Contrast Improvement of OLED Using Multi-layer of Metal and Metal Oxide

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Abstract

Inorganic metal multi-layer(IMML) consisting of Al/Al:SiO/Al was developed as a cathode for OLED to reduce the reflectance generated from ambient light. Device structure of green OLED was ITO/2-TNATA/α-NPD/Alq_3: C545T/Balq/Alq_3/LiF/IMML and IMML was composed of three different layers: thin aluminum layer, aluminum layer doped with silicon monoxide and thick aluminum layer. Average reflectance of green OLED was 9.63% while that of conventional OLED with or without polarizer showed the average reflectance of 8.54% and 66% respectively at visible range from 380 nm to 780 nm.

1. Introduction

A typical conventional OLED includes two electrodes such as transparent indium tin oxide (ITO) as anode and highly reflective Mg/Ag, [1] Ca/Al [2] or LiF/Al [3] as a cathode. Also most of OLEDs are fabricated on the glass substrate degrading the contrast ratio and increasing the reflectance caused by ambient light. In general, light absorbing layers,[4] circular polarizers,[5] or optical interference layers[6] has been used to reduce ambient light reflection in the electroluminescent display. Various high contrast OLEDs have been reported recently by using different methods; for example, light absorbing electron transport layer made of mixture of organic materials and metals [7] and dark cathode [8, 9] although circular polarizer seems to be best solution for current OLED products.

In this paper, we report inorganic metal multi-layer composed of thin metal, metal oxide and thick metal was designed with development of simple deposition process and it enhanced contrast ratio of the OLED device as replacing incompatible polarizer. Electrical and optical characteristics of IMML-OLED was analyzed and compared with conventional OLED with circular polarizer.

2. Experiment

The device is composed of the following layers: ITO as an anode, 2-TNATA as a hole injection layer, α-NPD as a hole transport layer, tris(8-quinolinolato) aluminum (Alq_3) and 10-2-(benzothiazolyl)-2,3,6,7-tetrahydro-1,1,7,7-tetramethyl - 1H, 5H, 11H- (1) benzopyropyrano(6,7,-8-ij)quinolizin-11-one (C545T) a green emitting host material and an emitting dopant material, Balq as hole blocking layer, Alq_3 as an electron transport layer and LiF as an electron injection layer. IMML was composed of three different layers: thin aluminum later, aluminum layer doped with silicon monoxide and thick aluminum layer.

ITO-coated glass substrates were cleaned with acetone and ethanol by using an ultrasonic bath, rinsed with de-ionized water, and then dried in an oven. Organic layers and cathodes were sequentially deposited on the ITO-glass substrates without breaking the vacuum. Organic thin film layers were deposited under high vacuum of 5×10^{-7} Torr with preheating for 30 minutes followed by main heating under 10 minute term. Green OLED device was prepared with size of 20×20mm. Reflectance of OLED device was measured based upon 15 degree angle of incident and reflected light each.

3. Results and discussion

Figure 1 describes layer structures of green OLED with inorganic metal multi-layer and conventional green OLED. The reflectance of conventional OLED without circular polarizer is around 70% in green region and that of OLED device with circular polarizer is less than 8% while OLED with inorganic metal multi-layer showed 9-10% of reflectance as describing in Figure 2. Considering reflectance of Al metal as 88~93%, reflectance results of each OLED device was summarized in Table 1. Green OLED with circular polarizer performs 8.5% of average reflectance but it does 9.6% of average reflectance with inorganic metal multi-layer, which could be assumed similar level of reflectance.

Table 1 shows the luminous reflectance, or *RL*, of a device is defined as

$$R_L = \frac{\int_{\lambda_1}^{\lambda_2} V(\lambda)S(\lambda)R(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} V(\lambda)S(\lambda)d\lambda}$$

where λ_1 and λ_2 are 380 nm and 780nm, respectively; $V(\lambda)$ is the standard photonic curve; $R(\lambda)$ is the optical reflection of the device; and $S(\lambda)$ is the spectral power distribution of the light source D65.[10] The calculated luminous reflection of green OLED is 65.63%, while that of green IMML OLED is 9.63%.

Table 2 shows change of contrast ratio of green OLED device as increasing driving voltage from 5V to 12.5V and the results implies that green OLED with inorganic metal multi-layer has better contrast ratio than with circular polarizer in higher driving voltage than 7.5V.

It also shows maximum contrast ratio of 3000:1 and 5800:1 approximately at 12.5V in green OLED with circular polarizer and inorganic metal multi-layer respectively, which proves contrast ratio to enhance almost twice as applying inorganic metal multi-layer into conventional OLED especially under higher voltage although it does not improve contrast ratio much in lower voltage.

Fig. 1. Device structure of green OLED with and without IMML.

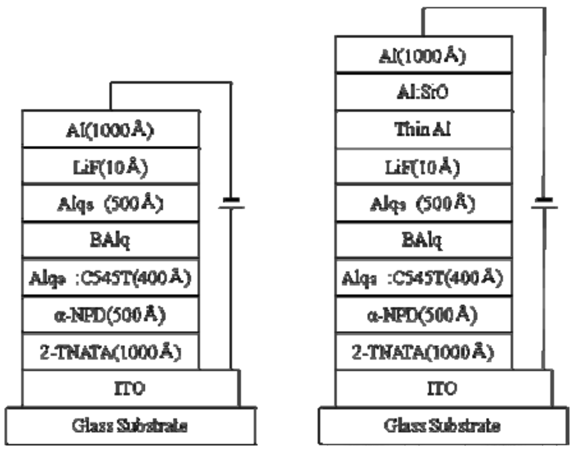

Table 1. The reflectance of green OLED

	Min Reflectance (%)	Max Reflectance (%)	Ave Reflectance (%)
reference	88.19	93.37	91.32
IMML	6.73	15.85	9.63
normal	24.85	72.46	65.63
pol	6.25	27.74	8.54

Table 2. The contrast ratio of green OLED

	Voltage (V)	Luminance		Contrast Ratio
		On (cd/m^2)	Off (cd/m^2)	
IMML	5.0	74	4	15
	7.5	1009	4	214
	10.0	5793	4	1214
	12.5	27900	4	5794
normal	5.0	90	4	21
	7.5	1319	4	290
	10.0	8483	4	1908
	12.5	56620	4	13443
pol	5.0	42	5	8
	7.5	655	5	132
	10.0	3707	5	726
	12.5	15000	5	2955

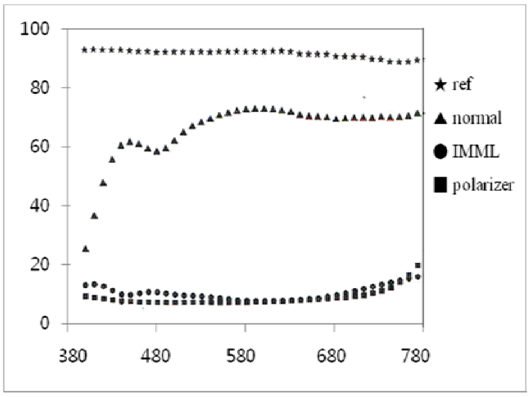

Fig. 2. Reflectance of green OLED

Figure 3 compares current efficiency between green OLED with polarizer and IMML. OLED with IMML has 1-2cd/A better efficiency than that of OLED with polarizer and more stable in visible region as increasing driving voltage.

Figure 4 also shows current density of OLED with IMML is higher than that of OLED with polarizer as increasing driving voltage.

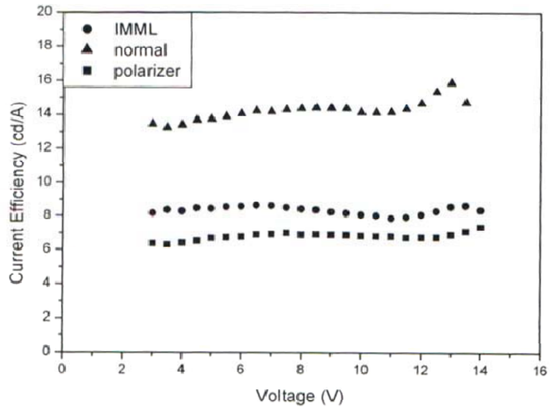

Fig. 3. The current efficiency cha of green OLED

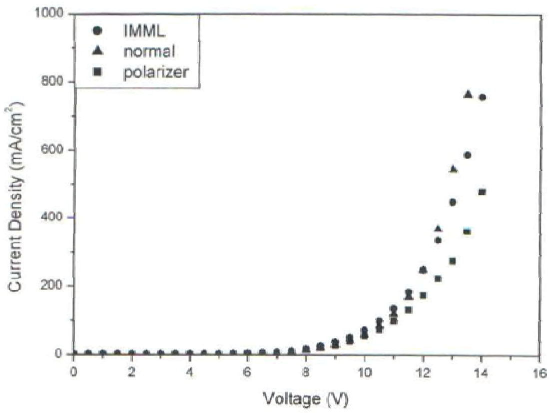

Fig. 4. The current-voltage curve of green OLED

4. Summary

Inorganic metal multi-layer between organic layer and metal cathode in normal OLED structure was proven to enhance the contrast ratio of OLED comparing with polarizer. The contrast ratio of normal OLED device without polarizer film was 2955:1, while OLED device using inorganic metal multilayer was 5794:1 which is superior than conventional OLED with polarizer film.

The deposition process of IMML is simple and compatible with current organic thin film process under high vacuum. Commercialization of IMML(Inorganic Metal Multilayer) in OLED display is expected to bring cost reduction and better display performance through replacement of present circular polarizer.

5. References

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