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Spectral Analysis of WOLEDs with Combination of Fluorescent Red and Phosphorescent Blue Emitting Layers

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The electroluminescence (EL) spectra of white organic light emitting diodes (WOLEDs) with combination of red fluorescent and blue phosphorescent emitting layers were analyzed spectroscopically as a function of applied voltage. The red dopant was (2Z,2′Z)-3,3′-[4,4″-bis(dimethylamino)-1,1′:4′,1″-terphenyl-2′,5′-diyl]-bis(2-phenylacrylonitrile) (ABCV-P) and blue one was iridium (III) bis[(4,6-difluorophenyl)-pyridinato-N,C2′]-picolinate (FIrpic). Two devices with and without hole blocking layer (HBL) were fabricated. EL emission of device with HBL was shifted to a greenish white color compared to that of device without HBL. However, EL emission from both devices with and without HBL showed a rather low color temperature with Commission Internationale de L'Eclairage (CIE_{xy}) coordinates from (0.416, 0.428) to (0.407, 0.431). Gaussian fitting of the EL spectra for fabricated WOLEDs supported that red emission was significantly affected by device structures and emission region became broader under high applying voltage.

Keywords: ABCV-P; FIrpic; Gaussian fitting; WOLEDs

1. INTRODUCTION

White organic light emitting diodes (WOLEDs) have drawn increasing attention as a full color display with color filters, flexible display, solid-state light source and backlights in liquid-crystal display (LCD)

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[1–4]. For the design of high-quality WOLEDs, the devices should meet not only high emission efficiency but also broad spectral range including three main color emission for practical applications. Three color emissions can be easier to tune color temperature and broaden the representing color area. Two colors also can cover the whole range of white emission, with fine tuning of electrical control of WOLED. The device temperature and current density have to be maintained in a certain level to reproduce the same color for the devices.

In this work, we fabricated and studied the new WOLEDs with combination of red fluorescent and blue phosphorescent emitting layers. To investigate color temperature and purity, measurement of the Commission Internationale de L'Eclairage (CIE_{xy}) coordinates and analysis of EL spectra for fabricated devices by Gaussian fitting were carried out.

2. EXPERIMENTAL SECTION

2.1. Fabrication of WOLEDs

The WOLEDs were fabricated under the high vacuum thermal deposition (8×10^{-7} torr) for the deposition of the organic materials onto the surface of indium–tin oxide (ITO) coated glass substrate. HBL was inserted in device A, and the total thickness of the device maintained the same. The structures of device A and B are following; [ITO (150 nm)/N,N′-bis-(1-naphyl)-N,N′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB) (50 nm)/4,4′-N,N′-dicarbazole-biphenyl(CBP):FIrpic (8%, 25 nm)/2-methyl-9,10-di(2-naphthyl) anthracene (MADN):ABCV-P (5%, 5 nm)/2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) (10 nm)/Tris(8-hydroxy-quinolinato)aluminium (Alq_3) (20 nm)/ lithium quinolate (Liq) (2 nm)/aluminum (Al) (100 nm)] (Device A) and [ITO (150 nm)/NPB (50 nm)/CBP:FIrpic (8%, 25 nm)/MADN: ABCV-P (5%, 5 nm)/Alq_3 (30 nm)/Liq (2 nm)/Al (100 nm)] (Device B). ITO, NPB, CBP, MADN, BCP, Liq and Al were used as a transparent anode electrode, a hole-transporting material (HTM), a blue-light host material, a red-light host material, a hole blocking material (HBM), a electron-injecting material (EIM) and a cathode electrode material, respectively. An ITO coated glass was cleaned in an ultrasonic bath by following sequences: in acetone, methanol, diluted water and isopropyl alcohol. The cleaned substrate was immediately loaded into the deposition chamber in order to prevent air contamination. The molecular structures of the above-mentioned materials were shown in Figure 1.

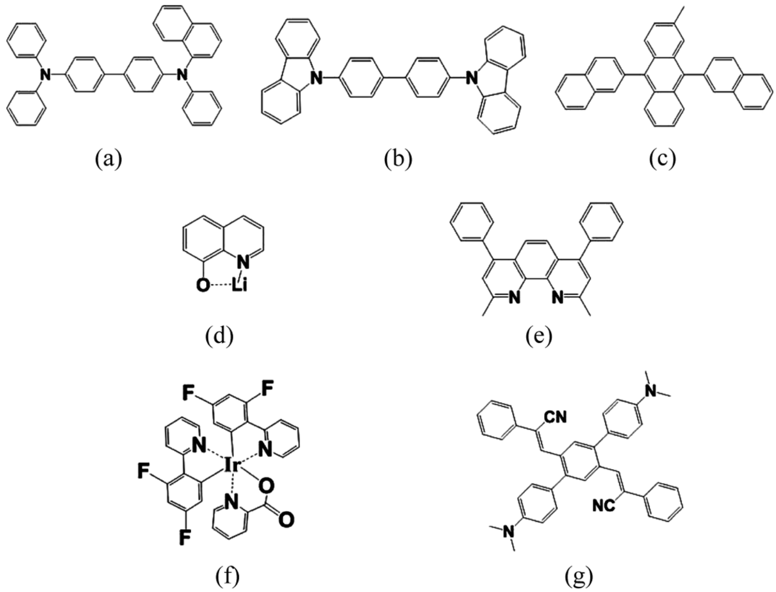


FIGURE 1 The molecular structures of materials used for WOLEDs; (a) NPB, (b) CBP, (c) MADN, (d) Liq, (e) BCP, (f) FIrpic and (g) ABCV-P.

2.2. Measurement

CIE_{xy} coordinates, EL spectra, color rendering index (CRI) and the emission intensities were measured with Keithley 236 and CS-1000A instruments. All the measurement was carried out under ambient conditions at room temperature. To compare the emission spectra obtained from WOLEDs, emission spectra were normalized. UV-visible absorption and photoluminescence (PL) spectra were measured by HP model 8453 and Perkin Elmer LS-50B, respectively. Gaussian fitting provides the emission intensities and area shape of electroluminescence spectra (Origin).

3. RESULT AND DISCUSSION

3.1. The Characteristics of CIE_{xy} Coordinates

The color temperature of WOLED determines spectral characteristic of images. Maintaining and variation of color temperature for different images and races improve human factors. As shown in Figures 2 and 3, two devices with and without HBL were fabricated, in which BCP could be a good HBM. We reported the synthesis of a new red dopant,

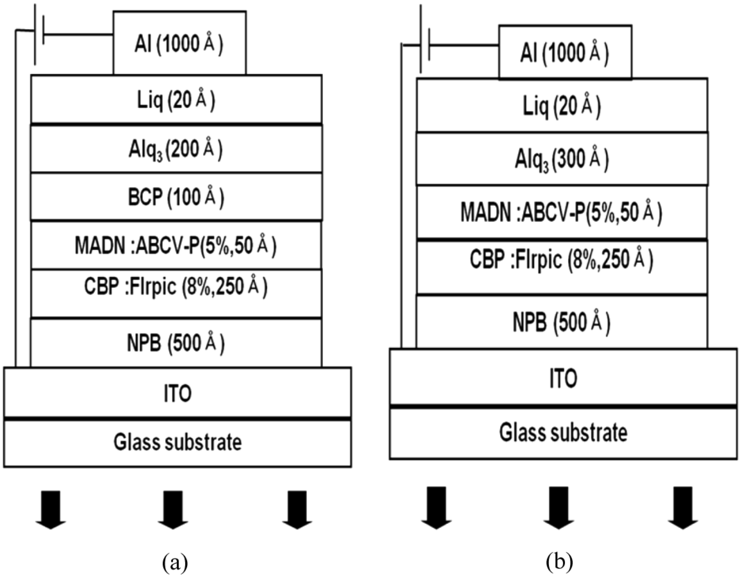
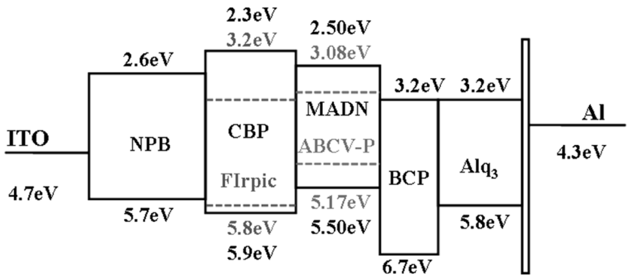


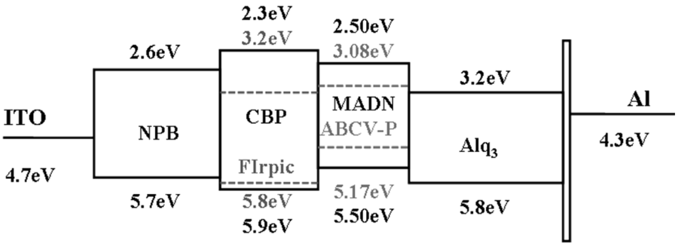
FIGURE 2 The device structures of two different WOLEDs (a) device A and (b) device B.

ABCV-P, used in these WOLEDs and its application for red OLEDs [5]. Emission region of WOLEDs could be affected by the insertion of a HBL, which could also change the color temperature and CIE_{xy} coordinate of device.

As shown in Figure 4(a), the CIE_{xy} coordinates of devices A and B are very similar in the range of 6–8 V, which probably means the hole and electron recombination zone of device A is analogous to that of device B in this range of applied voltage. However, as the applied voltage was increased, the difference of CIE_{xy} coordinate values between devices A and B was more enlarged. The CIE_{xy} coordinates of devices A and B were (0.4160, 0.4282) and (0.4074, 0.4312) at 6 V, (0.3634, 0.4148) and (0.3641, 0.4210) at 8 V and (0.3431, 0.4109) and (0.3634, 0.4244) at 10 V, respectively. Subtraction of the CIE_{xy} coordinate values of device A from those of device B ($\Delta x_{BA} = CIE_x^B - CIE_x^A$, $\Delta y_{BA} = CIE_y^B - CIE_y^A$) gave (−0.0086, 0.0030) at 6 V, (0.0007, 0.0062) at 8 V and (0.0203, 0.0135), respectively. As the applied voltage was increased, the increase of Δx_{BA} was larger than that of Δy_{BA}. As shown in Figure 4(b), this represented that, as the applied voltage was increased, EL emission of device A compared to that of device B was more shifted to green color. This also suggested that, at higher



(a) Device A



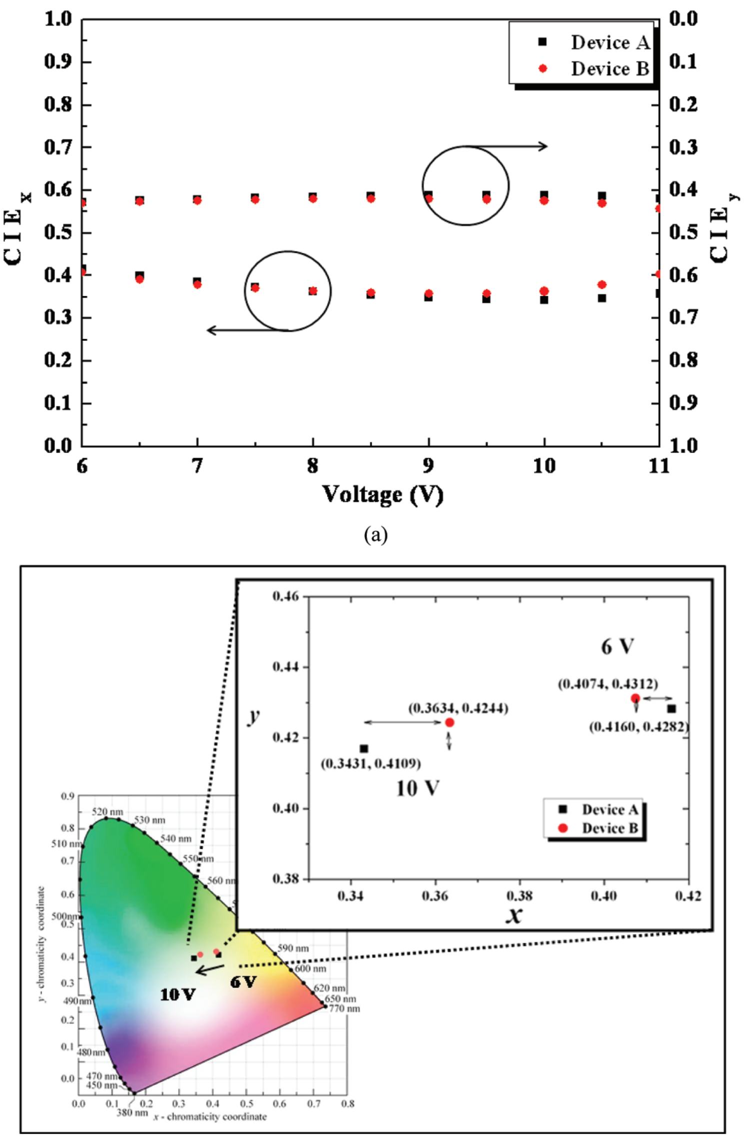
(b) Device B

FIGURE 3 The schematic energy band diagram for two different WOLEDs (a) ITO/NPB/CBP:FIrpic/MADN:ABCV-P/BCP/Alq_3/Liq/Al and (b) ITO/NPB/CBP:FIrpic/MADN:ABCV-P/Alq_3/Liq/Al.

applying voltage, the effect of HBL in device A was reduced and, therefore, the green emission from Alq_3 layer was enhanced. Both devices exhibited EL emission from yellowish-white to greenish-white according to applied voltage.

3.2. EL Characteristics

Figure 5 shows EL spectra of device A with HBL and device B without HBL, respectively. More structured EL spectra of device A compared to those of device B were observed. This is attributed to the HBL of device A. Although insertion of HBL in device A contributed to create more structured EL spectra, as shown in Figure 5(a), HBL did not work effectively at higher applied voltage. Device B without hole blocking effect was assumed to be more suitable for application in WOLEDs because the green emission from Alq_3 in device B provided less structured spectra with smooth and broader emission. This was further confirmed by measurement of CRI values for devices A and



(a)

(b)

FIGURE 4 (a) Commission Internationale de L'Eclairage (CIE_{xy}) coordinates as a function of applied voltage (V) and (b) CIE 1931 chromaticity diagram for devices A and B.

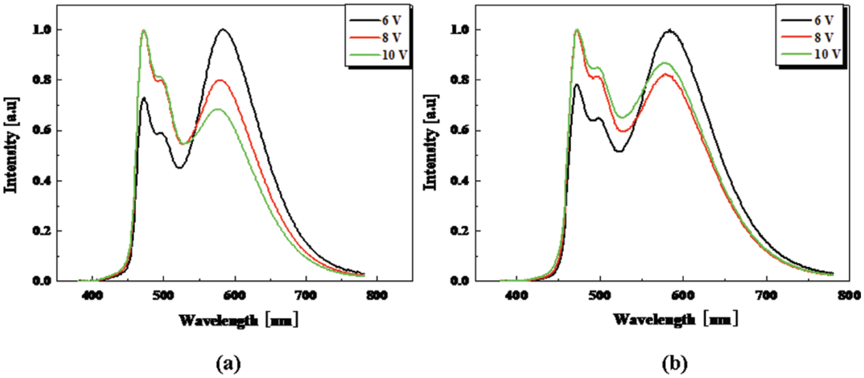


FIGURE 5 The normalized EL spectra of two different WOLEDs (a) device A and (b) device B.

B (Table 1), in which CRI value of 74 for device B was slightly larger than that of 73 for device A.

Figure 6 shows current density - applied voltage (I - V) characteristics and luminance - applied voltage (L - V) characteristics (inset) for devices A and B, respectively. Luminance of devices A and B at 10 V was measured to be 2095 cd/m^2, 5638 cd/m^2, respectively. The maximum luminance and luminance efficiency of device A were measured to be 4565 cd/m^2 at 11 V and 2.9 cd/A at 0.88 mA/cm^2 and those of device B were measured to be 11280 cd/m^2 at 11 V and 3.5 cd/A at 161.1 mA/cm^2, respectively. The efficiency of device A with HBL was measured to be lower than that of B without HBL. As shown in Figure 6, at the same applied voltage, current density of device A was measured to be lower than that of device B whereas luminance of device A exhibited much lower than that of device B. This suggested that the insertion of HBL in device A deteriorated hole and electron balance in light-emitting layers and efficiency of device.

TABLE 1 Gaussian Fits and Integration of EL Spectra, CRI Values and CIE$_{xy}$ Coordinates Obtained from Devices A and B at 6 and 10 V, Respectively

		CIE$_{XY}$	CRI	Gaussian fit at RED region	Gaussian fit at GREEN region	Gaussian fit at BLUE region
Device A	At 6 V	(0.41, 0.42)	73	106.4947	18.6210	21.0406
	At 10 V	(0.34, 0.41)	73	119.3729	32.2537	16.0782
Device B	At 6V	(0.41, 0.42)	74	109.0766	16.5653	28.4356
	At 10 V	(0.36, 0.42)	74	118.1316	31.9404	16.3831

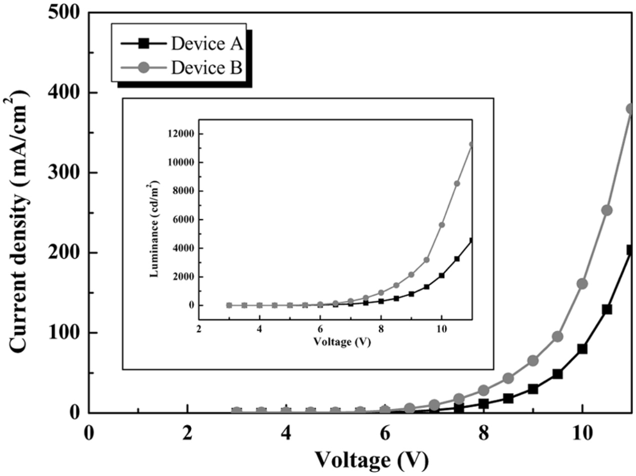
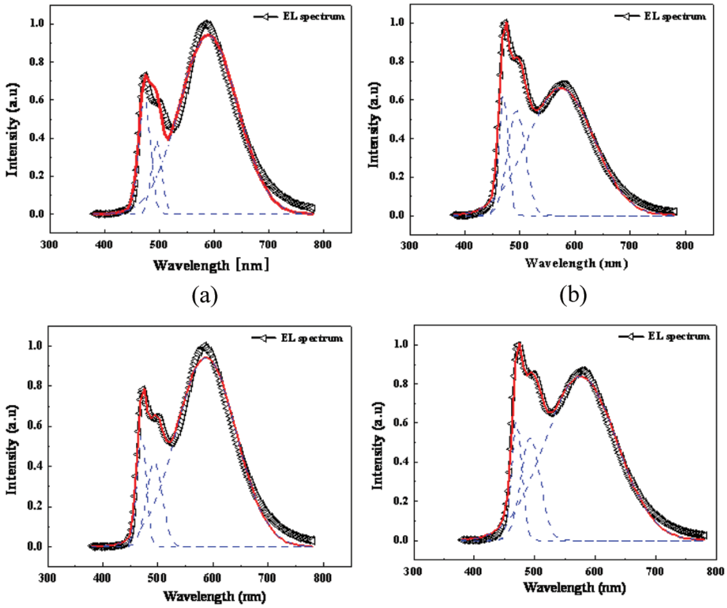


FIGURE 6 Current density – voltage (I – V) and luminance – voltage (L – V) (inset) characteristics for devices A and B.



(a) (b)

(c) (d)

FIGURE 7 Gaussian fitting of EL spectra (normalized) for two different WOLEDs (a) device A at 6 V, (b) device A at 10 V, (c) device B at 6 V, and (d) device B at 10 V.

3.3. Gaussian Fits of EL Spectra

In order to improve representing color characteristics, it is required suitably mixed three colors. The Gaussian fits of EL spectra can extract maximum areas and intensities for three different colors. Figure 7 shows that the Gaussian fitting covers broad range of emission region and fitted curves have good correlations. Three peaks at RGB region can be sufficient to analyze the EL spectra. The peak maxima were around 460 nm (B), 490 nm (G) and 590 nm (R), respectively. The Gaussian fitting did not generate the same peak wavelength for each spectrum. As shown in Figure 7 and Table 1, as the applying voltage was increased, the red emission was reduced whereas green emission was enhanced. These results unanimously supported the emission region broadened under high applying voltage.

4. CONCLUSIONS

New WOLEDs with combination of fluorescent red and phosphorescent blue emitting layers were fabricated and EL spectra for them were analyzed as a function of applying voltage. Although efficiency of device with HBL was lower compared to that of device without HBL, both devices exhibited a slightly low color temperature and bright EL emission from yellowish-white to greenish-white. These results were supported by measurement of CIE_{xy} coordinates, CRI and EL characteristics and analysis of EL spectra by Gaussian fitting for them. Therefore, although device efficiency was not sufficient for application in WOLEDs, it was concluded that this device could be a candidate for WOLEDs by further optimization of device such as device structure, a red or a blue emitting material and host materials.

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