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High-Performance Red Organic Light-Emitting Devices Based on Blue Host DPVBi and a Mixed Single Layer

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Abstract: Efficient red organic light emitting diode with a mixed single layer by mixing of blue-emitting DPVBi, Alq_3 and rubrene as host materials and DCM as a red fluorescent dopant material has been fabricated and investigated. The red OLED with optimum mixing ratio of Alq_3:DPVBi:rubrene:DCM= 40:35:15:10 achieved a maximum power efficiency of 4.02 lm/W, a maximum current efficiency of 5.64 cd/A, a maximum luminance of 11500 cd/m^2 and Commision Internationale de L'Eclairage ($CIE_{x,y}$) coordinates of (0.65, and 0.35) at 20 mA/cm^2. Here, the mixed red organic light-emitting diodes showed improved electroluminescence performance compared to DCM-doped Alq_3 single-host and that with the Alq_3:Rubrene mixed-host systems. Also, The EL intensity of the mixed single layer was increased by about 2.5 times than that of the Alq_3 single-host device and 1.5 times than that of the Alq_3:Rubrene mixed-host device.

Keywords: Red organic light emitting devices; mixed single layer; DCM; Rubrene; Electroluminescence performance

Introduction

Nowadays, organic light-emitting diodes (OLEDs) have attracted great interest due to their wide potential applications in solid-state lighting and full-color flat-panel displays [1-3]. Full-color OLED displays have unique advantages of high brightness, low power consumption, ultrathin thickness and wide viewing angle. It is well known that in the OLED display technology, three primary colors (red, green, and blue; RGB) must be optimized simultaneously to achieve the maximized intensity and high color purity. However, in an OLED display, green and blue devices exhibit higher performance than red one. The most important problem for red emitters is that they possess a strong aggregation tendency due to intermolecular interactions that increases quenching of excitons and thus the fluorescence of these emitters is very weak compared with green and blue emitters [4]. The best approach to obtain red OLEDs with high fluorescence performance is the use of host-guest systems with high-efficiency red dopants and host materials [5]. The most common and simplest red organic electroluminescent device is based on tris(8-quinolinolato) aluminium (Alq_3) host doped with 4-dicyanomethylene-2-methyl-6-(pdimethylaminostyryl)-4H-pyran (DCM) red fluorescent dye [6]. However, such devices have been shown to have low brightness and luminance efficiency. Moreover, the emission from them is often contaminated by the residual green emission from Alq_3. According to many other reports [7], the red light emitting devices performance and color stability can be improved by using an assist dopant or using a co-host emitter system.

In this work, we have fabricated red OLEDs with a mixed single layer by mixing various materials that potentially provides another degree of freedom to improve the device performance. 4,4-Bis(2,2-diphenyl-ethen-1-yl)-biphenyl (DPVBi) a wide band-gap blue emission material was mixed with Alq_3 and rubrene as host materials. Several red mixed single-layer OLEDs were investigated using different mixing fractions of DPVBi, Alq_3 and rubrene while maintaining fixed levels of the red dopand DCM fraction and the emissive layer thickness. The performance of these red mixed single-layer OLEDs were compared with those of similarly fabricated DCM-doped Alq_3 single-host and that with Alq_3:Rubrene mixed-host devices.

Experimental

Indium tin oxide (ITO)-coated glass with a sheet resistance of about 20 Ω/sq (purchased from Sigma-Aldrich Co.) was cleaned in an ultrasonic bath in the following sequence: in acetone, ethanol, propanol, deionized water and isopropyl alcohol for 10 min. Thereafter, pre-cleaned ITO was dried under nitrogen gas flow. The mixed single-layer device was fabricated with the structure as following:

D1: ITO/PEDOT:PSS (40 nm)/NPB (50 nm)/ Alq_3:DPVBi:rubrene:DCM (30 nm)/BCP (10 nm)/BPhen (30 nm)/LiF (0.6 nm)/Al (150 nm). Photophysical properties of D1 were compared to the mixed-host device of ITO/PEDOT:PSS (40 nm)/NPB (50 nm)/ Alq_3:rubrene:DCM (30 nm)/BCP (10 nm)/BPhen (30 nm)/LiF (0.6 nm)/Al (150 nm) (D2) and the single-host device of ITO/PEDOT:PSS (40 nm)/NPB (50 nm)/ Alq_3:DCM (30 nm)/BCP (10 nm)/BPhen (30 nm)/LiF (0.6 nm)/Al (150 nm) (D3). For all devices, PEDOT:PSS as a hole-injection layer was spin-coated onto the ITO anode and then dried in the oven at 120 ºC for 40 min.

The other materials were deposited using the thermal evaporation technique without a vacuum break at a pressure of about 10^{-5} Torr at a rate of 0.1-2 Å/s. The device area was 3×5 mm^2. Fig. 1 shows a schematic energy diagram of the red OLED devices. The device characteristics were measured using a Keithley 2400 source-meter and a JAZ spectrometer (Ocean optic). All measurements were achieved in air at room temperature without any encapsulation.

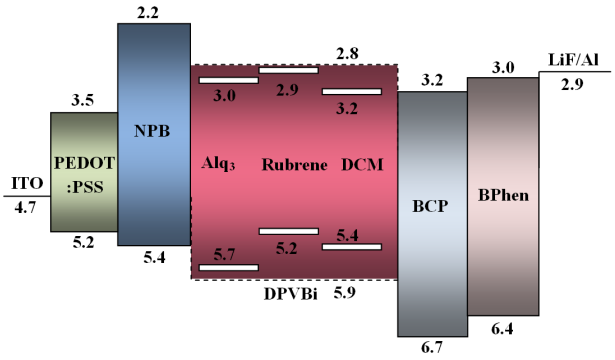

Fig. 1. Energy diagram of red mixed single-layer OLED

Results and Discussion

1. Optimization and selection of the best structure

The performance and EL intensity of mixed single layer red OLEDs were strongly influenced by the mixing ratio of organic materials [8]. Therefore, it is necessary to compare the photophysical properties of red devices with various mixing ratios of organic materials and introduced the red device with optimum mixing ratio.

Table 1 lists a comparison of characteristics of red OLEDs at different mixing ratios. Here, the fraction of red dopand DCM was kept at 10:100. By varying the mixing ratios of DPVBi, Alq_3 and rubrene, the luminance and the power and current efficiencies were changed and improved performances were achieved in the optimum case of Alq_3:DPVBi:rubrene:DCM=40:35:15:10.

Table 1: Photophysical properties of mixed single layer devices with different mixing ratios.

Structure	L_{Max}(cd/m^2)	$\eta_{p,max}$ (lm/W)	$\eta_{L,max}$ (cd/A)
40:35:15:10	11500	4.02	5.64
50:30:10:10	9730	3.61	4.21
30:40:20:10	7445	2.53	3.75

This optimum structure showed the maximum luminance of 11500 cd/m^2, the maximum power efficiency of 4.02 lm/W and the maximum current efficiency of 5.64 cd/A at the same current density. These results show that the red device performance with the optimum structure was superior to the other devices due to increase of the radiative recombination probability in the emitting layer as well as the balance in the number of holes and electrons.

2. Comparison of the different structures

In the following, we compared the optimum DCM-doped Alq_3 single-host and DCM-doped Alq_3:Rubrene mixed-host devices. Fig. 2 (a) and (b) depict current density vs voltage (J-V) and luminance vs voltage (L-V) characteristics for the three devices.

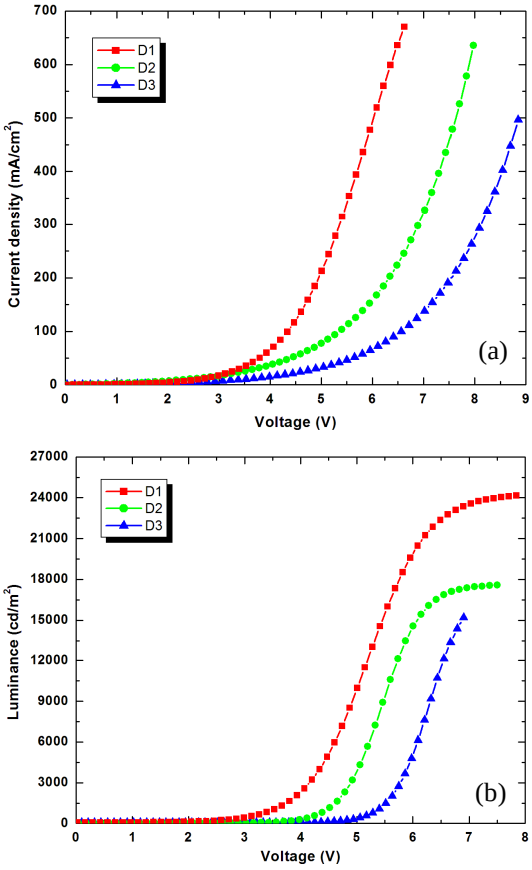

Fig. 2: (a) Current density-Voltage and (b) Luminance-Voltage characteristic of devices.

For the D3, the fraction of Alq_3 was 90:100 and for the D2, the optimum mixing ratios of Alq_3 and rubrene were 60:100 and 30:100. From Fig. 1 (a) and (b), it can be seen that the turn on voltage (V_{TO}) and the driving voltage (V_D) of D1 are dramatically decreased compared with the other two devices and the driving voltage is 1.6, 3.5 and 4.2 V for D1, D2 and D3, respectively. It is reasonable to assume that for D1 the large bipolar mobility of rubrene and hole-trapping of DPVBi were responsible for the observed reduction of the driving voltage [9].

On the other hand, as seen in Fig. 3 (a) and (b), the power and current efficiencies of D1 are better than D2 and D3. For example, the maximum current efficiency of the D1 was measured as 5.64 cd/A which was more than 1.2 times of that of the D3. It can be also observed that the performance of the D3 was better than that of the D2. This may be related to the characteristic of rubrene that existence of it at D3 can assist dopants and contribute to improving the performance via a cascading energy

transfer [10]. For D1, addition to the role of rubrene as an assist dopant, the existence of DPVBi as hole-trapping host material lead to the more carrier balance in recombination zone compared with other devices and as a result, the performance of D1 was improved.

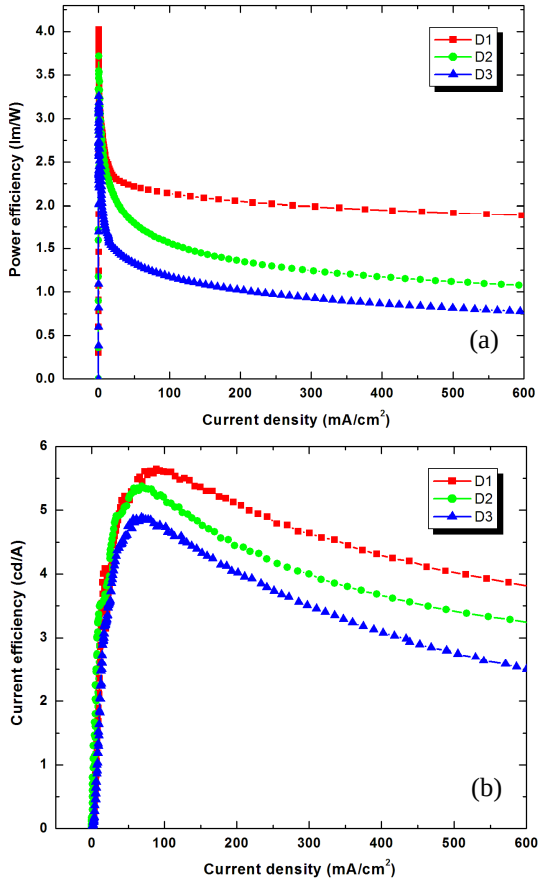

Fig. 3: (a) Power efficiency and (b) Current efficiency versus Current density for different devices.

Fig. 4 shows the EL spectra and the CIE color coordinate of D1, D2 and D3 under the current density of 20 mA/cm^2.

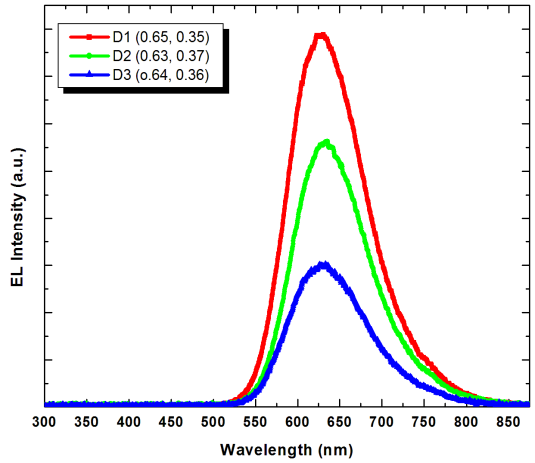

Fig. 4: Normalized EL spectra and CIE coordinates of different devices.

For all devices, the emission peak at around 630 nm were observed and originated from DCM molecules. It can be found that EL intensity of D1 is higher than that of other two devices. In the fact, this is due to the charge trapping at the DPVBi, which helped the recombination probability and the balancing of the charge carriers. At a current density of 20 mA/cm2, the CIE coordinates of D1, D2 and D3 are of (0.65, 0.35), (0.63, 0.37) and (0.64, 0.36), respectively. It is clear that pure red emission is observed for red OLED with D1 configuration.

Conclusions

In conclusion, we investigated red OLED device with a mixed single layer by optimum mixing of three host materials (DPVBi, Alq_3 and rubrene) and dopant material (DCM). This red OLED showed an improved performance compared to DCM-doped Alq_3 single-host and that with the Alq_3:Rubrene mixed-host red OLED devices. Its maximum current efficiency is 5.64 cd/A, which is enhanced by about ≈ 12%, compared with that of D3. The superior performances of the mixed single layer red OLED are attributed to the large bipolar mobility of rubrene and the hole-trapping of DPVBi, which leads to high power and current efficiencies.

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