Enhanced efficiency of organic light-emitting diodes by doping the hole-transport layer

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Abstract

We present that the carrier balance can be improved by doping a hole transport layer of 4,4'-bis[N-(1-napthyl)-N-phenyl-amino]-biphenyl (α-NPD) with a hole blocking material of 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP). The doping leads to disturb hole transport, which can enhance the balance of electrons and holes concentration in the emitting layer, aluminum tris(8-hydroxyquinoline) (Alq3), resulting in enhanced electroluminescence (EL) quantum efficiency for the device with the doped α-NPD.

1. Introduction

Since Tang and Van Slyke[1] reported the double-layer structure of organic thin films, organic light-emitting diodes (OLEDs) have been studied intensively.

The balance of electrons and holes injected from electrodes is one of crucial requirements for achieving high efficiency OLEDs.[2-3] The carrier injection is limited not only by the potential energy barrier at the electrode interface but also by the low mobility of organic semiconductors.[4] It is also well-known that the hole mobility of the hole transporting material (α-NPD) is higher than the electron mobility of electron transporting material (Alq_3)[5]. Therefore, there is an unbalance of electrons and holes injected from cathode and anode respectively.

There are various ways for achieving carrier balance such as the insertion of electron or hole injection layers, electron or hole blocking layers, blending polymers, and doping organic materials. E.W. Forsythe et al.[2] reported that the insertion of copper phthalocyanine (CuPc) layer reduces the hole injection efficiency and enhances the electron and hole balance, resulting in higher EL efficiency. In addition, the incorporation of CuPc[6] or rubrene[7] was reported to increase the device stability.

In this work, we report another approach to enhance electron-hole balance and the EL efficiency by doping a hole transport layer of 4,4'-bis[N-(1-napthyl)-N-Phenyl-amino]-biphenyl (α-NPD) with a hole blocking material of 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP).

2. Experimental

In order to investigate the influence of BCP doped hole transport layer, the organic light-emitting diodes were fabricated using thermal evaporation of organic materials on ITO glass substrates with a sheet resistance of about 15 Ω/ð. The routine cleaning procedure of ITO substrate included sequential ultrasonic in organic solvent (isopropyl alcohol, acetone and methanol), and rinsing in de-ionized water. Figure 1 shows the structure of the devices with the schematic energy level diagram. To enhance the hole injection efficiency, the hole injection layer of 3,4-polyethylenedioxythiophene:polystyrenesulfonate (PEDOT:PSS) was coated at 4000 rpm for 30 sec, followed by drying at 80 °C for 1 hour in vacuum. The organic layers were deposited on top of the PEDOT:PSS layer under a vacuum of about 10^{-6} Torr without breaking vacuum. The evaporation rates of organic materials, α-NPD, BCP and Alq_3, were about 1~2 Å/s, measured by a quartz crystal oscillator. Especially, to balance electron and hole, the hole blocking material, BCP, were coevaporated with hole transport material, α-NPD. Finally, the electron injection layer, LiF, and the aluminum cathode were also deposited without breaking vacuum.

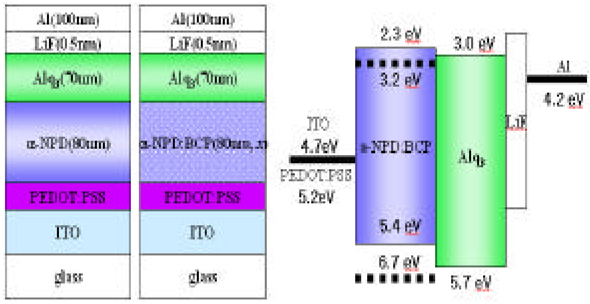

Figure 1. The structure of the devices with the schematic energy diagram.

3. Results and discussion

Figure 2 shows that the luminous efficiency for the devices with different BCP doping concentration (0, 10, 25, and 50 %) in α-NPD. Clearly, the luminous efficiency is increased for the devices with the BCP doped α-NPD. The maximum luminous efficiency is about 6.8 cd/A at 50mA/cm^2 for the device of ITO/PEDOT:PSS/a-NPD:BCP (1:1 weight ratio)/Alq_3/LiF/Al.

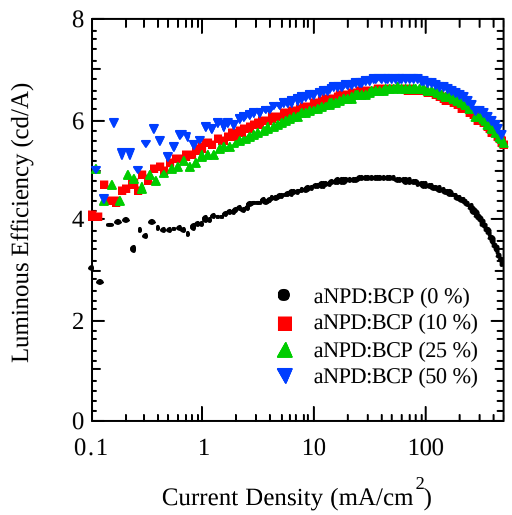

Figure 2. Luminous efficiency for the devices with different BCP doping concentration in a-NPD.

Figure 3 shows the current-voltage-luminance (I-V-L) characteristics for the devices with various BCP doping ratios in α-NPD at room temperature. The current decreases significantly at low bias, implying that BCP acts as trap for the hole transport in α-NPD. However, the current and luminance at high bias voltage are higher for the BCP doped α-NPD compared with α-NPD alone. The result is attributed to the combined effect of the improved electron injection and the electron-hole balance. Since BCP acts as hole trap, the trapped hole concentration is higher for the BCP doped α-NPD, resulting in the increased internal electric field near the cathode interface. Therefore, the electron injection at high

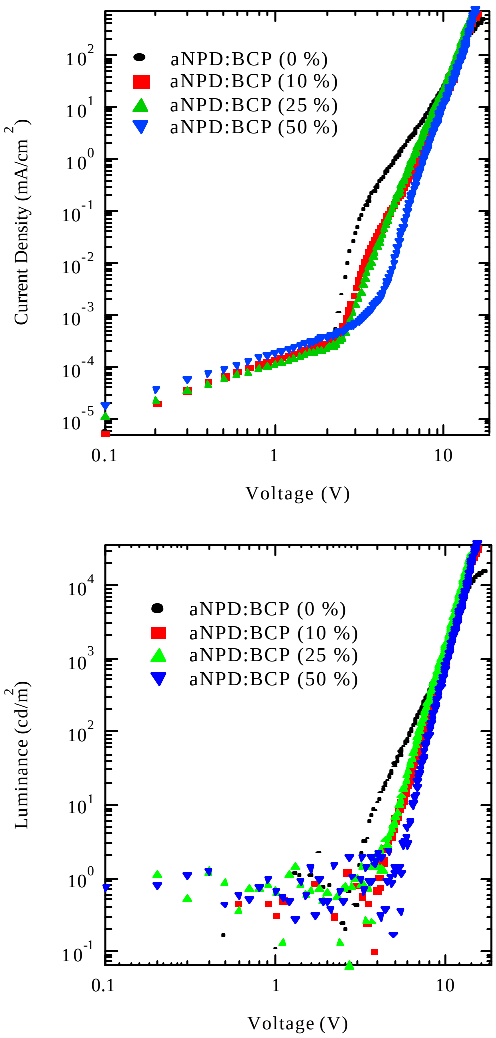

Figure 3. Current-voltage-luminance (I-V-L) characteristics for the devices with various BCP doping ratios in a-NPD (HTL) at room temperature.

BCP doping ratios	Efficiency for 100cd/m²		Driving voltage (V) for 100 mA/cm²	Current density (mA/cm²) for 100 cd/m²	Maximum luminance (cd/m²)
	(cd/m²)	(photons/carriers)			
0 %	4.2	1.2	12.3	2.3	15,157
10 %	5.8	1.7	12.4	1.8	31,860
25 %	5.4	1.6	11.9	1.7	30,801
50 %	5.9	1.8	12.7	1.7	35,664

Table 1. Performance of the EL device with different BCP doping ratios

field can be enhanced.

The performance of the devices is summarized in Table 1. For 100 cd/m^2, current density (mA/cm^2) of devices with BCP doped layer is small in comparison with device with an undoped HTL. But luminous efficiency (cd/A), external quantum efficiency (E.Q.E), and maximum luminance (cd/m^2) of devices with BCP doped HTL are higher than undoped device. This result shows that BCP doped a-NPD can enhance electron-hole balance. The electroluminance (EL) driving voltage for 100 cd/m^2 is not strongly increased compared to device with an undoped HTL.

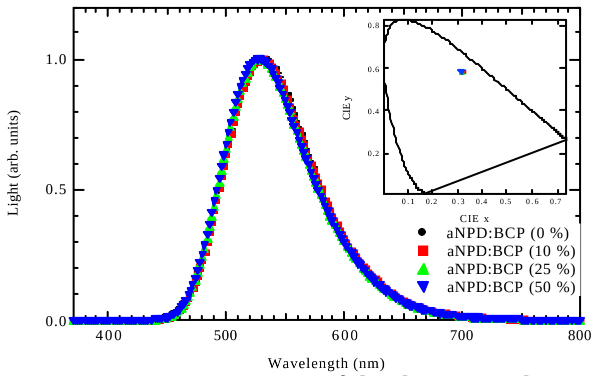

Figure 6. EL spectra of the devices without doped HTL and BCP doped HTL.

Figure 6 consists of the EL spectra and the Commission Internationale d'Eclairage (CIE) chromaticity coordinates (inset) of the devices different BCP doping ratios at a constant current density of about 50 mA/cm^2. From the same EL spectra and CIE coordinates (0.32, 0.58), the electron-hole recombination zone in Alq_3 layer is not varied by BCP doped HTL.

4. Conclusions

In conclusion, we demonstrated that the EL efficiency can be improved by doping the hole transport layer with the hole blocking material of BCP. The reduced hole mobility in the BCP doped α-NPD can enhance the balance of electron and hole concentrations, thereby enhancing the EL efficiency. This result contributes to developing high efficiency OLEDs.

5. Acknowledgements

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6. References

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