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Black film for improving the contrast ratio of organic light emitting diodes

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1. Introduction

Ambient light is incident upon a panel and reflects to the visual sensory organs of a user in bottom emission organic light-emitting diodes (OLED). Such design also reflects a scattered in addition to enhancing brightness [1], and thus relatively lowering the contrast ratio of a display. Therefore, it is necessary to take the improvement and enhancement of the contrast ratio into consideration to achieve a vivid lifelike effect.

A common method for effectively improving the contrast ratio is to attach a polarizer onto an external layer of a display [2]. Another common method for improving the contrast ratio is to add a black film into the structure of the OLED.

One of adding black film methods is adopting a transparent cathode on the traditional OLED to add a light absorbing layer at the rear of the cathode [3]. The other method adds a black film structure in front of the cathode to form a composite cathode [4-6].

It is noteworthy that when the black film is inserted between the cathode and the organic layer, not only the scattered light entering into the OLEDs is eliminated, but the brightness of the light reflected from the cathode is also lowered by this black-film.

2. Experiment

In this experiment, sheet resistors 5Ω/□ ITO glass are rinsed by ultrasonic cleaner in acetone, methanol, and DI water for ten minutes, and then cleaned by O_2 Plasma for 90 seconds. NPB and Alq3 are deposited sequentially onto the surface of the ITO by thermal resistance heating in organic chamber at pressure of $5x10^{-6}$. The evaporation rate of organic matters is controlled within 0.1~0.3 Å/sec. Then, the sample is sent to a metal deposition chamber for depositing. Table 1 shows the parameters adopted by the OLED with and without black film structures, Al/CuPC.

The OLED properties were tested under the atmosphere. This experiment used a xenon lamp as the background light during the measurements, and the brightness of the background light source was controlled at 33.5 cd/m^2.

3. Results and Discussion

Fig. 1 shows the graph of current density versus voltage for three black film structures having different thicknesses (Al/CuPC: 4/80, 4/90, 4/100 nm). In Fig. 1, the lowest current density - voltage curve was obtained from the Al/CuPC film of 4/80 nm thickness (device B). It is found that there is no significant difference in the light emitting brightness of three different types of black films for OLEDs. From Figs. 1 and 2, it is known that the current density of device B is lower, but its brightness is normally similar to the devices of other thicknesses, and the maximum brightness is up to 5000 cd/m^2 at 10 V.

Figure 3 shows a graph of luminance efficiency versus voltage of three black films with different thicknesses and w/o black film structure. It is discovered that devices having an Al/CuPC of 4/80 nm thick come with the best luminance efficiency. Based on the result of device B, device E having a double period black film structure, Al/CuPC/Al /CuPC: 4/40/4/40 nm, was designed.

Devices E, B and a normal structure without black film are compared to plot a graph of L-V as shown in Fig. 4. From device E with double period black films, it is found that the brightness of device E is very close to the brightness of Device B, and thus it is concluded that the effect of passing a current through Al/CuPC (4/80nm) or Al/CuPC/Al/CuPC (4/40/4/40 nm) does not cause a significant difference.

In Table 2 for different black film structures, the brightness of reflected light (Ref_{amb}) was measured by PR 650 during an ambient light (33.5 cd/m^2) was incident upon the OLED device while the device was turned off. As seen from Table 2, the double-period black film structure has the lowest reflected luminance of 2.61 cd/m^2. Using Table 2 data the contrast ratio, CR, was calculated by L_{on}/Ref_{amb}, where L_{on} was controlled at 2500 cd/m^2, i.e. OLED's total emitting luminance during device turned-on at ambient light of 33.5 cd/m^2. The calculated CR values for different black film structures are shown in Fig.5. From Fig. 5, the contrast ratio of device A (having no black film) is up to 82.2, device B is 267.1, and device E is the best among the three. A highest CR of 959 can be achieved from device E.

Fig. 5 shows that the contrast of Device E is higher than the contrast of other devices because Component E can effectively reduce the reflection of the ambient light, so that the denominator of Formula 1 becomes very small.

4. Conclusion

In the study of black films it is necessary to consider the factors related to the materials of making black films. These factors also include low work function materials, electron injection efficiency, and electric properties of buffer layer, in addition to the high absorption rate. Thus making the manufacture of black films becomes more difficult. The contrast ratio of device A (having no black film) is only 82.2, device B with one period of black film is up to 267.1, and device E is the best among the three. A highest CR of 959 can be achieved with a double period black film structure.

References

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Table 1. List of device structures and film thickness parameters.

Unit：nm

Device	Sub.	NPB	Alq3	LiF	Black film				Al
					Al	CuPC	Al	CuPC	
A	ITO	40	30	0.5	x	x	x	x	70
B					4	80	x	x	
C					4	90			
D					4	100			
E					4	40	4	40	

Table 2. The brightness of reflected light when Devices are turned off.

Ambient light (cd/m^2)	Reflected ambient light, Ref_{amb}, (cd/m^2)		
	Device A (w/o black film)	Device B	Device E
33.5	30.30	9.36	2.61

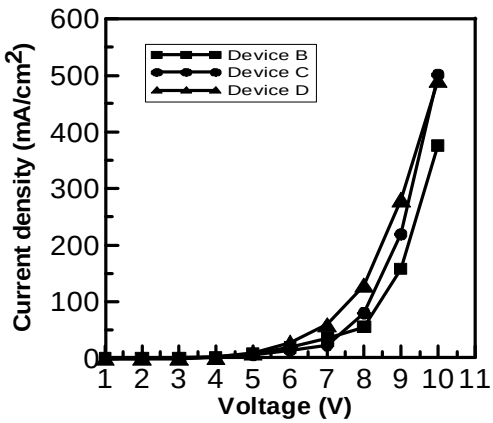

Fig. 1. Current density versus voltage for devices B, C and D.

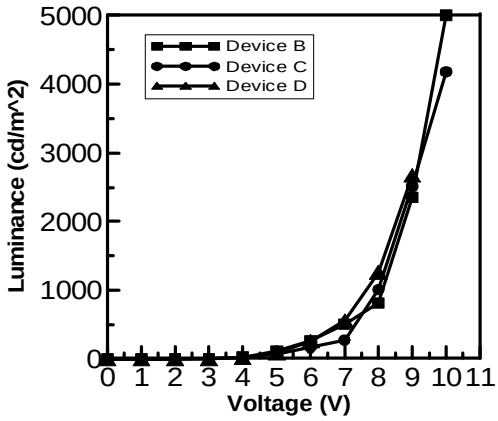

Fig. 2 Luminance versus voltage for devices B, C and D.

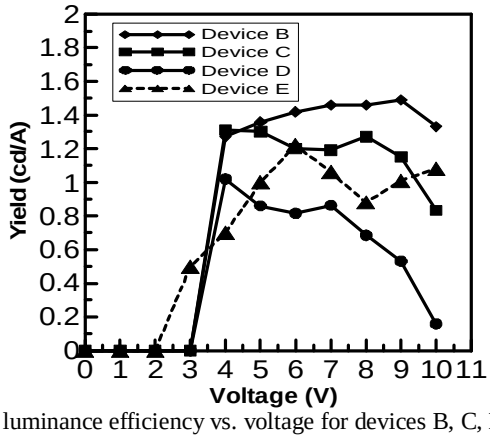

Fig. 3 luminance efficiency vs. voltage for devices B, C, D and E.

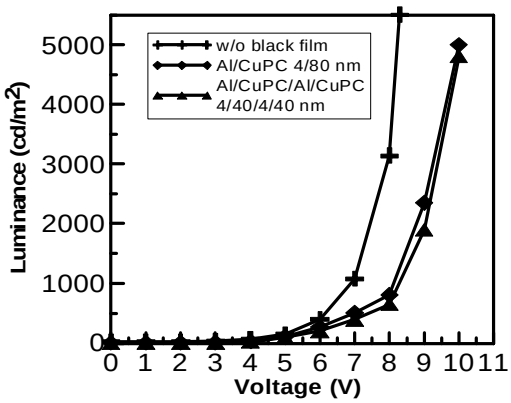

Fig. 4 Luminance vs. voltage for devices A, B and E.

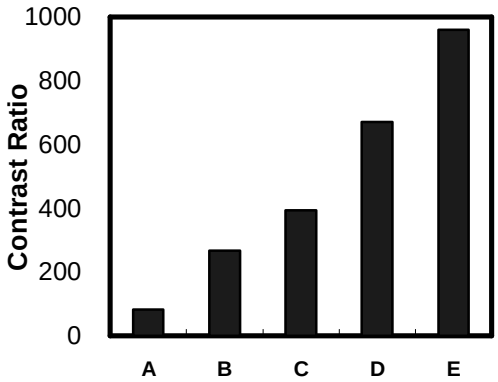

Fig. 5 Contrast ratio of different structures when devices turned on at luminance of 2500 cd/m^2 and Ref_{amb} as listed in Table 2.