Mol. Cryst. Liq. Cryst., Vol. 530: pp. 103/[259]–109/[265], 2010
Copyright © Taylor & Francis Group, LLC
ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2010.495915

High Efficient Green Phosphorescent OLED with Emission Layer of TPBI Selectively Doped with Ir(ppy)$_3$

JIN CHEOL JEONG, HYEONG SEOK KIM,
AND JI GEUN JANG

Department of Electronics Engineering, Dankook University,
Chungnam, Korea

A green phosphorescent organic light-emitting device with structure of N,N′-diphenyl-N,N′-bis-[4-(phenyl-m-tolylamino)-phenyl]-biphenyl-4,4′-diamine[DNTPD]/1,1-bis-(di-4-polyaminophenyl)cyclohexane[TAPC]/1,3,5-tris(N-phenylbenzimiazole-2-yl)benzene[TPBI] selectively doped with Ir(ppy)$_3$/SFC-137 between anode and cathode is newly reported in comparison with the devices entirely doped with Ir(ppy)$_3$ in TPBI with or without an additional exciton confining layer (ECL). The undoped region of TPBI in the proposed device functions itself as an effective ECL, and SFC-137 is an electron transporting material named by the proprietary company.

Electroluminescent characteristics of the device selectively doped in TPBI with an additional undoped layer, which showed the maximum current efficiency of 51 cd/A at 6 V and the central wavelength of 512 nm, were comparable to those of the device entirely doped in TPBI with an ECL of 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline[BCP]. The device with an additional undoped layer of TPBI exhibited the better roll-off characteristics of current efficiency according to the increasing voltage than the device without a specific ECL.

Keywords Exciton confining layer; green PhOLED; Ir(ppy)$_3$; selective doping; TPBI

Introduction

Recently, the development of highly efficient organic light emitting devices (OLEDs) has attracted considerable interests due to their importance in practical applications of flat panel display and lighting [1–3]. The key goal of OLED researches is to achieve good electroluminescent characteristics in the luminous efficiency and emission color with high stability from a simple structure. The high luminous efficiency in the OLEDs has been demonstrated by adopting phosphors such as Ir compounds in the emission region, where heavy metal effects have led to good intersystem crossing from singlets to triplets and strong phosphorescence even at room temperature [4,5].

Address correspondence to Ji Geun Jang, Department of Electronics Engineering, Dankook University, San 29, Anseo-dong, Cheonan, Chungnam 330-714, Korea (ROK). Tel.: (+82)41-550-3545; Fax: (+82)41-550-3589; E-mail: semicgk@dankook.ac.kr

However, triplet excitons have rather long lifetime so that they may diffuse to other layers by passing through the emission layer (EML). This effect results in the deterioration of luminous efficiency and color purity due to energy transfer and relaxation outside the emission layer [6,7]. Therefore, the structure which can confine triplet excitons in the emission layer is very important to obtain high efficient phosphorescent organic light emitting devices (PhOLEDs). In order to confine triplet excitons in the emission layer, conventional devices generally require the establishment of ECL on either side of emission layer [8–10], but the insertion of additional ECLs gives rise to several disadvantages such as the increase of dissipation power, complicated structure, and high production cost.

In this study, a green PhOLED showing the electroluminescent characteristics of high efficiency and good stability without an additional ECL was proposed by using the TPBI doped with $Ir(ppy)_3$ as an emission layer and the undoped TPBI as an effective ECL. Electroluminescent characteristics of this device were compared to those of the devices entirely doped in TPBI with/without a specific ECL. The structure of the proposed device is simpler than the device with an additional ECL due to the effective confinement of excitons in a single layer of TPBI.

Experimental Procedure

The substrates with an indium-tin-oxide (ITO) anode of about 10 Ω/sq on glass were cleaned by an ultrasonic cleaning process with acetone, methanol and isopropyl alcohol. To improve the surface quality of the ITO transparent electrode, the substrates were plasma-treated for two minutes with a RF power of 150 W under an O_2/Ar forming ambient of 8 mTorr. It is well known that plasma treatment before deposition of organic layers reduces the energy barrier for hole injection from anode to first organic layer [11,12]. Furthermore, the plasma treatment removes surface contaminations on the ITO surface and improves the adhesion between ITO and

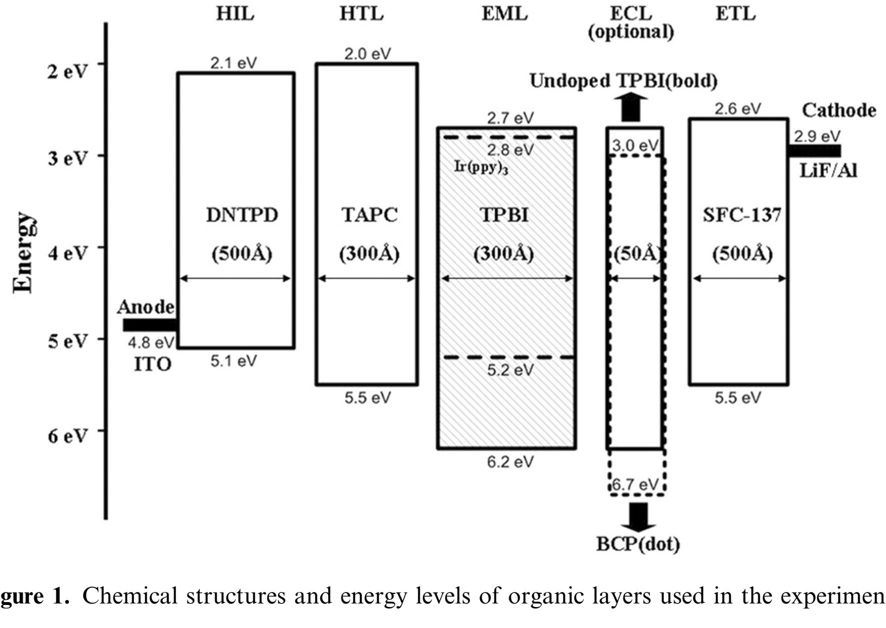

Figure 1. Chemical structures and energy levels of organic layers used in the experiments.

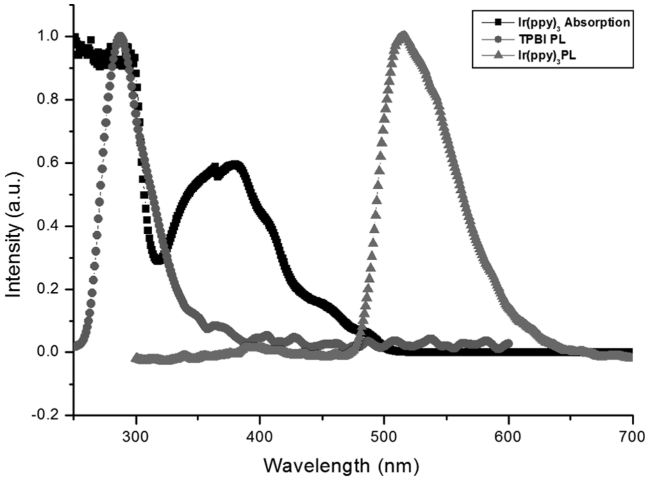

Figure 2. The PL spectra of TPBI and the UV-vis absorption and PL spectra of Ir(ppy)$_3$.

first organic layer. After the plasma treatment, the substrates were moved into the high vacuum chamber. All organic and metallic layers were deposited under 5×10^{-8} Torr by in-situ method.

Figure 1 shows the chemical structures and energy levels of organic layers used in the experiments. In Figure 1, DNTPD with a thickness of 500 Å as a hole injection layer (HIL) and TAPC with a thickness of 300 Å as a hole transport layer (HTL) were successively deposited on the ITO electrode. The TAPC layer also gives a function of exciton confining and electron blocking because of its high triplet energy and the large LUMO level offset at the interface of HTL and EML. In the formation of emission region, TPBI as a host material and Ir(ppy)$_3$ as a phosphorescent dye were co-evaporated with volume ratio of 1:0.08 until the total thickness came to 300 Å. Afterwards, the experimental devices were classified into three kinds according to the following ECL treatments:one was the device without any specific ECL, another with an undoped TPBI of 50 Å, and the other with an additional ECL of 50 Å-thick BCP. And then, 500 Å-thick SFC-137 was formed as an electron transport

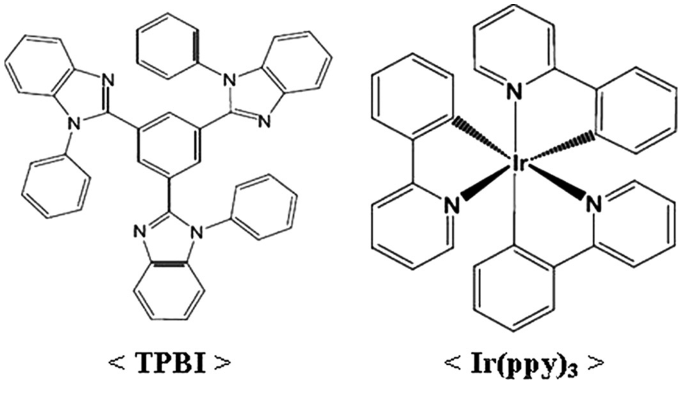

Figure 3. Molecular schemes of the TPBI host and the Ir(ppy)$_3$ dopant in the emission layer.

layer (ETL). Finally, 10 Å-thick LiF and 1200 Å-thick Al were successively deposited as a cathode.

In the host-dye system of emission region, exciton energy formed from the host material can be easily transferred to the phosphorescent dye of lower energy. The photoluminescence (PL) spectra of TPBI and the UV-vis absorption and PL spectra of $Ir(ppy)_3$ are shown in Figure 2. The wide overlap between the PL of TPBI and the absorption of $Ir(ppy)_3$ and the PL peak of $Ir(ppy)_3$ at around 510 nm show that the TPBI-$Ir(ppy)_3$ mixture can be a good host-dye system in the emission region for a high efficient green PhOLED. Figure 3 shows the molecular schemes of TPBI and $Ir(ppy)_3$ which were used as the host and dye materials in the emission layer.

Results and Discussion

The current density(J)-luminance(L)-voltage(V) characteristics of the fabricated devices were investigated using a Polaronix M6100 J-L-V test system. The emission properties such as electroluminescent spectrum and CIE color coordinates were evaluated using a CS-1000 spectro-radiometer in a dark box.

The current density-voltage and the luminance-voltage characteristics for the fabricated devices were shown in Figures 4 and 5, respectively. The current density-voltage characteristics shown in Figure 4 is similar to the luminance-voltage characteristics shown in Figure 5 because the light emission of OLED is due to the formation and release of excitons by the injection of carriers. As shown in Figures 4 and 5, the highest values of current density and luminance were obtained in the device without a specific ECL at a given voltage. On the other hand, the lowest values were obtained in the device with an additional ECL of BCP. This fact explains that the addition of ECL with the deeper HOMO level leads to the higher resistance resulting in the lower emission. The device with an undoped TPBI as an effective ECL showed the current density of 4.3 mA/cm^2 and the luminance of 1,900 cd/m^2 at an applied voltage of 10 V.

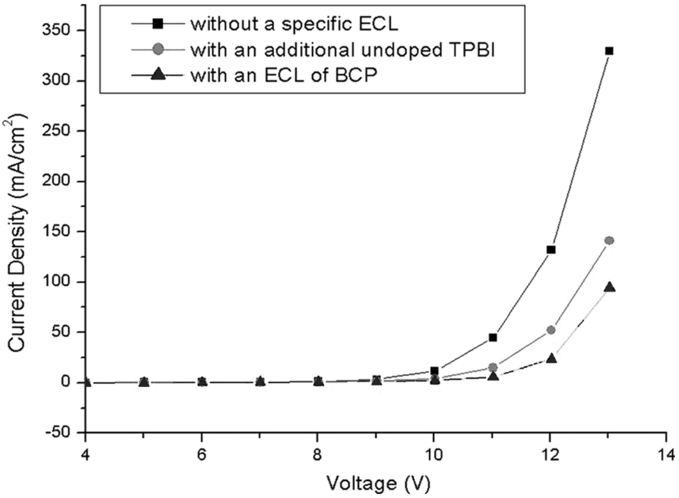

Figure 4. The current density-voltage characteristics for the experimental devices.

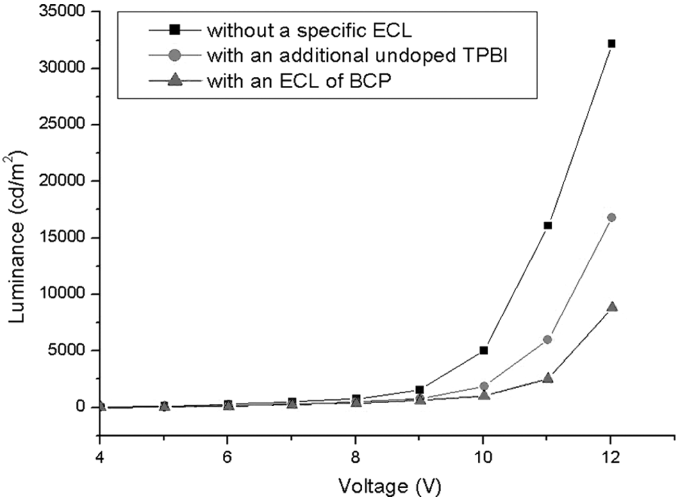

Figure 5. The luminance-voltage characteristics for the experimental devices.

The current efficiency is a convenient parameter to evaluate the electroluminescent characteristics of light emitting devices because it does not greatly depend on the applied voltages. The current efficiency (η) can be calculated by the equation of $\eta = L/J$ if the current density-voltage and luminance-voltage relationships are known [13], where L and J are luminance intensity and current density, respectively. Figure 6 represents the current efficiency vs voltage curves of the fabricated devices. The overall current efficiencies tended to monotonously decrease according to the increase of applied voltage on the condition of above 6 V. The highest current efficiency at a given voltage of above 8 V was obtained in the device with an additional ECL of BCP. The maximum current efficiency of the device with an additional ECL of

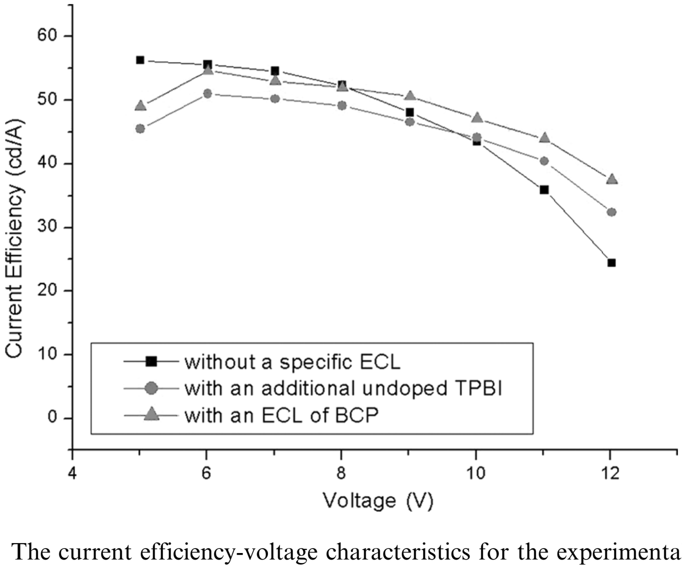

Figure 6. The current efficiency-voltage characteristics for the experimental devices.

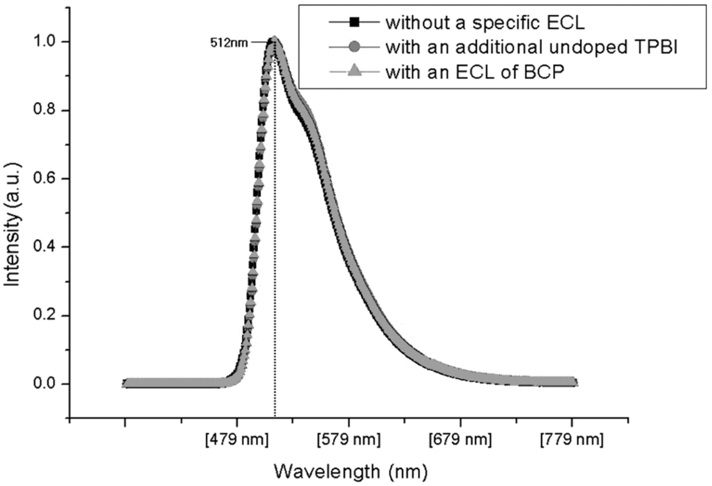

Figure 7. Electroluminescent spectra with central wavelength of 512 nm.

BCP was 54 cd/A at an applied voltage of 6 V. The roll-off characteristics of the devices with an undoped TPBI or an additional ECL of BCP were more stable than that of the device without a specific ECL. The current efficiency and roll-off characteristics of the device with an undoped TPBI were compatible to those of the device with an additional ECL of BCP. On the one hand, the device with an undoped TPBI showed the higher luminance at the same voltage than the device with an additional ECL of BCP. The device with an undoped TPBI showed the maximum current efficiency of 51 cd/A at 6 V and degraded to 45 cd/A at 10 V with the relatively stable roll-off characteristics.

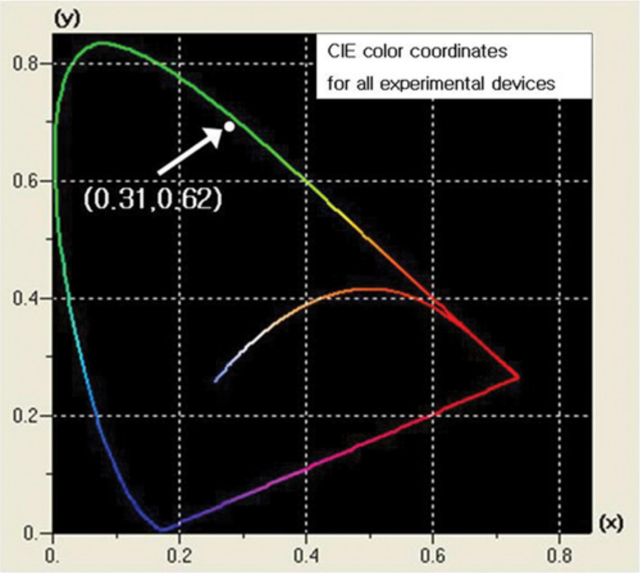

Figure 8. Color coordinates on the CIE chart.

The electroluminescent spectra and Commission Internationale de I'Eclairage (CIE) color coordinates for the fabricated devices were shown in Figures 7 and 8, respectively. All the devices showed the same peak wavelength of 512 nm in the electroluminescent spectra and the same color coordinates of (0.31, 0.62) on the (CIE) chart. The coordinates of (0.31, 0.62) on the CIE chart corresponds to the green light emission with a color purity of about 80%.

Conclusions

A new green PhOLED using the TPBI doped with Ir(ppy)$_3$ as an EML and the undoped TPBI as an effective ECL in the EML/ECL structure was proposed in this study.

The proposed device with an undoped TPBI showed the maximum current efficiency of 51 cd/A, which was compatible to that of the device with an additional ECL of BCP. The roll-off characteristics of the device with an undoped TPBI was more stable than that of the device without a specific ECL. The structure of the device with an undoped TPBI can be considered to be simpler than the device with an additional ECL of BCP due to the effective confinement of excitons in a single layer of TPBI.

As the device with an undoped TPBI proposed in this study shows the high current efficiency and roll-off stability compatible to those of the device with a conventional ECL of BCP with the characteristics of better luminance and simpler structure, the application of this device will be expected to be found in a wide variety of fields requiring the high efficient and simple structural OLEDs.

References

[1] Kin, Z., Kajii, H., & Ohmori, Y. (2006). *Thin Solid Films*, *499*, 392.
[2] Lee, J.-H., Wu, M.-H., Chao, C.-C., Chen, H.-L., & Leung, M.-K. (2005). *Chemical Physics Letters*, *416*, 234.
[3] Tseng, F.-M., Cheng, A.-C., & Peng, Y.-N. (2009). *Technological Forecasting and Social Change*, *76*, 897.
[4] Baldo, M. A., Thompson, M. E., & Forrest, S. R. (1999). *Pure Appl. Chem.*, *71*, 2095.
[5] Tang, K.-C., Liu, K. L., & Chen, I.-C. (2004). *Chemical Physics Letters*, *386*, 437.
[6] Adamovich, Vadim I., Cordero, Steven R., Djurovich, Peter I., Tamayo, Arnold, Thompson, Mark E., D'Andrade, Brian W., & Forrest, Stephen R. (2003). *Organic Electronics*, *4*, 77.
[7] Yichun Luo, Hany Aziz, Gu Xu, & Zoran D. Popovic. (2008). *Organic Electronics*, *9*, 1128.
[8] Ben Khalifa, M., Vaufrey, D., & Tardy, J. (2004). *Organic Electronics*, *5*, 187.
[9] Ikai, M., Tokito, S., Sakamoto, Y., Suzuki, T., & Taga, Y. (2001). *Applied Physics Letters*, *79*, 156.
[10] Kim, N. G., Shin, C. H., Lee, M. H., & Do, Y. (2009). *Journal of Organometallic Chemistry*, *694*, 1922.
[11] Park, S.-M., Ebihara, K., Ikegami, T., Lee, B.-J., Lim, K.-B., & Shin, P.-K. (2007). *Current Applied Physics*, *7*, 474.
[12] Kawai, T., Maekawa, Y., & Kusabiraki, M. (2007). *Surface Science*, *601*, 5276.
[13] Qu, B., Chen, Z., Xiao, L., Luo, F., & Gong, Q. (2009). *Frontiers of Optoelectronics in China*, *2*, 92.