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Efficient Deep-Blue Organic Light-Emitting Diodes

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We have demonstrated efficient deep-blue organic light emitting diodes using 4,4′-bis(9-ethyl-3-carbazovinylene)-1,1′-biphenyl (BCzVBi) doped in 4′-(dinaphthalen-2-yl)-1,1′-binaphthyl (DNBN) as emitting layer. There is more overlap between the photoluminescence (PL) spectrum of DNBN and ultra violet (UV)/visible absorption spectrum of BCzVBi than PL spectrum of 2-methyl-9,10-di(2-naphthyl) anthracene (MADN) and UV/visible absorption of BCzVBi, resulting in efficient energy transfer from DNBN to BCzVBi. The optimized deep-blue device showed a peak current efficiency of 5.12 cd/A, peak external quantum efficiency (EQE) of 4.72%, and as Commission Internationale d'Eclairage coordinates of (0.15, 0.12). The device using blue host, DNBN, exhibited higher EQE of 1.6 times at 1 mA/cm^2 than control device using blue host, MADN.

Keywords Deep-blue organic light emitting diodes; 4′-(dinaphthalen-2-yl)-1,1′-binaphthyl

Introduction

Since the first report on light emission from organic light-emitting diodes (OLEDs) by Tang and Van Slyke, many researchers of OLEDs have been developed to improve their luminance efficiency, device structures, and manufacturing processes of OLEDs [1–5]. As a result, low driving voltage and high power efficiency have been achieved for red- and green-emitting devices [6,7]. However, efficient and stable organic blue emitters still need to be improved for full-color displays and lighting applications. Therefore many researchers have studied various blue host material systems for guest-host doped emitter system [8–10]. Host-dopant system can significantly improve device performance, because of the efficient Förster energy transfer from the host to the dopant molecules. The spectral overlap between the emission of the host and the absorption of the dopant is important because it improved energy transfer efficiency.

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2-Methyl-9,10-di(2-naphthyl) anthracene (MADN) as anthracene derivatives and 4,4′-bis(9-ethyl-3-carbazovinylene)-1,1′-biphenyl (BCzVBi) are well known as fluorescent blue host and dopant, respectively [11,12]. In this paper, we demonstrated efficient deep-blue OLEDs by using BCzVBi doped in 4′-(dinaphthalen-2-yl)-1,1′-binaphthyl (DNBN) as emitting layer. There is more overlap between the photoluminescence (PL) spectrum of DNBN and ultra violet (UV)/visible absorption spectrum of BCzVBi than PL spectrum of MADN and UV/visible absorption of BCzVBi, resulting in efficient energy transfer from DNN to BCzVBi. The optimized deep-blue device showed a peak current efficiency of 5.12 cd/A, peak external quantum efficiency (EQE) of 4.72%, and as Commission Internationale d'Eclairage ($CIE_{x,y}$) coordinates of (0.15, 0.12).

Experimental

Fabrication of OLED

Indium tin oxide (ITO) films on glass substrates was formed and patterned by our colleagues in the laboratory at Hoseo University. N,N′-Bis-(1-naphyl)-N, N′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB), bis-(2-methyl-8-quinolinolate)-4-(phenylphenolato)aluminium (BAlq), and lithium quinolate (Liq) were purchased from the Dow Chemical Company. MADN and DNBN were synthesized by coworkers in the laboratory at Sungkyunkwan University. BCzVBi and Al were purchased from the Sigma-Aldrich Chemical Company.

Glass substrate coated with a 170-nm-thick ITO layer has a sheet resistance of 15 Ω/sq. ITO manufactured by Sunic System was cleaned with acetone, methanol, distilled water, and isopropyl alcohol in ultrasonic bath. Then, pre-cleaned ITO was treated by O2 plasma treatment with the conditions of 2×10^{-2} Torr, 125 W, and 2 min. All organic layers were sequentially deposited onto the substrate without breaking vacuum at a pressure of about 5×10^{-7} Torr, using thermal evaporation equipment. The deposition rates were 0.1 nm/s for organic materials and 0.01 nm/s for Liq, respectively. Finally, the Al cathode was deposited at a rate of 1 nm/s. The doping concentrations of dopant were optimized. The devices were encapsulated immediately after preparation under nitrogen atmosphere.

Measurements

With the DC voltage bias, current density, luminance, current efficiency, EQE, $CIE_{x,y}$ coordinates, and electroluminescence characteristics were measured with Minolta CS-1000 instrument to which a digital source meter (Keithley 236) and a desktop computer used to operate the devices were connected. All measurements were carried out under ambient conditions at room temperature.

Results and Discussion

Figure 1(a) shows the molecular structure of key materials used for fabrication, MADN as blue host (device A), DNBN as blue host (device B), and BCzVBi as blue dopant, respectively. Figure 1(b) shows blue device structures fabricated in this study, and the detailed structures are as follows: ITO/NPB (50 nm)/8% BCzVBi: MADN (device A) or DNBN (device B) (30 nm)/BAlq (30 nm)/Liq (2 nm)/Al

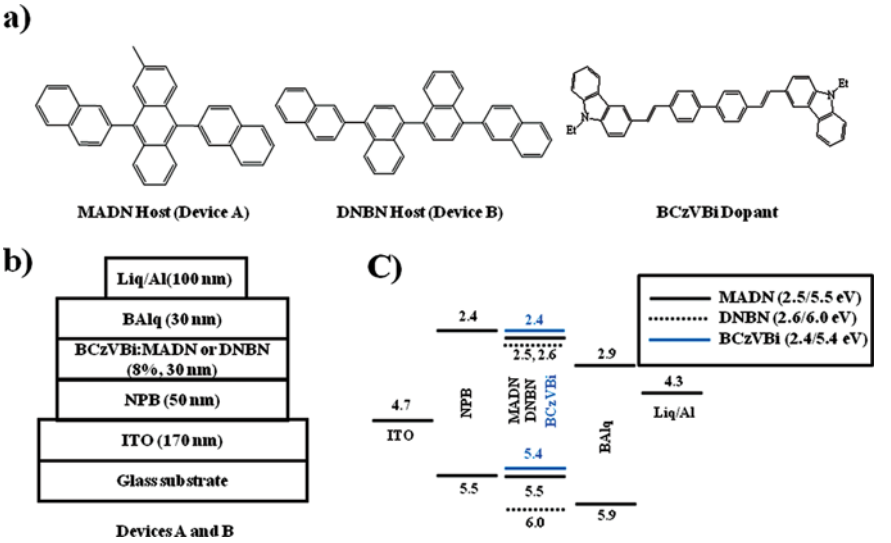

Figure 1. (a) Molecular structure of the key materials, MADN, DNBN, and BCzVBi used for fabrication. (b) The structures of blue devices fabricated in this study. (c) Energy level diagrams for blue devices. Numbers denote the energy level for the HOMO and LUMO of various materials used in this study.

(100 nm). Here, NPB, BAlq, and Liq were used as hole-transporting, hole-blocking and electron-transporting, and electron injection layers, respectively. The doping concentrations of BCzVBi in MADN or DNBN were optimized to 8%. Proposed energy level diagram of devices A and B are shown in Figure 1(c).

Figure 2 shows the UV/visible absorption spectrum of BCzVBi and PL spectra of MADN and DNBN, respectively. The BCzVBi showed the maximum UV/visible

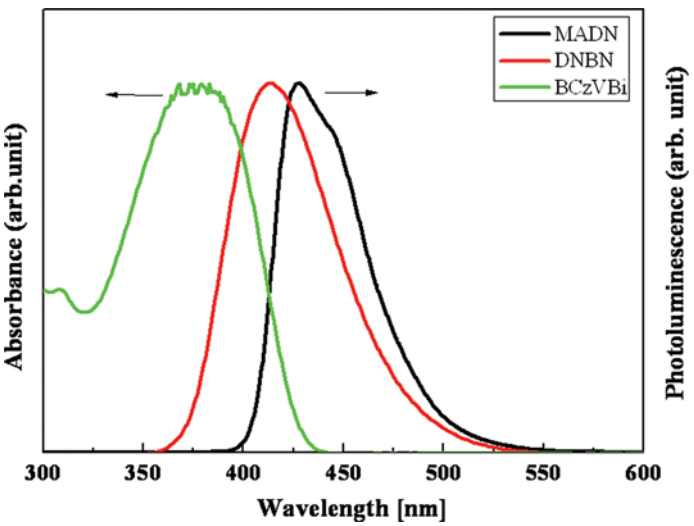

Figure 2. UV/visible absorption of BCzVBi and PL spectra of MADN and DNBN.

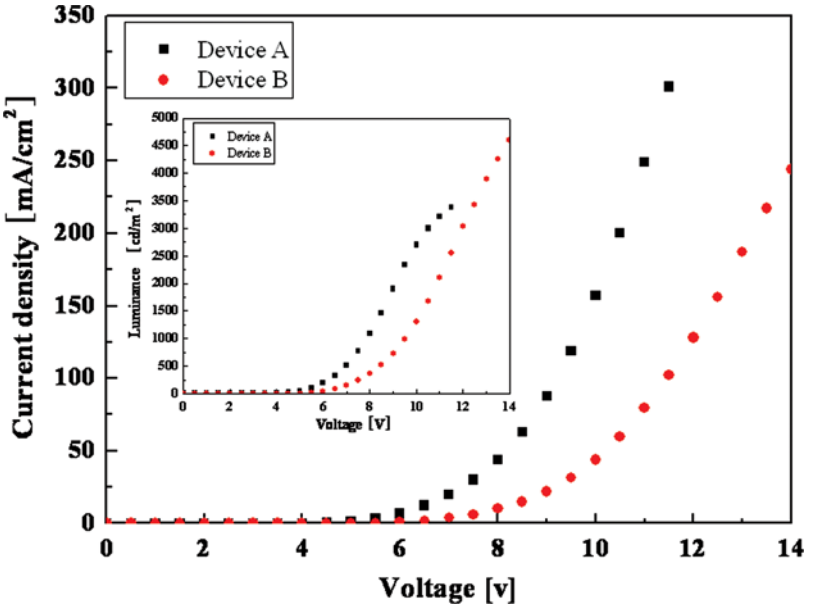

Figure 3. Current density versus voltage characteristics of blue devices. Inset: Luminance versus voltage characteristics of blue devices.

absorption peak of around 373 nm and MADN and DNBN also exhibited the maximum PL peaks of 427.5 and 414 nm. There is more overlap between the PL spectrum of DNBN and UV/visible absorption spectrum of BCzVBi than PL spectrum of MADN and UV/visible absorption of BCzVBi, resulting in efficient energy transfer from DNBN to BCzVBi. This indicate that Förster energy transfer from the DNBN host to the BCzVBi dopant is expected to be more efficient than that from the MADN host to the BCzVBi dopant.

Figure 3 and its inset show current density versus voltage characteristics and luminance versus voltage characteristics of blue devices. It was found in Figure 3 that the current densities for two devices were 301 and 102 mA/cm^2 at 11.5 V. Device B using DNBN host showed lower current density than device A using MADN host, which can be explained with the proposed energy level diagrams of devices A and B as shown in Figure 1(c). Device B had a much larger hole-injection barrier of nearly 0.5 eV between HOMO of the NPB and HOMO of DNBN than them (0 eV) of device A. In addition, DNBN also has unipolar characteristics with excellent electron-transporting ability compared with MADN, which has good hole-transporting ability [13]. Therefore, Devices A using MADN host is expected the recombination zone (RZ) at the interface of MADN and BAlq layer. On the other hand, devices B using DNBN host also is expected the RZ at the interface of NPB and DNBN. Devices A and B showed a maximum luminances of 3374 and 4600 cd/m^2 at 11.5 and 14.0 V, respectively. Device A exhibited saturated curve line around 11.5 V in inset Figure 3.

Figure 4(a) and (b) show the current efficiency and EQE versus current density of devices A and B, respectively. Devices A and B had peak current efficiencies of 3.85 and 5.12 cd/A and peak EQEs of 3.02 and 4.72% at 0.15 and 0.08 mA/cm^2, respectively. They also showed current efficiencies of 3.26 and 4.67 cd/A and EQEs

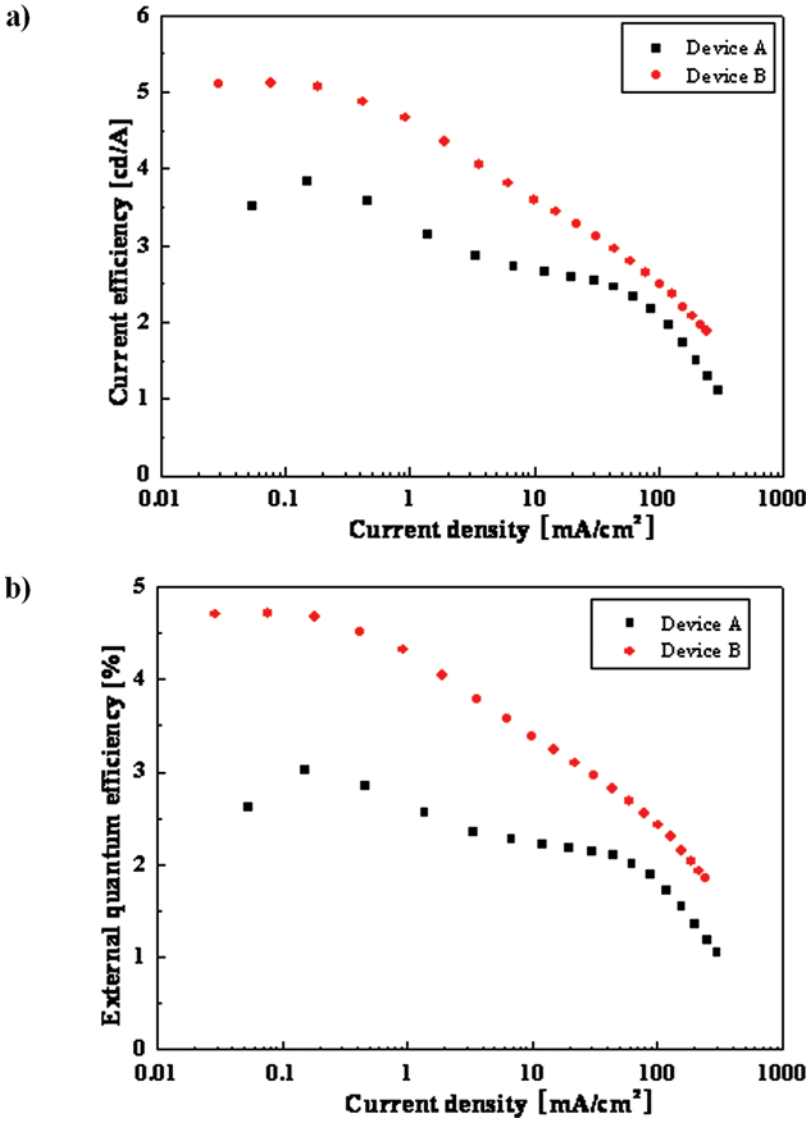

Figure 4. (a) Current efficiency versus current density characteristics of blue devices. (b) External quantum efficiency versus current density characteristics of blue devices.

of 2.65 and 4.32% at 1 mA/cm^2, respectively. Device B using DNBN host showed higher efficiency at the whole current density than device A using MADN because of the efficient overlap of PL spectrum of DNN host with the UV/visible absorption spectrum of BCzVBi in previous result as shown in Figure 2.

Figure 5(a) shows $CIE_{x,y}$ coordinates versus luminance characteristics from 100 to 5000 cd/m^2 of blue devices. They had emission characteristics of $CIE_{x,y}$ coordinates from (0.16, 0.15) and (0.15, 0.12) at 100 cd/m^2 to (0.16, 0.15) and (0.15, 0.12) at 3000 cd/m^2. Figure 5(b) also shows the EL spectra of all devices from the

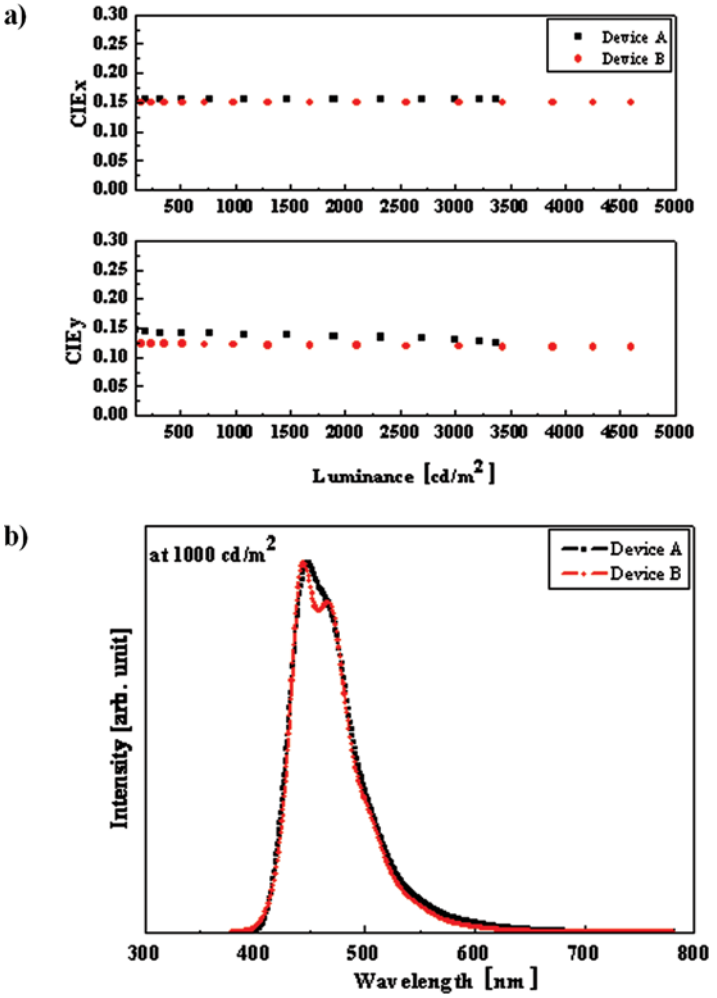

Figure 5. (a) Commission Internationale de I'Eclairage coordinates of blue devices from 100 to 5000 cd/m^2. (b) Electroluminescence spectra of blue devices from 300 to 800 nm at 1000 cd/m^2.

wavelength of 350 to 800 nm at 1,000 cd/m^2. Two blue devices showed maximum peak at 445 nm and sub-peak at 466 nm.

Conclusions

In conclusion, a deep-blue OLED has been successfully demonstrated by using BCzVBi dopant doped in DNBN host. The optimized deep-blue device showed a peak current efficiency of 5.12 cd/A, peak EQE of 4.72%, and as $CIE_{x,y}$ coordinates of (0.15, 0.12). The device using blue host, DNBN, exhibited higher EQE of 1.6 times at 1 mA/cm^2 than control device using blue host, MADN because Förster energy transfer from the DNBN host to the BCzVBi dopant is exhibited as more efficient than that from the MADN host to the BCzVBi dopant.

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