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Efficient White Organic Light-Emitting Diodes with Dual Blue Emitting Layer

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We have demonstrated efficient phosphorescent white organic light-emitting diodes (PHWOLEDs) by using iridium (III) bis(1-phenyl(quinolinato-N,C2′))acetylacetonate doped in 4,4,4-tris(N-carbazolyl)-triphenylamine as phosphorescent red emitting layer and iridium (III) bis[(4,6-di-fluoropheny)-pyridinato-N,C2] picolinate doped in dual blue-emitting layer (D-BEML), N,N′-dicarbazolyl-3,5-benzene and 2,2′,2″″-(1,3,5-benzenetryl) tris(1-phenyl)- 1H-benzimidazol, respectively. D-BEML structure have broad exciton formation zone than single BEML. The optimized PHWOLEDs showed an external quantum efficiency of 5.93%, current efficiency of 11.54 cd/A, and Commission Internationale de L'Eclairage coordinates of (0.45, 0.37) at 1000 cd/m^2.

Keywords phosphorescent white organic light-emitting diodes; dual blue-emitting layer

Introduction

Since the first report on light emission from organic light-emitting diodes (OLEDs) by Tang and Van Slyke, advances of red, green, and blue organic materials, device structures, and manufacturing processes have led to the demonstration of full-color OLEDs [1–5].

White OLEDs (WOLEDs) have many advantages over other displays or light sources such as flexibility, low cost manufacturing, thin and light, and design freedom [6,7]. There have been some demonstrations of white OLEDs as light sources for general illumination and backlight of liquid crystal displays. Phosphorescent WOLEDs (PHWOLEDs) have been investigated intensively because they can harvest both singlet and triplet excitons.

Currently main issues of PHWOLEDs are high efficiency, long life time, and stable color. Therefore many researchers have studied on the structure optimization of PHWOLEDs and dual blue-emitting layer (D-BEML) for the efficient charge trapping and proper recombination zone to achieve high efficiency. In this work we fabricated several PHWOLEDs by using iridium (III) bis(1-phenyl(quinolinato-N,C2′))acetylacetonate ($Ir(pq)_2(acac)$) doped in 4,4,4-tris(N-carbazolyl)-triphenylamine (TCTA) as phosphorescent red emitting layer and iridium (III) bis[4,6-di-fluoropheny)-pyridinato-N,C2]

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picolinate (FIrpic) doped in D-BEML, N,N′-dicarbazolyl-3,5-benzene (mCP) and 2,2″,2″-(1,3,5-benzenetryl) tris(1-phenyl)- 1H-benzimidazol (TPBI), respectively. The optimized PHWOLEDs showed an external quantum efficiency (EQE) of 5.93%, current efficiency (CE) of 11.54 cd/A, and Commission Internationale de L'Eclairage ($CIE_{x,y}$) coordinates of (0.45, 0.37) at 1000 cd/m^2.

Experimental

Fabrication of OLED

The ITO glass obtained from Sunic System Co. had 150-nm-thick indium tin oxide (ITO) layer and had a sheet resistance of 12 Ω/sq. The ITO glass was cleaned with acetone, methanol, distilled water, and isopropyl alcohol in ultrasonic bath. The pre-cleaned ITO was treated with O2 plasma treatment under the conditions of 2 × 10–2 Torr, 125 W, and 2 min. All organic layers were sequentially deposited onto patterned ITO glass substrate without breaking vacuum at a pressure of about 5 × 10–7 Torr using the thermal evaporation equipment. The deposition rates were 0.1 nm/s for organic materials and 0.01 nm/s for lithium quinolate (Liq), respectively. Finally the Al cathode was deposited at a rate of 1 nm/s.

Measurements

The optical and electrical properties of WOLEDs such as the current density, luminance, current efficiency (CE), power efficiency (PE), and CIEx,y color coordinates were measured with Keithley 236 and chroma meter CS-1000A under the DC voltage bias.

Results and Discussion

Figure 1(a) shows the chemical structures of the key materials used in this study including FIrpic as phosphorescent blue emitter, $Ir(pq)_2(acac)$ as phosphorescent red emitter, TCTA as phosphorescent red host, TPBI and mCP as phosphorescent blue hosts, respectively. As shown in Figure 1(b), two OLED devices had structure of ITO (150 nm)as anode / N,N′-bis-(1-naphyl)-N,N′-diphenyl-1,1′-biphenyl-4,4′-diamine (45 nm) as hole transporting layer/TCTA (5 nm) as electron blocking layer/$Ir(pq)_2(acac)$ doped in TCTA (1 nm) as red EML (REML)/FIrpic doped in mCP (device A) or FIrpic doped in TPBI (device B) as BEML/4,7-diphenyl-1,10-phenanthroline (BPhen) (30 nm) as electron transporting layer and hole blocking layer/Liq (2 nm) as electron injection layer/Al (100 nm) as cathode, respectively. Here, Device A and B had Firpic doped in mCP (8 wt.%, 9 nm) as single BEML (S-BEML) and FIrpic doped in mCP (8 wt.%, 4.5 nm) and FIrpic doped in TPBI (8 wt.%, 4.5 nm) as D-BEML, respectively. The doping concentrations of $Ir(pq)_2(acac)$ in TCTA and FIrpic in mCP and TPBI were optimized at 8 wt.%, respectively.

Figure 2 shows the current density and luminance versus voltage characteristics of PHWOLEDs with different BEML structure. Device A and B showed the maximum current density 215 and 190 mA/cm^2 at 7 V, respectively. Device A and B also had a maximum luminance of 4088 and 5252 cd/cm^2 at 6 V, respectively. Device B showed lower current density than device A because TPBI of device B had a considerably lower hole mobility than mCP of device A.

Figure 3(a) and (b) show the CE and PE versus luminance characteristics of device A and B with different BEML structure, respectively. Two devices showed a maximum

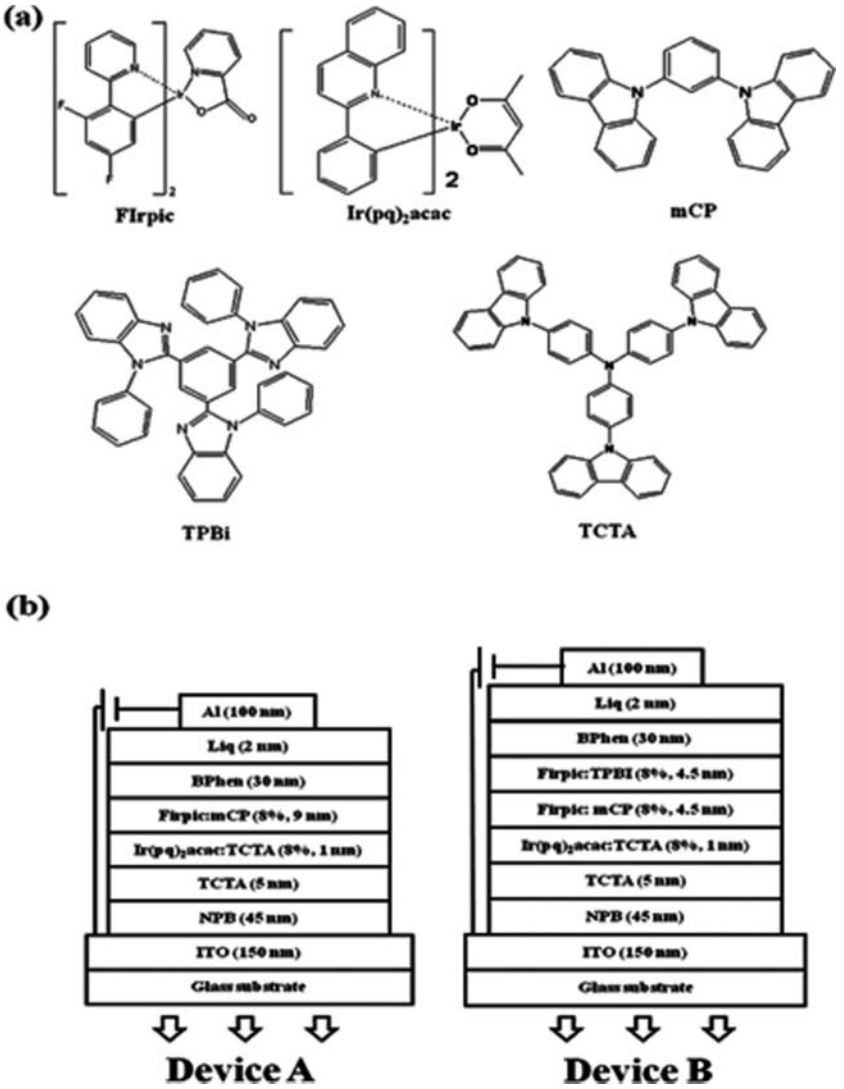

Figure 1. (a) Molecular structure of the key materials used for fabrication. (b) The structures of the device A and B fabricated in this study.

CE of 8.27 and 12.11 cd/A at 95.8 and 493 cd/m^2, and a maximum PE of 7.42 and 11.78 lm/W at 95.8 and 35 cd/m^2 respectively. Two devices also showed a CE of 7.11 and 11.54 cd/A and a PE of 5.33 and 9.47 lm/W at 1000 cd/m^2, respectively. Device B showed higher efficiency than device A because of brode recombination zone [8]. Device A with SBEML have exciton formation zone (EFZ) at mCP side at the interface of mCP and BPhen. On the other hands, device B with D-BEML is expected to have EFZ both at mCP and TPBI side at the interface of mCP and TPBI. This indicates that device B having D-BEML can exploit broader EFZ than device A having single EML. Moreover, mCP, and TPBI are a well-known hole-transport -and electron transport - type material, respectively. Therefore, holes and electronsare accumulated at the interface of mCP and TPBI layer.

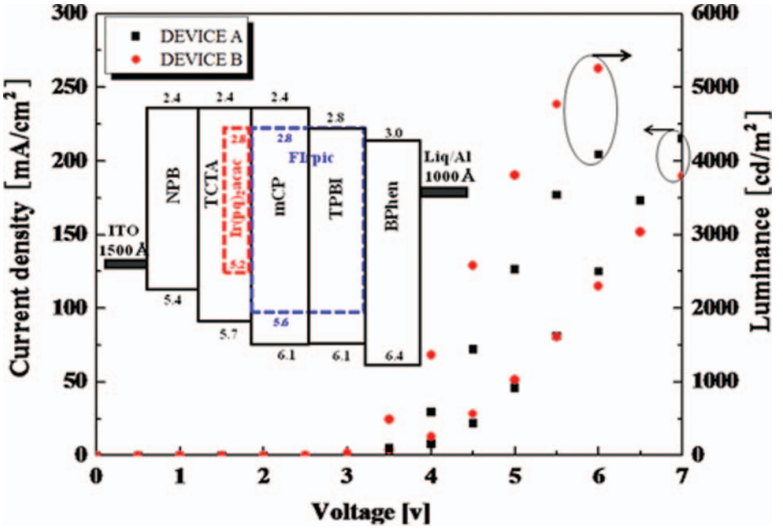

Figure 2. Current density (J) and luminance (L) versus voltage characteristics of device A and B. Inset: energy level diagram for the device B.

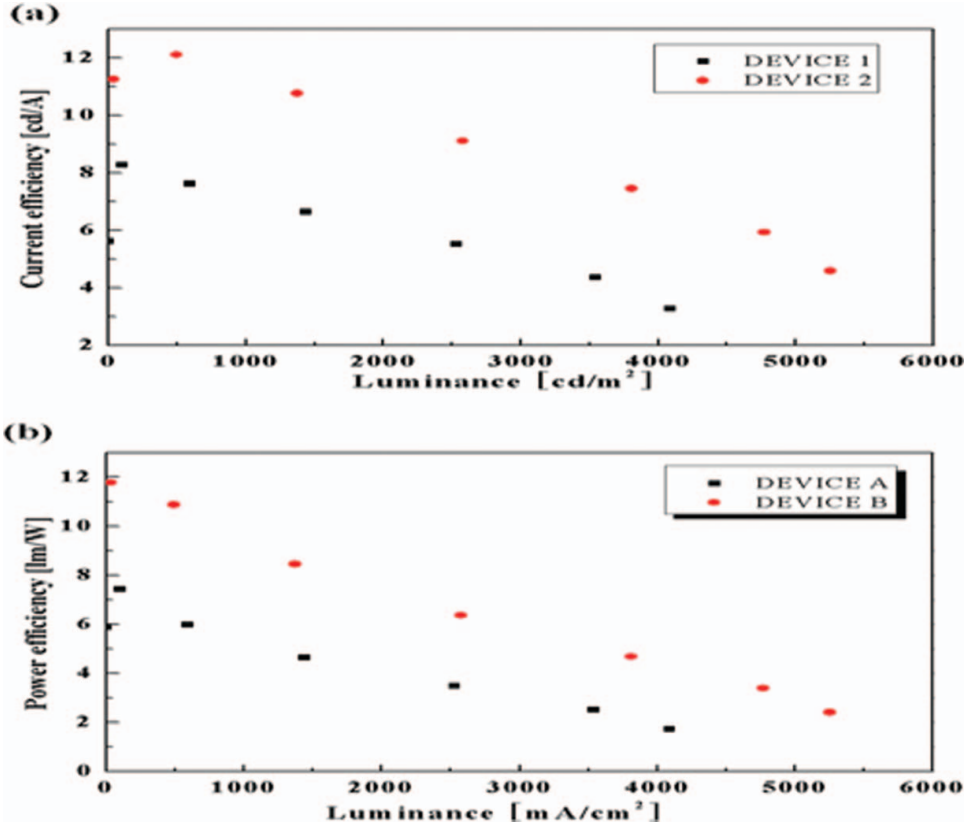

Figure 3. (a) Current efficiency versus luminance characteristics of device A and B. (b) Power efficiency versus luminance characteristics of device A and B.

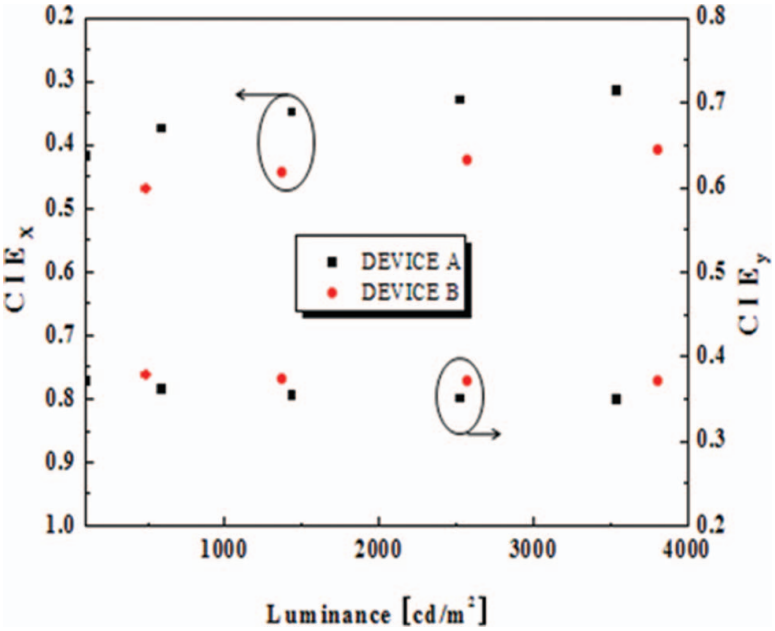

Figure 4. Commission Internationale de L'Eclairage coordinates versus luminance characteristics of device A and B.

Figure 4 shows the $CIE_{x,y}$ coordinates versus luminance characteristics of the devices A and B from 100 to 4000 cd/m^2. The device A and B showed $CIE_{x,y}$ coordinates (x = 0.36, y = 0.36) and (x = 0.45, y = 0.37) at 1000 cd/m^2, respectively. Device B showed reddish white emission because recombination zone was formed between red EML and blue EML.

Conclusions

In this paper, we demonstrated efficient blue PHWOLEDs by using $Ir(pq)_2(acac)$ doped in TCTA and FIrpic doped in D-BEML, mCP and TPBI. White device using D-BEML exploited broaden EFZ than that of S-BEML. The optimized PHWOLEDs of D-BEML showed an EQE of 5.93%, CE of 11.54 cd/A, and $CIE_{x,y}$ coordinates of (0.45, 0.37) at 1000 cd/m^2.

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