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Efficiency improvement in flexible phosphorescent organic light-emitting diode

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1. Introduction

Phosphorescent dye gains energy from the radiative recombination of both singlet and triplet excitons [1] to improve the internal quantum efficiency of fluorescent OLED from typically 25% at maximum to nearly 100% [2].

The topic of enhancing the luminance efficiency of phosphorescent OLED has attracted the interest of many researchers. The host materials that have been under study include Tris(8-hydroxy-quinolinato)aluminum (Alq3) [3,6], 3-phenyl-4-(1'-naphthyl)-5-phenyl-1,2,4-triazole (TAZ) [4], 2,9-Dimethyl-4,7-diphenyl-1,10-phenanhroline (BCP) [4], 4,4',4''-Tris(carbazol-9-yl)triphenylamine (TCTA) [5] and 4,4'-Bis(carbazol-9-yl)biphenyl (CBP) [4-6]; for hole and exciton blocking layer, BCP [6], TPBi [7], BAlq [8] and BPhen [9] have been employed in the attempt to enhance the luminance efficiency of device.

Electron injection materials include alkali metal fluoride, e.g. LiF, NaF, and CsF. It is known from the literature reports that when CsF or LiF is used as electron injection layer, the CsF can react with Al and release the metal more easily than LiF [10].

This study employs LiF or CsF as electron injection layer and compare their effects on electron injection and luminance efficiency, and furthermore, uses BCP or TPBi as hole and exciton blocking layer to compare their effects on the luminance characteristics of flexible phosphorescent OLED.

2. Experiment

The ITO substrate employed in the study was 80Ω/□ PET substrate. Before the deposition of organic layer, the patterned ITO substrate was placed in O_2 plasma for surface cleaning. The substrate was placed in the organic evaporation chamber for the deposition of organic thin films under 2×10^{-6} torr, NPB was deposited as hole transport layer (HTL), CBP was deposited as host, $Ir(ppy)_3$ was deposited at the rate of 0.1 nm/sec as guest, 2,9-Dimethyl-4,7-diphenyl-1,10-phenanhroline (BCP) or 2,2',2''-(1,3,5-Benzinetriyl)-tris(1-phenyl-1-H-benzimidazole) (TPBi) was deposited as holes and excitons blocking layer, and Alq_3 was deposited as electron transport layer (ETL). After the deposition of organic thin films, the substrate was moved to the metal evaporation chamber for the deposition of LiF or CsF as electron injection layer (EIL) under 4×10^{-6} torr and finally the deposition of Al cathode. SpectraScan PR650 and Keithley 2400 were employed to measure the luminance and current-voltage characteristics.

3. Results and Discussion

The study first examined CBP:$Ir(ppy)_3$ of varying thickness in devices with the structure and energy band as shown in Fig. 1(a). The emitting layer thickness was varied to augment the electron-hole recombination region and enhance luminance and yield. It is found in Fig. 2 and Fig. 3 that when the thickness of emitting layer increased from 10 to 40 nm, luminance was raised from 4400 to 10220 cd/m^2 at 10V, and the yield also improved from 13 to 30.4 cd/A at 6V as shown in Fig.3.

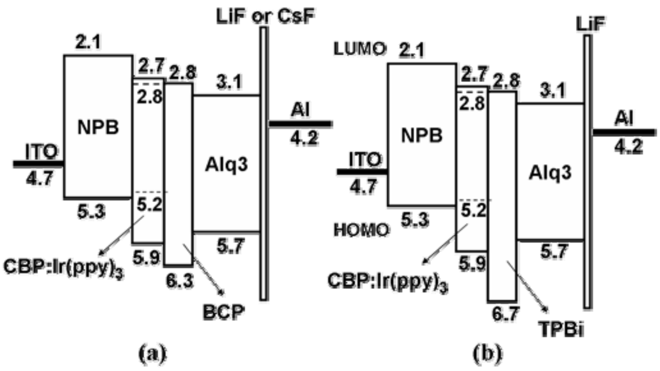

Fig. 1. (a) Energy band of device with LiF or CsF as electron injection layer; (b) Energy band of device with TPBi as hole blocking layer.

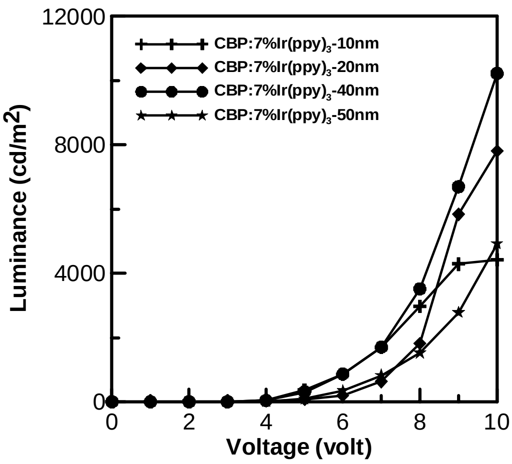

Fig. 2 Luminance vs. voltage under varying thickness of emitting layer

Next the effect of different electron injection materials, namely CsF and LiF was examined. For the device with energy band as shown in Fig. 1(a), the thickness of Al electrode was fixed at 65 nm. It is found from the current density vs. voltage in Fig. 4 that CsF can react more easily with Al to produce electrons [10] so 0.5 nm CsF has higher current density than 0.5 nm LiF. Thereby CsF can enhance the luminance reaching 10690 cd/m^2 at 10V and luminance yield rising to 32.5 cd/A at 5V as shown in Fig. 5. But the CsF thickness can not be too thick (<1 nm), otherwise will decrease the injected current density and luminance yield, as shown in Fig. 4 and 5 (as curve ④), respectively.

Finally this study examined different hole blocking layers (HBL), BCP and TPBi, whose energy band diagrams are shown in Fig. 1 (a) and (b), respectively. It is found from luminance yield vs. current density in Fig. 5 that using TPBi as blocking layer could enhance the luminance yield further to 34.2 cd/A at 5V . This is because the Highest Occupied Molecular Orbital (HOMO) of TPBi (6.7 eV) is higher than the HOMO of BCP (6.3 eV), which confines holes and excitons in the emitting layer more effectively and prevents directly diffusion of holes or excitons to Alq3 layer. After comparing the effects of EIL and HBL on luminance efficiency, it is found from curves ① and ② in Fig. 5 that a suitable HBL can improve the luminance efficiency of device more effectively than EIL.

4. Conclusions

The study successfully fabricated a phosphorescent OLED on flexible substrate, which used BCP or TPBi as hole and exciton blocking layer and LiF or CsF as electron injection layer, and achieved high luminance and yield with maximum luminance reaching 10680 cd/m^2 at 10V and maximum yield reaching 34.2 cd/A at 5V.

Acknowledgments

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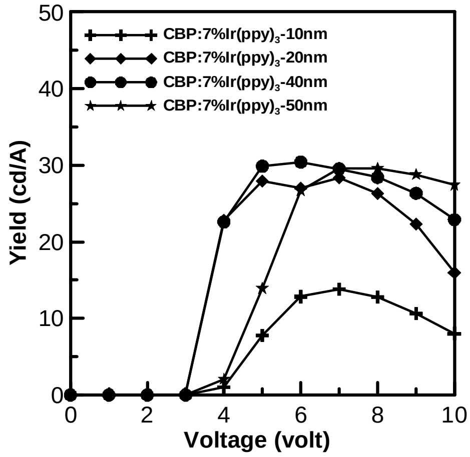

Fig. 3 Yield vs. voltage under varying thickness of emitting layer.

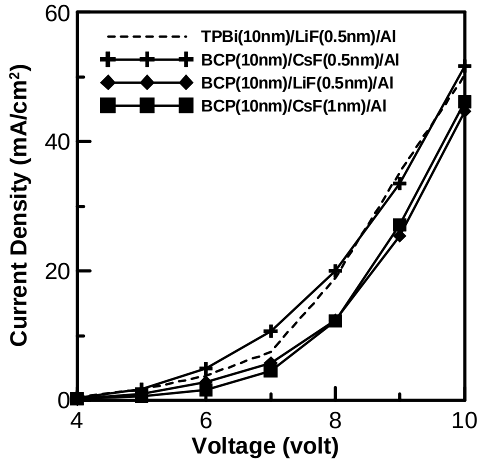

Fig. 4 Voltage vs. current density of different device structures.

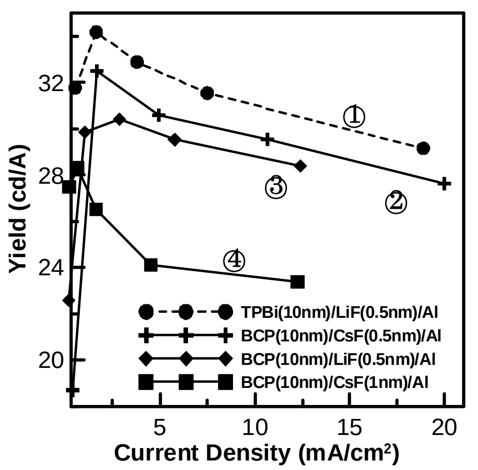

Fig. 5 Yield vs. current density of different device structures.