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Destructive Optical Interference of Ambient Light for High Contrast Organic Light-Emitting Diode Using Inorganic Metal Multi-Layer

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We fabricated high contrast red, green, blue organic light-emitting diodes using inorganic metal multi layer (IMML) composed of thin Al, KBr, and thick Al. High contrast OLEDs using IMML were observed to compare with conventional OLEDs with circular polarizer and bare metal-electrode normal OLEDs. Average ambient reflectance of OLEDs using inorganic multi layer, polarizer OLEDs, and normal OLEDs were 18.2, 31.1, and 82.5% respectively. Contrast ratio of inorganic metal multi-layer OLED with red emission and polarizer attached OLED were same as 186:1 especially.

Keywords Ambient light cancelation; high contrast; IMML; non-polarizer; OLED

Introduction

Organic light-emitting devices (OLEDs) have been a subject of increasing interest in recent years, and numerous works have been devoted to the improvements of efficiencies [1,2] and reliability [3,4]. The growing interest is largely motivated by its potential application in flat panel displays. In a conventional OLED, the reflective metal layer benefits the out coupling efficiency because the back emission from organic is also reflected forward. Concurrently, such OLEDs have the drawback of lower display contrast due to the reflection of ambient light by the highly reflective metal cathode; however, high contrast between an image and the ambient reflections is essential for all display applications. This problem becomes particularly serious for outdoor display applications under strong ambient light.

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Low ambient light reflectivity can be achieved by using circular polarizes [5], light-absorbing layers [6–8] and optical interference layers [9–13] etc. Among them, structure with optical interference layer is considered as a good approach to balance the device performance and fabrication simplicity [14] which is also crucial for mass production. This structure consists of a thin semitransparent metal layer, inorganic light transition layer, and a thick reflective metal layer. Low reflection is realized by the cancellation (destructive interference) of two reflected light waves, one from the front thin metal layer and another one with π phase difference from the rear thick metal layer.

In this paper, low reflection was realized by the cancellation, namely destructive optical interference between two reflected light waves from inorganic metal multi layers (IMML). Optical and electrical performances of red, green and blue OLEDs with IMML composed of Al, KBr, and thick Al were observed and compared with conventional OLEDs with polarizer.

Experimental

ITO coated glass was cleaned in ultrasonic bath by regular sequence: in acetone, methanol, diluted water and isopropyl alcohol. Hereafter, pre-cleaned ITO was treated by O_2 plasma under condition of 2×10^{-2} Torr, 125 W during 2 minutes [15]. High contrast OLEDs were fabricated using the high vacuum (1.0×10^{-7} Torr) thermal evaporation and NPB as hole transport layer, Alq^3 as electron transport layer, LiF as electron injection layer, thin Al, KBr, and thick Al as inorganic metal multi layers were deposited by 1, 1, 0.1, 0.5, 0.5, and 5 Å/s, respectively.

Figure 1 shows the schematic configuration of the high contrast red, green, blue OLED using inorganic metal multi layer, RGB OLED using polarizer, and RGB OLED control device in this study, and Figure 2 shows the molecular structures of the chromophores in the devices as organic emitting layer materials. The inorganic metal multi layer red, green, and blue OLED emissive materials were as follows: Alq_3:DCJTB-0.4%, Alq_3, MADN, respectively. Three kinds of RGB devices were fabricated using inorganic metal multi layer, polarizer, and conventional metal layer. Contrast measurement of OLEDs with ambient lights was determined by extrinsic reflection of fabricated OLEDs with measured reflection ambient light of control device with OLYMPUS BX51 and TOPCON BM-7, respectively. With various DC voltage bias, the optical and electrical properties of high contrast OLEDs such

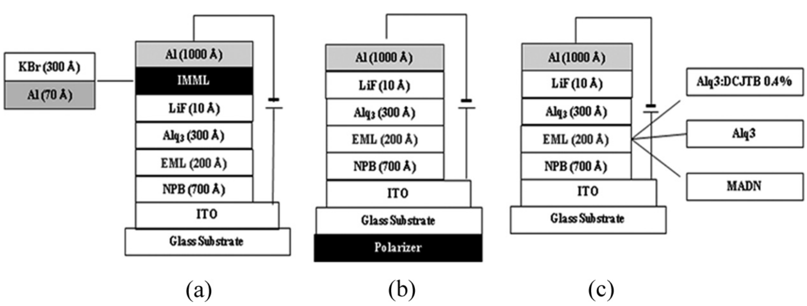

Figure 1. OLED devices with (a) inorganic metal multi layer, (b) polarizer attached, and (c) conventional metal layer.

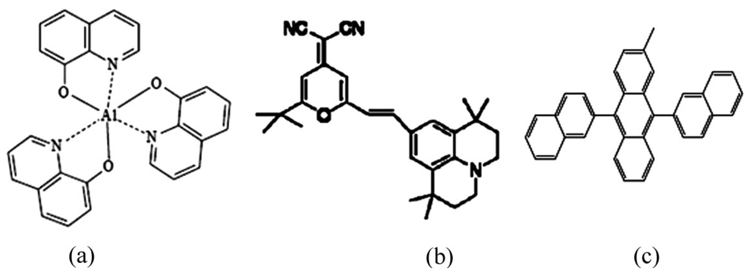

Figure 2. Molecular structures of organic materials in OLEDs (a) Alq_3, (b) DCJTB, and (c) MADN.

as the current density, luminance, luminous efficiency, Commission Internationale de L'eclairage (CIExy) coordinates and electroluminescence characteristics were measured with Keithley 236 and LMS PR-650.

Results and Discussion

Device A used inorganic metal multi layers such as thin Al (70 Å)/KBr (300 Å)/thick Al (1000 Å) with red, green, and blue OLEDs of functional layers of NPB (700 Å)/ Alq_3:DCJTB-0.4% (200 Å), Alq_3 (200 Å), and MADN (200 Å)/Alq_3 (300 Å)/LiF

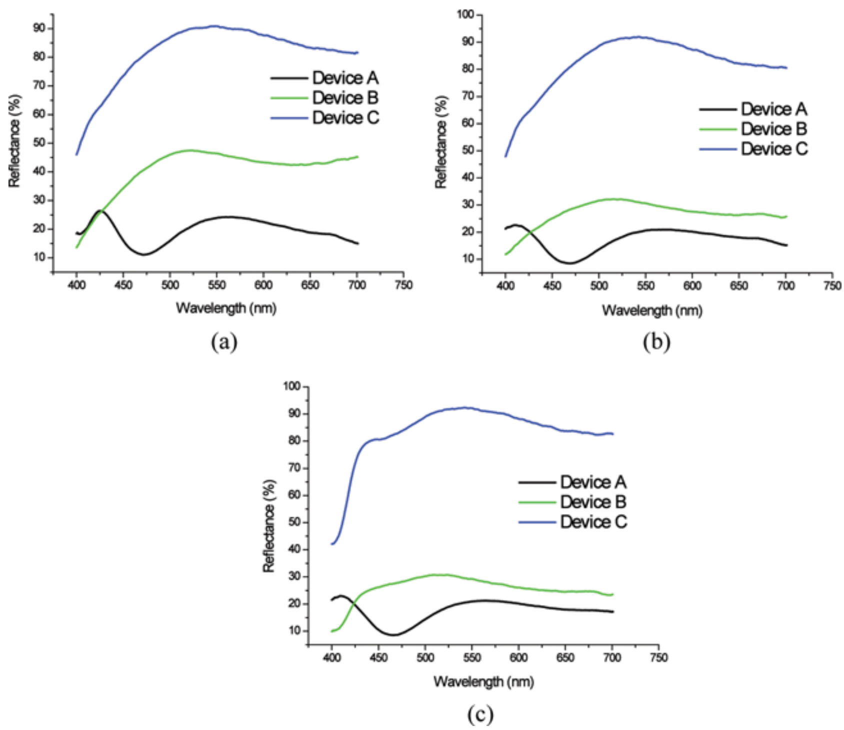

Figure 3. Reflectance characteristics of OLEDs with inorganic metal multi layer (Device A), polarizer (Device B), and bare metal layer (Device C) under ambient light in 400~600 nm (a) red OLEDs, (b) green OLEDs, and (c) blue OLEDs.

(10 Å) whereas devices B and C were polarizer-attached, using conventional OLED devices with bare metal electrode layer with the same red, green and blue emitting layer each.

OLED's reflectance characteristics under ambient light are shown in Figure 3. Average reflectance of devices A, B, and C in the region of 400~700 nm was 18.2, 31.1, and 82.5%, respectively. This result implies that inorganic metal multi-layer shows low reflectance under ambient light and be able to obtain high contrast OLED devices without polarizer.

Luminescence characteristics with current densities of red, green, blue OLEDs using IMML were 3564, 2820, and 1779 cd/m^2 at 240, 214, and 221 mA/cm^2 of current densities respectively, whereas polarizer attached OLEDs were 3203, 2502, and 1450 cd/m^2 at 223, 241, and 253 mA/cm^2 of current densities, respectively in Figure 4. This result indicates that inorganic metal multi-layer OLEDs will be expected to achieve higher efficiency and longer lifetime than polarizer-attached OLEDs because luminescence of device A was higher than that of device B at same current density.

As shown in Figure 5, luminous efficiencies of red, green and blue OLEDs using IMML with current densities such as 1.7, 1.4, and 0.9 cd/A at 14.4, 11.7, and 11.3 mA/cm^2 of current densities were higher than that of OLEDs with polarizer such as 1.6, 1.0, and 0.6 cd/A at 9.7, 9.7, and 10.3 mA/cm^2, respectively. Contrast ratio of inorganic metal multi-layer OLED with red emission and polarizer attached

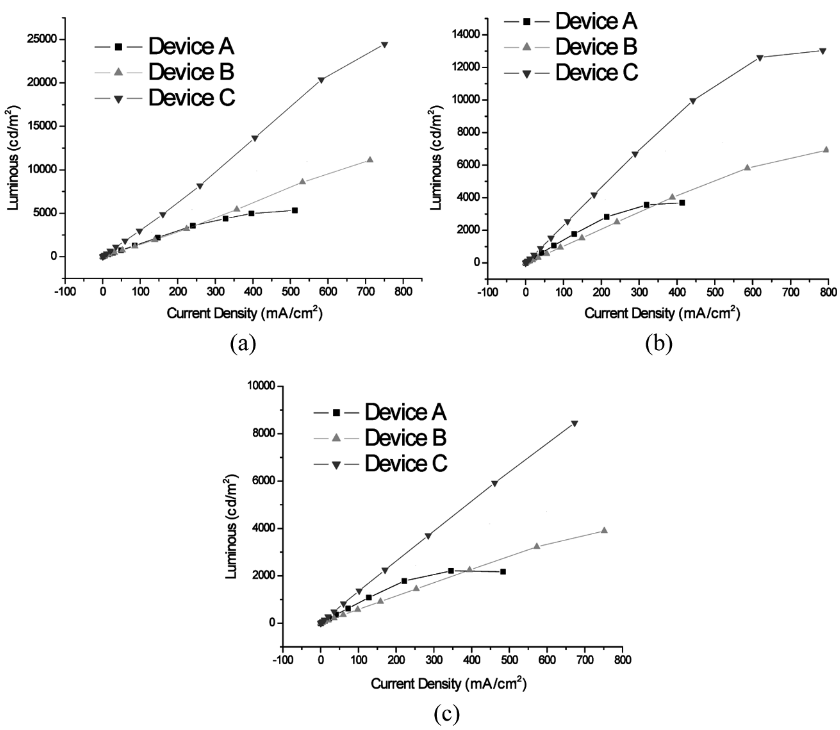

Figure 4. Luminescence characteristics with various current densities of OLEDs (a) red OLEDs, (b) green OLEDs, and (c) blue OLEDs with inorganic metal multi layer (Device A), polarizer (Device B), and bare metal layer (Device C) respectively.

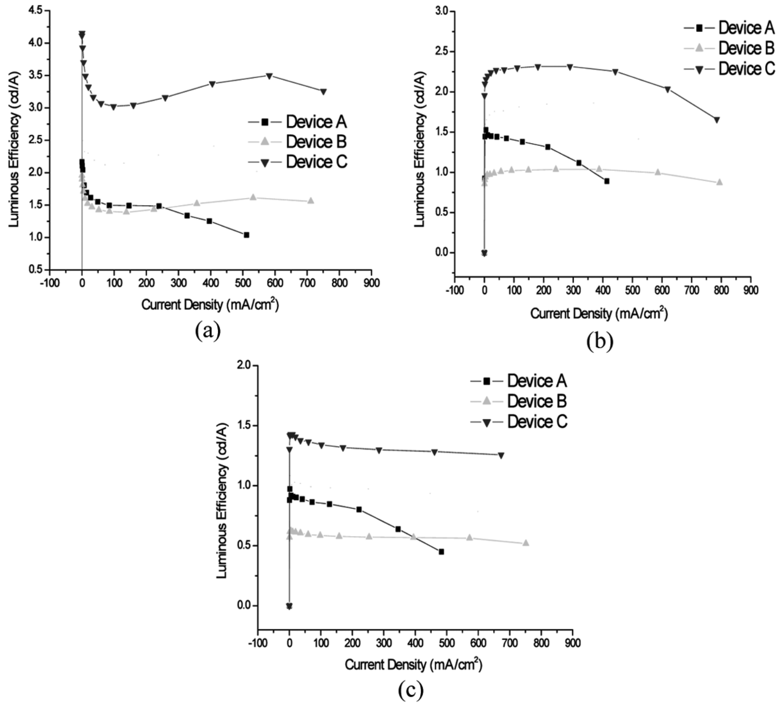

Figure 5. Luminous efficiency of (a) red, (b) green, and (c) blue OLED devices with inorganic metal multi layer (Device A), polarize r(Device B), and bare metal layer (Device C), respectively.

OLED were same as 186:1 based upon the brightness of the room. The contrast ratio was calculated by the equation below.

$$\text{Contrast ratio} = \frac{\text{Luminescene}_{\text{on}} + \text{Reflected ambient light}}{\text{Luminescene}_{\text{off}} + \text{Reflected ambient light}}$$

Table 1. CIExy coordinates of fabricated OLEDs

	6 V	8 V	10 V
Device A			
Red	(0.60, 0.39)	(0.57, 0.40)	(0 57, 0.41)
Green	(0.33, 0.53)	(0.33, 0.53)	(0.33, 0.52)
Blue	(0.20, 0.20)	(0.19, 0.18)	(0.20, 0.20)
Device B			
Red	(0.58, 0.40)	(0.57, 0.41)	(0.58, 0.40)
Green	(0.31, 0.52)	(0.31, 0.51)	(0.30, 0.49)
Blue	(0.17, 0.15)	(0.18, 0.16)	(0.20, 0.24)
Device C			
Red	(0.58, 0.40)	(0.57, 0.41)	(0.58, 0.40)
Green	(0.32, 0.52)	(0.31, 0.50)	(0.30, 0.48)
Blue	(0.17, 0.15)	(0.18, 0.15)	(0 27, 0.44)

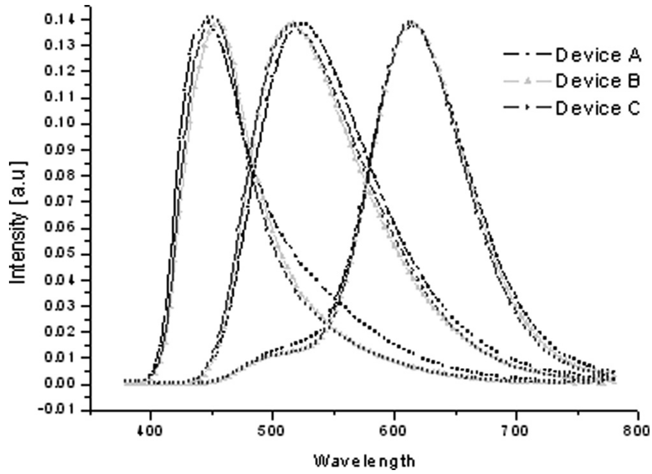

Figure 6. Electroluminescence of fabricated OLEDs with inorganic metal multi layer, polarizer attached, and normal at 8 V.

Table 1 summarizes CIExy coordinates of red, green and blue OLEDs at various driving voltages, and Figure 6 shows electroluminescence of fabricated OLEDs with inorganic metal multi-layer, polarizer attached, and bare metal electrode at 8 V which could suggest inorganic metal multi-layer does not effect on color shift and intensity of wavelength significantly comparing with polarizer-attached OLEDs.

These results suggest inorganic metal multi-layer OLEDs will eventually obtain better performance than polarizer-attached OLEDs in brightness, luminous efficiency, contrast ratio and probably lifetime while their optical properties are independent with bias voltages, electroluminescence intensity, and color purities.

Conclusions

Inorganic metal multi-layer OLEDs using thin Al, KBr, and thick Al show possibility of high contrast ratio, high luminescence, high efficiency, and lower reflectance of 18.2% than 32.1% of the OLED with polarizer according to ambient light's destructive interference. OLEDs with polarizer film preventing ambient light have several technical problems such as the higher cost of polarizer and additional expenses in manufacturing processes. Inorganic metal multi-layer can solve these issues via less reflectance performance, compatible thin film process and lower material cost of metals and inorganic materials. Therefore, OLEDs using inorganic metal multi-layer have significant advantages of low cost and high yield production as well as high performance of OLED display with improved contrast ratio of 186:1.

Acknowledgments

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