P-107: Very Bright and Efficient Phosphorescent Organic Light-Emitting Diode with Hole Transport Layer Deposited under Relatively High Pressure

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Abstract

The characteristics of an organic light-emitting diode depend on the deposition pressure of the hole transport layer. This effect and the effect of dopant concentration in the emitting layer were investigated. Diodes were constructed using NPB as hole-transport layers, phosphorescent fac tris(2-phenylpyridine) iridium (III) [Ir(ppy)$_3$] doped CBP materials as emitting layer, BCP as hole blocking layer and Alq$_3$ as an electron injection-transport layer. The peak efficiencies of the diodes were sensitive to the deposition pressure of the hole transport layer, and to the dopant concentration. With an optimal pressure, an current efficiency of 44Cd/A with 12wt% Ir(ppy)$_3$ concentration was obtained. A maximum brightness of 210,000 Cd/m^2 (cw) was obtained with 15wt% Ir(ppy)$_3$ concentration.

Keywords: Brightness, organic light-emitting diode, phosphorescence, deposition pressure.

1. Introduction

Organic-light emitting diodes (OLEDs) as pixels for flat-panel displays are being hotly pursued because of their relatively simple structure, high brightness and self-emitting nature [1,2].

Recently phosphorescent OLEDs have received considerable attention due to the ability of highly efficient emission compared with fluorescent OLEDs[3-9]. The nearly 100%[5-7] internal emission quantum efficiency has been obtained by harvesting both singlet and triplet excitons in OLEDs doped with phosphorescent emitters containing heavy metals[5-7]. The strong spin-orbit coupling of a heavy metal enhances inter-system crossing and mixes the singlet and triplet states. Effective external quantum efficiency (η_{EQE}) of 19% photons/electron and luminance power efficiency (η_P) of 70lm/W have been demonstrated in OLEDs based on small molecules. The dependence of the performances of phosphorescent OLEDs on the host material and hole blocking layer materials were seriously studied [5-9].

Since the performance of an OLED is sensitive to both the hole transportation and electron transportation and the choice of the constituent organic layers. So the characteristic of the hole transportation layer is important to improve the performance of OLEDs. A simple sandwich structure of diode is fabricated (Fig. 1), consisting of NPB as the hole-transportation layer, Ir(ppy)$_3$ doped CBP as emitting layer and BCP as hole blocking layer and Alq$_3$ as an electron-transport layer. The performance of OLEDs with hole transportation layer deposited under deferent pressure were investigated and Ir(ppy)$_3$ concentration were optimized. At optimal deposition pressure and Ir(ppy)$_3$ concentration of 12wt%, an η_J = 44Cd/A, 150,000 Cd/m^2 brightness at constant current drive had been obtained. The brightness of 210,000 Cd/m^2 at continuous current with Ir(ppy)$_3$ concentration of 15wt% had been obtained. According to our knowledge, it was the highest brightness driving under the continuous current had been reported.

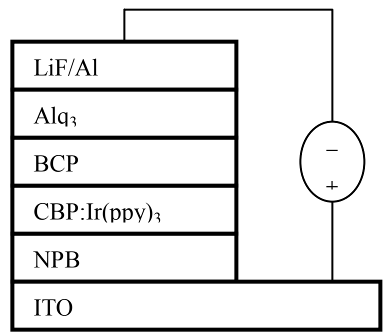

Fig. 1. The structure of EL devices.

2. Experimental and discussion

Glass panels coated with 75nm indium-tin oxide (ITO) were used as the starting substrates. The sequence of pre-cleaning prior to loading into the evaporation chamber consisted of soaking in ultra-sonic detergent for 30mins, spraying with de-ionized (DI) water for 10mins, soaking in ultra-sonic DI water for 30mins, oven bake-dry for 1-2hrs and ultra-violet ozone illumination for 9mins.

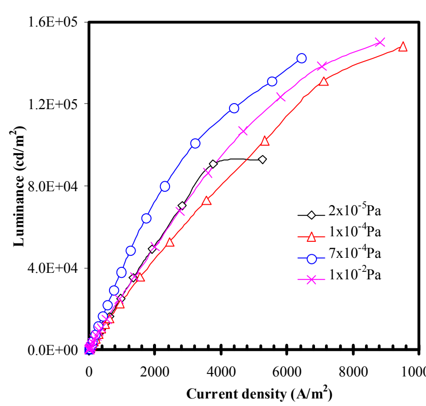

Fig. 2. The *L-J* characteristic of the diodes.

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A set of shadow masks was used to define the 3x2mm OLEDs with *NPB(40nm)/CBP:Ir(ppy)$_3$(40nm)/BCP(10nm)/Alq$_3$* consequent layers. The organic thin films were deposited from sublimation of commercial grade. The constituent organic layer NPB, CBP, Ir(ppy)$_3$, BCP and Alq$_3$ loaded in resistively heated evaporation cells. The base pressure in the evaporator was 0.2µTorr. Before deposit NPB layer, the NPB evaporation cell were heated to let it evaporating and the pressure will go up. The pressure can be controlled by valve, the hole transportation layer of NPB were deposited at deferent pressure. After coating hole transport layer, the pressure of the chamber were pumped to the base pressure 0.2µTorr, the consequent layers were deposited. For the doped emitting layer, powder Ir(ppy)$_3$ was co-evaporated with CBP. While the ITO formed the anodes of the OLEDs, composite layers of 0.1nm lithium fluoride (LiF) capped with 150nm aluminum (Al) were used as the cathodes [10].

The deposition rates of the organic thin films were 0.1-0.2nm/s. Those of LiF and Al were 0.02-0.05nm/s and 1-1.5nm/s, respectively. Film thickness was determined *in situ* using a crystal monitor. The devices were characterized in room ambient and temperature without encapsulation. EL intensity was measured using a PR650 SpectraScan spectrophotometer or with attenuator at high brightness. Current-voltage (I-V) characteristics were measured using a Advantest R6145 DC Voltage Current Source and Fluke 45 Dual Display Multimeter

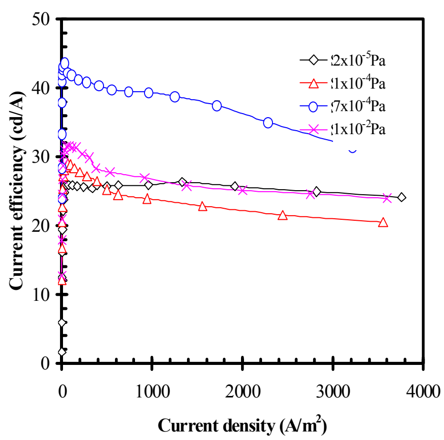


Fig. 3. The η_J-J characteristic of the diodes at various deposition pressure.

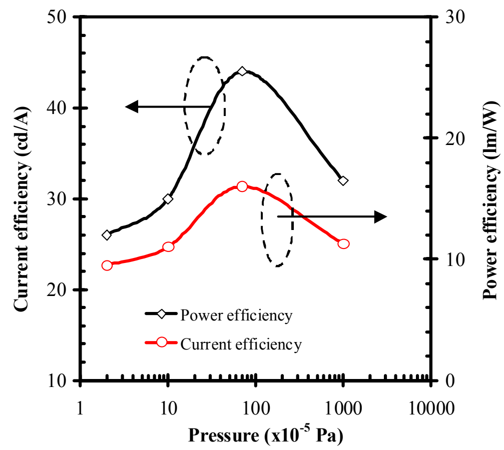


Fig. 4 The η_J - η_p –*Pressure* curve of the diodes

The luminance-voltage ***(L-J)*** characteristics of devices which the hole transportation layer were deposited at various pressure are shown in Figure 2. It can be seen that the brightness at given current density is changed with the deposition pressure.

The current efficiency – current density **(η_J – *J*)** curve are shown in figure 3. It is clear to be seen that the efficiency depend on the deposition pressure. The figure 4 shows the current efficiency –power efficiency – deposition pressure **(η_J – η_p *-pres*)** curve. At 7x10^{-4} Pa deposition pressure, the efficiency is highest.

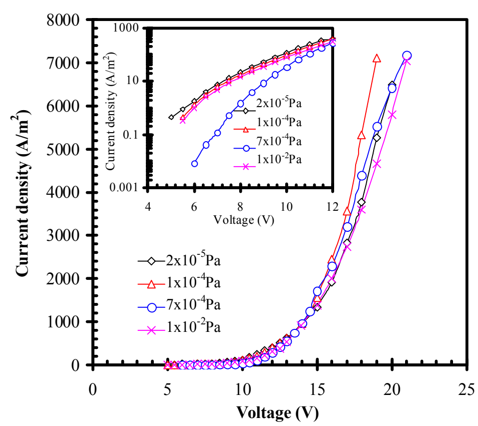


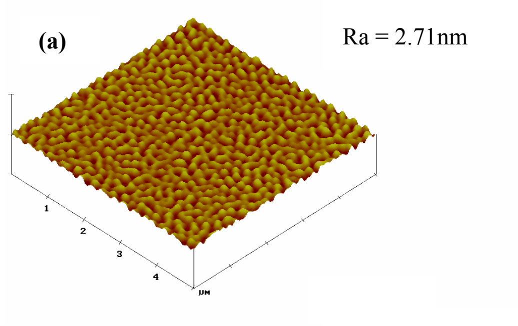
Fig. 5. The *J-V* characteristic of the diodes at various deposition pressure.

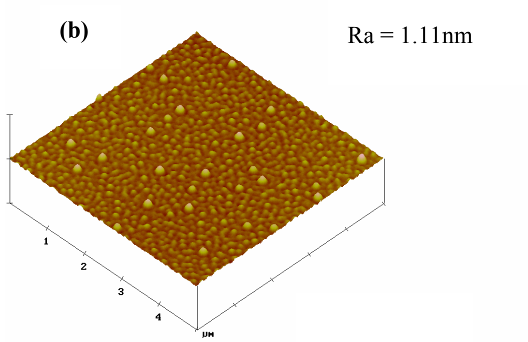
The current density-voltage ***(J-V)*** characteristics of the device were shown in figure 5. Insert figure 3 is the relative low voltage (***J-V***) curve. Compare to those curves, the turn-on voltage (V_{on}) is decreased and L at a give voltage is increased with deposition pressure, then they reverse. In order to understand the reason of the efficiency change with the deposition pressure, we measured the morphology of the hole transport layer deposited at various pressure. Figure 6 show the AFM graphs and surface roughness. Compare the surface roughness with insert figure 5 curve of ***(J-V)***, at the certain voltage, the smooth morphology has low current density. Due to the same cathode, we can say that the smooth surface has lower leakage current, it is good for improve current efficiency.

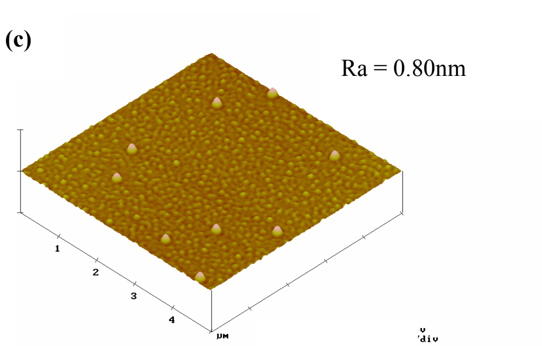
The relationship between the current efficiency (η_I) and current density with various doped concentration are shown in figure 7. It can be seen that with increasing doped concentration, the efficiency will be higher, and efficiency become more stable with increasing current density.

The dependence of both peak η_J and η_P on Ir(ppy)$_3$ concentration is shown in Figure 8. Both efficiencies first increase, peak at ~12wt%, then decrease with increasing Ir(ppy)$_3$ concentration. The reduction in the efficiencies beyond the optimal concentration has been attributed to aggregate quenching[11,12].

The "Current density (*J*) – *V*" characteristics of Diodes with various Ir(ppy)$_3$ concentration. Among these devices, the current turn-on voltage of the first increase with increasing the Ir(ppy)$_3$ concentration, then decrease.. This is not surprising because dopant molecules give rise to traps that invariably lead to reduced charge carrier mobility [13,14]. A larger increase in the turn-on voltage is obtained with dopant placed in host materials.







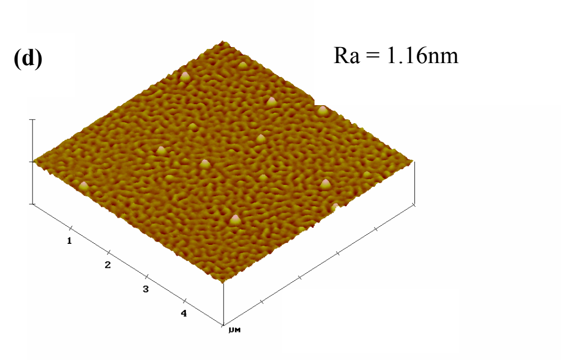


Fig.6 AFM Surface morphology measurement of hole transport layer deposited at various pressure . (a) 2x10^{-5} Pa, (b) 1x10^{-4} Pa, (c) 1x10^{-3} Pa, (d) 1x10^{-2} Pa.

With increasing the dopant concentration, the dopant molecules is close enough to course electron transport from dopant to dopant,, it decrease the turn on voltage[14].

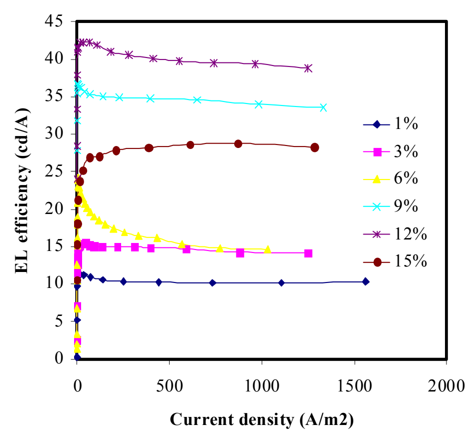


Fig. 7. The η_J -J characteristic of the diodes with various Ir(ppy)$_3$ concentration.

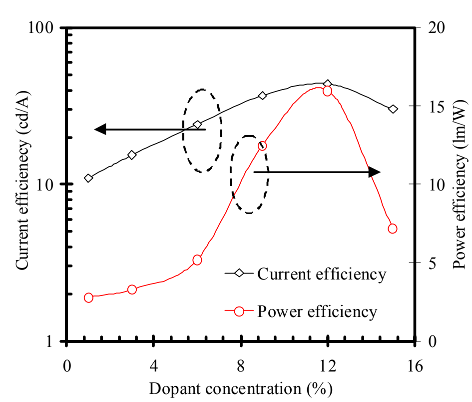


Fig. 8 The η_J - η_p – Ir(ppy)$_3$ concentration curve of the diodes

At the continuous current drive, the maximum luminance were obtained. The maximum luminance of the devices with various $Ir(ppy)_3$ concentration are shown in figure 10. The maximum luminance increase with increasing $Ir(ppy)_3$ concentration. The 210,000cd/m^2 was obtain at the 15wt% $Ir(ppy)_3$ concentration at continues current drive.

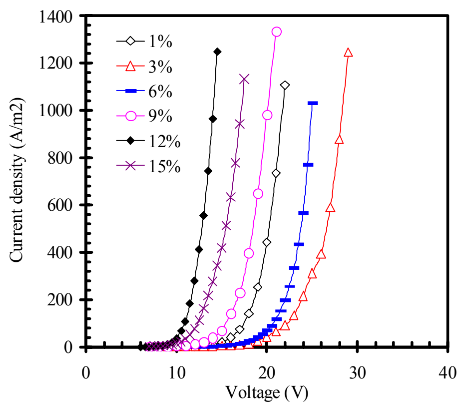


Fig. 9. The *J-V* characteristic of the diodes at various $Ir(ppy)_3$ concentration

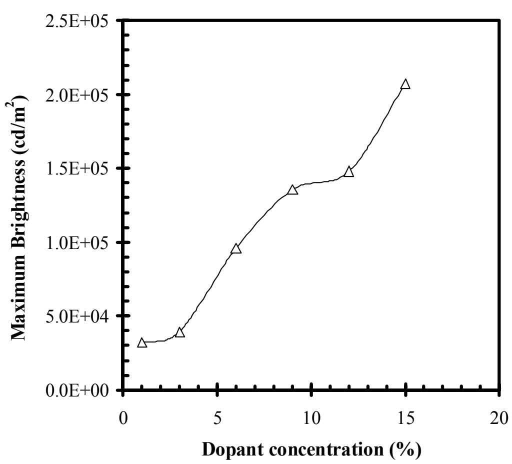


Fig. 10 Maximum luminance of the devices with various $Ir(ppy)_3$ concentration

3 Conclusion

The characteristics of an organic light-emitting diode depend critically on the hole transport layer and the dopant concentration of emitting layer. Diodes were constructed using NPB as hole-transport layers, phosphorescent fac tris(2-phenylpyridine) iridium (III) [$Ir(ppy)_3$] doped CBP materials as emitting layer, BCP as hole blocking layer and Alq_3 as the electron injection-transport layers. The peak efficiencies of the diodes were sensitive to the deposition pressure of the hole transport layer, and dopant concentration. With an optimal pressure, an current efficiency 44Cd/A with 12wt% $Ir(ppy)_3$ concentration, and maximum brightness of 210,000cd/m^2 with 15wt% $Ir(ppy)_3$ concentration were obtained at continues bias drive.

Acknowledgement

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