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Utilization of a composite hole transporting layer and novel homogeneous double emitting layers for performance improvement and low efficiency roll-off in organic light-emitting diodes

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Blue organic light-emitting devices (OLEDs) combing a composite hole transporting layer (c-HTL) and novel homogeneous double emitting layers (DELs) have been fabricated. The c-HTL plays a significant role of rectification in balancing the carriers' injection concentration which matches well with the DELs structure. The DELs is consisted of two homogeneous hosts, such as 2-methyl-9,10-di(2-naphthyl) anthracene (MADN) and 9,10-di(2-naphthyl) anthracene (ADN). The optimal device presents the maximal current efficiency of 15.9 cd/A at 4.9 mA/cm^2 and the minor efficiency roll-off of 13.4% under the driving voltage varying from 5 V to 10 V, respectively. Meanwhile, the device's maximal current efficiency and the corresponding efficiency roll-off have been obviously improved by 55.9% and 63.9% compared with those of the conventional device. These results indicate that the homogeneous DELs not only greatly facilitate carriers' injection into the emitting layer (EML), but also evenly modulate carriers' distribution due to natural energy barrier of the interface. The transient photoluminescence decay of double hosts further illustrates that the DELs structure can increase the recombination ratio of electron–hole pairs and improve the exciton's utilization. Additionally, the optimal device' current density is reduced by 44.1% under the same luminance of 25,780 cd/m^2 compared with that of the conventional device.

1. Introduction

Organic light-emitting devices (OLEDs) have attracted considerable attention due to their unsurpassable advantages in display and illumination [1–3]. Therefore, tremendous efforts have been made to improve the device performances. Some important issues needed to be resolved are the high current efficiency and good device stability achieved at various driving voltage [4]. To fulfill this goal, the balanced carriers' concentration and effective excitons' radiation in emitting layer (EML) are necessary. However, increasing the number of electrons is comparatively difficult as a result of the limitation of materials. In comparison, the strategy on depressing the amount of holes is easier although it may give rise to the higher operation voltage. In order to control the amount of holes without compromising much of its operation voltage, the structure of a composite hole transporting layer (c-HTL) is employed. On the other hand, a narrow recombination zone of the devices with single emission layer may results in the limitation of electroluminescence (EL) performances due to the excessive holes and accumulated space charges which could quench the radiation of excitons [5]. Some works recently have reported that double emission layers (DELs) may broaden the carriers' recombination zone and enhance the excitons' utilization [6–8]. However, the common DELs structure based on the same host could not evenly modulate the carriers' distribution in the EMLs, which would results in an obvious efficiency roll-off under the high current density [9,10]. In order to improve the device's EL performance, the novel homogeneous DELs structure is also introduced.

In this work, we have demonstrated an improved efficiency with minor roll-off for blue fluorescent OLEDs, which are consisted of the c-HTL and homogeneous DELs. The homogeneous DELs structure cannot only match well with the rectification characteristic of the c-HTL, but also evenly modulate carriers' distribution and further to confine excitons at the interface effectively.

2. Experiment

The devices' structures are shown in Fig. 1. In these devices, NPB doped with MADN is used as c-HTL, MADN doped with DSA-ph is

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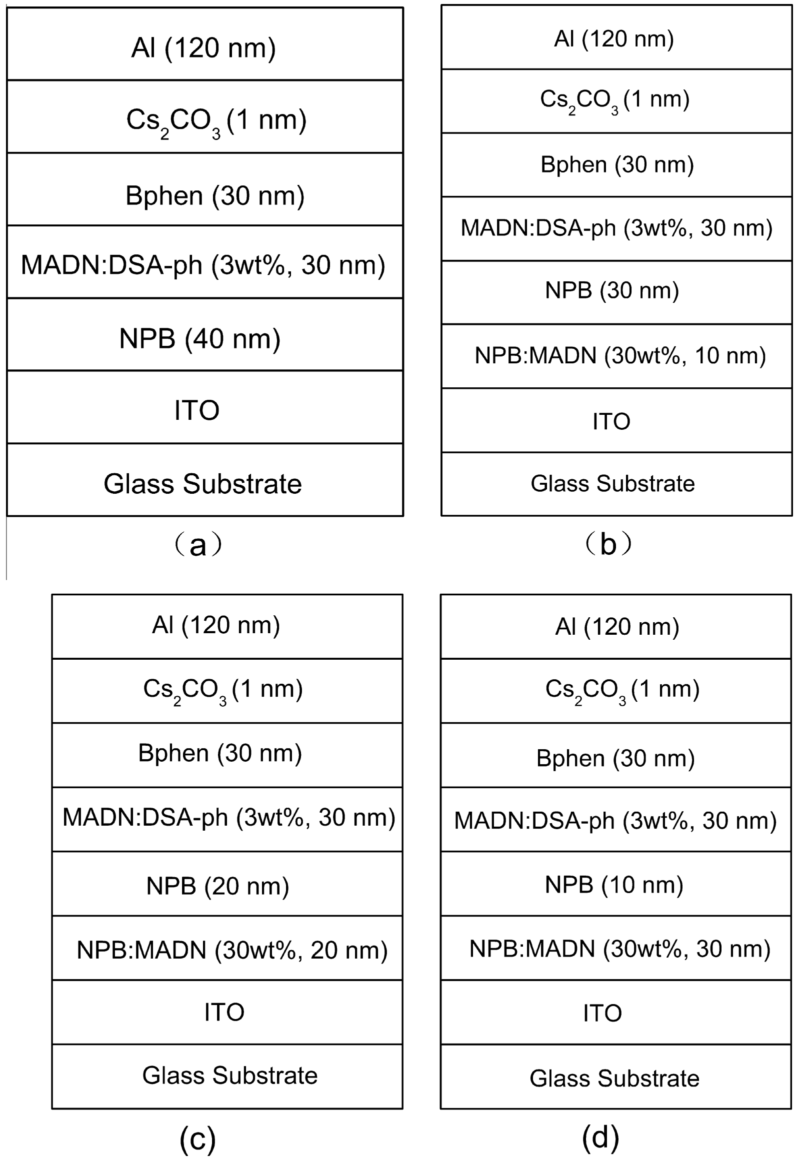

Fig. 1. The structures of the OLEDs with different HTLs based on the same EML, (a) Device A:NPB as the HTL, (b) Device B:NPB:MADN (30 wt%, 10 nm)/NPB (30 nm) as the c-HTL, (c) Device C:NPB:MADN (30 wt%, 20 nm)/NPB (20 nm) as the c-HTL, (d) Device D:NPB:MADN (30 wt%, 30 nm)/NPB (10 nm) as the c-HTL.

used as emitting layer, and Bphen is used as ETL. All devices are fabricated on the glass substrates coated with indium tin oxide (ITO) with a sheet resistance of about 20 Ω/sq. The cleaning of ITO glass is subsequently performed with detergent, deionized water, acetone, and isopropanol in an ultra-sonic bath for 15 min each to remove the organic contaminants. All the organic layers, Cs_2CO_3, and Al are deposited onto the ITO by using a thermal evaporation of BOC Edwards Auto-500 thermal evaporation coating system in an M. Braun 20G glove box at a pressure of about 7×10^{-5} Pa. The deposition rates and thicknesses of the various layers are monitored using a quartz crystal oscillator. The evaporation rate is 0.05 nm/s for the organic layers, and the evaporation rate for the doped layer is determined by its weight doping ratio. Cs_2CO_3 and Al are evaporated onto the organic layer as the cathode with the rates of 0.01 nm/s and 0.3 nm/s, respectively. The active area of the emitting device is 3 mm × 3 mm. The EL characteristics of the devices are measured by a Keithley model 2400 programmable voltage–current source and PR-650 spectra scan spectrometer. The transient photoluminescence spectra of organic materials are measured by Jobin Yvon FL3-212-TCSPC fluorescence spectrophotometer. All the measurements are carried out in ambient atmosphere at room temperature (except for the lifetime tests).

3. Results and discussion

Fig. 2 depicts the EL performances for devices with various thickness of the c-HTL. The corresponding *L–J–V* characteristics are shown in Fig. 2(a), and the inset shows the structures of the devices. It is indicated that the current densities of the devices with c-HTL are gradually reduced with increasing the c-HTL's thickness, and the lower current density leads to the corresponding lower luminance. However, the devices with c-HTL exhibit the higher current efficiency. It should be noted that, for device A, the carriers' concentration in EML is unbalanced, which may bring on the lower recombination rate since some excessive carriers have not been utilized completely.

It is expected that balanced carriers are achieved by employing the structure of c-HTL which may adjust the mobility of holes to a certain extent, further to improve the device performances. As