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Host Engineering for High Efficiency in Phosphorescent White Organic Light-Emitting Diodes

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High efficiency phosphorescent white organic light emitting diodes (PHWOLEDs) were fabricated by controlling the charge transport properties of host materials. Blue/red/blue stack structure was used and the use of hole transport type host material in red emitting layer was effective to improve the quantum efficiency of PHWOLEDs. High quantum efficiency of 12.2% was obtained in PHWOLEDs.

Keywords: charge transport; phosphorescent white organic light emitting diodes; quantum efficiency

INTRODUCTION

White organic light emitting diodes (WOLEDs) have been intensively studied for the last decade for applications such as a display, a back-light and a general lighting because of their merits of high efficiency, simple processing and various colors. However, device performances of WOLEDs need to be improved further to expand the application of WOLEDs.

Light emitting efficiency is the most critical device performance of WOLEDs and there have been many studies to improve the efficiency of WOLEDs [1–10]. The most effective way of enhancing the device performances of WOLEDs is to use a phosphorescent emitting material instead of a fluorescent emitting material [1–7]. Phosphorescent emitting material has four times higher quantum efficiency than fluorescent emitting material and high efficiency can be achieved in

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phosphorescent white organic light emitting diodes (PHWOLEDs). Red/blue/green stacked structure of phosphorescent emitting layer was effective to improve the quantum efficiency and efficiency roll-off WOLEDs [1]. In particular, efficiency roll-off was minimized in red/blue/green stacked structure by using a mixed host structure in red and green emitting layers. High efficiency of 16% was reported in PHWOLEDs by broadening the recombination zone of PHWOLED[2]. Other than these, several different PHWOLED structures were reported in the literature [3–7].

In this work, a high efficiency PHWOLEDs was developed by using a blue/red/blue stack structure with blue triplet host materials in all emitting layers. N,N′-dicarbazolyl-3,5-benzene (mCP) and 2,3-phenylenebis(triphenylsilane) (UGH-3) were used as host materials in emitting layer and the relationship between host materials and device performances of PHWOLEDs was investigated.

EXPERIMENTAL

The device configuration used in this study was indium tin oxide (ITO, 150 nm)/N,N′-di(1-naphthyl)-N,N′-diphenylbenzidine (NPB, 60 nm)/mCP(10 nm)/mCP: bis[(4,6-difluorophenyl)-pyridinato-N, C2](picolinato)-Ir(III) (FIrpic) (15 nm, 15%)/host: bis(1-phenylquinoline) acetylacetone (Ir(pq)2acac) (3 nm: 10%)/UGH-3:FIrpic(15 nm: 15%)/4,7-diphenyl-1,10-phenanthroline(BPhen, 20 nm)/LiF(1 nm)/Al(200 nm). The host materials for red emitting layer were mCP (Device I), UGH-3 (Device II) and 1:1 mixed host of mCP:UGH-3 (Device III). All organic materials except dopant materials were evaporated at a deposition rate of

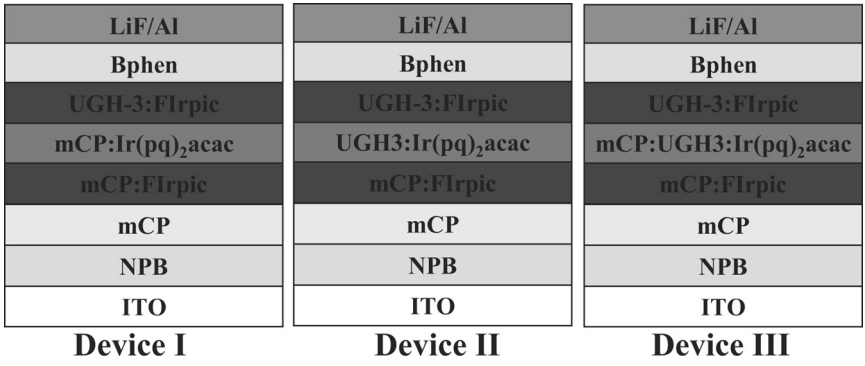

FIGURE 1 Device structures of phosphorescent white organic light emitting diodes with different host materials in red emitting layer.

0.1 nm/s and doping concentration was controlled by managing the deposition rate. Device structures are shown in Figure 1. Pixel area was 4 mm^2 with 2 mm by 2 mm size. Pixel was defined by using a organic pixel define layer. Current density-voltage-luminance (I-V-L) characteristics and electroluminescence (EL) spectra of PHWOLEDs were measured with Keithley 2400 source measurement unit and a CS 1000 spectrophotometer.

RESULTS AND DISCUSSION

The management of device structure is an effective way of improving the device performances of PHWOLEDs [1,2]. One efficient method is to use a two layer charge confining emitting structure which can confine holes and electrons inside an emitting layer [11]. A stack of a hole transport type hole transport material and an electron transport type material could enhance the light-emitting efficiency of PHWOLEDs. A similar concept was applied in this work and a red emitting structure was sandwiched between a hole transport type blue emitting layer and an electron transport type blue emitting layer. The hole transport or electron transport type host materials were also applied in red emitting layer and the device performances of PHWOLEDs were correlated with the host structure of red emitting layer. In our previous work, the emission zone of hole transport type host/electron transport type host double emitting layer structure was concentrated at the interface between the two emitting layers. Therefore, a thin layer of red emitting material was positioned at the interface between the two emitting layers.

Current density-voltage-luminance curves of PHWOLEDs are shown in Figure 2. The red host structure affected the current density of the devices and a high current density was obtained in device II with a mixed host structure in red emitting layer. The mixed host structure is advantageous in terms of current density because both hole and electron injection can be facilitated due to the presence of hole transport and electron transport materials. In the case of mCP, electron injection is limited due to the lowest unoccupied molecular orbital (LUMO) of 2.4 eV for poor electron injection as can be seen in Figure 3. Compared with mCP, hole injection is difficult in UGH-3 because of the highest occupied molecular orbital of 7.1 eV for hole injection. There is an energy barrier of 1.0 eV between mCP and UGH-3, leading to poor hole injection in UGH-3. The poor hole injection in UGH-3 resulted in low current density in the PHWOED with UGH-3 host material in red emitting layer. A rather higher current density of device I compared with device II is due to good hole

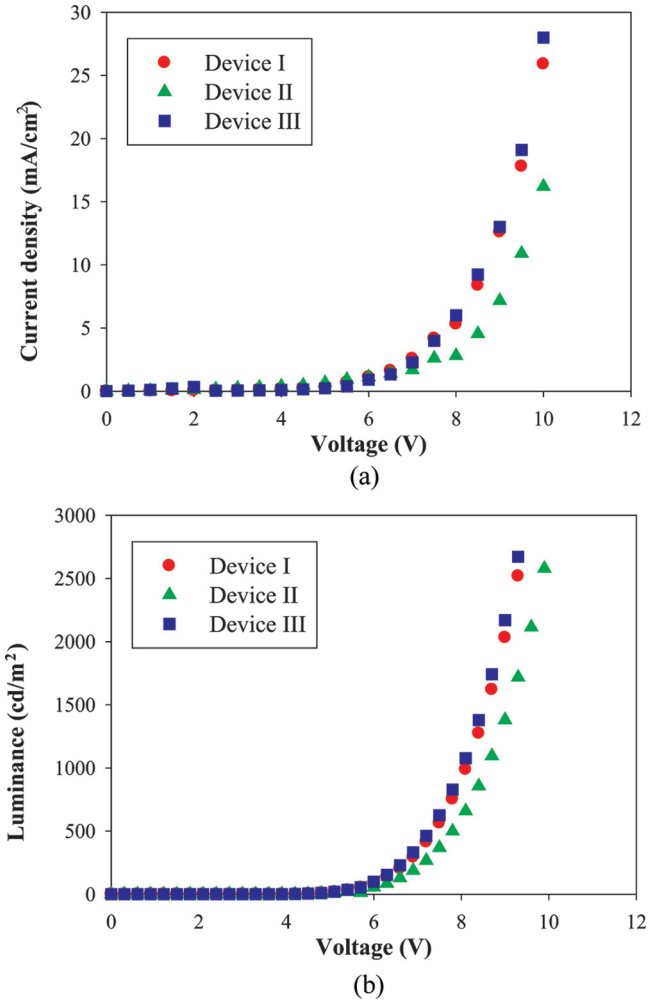

FIGURE 2 Current density-voltage-luminance performances of phosphorescent white organic light emitting diodes. (a) current density-voltage (b) luminance-voltage.

transport properties of mCP. Electron transport properties of UGH-3 are not good enough compared with hole transport properties of mCP, resulting in low current density in device II. In addition, strong hole trapping by red emitting dopant material also has negative effect on current density because hole transport is retarded by the hole trapping effect. Luminance of PHWOLEDs with different host materials in red emitting layer followed the same trend as current density because

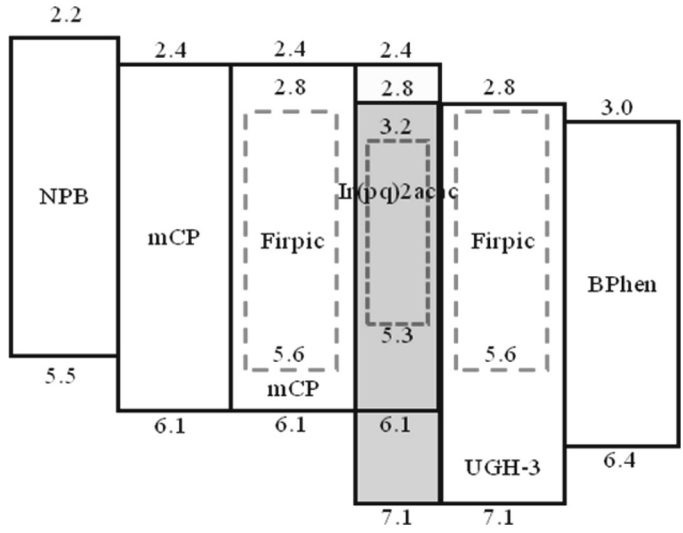

FIGURE 3 Energy level diagram of materials.

luminance is high in the device with high charge density in light emitting layer. In addition to current density, recombination efficiency of holes and electrons affects the luminance, which will be shown in Figure 4.

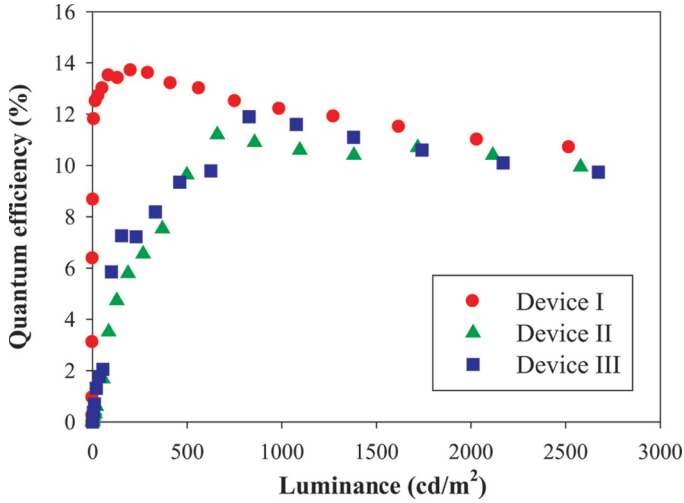

FIGURE 4 Quantum efficiency-luminance curves of phosphorescent white organic light emitting diodes.

Quantum efficiency-luminance curves of PHWOLEDs are shown in Figure 4. Device I with mCP host in red emitting layer showed the highest efficiency, while device II and device III showed similar quantum efficiency. Quantum efficiency is mostly determined by the holes and electrons balance in light emitting layer. In the double layer device without red emitting layer, holes are major carriers and recombination efficiency can be improved by decreasing the hole density in light emitting layer. In the case of device I, hole density is decreased as holes are strongly trapped by red emitting dopant. Therefore, holes and electrons balance are improved by red emitting layer. However, the charge balance is not improved in UGH-3 device as red dopant acts as a charge transporting media. Holes are injected from mCP layer to red dopant in UGH-3 layer. Therefore, hole injection is improved by the red dopant. Electron injection is also retarded by the red dopant.

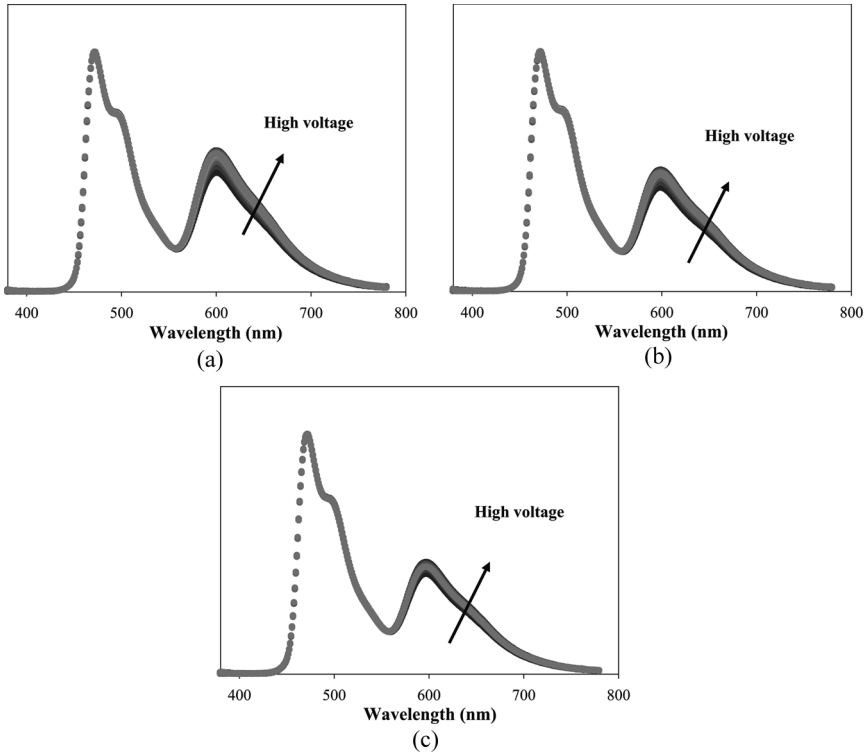

FIGURE 5 Electroluminescence spectra of phosphorescent white organic light emitting diodes according to driving voltage. (a) device I (b) device II (c) device III.

Therefore, charge balance is not improved in device II with UGH-3 host material. In the device III with a mixed host in red emitting layer, holes and electrons balance is not enhanced, leading to similar quantum efficiency as device II. A maximum quantum efficiency of 14% was obtained in device I and the quantum efficiency at 1,000 cd/m^2 was 12.2%.

Color stability of three devices was measured according to driving voltage and they are represented in Figure 5. All three devices showed good color stability and there was little change of EL spectra according to voltage. The good color stability of the blue/red/blue stacked devices can be explained by the balanced recombination zone shift in light emitting layers. There is a change of charge density in red emitting layer depending on the driving voltage. However, the change of charge density is compensated by the two blue emitting layers, resulting in color stability in the device. The use of red phosphorescent host in red emitting layer was effective to get stable EL spectra irrespective of driving voltage. Therefore, the blue/red/blue stack structure was effective to get good color stability in white devices.

CONCLUSIONS

In summary, blue/red/blue emitting structure was effective to get high quantum efficiency and good color stability. A high maximum quantum efficiency of 14% and a quantum efficiency of 12.2% at 1,000 cd/m^2 were achieved in the PHWOLED with a mCP host in red emitting layer. In addition, there was no change of EL spectra according to driving voltage irrespective of host materials in red emitting layer by using a blue phosphorescent host material in red light emitting layer.

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