Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 78-79

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The Experiment and Simulation Study Top Emission PLEDs Using LiF/Ag/ITO Cathode

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1. Introduction

Top emission PLEDs are considerable interest for their application in high resolution flat panel display. To fabricate a high performance of top emission PLEDs, it is important to deposit transparent cathode such as ITO, which has the high transmittance as well as low resistivity. However, sputtering process generally accompanies damage that cause the degradation and large leakage current, there are several methods to achieve the low sputtering damage such as well designed sputtering target [1], and insertion of buffer layer. The insertion of buffer layer, for example, Mg:Ag [2], CuPc [3], and BCP/Cs[4] are generally used between ITO cathode and emitting layer. According to Hung reported, metal layers normally would provide better protection against plasma damage than organic layers [5]. Thus, instead of Mg:Ag, using LiF/Al and Ca [6] as buffer layer to avoid plasma damage and simultaneously enhance electron injection had been also investigated. However, the negative ion (O^-) and neutral oxygen atom will be generated during ITO sputtering [7] that may cause the oxidation of Al and Ca that leads the degradation of top OLEDs. In this work, LiF/Ag, the more stable material was used as the buffer layer to protect the underlying emitting layer and enhance the performance of TEPLEDs. The different thickness of Ag devices was studied to obtain the high transmittance and low operating voltage of TEPLEDs in this study.

2. Experiment

Organic layers were deposited by spin coating onto a glass substrate coated with a patterned indium-tin-oxide (ITO) electrode. A hole injection layer PEDOT:PSS was spin coated onto ITO glass substrate with a 70nm-thick layer and baked in atmosphere at 120 ^{o}C for 15min. Next, the active luminescent polymer film PFO with the thickness of 70nm was spin coated onto PEDOT:PSS layer, and baked in glove box at 120 ^{o}C for 30 min. Thereafter, the samples were transferred into thermal evaporation chamber. The electron injection layer, LiF (1.5 nm) and Ag interlayer (0, 1, 3, and 5 nm) were evaporated sequentially. Then, the ITO cathode was deposited by dc-sputtering 50 W at room temperature (~ 120 nm). All measurements were carried out at room temperature under atmosphere.

3. Result and discussion

The I-V property of TEPLEDs with various Ag thickness (1, 3, 5nm) is shown in Fig. 1 The current injection enhances with increasing the thickness of thin Ag buffer layer. The result can be explained by the resistivity reduction (Fig.2) [8] and reaction between Ag/LiF interface. Although the preview investigation shows the non-reaction between Ag/LiF interface [9], the phenomenon of carrier injection enhancement still can be found in this work. In order to understand the effects of Ag/LiF interface, the devices were fabricated using LiF/Al/ITO cathode for comparison which is shown in Fig.3. The effect of LiF/Al which enhances the OLEDs performance is well known [10]. However, base on our observation, the devices with Ag interlayer exhibit the similar trend as the devices with Al layer to improve the performance of the devices. Therefore, we conjecture that Ag may have reaction with LiF, too. According to Kim et al. reported [1], the effect of sputtering damage can be observed from the leakage current at reverse bias. However, in our experiments, all devices keep low leakage current density at reverse bias (the insertion of Fig. 4). It is hard to examine the damage effects during sputtering by comparing the leakage current at reverse bias in our devices. According to Burrows et al. [11] and our previous work reported [12], the trap concentration can be examined by the slope of double-log scale electrical property. It can be observed that the value of slope increases (from 7.8 to 9.5) as increasing Ag thickness. It indicated that the devices with thick Ag interlayer have the low trap concentration. This result indicates that the Ag interlayer can work as well as buffer layer to protect the underlying emitting layer during ITO deposition. In addition to the electrical property, the devices with Ag buffer layer also exhibit the superior optical characteristic. Fig. 5 shows the bottom side luminance of devices. It can be observed that the luminance of devices from high to low is Ag 5 nm, 3 nm, 1 nm, and ITO only device, sequentially. This result also consists to our simulation result. Fig. 6 shows the simulation result of light intensity of devices with different Ag thickness at various operating voltage. The Ag buffer layer devices all show the high luminance. It may be explained the devices with Ag layer have the high injection carrier and cause more carrier involved the recombination process. Fig. 7 shows the luminance of TEPLEDs with different Ag thickness (0, 1, 3, and 5 nm) which were measured from the top side. Although the device with 5 nm-thick Ag shows the highest luminance from the bottom side, it exhibits the lower luminance than Ag 1nm and 3nm-thick devices from the top side. This result can be attributed to the transmittance of cathode which is shown in Fig. 2. The 5 nm-thick Ag cathode shows the transmittance of 47.1 % that is quite lower than 1 nm-thick Ag cathode (80.1 %), therefore the light emitting from top side will be decreased due to lower

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transmittance and show the lower luminance than that of 1 nm-thick Ag device. The current efficiency of devices with different Ag thickness is shown in the insertion of Fig. 7 The 1 nm-thick Ag device shows the highest current efficiency among of all devices. Table. 1 shows the composition concentration of ITO material in organic emitting layer (PF). By observing the penetration depth of elements, we can understand the situation of sputtering bombard damage. It can be observed that as increasing the Ag buffer layer thickness, the ITO composition concentration in organic layer is getting less. It indicates that the insertion of Ag buffer layer can efficiently resist the sputtering bombard damage and this phenomenon consists with the previous TCL analysis. The higher concentration of In, Sn, and O elements in organic layer, the more trap concentration will be generated due to the penetration during sputtering.

4. Conclusion

In this work, we fabricated the top emission PLEDs using LiF/Ag/ITO cathode. The insertion of Ag buffer layer can reduce the turn-on voltage and increase the electroluminescence. The results can be attributed to the improvement of injection current. In addition to the improvement of performance, Ag buffer layer can sufficiently resist the sputtering bombard damage during the ITO cathode deposition. Although the thicker Ag buffer layer can improve the performance and resist sputtering damage efficiently, the transmittance of cathode will be sacrificed. Base on the experiment result, 1 nm-thick Ag is the suitable thickness to be the buffer layer that can improve the performance of top PLEDs and has the high transmittance simultaneously

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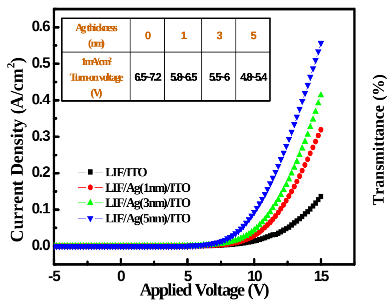

Fig. 1. I-V characteristics of TEPLED with different thickness Ag buffer layer inserted at the LiF/ITO interfaces.

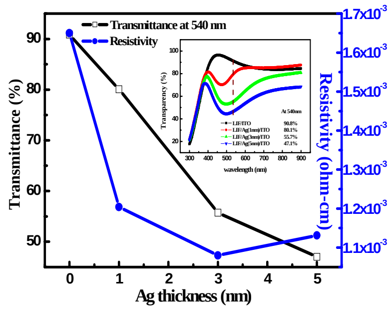

Fig.2. The transmittance and resistivity with different Ag thickness.

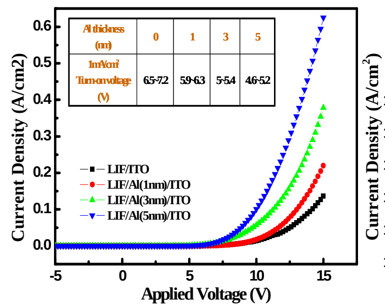

Fig.3. I-V characteristics of TEPLED with different thickness Al buffer layer inserted at the LiF/ITO interfaces.

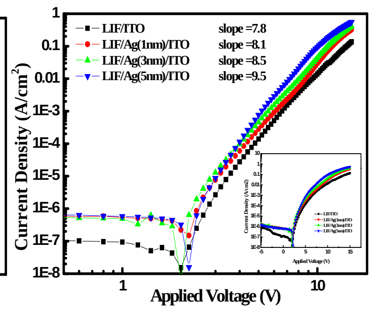

Fig.4. Double-logarithmic plot of I –V curves. The inset is the semi-log current density vs. voltage.

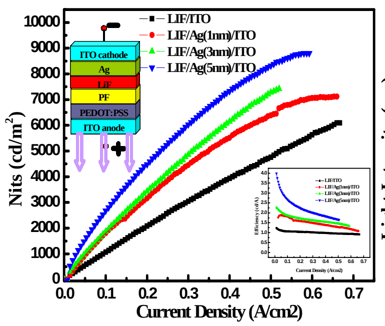

Fig.5. L-I characteristics and efficiency of TEPLEDs which were measured from bottom side.

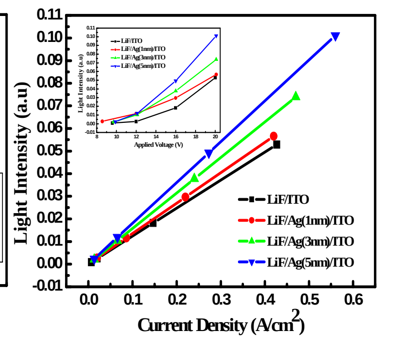

Fig.6. The simulation result of light intensity of devices(from bottom side) with different Ag thickness at various operating current and various operating voltage (insertion).

Table.1. The composition of ITO in PF (EML) using XPS measurement

Sample structure	The composition of ITO in PF		
PF/LiF/Ag/ITO	In %	Sn %	O %
Ag(0nm)	9.01	0.72	1.24
Ag(1nm)	3.77	0.67	0.85
Ag(3nm)	1.88	0.6	0.63
Ag(5nm)	1.44	0.56	0.56

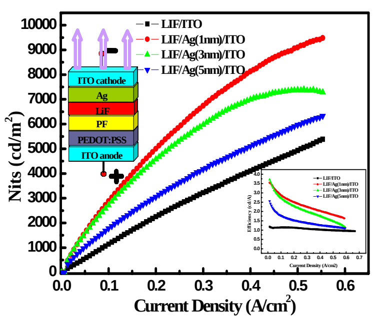

Fig.7. L-I characteristics and efficiency of TEPLEDs which were measured from top side.