Compared electrical and optical characteristics of white organic light-emitting diodes using two complementary and three primary colors

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Abstract

We fabricated white organic light emitting diodes(WOLED) having two complementary and three primary colors with emission layers of DPVBi / MADN : DCM2-0.5% and DPVBi / Alq_3 / MADN : DCM2-1.5%, respectively. WOLED using three primary colors shows broad electroluminescence including green emission peak at 510nm while optical properties of the two complementary WOLED was higher current efficiency of 6.2 cd/A than 4.9 cd/A of three primary color WOLED. The maximum luminescence of WOLED with two complimentary color was 15200cd/m^2 along with luminous efficiency 6.2cd/A, as achieving stable white color coordinates for both of WOLEDs at (0.33 , 0.33) almost.

1. Introduction

Recently white organic light emitting diodes (WOLEDs) are very attractive for their applications to a full-color display combined with a color filter, a backlight of liquid crystal displays and solid-state lightings[1]. These applications require OLEDs with high brightness, high efficiency, high-color stability, and long lifetime[2-4].

There are commonly two ways of achieving white OLED, one of which is the single-emitting layer white OLEDs[5-6], whose $CIE_{X,Y}$ coordinates are independent to current density. This is because there is only one exciton-recombination zone but its EL efficiency is usually low. The other type is the multi-emitting layer white OLEDs[7-8], the major advantage of which is that it has much higher efficiency than that of the single emitting layer device. The drawback of multi-layered white OLEDs is that the variation of CIE $_{X,Y}$ coordinates are often dependent upon drive current density which is due to the shift of exciton-recombination zone. Careful control of the location of exciton-recombination zone[9] and the energy transfer between the host and dopant molecules have been shown to be critical in obtaining a balanced white emission of high efficiency and color with CIE $_{X,Y}$ coordinates near (0.33, 0.33).

Currently, there are two major methods for achieving white emission from multi-layered white OLEDs, it is to construct the red-green-blue primaries or their complementary colors from their multi-emitting layer structures[10-11]. White light emission is obtained by mixing two complementary colors (e.g. blue and orange) or three primary colors (e.g. red, green and blue) from different emitting layers. In order to obtain a white emission from an OLED, an excitation of more than one molecular species is essential because the luminescence of a single organic molecule does not span the entire visible spectrum. The drawback of multi-layered WOLEDs is that the variation of $CIE_{X,Y}$ coordinates are often effected by drive current density due to the color shift of exciton-recombination zone.

In this paper, we will report a new WOLEDs prepared and compared electrical and optical properties between two complementary colors and three primary colors using DPVBi/MADN:DCM2-0.5% and DPVBi/Alq_3/MADN:DCM2-1.5% as emission layers respectively.

2. Experimental

ITO coated glass was cleaned in ultrasonic bath by regular sequence: in acetone, methanol, diluted water and isopropyl alcohol. Hereafter, pre-cleaned ITO was treated by O_2 plasma under condition of 2×10^{-2} Torr, 125W and 2min[11]. WOLEDs were fabricated using the high vacuum (1.0×10^{-6} Torr) thermal evaporation.

The multilayered WOLED device structures using two complementary and three primary colors were as follows: ITO/N,N′-bis-(1-naphyl)-N,N′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB) as a hole transport layer / 4,4′-bis(2,2′-diphenylyinyl)-1,1′-biphenyl (DPVBi) as a blue emissive layer / ultrathin [2-methyl-6-[2-(2,3,6,7-tetrahydro-1H,5H-benzo[ij] quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene]propane-dinitrile (DCM2) in 2-methyl-9,10-di(2-naphthyl) anthracene (MADN) as a red emissive layer / 4,7-diphenyl-1,10-phenanthroline (Bphen) as an electron transport layer / lithium quinolate (Liq) as an electron injection layer/aluminum (Al) as a cathode and tris(8-hydroxylquinoline)aluminum (Alq_3) between DPVBi and DCM2 doped MADN as green emissive layer, respectively. Two kinds of the devices were fabricated according to use embedded Alq_3 and non-embedded between DPVBi and DCM doped MADN which were contained by the different thick and DCM2 concentration. Thickness of blue and red emissive layer and DCM2 concentrations of WOLED devices were 90 Å, 170 Å and DCM2 0.5% in the two complementary OLED while those of three primary colored OLED were 55 Å(blue) 60 Å(green), 60 Å(red) and 1.5%, respectively. With the specific DC voltage bias, the optical and electrical properties of WOLEDs such as the current density, luminance, luminous efficiency, Commission Internationale de L'eclairage (CIE) coordinates and electroluminescence characteristics were measured with Keithley 236, CHROMA METER CS-100A and JBS OLED analysis system IVL-200 each.

3. Results and discussion

The WOLEDs investigated in this study were composed of ITO(1000Å) / NPB(500Å) / DPVBi(xÅ) / Alq_3(yÅ) / MADN:DCM2(α%, zÅ) / Bphen or Alq_3(300Å) / Liq(20Å) / Al(1000Å) layers. Table 1 also shows photometric properties, level of DCM2 doping, and thickness of emitting layers.

Table 1. Characteristics and conditions of WOLEDs

	DeviceA	Device B	Device C	Device D
Colors type (two or three)	two colors	two colors	three colors	three colors
DPVBi(Å)	65	65	45	55
Alq_3(Å)	none	none	100	65
MADN:DCM2(Å)	180	170	75	60
DCM2(wt%)	0.5	0.5	1.5	1.5
ETL	Alq_3	Bphen	Alq_3	Bphen
J(mA/cm^2) [a]	31.4	18.6	47.8	28.9
L max (cd/m^2)	18100	15200	11700	11600
Efficiency(cd/A) [a]	3.51	5.04	2.35	4.00
CIE coordinates [a]	0.32, 0.33	0.34, .33	0.34, 0.36	0.33, 0.36

[a] At 1000cd/m^2

Device A and B were WOLEDs using two complementary color without green emissive layer which is mixed by DPVBi and DCM2 doped MADN as deep blue and orange colors, respectively. Device C and D were three primary colors to include green emissive layer for WOLEDs. According to DCM2 concentration from 0.5% to 1.5%, in here, CIE color coordinate of MADN:DCM2 layer as red color moved from orange to red colors. Thus WOLEDs using two complementary color and three primary color method employed 0.5% and 1.5% as red emissive layer, respectively.

WOLEDs using Bphen as electron transport layer had higher current efficiency better than WOLEDs using Alq_3 because HOMO levels of Bphen is 0.8eV lower than that of Alq_3 and electron mobility of Bphen is 100 times higher than Alq_3 with hole blocking effect as well as fast electron transfer by Bphen as shown Fig 1.

Table 2. CIE coordinates of WOLEDs with voltages

	Device A	Device B	Device C	Device D
6V	(0.32, 0.33)	(0.33, 0.34)	(0.34, 0.36)	(0.32, 0.35)
9V	(0.33, 0.33)	(0.34, 0.33)	(0.33, 0.35)	(0.31, 0.34)
12V	(0.33, 0.34)	(0.34, 0.33)	(0.32, 0.35)	(0.31, 0.33)

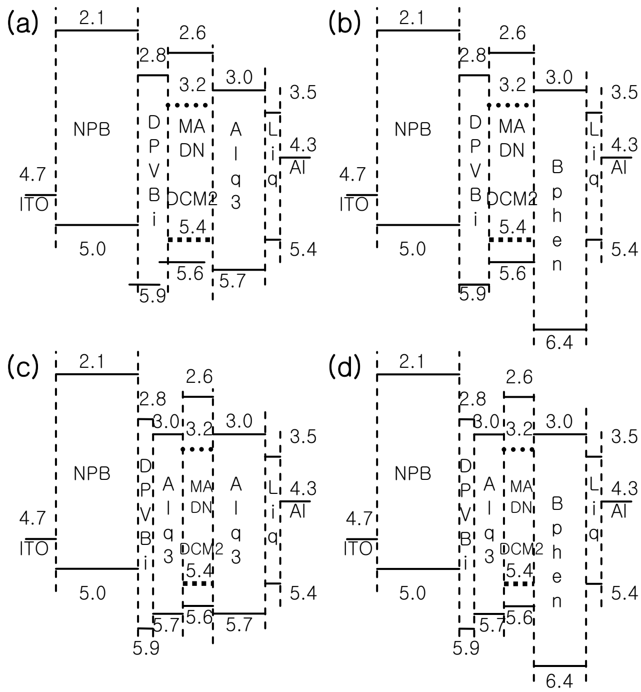

Fig. 1. Energy level diagrams and structures of WOLEDs (a) device A (b) device B (c) device C (d) device D

Table 2 shows CIE coordinates of WOLEDs with increasing voltages. It explained hole and electron recombination in energy diagram of devices. First, DPVBi was mainly influenced on CIE coordinate of devices by low HOMO levels of 5.9eV. Therefore electron and hole recombination of devices were effected by DPVBi thickness because HOMO levels of NPB was higher 0.9eV than DPVBi HOMO levels. Two complementary color method of device A and B were independently electron-hole recombination with increasing voltages. However three primary color method of device C and D had a little changed CIE coordinates with increasing voltages due to different recombination zone of three primary colors. Devices using two complementary color methods were little shifted its color coordinates to red region. Under low voltage bias, recombination zone is influenced by DPVBi having low HOMO levels, therefore recombination probability is higher in the condition of low voltages due to harder hole transfer through DPVBi to MADN:DCM2 layer. In increasing voltages, however, electron-hole recombination zone was shifted from MADN:DCM2 layer due to increased hole hopping energy. In the devices using three primary color method, when increasing voltages, CIE coordinates was a little shifted to blue zone. Because DPVBi thickness was lower than that of two complementary color method devices for white emission, electron-hole recombination mostly occurs in Alq_3 and MADN:DCM2 layer interface. In higher driving voltages, recombination zone was shifted to Alq_3 and DPVBi interface due to increased electron mobility. Shown in Table 1, the reason of current efficiency of three primary color method lower than two complementary color method can be implied that recombination is mainly occured in Alq_3 with low efficiency as indicated in Fig 2.

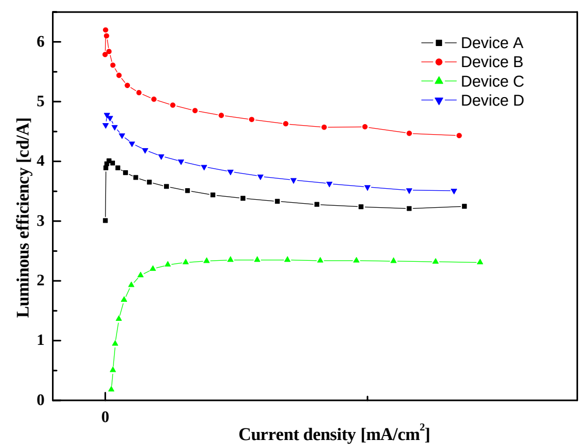

Fig. 2. Compared current efficiency of WOLEDs

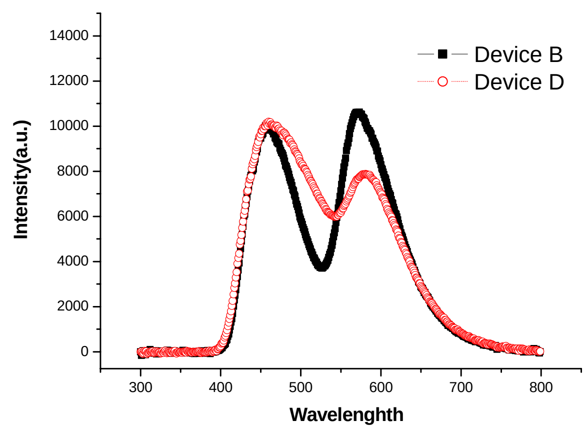

Fig. 3. Electroluminescence of WOLEDs at 12 voltages which square and circle line are device B and device D, respectively.

Fig.. 3. shows electroluminescence of WOLEDs with two complementary and three primary color methods. Electroluminescence of device D using three primary color method had green peak as well as blue and red whereas device B using two complementary color method does not have green emissive peak.

WOLED devices with two or three layered were prepared to utilize mixture of two complementary and three primary colors for back light in full color OLED and LCD. Three layered WOLED achieved color gamut to meet RGB spectra of color filter to achieve full color display although its luminance efficiency should keep being improved to be used as backlight. Two layered WOLED has relatively higher luminance efficiency but it still has difficulty to perform best color gamut as backlight purpose.

4. Summary

We are fabricated WOLED by multi-emissive layers using two complementary and three primary color method and then compared WOLEDs to have different color mixing. WOLEDs using two complementary colors showed dominated recombination in DPVBi layer and its diffusion of into cathode direction as increasing voltage while WOLEDs using three primary colors did from interface of MADN:DCM2 to DPVBi layer. Luminous efficiency of three primary colored WOLEs was relatively higher than that of two complementary colored one due to higher probability of recombination in Alq_3 layer. There were three emissive peaks of red, green and blue region in three primary coloered WOLEDs but only two emissive peaks of red and blue region in two complementary colored WOLEDs and this suggests these two different structure of WOLEDs can be applied for backlight in LCD and full color OLED as well as white lighting in the near future.

5. References

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