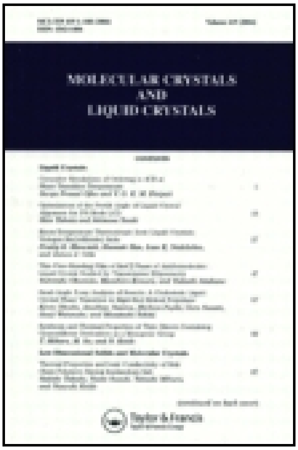

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Enhancement of the Efficiency in Color-Stabilized Green Organic Light-Emitting Devices Utilizing a Hole-Blocking Layer Between a Hole Transport Layer and an Emission Layer

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The efficiency of the organic light-emitting devices (OLEDs) with a 2,9-dimethyl-4,7-diphenylphenanthroline (BCP) hole blocking layer (HBL) between a N, N′-bis-(1-naphthyl)-N, N′-diphenyl-1, 1′-biphenyl-4,4′-diamine (NPB) hole transport layer (HTL) and a tris-(8-hydroxyquinoline) aluminum (Alq_3) emitting layer (EML) was higher than that of the OLEDs without a HBL. The dominant electroluminescence (EL) peak corresponding to the Alq_3 layer for the OLEDs with a BCP HBL between a NPB HTL and an Alq_3 EML appeared at the almost same position

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as the EL peak for the OLEDs without a HBL. The Commission Internationale de l'Eclairage chromaticity coordinates of the OLEDs corresponded to a stabilized green color, regardless of the existence of the BCP HBL layer.

Keywords: color stabilized; efficiency; hole blocking layer; Organic light-emitting devices.

PACS numbers: 73. 20. At, 78. 60. Fi, and 78. 66. Qn

I. INTRODUCTION

Organic light-emitting devices (OLEDs) have been particularly interesting because of their many potential applications in promising next-generation full-color flat-panel displays [1–6]. Recently, OLED displays have emerged as promising candidates for potential applications because they have the unique advantages of low driving voltage, low power consumption, high contrast, wide viewing angle, low cost, and fast response [7,8]. Even though studies on enhancing the efficiency and the color stabilization of OLEDs have been performed, the level of the efficiency for use in full-color displays utilizing OLEDs is still insufficient due to limited self-luminescence [9,10], short lifetime [11,12], and poor color stability [13] resulting from degradation. The potential applications of high-efficiency OLEDs have driven extensive efforts to overcome these degradation problems. An electron injection layer (EIL) and a hole injection layer (HIL) were introduced to enhance the injection of carriers [14,15]. An electron transport layer (ETL) and a hole transport layer (HTL) were used to accelerate carrier transport [16], and a hole-blocking layer (HBL) and an electron-blocking layer (EBL) were inserted between the ETL and the emission layer (EML) or between the HTL and the EML to increase exciton recombination. Even though some works on OLEDs with various kinds of HTLs and HBLs have reported enhanced efficiencies [17–21], systematic studies concerning the electrical and the optical properties of green OLEDs utilizing a HBL between a HTL and an EML have not been reported yet because of the complicated device-fabrication process.

This article reports the electrical and the optical properties of OLEDs with and without HBLs deposited by using organic molecular-beam deposition (OMBD). Current density-voltage, luminance-current density, efficiency-current density, and electroluminescence (EL) measurements were carried out to investigate the efficiency and the color stabilization of the aluminum (Al) cathode/lithium quinolate

(Liq) EIL/tris (8-hydroxyquinoline) aluminum (Alq_3) EML/a 2,9-dimethyl-4,7-diphenylphenanthroline (BCP) HBL layer or no layer/ N, N′-bis-(1-naphthyl)-N, N′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB) HTL/indium-tin-oxide (ITO) anode/glass structures. The Commission Internationale de l'Eclairage (CIE) chromaticity coordinates corresponding to the emission colors for the OLEDs with and without HBLs were determined in order to compare with the green color stabilization.

II. EXPERIMENTAL DETAILS

The sheet resistivity of the ITO thin films coated on glass substrates used in this study was 15 Ω/sq.. The ITO substrates were cleaned using acetone and methanol at 60°C for 5 min, and then rinsed in de-ionized water thoroughly. After the chemically cleaned ITO substrates had been dried by using N_2 gas with a purity of 99.9999%, the substrates were treated with an oxygen plasma for 10 min. The three kinds of samples used in this study were deposited on ITO thin films coated on glass substrates by using OMBD with effusion cells and shutters and consisted of the following structures from the top: an Al (100 nm) cathode electrode, a Liq (2 nm) EIL, an Alq_3 (60 nm) EML, either no layer or a layer consisting of a BCP HBL (1 nm), a NPB (50 or 49 nm) hole transport layer, an ITO anode electrode, and the glass substrate. The fabricated Al/Liq/Alq_3/HBL/NPB/ITO/glass /glass structures with a BCP HBL and without the HBL are denoted as devices I and II, respectively. The thickness of the BCP HBL was approximately 1 nm, and the total thickness of the BCP/NPB was 50 nm. A Liq layer was used as an EIL, leading to a lower turn-on voltage and higher power efficiency [22]. The depositions of the OLED layers were done at a substrate temperature of 27°C and a system pressure of 5×10^{-6} Torr. The growth rates of the organic layers and the metal layers were approximately 0.1 and 0.5 Å/s, respectively. The emitting area was $5 \times 5\,\mathrm{mm}^2$. The structures of the OLEDs fabricated in this work are shown in Figure 1.

III. RESULTS AND DISCUSSIONS

Figure 2 shows schematic energy band diagrams of the fabricated OLEDs of devices (a) I and (b) II. The highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) levels of the BCP are −6.7 and −3.2 eV, respectively [23], and the HOMO and the LUMO levels of the NPB layer, as obtained by

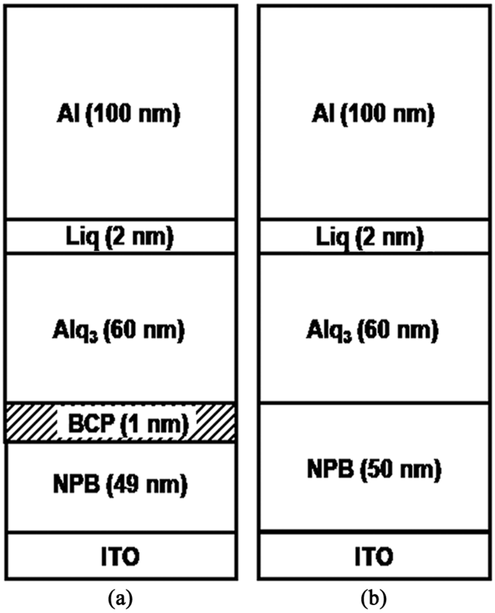

FIGURE 1 Schematic diagrams of the OLEDs of devices (a) I and (b) II.

using cyclic voltammetry, are -5.4 and -2.3 eV, respectively [21]. The HOMO and LUMO levels of the Alq_3 EML are -5.7 and -3.0 eV, respectively [24].

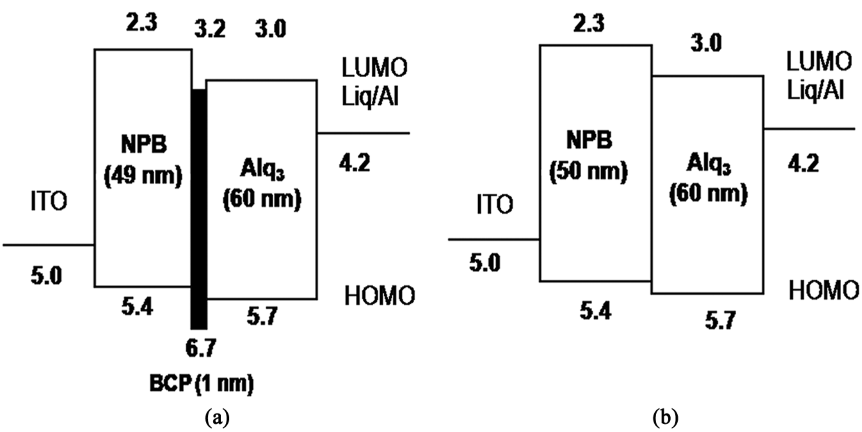

FIGURE 2 Schematic energy band diagrams of the OLEDs of devices (a) I and (b) II.

Figure 3 shows (a) the current densities as functions of the applied voltage, (b) the luminances as functions of the current density, and (c) the efficiencies as functions of the current density for the OLEDs with and without a BCP HBL. Filled and open rectangles represent the OLEDs of devices I and II, respectively. The luminance and the efficiency of device I are higher than those of device II. Because the HOMO level of the BCP HBL is deeper than those of the Alq_3 EML and the NPB HTL, the role of the hole or the exciton blocker of the BCP HBL is effective. A decrease in the mobility of the hole in the HTL results in an enhanced efficiency of the OLEDs due to a high balance between the number of electrons and the number of holes in an Alq_3 EML. The recombination probability in the Alq_3 EML increases due to an improved balance between the electrons and the holes. The electrical and the optical properties of the OLEDs might be significantly affected by the existence of the BCP HBL. The maximum efficiency of device I and II at 112 mA/cm^2 are 4.6 and 4.0 cd/A, respectively.

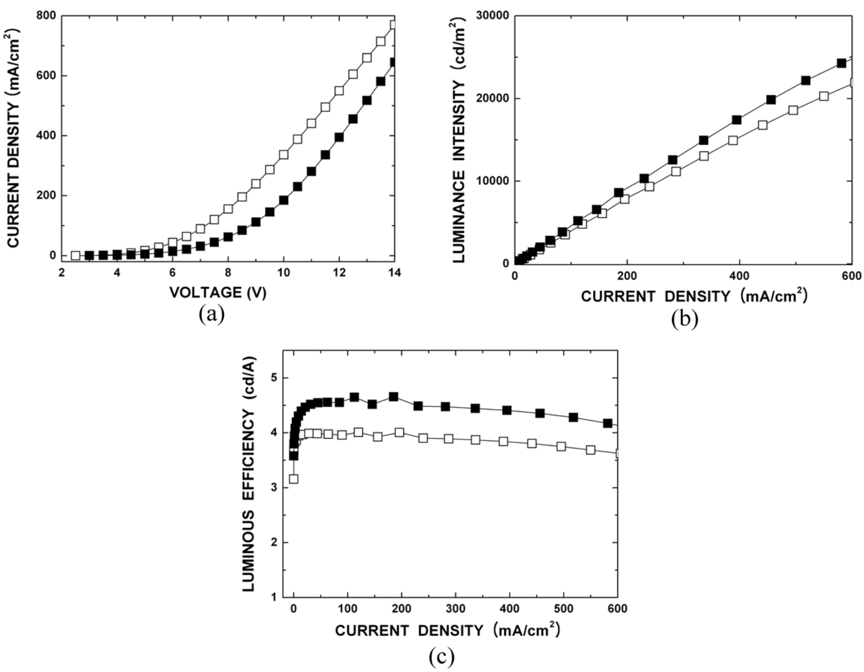

FIGURE 3 (a) Current densities as functions of the applied voltage, (b) luminances as functions of the applied current density, and (c) efficiencies as functions of the current density for OLEDs with and without a BCP HBL. Filled and open rectangles represent the OLEDs of devices I and II, respectively.

Figure 4 shows the EL spectra at 12 V for devices (a) I and (b) II. While the EL spectrum of device I shows one dominant peak at 510 nm related to the BCP layer, the EL spectrum of device II shows one dominant peak at 505 nm related to Alq_3 layer. The EL peak corresponding to the Alq_3 layer for the OLEDs with a BCP HBL between a NPB HTL and an Alq_3 EML appeared at the almost same position as the EL peak for the OLEDs without a HBL in a green color region. Even though the difference between two dominant peaks for OLEDs with and without BCP HBL is as small as 5 nm, a slight red shift of the dominant peak for device I in comparison with the peak for device II might originate from the appearance of an exciplex peak resulting from the existence of the BCP HBL [25].

Figure 5 shows the CIE x and y coordinates of the OLEDs with and without a BCP HBL as functions of the applied voltages. The CIE x and y coordinates of device I with a HBL are more stabilized than those

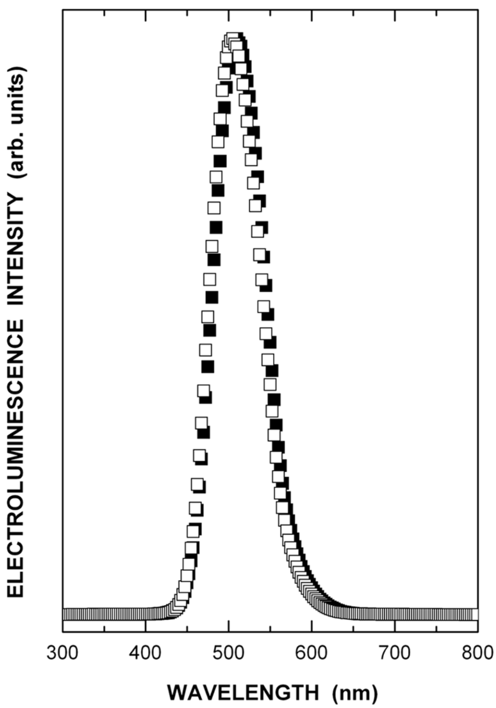

FIGURE 4 Electroluminescence spectra at 12 V for OLEDs of devices (a) I and (b) II. Filled and open rectangles represent devices I and II, respectively.

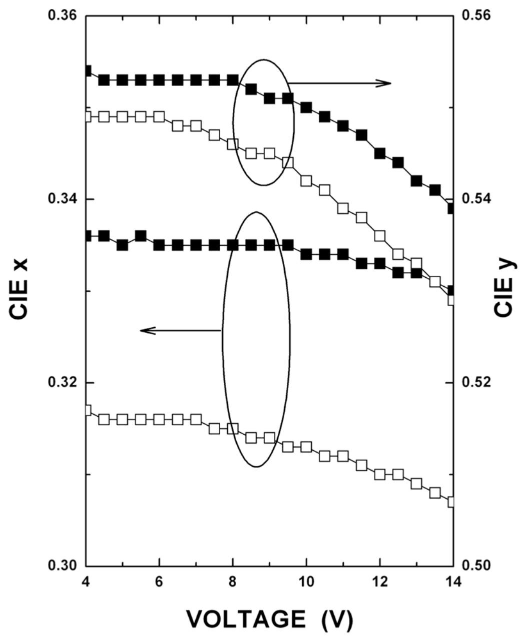

FIGURE 5 Commission Internationale de l'Eclairage (CIE) coordinates as functions of the applied voltage for OLEDs with and without a BCP HBL. Filled and open rectangles represent devices I and II, respectively.

of device II without a HBL. Because the electron and the hole existing at the HBL and the EML heterointerface are heavily confined due to the existence of the BCP HBL, the position of the exciton recombination zone does not change with increasing applied voltage. Therefore, the variation of CIE coordinates dependent on the applied voltage for device I with a HBL become smaller with increasing applied voltage.

IV. SUMMARY AND CONCLUSIONS

The electrical and the optical properties of OLEDs utilizing a BCP HBL between a NPB HTL and an Alq_3 EML were investigated. The efficiency of the OLEDs with a BCP HBL between a NPB HTL and an Alq_3 EML is higher than that of the OLEDs without a HBL. The dominant EL peak corresponding to the Alq_3 layer for the OLEDs with a BCP HBL between a NPB HTL and an Alq_3 EML appeared at the almost same position as the EL peaks for the OLEDs without a HBL, regardless of the existence of the BCP HBL layer. The CIE chromaticity coordinates of the OLEDs with and without HBL indicate a stabilized green color. These results indicate that the efficiency in green OLEDs is significantly enhanced by using a BCP HBL between a NPB HTL and an Alq_3 EML and that highly efficient green OLEDs can be fabricated by using a BCP HBL between a NPB HTL and an Alq_3 EML.

REFERENCES

[1] Tang, C. W. & Van Slyke, S. A. (1987). *Appl. Phys. Lett.*, *51*, 913.
[2] Baldo, M. A., O'Brien, D. F., You, Y., Shoustikov, A., Sibley, S., Thompson, M. E., & Forrest, S. R. (1998). *Nature*, *395*, 151.
[3] Aziz, H., Popovic, Z. D., Hu, N-X., Hor, A-M., & Xu, G. (1999). *Science*, *283*, 1900.
[4] Baldo, M. A., Thompson, M. E., & Forrest, S. R. (2000). *Nature*, *403*, 750.
[5] He, Y. & Kanicki, J. (2000). *Appl. Phys. Lett.*, *76*, 661.
[6] Paetzold, R., Heuser, K., Henseler, D., Roeger, S., Wittmann, G., & Winnacker, A. (2003). *Appl. Phys. Lett.*, *82*, 3342.
[7] Yu, W., Pei, J., Huang, W., & Heeger, A. J. (2000). *Adv. Mater.*, *12*, 828.
[8] Chan, L., Yeh, H., & Chen, C. (2001). *Adv. Mater.*, *13*, 1637.
[9] Kim, Y., Shin, D., Ko, C., Yu, H., Chae, Y., & Kwon, S. (2001). *Adv. Mater.*, *13*, 1690.
[10] Liew, Y.-F., Aziz, H., Hu, N.-X., Chan, H. S.-O., Xu, G., & Popovic, Z. (2000). *Appl. Phys. Lett.*, *77*, 2650.
[11] Zhu, F., Low, B., Zhang, K., & Chua, S. (2001). *Appl. Phys. Lett.*, *79*, 1205.
[12] Popovic, Z. D. & Aziz, H. (2002). *IEEE J. Selected Topoics in Quantum Electronics*, *8*, 362.
[13] Adachi, C., Tsutsui, T., & Saito, S. (1989). *Appl. Phys. Lett.*, *55*, 1489.
[14] Zhu, F., Low, B., Zhang, K., & Chua, S. (2001). *Appl. Phys. Lett.*, *79*, 1205.
[15] Zhao, Y., Liu, S. Y., & Hou, J. Y. (2001). *Thin Solid Films*, *397*, 208.
[16] Adachi, C., Tsutsui, T., & Saito, S. (1989). *Appl. Phys. Lett.*, *55*, 1489.
[17] Huang, Q., Cui, J., Veinot, J. G. C., Yan, H., & Marks, T. J. (2003). *Appl. Phys. Lett.*, *82*, 331.
[18] Wang, Y., Gao, W., Braun, S., Salaneck, W. R., Amy, F., Chan, C., & Kahn, A. (2005). *Appl. Phys. Lett.*, *87*, 193501.
[19] Tsai, C-H., Liao, C-H., Lee, M-T., & Chen, C. H. (2005). *Appl. Phys. Lett.*, *87*, 243505.
[20] Divayana, Y., Chen, B. J., Sun, X. W., & Sama, K. S. (2006). *Appl. Phys. Lett.*, *88*, 083508.
[21] Kim, Y., Oh, E., Lim, H., & Ha, C-S. (2006). *Appl. Phys. Lett.*, *88*, 043504.
[22] Liu, Z., Salata, O. V., & Male, N. (2002). *Syn. Met.*, *128*, 211.
[23] Baldo, M. A., Lamansky, S., Burrows, P. E., Thompson, M. E., & Forrest, S. R. (1999). *Appl. Phys. Lett.*, *75*, 4.
[24] Ikai, M., Tokito, S., Sakamoto, Y., Suzuki, T., & Taga, Y. (2001). *Appl. Phys. Lett.*, *79*, 156.
[25] Cheng J.-A. & Chen, C. H. (2005). *J. Mater. Chem.*, *15*, 1179.