Enhancement of the efficiency stabilization and the color coordinates in blue organic light-emitting devices with double emitting layers

H. S. Bang, S. M. Han[1], D. U. Lee, T. W. Kim, J. H. Kim[2], J. H. Seo[3], Y. K. Kim[3]
Research Institute of Information Display, Division of Electronics and Computer Engineering, Hanyang University, Seoul 133-791, Korea
[1]Department of Information Display Engineering, Hanyang University, Seoul 133-791, Korea
[2]Department of Electronics, Hong-ik University, Seoul 121-791, Korea
[3]Department of Information Display Engineering & Center for Organic Materials & Information Display (COMID), Hong-ik University, Seoul 121-791, Korea
Phone: +82-2-2220-0354, E-mail: hsbang@hanyang.ac.kr

Abstract
The efficiency stabilization and the color coordinates in blue organic light-emitting devices (OLEDs) with a double emitting layer (DEL) consisting of 4,4'-Bis(carbazol-9-yl)biphenyl (CBP) and 4,4'-Bis(2,2-diphenyl-ethen-1-yl)diphenyl were investigated. The efficiency of the OLEDs with a DEL did not significantly change with an increase in current density. The Commission Internationale de l'Eclairage coordinates of the OLEDs with a DEL 11 V were (0.150, 0.137), indicative of a deep blue color.

1. Introduction
Organic light-emitting diodes (OLEDs) have become particularly attractive because of the interest in promising applications in full-color display application [1-3]. OLEDs have emerged as potential candidates for applications in promising next-generation flat panel display because they have unique advantages of color gamut, luminance efficiency, high contrast, slim size, and fast response [4]. The fabrication of the high-efficiency blue OLEDs are important for improving the efficiencies of full-color flat-panel displays [5]. After Tang and Van Slyke reported on OLEDs with a double layer [6], studies concerning OLEDs with various kinds of device structures, fluorescent materials, carrier-transporting layers and electrodes have been performed to improve their efficiency and stability [7-11]. Because a doping concentration in the blue OLEDs is very sensitive to the doping method [12], the fabrication of the blue OLEDs high efficiency and good color purity is still necessary if high efficiency devices are to be fabricated. Even though some works concerning enhancements of the efficiency and color purity utilizing various structures have been performed, systematic studies concerning enhancement of the efficiency stabilization in deep-blue OLEDs with a double emitting layer (DEL) acting as electron and hole trapping layers have not been reported yet.

This paper reports the efficiency stabilization and the color coordinates in blue OLEDs with a DEL deposited by using organic molecular-beam deposition (OMBD). Current density-voltage (J-V), and luminance efficiency-current density measurements were performed to investigate the electrical properties and the efficiency of the OLEDs with a DEL consisting of 4,4'-Bis(carbazol-9-yl)biphenyl (CBP) and 4,4'-Bis(2,2-diphenyl-ethen-1-yl)diphenyl (DPVBi) acting as electron and hole accumulating layers, respectively. The Commission Internationale de l'Eclairage (CIE) chromaticity coordinates corresponding to the emission colors for OLEDs with two kinds of structures were investigated in order to clarify the stable blue color. The efficiency stabilization and the color coordinates in the blue OLEDs with a DEL were compared with those of OLEDs with a CBP layer.

2. Experimental Details
The sheet resistivity and the thickness of the indium-tin-oxide (ITO) thin films coated on glass substrates used in this study were 15 Ω/□ and 100 nm, respectively. The ITO substrates were cleaned using ultrasonications in acetone, methanol, and distilled water at 60°C for 15 min

and were rinsed in de-ionized water thoroughly. The chemically cleaned ITO substrates were kept for 48 h in isopropyl alcohol. After the chemically cleaned ITO substrates had been dried by using N_2 gas with a purity of 99.9999%, the surfaces of the ITO substrates were treated with an oxygen plasma for 2 min at an O_2 pressure of approximately 2×10^{-2} Torr. The two kinds of samples used in this study were deposited on ITO thin films coated on glass substrates by using OMBD with tungsten effusion cells and shutters in a growth chamber at a pressure of 5×10^{-6} Torr and consisted of the following structures from the top: an aluminum (Al) (100 nm) cathode electrode, a lithium quinolate (Liq) (2 nm) electron injection layer (EIL), a tris(8-hydroxyquinolate) aluminum (Alq_3) (25 nm) electron transport layer (ETL), a 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) (5 nm) hole blocking layer HBL, two kinds of the EMLs, an N,N'-Bis(naphthalene-1-yl)-N,N'-bis(phenyl)-benzidine (NPB) (50nm) HTL, an ITO anode electrode, and a glass substrate. The EMLs consisting of a CBP (30 nm), or a CBP (15 nm)/ DPVBi (15 nm) DEL acting as electron and hole accumulating layers are denoted by devices I and II, respectively. After organic and metal depositions, the OLED devices were encapsulated in a glove box with O_2 and H_2O concentrations below 1 ppm. A desiccant material consisting of a barium-oxide powder was used to absorb the residual moisture and oxygen in the encapsulated device. The deposition rates of the organic layers and the metal layers were approximately 0.1 and 0.15 nm/s, respectively, and the deposition rates were controlled by using a quartz crystal monitor. The emitting area in the pixel was 3×3 mm^2. The J-V characteristics of the OLEDs were measured on a programmable electrometer with built-in current and voltage measurement units (model SMU-236, Keithely). The brightness was measured by using a brightness meter, chroma meter CS-100A (Minolta).

3. Results and Discussion

A schematic device structure and the corresponding schematic energy diagram of the fabricated OLEDs with a DEL are shown in Figures 1(a) and 1(b), respectively. The EML of the conventional blue OLEDs consists of a CBP instead of the CBP/DPVBi DEL. The highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) levels of the NPB are -5.5 and -2.5 eV, as obtained by using cyclic voltammerty, respectively [13], and the HOMO and the LUMO levels of the CBP layer are -6.3 and -3.2 eV, respectively [14]. The HOMO and the LUMO levels of the corresponding DPVBi layer are -5.9 and -2.8 eV, respectively [15], and the corresponding levels of the BCP layer are -6.7 and -3.2 eV, respectively [16]. While the electrons are accumulated in the CBP heterointerfaces single well due to the existence of the CBP EML in device II, the holes are accumulated in the DPVBi heterointerfaces single well due to the existence of the DPVBi EML in device II.

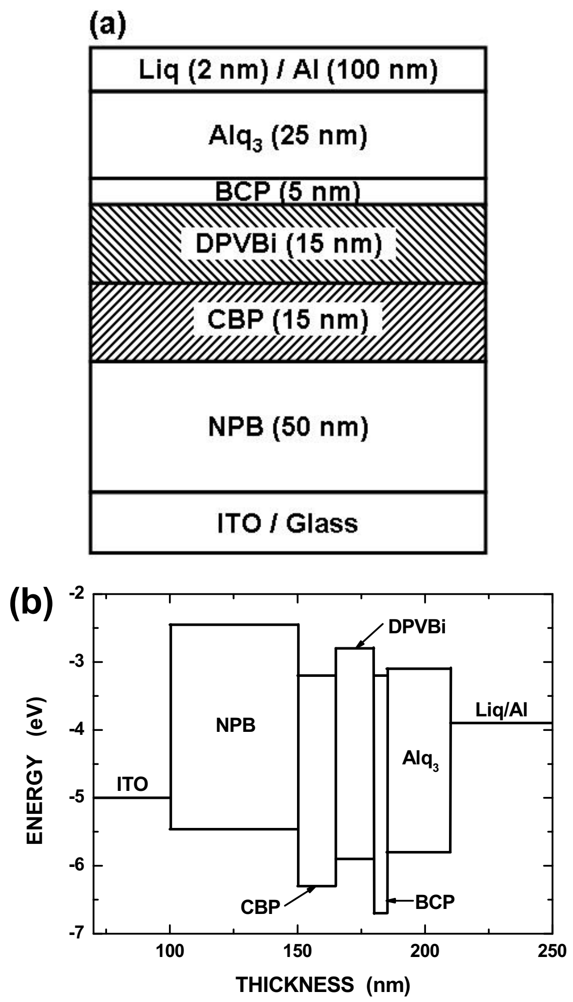

Figure 1. (a) Schematic device structure and (b) the corresponding energy band diagrams for the OLEDs with a CBP/DPVBi double emission layer.

Figure 2 shows the current densities as functions of the applied voltage for the OLEDs with different structures. Filled rectangles and circles represent the OLEDs of devices I and II, respectively. The J-V characteristics of two fabricated devices show almost similar behaviors. The J-V behavior of device II is almost similar to conventional device I with a CBP EML. Because the electrons and holes are accumulated at the DEL of device II, the carrier transport and the mobility in the DEL of device II are the same as electrical properties of device I, regardless of the existence of the DEL. The luminance efficiency of device I is low, because the electron mobility in the CBP EML of device I is low.

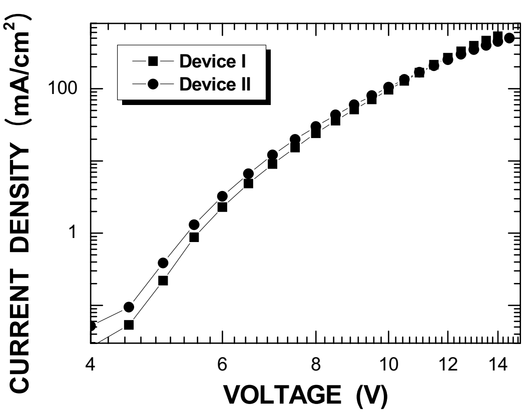

Figure 2. Current densities as functions of the applied voltage for OLEDs with different structures. Filled rectangles and circles represent the OLEDs of devices I and II, respectively.

The luminance efficiencies as functions of the current density characteristics are shown in Figure 3. The luminance efficiency of device I is the lowest value, and the luminance efficiency slightly decreases with an increase in current density. The luminance of device II is higher than that of device I. Therefore, the enhanced luminance of device II in comparison with device I is attributed to the existence of the NPB/CBP/DPVBi single well acting as an electron trapping layer, resulting in a better balance between the holes and the electrons in the CBP layer. The rates of decrease of the luminance efficiencies in the OLEDs of devices I and II are small, indicating that the efficiency stabilities of devices I and II are better.

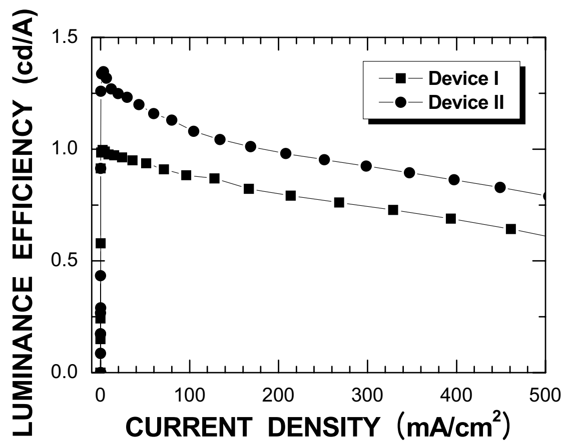

Figure 3. Luminance efficiencies as functions of the current density for OLEDs with different structures. Filled rectangles and circles represent the OLEDs of devices I and II, respectively.

Figure 4 shows CIE coordinates at 11 V for OLEDs of devices I and II. The CIE coordinates of devices I and II are (0.163, 0.137) and (0.150, 0.137), respectively. The CIE chromaticity coordinates of device II are much closer to the blue coordinates of the national television system committee standard (0.140, 0.08) than that of device I. Since the blue portion of the emission spectrum for OLEDs with a CBP layer is deeper than that for OLEDs with a DPVBi layer, the emission region of the OLEDs with a DEL consisting of a CBP layer and a DPVBi layer is limited by the CBP layer. Furthermore, since the intensity of the additional emission form the DPVBi single-well layer in the DEL heterointerface between the CBP layer and the DPVBi layer is lower, the color stability of device II with a DEL becomes enhanced.

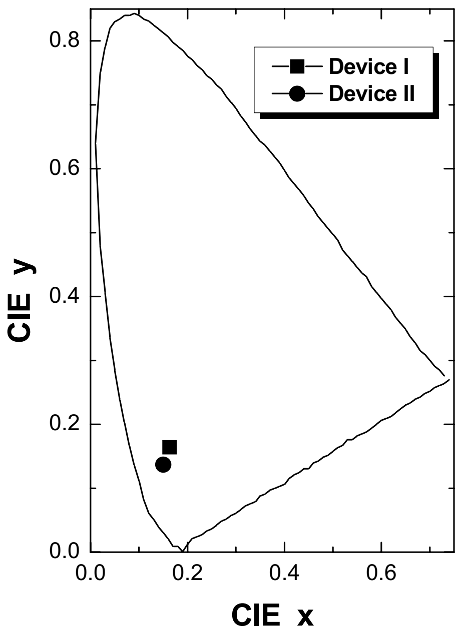

Figure 4. Commission Internationale de l′Eclairage (CIE) coordinates at 11 V for the OLEDs with different structures. Filled rectangles and circles represent the OLEDs of devices I and II, respectively.

4. Summary and Conclusions

The stabilization and the color coordinates in blue OLEDs with a CBP EML or a CBP/DPVBi DEL were investigated. While the efficiency of the OLEDs with a DEL was stable, regardless of variations in the current density, that of the OLEDs with a CBP layer varied. The CIE coordinates with a DEL at 11 V were (0.150, 0.137), indicative of a deep, stabilized blue color. These results indicate that efficiency-stabilized blue OLEDs can be fabricated using a CBP/DPVBi DEL acting as electron and hole accumulated layers.

5. Acknowledgements

This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD) (KRF-2004-005-D00166).

6. References

[1] C. W. Tang, S. A. Van Slyke, and C. H. Chen, J. Appl. Phys. 65, 3610 (1989).
[2] C. Adachi, T. Tsutsui, and S. Saito, Appl. Phys. Lett. 55, 1489 (1989).
[3] L. J. Rothberg and A. J. Lovinger, J. Mater. Res. **11**. 3174 (1996).
[4] L. S. Hung and C. H. Chen, Mater. Sci. Eng. R **38**, 143 (2002).
[5] Y. Zhang, G. Cheng, Y. Zhao, J. Hou, S. Liu, S. Tang, and Y. Ma, Appl. Phys. Lett. **87**, 241112 (2005).
[6] C. W. Tang and S. A. VanSlyke, Appl. Phys. Lett. **51**, 913 (1987).
[7] S. W. Liu, C. A. Huang, J. H. Yang, C. C. Chen, and Y. Chang, Thin Solid Films. **453-454**, 312 (2004).
[8] H. T. Lu, C. C. Tsou, M. Yokoyama, J. Crystal Growth **277**, 388 (2005).
[9] L. Zou, V. Savvate'ev, J. Booher, C. H. Kim, and J. Shinar, Appl. Phys. Lett. **79**, 2282 (2001).
[10] C. C. Wu, Y. T. Lin, H. H. Chiang, T. Y. Cho, C. W. Chen, K. T. Wong, Y. L. Liao, G. H. Lee, and S. M. Peng, Appl. Phys. Lett. **81**, 577 (2002).
[11] W. B. Im, H. K. Hwang, J. G. Lee, K. J. Han, and Y. K. Kim, Appl. Phys. Lett., **79**, 1387 (2001).
[12] B. Chen, X. H. Zhang, X. Q. Lin, H. L. Kwong, N. B. Wong, C. S. Lee, W. A. Gambling, and S. T. Lee, Synth. Met. **118**, 193 (2001).
[13] Y. Hamada, H. Kanno, T. Tsujioka, H. Takahashi, and T. Usuki, Appl. Phys. Lett. **75**, 1682 (1999).
[14] C. Adachi, M. A. Baldo, and S. R. Forrest, J. Appl. Phys. **87**, 8049 (2000).
[15] C. Hosokawa, H. Higashi, H. Nakamura, and T. Kusumoto, Appl. Phys. Lett. **67**, 3853 (1995).
[16] C. C. Tsou, H. T. Lu, and M. Yokoyama, J. Crystal Growth **280**, 201 (2005).