# Fabrication and Characteristics of Indium Tin Oxide Films on CR39 Substrate for OTFT

Sung-Yeol Kwon[a]
*Major of Electrical and Information Engineering, Pukyong National University, Yongdang-dong, Nam-gu, Busan 608-739, Korea*

[a]E-mail : sungyeol@kornet.net

(Received March 8 2006, Accepted October 2 2006)

The Indium tin oxide (ITO) films were deposited on CR39 substrate using DC magnetron sputtering. ITO thin films deposited at room temperature because CR39 substrates its glass-transition temperature of is 130 ℃. ITO thin films used bottom and top electrode and for organic thin film transparent transistor.(OTFT) ITO thin film electrodes electrical properties and optical transparency properties in the visible wavelength range (300 – 800 nm) strongly dependent on volume of oxygen percent. For the optimum resistivity and transparency of ITO thin film electrode achieved with a 75 W plasma power, 10 % volume of oxygen and a 27 nm/min deposition rate. Above 85 % transparency in the visible wavelength range (300 – 800 nm) measured without post annealing process and $9.83 \times 10^{-4}$ Ω cm a low resistivity was measured thickness of 300 nm.

*Keywords* : Indium tin oxide(ITO), CR39, Organic thin film transistor(OTFT), Thin film

## 1. INTRODUCTION

Indium tin oxide (ITO) thin films were found in a wide range of optoelectronic applications, such as transparent electrical contact electrodes in display, touch screens, thin film solar cells and organic light emitting diodes (OLED)[1-4,17]. ITO thin film is one of most frequently investigated and used transparent conductive oxides due to its high electrical conductivity and high transparency in the visible light wavelength range[5]. Theses type of film have been deposited by a variety of methods such as RF (radio frequency) sputtering, pulse laser deposition (PLD)[6,7], ion beam sputtering (IBS) and reactive thermal evaporation (RTE)[8] techniques. Among them, DC and RF magnetron sputtering are the most attractive techniques for industrial development because of their high deposition rate, good reproducibility and a wide range of commercially available sputtering systems[9,10,18]. Typically, magnetron sputtering processes are performed at high substrate temperature (> 200 ℃) as high temperature allows the best results in terms of layer transparency and conductivity to be obtained[11]. Nevertheless, several applications, for example solar cells, organic light emitting diodes (OLED) and organic thin film transistors (OTFT) require low deposition temperature[4,17]. It is because high temperature may damage the underlying electronic device structure and substrate itself. Therefore transparent electrode deposition process at near room temperature is essential for OTFT[4].

For RF deposition at room temperature leads to the poor structural and electrical properties[12]. And even ITO DC magnetron sputtering at room temperature, where the formed ITO layers are usually amorphous structure with a high electrical resistivity[13].

This research investigated DC magnetron sputtering deposition of ITO thin film on CR39 substrate for organic thin film transistors transparent electrode at room temperature. The investigation was mainly focused on the effect of plasma power and oxygen flow on the properties of ITO thin film without damaging to the CR39 substrates.

## 2. FABRICATION AND MEASUREMENTS

ITO thin film electrodes were deposited by DC magnetron sputtering on CR39 that will be used for substrate for organic thin film transparent transistor. The target was a 4 inch diameter and 0.25 inch thick sintered disk containing $In_2O_3$ (90 wt%) + $SnO_2$ (10 wt%). The distance between the target and substrates was 60 mm. Argon gas and oxygen gas flow were controlled by a mass flow controller. The vacuum chamber is evacuated down to pressure of $10^{-6}$ Torr before deposition. Then controlled reactive argon gas and oxygen gas were introduced into the chamber and required 3 mTorr pressure is set.

The range of sputtering power was 25 – 125 W, varying oxygen volume percentage from 0 to 20 %. And thermocouple was used to measure substrate temperature during sputtering. The deposition process was carried out at below 130 ℃, which is the CR39 substrates glasses temperature. The thickness of the ITO film was measured by alpha-step (Dektak 500), allowing the deposition rate to be calculated. The resistivity of the ITO film electrode was calculated based on the resistance measured by the standard four-point probe technique at room temperature. The optical transparency of ITO films was measured by an UV/VIS NIR spectrometer (SAFAS 200DES) in range of 300 – 800 nm. The crystal structure of ITO films was characterized by X-ray diffraction (MacScience M03XHF22, X-ray generator with Cu target 30 kV, 20 mA).

## 3. RESULTS AND DISCUSSION

Energy used for ITO films growth was provided by DC magnetron sputtering power, and the deposition rate increased as sputtering power increased. The increase of sputtering power caused more target atoms to be bombarded from the target[9,10].

Figure 1 shows the resistivity of ITO films according to sputtering power. Under sputtering power of 20 W, the resistivity of ITO films was high for as a transparent electrode for organic thin film transistor. So the minimum power for deposition is above 20 W. When plasma power changed from 30 to 100 W, the lowest resistivity is shown at 50 W. But it shows an 82.5 % transmittance which is not suitable for transparent electrode for OTFT. At sputtering power of over 100 W, the polycarbonate CR39 substrate began to be etched from target atoms. The ITO thin film shows a cracking pattern on the surface.

Figure 2 shows the variation of resistivity for 300 nm thick ITO films as a function of volume percent of oxygen. At plasma power of 50 W, the resistivity decreasing as a volume percent of oxygen decreased. But as the volume percent of oxygen was reduced, the ITO films showed a poor transparency. The resistivity dropped at 10 % of volume percent of oxygen. The resistivity showed an increase when the volume percent of oxygen was 20 % to $1.91 \times 10^{-2}$ Ω cm and increased as the volume percent of oxygen increased and the transparency of the ITO thin films decreased. At plasma power of 75 W, the resistivity was quite low regardless of the volume percent of oxygen. Nishio et al.[14] and Shabbir A. Bashar[15] showed that the electrical

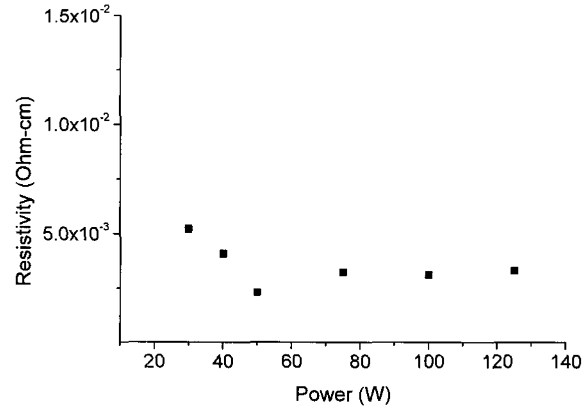


Fig. 1. Resistivity of ITO films according to sputtering power(thickness 300 nm).

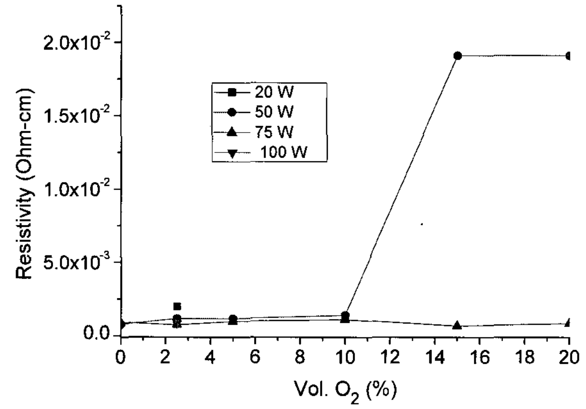


Fig. 2. Resistivity for ITO thin films according to the volume percent of oxygen(thickness 300 nm).

resistivity of ITO depends on Sn concentration and oxygen content.

Figure 3 shows the average transmission percentage of ITO thin films in the visible region at different plasma power. At 75 W of plasma power, the transmission was over 85 %, and at below 50 W of a plasma power, the transmission decreased.

Figure 4 shows the average transmission percentage of ITO films in the visible region at different volume percent of oxygen at 75 W. At below 5 % of volume of oxygen, the transmission dropped to 55 % and also began to reduce transmission at above 15 % of volume percent oxygen. The result can be explained that, when the volume percent of oxygen is lower the particle sputtered from the target cannot be oxidized enough, so the prepared ITO films are anoxic and sub-oxides such as InOx and SnOx in the film[15]. The transmission of ITO films is higher because sub-oxide can be oxidized with the increase of the volume percent of oxygen.

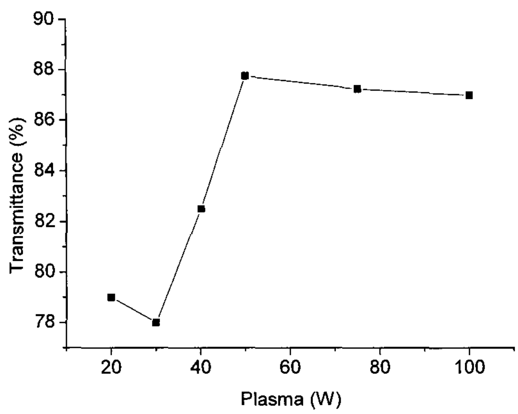


Fig. 3. Transmittance (%) of ITO thin films (300 nm) at different plasma power.

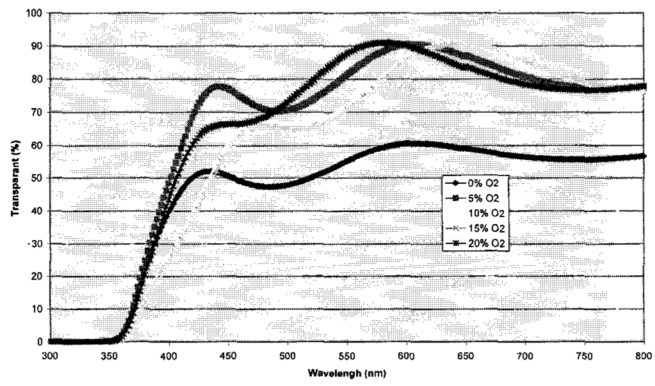


Fig. 4. Transmission spectra of ITO thin films (300 nm) at different volume percent of oxygen.

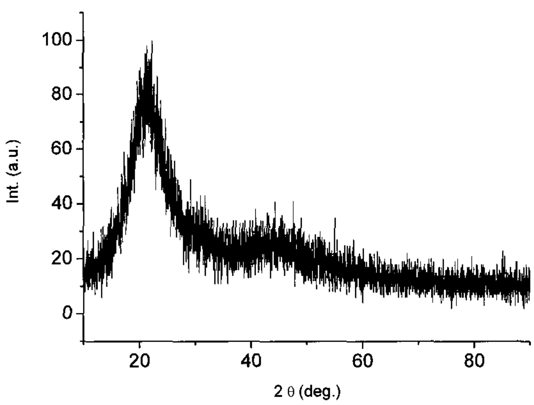


Fig. 5. XRD data of ITO thin films.

However, when volume percent of oxygen is over critical point, the redundant oxygen can be absorbed in defects such as grain boundary and micro crack[15]. The redundant oxygen can cause optical absorption and scattering.

All ITO thin films deposited by DC magnetron sputtering at room temperature show amorphous patterns regardless of the fabrication condition, as seen in XRD data(Fig. 5)[16].

## 4. CONCLUSION

The Indium tin oxide (ITO) films deposited on CR39 substrate using DC magnetron sputtering. ITO thin films deposited at room temperature without heating the substrate because glass temperature of CR39 substrate was 130 ℃. The electrical properties of ITO thin films and their optical transparency properties in the visible wavelength range (300 – 800 nm) strongly depend on the volume of oxygen percent when sputtering.

The optimum resistivity and transparency for ITO thin films were achieved with 5 % oxygen volume, 75 W plasma power, and 27 nm/min of deposition rate. Above 85 % transparency in the visible wavelength range (300 – 800 nm) was measured without post annealing process of ITO film. Resistivity as low as $9.83 \times 10^{-4}$ Ω cm was measured at thickness of 300 nm without post annealing process. All ITO thin films fabrication process did not exceed 80 ℃. Fabricated ITO thin films can be used as bottom and top electrodes and for organic thin film transparent transistor.

## ACKNOWLEDGEMENTS

This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD)(KRF-2005-214-D00299).

## REFERENCES

[1] Z. Zhilin, J. Xueyim, and X Schohong, “Energy transfer and white emitting organic thin film electroluminescence”, Thin Solid Films, Vol. 363, p. 61, 2000.

[2] Y.-H. Tak, K.-B. Kim, H.-G. Park, K.-H. Lee, and J.-R. Lee, “Criteria for ITO (indium-tin-oxide) thin film as the bottom electrode of an organic light emitting diode”, Thin Solid Films, Vol. 411 p. 12, 2002.

[3] S.-M. Park, H.-G. Kim, P.-K. Shin, K.-B. Lim, and D.-C. Lee, “A study on the enhancement of emission efficiency of an organic EL devices using the RF plasma”, Trans. KIEE, Vol. 52C, No. 9, p. 400, 2003.

[4] Y. H. Kwak, Y. S. Lee, J. H. Park, and Y. J. Kim, "A study on electron injection characteristics of organic light emitting diodes with doped cathodes of organic light emitting diodes", KIEE International Transactions on EA, Vol. 3C, No. 1, p. 19, 2003.

[5] I. Hamberg and C. G. Granqvist, "Theoretical model for the optical properties of In2O3: Sn films in the 0.3–50 μm range", Solar Energy Materials, Vol. 14, Iss. 3-5, p. 241, 1986

[6] H. Kim, A. Pique, J. S. Horwitz, H. Mattoussi, H. Murata, Z. H. Kafafi, and D. B. Chrisey, "Doped ZnO thin films as anode materials for organic light-emitting diodes", Thin Solid Films, Vol. 420-421, No. 2, p. 539.

[7] H. Kim, J. S. Horwitz, G. P. Kushto, Z. H. Kafafi, and D. B. Chrisey, "Indium tin oxide thin films grown on flexible plastic substrates by pulsed-laser deposition for organic light-emitting diodes", Appl. Phys. Lett., Vol. 79, p. 284, 2001.

[8] C. Nunes de Carvalho, A. Luis, G. Lavareda, A. Amaral, P. Brogueira, and M. H. Godinho, "ITO thin films deposited by RTE on flexible transparent substrates", Opt. Master., Vol. 17, p. 287, 2001.

[9] H.-C. Lee, J.-Y. Seo, Y.-W. Choi, and D.-W. Lee, "The growth of indium-tin-oxide thin films on glass substrates using DC reactive magnetron sputtering", Vacuum, Vol. 72, p. 269, 2004.

[10] J.-O. Park, J.-H. Lee, J.-J. Kim, S.-H. Cho, and Y.-K. Cho, "Crystallization of indium tin oxide thin films prepared by RF-magnetron sputtering without external heating", Thin Solid Films, Vol. 474, p. 127, 2005.

[11] F. Kurdesau, G. Khripunow, A. F. Da Cunha, M. Kaelin, and A. N. Tiwari, "Comparative study of ITO layers deposited by DC and RF magnetron sputtering at room temperature", J. of Non –Crystalline Solids, Vol. 352, No. 9, p. 1466, 2006.

[12] M. Quaas, H. Steffen, R. Hippler, and H. Wuff, "Investigation of diffusion and crystallization processes in thin ITO films by temperature and time resolved grazing incidence X-ray diffractometry", Surf. Sci., Vol. 540, p. 337, 2003.

[13] V. Teixeira, H. N. Cui, L. J. Meng, E. Fortunato, and R. Martins, "Amorphous ITO thin films prepared by DC sputtering for electrochromic applications", Thin Solid Films, Vol. 420, p. 70, 2002.

[14] K. Nishio, T. Sei, and T. Tsuchiya, "Preparation and electrical properties of ITO thin films by dip-coating process", J. Mater. Sci., Vol. 31, p. 1761, 1996.

[15] S. A. Bashar, "Study of Indium Tin Oxide (ITO) for Novel Optoelectronic Devices", Ph. D Thesis, University of London, p. 50, 1998.

[16] M. Boehme and C. Carton, "Properties of ITO on PET film in dependence on the coating conditions and thermal processing", Surface & Coating Tech., Vol. 200, p. 932, 2005.

[17] K.-S. Yang, B.-S. Kim, D.-S. Kim, H.-K. Shin, and Y.-S. Kwon, "A study on electrical optical properties of organic light emitting diode by oxygen plasma surface treatment of Indium-Oxide substrates", KIEE International Transactions on A, Vol. 54, No. 1, p. 8, 2005.

[18] S.-M. Park, H.-G. Kim, and D.-C. Lee, "A study on the enhancement of emission efficiency of an organic EL devices using the RF plasma", KIEE International Transactions on A, Vol. 52, No. 6, p. 261, 2003.