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Properties of IZTO Thin Films on Glass with Different Thickness of SiO_2 Buffer Layer

Jong-Chan Park, Seong-Jun Kang*, Yung-Sup Yoon†

Department of Electronic Engineering, Inha University, Incheon 402-751, Korea

**Department of Elcetrical and Semiconductor Engineering, Chonnam National University, Yeosu 550-749, Korea*

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ABSTRACT

The properties of the IZTO thin films on the glass were studied with a variation of the SiO_2 buffer layer thickness. SiO_2 buffer layers were deposited by plasma-enhanced chemical vapor deposition (PECVD) on the glass, and the In-Zn-Tin-Oxide (IZTO) thin films were deposited on the buffer layer by RF magnetron sputtering. All the IZTO thin films with the SiO_2 buffer layer are shown to be amorphous. Optimum SiO_2 buffer layer thickness was obtained through analyzing the structural, morphological, electrical, and optical properties of the IZTO thin films. As a result, the IZTO surface roughness is 0.273 nm with a sheet resistance of 25.32 Ω/sq and the average transmittance is 82.51% in the visible region, at a SiO_2 buffer layer thickness of 40 nm. The result indicates that the uniformity of surface and the properties of the IZTO thin film on the glass were improved by employing the SiO_2 buffer layer and the IZTO thin film can be applied well to the transparent conductive oxide for display devices.

Key words : IZTO, Transparent conductive oxide, SiO_2 buffer layer, Thin film

1. Introduction

Indium-tin-oxide (ITO) has an excellent electro-optical property as a transparent conductive oxide (TCO), and thus, has been successfully applied into display devices such as OLED (organic light-emitting diodes) and LCD (liquid-crystal displays).[1)] However, ITO has a tendency to crystallize during thin film deposition process, and to result in a less-satisfactory surface roughness.[2)] This rough surface deteriorates adhesiveness and depositing rate during thin film deposition. This leads to a limitation in applying the material to the hetero-structures of various bonded thin films, which is quite common in most display devices.[3,4)] To deal with this problem, an anti-crystallization element such as zinc is added into ITO, forming IZTO (indium-zinc-tin oxide) thin film. IZTO has high work function, high electric conductivity, and excellent transmittance, and becomes a highly-promising candidate for a new TCO of display device.[1,4)]

Considerable studies have been carried out on electro-optical properties of ITO thin films in terms of process method. However, only a few studies on IZTO as a transparent electrode are currently available. Note that study on the buffer-layered IZTO thin film is even rare in spite of the facts that the method can protect the thin film from contamination of humidity and gases during thin film deposition process, and can improve the surface roughness.[3)]

This study is involved in the formation of SiO_2 buffer layer on a glass substrate prior to the deposition of IZTO thin film. By adopting this process, we expect that the barrier blocks the infiltration of impurities, and property degradation during the deposition process can be prevented, and surface roughness can be also improved. We, thus, investigated the effects of buffer layer thickness on electro-optical properties of IZTO thin films.

2. Experimental Procedure

2.1 Preparation of substrate

Glass substrate (630 um, Corning Eagle^{2000}), size of 1 inch x 1 inch, was sonicated in a solution of acetone, alcohol, and de-ionized water, and dried in nitrogen gas.

2.2 Deposition of SiO_2 buffer layer

We deposited the SiO_2 buffer on a glass substrate in thickness of 10 ~ 50 nm by using plasma enhanced chemical vapor deposition (PECVD) under the condition shown in Table 1.

Table 1. Process Conditions of the PECVD

Working pressure	800 mTorr
Working temperature	Room temperature
RF power	40 W
N density	20 sccm
N_2O density	200 sccm
SiH_4 density	600 sccm

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†Corresponding author : Yung-Sup Yoon
E-mail : ysyoon@inha.ac.kr
Tel : +82-32-860-7437 Fax : +82-32-868-3654

2.3 Deposition of IZTO thin film

We deposited the IZTO thin film by using RF magnetron sputtering with a 2 inch-diameter sintered IZTO (In_2O_3; 90 wt.%, ZnO; 5 wt.%, SnO_2; 5 wt.%) as the target under the conditions shown in Table 2.

2.4 Measurement

We evaluated structural property of the IZTO thin film in terms of buffer layer thickness by X-ray diffraction analysis (HR-XRD, Xpert-Pro MRD). We also observed its surface morphology by atomic force microscopy (AFM, SII Nano Technology, SPA400). We measured sheet resistance via the 4-point-prove setup, and optical property within the wavelength range of 300 ~ 800 nm by UV-Vis Spectrometer (Varian, Cary-500). Based on the results, we calculated figure of merit (FoM) for transparent electrode designed by Haacke.

3. Results and Discussion

Figure 1 represents XRD patterns of the IZTO thin films deposited on the SiO_2 buffer layers with thickness of 10 ~ 50 nm. There are only halo patterns at 32° coming from indium structure are observed, which indicate all the IZTO thin films have amorphous structure.

Figure 2 represents AFM images of IZTO/SiO_2/Glass films. As reported previously, the main roles of SiO_2 buffer are as a protective barrier blocking contaminants from both surfaces prior to the IZTO deposition, and improving surface roughness of the deposited IZTO.[3,4] When a thin film becomes porous due to pin holes formed by chemical reactions during deposition, the following deposition will be affected accordingly since films are deposited preferentially at the dented parts of pin holes. Therefore, reducing pin hole is highly desirable to improve the overall property of device.[4,5]

Table 2. Process Conditions of the RF Magnetron Sputtering

Base pressure	4.5×10^{-6} Pa
Active gas (Ar) density	20 sccm
Working pressure	3 mTorr
Working temperature	Room temperature
RF power	50 W
Deposited time	10 min.
Deposited IZTO thickness	160 nm

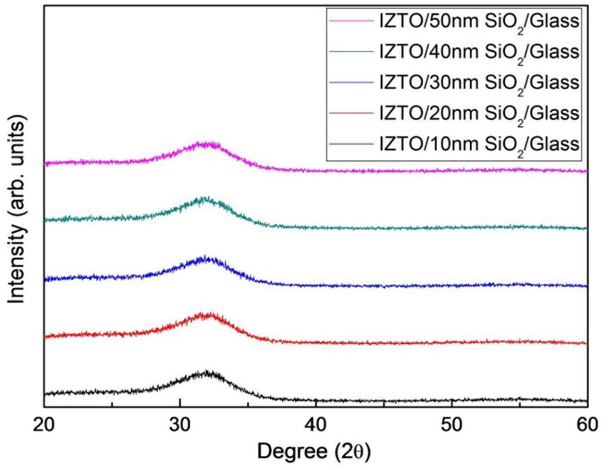

Fig. 1. X-ray diffraction patterns of IZTO/SiO_2/glass with various thickness of the SiO_2 buffer layer.

In addition, electrical property of the IZTO thin film is closely affected by surface roughness. The substitution between zinc and tin atoms generates carriers, and this process occurs mainly at the peak points on IZTO surface.[5] When the SiO_2 buffer layer was 40 nm thick, a relatively small number of pin holes and a rather large number of sharp peaks were observed on the surface. Therefore, the sample with 40 nm thick buffer layer is expected to show a superior electrical property.

Table 3 is a summary of surface roughness of IZTO thin films, expressed in RMS (root mean square) values with various thickness of SiO_2 buffer layer. The roughness was lowest at 0.158 nm with a buffer layer of 10 nm thick. As the

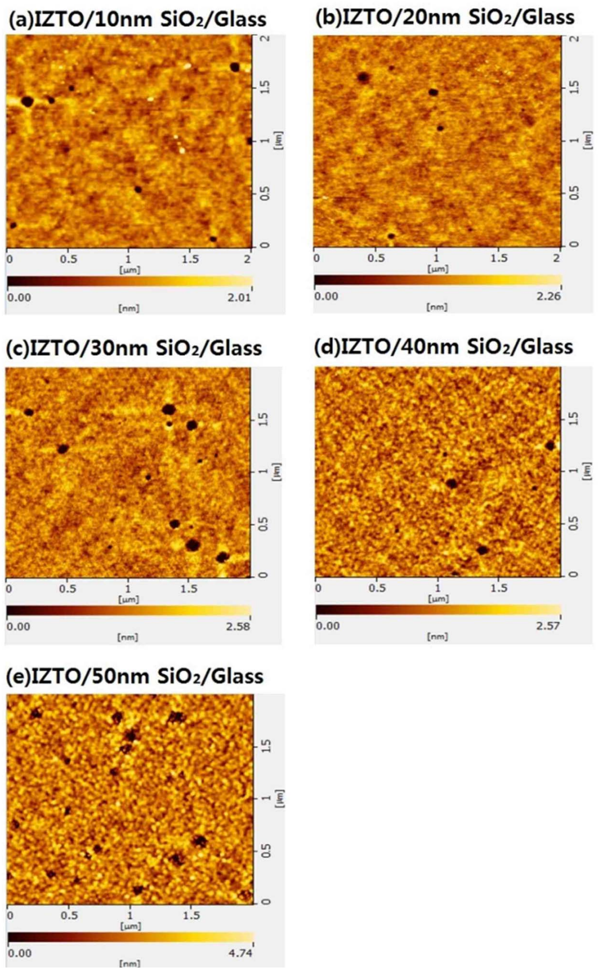

Fig. 2. AFM images of IZTO/SiO_2/glass with various thickness of the SiO_2 buffer layer.

Table 3. Average Surface Roughness of IZTO/SiO_2/Glass with Various Thickness of the SiO_2 Buffer Layer

Thickness (nm)	10	20	30	40	50
R_{rms} (nm)	0.158	0.169	0.242	0.273	0.533

buffer layer thickness increases, surface roughness increased up to 0.533 nm. With the increase in buffer thickness, the stress on the substrate decreases, and the IZTO films are deposited irregularly, resulting in increased surface roughness.[5] It seems that, at the buffer thickness of 50 nm, surface roughness further increased due to the presence of many pin holes.

It is reported that, without the buffer layer, surface roughness (R_{rms}) was as high as 0.5 nm.[6] It is confirmed that the surfaces of TCOs with buffer layers are generally more uniform than that of without it.

Figure 3 shows sheet resistances of IZTO thin films as a function of the buffer layer thickness. As shown in AFM images of Fig. 2, sharp peaks on the surface were most numerous at buffer thickness of 40 or 50 nm. However, considering the presence of many pin holes on IZTO thin film at the later case, we expect that the former case of 40 nm could result in the highest electric conductivity. And, as expected, the 40 nm-buffered sample showed the lowest resistance of 25.32 Ω/sq, owing to high carrier concentrations created by substitutions of zinc for tin around the peaks on the surface.

Figure 4 shows the transmittance of the IZTO/SiO_2/Glass films with different SiO_2 buffer layer thickness. The result shows that there is no noticeable change with different SiO_2 thickness, suggesting only the IZTO thickness and the process condition decide the transmittance pattern.

Figure 5 shows the figure of merit (FOM) and average transmittance in the visible range of 380 ~ 780 nm for the IZTO/SiO_2/Glass in relation to the SiO_2 buffer layer thickness. As already expected from Fig. 4, the average transmittance is almost independent of buffer layer thickness. Using both average transmittance and sheet resistance values from Fig. 3, the figure of merit (FOM) proposed by Haacke for transparent electrode is calculated by Eq. (1):[7]

$$\Phi_{TC}=T^{10}/R_{sheet} \tag{1}$$

In Eq. (1), T is average transmittance and R_{sheet} is sheet resistance. Since the average transmittances are all in the range of 82 ~ 84%, sheet resistance is the dominating factor in determining the FOM. As shown in Fig. 5, the FOM is highest at SiO_2 buffer layer of 40 nm with the value of $5.78 \times 10^{-3}\,\Omega^{-1}$.

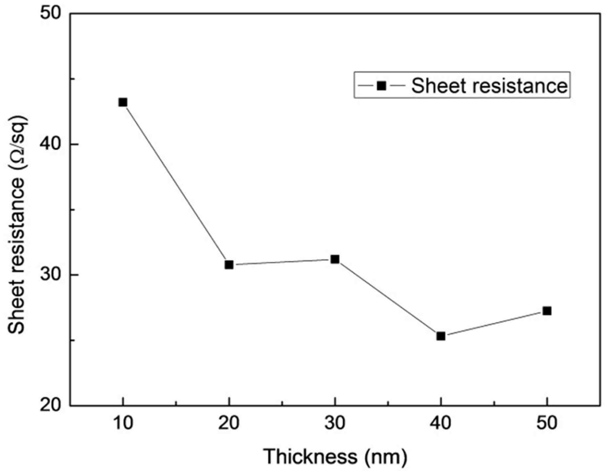

Fig. 3. Sheet resistance of the IZTO thin film with various thickness of the SiO_2 buffer layer.

4. Conclusions

In this study, SiO_2 buffer layers with different thickness were applied into IZTO thin films to enhance its electro-optical properties and surface roughness. We confirmed that all IZTO thin films with a SiO_2 buffer layer developed into an amorphous phase, which is necessary as a transparent conductive oxide (TCO). We confirmed that the surface

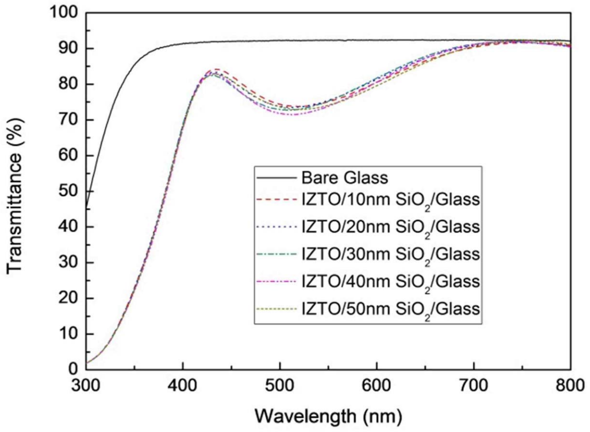

Fig. 4. Transmittance of IZTO/SiO_2/Glass with various thickness of SiO_2 buffer layer.

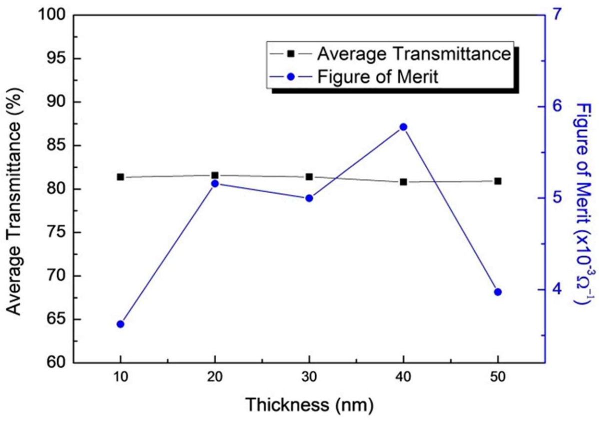

Fig. 5. Average transmittance & figure of merits of IZTO/SiO_2/glass with various thickness of SiO_2 buffer layer.

roughness of IZTO is less than 0.5 nm which is very low. They showed high average transmittances of 82-84% in the visible region.

The optimally-prepared IZTO sample at the SiO_2 buffer layer thickness of 40 nm showed the sheet resistance of 25.32 Ω/sq. and the figure of merit (FOM) of $5.78 \times 10^{-3}\ \Omega^{-1}$. The result indicates that, by employing the SiO_2 buffer layer of 40 nm, the IZTO thin film on a glass can be well suited to the transparent conductive oxide for display devices.

Acknowledgments

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