High efficiency phosphorescent organic light-emitting devices with a new organic material as the host of the emitting layer

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ABSTRACT

In this paper, we demonstrate a phosphorescent organic light emitting device (PHOLED) with low turn-on voltage by using a n-type organic material as the host of the emitting layer (EML) doped with green emitting complex, *fac* tris(2-phenylpyridine) iridium Ir(ppy)$_3$. This material exhibits high glass transition temperature (over 200 ^{o}C) that may help to elongate the operation lifetime. We compare our devices to the classical 4,4'-N,N'-dicarbazole-biphenyl (CBP) based green device. Driving voltage of the CBP and the new-host based OLED is 16 and 11 V with the current density of 100mA/cm2, respectively. The lower driving voltage of the new-host based device comes from the lower HOMO value, i.e. 5.7 eV, which is nearly the same as that of NPB. The current efficiency at 10000 cd/m2 is slightly decreased from 24 to 21 cd/A. However, the power efficiency is increased from 5 to 6 lm/W.

Keywords: OLED, phosphorescent

1. INTRODUCTION

High efficient phosphorescent light emitting diode (PHOLED) with carbazole based host materials has been demonstrated in recent years [1-3]. Due to the triplet state of metal-ligand charge transfer state (^{3}MLCT) of *fac* tris(2-phenylpyridine) iridium Ir(ppy)$_3$ is between 2.5 and 3 eV , a suitable host material for efficient energy transfer is necessary. Typically, 4,4'-N,N'-dicarbazole-biphenyl (CBP), is widely used as host materials of PHOLED since the peak wavelength of fluorophores is about 400 nm [4]. Thus, using (Irppy)3 in CBP can lead to efficient phosphorescent emission [5].

However, for the efficient energy transfer from host material to phosphor, the bandgap of host material is mostly large. The highest occupied molecular orbital (HOMO) value of CBP is about 6.3 eV which will result in a larger barrier for holes to inject from hole transmission layer (HTL) to emission layer (EML). Besides, Iridium based metal compounds are relatively more stable than the classical carbazole based host materials which is due to its low glass transition temperature (Tg). Thus, considering lower driving voltage and longer stability of device, the alternative for the host of PHOLED is required.

In this paper, we proposed a carbazole-free phosphorescent device by using a OXD based n-type materials which in rare and the result is far away form satisfactory [6]. As compared to the conventional CBP, this material shows a high glass transition temperature (over 200 ^{o}C) that may prolong the operation life time. Molecular structures of Ir(ppy)$_3$ and CBP are shown in Fig. 1. In order to investigate the energy transfer of our phosphorescent system, we compared the PL (photoluminescence) of this materials and the absorption spectrum of Ir(ppy)$_3$ and found the good spectrum overlap. We also optimized this PHOLED with different concentration of Ir(ppy)$_3$ and compared the operation life time with carbazole based PHOLED.

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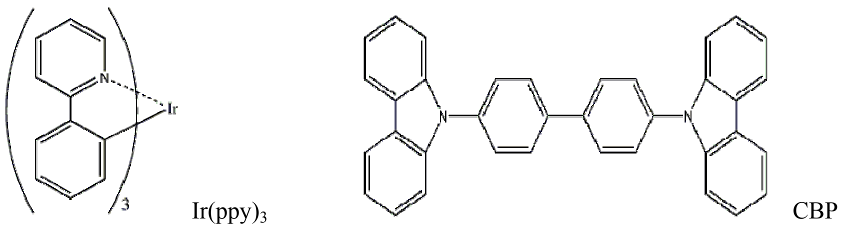

Fig. 1 Molecular structure of Ir(ppy)$_3$ and CBP.

2. EXPERIMENTS

In all of our devices, we used ITO glass substrate of low resistivity (10 Ohm/sqr) and flat surface roughness (Ra< 1nm). In order to lower ITO work function and clean ITO surface, we pretreated ITO surface with O_2 plasma. All the thermal evaporation of organic materials was in a batch-type chamber. The deposition rate was controlled at about 0.15 nm/sec and the chamber pressure is under $5x10^{-6}$ torr. As shown in Fig. 2, 40 nm N,N'-diphenyl-N,N'-bis(1-napthyl)-1,1'-biphenyl-4,4'-diamine (NPB) was used as a hole transport layer (HTL). The emitting layer (EML) consisted of this host materials with different concentration of Ir(ppy)$_3$ and CBP in our standard device. 10 nm 2,9-dimethyl-4,7-diphenyl 1,10- phenanthrolin (BCP) was used as hole blocking layer and 30 nm tris-(8-hydroxyquinoline) aluminum acted as electron transport layer (ETL). The concentration of the Ir(ppy)$_3$ is 0, 3, 5, 9, 15 % in the new-host based devices and 9% in standard device. After organic deposition, devices were exposed in atmosphere for about 20 seconds and delivered into glove box for encapsulation. The O2 and H2O concentrations of glove box are all below 10 ppm. Current-voltage characteristics of all devices were measured by using a Keithley 2400 source measurement unit. Brightness and emission spectrum was measured with Minolta CS1000 spectrophotometer. These instruments were connected to a personal computer and collaborated by software.

Al (150 nm)	**Al (150 nm)**
LiF (0.1 nm)	**LiF (0.1 nm)**
Bebq2 (30 nm)	**Bebq2 (30 nm)**
BCP (10 nm)	**BCP (10 nm)**
Host : x% Ir(ppy)$_3$ (30 nm)	**CBP : 9% Ir(ppy)$_3$ (30 nm)**
NPB (40 nm)	**NPB (40 nm)**

Fig. 2 Standard and compared device structures. The concentration of x is 0, 3, 5, 9, 15 % respectively

3. RESULTS AND DISCUSSIONS

Figure. 3 shows the absorption and PL spectra of $Ir(ppy)_3$ and the new-host based host. Phosphorescence proceeds via either direct injection into the triplet metal ligand charge transfer state (^{3}MLCT) or via inter system crossing (ISC) from the singlet charge transfer state (^{1}MLCT). In the figure, good spectrum overlap between the host emission (356 nm) and the absorption of and the singlet metal-to-ligand charge-transfer state (^{1}MLCT) of $Ir(ppy)_3$ (389.5 nm) has been demonstrated. Thus, energy transfer from the host to $Ir(ppy)_3$ seems possible.

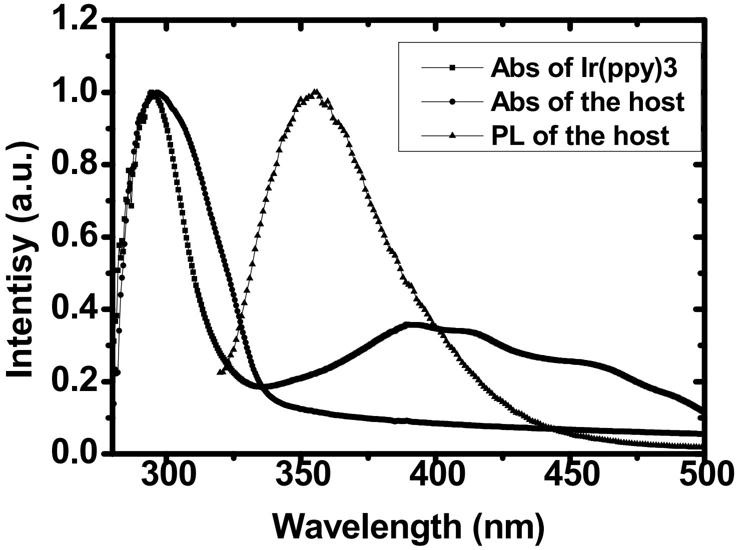

Fig. 3 The absorption spectrum of the host and $Ir(ppy)_3$ and PL of the host at room temperature.

Figure 4 shows current density and voltage curves (J-V) characteristics of host: x% $Ir(ppy)_3$ and CBP : 9% $Ir(ppy)_3$ devices. We can see that under the current density of 100mA/cm2, the driving voltage of the new-host and CBP based OLED is 11 and 16 V. Since the HOMO value of CBP is 6.3 eV which is lower than HTL material, NPB, the higher driving voltage is expected. However, since the HOMO value of our EML host is comparable to NPB, it results the lower driving voltage in these devices. With different dopant concentration, we can see that the driving voltage increases then decreases in the devices based on the new host. Here, we propose a model to explain this phenomenon. Since the host is a n-type material and Ir(ppy)3 is a kind of p-type molecule, holes (electrons) hop among the Ir(ppy)3 (the host) molecules in the EML. When the doping concentration is low, the distance between the Ir(ppy)3 molecules are large and it acts like a hole trap. Such a hole trap impedes further hole injection and the voltage increases. However, when the doping concentration increases, the hole mobility increases since the distance between the Ir(ppy)3 molecules decreases. Such an amipolar transport characteristics effectively decreases the driving voltage.

Figure 5 shows the luminance-current density characteristics of the new-host based device with different concentration of $Ir(ppy)_3$ and $Ir(ppy)_3$:CBP device. Compared the new-host: x% $Ir(ppy)_3$ with different concentration under the same voltage, 15% $Ir(ppy)_3$ has the highest luminance of 15000 cd/m^2 However, CBP: 9% $Ir(ppy)_3$ has the highest performance of luminance under the same current density. It seems that the better luminance can be attributed to more effective hole trapping on $Ir(ppy)_3$.

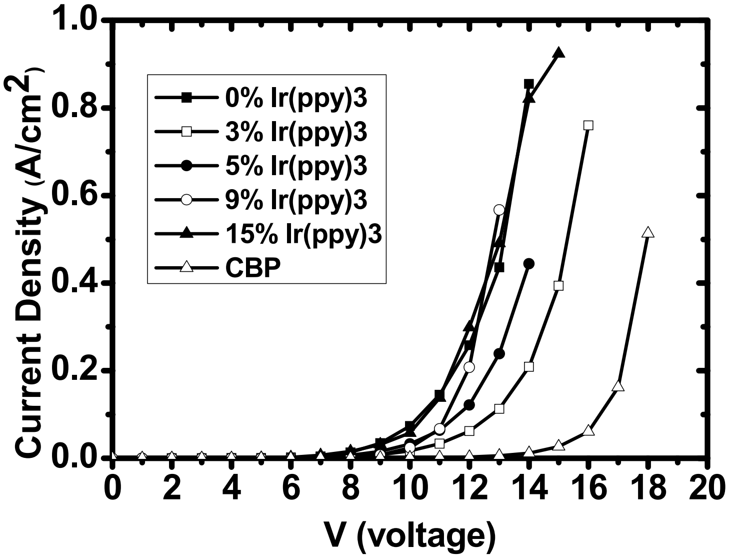

Fig. 4 J-V characteristics for host: x% and CBP : 9% devices. The concentration of x is 0, 3, 5, 9, 15% respectively.

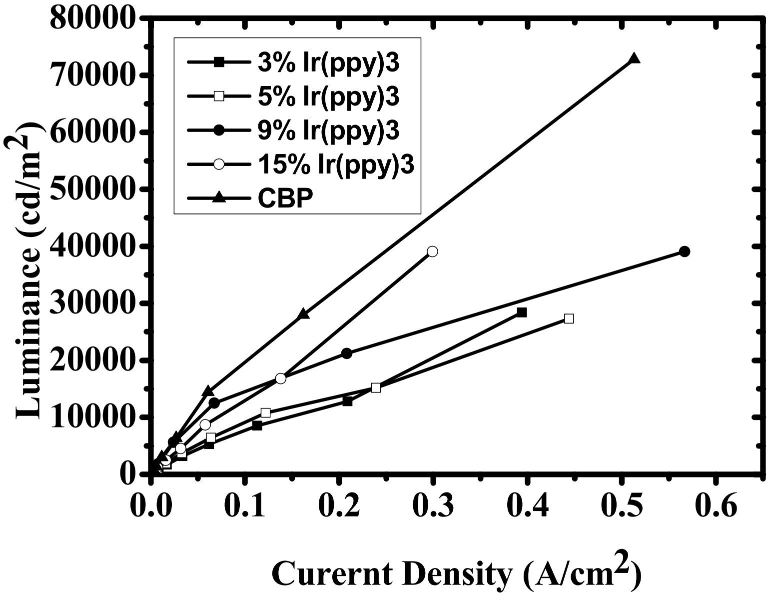

Fig. 5 The luminance versus current density curves of Ir(ppy)$_3$:the new-host and Ir(ppy)$_3$:CBP device.

Figure 6 shows the result of current efficiency versus current density curves. For the new-host: x% Ir(ppy)$_3$ devices, 9% Ir(ppy)$_3$ has the highest current efficiency of 21 cd/A under the luminance of 10000 cd/m^2. Although the luminance of the new-host : 15% Ir(ppy)$_3$ is higher than 9% Ir(ppy)$_3$, the higher current density of 15% Ir(ppy)3 caused by more efficient injection of holes through Ir(ppy)$_3$ has the lower current efficiency. Comparing the optimized the new-host based PHOLED with CBP based device, the current efficiency of CBP : 9% Ir(ppy)$_3$ is about 24 cd/A which is higher than the new-host : 9% $Ir(ppy)_3$.

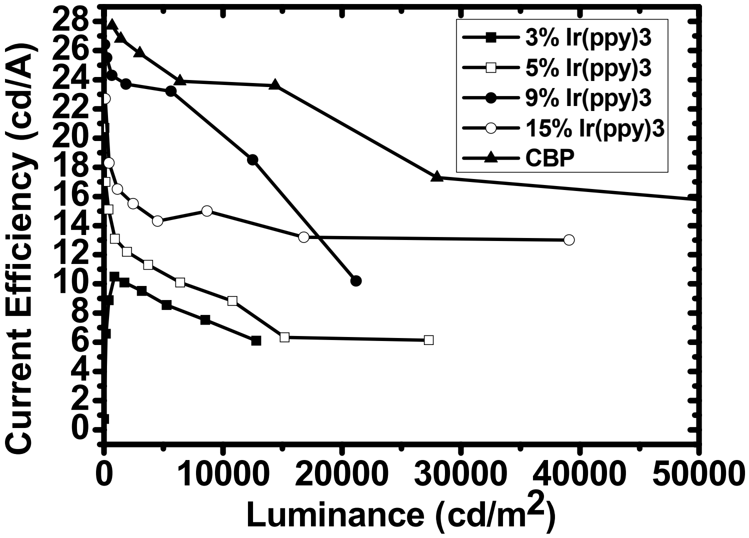

Fig. 6 Current efficiency versus luminance curves .

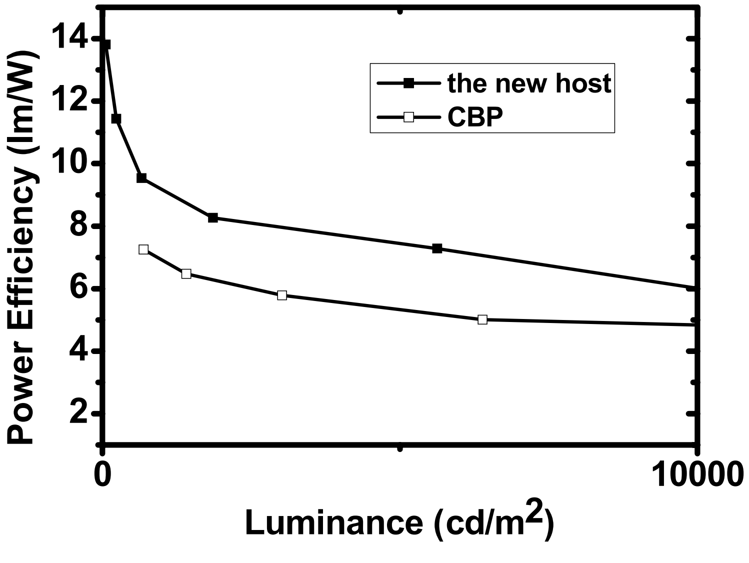

Fig. 7 Power efficiency versus luminance curves .

Figure 7 shows the power efficiency versus luminance characteristics. Due to the triplet-triplet annihilation at the interface between HBL and EML with increasing luminance, both the new-host and CBP based devices exhibit a gradual decrease in quantum efficiency. Besides, the higher power efficiency of the new-host based device can be explained in terms of the lower driving voltage of the new-host based device.

4. SUMMARY

In conclusion, high stability and high efficiency carbazole-free phosphorescent OLED has been demonstrated, utilizing a multilayer architecture with BCP as the hole blocking layer. Driving voltage of the traditional CBP based device and the new-host based OLED is 16 and 11 V with the current density of 100mA/cm2, respectively. The lower driving voltage of the new-host based device comes from the lower HOMO value and good electron transport characteristics. The current efficiency at 10000 cd/m2 is slightly decreased from 24 to 21 cd/A. However, the power efficiency is increased from 5 to 6 lm/W.

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