Indium Tin Oxide(ITO) Thin Film Deposition on Polyethylene Terephthalate(PET) Using Ion Beam Assisted Deposition(IBAD)

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Abstract

Tin-doped indium oxide(ITO) thin films were deposited on polyethylene terephthalate(PET) at room temperature by oxygen ion beam assisted evaporator system and the effects of oxygen gas flow rate on the properties of room temperature ITO thin films were investigated. Plasma characteristics of the ion gun such as oxygen ions and atomic oxygen radicals as a function of oxygen flow rate were investigated using optical emission spectroscopy(OES). Faraday cup also used to measure oxygen ion density. The increase of oxygen flow rate to the ion gun generally increase the optical transmittance of the deposited ITO up to 6sccm of O_2 and the further increase of oxygen flow rate appears to saturate the optical transmittance. In the case of electrical property, the resistivity showed a minimum at 6 sccm of O_2 with the increase of oxygen flow rate. Therefore, the improved ITO properties at 6 sccm of O_2 appear to be more related to the incorporation of low energy oxygen radicals to deposited ITO film rather than the irradiation of high energy oxygen ions to the substrate. At an optimal deposition condition, ITO thin films deposited on PET substrates showed the resistivity of 6.6×10^{-4} Ω cm and optical transmittance of above 90%.

Introduction

Transparent conductive thin films have been studied by many research workers because of their wide industrial applications. Major applications of these thin films are optical transparent electrodes in display devices. To satisfy technical requirements of applications, many new materials and various manufacturing techniques have been developed.[1-3]

The most widely used material for transparent conductive thin film is tin-doped indium oxide(ITO). It has the lowest electrical resistivity($\sim10^{-4}$Ω cm) and the highest optical transparency(above 85% at 550nm). Due to these properties, ITO film is becoming increasingly important in the field of electronic devices.

Recently, there is a growing interest in applying organic substrates instead of widely used glass substrates for liquid crystal display devices. Especially, personal digital assistants(PDAs), hand held PCs(HPCs), or mobile phones are very important application fields. If the glass is substituted for organic substrate, then it could offer several advantages such as lighter, more robust, and thinner devices.

Lower temperature ITO thin films have been typically produced by dc(or rf)-sputtering [4-6] and vacuum/reactive evaporation[7-10]. Plasma assisted evaporations could be promising techniques for low temperature deposition. In particular, ion beam assisted electron beam evaporation(IBAE) technique offers advantages such as more flexibility in controlling film properties, room temperature coating on organic substrates without any post deposition treatment, and low production cost.

In this study, the electrical and optical properties of ITO thin film deposited on PET substrates at room temperature by oxygen ion beam assisted-electron beam evaporation method were investigated.

Experimental conditions

The deposition of tin-doped indium oxide was carried out by an oxygen ion gun attached electron beam evaporator system. Polyethylene terephthalate(PET) was used as a substrate. Evaporation source material was indium oxide 90wt.%-tin oxide 10wt.% and the purity was 4N. Two grid internal type of rf inductively coupled plasma source was used as the oxygen ion source. The two grid ion gun was positioned to have the incident beam angle of the ion gun close to the normal of the substrate. To enhance the plasma density of the source, an array of permanent magnets(~2000G) was attached at the bottom of the ion source.

Optical emission spectroscopy(OES) was used to observe the condition of plasma in the source chamber. OES enables a quick determination of the species contained in a plasma. The current density of the ion beam in the process region was measured using a Faraday cup located near the substrate holder. The surface composition of deposited ITO film was investigated using X-ray photoelectron spectroscopy. The pressure in the chamber during the deposition process was changed from 1×10^{-4} torr to 2.3×10^{-4} torr by varying the oxygen flow to the rf ion source from 3 sccm to 7 sccm as a discharge gas.

The thickness of ITO thin film was measured using a thin film thickness monitor during the deposition and was also measured using a step profilometer after the deposition. The thickness of the deposited ITO thin films was varied in the range from 800Å to 2500Å while maintaining the deposition rate was 0.6Å/sec. Other deposition conditions such as rf power to ion gun, bias voltage to the extraction grid, voltage to the acceleration grid, and the distance between ion gun and the substrate were also kept at 100W, -900V, 2.1kV, and 65cm, respectively. The sheet resistance of the deposited ITO was also measured using a four point probe. An UV-spectrophotometer was used to measure the optical transmittance of the film.

Results and Discussion

Figure 1 shows the variation of peak intensities of O_2^+ and O as a function of oxygen gas flow rate to the ion gun. The rf power to the ion gun was maintained at 100W. As shown in the figure, the increase of oxygen gas flow rate decreased the O_2^+ peak intensities, therefore, possibly decreased the O_2^+ ion densities in the ion gun. In the case of oxygen radicals, the increase of oxygen gas flow rate increased the density of oxygen radicals until 6sccm of oxygen gas was flown to the ion gun, however, the further increase of oxygen flow decreased the density of oxygen radicals.

To compare the oxygen ion density estimated from the optical emission peaks of O_2^+ in the ion gun, with the actual oxygen ion flux to the substrate, positive ion beam flux extracted through the ion gun grid was measured using a Faraday cup located near the

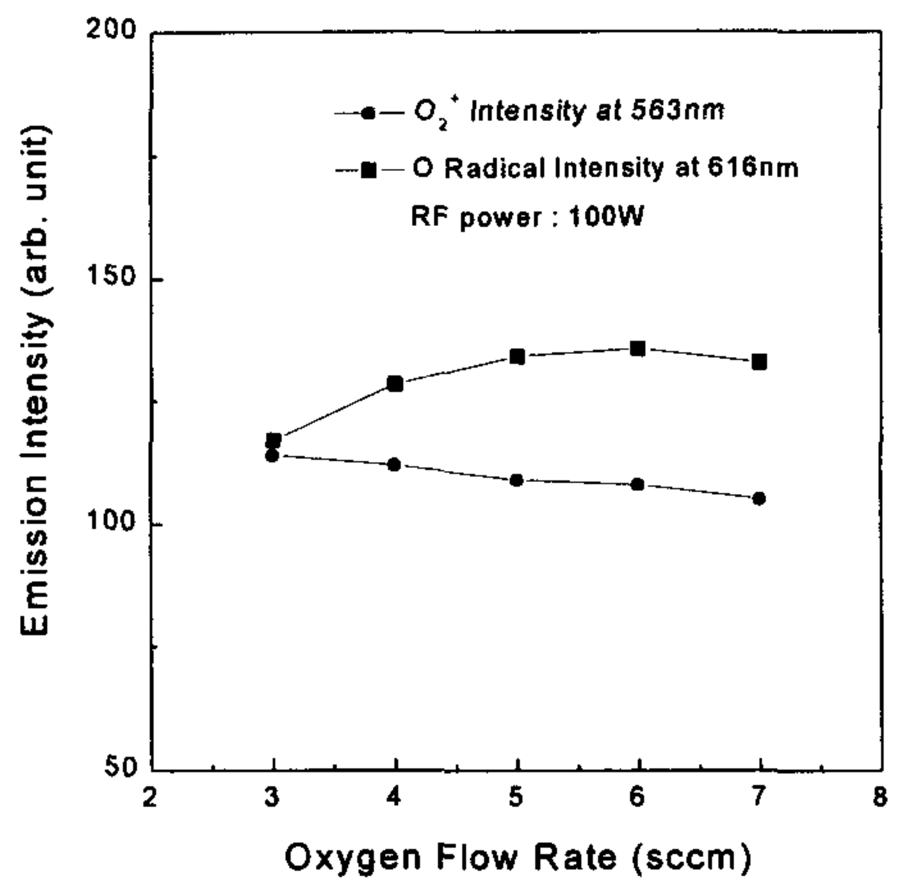

Fig. 1 Optical emission intensities of ionic molecular oxygen at 563nm and atomic oxygen radical at 616nm as a function of oxygen flow rate at 100W of rf power.

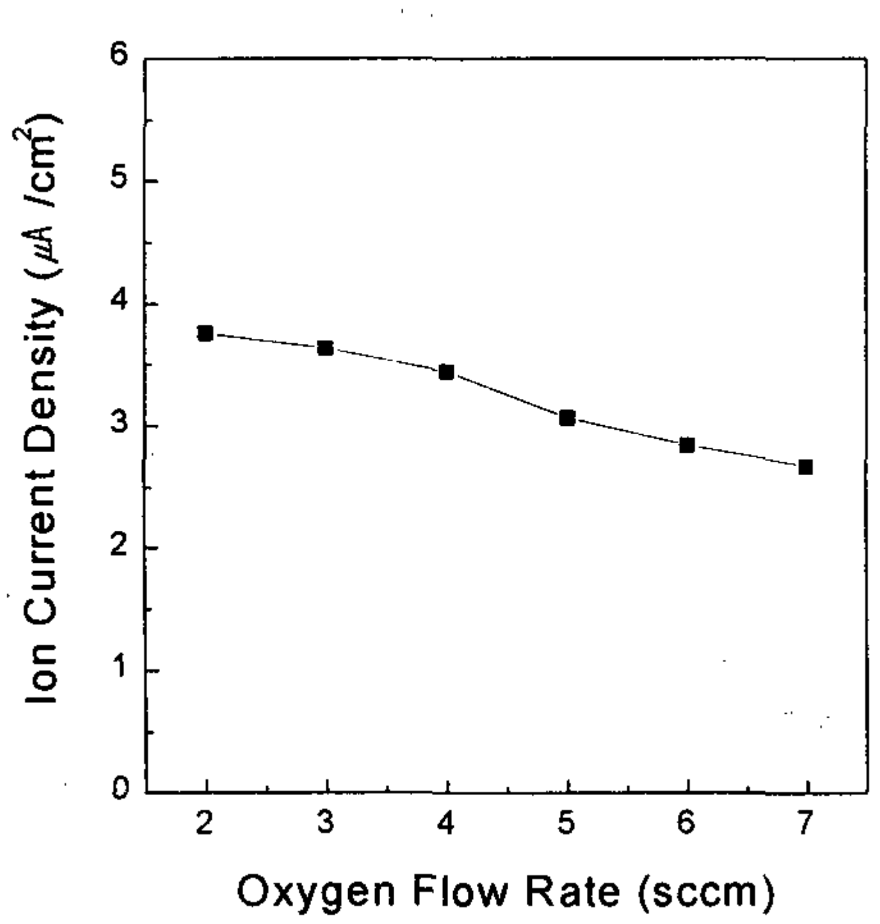

Fig. 2 Ion current density measured by a Faraday cup as a function of oxygen flow rate at 100W of rf power.

substrate holder at 100Watts of rf power, -900Volts of extraction voltage, and 2.1kVolts of acceleration voltage while varying the oxygen flow rate from 2 sccm to 7 sccm. The result is shown in Figure 2 and, as shown in the figure, the increase of oxygen flow rate to the ion gun decreased the flux of ions at the substrate similar to the data of oxygen ion density measured by OES.

ITO thin films were deposited on PET substrates at room temperature while varying the oxygen flow rate to the ion gun from 4sccm to 7sccm. Other deposition conditions such as rf power to the ion gun, acceleration voltage, extraction voltage, and the distance between the ion gun and the substrate were maintained at 100Watts, 2.1kVolts, -900Volts, and 65cm, respectively. The optical transmittance of the deposited ITO was investigated as a function of oxygen gas flow rate and the results are shown in Figure 3. As shown in the figure, the increase of oxygen gas flow increased the transmittance of the deposited ITO, however, the transmittance after 6 sccm of oxygen gas flow appeared to saturate. In general, the optical transmittance of ITO thin film increases with the

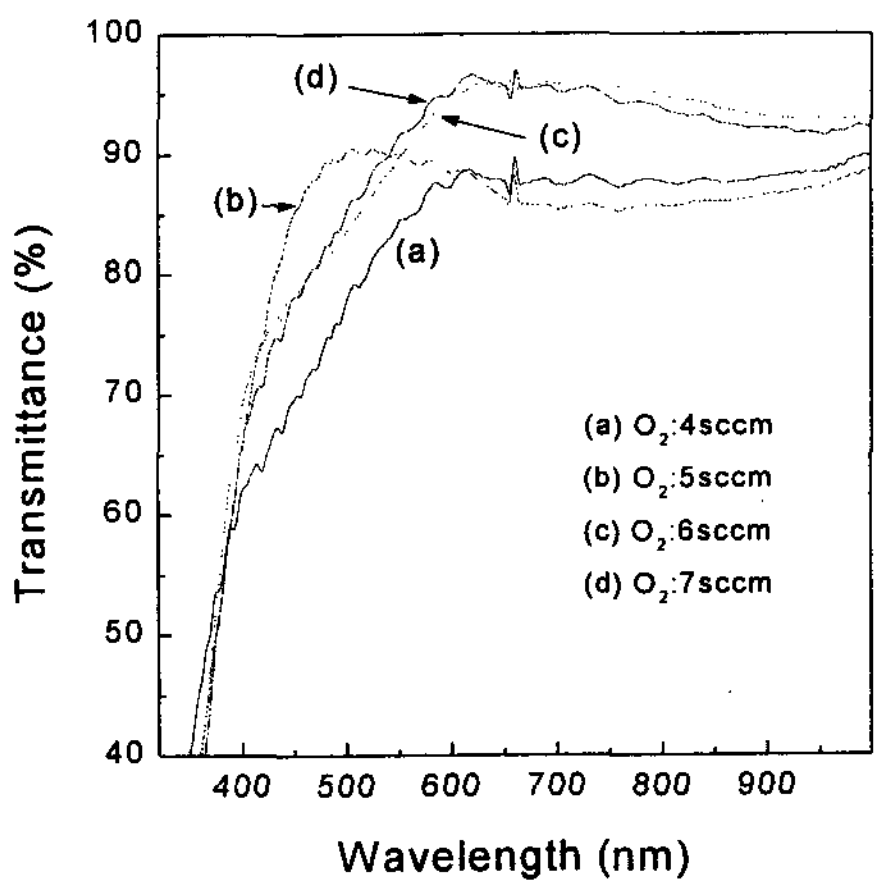

Fig. 3 Variation of the optical transmittance of ITO thin films as a function of oxygen flow rate.(rf power : 100W, Ve : -900V, Va : 2.1kV)

increase of oxygen incorporation into oxygen deficient ITO thin film. When the ITO thin films were deposited without the assistance of oxygen ion gun, metallic colored, therefore, oxygen excessively deficient ITO thin films were obtained and, by applying the oxygen ion gun, more transparent ITO thin films were obtained. When oxygen ion gun is applied to ITO deposition, not only the oxygen ion flux extracted from the ion gun but also the atomic oxygen radical dissociated from oxygen molecule in the ion gun can affect the incorporation of oxygen in the deposited ITO film. From Figure 1 and 2, the ion flux to the substrate decreases with the increase of oxygen gas flow rate, therefore, the increase of optical transmittance in Figure 3 appears not to be significantly related to the oxygen ion flux to the substrate. Instead, the variation of atomic oxygen radicals with the increase of oxygen gas flow appears to be more responsible for the variation of optical transmittance. The variation of atomic oxygen radical with the increase of oxygen gas flow changed the atomic oxygen radical flux to the substrate, therefore, changed the amount of oxygen incorporation to the deposited ITO.

The resistivities of the ITO thin films described in Figure 3 were measured and the results are shown in Figure 4. In the figure, the figure of merits defined by Haacke[11] to describe the quality of the transparent thin films was also included on the right side of the figure. As shown in the figure, the resistivity of ITO thin film deposited on PET decreased with the increase of oxygen gas flow up to 6sccm of oxygen flow and the further increase of oxygen flow increased the resistivity. The trend of the resistivity with oxygen flow was similar to that of atomic oxygen radicals in the ion gun. Therefore, the decrease of electrical resistivity of the deposited ITO thin film appears to be more related to the increased oxygen incorporation of oxygen radical to the ITO thin film for the conditions used in our experiment.

Conclusion

The optical transmittance of deposited ITO increased with the increase of oxygen flow rate and appeared to saturate at 6sccm of oxygen flow rate. In the case of electrical resistivity, the resistivity was the minimum at 6sccm of oxygen flow. Therefore, from the

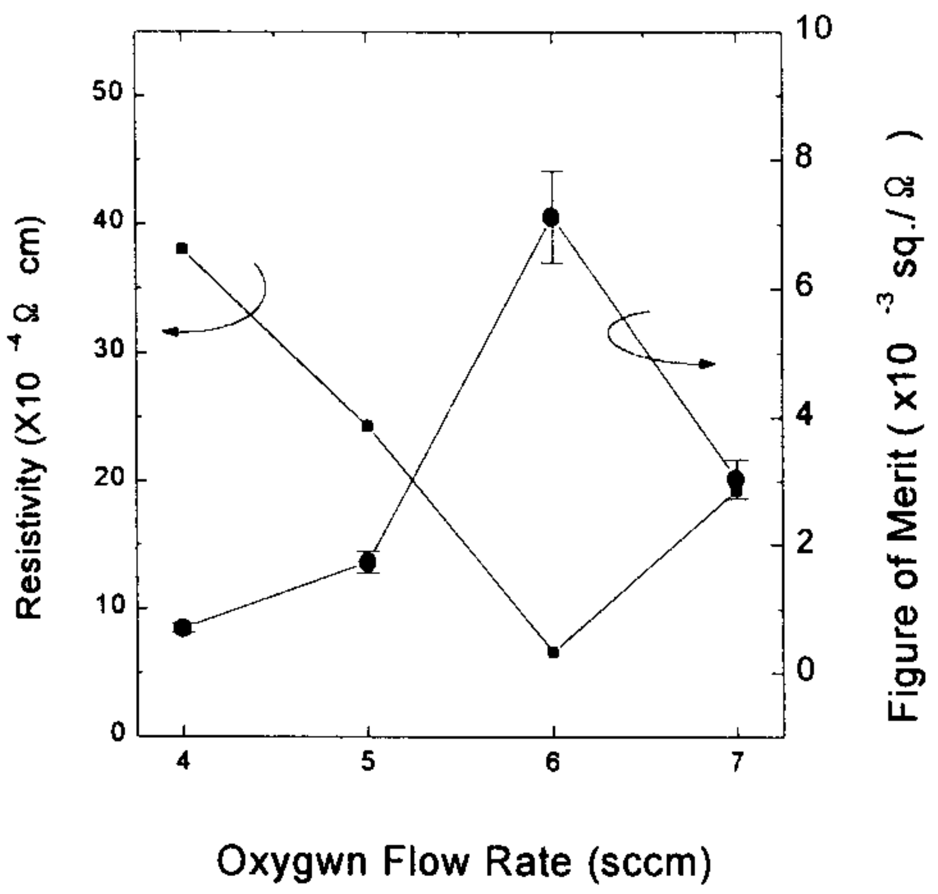

Fig. 4 Variation of sheet resistance and figure of merits as a function of oxygen flow rate.(rf power : 100W, Ve : -900V, Va : 2.1kV)

above results, in increasing the optical transmittance and the electrical conductance of the ITO, not only the oxygen ion beam flux to the substrate but also the atomic oxygen radicals appears to be play an important role. At an optimal condition, ITO thin films with the resistivity of $6.6x10^{-4}$ Ω cm and 90% optical transmittance at 550nm could be deposited on PET at room temperature.

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