Mol. Cryst. Liq. Cryst., Vol. 532: pp. 91/[507]–97/[513], 2010

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2010.497036

The Characteristics of IZTO Thin Films Prepared by FTS with a Hetero-Target at Various Substrate Temperatures

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Indium zinc tin oxide (IZTO) thin films were prepared by a facing targets sputtering (FTS) system under various substrate temperature conditions, from R.T to 300°C. The dependence of their electrical, optical and structural properties on the substrate temperature was investigated by a Hall Effect measurement system, a UV/VIS spectrometer, an X-ray diffractometer (XRD) and an atomic force microscope (AFM). The X-ray diffraction measurements showed that amorphous IZTO films were formed regardless of substrate temperatures. The lowest value of the resistivity was 4.18×10^{-4} *[*$\Omega \cdot cm$*] at a substrate temperature of 100°C. All the IZTO thin films deposited showed an average transmittance of over 80% in the visible range.*

Keywords FTS; IZTO; substrate temperature

Introduction

Transparent conducting oxides (TCOs) have been used as coatings in a variety of applications which include flat panel displays (liquid crystal display, plasma display panel and organic light emitting diodes), solar cells, thin film resistors, gas sensors and photovoltaic devices owing to their high electrical conductivity, and high visible transmittance in the visible range [1]. Among the TCO materials, tin-doped indium oxide (ITO) is an outstanding TCO material for these applications because of its good electrical ($<10^{-4}\,\Omega \cdot cm$) and optical (>85%) properties.

However, it is widely known that because of the rarity of the indium element used in ITO, the cost of this material is comparatively expensive. Exposure in a hydrogen plasma also results in the degradation of the electrical and optical properties of ITO [2,3].

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In order to obtain high-quality ITO films, it has been found that they should be deposited at temperatures higher than 200°C and then annealed at a temperature higher than 300°C for it to have a high electrical conductivity and a high transmittance [4]. This annealing treatment makes the surface of ITO films to be rough due to crystallization leading to a significant deterioration of the device reliability [4,5]. For this reason in recent years, there have been many efforts to replace ITO films by amorphous IZTO (a-IZTO) films [6]. These amorphous IZTO films have been reported to not only have a continuous amorphous structure but also good electrical properties at high deposit temperatures. It is known that they have a smaller compressive stress and much smoother surfaces than the polycrystalline ITO films deposited under similar deposition conditions (e.g., oxygen gas flow, temperature and working pressure) [7,8].

There are several deposition techniques used to deposit these materials, namely sputtering, spray pyrolysis, metal organic chemical vapor deposition, laser deposition, and sol–gel deposition. The sputtering method takes advantage of a relatively high deposition rate and a high uniformity so that this method has been used in large-area and high quality depositions.

In this study, the IZTO films were deposited with a facing targets sputtering (FTS) system at various temperatures. The electrical, optimal and structural properties of the as-deposited thin films were then investigated.

The Experiment

The indium zinc tin oxide (IZTO) films were deposited on a glass substrate (Corning 2948) by facing targets sputtering (FTS) using two ceramic 2 inch ITO (90 wt.% In_2O_3, 10 wt.% SnO_2) and 2 inch IZO (90 wt.% In_2O_3, 10 wt.% ZnO) targets. The FTS equipment is shown in Figure 1 [9]. The FTS equipment system was designed to array two targets that face each other and forms a high-density plasma between the targets. It was well known that this system has many advantages, such as a low working pressure, a low substrate temperature, low damages, and a high plasma density. It protects the substrate and the as-deposited thin films from the bombardment of high energy particles during the sputtering processes. Before the

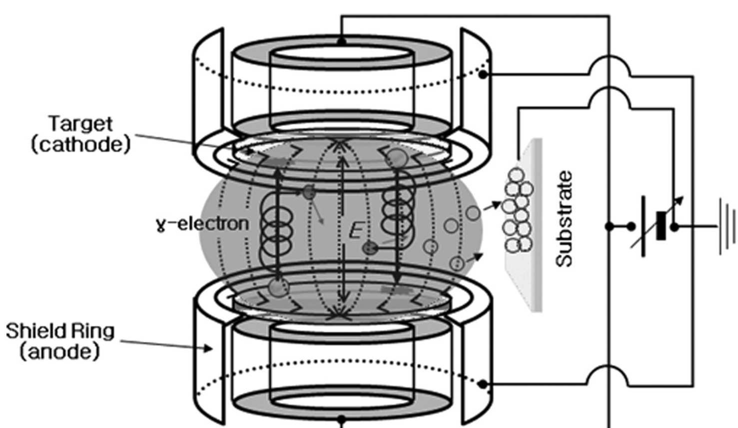

Figure 1. Facing targets sputtering system apparatus.

substrate was introduced into the chamber, it was cleaned with detergents and cleaned ultrasonically using D.I. water and isopropyl alcohol (IPA) for 15 minutes for each step and blown dry with N_2 gas.

The chamber was initially evacuated to 2.0×10^{-3} Pa using a turbo-molecular pump. Before the deposition of the thin films, a pre-sputtering in a pure argon atmosphere for 5 minutes was carried out in order to remove the natural surface oxide layer of the targets. The working gas is an oxygen and argon mixture. The Ar gas flow rate was fixed at 10 sccm and the O_2 gas flow rate at 0.4 sccm. When depositing the IZTO films, the substrate temperature was changed from R.T to 300°C. The working pressure was maintained at 0.1 Pa. The thickness of the ITO and IZO films was fixed at 100 nm.

The Measurements

The thickness of the IZTO films was measured by using a surface profiler system (Alpha-step, Tencor). The electrical properties (e.g., resistivity, carrier concentration, and Hall-mobility) were measured using a Hall measurement system (HMS-3000, Ecopia). The structural characterization was done using X-ray diffraction measurements with Cu-Kα radiation (RINT 2000 series, Rigaku). The optical transmittance spectra were measured using an UV-VIS spectrophotometer (HP8453, Hewlett-Packard) with the wavelengths ranging from 200 to 900 nm. The surface morphology of the films was measured by scanning probe microscopy (XE-150, PSIA).

The Results and Discussions

Figure 2(a) shows the behavior of the IZTO film's resistivity with the substrate temperature increased from R.T. to 300°C. The resistivity value of the films decreased slowly as the deposition temperature increased up to 150°C. When the IZTO thin film was prepared at a substrate temperature of 150°C, it showed the lowest resistivity value of 4.18×10^{-4} [$\Omega \cdot$cm]. On the other hand, when the substrate temperature was above 150°C, the resistivity value of the IZTO thin films increased. Figures 2(b) and (c) show the variation of the carrier concentration and the mobility of the samples that were investigated by the Hall Effect measurements. The carrier concentration of the films increases up to a substrate temperature of 100°C, while it decreases over 200°C. The Hall mobility of the films increases slightly up to 300°C. The decrease of the resistivity value was achieved by increasing either the carrier concentration or the carrier mobility of the IZTO films deposited at a substrate temperature of 150°C [10]. It seemed that the Zn^{2+} ions could obtain sufficient activation energy to occupy the In^{3+} sites at the high temperature, and these p-type dopant Zn^{2+} ions provide holes in the films, which results in the decrease of the free electron density and an increase of the electron scattering events with the holes supplied at the high deposition temperature [11]. The decrease of the free electron density and the increase of the electron scattering events were reported to not only increase the Hall mobility but also lower the resistivity value at high deposit temperatures [12,13].

Figure 3 shows the optical transmittance of the IZTO films deposited on glass at different substrate temperatures. When the substrate temperature increased, the transmittance of the films in the visible range increased. The optical absorption edge shifts slightly toward the short wavelength region as the substrate temperatures

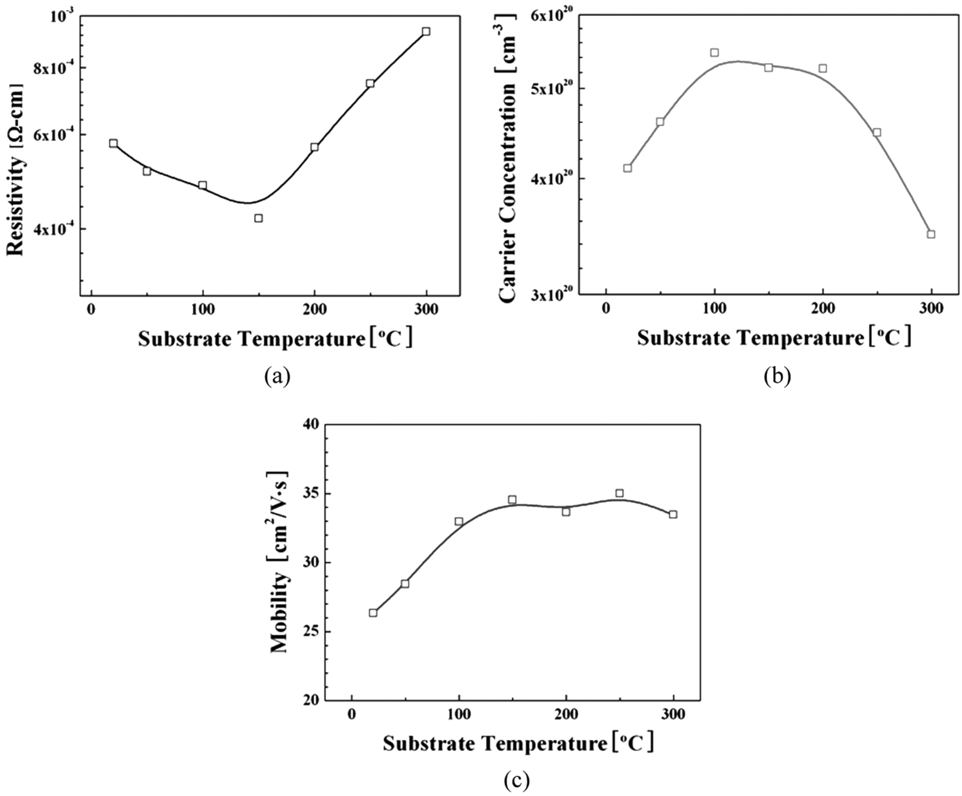

Figure 2. Electrical properties of IZTO films prepared as function of substrate temperature; (a) resistivity, (b) carrier concentration, and (c) mobility.

increased, as shown in Figure 3. It seemed that the optical band gap increased with the carrier concentration or with oxygen vacancies [14].

Figure 4 shows the X-ray diffractometer (XRD) patterns of the IZO thin film as a function of substrate temperature. All of the prepared IZO thin films showed a

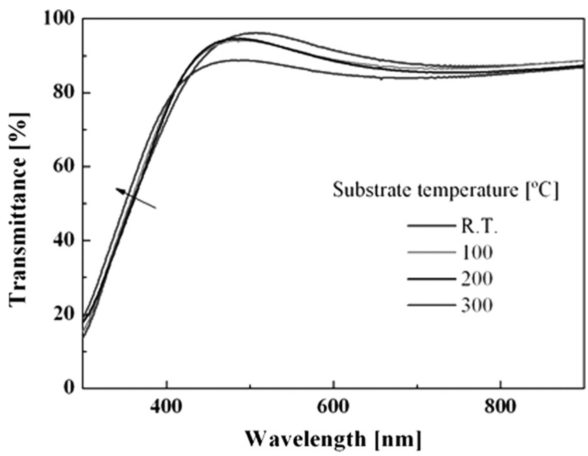

Figure 3. Transmittance of IZTO films prepared as function of substrate temperature.

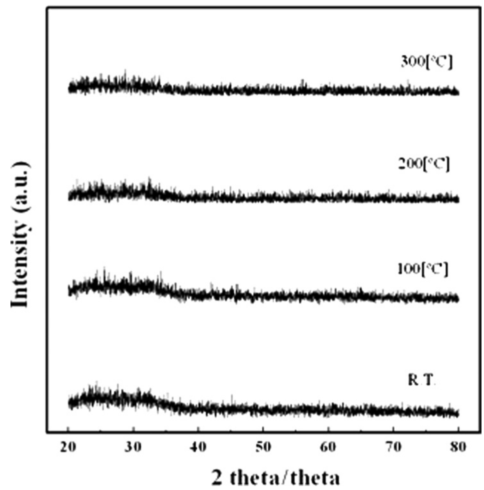

Figure 4. X-ray diffraction patterns of IZTO films prepared as function of oxygen substrate temperature.

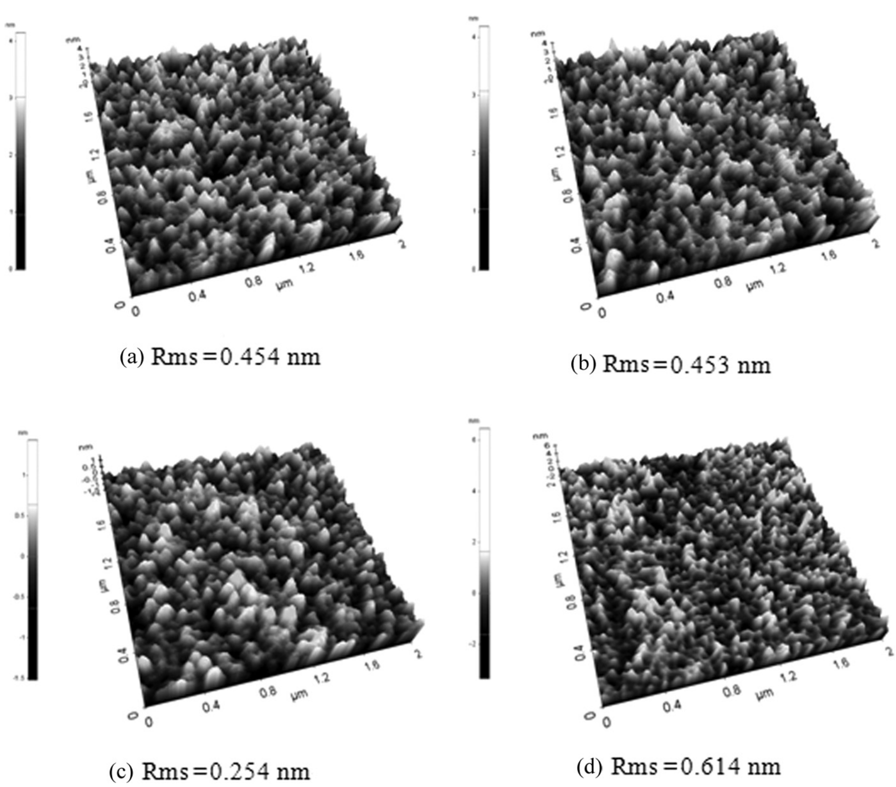

Figure 5. AFM images of IZTO thin films deposited at various substrate temperature; (a) R.T., (b) 100°C, (c) 200°C, and (d) 300°C.

broad pattern without a clear peak until the substrate temperature increased to 250°C. It was reported that Zn^{2+} is the reason for the decreased crystalline attribute in the In_2O_3 [15].

Figure 5 shows the AFM images of the films taken over a range of substrate temperatures. The AFM images were scanned for an area of $2 \times 2\,\mu m^2$. The three dimensional plane views were observed for the IZTO films that were deposited using different substrate temperatures. The RMS values calculated from these images are given in Figure 5. The lowest roughness value is 0.254 nm at a substrate temperature of 100°C. Conventional ITO films have a 2 nm surface roughness [16]. But, as stated, the OLED anode needs to be below a 1 nm surface roughness. In Figure 7, the RMS values of the IZO thin films were less than the required 1 nm surface roughness, regardless of the substrate temperature.

Conclusion

We prepared the IZTO thin films on glass substrates at various substrate temperatures using the FTS system. The as-deposited films deposited on the glass did not show any crystalline peaks, regardless of the substrate temperature. All the IZTO thin films have an average transmittance of 85% in the visible range (400–800 nm). The mobility value of the IZTO thin films increased at substrate temperatures from R.T. to 300°C, the highest value of the mobility was 35.01 [$cm^2/V \cdot s$] at the substrate temperature of 250°C. The highest value of the carrier concentration was 5.46×10^{20} [cm^{-3}]. The resistivity value of IZTO thin films decreased at the substrate temperatures from R.T. to 150°C; the lowest value of the resistivity was 4.18×10^{-4} [$\Omega \cdot cm$] at 150°C. When the substrate temperatures increased above 150°C, the resistivity value of the IZTO thin films increased. In addition, the lowest RMS value was 0.254 nm at a substrate temperature of 100°C. A surface roughness greater than 1 nm is detrimental to an OLED anode.

We have obtained IZTO thin films with a high transmittance, a high mobility value, and a smooth surface at various substrate temperatures by using FTS. In addition, we have prepared IZTO thin films with a low resistivity value. It seems that the as-deposited IZTO thin films prepared by FTS system have a potential use for the anode in OLED applications.

Acknowledgments

This work was supported by Energy Resource R&D program (20094010100060) under the ministry of knowledge economy, republic of korea, and supported by the Kyungwon University Research Fund in 2009.

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