

## White Organic Light Emitting Diodes using Red and Blue Phosphorescent Materials with Blocking Layer

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High-efficiency white organic light-emitting diodes (WOLEDs) were fabricated with two emissive layers and an blocking layer was sandwiched between two phosphorescent dopants, bis(3,5-difluoro-2-(2-pyridyl)phenyl-(2-carboxypyridyl) iridium III (FIrpic) as the blue emission and a newly synthesized red phosphorescent material guest, bis(5-acetyl-2-phenylpyridinato-N,C<sup>2'</sup>) acetylacetonate ((acppy)<sub>2</sub>Ir(acac)). This blocking layer prevented a T-T annihilation in a red emissive layer, and balanced with blue and red emission as blocking of hole carriers. The white device showed Commission Internationale d'Eclairage (CIE<sub>x,y</sub>) coordinates of (0.317, 0.425) at 22400 cd/m<sup>2</sup>, a maximum luminance of 27300 cd/m<sup>2</sup> at 268 mA/cm<sup>2</sup>, a maximum luminous efficiency and power efficiency of 26.9 cd/A and 18.6 lm/W.

*Keywords* : White organic light emitting diodes, Two phosphorescent dyes, Spacer

### 1. INTRODUCTION

White organic light-emitting diodes (WOLEDs) have attracted a great deal of spotlight due to their potential applications such as full colour flat-panel displays, backlight units (BLU) for liquid crystal display (LCD), and solid-state lighting technologies[1-5]. Recently, a number of papers appeared showing the high-efficiency WOLEDs with phosphorescent materials able to use both singlet and triplet excitons. These phosphorescent materials, iridium and platinum complexes with organic materials, could be doped in a host material in emissive layers. The internal quantum efficiency of the phosphorescent devices can be increased to 100 %, in principle. Although much research has investigated phosphorescent materials, a few has examined WOLEDs with two phosphorescent materials[7,8]. D'Andrade *et al.* demonstrated high-efficiency WOLEDs using bis(3,5-difluoro-2-(2-pyridyl)phenyl-(2-carboxypyridyl) iridium III (FIrpic) as the blue dopant material and bis(2-(2'-benzo[4,5-a]thienyl)pyridinato-N,C<sup>3'</sup>) iridium(acetylacetonate) (Btp<sub>2</sub>Ir(acac)) as the red dopant material, and 2,9-Dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) as the exciton blocking layer[7]. The maximum quantum efficiency and luminous efficiency was 5.2 % and 11 cd/A, respectively. Wang *et al.* demonstrated similar WOLED using both blue and red phosphorescent materials in

which FIrpic was doped in *N, N'*-dicarbazolyl-1, 4-dimethene-benzene (DCB) as a blue emissive layer and bis(1-(phenyl)isoquinoline) iridium (III) acetylacetonate (Ir(piq)<sub>2</sub>(acac)) was doped in 4,4'-bis(9-carbazolyl)-2,2'-biphenyl (CBP) as a red emissive layer without an exciton blocking layer. The WOLED exhibited white emission, the maximum luminous efficiency of 10.5 cd/A, and luminance of 22000 cd/m<sup>2</sup>[9].

In this study, we demonstrated high-efficiency WOLEDs with blue and red emissive layers using an blocking layer in order to prevent a triplet-triplet (T-T) annihilation in a red emissive layer, and balance with blue and red emission as blocking of hole carriers. As a results, WOLEDs presented a maximum luminance of 27300 cd/m<sup>2</sup> and maximum luminous efficiency of 26.9 cd/A.

### 2. EXPERIMENTAL DETAILS

WOLEDs were fabricated on a glass substrate precoated with a 1000 Å thick layer of indium-tin-oxide (ITO) having a sheet resistance of 30 Ω / square. The ITO substrates were chemically cleaned by using sonication with acetone, methyl alcohol, and distilled water for 15 minutes. After which they were kept in isopropyl alcohol for 48 hours and dried by N<sub>2</sub> gas gun.

Dried substrates were treated with an oxygen plasma under  $2 \times 10^{-2}$  Torr at 125 W for 2 minutes. All organic materials and metal were grown in succession without breaking the vacuum ( $\sim 8 \times 10^{-7}$  Torr). Figure 1 shows the schematic diagrams of the OLEDs with various structures. After patterning and plasma treatment of ITO anode, an *N,N'*-diphenyl-*N,N'*-(2-naphthyl)-(1,1'-phenyl)-4,4'-diamine (NPB) as a hole transport layer, two emitting layers (EMLs), 4,7-diphenyl-1,10-phenanthroline (BPhen) as an electron transport and hole block layer, a lithium quinolate (Liq) as a electron injection layer, and Al were deposited sequentially. A host material for EMLs of all devices was CBP, and blue and red dyes with their respective doping concentrations were 15 % of Flrpic and 2 % of (acppy)<sub>2</sub>Ir(acac). The structure of device I was ITO / NPB (500 Å) / Blue EML (380 Å) / Red EML (20 Å) / BPhen (300 Å) / Liq (20 Å) / Al (1000 Å), device II was ITO / NPB (500 Å) / Blue EML (360 Å) / Spacer BPhen (20 Å) / Red EML (20 Å) / BPhen (300 Å) / Liq (20 Å) / Al (1000 Å), and device III was ITO / NPB (500 Å) / Blue EML (330 Å) / Spacer BPhen (50 Å) / Red EML (20 Å) / BPhen (300 Å) / Liq (20 Å) / Al (1000 Å), respectively. After deposition of all organic materials and metal, the device was encapsulated in a glove box under 1 ppm concentrations of O<sub>2</sub> and H<sub>2</sub>O with a moisture absorbent, barium-oxide powder. The emission area of devices was 3 mm × 3 mm. The electroluminescence (EL) spectra were measured with a spectra meter IVL 2000 of (JBS International Co.). Current density-luminescence-luminous efficiency-Commission Internationale De L'Eclairage (CIE<sub>x,y</sub>) coordinates-power efficiency-voltage characteristics were measured and recorded on time with a Chroma meter CS-100A (Minolta) and current and voltage were controlled with a measurement unit (model 236, Keithley).

### 3. RESULTS AND DISCUSSION

Figure 2 shows the normalized EL spectra of the OLEDs from 8 V to 14 V. Device I does not have an blocking layer BPhen while device II and III have a 20 Å and 50 Å thick blocking layer, respectively. Device I showed a blue emission at the wavelengths of 475 nm and 500 nm due to Flrpic, and a red emission at the wavelength of 571 nm due to (acppy)<sub>2</sub>Ir(acac). Device II and III containing blocking layer of BPhen, also showed similar emission characteristics at the wavelengths of 476 nm, 505 nm, and 575 nm as in device II and 475 nm, 501 nm, and 571 nm as in device III, respectively. The device II and III exhibited the same spectral feature while device I has strong red emissive spectrum due to non blocking layer of BPhen.

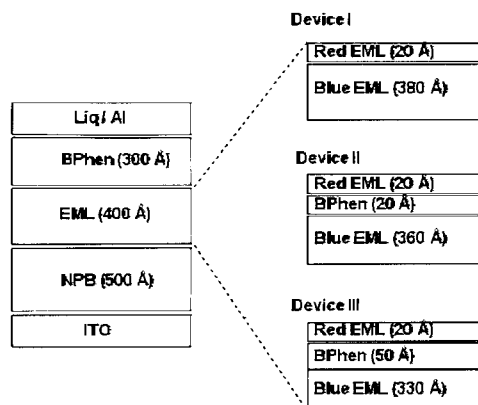


Fig. 1. Schematic diagrams of the various OLED structures used in this study (Blue EML: Flrpic 15 % doped in CBP, Red EML: (acppy)<sub>2</sub>Ir(acac) 2 % doped in CBP).

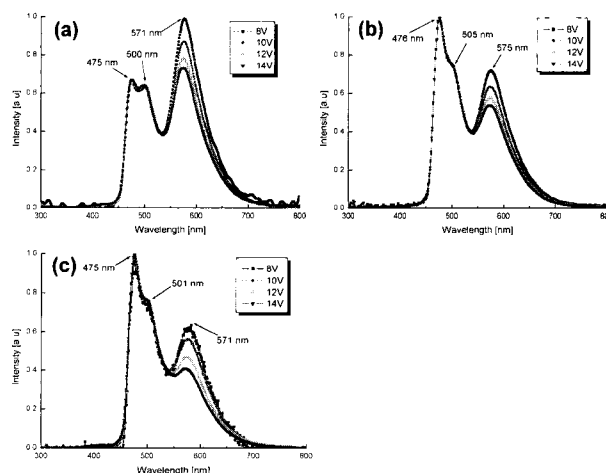


Fig. 2. Normalized EL spectra of the device I, II, and III, respectively. (a) Non-blocking layer (device I), (b) 20 Å thick blocking layer of BPhen (device II), (c) 50 Å thick blocking layer of BPhen (device III).

Figure 3 shows Commission Internationale De L'Eclairage (CIE<sub>x,y</sub>) coordinates with device I, II, and III at various current densities. The CIE<sub>x,y</sub> coordinates of device I changed from (0.431, 0.443) at 21.9 mA/cm<sup>2</sup> to (0.368, 0.436) at 269 mA/cm<sup>2</sup>, device II changed from (0.381, 0.429) at 20.4 mA/cm<sup>2</sup> to (0.317, 0.425) at 268 mA/cm<sup>2</sup>, and device III changed from (0.303, 0.419) at 20.1 mA/cm<sup>2</sup> to (0.242, 0.421) at 281 mA/cm<sup>2</sup>, respectively. The CIE x of all devices showed same slope even if device II and III which contained the blocking layer of BPhen between the blue emissive layer and red emissive layers. If blocking layer of BPhen could prevent diffusion of triplet exciton, CIE x slope of

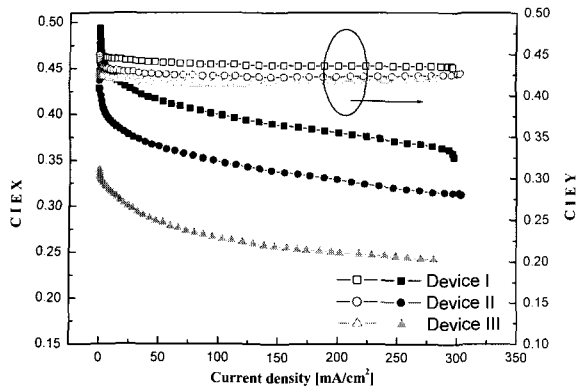


Fig. 3. The  $CIE_{x,y}$  coordinate variation of devices I, II, and III at various current densities (bold: CIE x, hole: CIE y,).

device II and III might be different as device I. The change of CIE x of device I, II, and III were 0.063, 0.064, and 0.061, respectively. It is prove that blocking layer of BPhen could not prevent diffusion of triplet exciton, it could just confine hole carriers in the interface of the blue emissive layer as the highest occupied molecular orbital (HOMO) energy level (6.2 eV) of BPhen[2,6]. Consequently, device II performed WOLED with suitable thickness of blocking layer of BPhen for improving recombination rate of hole and electron carriers.

Figure 4 shows the operational characteristics of devices I, II, and III, respectively. Figure 4(a) presents similar current density characteristics at all devices. However, device II shows better luminance, luminous efficiency, and power efficiency performance than device I and III in Figure 4(b), 4(c), and 4(d), respectively. Some hole carriers took part in recombination for blue and red emission, but other hole carriers leaked to cathode due to non blocking layer of BPhen in device I. Device III also had low recombination rate due to the very thick blocking layer of BPhen. However, 20 Å thick blocking layer of BPhen in device II, could generate more electron-hole pairs because BPhen confined with the hole carriers efficiently and prevented the leakage of the hole carriers to cathode. Moreover, BPhen has favorable electron carrier mobility (Alq<sub>3</sub> electron mobility:  $\sim 10^{-6}$  cm<sup>2</sup> V<sup>-1</sup> s<sup>-1</sup>, BPhen electron mobility:  $\sim 5 \times 10^{-4}$  cm<sup>2</sup> V<sup>-1</sup> s<sup>-1</sup>) [10,11]. Therefore, it could generate more hole and electron pairs in blue emitting layer[6]. The maximum luminance of devices I, II, and III was 20100 cd/m<sup>2</sup> at 269 mA/cm<sup>2</sup>, 27300 cd/m<sup>2</sup> at 268 mA/cm<sup>2</sup>, and 14900 cd/m<sup>2</sup> at 281 mA/cm<sup>2</sup>, respectively. The maximum luminous efficiency and power efficiency of OLEDs was 24.3 cd/A and 15.3 lm/W at 0.558 mA/cm<sup>2</sup> and 0.0417 mA/cm<sup>2</sup> (device I), 26.7 cd/A and 18.6 lm/W at 0.388 mA/cm<sup>2</sup> and 0.0619 mA/cm<sup>2</sup> (device II), and 18.7 cd/A and 14.7 lm/W at 0.0418 mA/cm<sup>2</sup> (device III), respectively.

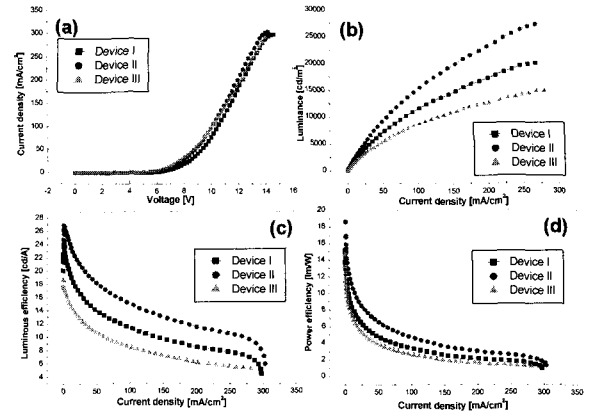


Fig. 4. The electric characteristics of WOLEDs: (a) Driving voltage vs current density, (b) Current density vs luminance, (C) Current density vs luminous efficiency, (d) Current density vs power efficiency.

#### 4. CONCLUSION

In conclusion, we fabricated WOLED by inserting blocking layer of BPhen between the blue and red emissive layers that confined the hole carriers in blue emissive layer with energy barrier and avoided T-T annihilation in red emissive layer. The luminance, luminous efficiency, and power efficiency of the devices containing a blocking layer were improved, respectively.

#### ACKNOWLEDGMENTS

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