

# Ideal Energy Level Alignment Technology for Phosphorescent OLEDs

Sun young Kim and Jang Hyuk Kwon

Dept. of Inform. Display, Kyung Hee University, Dongdaemoon-ku, Seoul  
130-701, Republic of Korea

TEL: 82-2-961-0948, e-mail: jhkwon@khu.ac.kr

**Keywords:** *Simple structure, Energy level alignment, PHOLED*

## Abstract

Using a  $\text{Ir}(\text{ppy})_3$  doped in the TCTA:Bepp<sub>2</sub> mixed host and N- and P-doped in TCTA:Bepp<sub>2</sub> charge transport layers, an ideal energy level alignment technology is developed. A very low roll-off current efficiency of 7.4 % at a luminance of 10,000 cd/m<sup>2</sup> with this technology is demonstrated in green phosphorescent OLEDs.

## 1. Introduction

Organic light-emitting diodes (OLEDs) have been developed as a new technology for next generation flat panel displays and for potential future use in the lighting industry, because they have attractive properties such as the possibility of ultra-thin and flexible displays, high picture quality with vivid color, and best suitability for movies because of its ultra-fast response time. Further more, essential requirements for these applications such as high current and power efficiencies are realized in phosphorescent organic light-emitting diodes (PHOLEDs) as phosphorescent materials can harvest both singlet and triplet excitons [1,2]. However, their performance suffers at high driving current densities exceeding 1 mA/cm<sup>2</sup>, and results in reduced quantum efficiency at high current density in PHOLEDs.

It has been known that P-I-N OLEDs can significantly reduce the operating voltage for fluorescent [3] as well as phosphorescent [4,5]. In these P-I-N OLEDs, the high conductive p- and n-doped layers enhance the charge injection properties from the contacts between the layers and reduce the ohmic losses in that layers [6-8]. These requirements are very well fulfilled in conventional light-emitting diodes (LED) from inorganic semiconductors by using heavily n- and p-doped electron- and hole-transport layers, leading to efficient tunnel injection and flat-band conditions under operation. In a conventional heterojunction OLED, the interface of the hole transporting layer (HTL) and emission layer (EML)

builds up a barrier to enhance carrier confinement, which improves the device efficiency [9]. However, the accumulated holes in the EML near the interface formed chemically unstable cations, which accelerated the formation of nonradiative trapping centers, thus resulting in luminance decay and voltage increase of an OLED [10]. Recently, we have reported the highly efficient green phosphorescent device comprising only of two organic layers with the host material of bis[2-(2-hydroxyphenyl)-pyridine] beryllium (Bepp<sub>2</sub>) [11]. The driving voltage value of 3.3 V and a power-efficiency value of 46.6 lm/W were reported in this device. The host material Bepp<sub>2</sub> has good electron transporting and energy transfer characteristics. 4,4',4''-tri(N-carbazolyl)triphenylamine (TCTA) hole transport material (HTL) is known to have excellent exciton blocking performance and reported as a suitable host material in green phosphorescent OLEDs [12,13]. It is suggested that the TCTA acts as an effective hole transport layer, and also plays the role of the emission layer. On the other hand, Bepp<sub>2</sub> acts as an effective electron transport layer, and also plays the role of the emission layer. In this letter, we utilized two host materials, TCTA with a predominant hole transporting character, and Bepp<sub>2</sub> with a predominant electron transporting character. The host was doped with green emitting iridium organic complex  $\text{Ir}(\text{ppy})_3$ . We report P-I-N structure of PHOLEDs with these materials.

## 2. Experimental

Devices were fabricated as following procedures. The sheet resistance of indium-tin-oxide (ITO) substrates used for our work was about 12 Ω/□ with 1,500 Å thickness. The ITO substrates of 2.5 cm × 2.5 cm were cleaned by ultra sonic in heated acetone and isopropyl alcohol (IPA) in sequence. Then, substrates were dried in air. Finally, UV ozone treatment was done in a chamber. The organic layers

were deposited onto an ITO coated glass substrate in a multi-chamber vacuum system at a pressure of  $1.0 \times 10^{-7}$  Torr. The TCTA doped with  $\text{WO}_3$  (doping concentration 30 wt%) serves as the p-doped HTL. A layer of Bepp<sub>2</sub> doped with  $\text{Cs}_2\text{CO}_3$  serves (doping concentration 10 wt%) as the n-doped ETL. Organic layers are controlled independently by measuring them with separate quartz thickness monitors. The Ir(ppy)<sub>3</sub> was doped with 4% doping concentration in a mixed emission layer of Bepp<sub>2</sub> and TCTA. The deposition rate of organic layer was about 0.5 Å/sec. Then, LiF and Al were deposited, successively, in metal chamber without breaking the vacuum of the. Figure 1 shows the device structure of our P-I-N device with the molecular structures of used materials. The emission area of devices was 2 mm × 2 mm. The current density-voltage (J-V) and luminance-voltage (L-V) characteristics of green PHOLEDs were measured with a Keithley SMU 238 and Minolta CS-100A. Electroluminescence (EL) spectra and CIE color coordinate were obtained by a Minolta CS-100A.

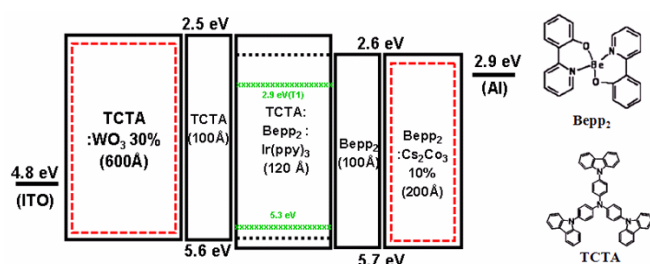


Figure 1. The molecular structures of the emitting host materials, and the energy levels of our P-I-N device.

### 3. Results and discussion

It has been known that P-I-N technology can significantly reduce the operating voltage of fluorescent as well as phosphorescent OLEDs. The NPB hole transport material was mostly used for a p-doped hole injection layer in several earlier studies. However, this has a poor HTL buffer layer characteristics in green PHOLEDs due to lower triplet energy than that of Ir(ppy)<sub>3</sub>. Therefore, a wide band gap material having a high triplet energy is required for buffer layer. The TCTA has been reported as an excellent host material in green PHOLEDs and HTL material.

P-doped TCTA characteristics is investigated to use as a hole injection layer, buffer and host material.

Formation of charge transfer complex between a charge transporting material and p-dopant has been studied by many researches to verify the possibility of conductivity enhancement and Ohmic contact. An additional absorption peak at the wavelength around 455 nm in  $\text{WO}_3$  doped TCTA film on the quartz glass was observed as a charge transfer band, indicating that TCTA could be a good hole injection layer with high hole mobility. Figure 2 (a) shows I-V characteristics of the hole-only devices consisting of doped and undoped TCTA layers.

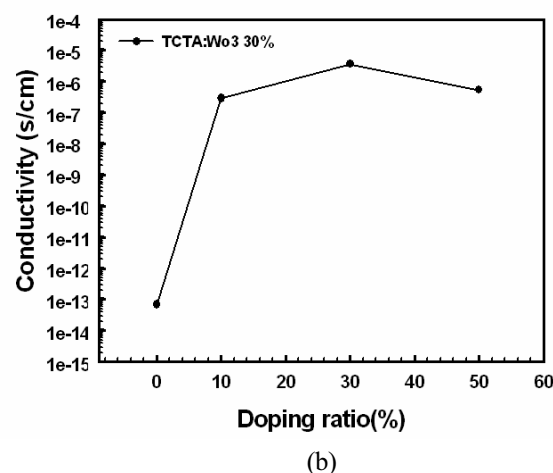
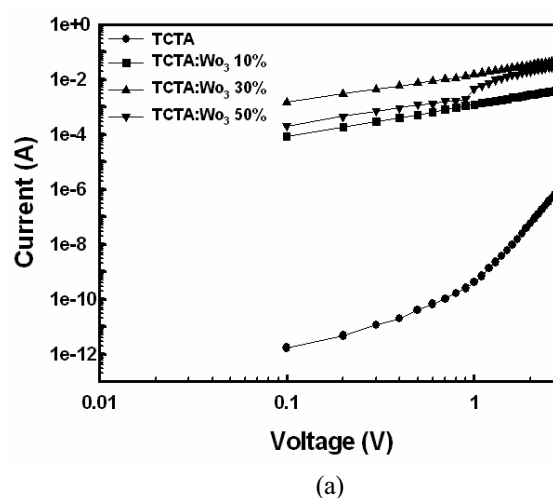
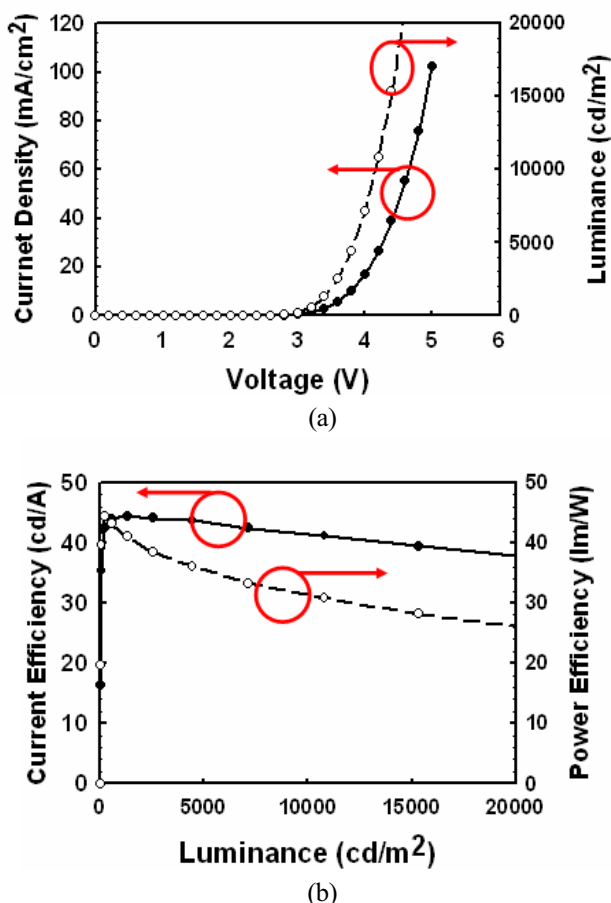


Figure 2. (a) Current vs. voltage and (b) Conductivity variation vs. doping concentration characteristics of hole only devices.

The I-V characteristics of devices with undoped layer follow general trapped charge limited current and space charge limited current. However, it is clearly shown that hole only devices with  $\text{WO}_3$  doped layer exhibit Ohmic-like I-V characteristic. Conductivity variation as a function of dopant

concentration in  $\text{WO}_3$  doped TCTA is shown in Figure 2 (b). At first, the conductivity is enhanced by the order of magnitude of  $10^7$  with 10% doping concentration and then reaches to optimum value at 30%  $\text{WO}_3$ . A further increase in concentration deteriorates the conductivity of devices. The conductivity value in 30% doped TCTA is reached the range  $\sim 10^{-5}$  S/cm as the maximum and this conductivity is very similar to our reported 30% doped NPB results. Based on these results, the 30% doped TCTA was used as a hole injection layer. TCTA also used as a buffer layer and host material for an emission layer to have no hetero-interface. For an n-doped ETL layer,  $\text{Cs}_2\text{CO}_3$  doped in  $\text{Bepp}_2$  was used. The  $\text{Bepp}_2$  also has a higher triplet energy than  $\text{Ir}(\text{ppy})_3$ . Conductivity of doped  $\text{Bepp}_2$  is similar to that of doped Bphen, also reaches about  $10^{-5}$  S/cm range.  $\text{Bepp}_2$  was used in a similar way for electron injection at the cathode side.



**Figure 3. (a) Current density and luminance vs. voltage characteristics, and (b) Current and power efficiency vs. voltage characteristics.**

Several PHOLEDs with simple P-I-N structure were fabricated using various emitting layer structures and compositions. Among them, a mixed host structure shows the best device performances.

Figure 3 shows the J-V-L and efficiency characteristics of this simple green P-I-N PHOLEDs. The paramount performances in terms of current and power efficiencies are obtained at 4% doping concentration. Turn-on (at 1 cd/m<sup>2</sup>) and operating voltage (at 1,000 cd/m<sup>2</sup>) are 2.4V and 3.3V, respectively. The maximum current and power efficiencies are 44.4 cd/A and 44.3 lm/W, respectively. Current and power efficiencies are 44.4 cd/A and 41 lm/W at a luminance of 1,000 cd/m<sup>2</sup>, respectively. The device maintain almost the same current efficiency characteristic and shows only slight variation from 44.4 cd/A to 41.1 cd/A until 10,000 cd/m<sup>2</sup>. The CIE color coordinate of this host device is (0.27, 0.61) at 1000 nits.

#### 4. Summary

In this paper, we have demonstrated an ideal energy level alignment technology for phosphorescent green devices. Low driving voltage value of 3.3 V and current- and power-efficiency values of 44.4 cd/A and 41 lm/W to reach a luminance of 1,000 cd/m<sup>2</sup> are reported in a mixed host device made by using a  $\text{Ir}(\text{ppy})_3$  metal complex doped in TCTA and  $\text{Bepp}_2$  materials. A very low roll-off of current efficiency of 7.4 % at a luminance of 10,000 cd/m<sup>2</sup> also is reported, respectively. This simple structure PHOLED can be very useful for passive matrix and active matrix OLED display application.

#### 5. References

1. X. Gong, J. C. Ostrowski, D. Moses, G. C. Bazan, and A. J. Heeger, *Appl. Phys. Lett.* **81**, 3711 (2002).
2. C. Adachi, M. A. Baldo, S. R. Forrest, and M. E. Thompson, *Appl. Phys. Lett.* **77**, 904 (2002).
3. J. Huang, M. Pfeiffer, A. Werner, J. Blochwitz, S. Liu, and K. Leo, *Appl. Phys. Lett.* **80**, 139 (2002).
4. M. Pfeiffer, S. R. Forrest, K. Leo, and M. E. Thompson, *Adv. Mater.* **14**, 1633 (2002).
5. G. F. He, O. Schneider, D. S. Qin, X. Zhou, M. Pfeiffer, and K. Leo, *J. Appl. Phys.* **95**, 5773 (2004).
6. B. Yamamori, C. Adachi, T. Koyama, and Y. Taniguchi, *Appl. Phys. Lett.* **72**, 2147 (1998).
7. J. Blochwitz, M. Pfeiffer, T. Fritz, and K. Leo, *Appl.*

- Phys. Lett.* **73**, 729 (1998).
8. X. Zhou, M. Pfeiffer, J. Blochwitz, A. Werner, A. Nollau, T. Fritz, and K. Leo, *Appl. Phys. Lett.* **78**, 410 (2001).
  9. C. W. Tang and S. A. VanSlyke, *Appl. Phys. Lett.* **51**, 913 (1987).
  10. D. Y. Kondakov, J. R. Sandifer, C. W. Tang, and R. H. Young, *J. Appl. Phys.* **93**, 1108 (2003).
  11. W. S. Jeon, T. J. Park, J. J. Park, S. Y. Kim, J. Jang, J. H. Kwon, and R. Pode, *Appl. Phys. Lett.* **92**, 113311 (2008).
  12. S. Reineke, G. Schwartz, K. Walzer, and K. Leo, *Appl. Phys. Lett.* **91**, 123508 (2007).
  13. J. Meyer, S. Hamwi, T. Bülow, H.-H. Johannes, T. Riedl, and W. Kowalsky, *Appl. Phys. Lett.* **91**, 113506 (2007).