

## Electrophosphorescent organic light-emitting diodes with modified hole blocking layer

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### Abstract

*The electrical and optical properties of electrophosphorescent organic light-emitting diodes (OLEDs) with modified hole blocking layer (HBL) were investigated. Well-known 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) HBL is mixed with electrophosphorescent host material (4,4'-N,N'-dicarbazole-biphenyl: CBP) or electrophosphorescent dopant material (fac-tris(2-phenylpyridine) iridium: Ir(ppy)<sub>3</sub>) or both. The highest external quantum efficiency was obtained in the device with BCP-CBP-Ir(ppy)<sub>3</sub> mixed HBL and we attribute this result to the additional charge recombination in mixed-HBL.*

### 1. Introduction

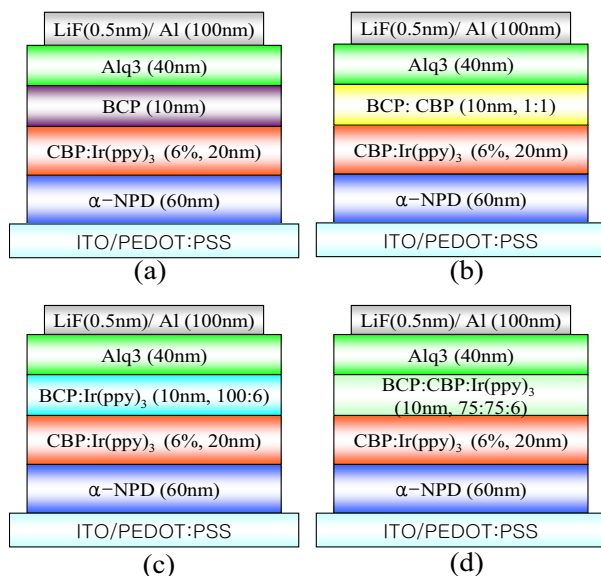
Since the first report of efficient organic light-emitting diodes (OLEDs) by C. W. Tang [1], intensive researches have been carried out to improve the performance. In particular, intensive researches have been devoted to increase the efficiency. Since the first report by Baldo and co-workers of efficient electrophosphorescent OLEDs based on platinum porphyrins [2-4], a large number of research articles and presentations have been reported. Especially, many researches are devoted to implement new structures for electrophosphorescent OLEDs to improve QE and reduce operation voltage [5-10]. But studies are mainly focused on the modification of emitting layer (EML) or transport layer, and few studies are devoted to the modification of hole blocking layer (HBL), which is usually used to block hole and exciton diffusion into electron-transport layer (ETL).

In this study, we fabricated electrophosphorescent OLEDs with modified HBL, and found that appropriate doping into HBL can enhance the device performance.

### 2. Results

The OLEDs with poly(ethylene-dioxythiophene): poly(styrene sulfonic acid) (PEDOT:PSS) hole injection layer, and N,N'-di(1-naphthyl)-N,N'-diphenylbenzidine ( $\alpha$ -NPD) hole transport layer, tris(8-hydroxyquinoline) aluminum (Alq<sub>3</sub>) electron transport layer, and LiF/Al cathode were fabricated. The pre-patterned ITO substrate (10 $\Omega$ /□, 150 nm thick) was used as the anode, and was cleaned ultrasonically in organic solvents (isopropyl alcohol, acetone, and methanol) for 10 minutes each, and rinsed in de-ionized (DI) water, and dried in an oven kept at 120°C for more than 30 minutes. After cleaning and drying, the ITO substrate was treated with ultraviolet ozone (UVO) for 4 minutes. The PEDOT:PSS layer is spin-coated for 30 seconds at 4000 rpm. After the fabrication of hole injection layer, the other layers were fabricated with the successive vacuum deposition under the high vacuum (< 3 x 10<sup>-6</sup> Torr) without breaking vacuum. The deposition rate was 0.1~0.2 nm/sec for organic materials, and 0.3~0.4 nm/sec for metal.

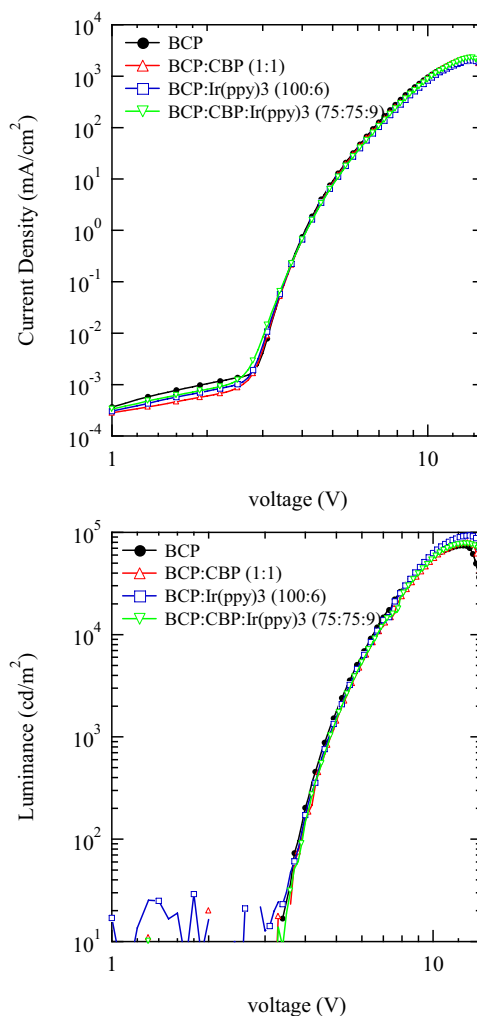
We have fabricated the OLEDs with modified hole blocking layer. Figure 1 shows the device structures of our experiments. Fig. 1-(a) is the reference device structure. The thickness of the hole transport layer, electron transport layer, and the LiF/Al cathode was 60 nm, 40 nm, and 0.5 nm/100 nm each. The EML was 6% fac-tris(2-phenylpyridine) iridium (Ir(ppy)<sub>3</sub>) doped 4,4'-N,N'-dicarbazole-biphenyl (CBP), which is commonly used emitting layer with green phosphorescent emission. The HBL of 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) was inserted between EML and ETL. The thickness of EML and HBL was 20 nm, and 10 nm each.



**Figure 1. The device structure of the devices:**  
**(a) the reference device with BCP HBL,**  
**(b) CBP doped BCP HBL,**  
**(c) Ir(ppy)<sub>3</sub> doped BCP HBL, and**  
**(d) CBP, Ir(ppy)<sub>3</sub> co-doped HBL**

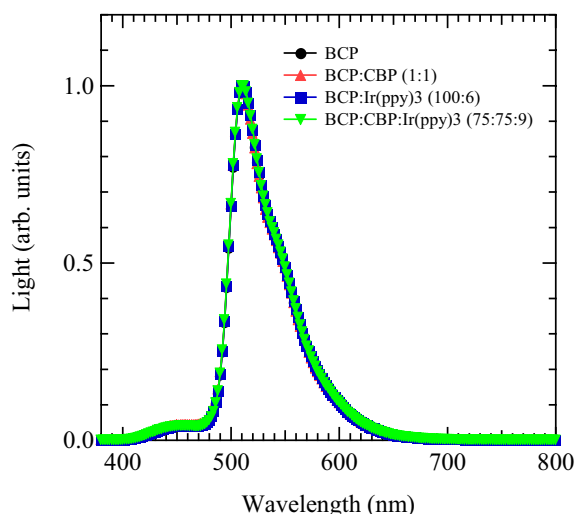
For the modification of HBL, CBP, Ir(ppy)<sub>3</sub> were doped into the HBL. Figure 1-(b) shows the device structure with CBP doped HBL. The ratio of CBP and BCP was 1:1. Figure 1-(c) show the device structure with 6% Ir(ppy)<sub>3</sub> doped HBL. Finally, figure 1-(d) shows the device with CBP, Ir(ppy)<sub>3</sub> co-doped HBL. The ratio of BCP, CBP was 1:1, and Ir(ppy)<sub>3</sub> was doped at the ratio of 6 % to the total BCP+CBP, so the ratio of BCP, CBP, and Ir(ppy)<sub>3</sub> was 75:75:9. The total thickness for the four test devices is all the same as 130 nm.

Figure 2 shows the current density-voltage (a) and luminance-voltage (b) characteristics of the modified HBL devices. Although different HBL was used, the modified HBL OLEDs did not show any difference at the current density-voltage and the luminance-voltage characteristics. As other materials like CBP and Ir(ppy)<sub>3</sub> were doped into the HBL, the net amount of the blocking material, BCP was decreased, but the OLEDs with modified HBL showed almost same device characteristics. So we can conclude that the different HBL do not disrupt or interfere with the current injection and transport property



**Figure 2. (a) The current density-voltage and (b) luminance-voltage characteristics**

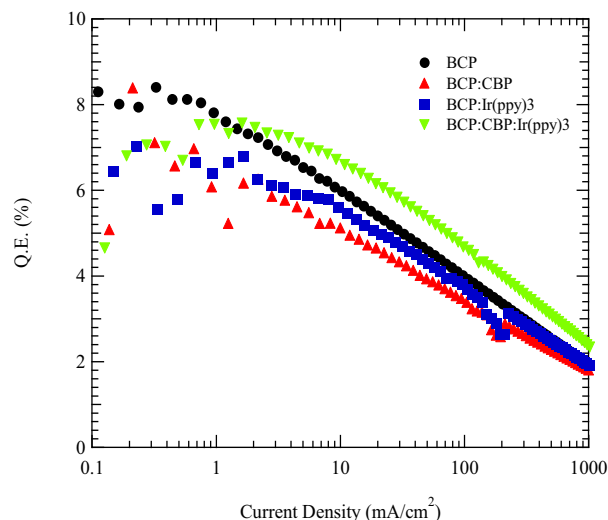
Figure 3 shows the electroluminescence (EL) spectrum of the OLEDs with modified HBL. Every device emitted bright green light. We found that the EL spectrum were almost the same for the devices, which were same as the triplet photoluminescence spectrum of Ir(ppy)<sub>3</sub>. So we can also be sure that modified HBL device do not disrupt or interfere with the charge recombination process in emitting layer.



**Figure 3. Electroluminescence spectrum of the devices**

Figure 4 shows the external QEs for the modified HBL devices. CBP doped device (b) and Ir(ppy)<sub>3</sub> doped device (c) showed no gain over the reference device, but CBP- Ir(ppy)<sub>3</sub> co-doped device (d) showed about 10 % higher external QE over the reference device. The device without both CBP and Ir(ppy)<sub>3</sub> did not show improved external QE. So the improvement of the external QE of the device (d) is the effect of both CBP and Ir(ppy)<sub>3</sub>. We attribute this efficiency enhancement to the additional charge recombination in HBL, which is enhanced by the electrophosphorescent host and dopant doped into HBL.

The HBL is commonly used in electrophosphorescent OLEDs. The HBL only acts the hole and exciton blocking function. But our result implies that by doping the electrophosphorescent host and dopant into the HBL, additional charge recombination can occur, and the external efficiency can be enhanced without any demerits in charge carrier transport property. This improvement is easily obtained by simply modifying the commonly used HBL, so our result can be easily applicable to the electrophosphorescent OLEDs.



**Figure 4. The external quantum efficiency as a function of the current densities**

### 3. Conclusion

We demonstrated that external QE can be enhanced by co-doping electrophosphorescent host and dopant together into HBL; this host and dopant do not change any I-V-L characteristics, but lead additional charge recombination in HBL, so enhance total QE about 10 %. This work will be a contribution for enhancing external QE of the electrophosphorescent OLEDs.

### 4. Acknowledgements

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### 5. References

- [1] C. W. Tang and S. A. Vanslyke, *Appl.Phys.Lett.* **51**, 913 (1987).
- [2] M. A. Baldo, D. F. O’Brien, Y. You, A. Shoustikov, S. Sibley, M. E. Thompson, and S. R. Forrest, *Nature (London)* **395**, 151 (1998).
- [3] D. F. O’Brien, M. A. Baldo, M. E. Thompson, and S. R. Forrest, *Appl. Phys.Lett.* **74**, 442 (1999).
- [4] R. C. Kwong, S. Sibley, T. Dubovoy, M. Baldo, S. R. Forrest, M. E. Thompson, *Chem. Mater.* **11**, 3709 (1999)
- [5] M. A. Baldo, S. Lamansky, P. E. Burrows, M. E. Thompson, and S. R. Forrest, *Appl.Phys.Lett.* **75**, 4 (1999).

- [6] M. Pfeiffer, S. R. Forrest, K. Leo and M. E. Thompson, *Adv. Mater.* **14**, 1633 (2002)
- [7] G. He, M. Pfeiffer, K. Leo, M. Hofmann, J. Birnstock, R. Rudzich, and J. Salbeck, *Appl.Phys.Lett.* **85**, 3911 (2004)
- [8] X. Zhou, D. S. Qin, M. Pfeiffer, J. Blochwitz-Nimoth, A. Werner, J. Drechsel, B. Maennig, and K. Leo, M. Bold and P. Erk, H. Hartmann, *Appl. Phys. Lett.* **81**, 4070 (2002)
- [9] B. D. Chin, M. C. Suh, M. H. Kim, S. T. Lee, H. D. Kim, and H. K. Chung, *Appl.Phys.Lett.* **86**, 133505 (2005)
- [10] K. Goushi, R. Kwong, J. J. Brown, H. Sasabe and C. Adachi, *J. Appl. Phys.* **95**, 7798 (2004)