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Low-voltage and high-efficiency white organic light emitting devices with carrier balance

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ABSTRACT

White organic light emitting devices with the structure of ITO/m-MTDATA:*x*%4F-TCNQ/NPB/TBADN:EBDP:DCJTB/Bphen:Liq/LiF/Al have been demonstrated in this paper. High-mobility m-MTDATA:4F-TCNQ is added into the region between ITO and NBP to increase hole injection and transport. The high-mobility Bphen:Liq layer is added into the region between cathode and emission layers to lower cathode barrier and facilitate carrier injection. In the meanwhile, an effective carrier balance (number of holes is equal to number of electrons) between holes and electrons is considered to be one of the most important factors for improving OLEDs. During the experiment, by modulating the doping concentration of 4F-TCNQ, we can control hole injection and transport to make the carriers reach a high-level balance. The maximum current efficiency and power efficiency of devices were 9.3 cd/A and 4.6 lm/A, respectively.

1. Introduction

White organic light emitting diodes (OLEDs) have attracted wide attention in view of practical applications for displays and lighting [1–4], since Kido et al. [5] reported white OLEDs in the year of 1995. However, the low efficiency of light emission and high drive voltage become a main difficulty, which urgently needs to be solved. Yamada et al. [6] proved that because of the differences in the aspects of injection and transport capabilities for two carriers, the carrier with higher transporting rate will directly pass through the light-emitting layer and reach the electrode to be quenched. Therefore, it will reduce the recombination probability and affect the luminous efficiency. Currently, several methods are widely used to enhance luminous efficiency: increasing effective injection and transport for both electrons and holes in the organic layer; balancing the injection between electrons and holes for guaranteeing effective recombintion of carriers with opposite charges; modifying the interfaces between electrode/organic layers and between organic/organic layers; and enhancing fluorescence quantum efficiency of the light-emitting devices. So far, the way to improve the performance of white OLEDs stressed the importance of increasing injection and transport capabilities, while relatively overlooking the role of modulating the carrier balance [7–10].

Researchers found that introduction of high-conductivity charge injection and transport layers can efficiently reduce the drive voltage of devices, while increasing the luminous efficiency to some extent. In addition, it is necessary to increase the charge balancing factor, that is, increase the injection balance of the carriers. One of our previous works has confirmed that m-MTDATA:4F-TCNQ can improve hole injection and transport, while Bphen:Liq can improve electron injection and transport [11]. Therefore in here, we added m-MTDATA:4F-TCNQ into the region between ITO and NPB, and Bphen:Liq layer into the region between cathode and light-emitting layer. By regulating the doping concentration of 4F-TCNQ, we can regulate hole injection and transport, and considerably increase the compound efficiency of the devices, and finally obtain low-voltage white OLEDs with high-level carrier balance.

2. Experimental process

The white OLEDs were fabricated on glass substrates precoated with indium tin oxide (ITO) with a sheet resistance of 20 Ω/square. We selected m-MTDATA:*x*%4F-TCNQ as the hole injection layer, N,N′-bis-(1-naphenyl)-N,N′-biphenyl-1,1′-bipheny1-4-4′-diamine (NPB) as the hole transport layer, TBADN:EBDP:DCJTB as the emission layer, Liq (33%):Bphen as the electron transport layer (ETL), metal Al as the cathode, which was evaporated for about 12 and 0.5 nm LiF as the buffer layer for better electron injection. The device structure was ITO/m-MTDATA:x%4F-TCNQ /NPB/TBADN:EBDP:DCJTB/ Bphen:Liq/LiF/Al. The molecular structures of the main organic materials and schematic structure of white devices are shown in Fig. 1. In the devices, the 4F-TCNQ volume

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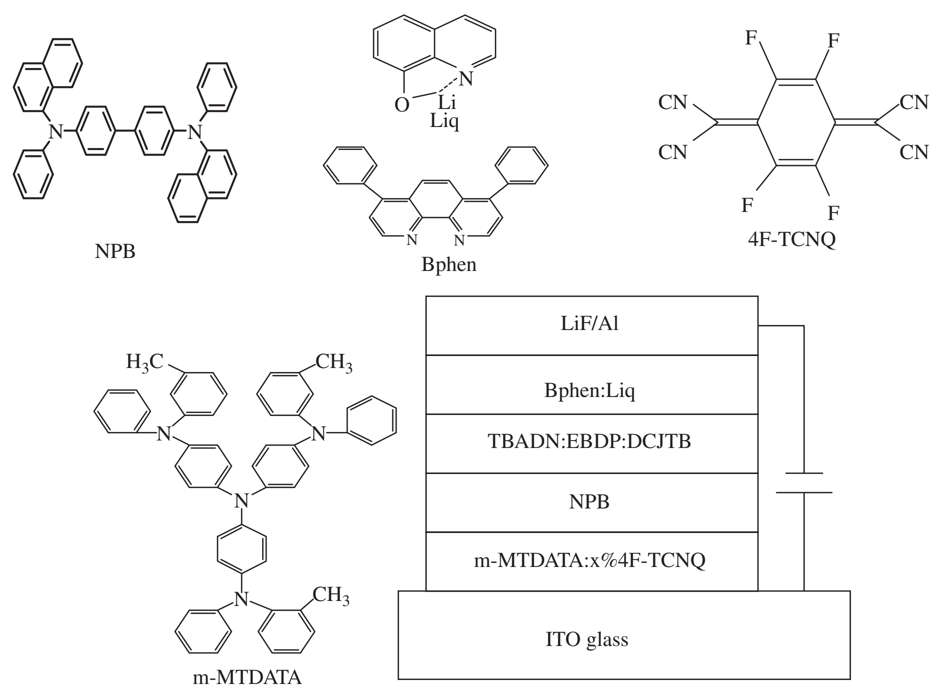

Fig. 1. Molecular structures of main organic materials and schematic structure of devices.

percentages varied from 0% to 3%, which are used to control the injection efficiency of the hole, so as to obtain high-efficiency white OLEDs with high carrier balance.

The organic layers and cathode LiF/Al were sequentially deposited by conventional vacuum vapor deposition in a chamber without breaking the vacuum. The pressure of the chamber was kept at 8×10^{-4} Pa. Electroluminescence (EL) spectrum and the Commission Internationale de I'Eclairage (CIE) coordinates were measured by a PR650 Spectroscanner, and luminance–current–voltage (*L–I–V*) characteristics were measured by a Keithley 2400 Source Meter. All the data were obtained in the unsealed condition and measured under room temperature.

3. Results and discussion

For the study of hole injection and transport capability of m-MTDATA:4F-TCNQ films, a series of hole-only devices were fabricated. These hole-only devices have the following structures:

device H_0:ITO/m-MTDATA (80 nm)/Al(120 nm)
device $H_{0.2}$:ITO/m-MTDATA:0.2 wt% 4F-TCNQ(80 nm)/Al(120 nm)
device H_2:ITO/m-MTDATA:2 wt%4F-TCNQ(80 nm)/Al(120 nm)
device H_3:ITO/m-MTDATA:3 wt%4F-TCNQ(80 nm)/Al(120 nm)

A series of electron-only devices were also fabricated in order to obtain data on the electron transport capability of Bphen:Liq films. The structures of the electron-only devices are as follows:

device E_0:ITO/BCP(5 nm)/Bphen(80 nm)/Al(120 nm)
device $E_{0.2}$:ITO/BCP(5 nm)/Bphen:20 wt%Liq(80 nm)/Al(120 nm)
device $E_{0.33}$:ITO/BCP(5 nm)/Bphen:33 wt%Liq (80 nm)Al(120 nm)
device $E_{0.5}$:ITO/BCP(5 nm)/Bphen:50 wt%Liq (80 nm)/Al(120 nm)

Fig. 2 shows the current density versus voltage characteristics at various doping ratios of F4-TCNQ to m-MTDATA for the hole-only devices. In the hole-only devices, a dramatic increase in device current was observed when 4F-TCNQ was doped into an m-MTDATA layer. Compared with the device with an undoped m-MTDATA layer, the slight doping strikingly decreased the onset voltage. The *J–V* characteristics are strongly dependent on the doping ratio of the hole transport layer. At the same voltage, the current density increased as doping rate increased.

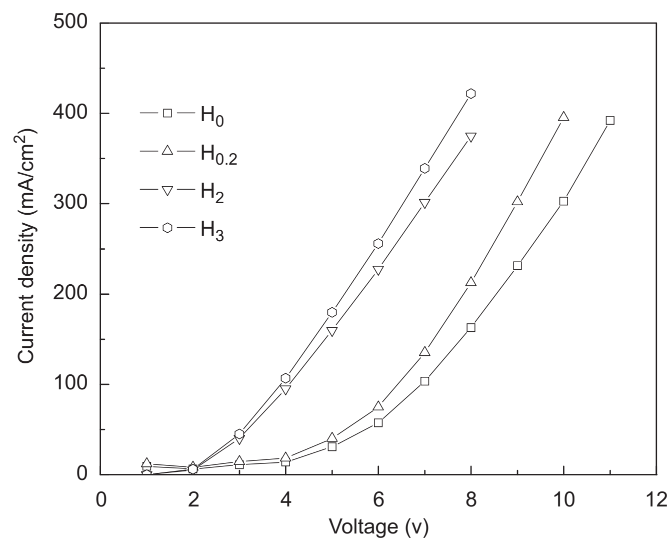

Fig. 2. Current versus voltage characteristics of hole-only devices.

Fig. 3 shows the current density versus voltage characteristics at various doping ratios of Liq to Bphen for the electron-only devices. In the electron-only devices, the Liq volume percentages varied from 20% to 50%, which is used to investigate the effect of Liq/Bphen ratio on electron injection and transport characteristics of the Liq:Bphen layer. A thin layer of BCP was used to prevent holes from entering the ETL because of its highly occupied molecular orbital (HOMO) level (6.7 eV). A dramatic increase in current was observed when Liq was doped into Bphen. The highest current density was observed for the devices with the Liq volume percentage of 33%, which is due to the highest conductivity, or mobility, of the electrons in the Liq:Bphen layer.