Stabilization of the luminance efficiency in the blue organic light-emitting devices utilizing CBP and DPVBi emitting layers

H. S. Bang[1], D. C. Choo[1], J. H. Park[2], J. H. Seo[2], Y. K. Kim[2] and T. W. Kim[1]
[1]Research Institute of Information Display, Division of Electronics and Computer Engineering, Hanyang University, Seoul 133-791, Korea
TEL:82-2-2220-0354, e-mail:twk@hanyang.ac.kr
[2]Dept. of Information Display Engineering, Center for Organic Materials & Information Display (COMID), Hong-ik University, Seoul, 121-791, Korea

Keywords: organic light-emitting device, multiple emitting layers, blue emission, optical property, electrical property

Abstract

The electrical and the optical properties of blue organic light-emitting devices (OLEDs) with a multiple emitting layer (EML) acting as electron and hole trapping layers were investigated. While the luminance efficiency of the OLEDs with a multiple EML was very stable, regardless of variations in the applied voltage.

1. Introduction

The organic light-emitting devices (OLEDs) have become particularly interesting for potential applications in promising next-generation full-color flat-panel displays [1, 2]. The potential applications of novel high-efficiency blue OLEDs have driven extensive efforts to fabricate OLEDs with unique structures [3]. However, blue OLEDs still have inherent problems in comparison with other red or green OLEDs [4]. Even though some works on enhancing the efficiency in green or white OLEDs with a hole transport layer (HTL) consisting of multiple heterostructures or with a multiple emitting layer have been performed to improve the balance of holes and electrons in an emitting layer (EML) [5], few studies concerning the blue OLEDs for high efficiency and pure color purity in blue OLEDs with a multiple emitting layer have been reported because of the complicated device-fabrication process.

This paper reports the electrical and the optical properties of blue OLEDs with a number of emitting layer deposited by using organic molecular-beam deposition (OMBD). Current density-voltage, luminance-voltage and luminance efficiencies measurements were performed to investigate the electrical properties and the efficiency of the OLEDs with a number of emitting layer consisting of 4,4'-Bis(carbazol-9-yl)biphenyl (CBP) and 4,4'-Bis(2,2-diphenyl-ethen-1-yl)diphenyl (DPVBi) to look like irregular structure acting as carrier trapping structures, respectively.

2. Experimental

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 ultrasonic cleaning methods in acetone, methanol, and distilled water and were rinsed in de-ionized water thoroughly. After the chemically cleaned ITO substrates had been dried by using N_2 gas, the surfaces of the ITO substrates were treated with an oxygen plasma for 2 min. The four kinds of samples used in this study were deposited on ITO thin films coated on glass substrates and consisted of the following structures from the top: an aluminum (100 nm) cathode electrode, a lithium quinolate (2 nm) electron injection layer, a tris(8-hydroxyquinolate) aluminum (25 nm) electron transport layer, a 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) (5 nm) hole blocking layer (HBL), various kinds of the EMLs, a N,N'-Bis(naphthalene-1-yl)-N,N'-bis(phenyl)-benzidine (NPB) (50 nm) HTL, an ITO anode electrode, and a glass substrate. The EMLs are a CBP (30 nm), a CBP (15 nm)/a DPVBi (15nm), a CBP (10 nm)/a DPVBi (10 nm)/a CBP (10 nm), and a CBP (7.5 nm)/a DPVBi (7.5 nm)/a CBP (7.5 nm)/a DPVBi (7.5 nm), the noted by devices I, II, III, and IV. After organic and metal depositions, the OLED devices were encapsulated in a glove box. The current density-voltage characteristics of the OLEDs were measured on a programmable electrometer with built-in current and voltage measurement units (model SMU-236, Keithely). The luminance was measured by using a brightness meter, chromameter CS-100A (Minolta).

3. Results and Discussion

The schematic energy diagrams of the fabricated OLEDs of devices (a) I, (b) II, (c) III, (d) IV are shown in Fig. 1. The conventional blue OLEDs with a CBP, a CBP/DPVBi, a CBP/DPVBi/CBP, and a CBP/DPVBi/CBP/DPVBi EML are shown in Figs. 1(a), 1(b), 1(c), and 1(d), respectively. 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 voltammetry, respectively [6], and the HOMO and the LUMO levels of the CBP layer are -6.3 and -3.2 eV, respectively [7]. The HOMO and the LUMO levels of the corresponding DPVBi layer are -5.9 and -2.8 eV, respectively [8], and the corresponding levels of the BCP layer are -6.7 and -3.2 eV, respectively [9].

Figure 2 shows the efficiencies as functions of the current density for the OLEDs with various structures. Filled rectangles, circles, and triangles represent the OLEDs of devices I, II, III, and IV, respectively. The current density-voltage characteristics of the three fabricated devices show almost similar behaviors. The LUMO state of the CBP single well is found to be surrounded by the NPB and the DPVBi barriers, and the HOMO state of the DPVBi single well is found to be surrounded by the CBP and the BCP barriers. Since the electrons are trapped and accumulated in the LUMO level of the CBP single well in the OLEDs of devices II, III, and IV due to the existence of barriers at the NPB/CBP and the CBP/DPVBi heterointerfaces, the mobility of the holes in the single well acting as an electron trapping layer decreases, resulting in an enhanced efficiency of the OLEDs due to a better balance between the number of the electrons and the number of the holes. While the luminance of device II is higher than that of device I, III, and IV, the luminance of device III and IV are similar to that of device II. Therefore, the enhanced luminance of device II in comparison with device I is attributed to the existence of the CBP single well acting as an electron trapping layer, resulting in a better balance between the holes and the electrons in the CBP layer. Since the dominant EL peak for the OLEDs of devices I, II, III, and IV appears at the CBP layer, the accumulated holes in the HOMO level of the DPVBi single well do not significantly affect the luminance of devices I, II, III, and IV.

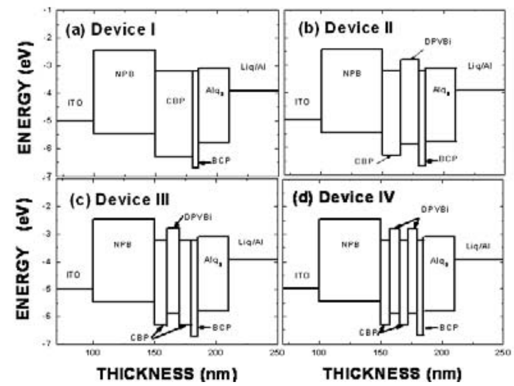

Fig. 1. Schematic energy band diagrams for the OLEDs of devices (a) I, (b) II, (c) III, and (d) IV.

The maximum efficiencies of devices I, II, III, and IV are 0.96, 1.24, 1.44, and 1.53 cd/A at 20 mA/cm^2. While the luminance efficiency of device IV is the highest among the devices, but the efficiency of device III and IV decrease with increasing current density. The rates of decrease of the luminance efficiencies in the OLEDs of devices I and II are smaller than that of device III and IV, indicating that the efficiency stabilities of devices I and II are better.

The EL spectra at 11 V for devices I, II, and III show that the dominant peaks of devices I, II, III, and IV appear at 450, 451, 451, and 453 nm, respectively, and the corresponding FWHMs are 68, 62, 65, and 66 nm, respectively. The dominant EL peaks of devices I, II, III, and IV are not shift, regardless of increasing applied voltage. The dominant peaks corresponding to the CBP layer in devices II, III, and IV are shifted to lower energy in comparison with that in device I. The red shifts of the dominant peaks in devices II, III, and IV in comparison with device I are attributed to the existence of the DPVBi layer, and a CBP layer is related to the deep blue emission at 450 nm. When the CBP single layer of device I is used as an EML, because the EML is covered with the whole CBP layer, an additional EL peak corresponding to the BCP layer also appears. Because the region of the EML in device I increase, the EL peak corresponding to the BCP layer appears. However, the EL peak corresponding to the BCP layer for the OLEDs of devices II, III, and IV do not appear, and the excitons are generated in only EML, which means to carriers are confined in CBP or DPVBi single well.

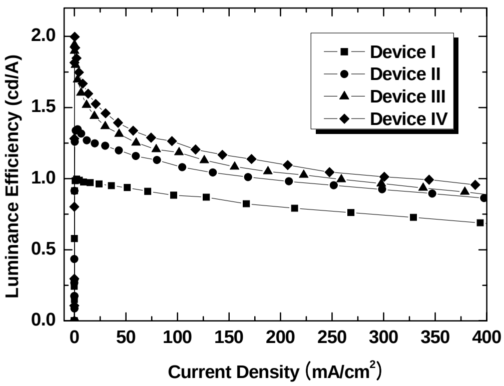

Fig. 2. luminance efficiencies as functions of the current density for OLEDs with various structures.

The variation of EML thickness to thin bring about result a broader FWHM of the dominant EL peak of device II, III, and IV. After the holes accumulated at the NPB/CBP heterointerface for the OLEDs of device II are recombined with the electrons trapped in the CBP single-well layer, the residual holes trapped in the DPVBi single-well layer capture the electrons injected into the CBP layer from the BCP HTL, resulting in the appearance of an EL peak at 451 nm due to a combination of the dominant peak corresponding to the CBP layer and the subordinate peak corresponding to the DPVBi layer. The narrower FWHM of the EL peak for device III in comparison with that of device II results from an enhancement of the electron accumulation due to the existence of the NPB/CBP and the CBP/DPVBi heterointerfaces and to better confinement of the exciton formation region in the CBP single well layer, however a device III has one more barrier to electron moving into EML, which is DPVBi/CBP barrier. So, some electrons are accumulated at DPVBi/CBP heterointerfaces, corresponding to excitons are more generated at DPVBi EML than device II. Therefore, a device III has broader FWHM than device II, and a device IV, too. These results indicate that color stability and a narrower spectral emission of the blue OLEDs can be achieved by using a multiple EML.

The CIE coordinates of devices I, II, and III are (0.163, 0.164), (0.150, 0.137), (0.155, 0.163), and (0.154, 0.167), 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 those of device I, III, or IV. Since the blue portion of the emission spectrum for OLEDs with a CBP/DPVBi layer is deeper than that for OLEDs with a CBP layer, the emission region of the OLEDs with a device II consisting of a CBP layer and a DPVBi layer is limited by the CBP layer. Because a device III becomes worse CIE coordinates, the FWHM is broader.

4. Summary

While the efficiency of the OLEDs with a CBP/DPVBi was stable, regardless of variations in the applied voltage, that of the OLEDs with a CBP/DPVBi/CBP and a CBP/DPVBi/CBP/DPVBi layer varied with the applied voltage. The EL spectrum for the OLEDs with devices I, II, III, and IV showed a dominant EL peak corresponding to the deep-blue region. The CIE coordinates with a CBP/DPVBi, a CBP/DPVBi/CBP, and a CBP/DPVBi/CBP/DPVBi at 11 V were (0.150, 0.137), (0.155, 0.163), and (0.154, 0.167), respectively, indicative of a deep, stabilized blue color.

Acknowledgement

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

5. References

1. M. A. Baldo, M. E. Thompson, and S. R. Forrest, *Nature* **403**, 750 (2000).
2. C. Adachi, M. A. Baldo, S. R. Forrest, S. Lamansky, M. E. Thompson, and R. C. Wong, *Appl. Phys. Lett.* **78**, 1622 (2001).
3. R. J. Holmes, S. R. Forrest, T. Sajoto, A. Tamayo, P. I. Djurovich, M. E. Thompson, J. Brooks, Y. J. Tung, B. W. D'Andrade, M. S. Weaver, R. C. Kwong, and J. J. Brown, *Appl. Phys. Lett.* **87**, 243507 (2005).
4. G. Li and J. Shinar, *Appl. Phys. Lett.* **83**, 5359 (2003).
5. C. H. Kim and J. Shinar, *Appl. Phys. Lett.* **80**, 2201, (2002).
6. Y. Hamada, H. Kanno, T. Tsujioka, H. Takahashi, and T. Usuki, *Appl. Phys. Lett.* **75**, 1682 (1999).
7. C. Adachi, M. A. Baldo, and S. R. Forrest, *J. Appl. Phys.* **87**, 8049 (2000).
8. C. Hosokawa, H. Higashi, H. Nakamura, and T. Kusumoto, *Appl. Phys. Lett.* **67**, 3853 (1995).
9. C. C. Tsou, H. T. Lu, and M. Yokoyama, *J. Crystal Growth* **280**, 201 (2005).