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Fabrication and Characteristics of Indium Tin Oxide Films on Polycarbonates CR39 Substrate for OTFTs

Sung-Yeol Kwon†

Department of Electrical Control and Instrumentation Engineering, Pukyong National University, San 100 Young-Dong, Nam-Gu, Pusan, 608-739, Korea

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Abstract Indium tin oxide (ITO) films were deposited on polycarbonate CR39 substrate using DC magnetron sputtering. ITO thin films were deposited at room temperature because glass-transition temperature of CR39 substrate is 130°C ITO thin films are used as bottom and top electrodes and for organic thin film transparent transistor (OTFT). The electrodes 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. The optimum resistivity and transparency of ITO thin film electrode was 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) was measured without post annealing process, and resistivity as low as $9.83\times$ ™$10^{-4}\,\Omega$cm was measured at thickness of 300 nm.

Key words 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 the most frequently investigated and used transparent conductive oxides due to its high electrical conductivity and high transparency in the visible light wavelength range.[5] This type of film has 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°C) as high tempera -ture 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 a transparent electrode deposition process at near room temperature is essential for OTFTs.[4]

RF deposition at room temperature leads to poor structural and electrical properties.[12] And even if the ITO layer is made through DC magnetron sputtering at room temperature, the film has amorphous structure with high electrical resistivity.[13]

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

2. Experimental Procedure

ITO thin film electrodes were deposited by DC magnetron sputtering on CR39 that will be used as substrate for organic thin film transparent transistors. The target was a 4 inch diameter and 0.25 inch thick sin -tered 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

†Corresponding author
E-Mail : sungyeol@pknu.ac.kr (S. - Y. Kwon)

by a mass flow controller. The vacuum chamber was 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^{o}C, 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]

Fig. 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 was shown at 50 W. But it showed transmittance of 82.5%, which is not suitable for transparent electrode for OTFT. At sputtering power of over 100 W, the poly-carbonate CR39 substrate began to be etched from target atoms. The ITO thin film showed a cracking pattern on the surface.

Fig. 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 decreased as a volume percent of oxygen decreased. However, as the volume percent of oxygen was reduced, the ITO films showed poor transparency. The resistivity

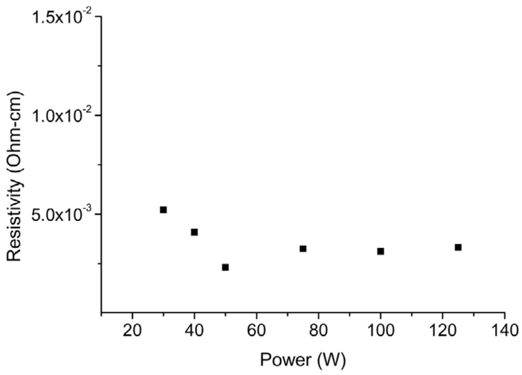

Fig. 1. Resistivity of ITO films according to sputtering power. (thickness 300 nm)

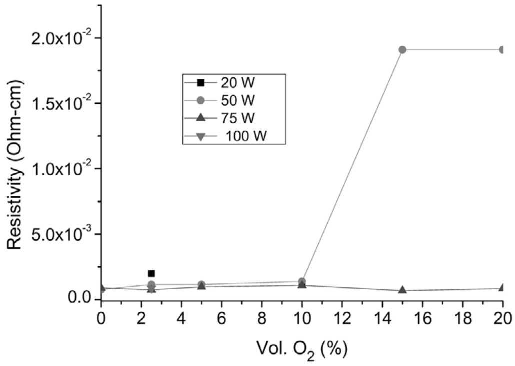

Fig. 2. Resistivity for ITO thin films according to the volume percent of oxygen. (thickness 300 nm)

dropped at 10% of volume percent of oxygen. The resistivity showed an increase when the volume percent of oxygen was 20% to 1.91×10^{-2} Ωcm 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 McQueen Winchkler[15] showed that the elec-trical resistivity of ITO depends on Sn concentration and oxygen content.

Fig. 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.

Fig. 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 it also began to decrease at above 15% of volume percent

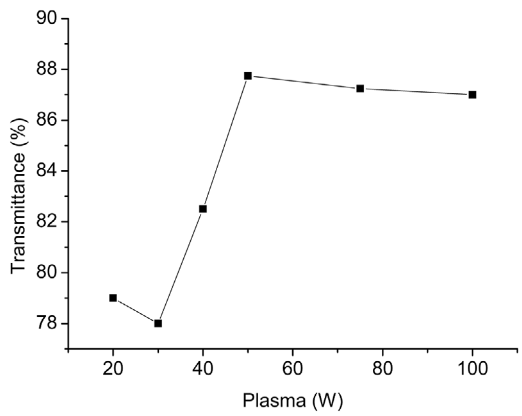

Fig. 3. Transmittance (%) of ITO thin films (300 nm) at different plasma power.

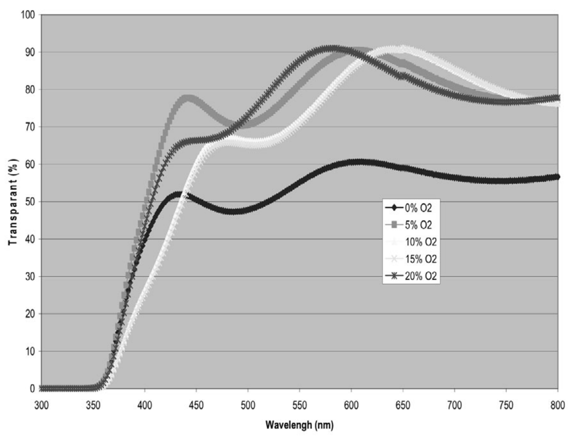

Fig. 4. Transmission spectra of ITO thin films (300 nm) at different volume percent of oxygen.

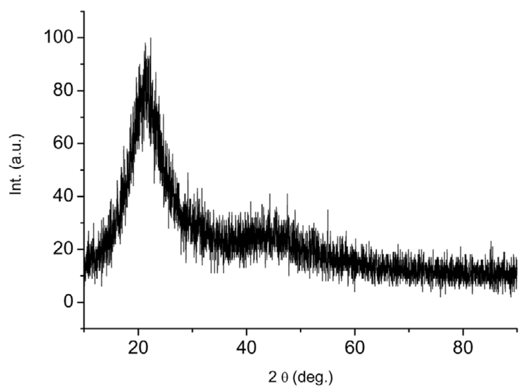

Fig. 5. XRD data of ITO thin films.

oxygen. The result can be explained that, when the volume percent of oxygen is low 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. 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. Conclusions

Indium tin oxide (ITO) films are deposited on CR39 substrate using DC magnetron sputtering. ITO thin films are deposited at room temperature without heating the substrate because glass temperature of CR39 substrate was 130°C. 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 9.83×10^{-4} Ω cm was measured at thickness of 300 nm without post annealing process. All ITO thin films fabrication process did not exceed 80°C. Fabricated ITO thin films can be used as bottom and top electrodes and for organic thin film transparent transistor.

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