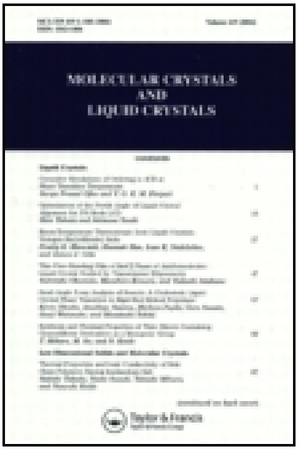

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Enhancement of Efficiency Stabilization and Color Purity in Blue Organic Light-Emitting Devices Fabricated Utilizing a CBP/DPVBi Double Emitting Layer

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Enhancement of Efficiency Stabilization and Color Purity in Blue Organic Light-Emitting Devices Fabricated Utilizing a CBP/DPVBi Double Emitting Layer

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The luminance efficiency as a function of the applied voltage for the blue organic light-emitting devices (OLEDs) with a 4,4′-Bis(carbazol-9-yl)biphenyl (CBP)/4,4′-Bis(2,2′-diphenyl-ethen-1-yl)biphenyl (DPVBi) double emitting layer (DEML) was more stable than that of the OLEDs with a DPVBi emitting layer (EML), a CBP EML, or a DPVBi/CBP DEML, regardless of the variation of the applied voltage. The electroluminescence spectra showed that the dominant peak in the OLEDs with a CBP/DPVBi DEML was shifted to higher energy in comparison to that with a DPVBi EML, a CBP EML, or DPVBi/CBP DEML, indicative of the enhancement of the blue color purity.

Keywords: blue color purity; color stabilization; deep blue emission; double emitting layer; luminance efficiency; organic light-emitting devices

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I. INTRODUCTION

Organic light-emitting devices (OLEDs) have been particularly interesting due to their potential applications for full-color flat-panel displays because they offer unique advantages of fast response, low driving voltage, low power consumption, high color gamut, high contrast, and fast response [1–5]. The potential applications of blue OLEDs with high efficiency and color stabilization have driven extensive efforts to fabricate OLEDs with various active layers [6]. However, blue OLEDs still have inherent problems of low efficiency, poor color purity, and short lifetime in comparison with other red or green OLEDs [7]. Blue OLEDs with various structures were reported for enhancing their efficiency and color stabilization [8–12]. Even though some works concerning OLEDs with various structures consisting of a multiple heterostructure, a doped emitting layer (EML), a hole injecting layer, or an exciton blocking layer have been performed to enhance efficiency, lifetime, and color stabilization [13–17], systematic studies concerning the enhancement of efficiency stabilization and color purity in the blue OLEDs utilizing a double EML (DEML) have not been reported yet because of the delicate problems encountered in the complicated growth techniques.

This paper reports the enhancement of efficiency stabilization and color purity in blue OLEDs with a DEML deposited by using organic molecular-beam deposition (OMBD). Current density-voltage, luminance-voltage, and luminance efficiency-current density measurements were carried out to investigate the carrier injection and the luminance efficiency of the OLEDs fabricated utilizing a DEML consisting of a 4,4′-Bis(carbazol-9-yl)biphenyl (CBP) layer and a 4,4′-Bis(2,2-diphenyl-ethen-1-yl)biphenyl (DPVBi) layer, acting as an electron trapping layer and a hole trapping layer, respectively. Electroluminescence (EL) measurements were performed to investigate optical properties of the blue OLEDs utilizing a DEML and to clarify the origin of the blue shift for the EL spectra. The Commission Internationale de l'Eclairage (CIE) chromaticity coordinates corresponding to the emission colors for OLEDs with various kinds of structures were investigated in order to investigate and compare with their color purity.

II. EXPERIMENTAL DETAILS

The sheet resistivity and the thickness of the indium-tin-oxide (ITO) thin films coated glass substrates used in this study were 15 Ω/square and 100 nm, respectively. The ITO coated glass substrates were cleaned by using an ultrasonic cleaning method in acetone and methanol 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 the 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 four kinds of OLEDs used in this study were deposited on ITO coated glass substrates by using OMBD 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) (30 nm) electron transport layer (ETL), various kinds of EMLs (30 nm), an N,N′-Bis(naphthalene-1-yl)-N,-N′-bis(phenyl)-benzidine (NPB) (50 nm) hole transport layer (HTL), an ITO anode electrode, and a glass substrate. The four kinds of fabricated OLEDs consisting of a 4,4′-Bis(2,2′-diphenyl-ethen-1-yl)-biphenyl (DPVBi) EML (30 nm), a 4,4′-Bis(carbazol-9-yl)biphenyl (CBP) EML (30 nm), a DPVBi (15 nm)/CBP (15 nm) DEML, or CBP (15 nm)/DPVBi (15 nm) DEML are denoted as devices I, II, III, and IV, respectively, as shown in Figure 1. The fabrication of the OLEDs was completed with encapsulation in a glove box under O_2 and H_2O

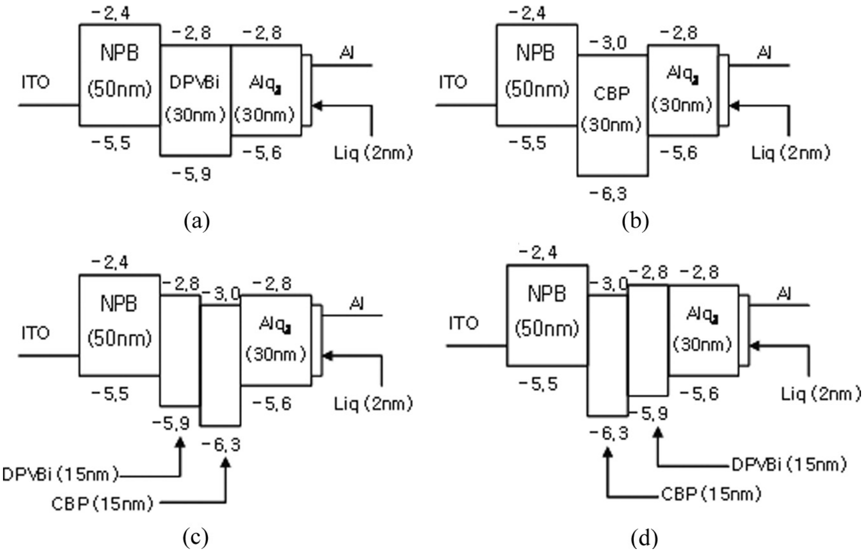


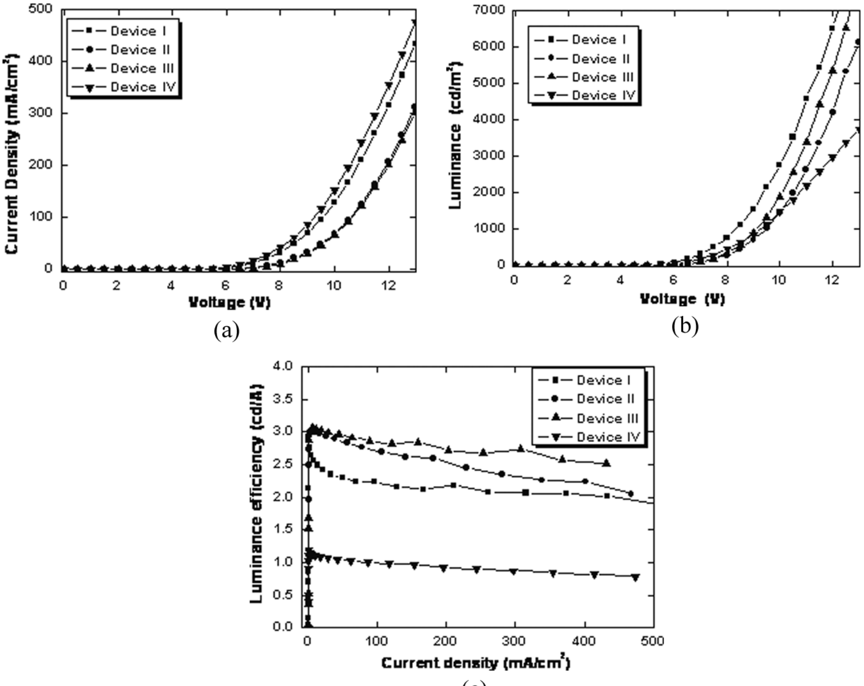
FIGURE 1 Schematic diagrams for the OLEDs of devices (a) I, (b) II, (c) III, and (d) IV.

concentrations below 1 ppm. The residual moisture and oxygen in the encapsulated device was absorbed by a desiccant material consisting of a barium-oxide powder. The deposition rates of the organic layers and the metal layer were approximately 0.1 and 0.15 nm/s, respectively, which were controlled by using a quartz crystal monitor. The current density-voltage characteristics of the OLEDs were measured by using the programmable electrometer with built-in current and voltage measurement units (model SMU-236, Keithely). The luminances were measured by using a chromameter CS-100A (Minolta), and the EL spectra were measured by using a luminescence spectrometer LS50B (Perkin-Elmer).

III. RESULTS AND DISCUSSION

The schematic energy diagrams of the fabricated OLEDs of devices (a) I, (b) II, (c) III, and (d) IV are shown in Figure 1. The blue OLEDs with a DPVBi EML or a CBP EML are shown in Figures 1(a) and 1(b), respectively, and the blue OLEDs with a DPVBi/CBP EML or a CBP/DPVBi DEML are shown in Figures 1(c) and 1(d), respectively. The lowest unoccupied molecular orbital (LUMO) levels of the NPB, the CBP, the DPVBi, and the Alq_3 layers are −2.4, −3.0, −2.8, −2.8 eV, and the corresponding highest occupied molecular orbital (HOMO) levels are −5.5, −6.3, −5.9, −5.6 eV, as obtained by using cyclic voltametry, respectively [18–21]. The LUMO levels of the layers in devices II, III, and IV form a single well, which can be occupied by the electrons in the single well.

Figure 2 shows (a) current densities as functions of the applied voltage, (b) the luminances as functions of the applied voltage, and (c) the luminance efficiencies as functions of the current density for devices I, II, III, and IV. While the luminance of device I is larger than those of devices II and III, the luminance efficiency of device I is smaller than those of devices II and III due to a large leakage current. The current densities-applied voltages characteristics of devices II and III show almost similar behavior. However, the luminance and the luminance efficiency of device III are higher than those of device II resulting from a better balance between the holes and the electrons in the EML. While the luminance of device IV is the smallest value among the four devices, the current density of device IV is the largest value. Even though the electrons are accumulated in a NPB/CBP/DPVBi single well for device IV, the holes accumulated in the NPB/CBP heterointerface do not significantly affect the hole mobility, resulting in a decrease in the luminance efficiency of device IV due to the less balance between the electrons and the holes in the EML. While the



(a) (b)

(c)

FIGURE 2 (a) Current densities as functions of the applied voltage, (b) luminances as functions of the applied voltage, and (c) luminance efficiencies as functions of the current density for OLEDs with various structures. Filled squares, circles, triangles, inverted triangles represent the OLEDs of devices I, II, III, and IV, respectively.

luminance efficiency of device IV decreases due to the unbalance of electrons and holes in the EML, the decrease rate in the luminance efficiency with an increase in the applied voltage is the smallest value, which indicates that the luminance efficiency of device IV is more stable than those of devices I, II, and III.

Figure 3 shows the EL spectra at 11 V for devices I, II, III, and IV. The dominant peaks for devices I, II, III, and IV are located at 462, 504, 505, and 447 nm, respectively, and the corresponding full widths at half maximum (FWHMs) are 74, 72, 70, and 65 nm, respectively. The dominant peaks for devices II and III are shifted to lower energy in comparison with those for devices I and IV. The red shift of the dominant peaks is attributed to an increase in the Alq_3 emission due to a decrease in the hole injection barrier of the EML in devices II and III. The residual holes accumulated at the NPB/CBP heterointerface

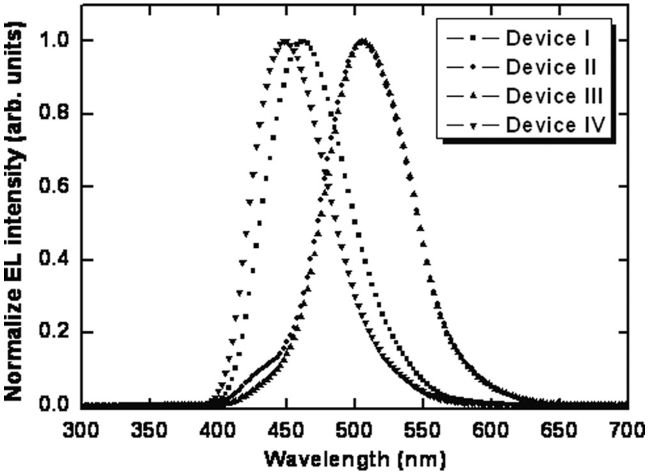
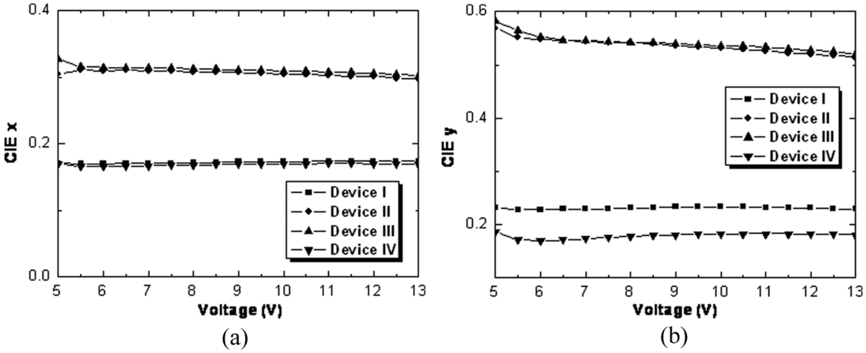


FIGURE 3 Electroluminescence spectra at 11 V for the OLEDs of devices I, II, III, and IV. Filled squares, circles, triangles, and inverted triangles represent the OLEDs of devices I, II, III, and IV, respectively.

in device II are contributed to the emission, resulting in the subordinate peak corresponding to the CBP layer. The appearance of the dominant peak at 447 nm for device IV with a CBP/DPVBi DEML indicates the deep-blue color emission. The holes accumulated at the NPB/CBP heterointerface of device IV recombine with the electrons occupied by the NPB/CBP/DPVBi single well, resulting in a blue-shift of the EL peak in comparison with those of devices I, II, and III. The FWHM of device IV is much smaller in comparison with those of devices I, II, and III due to the more electron confinement in the CBP single well and the larger hole injection CBP layer.

Figure 4 shows the CIE x and y coordinates for the OLEDs of devices I, II, III, and IV as functions of the applied voltages. The CIE x and y coordinates of devices I and IV are more stable than those of devices II and III. The emitting zones of devices II and III are slightly shifted to a CBP region with increasing applied voltage, resulting in the movement toward the lower position of the CIE y coordinate. However, the CIE coordinates of devices I and IV are not changed, regardless of the variation of the applied voltage. Because the DPVBi can increase an electron mobility enough to arrive at the middle of the EML, the emitting zone of device IV is located at the middle of the EML. This result is that the CIE coordinates of device IV are not changed, regardless of the variation of the applied voltage.



(a) (b)

FIGURE 4 Commission Internationale de l'Eclairage (a) x and (b) y coordinates as functions of the applied voltages for the OLEDs of devices I, II, III, and IV. Filled squares, circles, triangles, and inverse triangle represent the OLEDs of devices I, II, III, and IV, respectively.

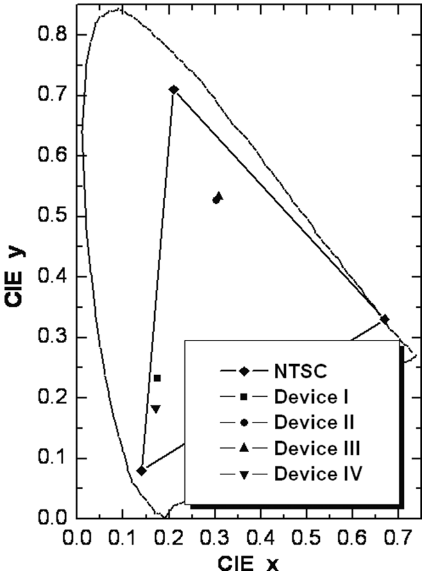


FIGURE 5 Commission Internationale de l'Eclairage coordinates at 10 V for the OLEDs of devices I, II, III, and IV. Filled squares, circles, triangles, inverse triangle, and diamond represent the OLEDs of devices I, II, III, and IV, and the standard color coordinates of the national television standard committee, respectively.

Figure 5 shows CIE coordinates as functions of the applied voltage for the OLEDs of devices I, II, III, and IV. The CIE coordinates of device IV are (0.166, 0.196), which are very close to the blue coordinates of the national television standard committee (NTSC). While the CIE coordinates of device I are stable, regardless of the variation of the applied voltage, the CIE coordinates of device I shift far away from the blue coordinates of the NTSC. The CIE coordinates of device IV with a CBP/DPVBi DEML are very close to the blue coordinates of the NTSC and very stable because the emitting zone is located at the middle of the EML.

IV. SUMMARY AND CONCLUSIONS

The electrical and the optical properties of OLEDs with a single EML or a DEML consisting of CBP and DPVBi layers were investigated. The luminance efficiency of the OLEDs with a CBP/DPVBi DEML was more stable than those of OLEDs with a CBP EML, a DPVBi EML, or a DPVBi/CBP DEML, regardless of the variation of the applied voltage. The dominant peak of the EL spectrum for the OLEDs with a CBP/DPVBi DEML was shifted to higher energy in comparison to that with a DPVBi EML, a CBP EML, or a DPVBi/CBP DEML, indicative of the enhancement of the blue color purity. The CIE coordinates of the OLEDs with a CBP/DPVBi DEML at 13 V were (0.166, 0.296), indicative of a blue color. These results can help understanding of the enhancement of efficiency stabilization and color purity of blue OLEDs utilizing a CBP/DPVBi DEML.

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