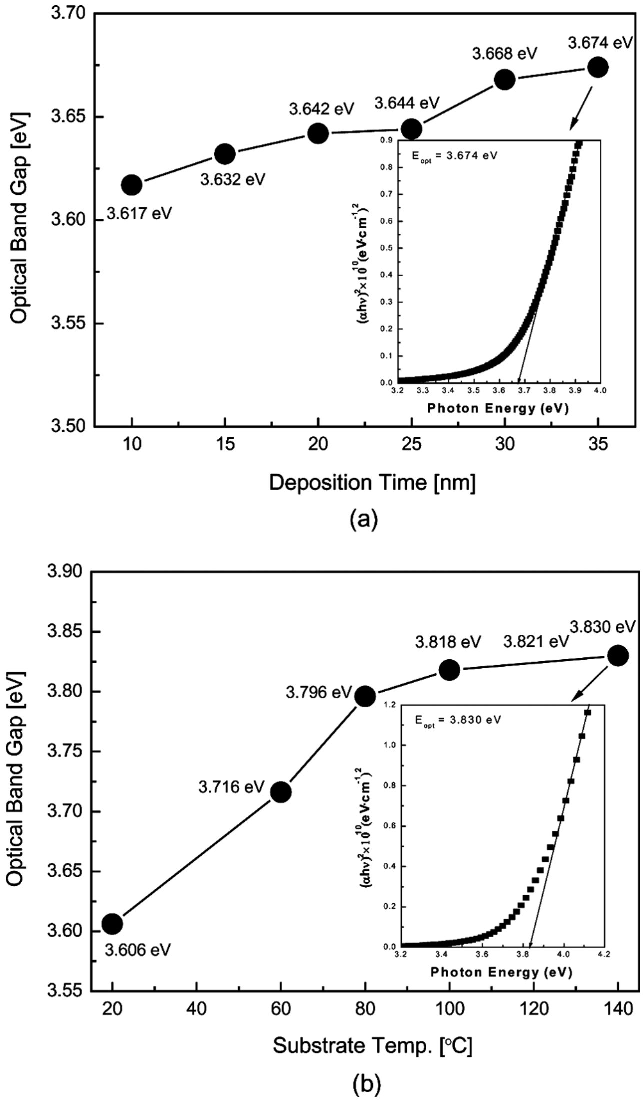

FIGURE 6 The bandgap of ITO films with (a) deposition time and (b) substrate temperature on PES substrate. Inset shows a typical plot of hv vs. $(\alpha hv)^2$ for ITO film deposited at a (a) deposition time 35 min and (b) substrate temperature 140°C.

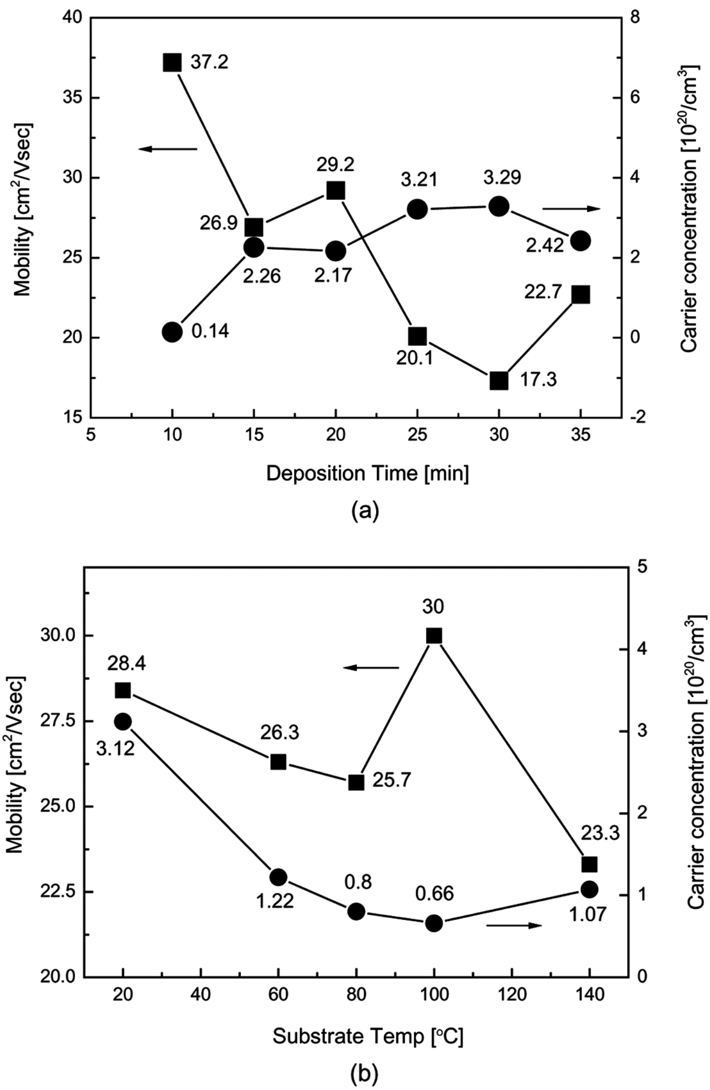

FIGURE 7 The Hall mobility and carrier concentration of ITO thin films prepared at a different (a) deposition time and (b) substrate temperature on PES substrate.

CONCLUSIONS

We tried to find out a good way to grow high quality ITO thin films without any post treatments. For the purpose of this, we used by low frequency magnetron sputtering system to deposit ITO films at room temperature and investigated the optical, electrical and structural properties of the polymer films. The ITO films were deposited in this method, it showed very smooth surface morphology (Rp-v: 4.024 nm), high transmittance ($>84\%$) and low sheet resistance (56 ohm/sq.). The resistivity of deposited film at RT is about 9×10^{-4} ohm·cm.

We suggest that the low frequency plasma processing can be a candidate for a useful method of fabricating high quality ITO thin films on the polymer substrates at the room temperature.

REFERENCES

[1] Park, N. G., Kwak, M. Y., & Kim, B. O., *et al.* (2002). *Jpn. J. Appl. Phys.*, *41*, 1523.
[2] Kim, H. & Gilmore, C. M., *et al*. (1999). *J. Appl. Phys.*, *86*, 1.
[3] Nunes de Carvalho, C., *et al*. (2002). *Surface and Coatings Technology*, *151*, 252.
[4] Guillen, C. & Herrero, J. (2005). *Thin Solid Films*, *480*, 129.
[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] Jung, Y. S., Lee, D. W., Lee, D. W., & Jeon, D. Y. (2004). *Applied Surface Science*, *221*, 136.
[8] Kim, D. & Kim, S. (2003). *Surface and Coatings Technology*, *176*, 23.
[9] Zhang, K., Zhu, F., 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.