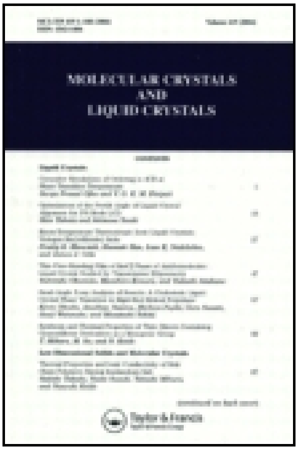

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Color Variation Improvement by Introducing Double Emission Layers in WPLEDs

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Version of record first published: 22 Sep 2010

To cite this article: Soon Kab Kwon, Yong Kyun Lee, Tae Jin Park, Su Hyeon Jeong, Woo Sik Jeon, Jin Jang & Jang Hyuk Kwon (2007): Color Variation Improvement by Introducing Double Emission Layers in WPLEDs, Molecular Crystals and Liquid Crystals, 470:1, 297-304

To link to this article: http://dx.doi.org/10.1080/15421400701496060

Mol. Cryst. Liq. Cryst., Vol. 470, pp. 297–304, 2007
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ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701496060

Color Variation Improvement by Introducing Double Emission Layers in WPLEDs

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We have fabricated white polymeric light-emitting devices (WPLEDs) from polyfluorene-based (PFO) blue and MEH-PPV polymer blending systems. A device structure of ITO/PEDOT:PSS/Blending polymer/Blue polymer/LiF/Al was employed. This double emissive structure results in the significant improvement of white color shift phenomenon. A current efficiency of 4.67 cd/A (3,900 cd/m^2, 6.4 V) and a brightness value of 17,600 cd/m^2 at 9.4 V with (0.34, 0.35) CIE coordinates at 5 V and (0.29, 0.29) at 9 V were obtained.

Keywords: color variation; double emission structure; light-emitting devices; MEH-PPV

INTRODUCTION

White organic light-emitting devices (WOLEDs) have been studied for various applications such as lighting, full color displays with color filters and backlights for liquid crystal displays. Especially, large area

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This research was supported by the Kyung Hee University Research Fund in 2005. (KHU-20051036) The authors gratefully acknowledge SK Corporation. They supplied SKB (Blue emissive material) for this research.

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white light-emitting diode (LED) is of paramount importance for the full-color flat-panel displays. It can be combined with color filters to give red, green, and blue light-emitting pixels. There have been many methods to obtain white OLEDs from small-molecule or polymer materials. The small-molecular based WOLEDs using vacuum deposition process have shown quite high efficiency with complicated structure of multiple emissive layers [1]. This approach is somewhat difficult to achieve low cost mass-production for large area displays [2–6]. In the polymer-based devices, white polymer LEDs (WPLEDs) fabricated by spin-coating or ink jet printing have advantages for simple and less expensive manufacturing process [7,8] and can be easily applied to large-area applications. Therefore, the blending with blue and red polymers was previously reported for such WPLED applications [9]. Incomplete energy transfer from the host to the guest in this system is necessary to get a white light as combined emission of both host and guest [10]. However, due to this mechanism, white color coordinates vary toward blue-emitting region when the applied voltage is increased. Phase separation phenomenon in polymer blending systems is well known and results different turn-on voltages of Red and Blue components [11,12]. Electron injection barrier of the blue polymer device is usually higher than those of other color devices because of high LUMO energy and wide band gap. Therefore, WPLEDs made by polymer blending systems have shown such color variation issue.

In this study, we have fabricated WPLEDs with a double emission structure to improve white color variation. As emissive layers, the polyfluorene-based (PFO) blue and MEH-PPV polymer blended layer and a blue emissive layer were employed.

EXPERIMENTAL

The sheet resistance of ITO (Indium Tin Oxide) for WPLEDs was ~10 Ω/sq.. Line patterns of ITO were formed on the glass by the photolithography. The substrates of 2 cm × 2 cm were cleaned by sonification in an isopropylalcohol (IPA), rinsing in deionized water, acetone and methanol and finally irradiated UV/Ozone before use. Figure 1 shows the device structure used in this study, ITO (150 nm)/PEDOT:PSS (40 nm)/SKB(PFO Blue supplied from SK Corp.):MEH-PPV/SKB (x rpm)/LiF (2 nm)/Al (100 nm). The PEDOT:PSS was spin-coated on the ITO substrate pretreated with UV/Ozone. Samples were dried at 100°C for 10 min on a hot plate to remove water from the polymer layer. SKB polymer was dissolved in toluene with 0.9 wt%, MEH-PPV dissolved in toluene with 0.05 wt%, and then two solutions were mixed by stirring with a magnetic bar.

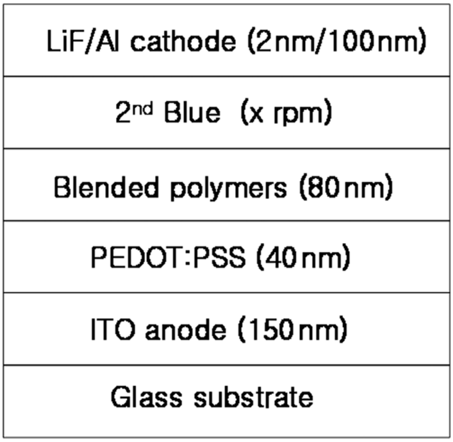


FIGURE 1 Device structure used in the study.

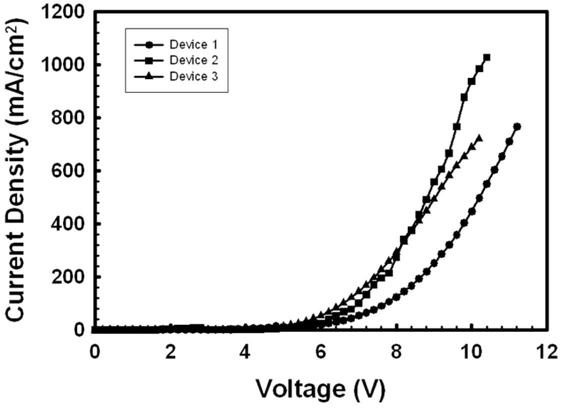
The blended solution was spin-coated on the PEDOT:PSS layer with 1000 rpm. The thickness of the SKB:MEH-PPV layer was 80 nm. The film was baked for 1 hour at 100°C. The SKB was spin-coated on the blending layer with different speed. And then the film was baked for the same condition. Next, LiF and Al layers were deposited in a vacuum system. The deposition rates of LiF and Al were 0.1 Å/s and 5 ~ 10 Å/s, respectively. The current density-voltage (I-V) and luminance-voltage (L-V) characteristics of these PLEDs were measured with a Keithley SMU 238 and a Minolta CS-100A, respectively. Electroluminescence (EL) spectra and CIE color coordinate were obtained using a PR-650 (Photoresearch Co.).

RESULTS AND DISCUSSION

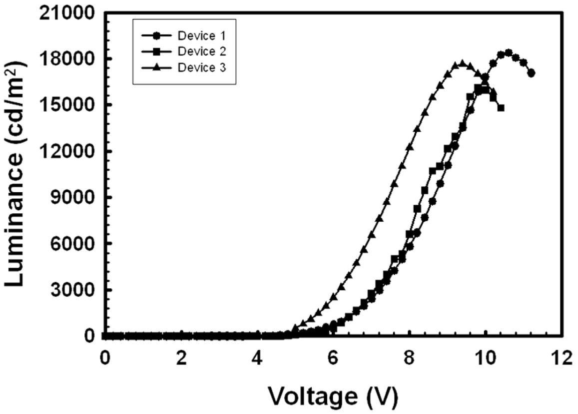
The MEH-PPV ratio in PFO of blending polymer was 1.1%(w/w) to get a white OLED. In our previous results, the composition ratio of red to blue polymers was fixed based on the balance of light intensity in blue and red colors [13]. The second polymer blue layer was introduced on this blended layer. Table 1 shows the spin speed for coating a blue polymer. The second blue layer was successfully coated without any

TABLE 1 Spinning Rates for Coating Second Polymer Layer

	Device 1	Device 2	Device 3
2nd Blue layer	0	2000 rpm	3000 rpm



(a) I-V data

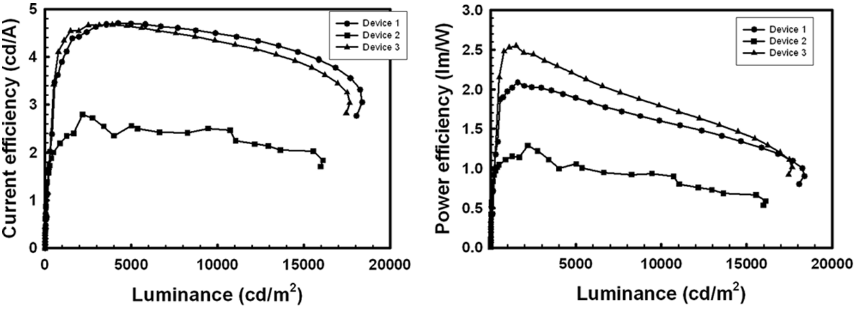


(b) L-V data

FIGURE 2 The I-V-L characteristics of three WPLEDs. (a) I-V and (b) L-V data.

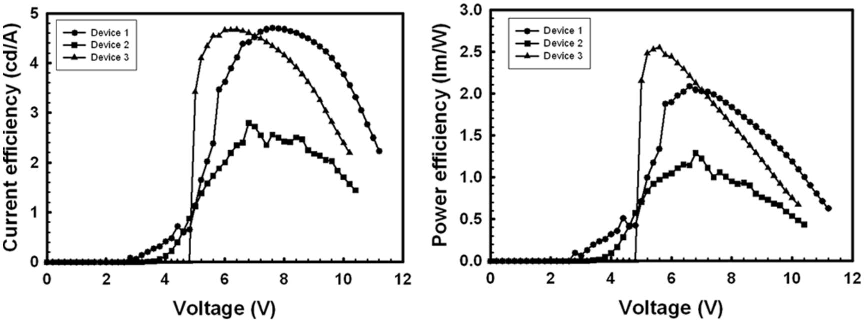
process difficulty. A device 1 was made as the control sample. Device 2, and 3 were made with 2000 rpm and 3000 rpm coating conditions, respectively. The thickness of second blue layer found to be 15 nm and 12 nm for device 2 and 3 respectively. These thickness were obtained by eliminating of PEDOT:PSS thickness (40 nm) and first blended layer (80 nm) from total thickness of polymer layers. All thickness data were measured by a surface profiler.

Figure 2 shows the I-V and L-V data for device 1–3. The voltages needed for 1,000 cd/m^2 of the device 1 and 2 were ~6.4 V and ~5.4 V for the device 3. The device 3 showed about 1 V lower driving



(a) cd/A-L data

(b) lm/W-L data



(c) cd/A-V data

(d) lm/W-V data

FIGURE 3 Efficiency performances of devices (a) cd/A-L, (b) lm/w-L, (c) cd/A-V and (d) lm/W-V data.

voltage. As shown in Figure 2(b), the maximum luminance were 18,380 cd/m^2 (at 10.6 V), 16,110 cd/m^2 (at 9.8 V), and 17,660 cd/m^2 (at 9.4 V) for devices 1, 2 and 3, respectively.

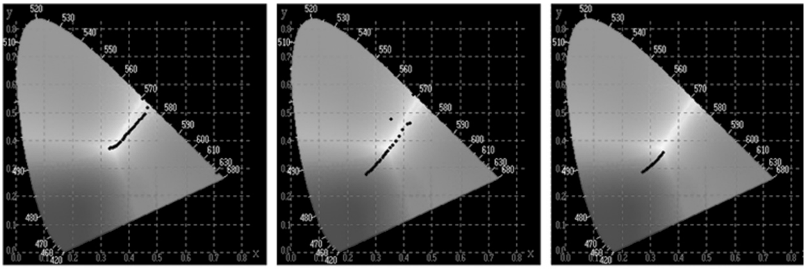
Figure 3 shows the current efficiency versus luminance (a), power efficiency versus luminance (b), current efficiency versus voltage (c) and power efficiency versus voltage (d) for the devices 1, 2 and 3. The maximum current efficiency for the device 1 was 4.69 cd/A at 7.6 V (4,234 cd/m^2) and power efficiency was 2.08 lm/W at 6.6 V (1,580 cd/m^2). In case of the device 2, the maximum current efficiency was 2.79 cd/A at 6.8 V (2,172 cd/m^2) and power efficiency was 1.29 lm/W at 6.8 V (2,172 cd/m^2). Device 3 showed a 4.67 cd/A current efficiency at 6.4 V (3,898 cd/m^2) and a 2.54 lm/W power efficiency at 5.6 V (1,491 cd/m^2). Table 2 summarizes these device characteristics. The current efficiency of device 3 was similar to that of device 1. But power efficiency of device 3 was improved by 25% compared to that of device 1. Introduction of the blue polymer layer on a blending

TABLE 2 The Summary of Device Characteristics

	Max. luminance (cd/m^2)	Current efficiency (cd/A)	Power efficiency (lm/W)
Device 1	18,380 (10.6 V)	4.69 (7.6 V)	2.08 (6.6 V)
Device 2	16,110 (9.8 V)	2.79 (6.8 V)	1.29 (6.8 V)
Device 3	17,660 (9.4 V)	4.67 (6.4 V)	2.54 (5.5 V)

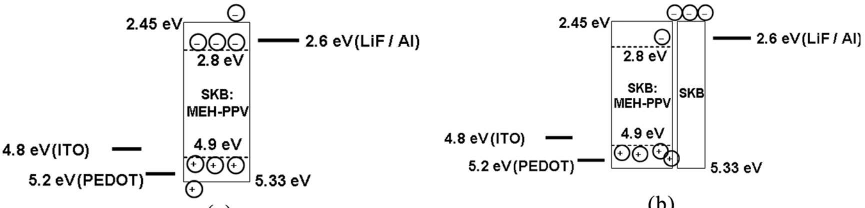
polymer layer seems to prevent direct electron injection from cathode to MEH-PPV polymer and improve the electron transport performance due to absence of trap sites in the MEH-PPV polymer. Because of these reasons, device 2 and 3 showed relatively better I-V characteristics and device 3 showed much improved power efficiency. However, the efficiency of device 2 was about half range of other devices, in spite of an additional blue layer was employed. The coating solvent for first and second emissive layer was the same. Mixing of two polymer layers during second polymer coating process seems to occur at the surface on a blending layer in the device 2. The spinning rate of 2000 rpm may be too slow to prevent this layer mixing phenomenon between two emissive layers.

Figure 4 shows the 1931 CIE coordinates at various applied voltages for the devices 1, 2, and 3. The CIE coordinate of the devices 1 and 2 shifted significantly toward blue emitting region when the applied voltage was increased. The emission from dopant MEH-PPV polymer by capturing charge carriers directly from cathode makes reddish white color at low voltage region. At the high voltage region, blue itself emission and energy transfer emission of red-orange from the blue polymer make a good white color. These different emission mechanisms depending on driving voltage resulted in large color shift



(a) Device 1 **(b) Device 2** **(c) Device 3**

FIGURE 4 CIE coordinates of (a) device 1, (b) device 2, and (c) device 3.



(a) (b)

FIGURE 5 Device Mechanisms (a) blended single layer WPLED, (b) double layer WOLED.

phenomenon [15]. On the other hand, the color variation in device 3 is relatively small. In the device 3, the emission started at (0.34, 0.35) CIE coordinates at 5 V and shifted to (0.29, 0.29) at 9 V.

As shown in Figure 5, electron injection from LiF/Al cathode to MEH-PPV has almost no energy barrier. LUMO energy of MEH-PPV was reported to be about 2.8 eV. The work function of LiF/Al was reported as 2.9 ~ 2.6 eV. Therefore, electron carrier fills up low energy state of MEH-PPV at low voltage and then fills up blue LUMO energy state with increasing voltage in a blended single layer device. As the results, orange emission occurred at low driving voltage and shifted to blue region with increasing voltage. However, initial carrier injection from cathode to MEH-PPV was protected by the double emissive device structure (Fig. 5(b)) because of an additional blue layer. Direct capturing of charge carriers was prevented by high LUMO energy of blue material. Therefore, light emission from MEH-PPV at low voltage region was not observed and white color variation also was improved. Figures 3(c) and 4(c) showed very good agreement results of our suggested mechanisms. The luminescence versus voltage characteristics of device 2 was very similar to those of device 1 at low driving region. In addition, there was no improvement of white color variation in device 2 even though an additional blue layer was introduced. These results indicate that first and second emissive materials may be mixed during spin coating process. The spin speed for the second polymer coating must be fast to be prevented layer mixing. It seems difficult to make separately double emissive structure with 2000 rpm condition.

The device 2 has relatively lower efficiency than other devices. These results may be understood several reasons. The total amount of blue polymer was increased due to lower spin rate and two emissive layer mixing. Therefore, blue emission portion in this device was enhanced relatively. Usually current efficiency of blue color is lower than other colors at the same quantum efficiency because the efficiency term includes human eye sensitivity functions. Due to strong contribution of blue emission instead of orange-red part, efficiency of device 2 seems be reduced. As shown in Figure 4, device 2 shows very strong blue emission at high voltage. This is indirect evidence of strong blue emission. The second reason seems to be related to bad charge balance in the device. The total thickness of device 2 was increased with lower spin rate and blue polymer amount was also increased due to layer mixing. Therefore, charge balance situation must be changed a lot compared to other two devices. This changed charge balance situation seems to be bad in the device 2.

CONCLUSION

The structure of double emission layers in WPLEDs was designed to improve white color variation. Introduction of the second blue polymer layer in WPLEDs resulted in the improvement of white color variation. This WPLED showed a 4.67 cd/A current efficiency at 6.4 V (3,898 cd/m^2) and a 2.54 lm/W power efficiency at 5.6 V (1,491 cd/m^2). The CIE coordinates (0.34, 0.35) at 5 V and (0.29, 0.29) at 9 V were obtained. The proposed device structure of WPLEDs will be applied for large-area full color display and lighting applications.

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