The Optimization of Efficient White Organic Light-Emitting Diodes Using a Blue Fluorescent and a Red Phosphorescent Dopant

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Abstract

We have demonstrated the optimization of white organic light-emitting diodes with two separated emissive layers using a blue fluorescent and a red phosphorescent dopant. The maximum luminous efficiency of the devices showed 7.93, 9.70, 11.8, and 14.3 cd/A. The $CIE_{x,y}$ coordinates also showed (x = 0.33, y = 0.36), (x = 0.33, y = 0.35), (x =0.31, y = 0.35), and (x = 0.29, y = 0.36) at 6V, respectively.

1. Introduction

Organic light-emitting diodes (OLEDs) have attracted increasing attention in recent years.[1-5] Today, OLEDs are considered to be one of the flat-panel displays of the next generation due to low-voltage operation, wide-viewing angle, a high contrast and mechanical flexibility.[6] After Tang and VanSlyke firstly demonstrated new OLEDs with the structure of double layered organic materials between two electrodes, numerous fluorescent materials, either material as host or dopant, have been synthesized and developed.[4] It is hard to balance the holes and electrons in the emitting layer, because hole mobility is faster than electron mobility. Thus, multi-layered OLEDs (which consist of several layers such as HTL, ETL, EML, etc.) have been studied.[7] White Organic light-emitting diodes (WOLEDs) have drawn increasing attention as a solid-state light source and backlights in liquid-crystal displays and full-color OLEDs due to their light weight, low operating voltage and high contrast.[8-13] A many of fabrications have been proposed to realize WOLED. Many researchers consider small molecule for WOLED because of their lower efficiency, a difficult stack of organic molecules, and absence of emission materials in polymer OLED (PLED). For full-color OLED and liquid crystal displays (LCD), WOLED using color filter have been proposed to next generation technique. In this letter, We demonstrated an efficient WOLED with a fluorescent and phosphorescent emissive dopants and two different hosts, 2-methyl-9,10-di(2-naphthyl)anthracene (MADN) and bis(2-methyl-8-quinolinato)-4-phenylphenolate (BAlq). For highly efficiency, we controlled hole-electron recombination probability, emitting layer thickness, and a simplified process. The characteristics of WOLEDs were studied and emission mechanism was also investigated.

2. Experimental

Indium tin oxide (ITO) coated glass was cleaned in an ultrasonic bath by regular sequence: in acetone, methanol, diluted water and isopropyl alcohol. Hereafter, pre-cleaned ITO was treated by O_2 plasma treatment whose condition were 2×10^{-2} Torr, 125

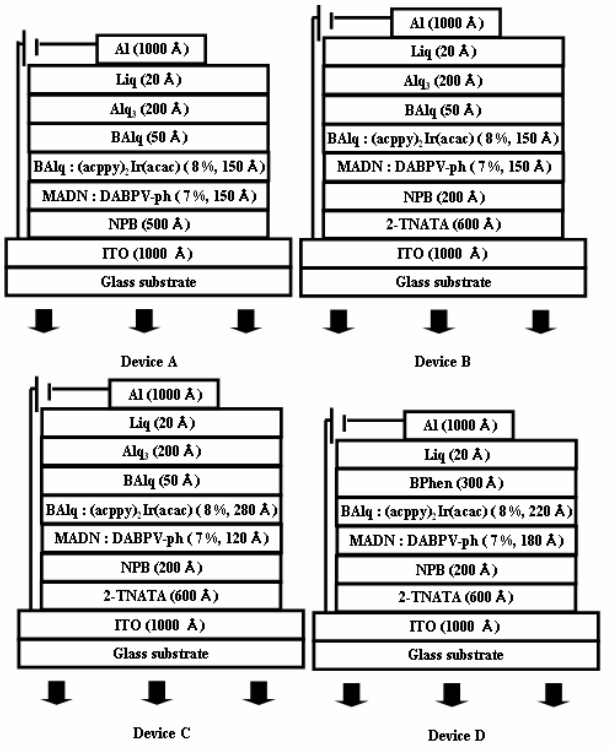

Fig. 1. The structures of device A, B, C, and D.

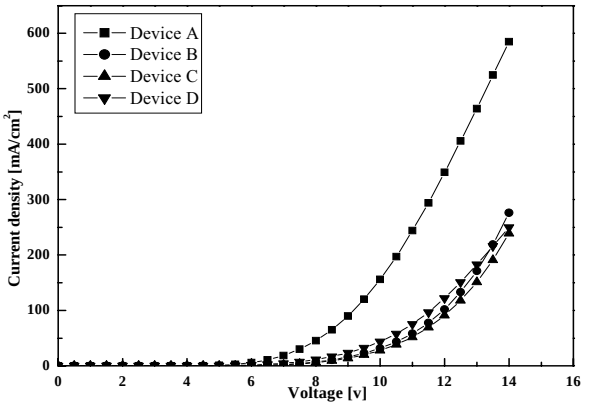

Fig. 2. The characteristics of current density (J) versus voltage (V) of device A, B, C, and D.

W and 2 min.[14] WOLEDs were fabricated using the high vacuum (5 x 10^{-7} Torr) thermal evaporation of organic materials onto the surface of ITO (30 Ω/sq, emitting area is 3 mm x 3 mm) coated glass substrate. All organic materials were purified by temperature-gradient sublimation except dopants in vacuum. The doping rates were 1.0 – 1.1 Å/sec on organic materials and 0.1 Å/sec on lithium quinolate (Liq), approximately. After the deposition of the organic layers and without a vacuum break, the Al cathode was deposited at a rate of 10 Å/sec. The device structures are as follows: ITO as a anode, 4,4′,4′′-tris[2-naphthyl(phenyl)amino] triphenylamine (2-TNATA) as a hole injection material, N,N′-bis-(1-naphyl)-N,N′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB) as a hole transport material, MADN as a blue host, 1,4-Bis[2-(4'-diphenylaminobiphenyl-4-yl)vinyl]benzene (DABPV-ph) as a blue dopant, BAlq as a red host, iridium(III) bis(5-acetyl-2-phenylpyridinato-N,C2') acetylacetonate $(acppy)_2Ir(acac)$ as a red dopant material, 4,7-diphenyl-1,10-phenanthroline (BPhen) as a hole blocking material, tris-(8-hydroxy-quinolinato) aluminum (Alq_3) and BPhen as an electron transfer material, Liq as electron injection material and Al as a cathode. The doping concentration of the dopant was optimized. Dopant of DABPV-ph in MADN as a host were 7%. concentration and dopant of $(acppy)_2Ir(acac)$ in BAlq as a host were 8%. concentration. With the DC voltage bias, the optical and electrical properties of WOLEDs such as the current density, luminance, luminous efficiency, and Commission Internationale de L'eclairage (CIE) coordinates characteristics were measured with keithley 236 and CHROMA METER CS-100A, respectively.

3. Results and discussion

Fig. 1 shows the device structures. Device A, B, C, and D fabricated the following sequence: indium tin oxide (ITO) / 4,4′,4′′-tris[2-naphthyl(phenyl)amino] triphenylamine (2-TNATA) (device B, C, and D) / N,N′-bis-(1-naphyl)-N,N′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB) / 1,4-Bis[2-(4'-diphenylaminobiphenyl-4-yl)vinyl]benzene (DABPV-ph) : 2-methyl-9,10-di(2-naphthyl)anthracene (MADN) (7%) / iridium(III) bis(5-acetyl-2-phenylpyridinato-N,C2') acetylacetonate ($(acppy)_2Ir(acac)$) : bis(2-methyl-8-quinolinato)-4-phenylphenolate (BAlq) (8%) / BAlq (device A, B, and C) / tris-(8-hydroxy-quinolinato) aluminum (Alq_3) (device A, B, and C) or 4,7-diphenyl-1,10-phenanthroline (BPhen) (device D) / lithium quinolate (Liq) (20 Å) / aluminum (Al) (1000 Å).

In case of device A, it showed the maximum current density of 585 mA/cm^2 at 14V in Fig. 2, the maximum luminous efficiency of 7.93 cd/A at 18.6 mA/cm^2 in Fig. 3, and $CIE_{x,y}$ coordinates from (x=0.33, y=0.36) to (x=0.30, y=0.34) at operating voltages from 6 V to

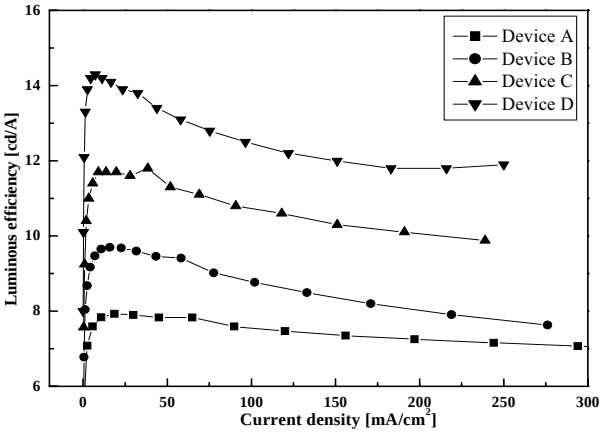

Fig. 3. The characteristics of luminous efficiency (LE) versus current density (J) of device A, B, C, and D.

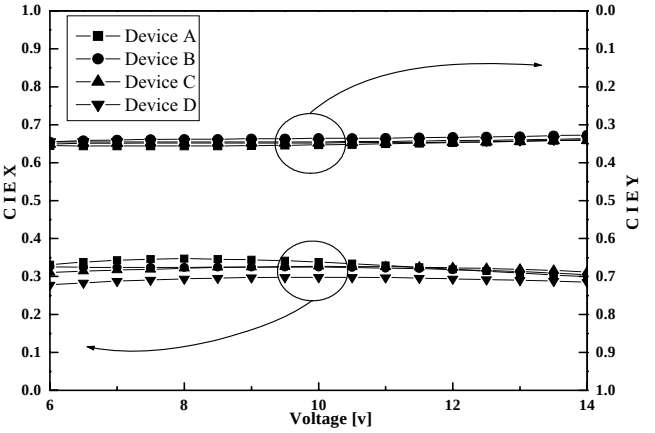

Fig. 4. $CIE_{x,y}$ coordinates device A, B, C, and D with operation bias from 6 V to 14 V.

14 V in Fig. 4, respectively. However at device A, hole-electron recombination probability come down, because mobility of holes and electrons was different each other. Here, NPB possesses a considerable high electron mobility of 10^{-4} cm^2 V^{-1} s^{-1} and Alq_3 possesses a low electron mobility of 10^{-6} cm^2 V^{-1} s^{-1}.[2] Consequently, the efficiency of device A was affected by unbalance charges between hole mobility in the NPB and electron mobility in the Alq_3.

Device B inserted a buffer layer, 2-TNATA, between ITO and NPB for balance of charges. Its luminous efficiency improved about 1.2 times than device A in Fig. 3. Device B showed the maximum current density of 276 mA/cm^2 at 14 V in Fig 2. It also showed inserted hole buffer layer decreased amount of hole carrier, therefore current density showed lower characteristics on the whole voltages than device A. It showed similar $CIE_{x,y}$ coordinates from (x=0.33, y=0.35) to (x=0.31, y=0.33) at operating voltages from 6 V to 14 V in comparison with device A in Fig. 4.

On the basis of device B and device C fabricated change of emission layer thickness for higher efficiency which had blue emission layer of 120 Å and red emission layer of 280 Å. Emission layer thickness, 400 Å, of device C had thicker than it of device B, 300 Å. A thickness of each emission layers was difference for white emission in comparison with device B. Device C showed the maximum current density of 239 mA/cm^2 at 14 V in Fig. 2 and also showed lower current density on the whole than device B because of thicker emission layer. But its luminous efficiency showed higher characteristics which were 11.8 cd/A at 38.4 mA/cm^2 than device B in Fig. 3. Device C demonstrated better recombination probability of hole-electron recombination than device B. It also showed $CIE_{x,y}$ coordinates from (x=0.31, y=0.35) to (x=0.31, y=0.34) at operating voltages from 6 V to 14 V in Fig. 4.

On the basis of device C and device D which had electron transporting layer, BPhen, fabricated change of hole blocking layer of BAlq and electron transporting layer of Alq_3 at device C. BPhen was used as the electron transporting layer, because it also possesses a considerably higher electron mobility of 5 x 10^{-4} cm^2 V^{-1} s^{-1}, compared to 10^{-6} cm^2 V^{-1} s^{-1} of Alq_3, as a general electron transfer material.[3] Device D showed the maximum current density of 250 mA/cm^2 at 14 V and it showed lower current density than device C at the operating voltages between 0 V and 13.5 V in Fig. 2, while the current density of device D excelled those of device C above the voltage of 13.5 V because the highest occupied molecular orbital (HOMO) of BPhen prevent more hole than device C and BPhen possesses a higher electron mobility than Alq_3 in previous demonstration. Its two effects showed lower current density till 13.5 V and higher current density above 13.5 V in comparison with device C. Device D showed luminous efficiency of 14.3 cd/A at 7.34 mA/cm^2 at 14 V in Fig 3. Its luminous efficiency had about 1.2 times than device C. It also showed $CIE_{x,y}$ coordinates from (x=0.29, y=0.36) to (x=0.29, y=0.34) at operating voltages from 6 V to 14 V in Fig 4.

4. Summary

We have fabricated WOLED with two separated emissive materials and control hole-electron recombination probability, emission layer thickness, and a simplified process for highly efficiency. Consequently, the WOLED exhibited white emission and the maximum luminous efficiency were 14.3 cd/A. A luminous efficiency of WOLED fabricated showed about 1.8 times than first device. It also showed white $CIE_{x,y}$ coordinates without fluctuation at operating voltages. We expect that the WOLED fabricated using device structures and materials described here may be applicable for backlights in LCDs.

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