Color variation improvement by introducing double emission layers in WPLEDs

Soon Kab Kwon, Yong Kyun Lee, Tae Jin Park,

Su Hyeon Jeong, Woo Sik Jeon,

Jang Hyuk Kwon and Jin Jang

Advanced Display Research Center, Kyung Hee University, Dongdaemoon-ku, Seoul 130-701, Korea

Dept. of Information display, Kyung Hee University, Dongdaemoon-ku, Seoul 130-701, Korea

Tel   : (+82)2-961-0270

Fax   : (+82)2-961-9154

, E-mail: jjang@khu.ac.kr

Abstract

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 structure of double emission layers results in the significant improvement of white color shift phenomenon. A current efficiency of 4.67 cd/A (3,900 cd/m^2, 6.4V) and a brightness value of 17,600 cd/m^2 at 9.4 V with (0.34, 0.35) CIE coordinates at 5V and (0.29, 0.29) at 9V were obtained.

1. 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 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]

Usually the blending system has shown much higher efficiency and brightness values compared to individual devices because of some additional pathways of light production. The dopant can be excited directly by capturing the charge carriers or by energy transfer from the host to guest, as a result light emission can come from both host and guest, the combined effect of which results in the high efficiency and high brightness. 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 above mechanism, white color coordinates varies toward blue-emitting region when the applied voltage is increased. Phase separation phenomenon in polymer blending systems is well known and results from 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 of blue materials. Therefore, WPLEDs made by polymer blending systems have shown such color variation issue. In this study, we have fabricated WPLEDs from 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.

| LiF/Al cathode (2nm/100nm) |
| 2nd Blue (x rpm) |
| Blended polymers (80nm) |
| PEDOT:PSS (40nm) |
| ITO anode (150nm) |
| Glass substrate |

Figure 1. Device structure used in the study.

2. Results

The sheet resistance of ITO (Indium Tin Oxide) for WPLEDs was ~10 $\Omega/$. 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 with UV/Ozone.

 Figure 1 shows the structure of device, ITO(150nm) / 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.

The blended solution was spin-coated on the PEDOT:PSS layer with 1000 rpm. The thickness of the SKB : MEH-PPV layer was 80nm. The film was baked for 1 hour at 100°C. The SKB layer was spin-coated on the blending layer with different speed. Then, the sample was baked at the same condition. These processes were carried out in a glove box system. Next, LiF and Al layers were deposited in a vacuum system without breaking vacuum. 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
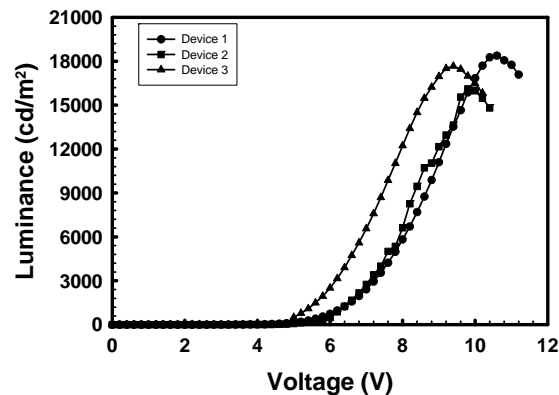
CS-100A, respectively. Electroluminescence (EL) spectra and CIE color coordinate were obtained using a PR-650 (Photoresearch Co.).

Table 1. Spinning rate for coating of the second polymer layer

	Device 1	Device 2	Device 3
2nd Blue layer	0	2000rpm	3000rpm
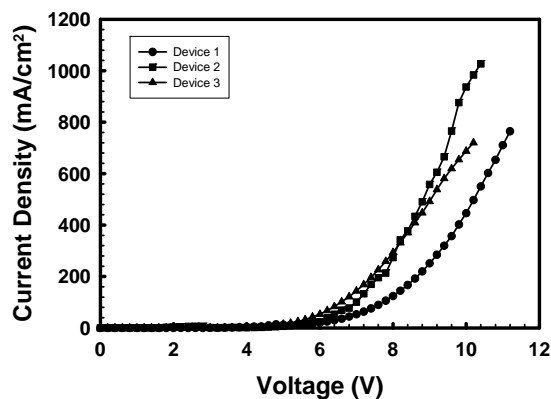
(a) I-V data

(b) L-V data

Fig. 2. The I-V-L performance of the three WPLEDs. (a) I-V and (b) L-V data

Table 1 shows the spin speed of the second polymer layer. 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]

Figure 2 shows the I-V and L-V data for the different speed of second layer. The voltages needed

for 1,000 cd/m^2 of the devices 1 and 2 were ~6.4V and ~5.4V for the device 3. As you can see, the driving voltage was reduced to ~1V. As shown in Fig. 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 6.6V (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 6.8V (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 5.6V (1,491 cd/m^2).

Table 2 summarizes the 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 a blue polymer layer on a blending polymer layer seems to prevent direct electron injection to MEH-PPV polymer from cathode and to improve the electron transport performance due to absence of trap site in the MEH-PPV polymer. In addition, as can seen in semi-log scale L-V graph for Fig. 4, delayed exciton recombination are made by accumulated hole between two EML and injected electron to the LUMO of MEH-PPV from cathode. Therefore, the device has a high luminance at 5V.

Because of these effects, devices 2 and 3 showed relatively better I-V characteristics than device 1 and device 3 showed much improved power efficiency. However, the efficiency of device 2 was reduced to half, even though there was a blue layer, as in device 3. The damage of blending polymer layer during the blue polymer coating process seems to exist for the device 2. The spinning rate of the 2nd blue layer appears to be too slow to prevent surface attack from the blue solution.

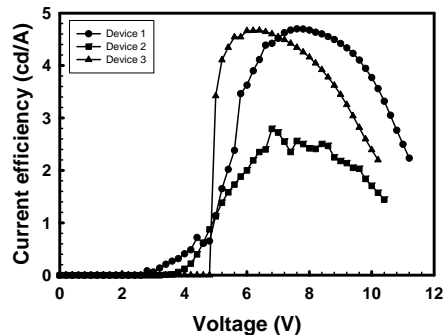**Table 2. The summary of the device characteristics.**

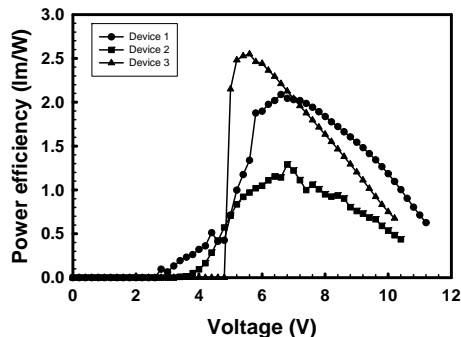|	Max. Luminance (cd/m^2)	Current Efficiency (cd/A)	Power Efficiency (lm/W)
Device 1	18,380 (10.6V)	4.69 (7.6V)	2.08 (6.6V)
Device 2	16,110 (9.8V)	2.79 (6.8V)	1.29 (6.8V)
Device 3	17,660 (9.4V)	4.67 (6.4V)	2.54 (5.6V)
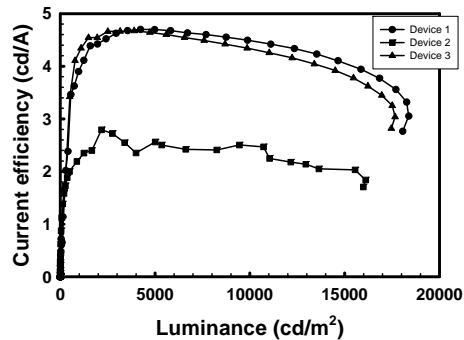
(a) cd/A-L data
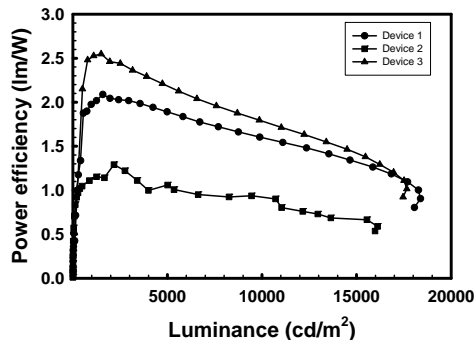
(b) lm/W-L data

(c) cd/A-V data

(d) lm/W-V data

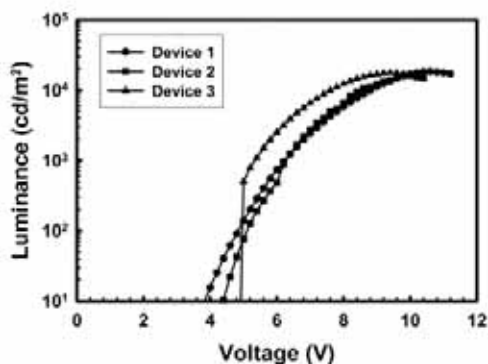**Fig. 3. The performance of the devices (a) cd/A-L, (b) lm/w-L, (c) cd/A-V and (d) lm/W-V data**

Fig. 4. The semi-log plot of the L-V data for the devices 1,2 and 3

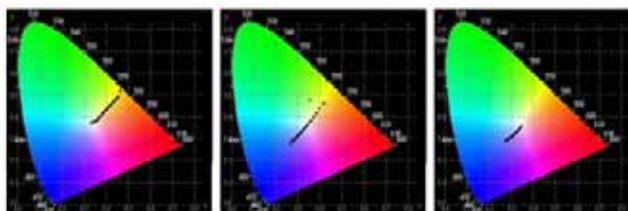(a) Device 1   (b) Device 2   (c) Device 3

Fig. 5. The CIE coordinates of (a) device 1, (b) device 2, and (c) device 3

Figure 5 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. 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 combined emission mechanisms result in large color shift phenomenon [14].

On the other hand, the color variation in device 3 is relatively small compared to the devices 1 and 2. Direct capturing of charge carriers from the cathode at low voltage was prevented by the introduction of an additional blue layer in the device 3. Therefore, the emission started at (0.34, 0.35) CIE coordinates at 5V and shifted to (0.29, 0.29) at 9V.

3. Conclusion

We introduced a blue polymer layer in WPLEDs to reduce the color shift with varying driving voltage. The device 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 5.6V (1,491 cd/m^2). This was a good approach to minimize color variation in WPLEDs. The proposed device can be applied to large-area WPLED on flexible substrate.

4. Acknowledgements

5. References
[1] B.W. D'Andrade, R.J. Holmes, and S.R. Forrest, Adv. Mater. 16, 7 (2004).

[2] J.H. Park, T.W. Lee, Y.C. Kim, O.O. Park, J.K. Kim, Chem. Phys. Letter, 403, 293 (2005).

[3] Z. Zhilin, J. Xueyin and X. Shaohong, Thin Solid Films 363, 61 (2002).

[4] C. H. Kim and J. Shinar, Appl. Phys. Lett. 80, 2201 (2002).

[5] D. Qin and Y. Tao, Appl. Phys. Lett. 86, 113507 (2005).

[6] J. H. Park, T. W. Lee, Y. C. Kim, O. O. Park and J. K. Kim, Chem. Phys. Letter, 403, 293 (2005).

[7] X. Gong, W Ma, J.C. Ostrowski, G.C. Bazan, D Moses, A.J. Heeger, Adv. Mater. 16, 615 (2004).

[8] G. Cheng, F. Li, Y Duan, J. Feng, S. Liu, S. Qiu, D. Lin, Y. Ma, S.T. Lee, Appl. Phys. Lett. 82, 4224 (2003).

[9] S.Tasch, E.J.W. List, O. Ekstrom, W.Craupner, and G. Leising Appl. Phys. Lett. 71, 20 (1997).

[10] C.H. Cheun, Y.T. Tao, Appl. Phys. Lett. 81 4499 (2002).

[11] M. Granstro and O. Ingana, Appl. Phys. Lett. 68 (2), 8 (1996)

[12] M. Salerno, M. Mazzeo and M. C. Frassanito, Appl. Phys. Lett. 86, 081907 (2005)

[13] Y. K. Lee, S. K. Kwon, J. Y. Kim, T. J. Park, D. H. Song, J. H. Kwon, D. J. Choo, J. K. Jin, H. You, and J. Jang, J. Korean Phys. Soc. (accepted).

[14] Y. Kawamura, S. Yanagida, and S. R. Forrest, J. Appl. Phys. 92, 87 (2002).