Optical and electrical properties of organic light-emitting diodes with ITO and AZO base various anode configurations

Jin-hyung An*, Sang-ho Kim
Materials science and engineering, Korea University of Technology and Education
307, Gajeon-ri, Byungchun-myun, Chuan-city, Chungnam, 330-708, Korea
Phone: +82-41-560-1376 , E-mail: jin89@kut.ac.kr

Abstract

Optical and electrical properties of various transparent conducting oxides (ITO, AZO, ITO/Ag/ITO, AZO/Ag/AZO) were investigated for anode of OLED display. ITO/Ag/ITO multi-layer anode has much better electrical and optical characteristics than other films, and OLED on that anode showed lower threshold voltage and better luminescence.

1. Objectives and Background

Transparent conducting indium tin oxide (ITO) and aluminum doped zinc oxide (AZO) have been widely used as anode materials in organic light-emitting diodes (OLEDs) due to those good optical transparency, low electrical resistivity, high work function and efficient hole injection properties.

The organic light-emitting diode (OLED) consists of organic films between two electrodes one of which must be transparent. In conventional OLEDs, the interface between the anode and organic layer has been reported as an important factor to influence the electrical and luminescent properties of OLEDs.

ITO/Ag/ITO and AZO/Ag/AZO multi-layer films deposited by RF magnetron sputtering have much better electrical properties than ITO and AZO single layer films.

In this study we investigated the electrical and optical properties of various transparent conducting oxide films such as ITO and AZO in single and multi-layer, and related those characteristics to the resultant electrical and luminescent characteristics of the OLEDs fabricated on the various anode materials.

2. Experimental

Various transparent conducting oxide (ITO, AZO, ITO/Ag/ITO, AZO/Ag/AZO) were deposited on glass substrates by RF magnetron sputtering . The deposition was performed using a silver target(99.95%), an aluminum doped zinc oxide target(Al2O3 2wt%, ZnO 98wt%) and indium tin oxide target (In_2O_3 90wt%, SnO_2 10wt%). glass substrates were cleaned with standard cleaning procedure and then loaded in the central region of the substrate holder located 65 mm away from the targets. The sputtering chamber was evacuated to 1.2 X 10-5 torr by diffusion pump and Ar and O_2 gas were used as a sputtering gas. The thickness of total multi-layer films, ITO single layer and AZO single layer were controlled to about 190nm, 200nm and 350nm, confirmed by surface profiler(Tencor, p-2). X-ray diffraction (XRD, Rigaku, RTP 300 RC) analysis was performed to investigate the crystallographic structure of films. The surface image and morphology of the films were observed by scanning electron microscopy (SEM, Jeol, JSM-6500F) . The sheet resistance of the films were investigated by 4-point probe (Guardian, 402S). The resistivity, carrier concentration and hall mobility of the films were investigated by hall effect measurement system (Ecopia, HMS-3000). The optical transmittances of the films were measured by spectraphotometer (Varian, Cary-500).

We have used various TCO thin films as anode contact for OLED devices. The devices reported here has the configuration of TCO/NPB (40nm)/AlQ3 (60nm)/LiF (0.2nm)/Al (150nm). The hole transport layer (HTL) of 4,4'-bis[N-(1-naphthly)-N-phenylamino]bi-phenyl (NPB) and electron transport/emitting layer (EIL/EML) of tris(8-quinolinolato)-aluminum (AlQ) were selected, respectively. LiF was used as the electron injection layer (EIL) on the interface of AlQ and Al cathode.

2. Results

We investigated the optical and electrical properties of various transparent conducting oxides (ITO, AZO, ITO/Ag/ITO, AZO/Ag/AZO).

In RF magnetron sputter, the insert of Ag layer is strongly correlated with the electrical resistivity and optical transmittance of deposited film.

Table 1 shows the electrical properties of various transparent conducting oxides films. ITO/Ag/ITO and AZO/Ag/AZO films show lower sheet resistance than single ITO and AZO layers

Inserting of ITO and AZO single-layer with Ag layer can improve their electrical properties, such as electrical resistivity and Hall mobility, etc. The inserted Ag layer may supply the free carrier concentrations and reduce the resistivity of the film

Table 1. Sheet resistance and resistivity of various conducting oxide films

	Sheet resistance (Ω/□)	Resistivity (Ω cm)
ITO	41.5	7.1×10^{-4}
AZO	30.3	9.7×10^{-4}
ITO/Ag/ITO	8.7	1.3×10^{-4}
AZO/Ag/AZO	7.29	1.2×10^{-4}

Figure 1 shows the optical transmittance of various transparent conducting oxides films. The optical transmittance of multilayer films was slightly lower than single layers films. The average optical transmittance (wavelength : 550nm) of ITO, AZO single-layer and multi-layer reached over 80%. In case of Ag inserted multi-layer films, both the electrical resistivity and the transmittance rapidly decreases. But when Ag layer has optimum thickness, the transmittance of films showed above 80%. The optimum thickness of Ag layer depends on the substrate and the deposition condition, and placed mostly between 50 and 150 Å.

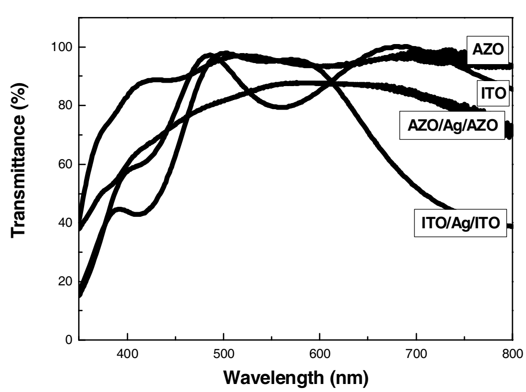


Figure 1. Optical transmittance of various conducting oxide films.

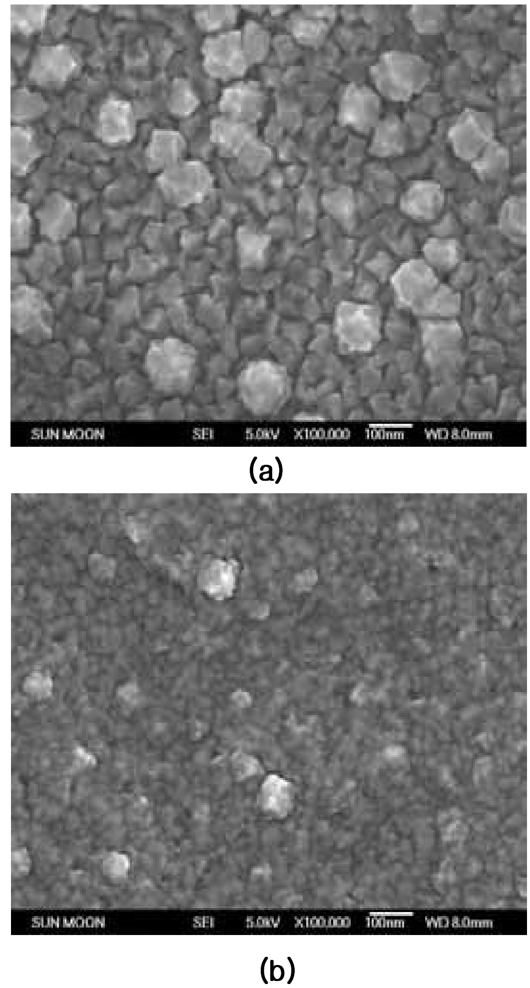
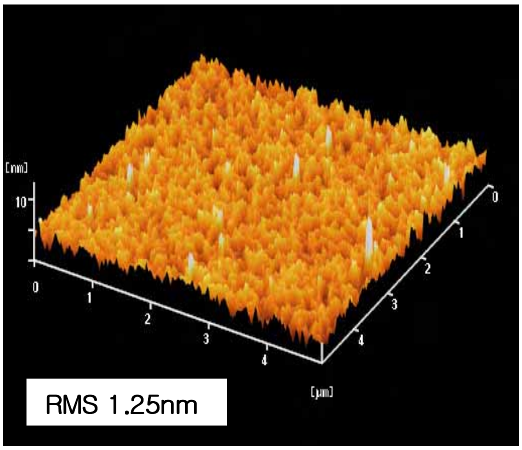


Figure 2. SEM images of AZO single-layer and multi-layer.
(a) AZO, (b) AZO/Ag/AZO

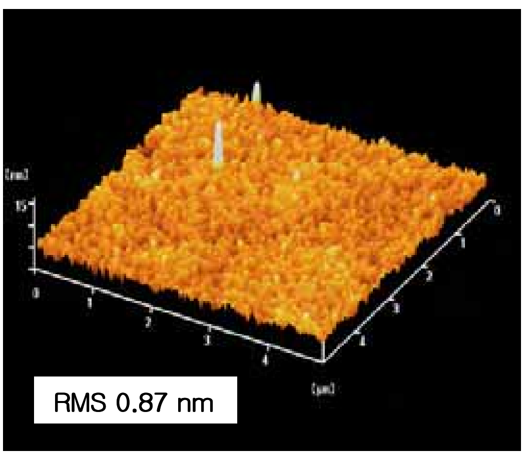
The luminance and turn on voltage of the OLEDs were known to be dependent on surface morphology. The surface morphology of the films was observed by scanning electron microscopy (SEM) and atomic force microscopy (AFM). The SEM image of AZO single-layer films and AZO/Ag/AZO multi-layer films are shown in figure 2. AZO single-layer film has angular shaped grains of about 50~100nm. As the Ag thin layer inserted, the shapes of AZO film grains became smoother and finer than the without Ag layer.

Figure 3 shows the AFM images of ITO single-layer and multi-layer films. ITO/Ag/ITO multi-layer films showed lower RMS value than the single-layer. In case of multi-layer, the RMS of 0.87nm was obtained, and single-layer, the RMS of 1.25nm was obtained.

The insert of thin Ag layer, used in this study, appeared td be a lower surface roughness due to the formation of Ag layer that was grown with (111) preferred orientation.



(a)



(b)

Figure 3. AFM images of ITO single-layer and multi-layer. (a) ITO, (b)ITO/Ag/ITO

J-V characteristics of OLEDs fabricated on the several transparent conducting oxide films are investigated. Figure 3 shows the current density (J) versus apllied voltage (V) characteristics of OLED devices of ITO, AZO single-layer and multi-layer. The current density of the OLEDs with ITO/Ag/ITO multi-layer film was higher than another films. A turn-on voltage of the OLEDs fabricated on the ITO/Ag/ITO multi-layer is about 4.2V, which is 1V smaller than OLEDs with AZO/Ag/AZO multi-layer anode. This reduction may be due to an increase in hole injection efficiency from the ITO/Ag/ITO layer into NPB layer, as compared with AZO/Ag/AZO , ITO and AZO single-layer devices.

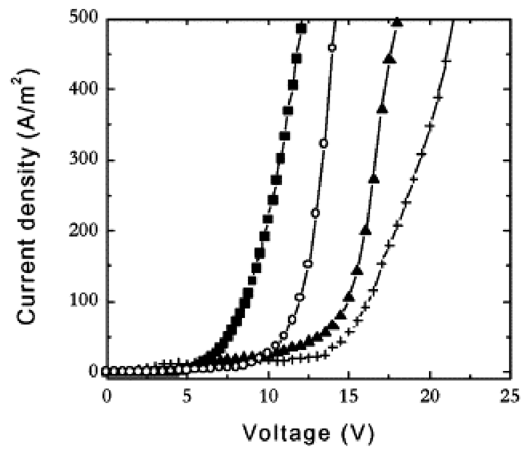


Figure 4. J-V characteristics for OLED device .
■ ITO/Ag/ITO, ▲ITO,○ AZO/Ag/AZO, ‡ AZO .

3. Impact

In this study, Ag metal film having lowest resistivity was located on the center of ITO and AZO films in order to investigate the effects on the electrical and luminescent properties of OLEDs. OLEDs with ITO/Ag/ITO multi-layer anode showed much better electrical and luminescent characteristics.

4. Acknowledgements

This work was supported by grant No. RTI04-01-01 from the Regional Technology Innovation Program and Regional Innovation HRD Program of the Ministry of Commerce, Industry and Energy(MOCIE).

5. References

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