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Properties of Transparent Conducting ATO Films Deposited by RF Magnetron Sputtering

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We have discussed the effects of substrate temperature and Sb_2O_3 composition on properties of ATO thin films by RF magnetron sputtering. Above 250°C of substrate temperature, the films exhibited good crystallographic and electrical properties. At fixed substrate temperature of 250°C, the electrical properties of ATO film were enhanced with increasing Sb concentration. From the AES depth profile and XRD pattern for the film with 92:8 of SnO_2:Sb_2O_3 composition, we found that Sb was uniform and there was no secondary phase or phase separation in ATO film. The rms roughness of the films was minimum value, 1.54 nm, at the composition of 92:8 wt%. For the ATO thin film with 92:8 composition exhibited good chemical endurance and thermal stability, which seems to be good for touch panel applications.

Keywords ATO; optical transmittance; sheet resistance; sputtering; TCO; touch panel

Introduction

Transparent conductive oxides (TCOs) have been extensively studied because they are one of the most important components for large area electronics devices such as solar cells, flat panel displays, optical sensors or touch screens [1,2]. In recent years, there is much interest in the touch panel applications like mobile phone, PDA, ATM and internet appliance and so on. Indium oxide doped with tin (In_2O_3:Sn, ITO) is known for a most typical material for a transparent electrode. However, its resistivity is too low to use for touch panel with high positional resolution [3]. The rare and expensive indium in ITO is also blocking the use of ITO. So it is necessary to find the substitute of ITO and Antimony tin oxide (ATO) is an

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excellent candidate. ATO is a promising TCO material for touch screen panel because of its high thermal stability and chemical durability [4,5].

In this work, we reported on the crystallographic and electrical properties of ATO films on glass substrate with different substrate temperatures and SnO_2: Sb_2O_3 compositions.

Experimental

Antimony tin oxide (ATO) thin films were deposited by RF (13.56 MHz) magnetron sputtering system under high vacuum conditions with a base pressure of $\sim 5 \times 10^{-6}$ Torr. High-purity ATO sputtering targets (4 N) were used as source materials. Glass with 0.7 mm of thickness was prepared as substrate prior to the deposition of ATO layer. The glass was cleaned with a standard cleaning procedure (TCE-Acetone-Methanol) and rinsed with deionized water.

In order to investigate the effects of substrate temperature and antimony concentration on properties of ATO films, We prepared two sets of ATO films by RFmagnetron sputtering with substrate temperature (T_S) in the range of RT $\sim$450°C and Sb_2O_3 composition of ATO films in the range of 2$\sim$8 wt%. To enhance the uniformity of the deposited film, the substrate was rotated at 15 rpm. The total thickness of the ATO films measured by surface profiler was in the range of 120–130 nm.

Measurements

The surface morphology and crystallinity of the films were investigated by field emission scanning electron microscopy (FESEM) and x-ray diffraction (XRD) measurement using Ni-filtered CuK_α source, respectively. The van der Pauw Hall measurement was performed by applying a magnetic field up to 0.5 T at room temperature in order to investigate the electrical properties of the ATO films. To investigate depth profile of ATO film, Auger electron microscope (AES) was used. The roughness of the surface was observed using atomic force microscope (AFM). To evaluate thermal stability, we put the ATO film in electric furnace which was maintained at 400°C for 30 min. For testing chemical endurance, we made 10 wt% NaOH solution and dipped ATO film in the solution at 60°C for 5 min.

Results and Discussion

The crystallographic properties of ATO films deposited by RF magnetron sputtering at different temperature were investigated by XRD measurement, and the results are shown in Figure 1. The films deposited at room temperature and 150°C were not crystallized. Above 250°C of substrate temperature (T_S), the films mainly exhibited (110), (101), (200), (211) peaks of ATO films and amorphous peak of glass substrate, which means that the films have been crystallized more than 250°C of T_S. The intensity of the XRD peaks increased with increasing T_S due to crystallization and grain growth at higher deposition temperature. The surface morphology of the ATO films deposited at different temperature were studied by FE-SEM. In Figure 2, the ATO films deposited at low temperatures (R.T., 150°C) consisted of a lot of large aggregations not crystallized grains, whose size decreased with increasing T_S. At 250°C of T_S, the film seems to be crystallized and the grain size increased as the T_S increased in the range of 250°C$\sim$450°C, which is in good agreement with the XRD results. The

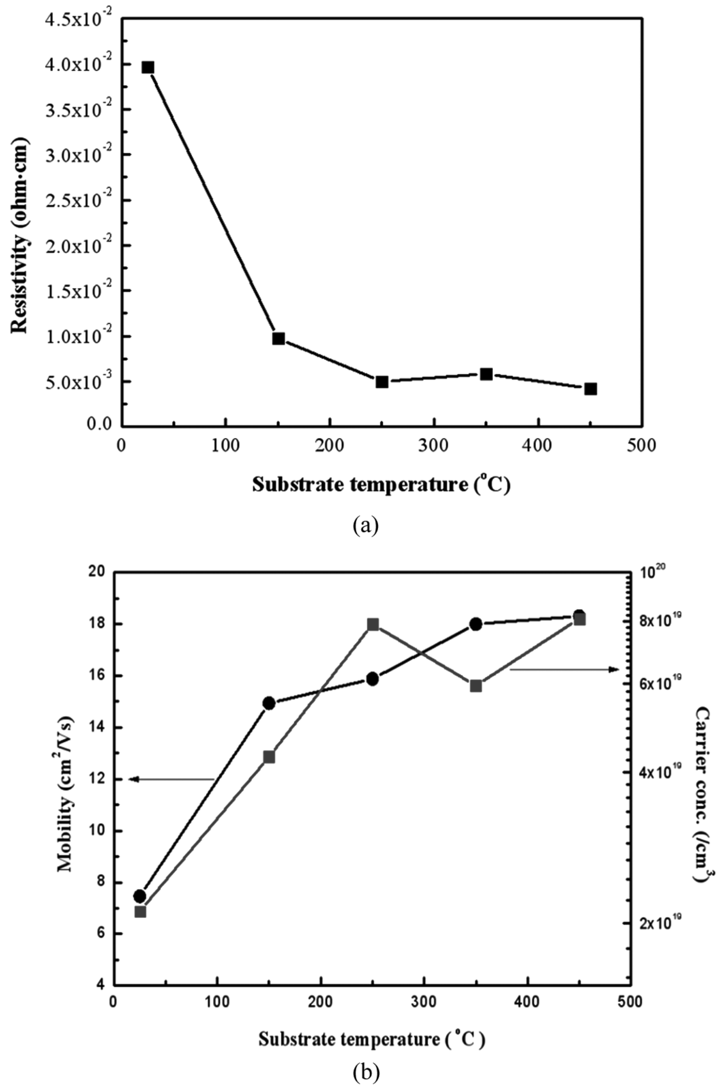

Figure 1. (a) Resistivity, and (b) electron concentration and mobility of ATO films deposited at different temperature.

Electrical behavior for the ATO films has been studied as a function of T_S. Figure 3(a) shows the resistivity of the films. The resistivity of the film decreased as the T_S increased and saturated above 250°C of T_S. In Figure 3(b), the electron concentration and mobility of the film were enhanced up to 250°C of T_S and saturated above the temperature. It is due to the crystallization of the ATO film at 250°C of deposition temperature.

From the results of the experiment we fixed T_S at 250°C and varied the composition of ATO target from SnO_2:$Sb_2O_3 = 98:2$ to 92:8 wt%. The dependence of antimony contents on the properties of ATO films was also investigated by AES, XRD, Hall measurement and AFM. Figure 4 shows the electron concentration

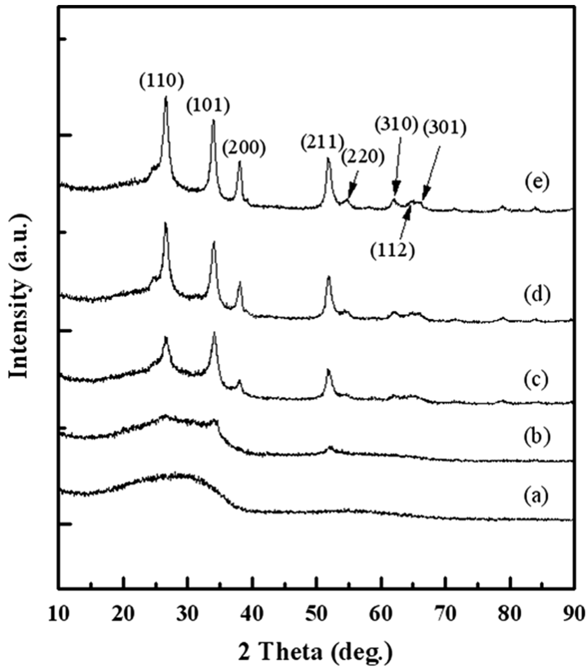

Figure 2. XRD patterns of ATO films deposited at different temperature; (a) R.T., (b) 150°C, (c) 250°C, (d) 350°C, and (e) 450°C.

and mobility of ATO films with different SnO_2:Sb_2O_3 composition. It is found that the electron concentration and mobility are enhanced with increasing the composition of Sb_2O_3. The enhancement of electrical properties of ATO film with increasing antimony concentration can be explained that some of the Sn^{4+} ions in the lattice are replaced by Sb^{5+}, resulting in the generation of conduction electrons [6–8]. At 92:8 of SnO_2:Sb_2O_3 composition, the film exhibited the best result in electrical properties; $6 \times 10^{-4}\ \Omega \cdot cm$ of resistivity, $2.7 \times 10^{21}/cm^3$ of electron concentration and $3.6\,cm^2/Vs$ of electron mobility. In Figure 5, the representative depth profiles of Sn, Sb, and Si are presented for the ATO film with 8 wt% of Sb_2O_3 composition, obtained by Auger electron spectroscopy (AES). The Sb profiles were found to be uniform for the films throughout the entire thickness with no appreciable segregation. For the ATO film with 8 wt% of Sb_2O_3, we performed XRD measurement and the result is shown in Figure 6. The film exhibit (110), (101), (200), (211) peaks of ATO film, indicating that single phase ATO films were deposited by RF magnetron sputtering without formation of any secondary phases. The inset in Figure 6 shows that the FWHM of the peaks has been broadened with increasing Sb concentration. It means that the difference between the radius of Sb^{5+} and Sn^{4+} causes strain in the film when Sb^{5+} substitutes Sn^{4+}, which makes the peaks broaden [9,10]. The surface morphology of the ATO films with different SnO_2:Sb_2O_3 composition was investigated by AFM and the results are shown in Figure 7. Figure 7 showed that the surface of ATO film is smoother with increasing sb concentration. The rms roughness varied from 1.54 nm to 3.58 nm according to the SnO_2:Sb_2O_3 composition. The ATO film with 92:8 of SnO_2:Sb_2O_3 composition

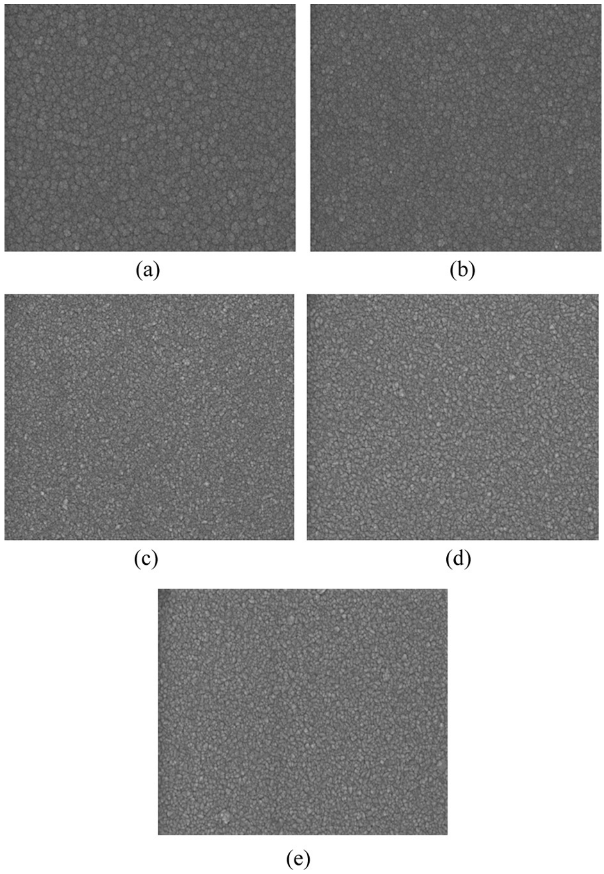

Figure 3. SEM images of ATO films deposited at different temperature; (a) R.T., (b) 150°C, (c) 250°C, (d) 350°C, and (e) 450°C.

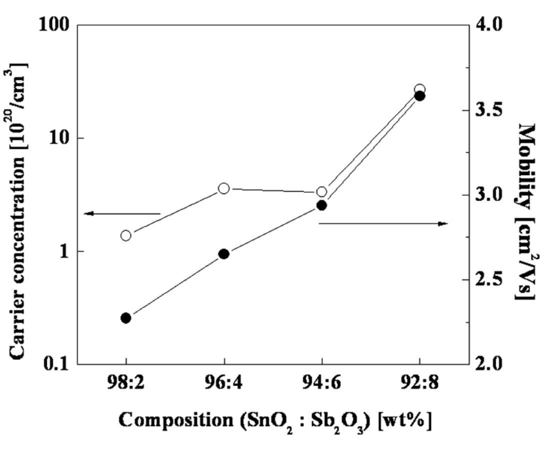

Figure 4. Electron concentration and mobility of ATO films with different SnO_2:Sb_2O_3 composition.

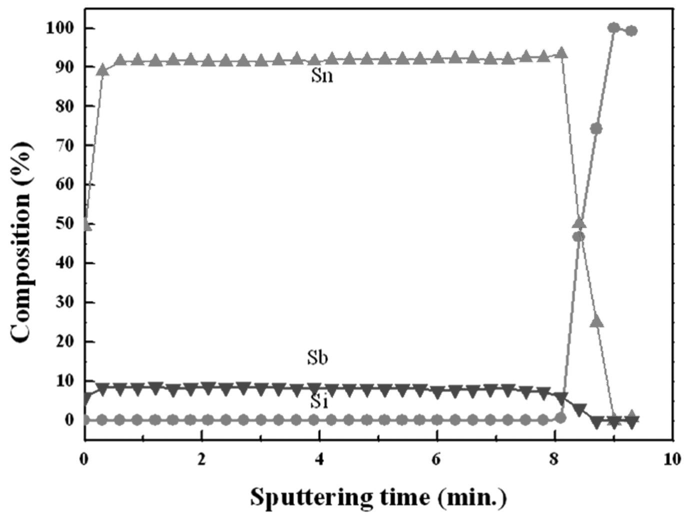

Figure 5. The depth profiles of Sn, Sb, and Si for the ATO film with 92:8 of SnO_2:Sb_2O_3 composition.

exhibited smooth surface with minimum rms value, 1.54 nm. For the film with 92:8 of SnO_2:Sb_2O_3 composition deposited at 250°C, chemical endurance and thermal stability test were performed in the 10 wt% NaOH solution and electric furnace at 400°C for 30 minutes, respectively. After chemical and heat treatment, the resistance change of the film was found to be 110% and 122%, respectively.

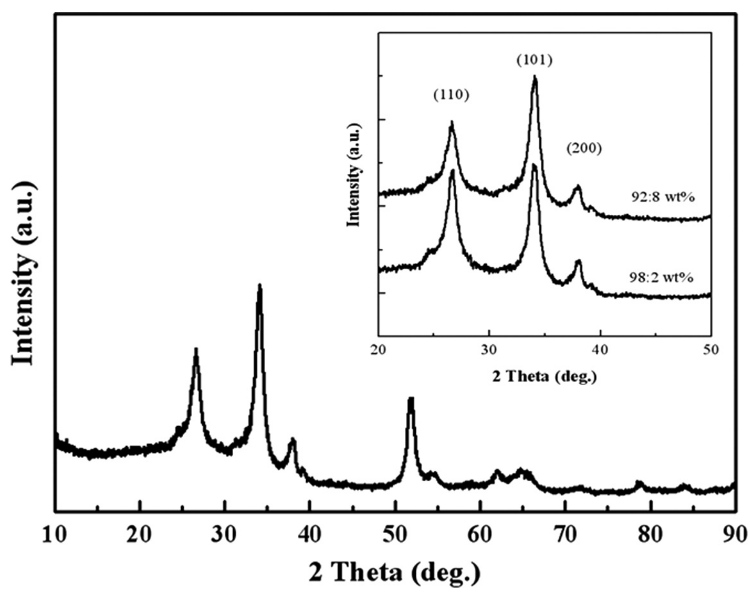

Figure 6. The XRD pattern of ATO film with 92:8 of SnO_2:Sb_2O_3 composition. The inset shows the comparison of FWHM for ATO films with 92:8 and 98:2 of SnO_2:Sb_2O_3 composition.

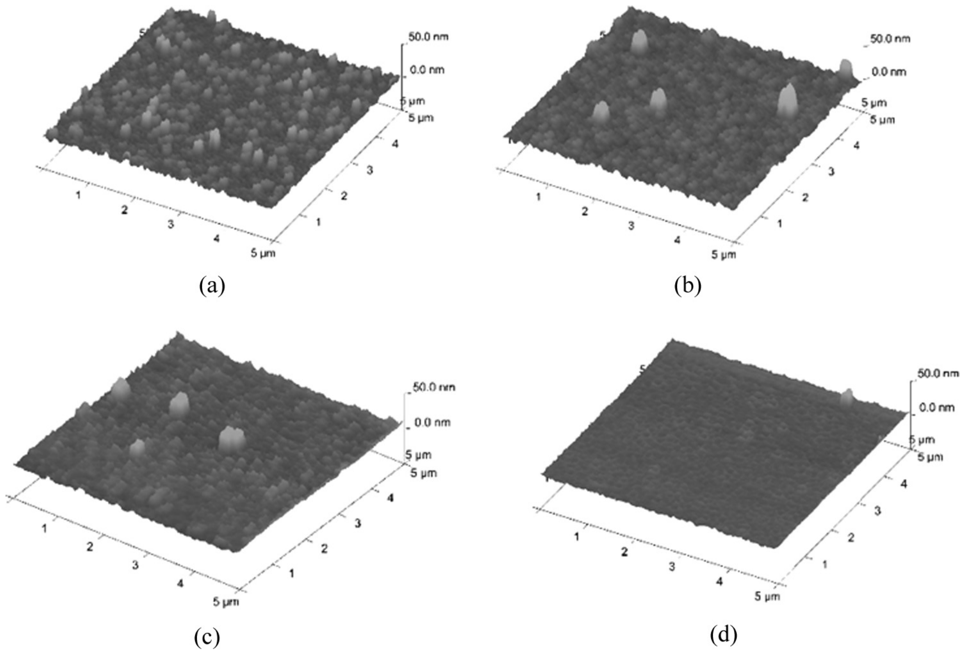

Figure 7. Typical AFM images of ATO films with different SnO_2:Sb_2O_3 composition, (a) 98:2, (b) 96:4, (c) 94:6, and (d) 92:8.

Conclusions

We have investigated the properties of ATO thin films for touch panel. First, We studied the effects of substrate temperature on properties of ATO films. Above 250°C of substrate temperature, the films exhibited good crystallographic and electrical properties. At 250°C of substrate temperature, the composition of ATO film was varied from SnO_2:Sb_2O_3 = 98:2 to 92:8 wt%. At the composition of 92:8 wt%, the film showed good electrical properties surface morphology without no secondary phases or phase separation. The film exhibit little change in resistance after chemical and thermal treatment.

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