

## A Hybrid Spacer Effect on White Organic Light-Emitting Diodes with Phosphorescent Emitters

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(Received December 17, 2008 ; Accepted February 26, 2009)

### 인광 발광 물질을 이용한 백색 유기 발광 다이오드에서의 혼합된 스페이서의 영향에 관한 연구

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(2008년 12월 17일 접수 ; 2009년 2월 26일 채택)

**Abstract** : 본 논문에서는 청색 인광 발광 물질인 bis(3,5-Difluoro-2-(2-pyridyl)phenyl-(2-carboxypyridyl) iridium (III) (FIrpic)과 녹색 인광 발광 물질인 fac-tris(2-phenylpyridine) iridium(III) (Ir(ppy)<sub>3</sub>)와 적색 인광 발광 물질인 bis(5-benzoyl-2-phenylpyridinato-C,N)iridium(III) (acetylacetonate) ((Bzppy)<sub>2</sub>Ir(acac))를 각각 적층하여 백색 유기 발광 다이오드를 제작하였고, 각각의 발광층 사이에 혼합된 스페이서인 4,4'-N,N'-dicarbazole-biphenyl (CBP):4,7-diphenyl-1,10-phenanthroline (BPhen)을 적층하여 그 때의 영향에 대하여 연구하였다. 최적화된 구조에서의 전력 효율은 0.014 mA/cm<sup>2</sup>에서의 19.7 lm/W를 나타내었으며, 0.127 mA/cm<sup>2</sup>에서의 11.5%의 외부 양자 효율을 나타내었고, 8 V에서 Commission Internationale de l'Eclairage (CIE<sub>x,y</sub>) coordinates (x=0.36, y=0.44)의 색좌표를 나타내었다.

**Keywords** : 백색 유기 발광 다이오드, 혼합된 스페이서

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## 1. Introduction

Organic light-emitting diodes (OLEDs) have attracted increasing attention in recent years.[1-5] OLEDs are also considered to be one of the flat-panel displays for the next generation due to low-voltage operation, wide-viewing angle, a high contrast ratio, and mechanical flexibility. So, many researchers have investigated synthesis of organic materials and optimization of device structures, etc.

White OLEDs(WOLEDs) have drawn increasing attention as a solid-state light source and backlights in liquid-crystal displays and full-color OLEDs.[6-12] Many researchers consider phosphorescent emitters because of the higher theoretical efficiency close to 100% than fluorescent emitters close to 25%. 4,4'-N,N'-dicarbazole-biphenyl (CBP) spacer firstly used between blue fluorescent and red-green phosphorescent emitters for preventing singlet energy transfer from the blue fluorescent emitter to the red-green phosphorescent emitters and minimized exchange energy losses to increase the efficiency, lifetime, and brightness by Y. Sun et al.[13] Hybrid spacer (HS) was previously used by G. Schwartz et al. and J. H. Seo et al. for balance of charge carrier between fluorescent and phosphorescent emitting layers (EML). In this letter, we controlled HS between all phosphorescent emitters to achieve high efficiency. The optimized device showed the power efficiency of 19.7 lm/W at 0.014 mA/cm<sup>2</sup> and the external quantum efficiency(EQE) of 11.5% at 0.127 mA/cm<sup>2</sup>, respectively. The various 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 the

following sequence: in acetone, methanol, distilled water and isopropyl alcohol. Thereafter, pre-cleaned ITO was treated by O<sub>2</sub> plasma with the conditions of 2 × 10<sup>-2</sup> Torr, 125 W for 2 min. WOLEDs were fabricated using the high vacuum (5 × 10<sup>-7</sup> Torr) thermal evaporation of organic materials on to the surface of the ITO-coated glass substrate (30 Ω/sq, emitting area was 3 mm × 3 mm). The deposition rates were 1.0~1.1 Å/sec for organic materials and 0.1 Å/sec for lithium quinolate (Liq), respectively. Without a vacuum break after the deposition of organic layers, the aluminum (Al) cathode was deposited at a rate of 10 Å/sec. The doping concentrations of the emitters were also optimized. With the DC voltage bias, the optical and electrical properties of WOLEDs such as the current density, luminance, power efficiency (PE), and electroluminescence (EL) spectra of the emission characteristics were measured with Keithley 2400 and CHROMA METER CS-1000A instruments respectively. The EQE and Commission Internationale de l'Eclairage (CIE<sub>x,y</sub>) coordinates were calculated. All measurements were carried out under ambient conditions at room temperature.

## 3. Results and Discussion

Figure 1 shows the device structures of WOLEDs fabricated in this study. Device A and B fabricated as the following sequence: ITO (1000 Å)/N,N'-bis-(1-naphyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine (NPB) (500 Å)/bis(3,5-Difluoro-2-(2-pyridyl)phenyl-(2-carboxypyridyl) iridium(III) (FIrpic):CBP (8%, 280 Å)/CBP: 4,7-diphenyl-1,10-phenanthroline (BPhen) (1:1, 30 Å, device B)/bis(5-benzoyl-2-phenylpyridinato-C,N)iridium(III) (acetylacetonate) (Bzppy2Ir(acac)):CBP (8%, 5 Å)/CBP:BPhen (1:1, 30 Å, device B)/fac-tris(2-phenylpyridine) iridium(III) (Ir(ppy)<sub>3</sub>):CBP(8%, 10 Å)/BPhen (300 Å)/Liq (20 Å)/Al

(1000 Å).

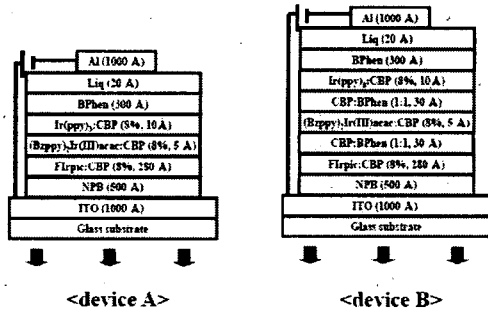


Figure 1. Structures of device A and B.

Figure 2 shows the current density and luminance versus voltage characteristics of device A and B. The devices had the maximum current density of 106.17 and 95.98 mA/cm<sup>2</sup> at 10 V. Device B showed lower current density at operating voltages because of inserted HSs of 60 Å. They also showed maximum luminance of 10 450 and 13 590 cd/m<sup>2</sup> at 10 V. Device B had higher luminance at the whole operating voltages.

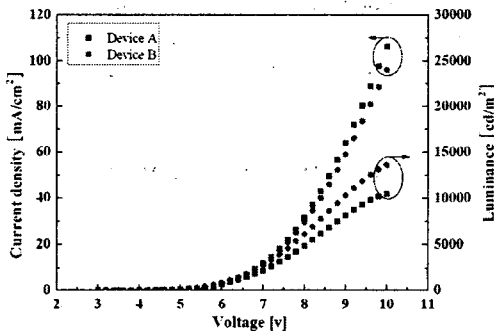


Figure 2. Current density (J) and Luminance (L) versus voltage (V) characteristics of device A and B.

Figure 3 shows the PE and EQE versus current density characteristics of device A and B. The devices showed the maximum PE of 14.21 and 19.70 lm/W at 0.133 and 0.014 mA/cm<sup>2</sup> and the PE of 12.82 and 15.68 at 1 mA/cm<sup>2</sup>, respectively. They also showed the

maximum EQE of 8.99 and 11.50% at 1.458 and 0.127 mA/cm<sup>2</sup> and the EQE of 8.99 and 11.20% at 1 mA/cm<sup>2</sup>, respectively. Device A and B had the EQE variation from 8.84 and 11.4% at 100 cd/m<sup>2</sup> to 4.10 (Δ53.62%) and 6.92% (Δ39.30) at 10 000 cd/m<sup>2</sup>, respectively. (not shown here) The device B had higher efficiency and lower efficiency variation at operation voltages because HSs enhanced the recombination of holes and electrons as pass through well of electron of BPhen in HSs and reduced the density of exciton to avoid triplet-triplet(T-T) annihilation.[14]

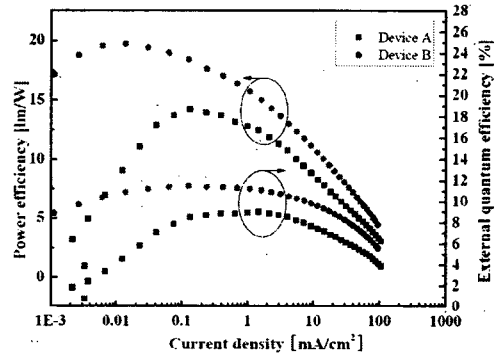


Figure 3. Power efficiency (PE) and external quantum efficiency (EQE) versus current density (J) characteristics of device A and B.

Figure 4 shows the CIE<sub>x,y</sub> coordinates changes in the two devices as a function of the applied voltage from 6 to 10 V. Devices A and B showed an emission of CIE<sub>x,y</sub> coordinates from (x=0.41,y=0.45) and (x=0.39,y=0.44) at 6 V to (x=0.37,y=0.46) and (x=0.36,y=0.46) at 10 V, respectively. They showed an emission of CIE<sub>x,y</sub> of (x=0.38,y=0.45) and (x=0.36,y=0.44) at 8 V. Device B demonstrated minimal change in CIE<sub>x,y</sub> over the entire driving voltages because the HSs also effectively prevented Dexter energy transfer.[15]

Figure 5 shows the normalized EL spectra of two devices at driving voltages of 6, 8, 10 and 12 V. Devices A and B had a blue peak

for Irpic at 473 nm, a green peak for Ir(ppy)<sub>3</sub> at 505 nm, and a red peak for (Bzppy)<sub>2</sub>Ir(III)acac at 587 nm, respectively. Device A showed higher tendency of red emission decreases the driving voltage increases than device B because no spacer act Dexter energy transfer from blue and green EML to red EML. So, device A showed the increased the exciton density in red EML and T-T annihilation. Device B showed tendency of blue and red decrease because the highest occupied molecular orbitals of BPhen in HS accumulated hole carriers. Therefore, blue and red EMLs also showed the increased the exciton density.

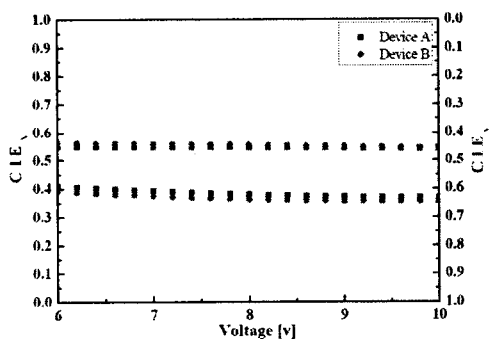


Figure 4. Commission Internationale de l'Eclairage (CIE<sub>x,y</sub>) coordinates device A and B with operation bias from 6 V to 10 V.

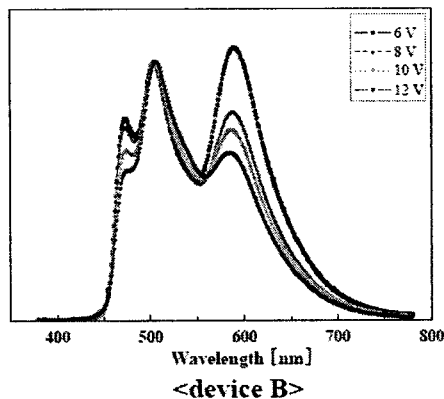
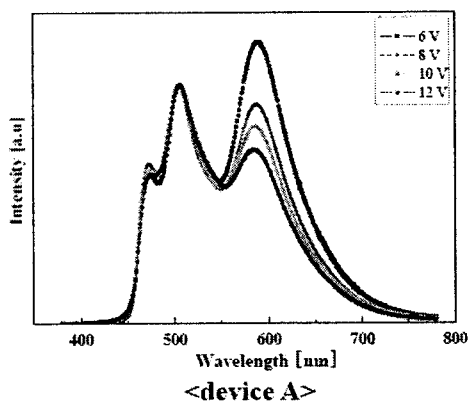


Figure 5. The normalized electroluminescence (EL) spectra of the devices A and B, and C at driving voltages ranging from 6 V to 12 V.

## 4. Conclusions

In summary, we have fabricated WOLEDs using the HS between separated EMLs with three phosphorescent emitters. In phosphorescent EMLs, HS enhanced the recombination of carriers, reduced the density of exciton, and prevented Dexter energy transfer, respectively. So, optimized device showed the power efficiency of 19.7 lm/W at 0.014 mA/cm<sup>2</sup>, the EQE of 11.5% at 0.127 mA/cm<sup>2</sup>, and CIE<sub>x,y</sub> coordinates of (x=0.36,y=0.44), respectively.

## Acknowledgment

This work was supported by the ERC program of the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea Ministry of Education, Science and Technology (MEST) (No. R11-2007-045-03001-0).

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