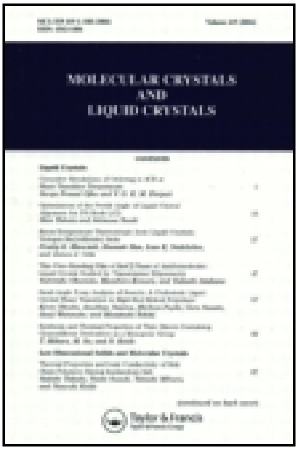

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White Organic Light-Emitting Diodes Based on Three Emissive Layers

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White Organic Light-Emitting Diodes Based on Three Emissive Layers

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We report white organic light-emitting diodes (WOLEDs) based on 4,4′-bis(2,2′-diphenyl vinyl)- 1,1′-biphenyl (DPVBi), fac tris(2-phenylpyridine)iridium ($Ir(ppy)_3$) and bis(2-(2′-benzo[4,5-a]thienyl) pyridinato-N,$C^{3'}$) iridium (acetylacetonate) ($Btp_2Ir(acac)$). White OLEDs with the structure of ITO/NPB/DPVBi/CBP: $Ir(ppy)_3$/BCP: $Btp_2Ir(acac)$/Alq_3/Liq/Al were fabricated and characterized, where $Ir(ppy)_3$ and $Btp_2Ir(acac)$ were used as a green phosphorescent dye and red phosphorescent dye, respectively. And DPVBi was used as blue emitting layer. The electroluminescent spectra of the device consisted of blue fluorescent, green phosphorescent and red phosphorescent emissions. The optimized device exhibited white light emission between 10 and 15 V. A maximum luminance of 11000 cd/m^2 with CIE coordinates of (0.322, 0.344) was reached at 15 V. The white light emission is related to the simultaneous exciton formation on both sides of the CBP/BCP interface. The main exciton formation zone gradually shifts to the CBP side from the BCP side with increase of voltage in the devices. As a result, the intensity of the green and blue emission increased gradually relative to the red emission with increasing voltage.

Keywords: exciton formation zone; white OLEDs

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1. INTRODUCTION

Since Tang and VanSlyke reported efficient thin film organic light emitting diodes (OLEDs), there has been significant improvement in the performance and stability of OLEDs [1]. OLEDs have attracted much attention because of their low power consumption, fast response, wide viewing angle, flexibility and the possibility of wide application [2–3]. Considerable interest is given to OLEDs due to their potential applications namely in flat display technology. The efficiency of electroluminescent organic light-emitting devices can be improved by the introduction of a phosphorescent dye. Energy transfer from the host to the dye occurs via excitons, but only the singlet spin states induce fluorescent emission; these represent a small fraction (about 25%) of the total excited-state population (the remainder are triplet states). Phosphorescent dyes, however, offer a means of achieving improved light emission efficiencies, as emission may result from both singlet and triplet states.

White emission is important for applying OLEDs to full-color flat panel displays and a back-light for liquid crystal displays (LCDs). Doping an organic material host with red, blue, and green dyes or a combination of several electroluminescent organic material blends has been shown to generate white-light emission [4–6]. A lot of efforts have been devoted to developing WOLEDs, for example, stacking the emissive layers of three basic colors in a single device structure, using two different emissive layers separated by a thin wide-bandgap layer, employing low-concentration doping and combining blue and red emissions in a single emissive interface [7–10].

We report white organic light-emitting diodes (WOLEDs) based on 4,4′-bis(2,2′-diphenyl vinyl)-1,1′-biphenyl (DPVBi), *fac* tris(2-phenylpyridine)iridium ($Ir(ppy)_3$) and bis(2-(2′-benzo[4,5-a] thienyl)pyridinato-N,$C^{3\prime}$)iridium(acetylacetonate) ($Btp_2Ir(acac)$). White OLEDs with the structure of ITO/NPB/DPVBi/CBP: $Ir(ppy)_3$/BCP: $Btp_2Ir(acac)$/Alq_3/Liq/Al were fabricated and characterized, where $Ir(ppy)_3$ and $Btp_2Ir(acac)$ were used as a green phosphorescent dye and red phosphorescent dye, respectively. And DPVBi acted as a blue light emitting layer. The electroluminescent spectra of the device consisted of blue fluorescent, green phosphorescent and red phosphorescent emissions.

2. EXPERIMENTAL

ITO (indium-tin-oxide, sheet resistant: 30 Ω/sq) glass substrates were cleaned in the ultrasonic bath of acetone and methanol consecutively, and then rinsed with the distilled water. After dried, ITO-coated glass substrates were treated by O_2 plasma before the usage. The glass substrates were loaded in a deposition chamber for successive thermal deposition of the organic and metal layers under 8×10^{-7} Torr. The deposition rates were 0.01–1 Å/s, and 5–10 Å/s for organics and metal, respectively.

Figure 1 shows the molecular structures of the materials used in the experiments and the structure of the device. A scheme of device structure is ITO/NPB/DPVBi/CBP: Ir(ppy)$_3$/BCP: Btp$_2$Ir(acac)/Alq$_3$/Liq/Al. The device's pixel area was $0.3 \times 0.3\,\text{cm}^2$. Ir(ppy)$_3$ and Btp$_2$Ir(acac) were used as green phosphorescent dye and red phosphorescent dye, respectively. And DPVBi was used as blue emitting layer. NPB was used as hole injection and transport material, and Alq$_3$ was used as electron injection and transport material. CBP and BCP were used as host materials to Ir(ppy)$_3$ and Btp$_2$Ir(acac). The

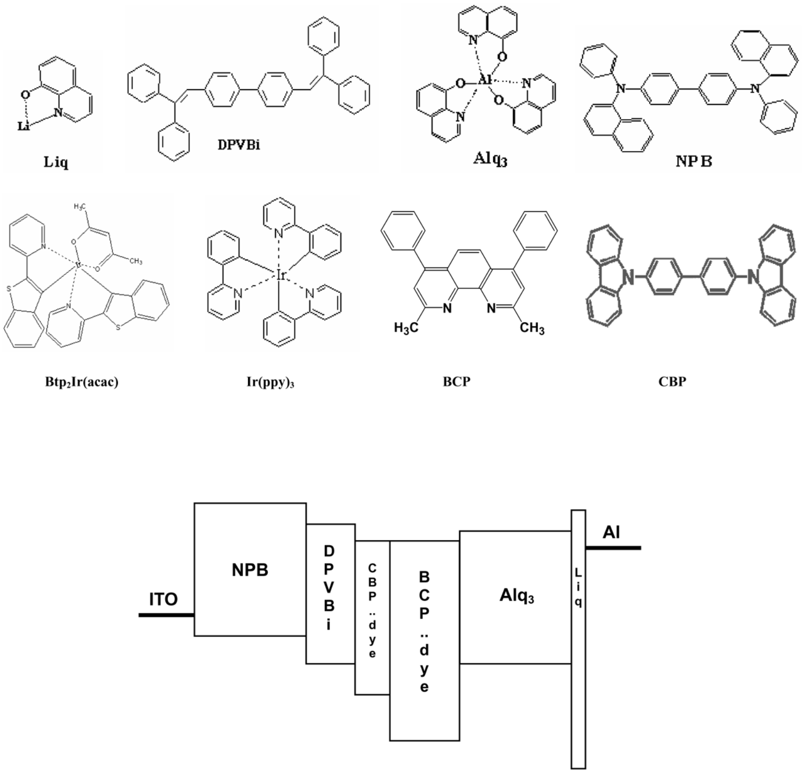


FIGURE 1 The molecular structures of the materials used in the experiment and the structure of the device.

TABLE 1 The Structure of the Device

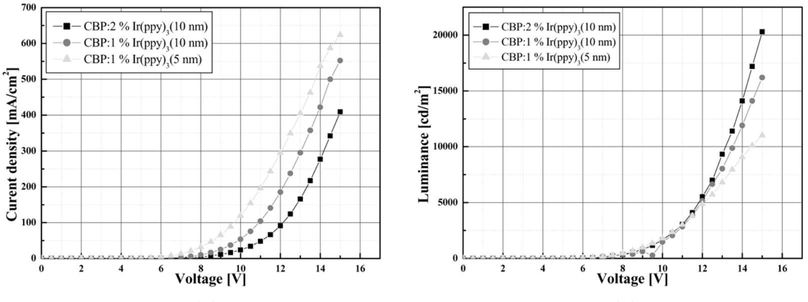
Device 1	ITO/NPB(40 nm)/DPVBi(10 nm)/CBP: 2% Ir(ppy)$_3$(10 nm)/ BCP: 6% Btp$_2$Ir(acac)(20 nm)/Alq$_3$(40 nm)/Liq(2 nm)/Al
Device 2	ITO/NPB(40 nm)/DPVBi(10 nm)/CBP: 1% Ir(ppy)$_3$(10 nm)/ BCP: 6% Btp$_2$Ir(acac)(20 nm)/Alq$_3$(40 nm)/Liq(2 nm)/Al
Device 3	ITO/NPB(40 nm)/DPVBi(10 nm)/CBP: 1% Ir(ppy)$_3$(5 nm)/ BCP: 6% Btp$_2$Ir(acac)(20 nm)/Alq$_3$(40 nm)/Liq(2 nm)/Al

emitting color was tuned to white by controlling the concentration of dopants and the thickness of emitting layers. Therefore, several devices with various doping concentration and different thickness were fabricated. In this paper, we fabricated three different devices. Table 1 shows the structure of the device.

After the fabrication, all devices were encapsulated with the glass in a glove box attached to the deposition system. The current density–voltage-luminance (J-V-L) characteristics of the OLEDs were measured with source measure unit (Kiethly 236). The luminance and CIE chromaticity coordinates of the fabricated devices were measured by using a MINOLTA CS-100A chromameter.

3. RESULTS AND DISCUSSION

Figures 2 (a) and (b) show the characteristics of the current density versus the voltage of the devices and the characteristics of the luminance versus the voltage of the devices, respectively. The thickness and doping concentration of the emitting layers influences the electrical properties of the devices. The current density of the devices increased with the decreases of Ir(ppy)$_3$ concentration in CBP layer



(a) (b)

FIGURE 2 The characteristics of (a) the current density and (b) the luminance versus applied voltage of the devices.

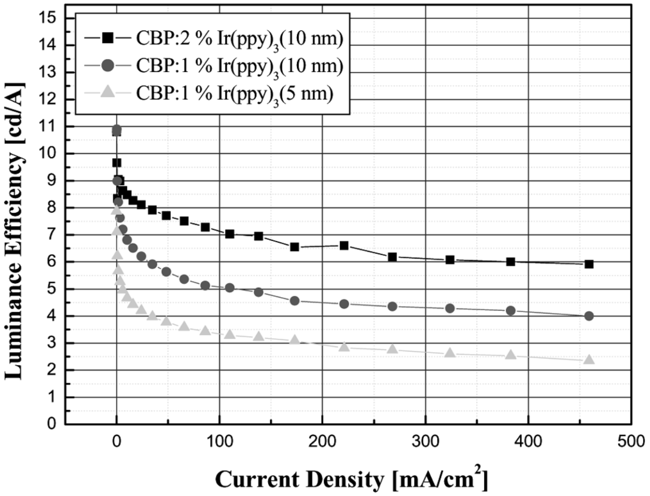


FIGURE 3 The characteristics of the luminance efficiency of the devices.

and thickness of doped CBP layer. On the contrary, the luminance of the devices increased with the increases of $Ir(ppy)_3$ concentration in CBP layer and thickness of doped CBP layer. Therefore, the luminance efficiency of the device 1 was highest, as shown in Figure 3. These result was caused by higher luminous efficiency of $Ir(ppy)_3$ than that of DPVBi and $Btp_2Ir(acac)$.

The emission color was influenced with the thickness and doping concentration of the emitting layers, too. As shown in Figure 4 (a), the CIE X coordinates of the devices get higher with the decreases of

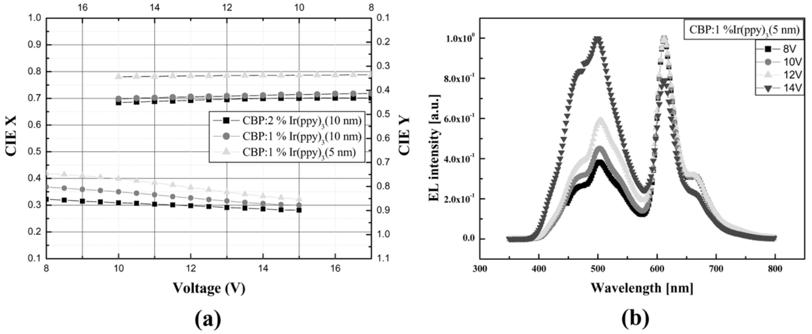


FIGURE 4 The characteristics of (a) the CIE coordinates of the devices and (b) the EL spectra of the white OLEDs.

$Ir(ppy)_3$ concentration in CBP layer and thickness of doped CBP layer, and the CIE Y coordinates of the devices get lower with the decreases of $Ir(ppy)_3$ concentration in CBP layer and thickness of doped CBP layer. As a result, the device 3 showed the optimized white balance. With the consequence that the device 3 was optimize. The device 3 exhibited white light emission between 10 and 15 V. A maximum luminance of 11,000 cd/m^2 with CIE coordinates of (0.322, 0.344) was reached at 15 V.

The CIE X coordinates of the devices gradually shift with the change of the driving voltage. It is thought that the exciton formation zone shifts from BCP side to CBP side of CBP/BCP interface with the increase of the driving voltage, thus the emission intensity of $Ir(ppy)_3$ and DPVBi increase gradually relative to the emission of $Btp_2Ir(acac)$ causing the shift of the color from yellowish to greenish or bluish white. These result was cause a by the intensity of the $Ir(ppy)_3$ and DPVBi emission increased gradually relative to the $Btp_2Ir(acac)$ emission with the main exciton formation zone in the device shift gradually from the BCP side to the CBP side. The CIE Y coordinates of the devices get little higher with the increase of the driving voltage caused by the same reason. These results were confirmed from Figure 4(b).

Figure 4(b) shows the evolution of the EL spectra of device 3 with the applied voltage from 8 V to 15 V. The EL spectra of the device 3 showed an apparent dependence on the operating voltage: At low voltage, holes are the majority carriers in the devices, therefore a number of holes that enter the BCP to form excitons with electrons exceed that of electrons in CBP. As a result, the BCP side is the main exciton formation zone at low voltage and the color of emission was reddish. With the increase of voltage, more and more electrons reach the CBP/BCP interface, and a number of electrons entering the CBP side increases relatively to that of holes entering the BCP side. Therefore, the main exciton formation zone gradually shifts to the CBP side from the BCP side with increase of voltage. As a result, the intensity of the red emission peak decreased and the intensity of blue and green emission peak increased with the increase of the driving voltage [11]. Correspondingly, as shown in Figure 4(a), the CIE coordinates of the device 3 moved from (0.419, 0.336) at 8 V to (0.322, 0.344) at 15 V.

The CBP side of the CBP/BCP interface is generally considered the main exciton formation zone, favored by the fact that the hole injection barrier of 0.4 eV is higher than the electron injection barrier of 0 eV [12–14]. However, the voltage dependence of the EL spectra of the devices in Figure 4 (b) suggest that the main exciton formation zone in the device should likely shift gradually from the BCP side to the CBP side with the increase of the driving voltage. From this, it is reasonable to deduce that the excitons should form on both sides of the CBP/BCP interface simultaneously [15].

4. CONCLUSION

We report white organic light-emitting diodes based on DPVBi, Ir(ppy)$_3$ and Btp$_2$Ir(acac). The thickness and doping concentration of the emitting layers influences the electrical properties and emission color of the devices. The intensity of the green and blue emission increased gradually relative to the red emission with increasing voltage. The device 3 exhibited white light emission between 10 and 15 V. The white light emission is related to the simultaneous exciton formation on both sides of the CBP/BCP interface. The main exciton formation zone in the device should likely shift gradually from the BCP side to the CBP side with the increase of the driving voltage. A maximum luminance of 11,000 cd/m^2 with CIE coordinates of (0.322, 0.344) was reached at 15 V.

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