

A high efficiency green phosphorescent OLED with simple double emission layer structure

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Abstract

Using a $\text{Ir}(\text{ppy})_3$ doped in hole and electron transport host materials, simple three layers green PHOLEDs comprising double emissive layers have been fabricated. A low driving voltage value of 3.3 V to reach a luminance of 1000 cd/m^2 and maximum current- and power-efficiency values of 53.9 cd/A and 57.8 lm/W are demonstrated in this simple structure phosphorescent OLED.

1. Introduction

Organic light-emitting diodes (OLEDs) are of considerable interest in recent years for flat panel display applications. OLEDs with fluorescent dyes as the emissive layer, wherein only the singlet states of the organic molecule contribute to the light emission, exhibit an upper limit on the internal quantum efficiency of 25%. This efficiency could be improved by introducing the phosphorescent dyes that can harvest both singlet and triplet excitons, generated by electron injection.[1~3] Therefore, the recent demonstration of high efficiency phosphorescent OLEDs (PHOLEDs) has generated intense research interest since they theoretically allow to have displays with 100 % internal quantum efficiency.[3,4] To achieve high quantum efficiency in phosphorescent OLEDs, the excited energy of the phosphorescent emitter need to be confined within the emitter itself using wide-energy-gap host materials and carrier-transporting materials, which have higher triplet excited energy levels than that of the emitter and multilayer architecture comprising electron/hole injection and transport layers.[5,6] Four to five organic layered structure in PHOLEDs was commonly used to achieve high current efficiency values. Such

multilayer structure often enhances the drive voltages of PHOLEDs. Chemical doping with either electron donors (for electron transport materials) or electron acceptors (for hole transport materials) can significantly reduce the voltage drop across these films.[7-10] Earlier, the maximum power efficiency of 53 lm/W and a luminance of 1000 cd/m^2 reached at 3.1 V with a power efficiency of 45 lm/W in green phosphorescent p-i-n OLEDs were reported.[11] Wellermann *et al.* reported green emitting p-i-n OLED with efficiencies 69 cd/A and 79 lm/W . [12] A green phosphorescent device with $\text{Ir}(\text{ppy})_3$ metal complex to achieve high quantum efficiency, and chemical doping of electron transport layer with cesium (Cs) to achieve high power efficiency shows external quantum efficiency of 27% (95 cd/A) and high power efficiency of 97 lm/W at 100 cd/m^2 at 3.1 V.[13] Indeed, all these devices have multilayer structure with high current- and power-efficiencies, but thin emitting layer. Nevertheless, narrow thickness of emitting layer in p-i-n PHOLEDs and complex design architecture of phosphorescent OLEDs are not desirable from the manufacturing perspective. Therefore, the simple structure with extremely low driving voltage and high efficiency is very imperative in PHOLEDs. Recently, we have reported that the simple bilayered green PHOLED structure was fabricated by the host Bepp₂. [14] The driving voltage value of 3.3 V and a power-efficiency value of 46.6 lm/W are reported in this device. In this study, we demonstrate much higher efficiency green phosphorescent devices comprising a hole transport layer and double emissive layers.

2. Experiment

Devices were fabricated as following procedures. A clean glass substrate of size was 2 cm X 2 cm precoated with a 150-nm ITO layer and sheet resistance of 10 ~ 12 Ω/\square was used. The patterns of 2 X 2 mm² were formed by photolithography and wet etching processes and used as an anode. The glass substrate was cleaned by sonification in an isopropyl alcohol, acetone, and methanol, rinsed in deionized water, and finally irradiated in a UV-ozone chamber. All organic materials were deposited by the vacuum evaporation technique under a pressure of $\sim 3.0 \times 10^{-7}$ Torr. Doping is carried out by co-evaporation from independent sources and effusion rates were monitored using a quartz crystal microbalance (QCM). Subsequently, Al with a deposition rate of ~ 5 Å/s was deposited in vacuum chamber without breaking the vacuum and used as a cathode. The current density-voltage (J-V) and luminance-voltage (L-V) data of PHOLEDs were measured with a Keithley SMU 238 and Minolta CS-100A, respectively. Electroluminescence (EL) spectra and CIE color coordinate were obtained using a Photo-research PR-650 spectroradiometer.

3. Results and discussion

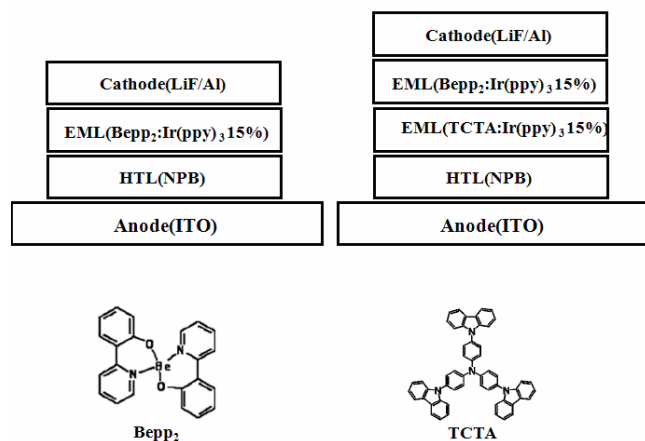


Fig. 1. Device structures and molecular structures used in the present studies.

Figure 1 shows device structures of the single (device 1) and double (device 2) emission layers PHOLEDs. Organic bilayered PHOLED device having a single emission layer was used as a control device. This device was consisted ITO / NPB 40 nm / Bepp₂:Ir(ppy)₃ 50 nm / LiF 1 nm / Al. In order to

improve emission efficiencies and confine excitons within emission layers, TCTA host layer in the simple bilayered PHOLED for good charge balance was inserted between the hole transport layer and electron transporting emitting material layer. Double emission layer devices were made with ITO / NPB 40 nm / TCTA:Ir(ppy)₃ 15 nm / Bepp₂:Ir(ppy)₃ 35 nm / LiF 1 nm / Al structure. The performance of double emissive layer device was optimized by changing the concentration of Ir(ppy)₃. The dopant concentration in each emissive layer was varied by same amount.

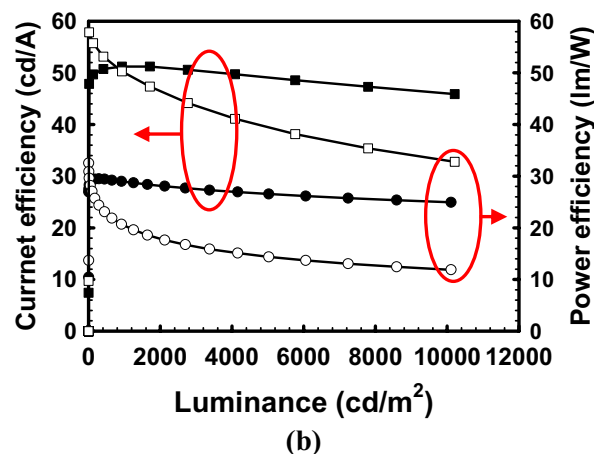
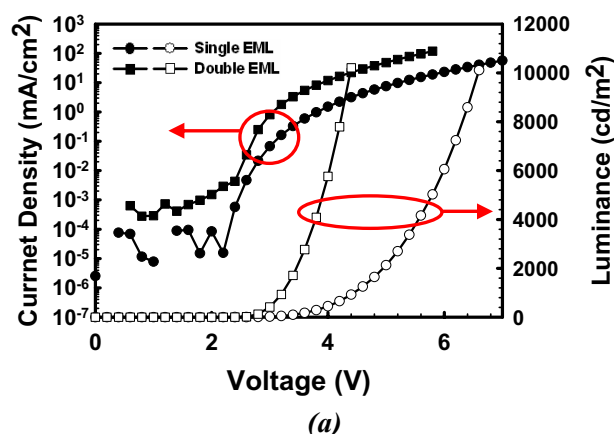


FIG 2. (a) J-V-L and (b) efficiency characteristics of fabricated single and double emission layer green PHOLEDs (15% dopant concentration).

Figure 2 shows I-V-L characteristics of the single and double emissive layers PHOLEDs, measured until 10,000 cd/m² brightness values. The operation driving voltage value to reach 1000 cd/m² was 4.5 V for device 1 and 3.3 V for device 2. At a given constant luminance of 1000 cd/m², the current and power efficiencies were 51.23 cd/A and 50.30 lm/W for

device 2, respectively while these values are 28.71 cd/A and 19.60 lm/W for device 1. The power and current efficiency values of double emission layer PHOLED were improved by about 1.7 and 2.5 times compared with those of single emission layer PHOLED. These results reveal that double emission layer PHOLED using TCTA host layer displays good charge balance and confinement of excitons within emission layers.

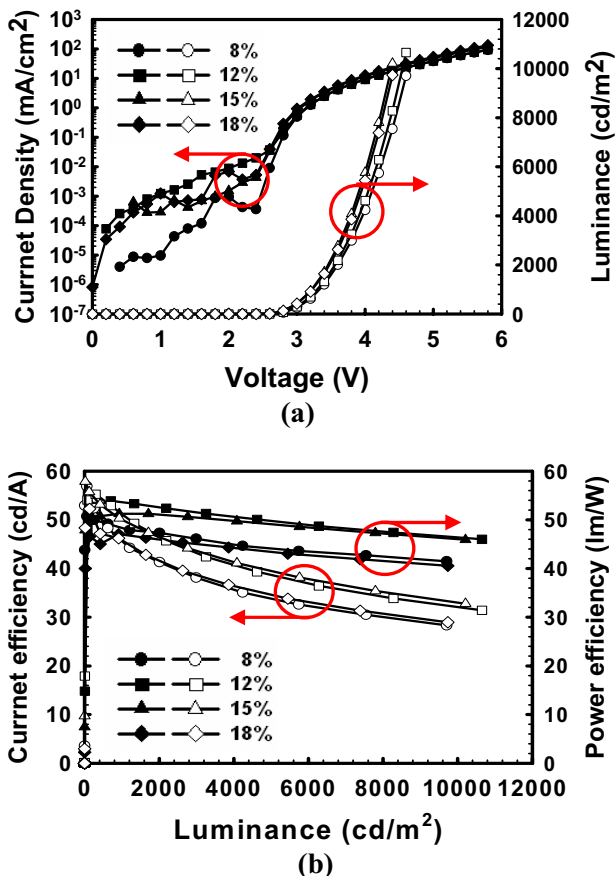


FIG. 3. (a) J-V-L and (b) efficiency characteristics of fabricated double emission layer green PHOLEDs with different doping concentration of Ir(ppy)₃.

Figure 3 show the J-V-L characteristics and efficiency of the double emission layer PHOLEDs as a function of doping concentration of Ir(ppy)₃. At a given constant luminance of 1000 cd/m², the current efficiency and power efficiency of each device were 47.88 cd/A and 44.24 lm/W, 53.31 cd/A and 49.26 lm/W, 51.23 cd/A and 50.30 lm/W, and 47.06 cd/A and 46.20 lm/W for 8, 12, 15, and 18% Ir(ppy)₃, respectively. The green PHOLEDs with 15% doping concentration of Ir(ppy)₃ exhibits the best current and power efficiency characteristics among four green

PHOLEDs. The J-V characteristics were saturated over 15% doping condition and efficiency also commence to deteriorate from 18% doping condition. As shown in Fig. 4, hole trapping by dopant sites in these devices are so severe. Therefore, high doping (about 15%) is required for facile hole movement through dopant materials.

Interesting and intriguing results on the performance of double emissive layer devices have been obtained. Interesting and intriguing results on the performance of double emissive layer devices have been obtained. The leakage of electrons and exciton energy transfer to NPB hole transporting layer were reported in our previous organic bilayered device.[14]

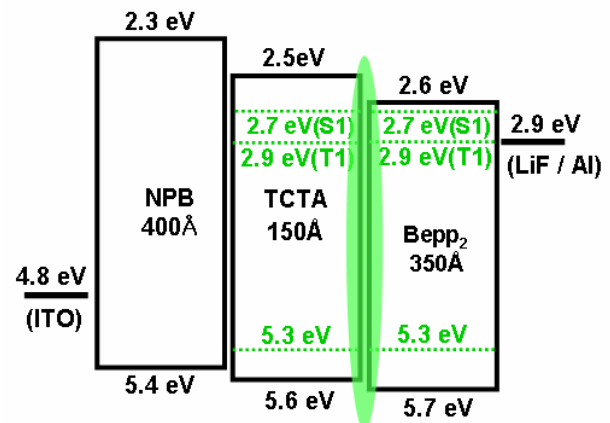


FIG. 4. Energy diagram of double emissive layer PHOLEDs

Insertion of TCTA emissive layer results in the movement of exciton formation zone from NPB interface to TCTA and Bepp₂ interface as TCTA is an excellent hole transporting host material. Double emissive layer device structure easily can confine all excitons at the interface of TCTA and Bepp₂ owing to different natures of both host materials. As the results, high efficiency green PHOLEDs were possible. Furthermore, excellent hole transporting property of TCTA material favors to mobility of holes which provides driving voltage improvement in these double layer devices.

4. Summary

In this paper, we have demonstrated high power efficiency green PHOLEDs using only organic triple layers. The low driving voltage value of 3.3 V to reach

a luminance of 1000 cd/m² and maximum current- and power-efficiency values of 53.9 cd/A and 57.8 lm/W are demonstrated, respectively. This simple structure PHOLED can be very useful for passive matrix and active matrix OLED display application. Cost reduction and increase of yield in OLED display production is expected by this simple structure.

5. References

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