P-57: Study on the Wet Processable Antimony Tin Oxide (Transparent Conducting Oxide, TCO) using Anode for PLED Device Instead of ITO

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Abstract
In this study, fabricated a PLED device by using the wet processable Antimony Tin Oxide(ATO) as the transparent electrode instead of the Indium Tin Oxide (ITO) and measured its electrical and optical characterization. By controlling annealing temperature and thickness of the ATO, 90% or more of visible region transparency and sheet resistance of 30Ω/°C was obtained.

1. Introduction
Transparent conducting oxide (TCO) is an essential part of technologies that require both large area electrical contact and optical access in the visible region. Among them, indium tin oxide (ITO) is one of the most widely used transparent electrode for organic light emitting diodes (OLEDs), organic photovoltaic cells (OPVs), organic thin film transistors (OTFTs) and other solid state applications. Some of the problems encountered with ITO are a large surface roughness, and an oxidative destruction at the overlying emissive polymer interface. Also, the amount of deposits of indium is limited, the demand for indium is increasing while the supply is insufficient thereby causing a great increase in the price of ITO.

In this study, a PLED device was fabricated by using the wet processable antimony tin oxide (ATO) [1, 2] as the transparent electrode and electrical and optical properties were measured. Transmittance of ATO thin film was more than 90% in the visible region, sheet resistance was 30Ω /°C, and had a strong solvent resistance.

2. Experimental

2.1. Solvent Resistance Test of Antimony Tin Oxide (ATO) Thin Films
To use as the transparent electrode for OLED or PLED of ATO, we had do solvent resistance test of ATO thin films. The glass substrates were cleaned with detergent, distilled water, acetone, isopropylalcohol (IPA) in an ultrasonic bath, respectively, and then dried by nitrogen gas and baked in hot plate for 10min at 110℃. ATO was filtered through 0.45㎛ PTFE syringe filter, and was than spin coated onto cleaned glass substrate with a rotary speed of 1000rpm. The thickness of thin film was measured by Alpha Step 500 surface profiler and it was 350nm. ATO thin films were annealed in furnance for 3hr at 300℃, and than they were rinsed distilled water, chlorobenzene and chloroform. After rinsed in various solvents, absorbance of ATO thin films was observed by UV-visible spectroscopy.

2.2. Thickness and Transmittance Test of Antimony Tin Oxide (ATO) Thin Films
ATO was spin coated on the precleaned glass substrate with a spin speed of 1000rpm (1~6 times), the thickness and transparency were measured, after the solvent had dried, by Alpha Step 500 surface profiler and UV-visible spectroscopy, respectively.

2.3. Sheet Resistance of Antimony Tin Oxide (ATO) Thin Films by Annealing Temperatures
ATO was spin coated on the precleaned glass substrate. Thickness of ATO thin films were ~350nm, they were annealed from 100℃ to 600℃ for 5hrs in furnance. Sheet resistance was measured by four point probe station.

2.4. Device Fabrication
Patterned ATO/ITO substrate was cleaned with detergent, distilled water, acetone, isopropylalcohol (IPA) in an ultrasonic bath, respectively, and then dried by nitrogen gas and baked in hot plate for 10min at 110℃. Finally, treated with UV-ozone for 10min. PEDOT:PSS was spin coated on the patterned ATO/ITO substrate at a thickness of 25nm and dried by baking in a nitrogen glove box at 120℃ for 20min. Then, the polymer was spin cast from chlorobenzene solution (0.5wt%) through a 5㎛ PTFE syringe filter. The thickness of polymer was 80nm. Then the coated ATO/ITO were transferred into a deposition chamber with a base pressure of 1.0×10^{-6} Torr, BaF_2(2nm), Ba(2nm), Al(200nm) layer was evaporated onto the polymer layer. The emitting area was 2mm × 2mm. Figure 1 shows structure of PLED in this study. The EL spectra were measured with a Keithley 2400 source meter unit and PR670 spectroscopy for I-V-L measurements. Also, morphology of thin film of fabricated device was measured by Atomic Force Microscopy.

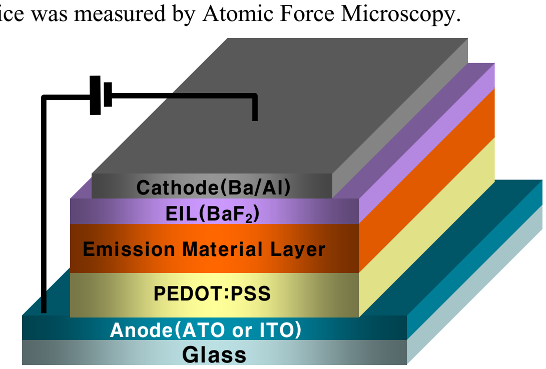

Figure 1. Structure of PLED in this sturdy.

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3. Results and Discussion

3.1. Solvent Resistance Characterization

Figure 2 shows the optical absorption spectra of ATO thin films were not changed by various solvents after rinsing. It means that ATO thin films have a strong solvents resistance. Therefore, ATO thin films can use an anode for PLED.

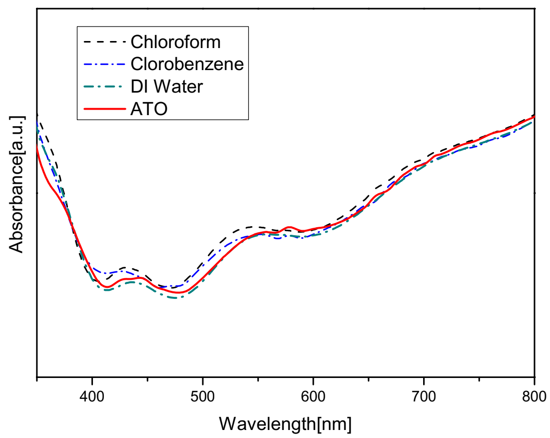

Figure 2. Absorption spectrums of before/after solvents rinsing

3.2. Thickness and Transmittance Characterization

As can be seen in Figure 3, thickness and transmittance of ATO thin films were measured. Especially, when the thicknesses of ATO thin films are 350nm and 720nm, the transmittance are 94.8%, 91.6%, respectively.

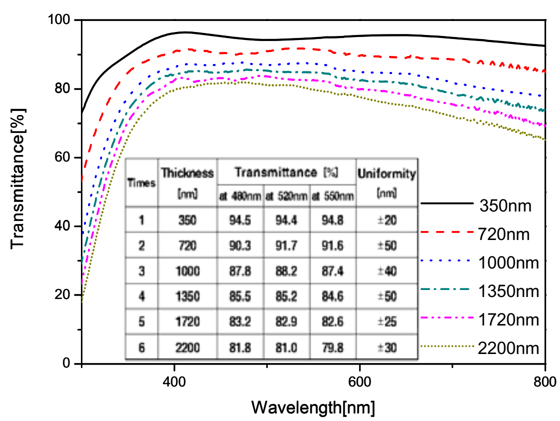

Figure 3. Transmittance of ATO thin films by thickness.

3.3. Sheet Resistance Characterization

Table 1 shows the change in sheet resistance of ATO in accordance to the annealing temperature. Measurement of sheet resistance was taken with thicknesses of 350nm. The sheet resistance decreased as the annealing temperature increased and the lowest sheet resistance was 30Ω /□ at annealing temperature of 500℃.

Table 1. Sheet resistance of ATO thin films by annealing temperature.

Temperature [℃]	200	300	400	500	600	Thickness [nm]
Sheet resistance [Ω /sq]	15k	2k	250	30	75	350nm

3.4. Device Characterization

The device was fabricated and characterized with the structure of ATO / PEDOT:PSS / Polymer / BaF_2 / Ba / Al. Figure 4 and 5 show the brightness-voltage and efficiency-brightness characteristics of fabricated device. When comparing with a device fabricated with the structure of ITO / PEDOT:PSS / Polymer / BaF_2 / Ba / Al, the results were shown Table 2. The maximum efficiency and maximum brightness of ATO device was achieved at 80% and 19%, respectively, when compared with ITO.

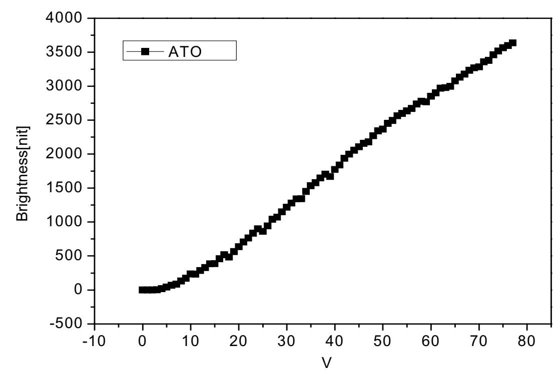

Figure 4. Brightness-voltage characteristics of fabricated device.

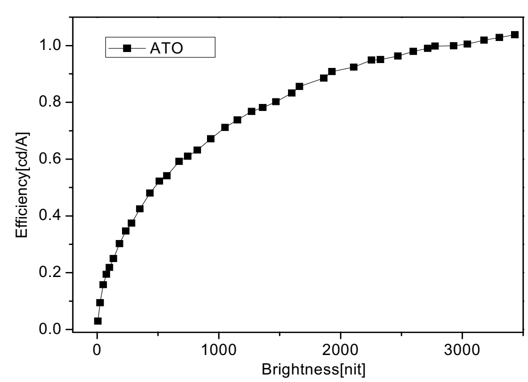

Figure 5. Efficiency-brightness characteristics of fabricated device.

Table 2. Characterization of devices

	Turn On [V]	Max Brightness [cd/m2]	Max Efficiency [cd/A]	CIE coordinate	max [nm]
ATO	3	3637	1.03	(0.52, 0.42)	584
ITO	1.5	19585	1.30	(0.52, 0.42)	586

Figure 6 shows a TEM image of ATO thin film. We can see the channels made by antimony particles. The holes go through these channels. But, if the thickness of film is too thin, it is difficult too dispersion of antimony particles, the charge mobility is decreased. Also, if the thickness of film is too thick, internal resistance of in the ATO thin film is more larger, the charge mobility is decreased. Optimized thickness of ATO thin film was 350nm and sheet resistance was 30Ω /□. Especially, sheet resistance is two times larger than ITO(~15Ω /□).

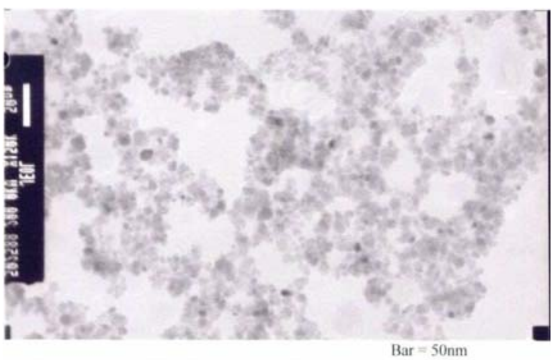

Figure 6. Transmission electron microscopy(TEM) image of ATO thin film

Figure 7 and Figure 8 show AFM images of morphology of ITO and ATO thin film. Root Mean Square(RMS) values of ATO and ITO thin films are 6.63nm, 5.40nm, respectively. Therefore, roughness of ATO thin film is larger than ITO, charge mobility is lower than ITO. And hole injection is also difficult from ATO surface to PEDOT:PSS layer.

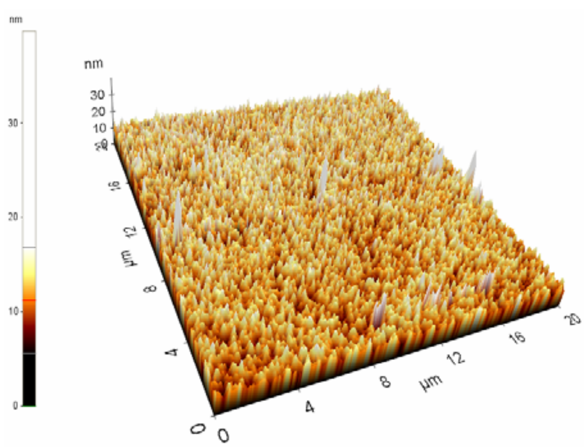

Figure 7. Surface morphology of ITO(RMS:5.40nm)

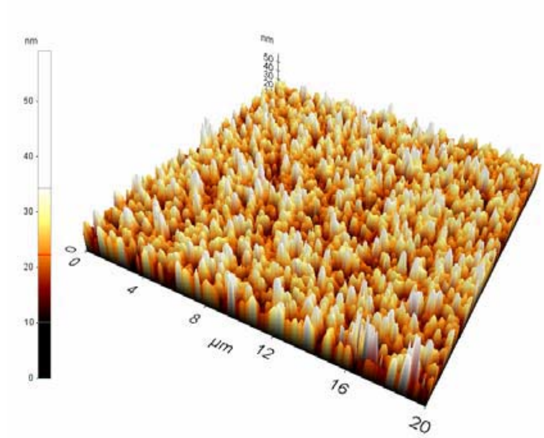

Figure 8. Surface morphology of ATO(RMS:6.63nm)

4. Conclusions

In this study, we fabricated a PLED device by using the wet processable Antimony Tin Oxide(ATO) as the transparent electrode instead of the Indium Tin Oxide (ITO) and measured its electrical and optical characterization. By controlling thickness of ATO thin films and annealing temperature, more than 90% of visible region transparency and sheet resistance of 30Ω /□ was obtained. Nowadays, the performances of ATO transparent anode are not as good as ITO, ATO is wet processable so that patterning can be done by such methods as inkjet printing or screen printing. Furthermore, the manufacturing process is simplified so that when applied to production, the effect to lower the cost is very large.

5. References

[1] K. Ravichandran, P. Philominathan, "Fabrication of antimony doped tin oxide (ATO) films by an inexpensive, simplified spray technique using perfume atomizer" Materials letters, **62**, 2980-2983, (2008)

[2] M. R. S. Castro, P. W. Oliveira, H. K. Schmidt, "Enhanced mechanical and electrical properties of antimony-doped tin oxide coatings" Semiconductor science and technology, **23,** 035013, (2008)