The electronic structures and the electrical properties of ITO thin films by REELS and c-AFM

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Keywords : ITO, AFM, REELS, resistivity, I-V

Abstract

We studied the surface defects and the current distributions of ITO thin films by reflected electron energy loss spectroscopy (REELS) and conductive-atomic force microscope (c-AFM). The ohmic behavior of ITO thin film was observed at 230 ℃ annealed sample. The defects related to the electronic structure decreased after anneal process.

1. Introduction

Indium tin oxide (ITO) thin film is widely used as an electrode owing to its optically transparent and electrical conducting properties [1, 2]. Commercial poly-ITO thin film on glass was used for passive matrix organic light emitting diodes (PM OLEDs). In the case of active matrix (AM) OLEDs, ITO anode must be deposited on various structures because of thin film transistor (TFT) applications. The process condition of ITO thin film has critical effects on device performance in OLEDs.

It is well known that the properties of ITO thin films are changed by sputter condition and post anneal process [3, 4]. Surface properties of ITO make an important role of OLEDs because organic materials are very susceptible to surface condition of ITO [5]. It is worthy of investigation when sputter condition and thermal budget of ITO are considered. In this paper, the effects of thermal budget on electrical and surface properties of ITO are reported using reflected electron energy loss spectroscopy (REELS) and conductive AFM (c-AFM).

2. Experimental

The 500 Å thick ITO films were deposited on Si substrate by sputtering at room temperature. For the investigation of the effects of thermal budget, ITO films were annealed at 120 ℃ and 230 ℃ for 1 hour at air. The structural properties were characterized by X-ray diffraction (XRD) and atomic force microscope (AFM). For the investigation of surface properties of ITO films, we conducted reflected electron energy loss spectroscopy (REELS) using low electron energy (200 eV) by auger electron spectroscopy (AES). The distribution of electrical properties was obtained by conductive AFM (c-AFM). We also measured resistivity of ITO using 4-point probe method.

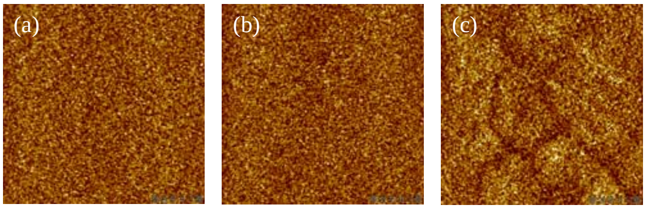

Fig. 1. AFM images obtained from the area of 3 × 3 μm^2 on ITO films deposited on Si substrate. (a) As-deposited sample was a reference. (b) Samples were annealed at 120 ℃ and (c) 230 ℃ for 1hour.

3. Results and discussion

Figure 1 shows the surface morphology of ITO films with anneal temperature. According to root-mean-square (RMS) value estimated by AFM, surface roughness was not changed after anneal process showing about 2 Å RMS one. However, the sample annealed at 230 ℃ revealed different morphology with grain boundaries in figure 1 (c). ITO films were crystallized during annealing at 230 ℃ confirmed by XRD. According to XRD results for ITO thin films, the samples as-deposited and annealed at 120 ℃ were composed of micro-crystalline structures. In the case of ITO thin film annealed at 230 ℃, (222) peak were sharply increasing.

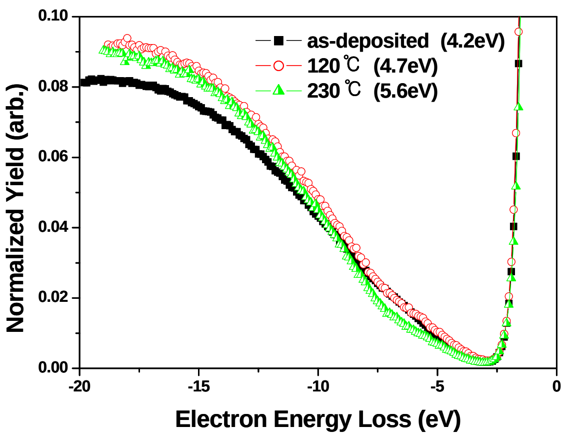

Fig. 2. REELS spectrum from ITO films, Ep = 200 eV. Samples were annealed at 120 ℃ and 230 ℃. As-deposited sample was also measured. The value of parenthesis indicates the surface band gap of ITO films.

REELS was used to obtain ITO defects and band gap at the surface. Figure 2 shows the surface band gap of REELS for the ITO surface, for electron primary energy equal to 200 eV. The width of surface band gap was estimated by extrapolating the segment of maximum negative slope to the background level. As the anneal temperature of ITO thin films increased, the surface band gap was larger and the defects level decreased. This difference behavior may be explained according to the following point: the presence of residual defects related to crystal structure, amorphous state, may be responsible for narrowing surface band gap because low energy electron is very sensitive to ITO surface.

Surface resistivities of ITO films were 174, 157 and 45 Ω/square for as-deposited sample and annealed samples at 120 ℃ and 230 ℃ respectively evaluated by 4-point probe method. The large decrease of resistivity at 230 ℃ annealed sample seems to be the consequence of the enhancement of electron mobility by grain growth and crystallization.

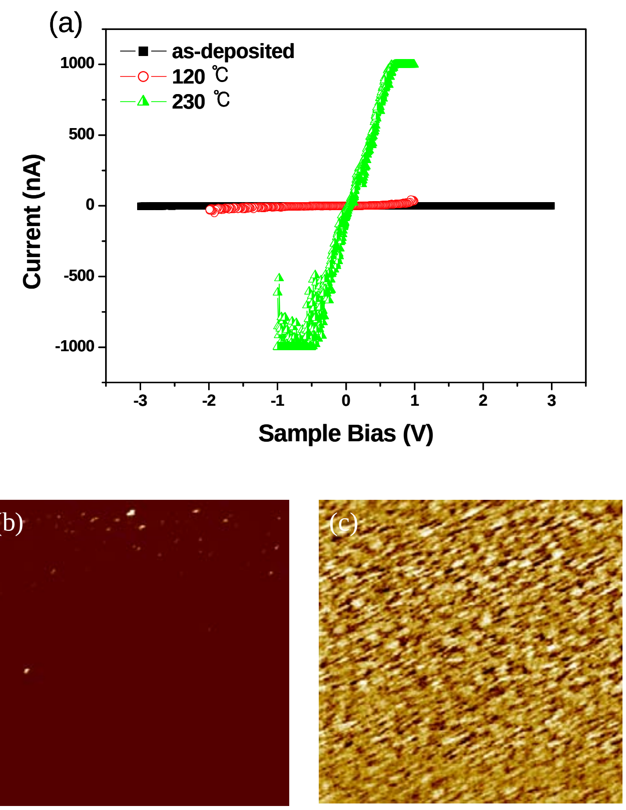

Fig. 3. (a) I-V characteristics of local points on ITO films and (b) current mapping images by c-AFM for as-deposited and (c) 230 ℃ annealed ITO films.

To discuss more detail results, we performed c-AFM for the characterization of the conductivity distribution of ITO surface. Figure 3 shows c-AFM results; *I-V* characteristics from local points and current mapping image from the area of 1 × 1 μm^2. The as-deposited sample exhibit no significant *I-V* characteristics and current distribution showing shottky behavior. After annealed at 230 ℃, electrical properties by c-AFM represent distinctly ohmic behavior. It is well matched with the results of surface resistivity. Current flow in the grain boundary was not detected showing dark region in figure 3 (c).

4. Summary

Indium tin oxide (ITO) is currently used as transparent electrode for organic lighting emitting diodes (OLEDs). In thin film transistor (TFT) applications, ITO thin films were deposited on various structures such as buffer materials. The characterization of sputtered ITO is very important to optimize device properties because the electrical properties of sputtered ITO were easily affected by sputter conditions and thermal treatments.

In this paper, we studied the structure of the ITO thin film after different anneal conditions. The electronic structures of the surface band gap were investigated by reflected electron energy loss spectroscopy (REELS) and the electrical behaviors of resistivity by conductive-atomic force microscope (c-AFM). The structure related to crystallinity enhances the electrical properties of ITO thin film annealed at 230 ℃ showing ohmic behaviors by c-AFM. The reconstructed surface of 230 ℃ annealed ITO thin film presents a large surface band gap (5.6 eV) showing decreasing defects level. Our results show the defect related the electronic structure and the electrical behavior of the ITO thin films.

5. References

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