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Study of ITO/ZnO/Ag/ZnO/ITO Multilayer Films for the Application of a very Low Resistance Transparent Electrode on Polymer Substrate

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Abstract

Multilayer transparent electrodes, having a much lower electrical resistance than the widely used transparent conducting oxide electrodes, were prepared by using radio frequency magnetron sputtering. The multilayer structure consisted of five layers, indium tin oxided (ITO)/zinc oxide (ZnO)/Ag/zinc oxide (ZnO)/ITO. With about 50 nm thick ITO films, the multilayer showed a high optical transmittance in the visible range of the spectrum and had color neutrality. The electrical and optical properties of ITO/ZnO/Ag/ZnO/ITO multilayer were changed mainly by Ag film properties, which were affected by the deposition process of the upper layer. Especially ZnO layer was improved to adhesion of Ag and ITO. A high quality transparent electrode, having a resistance as low as and a high optical transmittance of 91 % at 550 nm, was obtained. It could satisfy the requirement for the flexible OLED and LCD.

Key Words : Indium tin oxide, Zinc oxide, Transmittance, Multilayer

1. INTRODUCTION

Indium tin oxide (ITO) thin films show a low electrical resistance and high transmittance in the visible range of the spectrum. And thus they play an important role as transparent electrodes for current flat panel displays, but its resistivity is rather high to adapt as a transparent electrode in case of improved flexible OLED and LCD, having higher resolution and shorter response time[1-3].

One of the ways to realize an improved flexible OLED and LCD is to use multilayer electrodes, which have lower sheet resistance than those single layer of ITO films of the same thickness, as pixel electrodes. The multilayer structure having a Ag metal layer was initially investigated for the application of low resistivity coating. Most of the studies were concentrated on the durability and thermal stability of such films. Only a few, researchers referred to the possibility of its usage as a very low resistance electrode[4,5]. In case of their study, ITO/Ag/ITO film had a low resistance but patterning work was very difficult because of lack of durability and chemical reaction of Ag. For this reason, Ag just was used for common electrode of LCD.

In this study, to solve the durability of Ag, multilayer film was developed with structure of ITO/ZnO/Ag/ZnO/ITO. The electrical and optical charateristics of ITO/ZnO/Ag/ZnO/ITO had as same as those of ITO/Ag/ITO, and ITO/ZnO/Ag/ZnO/ITO had enhanced durability.

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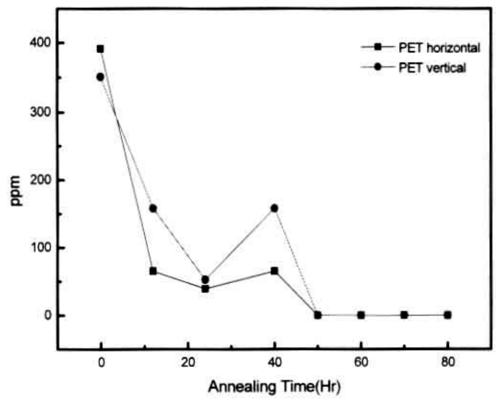

Fig. 1. Shrinkage rate of PET.

2. EXPERIMENTAL

In case of polymer substrate, shrinking and transformation were generated as Fig. 1 under deposition process. This made some minute cracks. Finally, the resistivity and reliability of electrode went down. To prevent this problem, the substrate went through annealing process before deposition. Table 1 showed deposited condition of indium tin oxide and zinc oxide.

Coating of both ITO and ZnO and Ag thin films was performed in a magnetron sputtering system that was equipped with three cathodes. RF (13.56 MHz) and DC powers were supplied into two cathodes[6,7]. And thus ITO/ZnO/Ag/ZnO/ITO multilayer films were successively formed or commercial polyethylene terephthalate (PET) without vacuum break. ITO films were deposited using a sintered ITO target of the 76.2 mm in diameter and Ag, ZnO films were sputtered using a target with the same diameter. The sputtering chamber was pumped down to $3*10^{-3}$ Torr using diffusion pump prior to deposition.

The thickness of the films was measured by the stylus method using the Alphastep 200. The film resistivity was measured using a 4 point probe. Surface morphology was observed using a scanning electron microscope (SEM) and atomic force microscope (AFM). The optical property of the films was measured using UV/Vispectrophotometer (spectra).

Table 1. Deposited condition of indium tin oxide and zinc oxide.

Condition	Value
Ar gas flow (sccm)	12
O2 gas flow (sccm)	0
Target-substrate distance (mm)	10
Pressure (mTorr)	2~3
Temperature (℃)	RT
Power density (Wcm^{-2})	5

Table 2. Characteristics of ITO/ZnO/Ag/ZnO/ITO film.

	Electrode	Unit
Sheet resist	8.3	Ω/□
Transmittance	92.8	%
haze	0.59	%
550 nmT	91.70	%
Reflectance	8.49	%

3. RESULTS AND DISCUSSION

It is well known that ITO films deposited at a high substrate temperature show improved electrical and optical properties. However, for the application of a flexible OLED and LCD pixel electrode on the polymer substrate should be formed at low temperature.

To deposit ITO films on the polymer substrate should be formed at lower than 150 ℃. PET was deposited at room temperature and ITO/ZnO/Ag/ZnO/ITO was deposited continuously because of lack of durability. On the occasion of ITO/Ag/ITO of the past, Ag was inflated such as Fig. 2 or melted such as Fig. 3 now and then. Hence, Ag was applied to special field such as common electrode of LCD that patterning work was unnecessary. However, adhesive strength between Ag and ITO was improved and Ag layer was protected from chemical reaction. ZnO had high transmittance and excellent electrical characteristic. The transmittance and electrical characteristic of ITO/ZnO/Ag/ZnO/ITO multilayer was similar to those of ITO/Ag/ITO in Table 2.

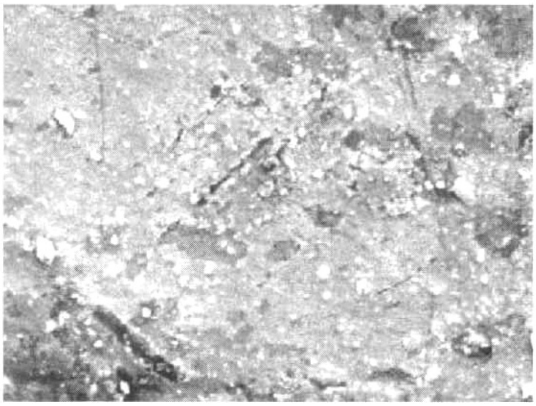

Fig. 2. SEM image of ITO/Ag/ITO surface.

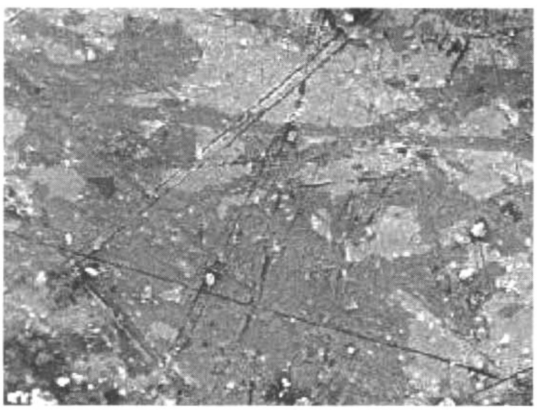

Fig. 3. SEM image of ITO/Ag/ITO surface.

Figure 4 and Fig. 5 showed transmittance and reflectance. In case of transmittance, there was all the difference near 400 nm transmittance but there was no difference near 550 nm. Consequently, it was out of the question when it was used for pixel electrode.

The multilayer films of ITO/ZnO/Ag/ZnO/ITO structure having the high optical transmittance in the visible range and the low sheet resistance of about 8.3 Ω/□ were fabricated by a magnetron sputtering. Both the upper and lower ITO layer was 55-60 nm and ZnO layer was 5~10 nm thick and the best electrical and optical properties of ITO and ZnO layers were achieved when they were deposited at room temperature.

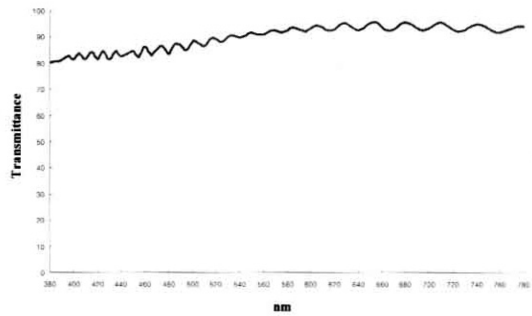

Fig. 4. Transmittance of ITO/ZnO/Ag/ZnO/ITO film.

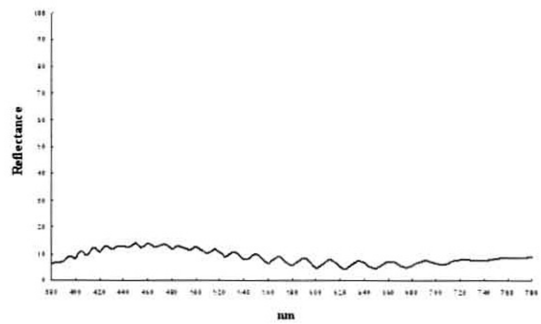

Fig. 5. Reflectance of ITO/ZnO/Ag/ZnO/ITO film.

4. CONCLUSION

Electrical conduction and optical transmission were interdependent properties among others mainly affected by the film structure. The properties of multilayer films, especially the optical and electrical properties, depended dominantly on the characteristic of Ag film. The morphology and structure of very thin Ag film were sensitive to the room temperature. During the upper ITO layer deposition, the Ag film was damaged by substrate heating. Moreover, during wet etching, the Ag film was spoiled by problems of ITO interface and commissure. ZnO film were deposited on Ag layer before ITO deposition to prevent these problems.

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