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Effects of Doped Emitter on Performance of Red Organic Light Emitting Diodes

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Abstract: Organic Light Emitting Diodes (OLEDs) with two emitters, doping DCJTB and C₅₄₅T into Alq₃ to form a double emitting layers respectively, were presented to investigate enhancement of doped emitter on performance of red organic light emitting diodes. The devices structure used are: Glass/ITO/4,4',4''-tris[2-naphthylphenyl-1-phenylamino]triphenylamine (2T-NATA)/N,N'-di(naphthalene-1-yl)-N,N'-diphenyl benzidine (NPB)/Tris-(8-hydroxyquinoline) aluminum (Alq₃):4-(dicyanomethylene)-2-tert-butyl-6(1,7,7,7-tetramethyljulolidin-4-yl-vinyl)-4H-pyran(DCJTB)/Alq₃:10-(2-benzothiazolyl)-2,3,6,7-tetrahydro-1,1,7,7,-tetramethyl-1H,5H,11H-(1)-benzopyrpyrano-(6,7-8-i,j)quinolizin-11-one (C₅₄₅T)/Alq₃/LiF/Al, and the devices were compared with single emitting-layer red and green devices. The results indicated the red emission was indeed enhanced by the green emitter as comparing with the single emitting-layer red organic light emitting devices, and the optimal doping proportion for green emitter enhanced red device is [Alq₃:(1.5%)DCJTB]/[Alq₃:(2.5%)C₅₄₅T](mass fraction), which exhibited a maximum brightness of 6 830 cd/m² at a voltage of 11.5 V, a maximum current efficiency of 4.59 cd/A at a voltage of 11 V, respectively, yet the means sacrifice the color purity of red light.

Key words: red emission;enhancement;double-emitting layer;efficiency;luminance

掺杂发光体对红色有机电致发光的影响

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摘 要:为了研究掺杂发光体对红色有机电致发光二极管的增强效果,将DCJTB和C₅₄₅T分别掺入Alq₃,制备了双发光层的OLED器件,器件结构为玻璃/ITO/4,4',4''-tris[2-naphthylphenyl-1-phenylamino]triphenylamine (2T-NATA)/N,N'-di(naphthalene-1-yl)-N,N'-diphenyl benzidine (NPB)/tris-(8-hydroxyquinoline) aluminum (Alq₃):4-(dicyanomethylene)-2-tert-butyl-6(1,7,7,7-tetramethyljulolidin-4-yl-vinyl)-4H-pyran(DCJTB)/Alq₃:10-(2-benzothiazolyl)-2,3,6,7-tetrahydro-1,1,7,7,-tetramethyl-1H,5H,11H-(1)-benzopyrpyrano-(6,7-8-i,j)quinolizin-11-one (C₅₄₅T)/Alq₃/LiF/Al,并且将其与单发光层的红、绿光器件相比较。实验结果表明,与单发光层的红光器件相比,加入绿光发光层的红光器件的发光特性被增强了,这种双发光

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层器件的最优掺杂比例为 $[\text{Alq}_3:(2.5\%)\text{C}_{545}\text{T}]/[\text{Alq}_3:(1.5\%)\text{DCJTb}]$ (质量分数),在电压为 11.5 V 时得到最大发光亮度为 6 830 cd/m²,在 11 V 电压时能得到 4.59 cd/A 的最大电流效率。但是,这种方法的缺点是削弱了红光的色纯度。

关 键 词:红光 OLEDs;增强;双发光层;效率;亮度

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1 Introduction

Organic Light Emitting Diodes (OLEDs) have shown a significant and promising application in flat panel display and solid light source because of its superior characteristics: high brightness, low power consumption, solid state nature, fast response speed, wide viewing angle, etc^[1]. The red emission is usually obtained by doping red fluorescent dye into host materials^[2,3]. Now Alq₃ host doped with DCJTb is a commonly means to realize red emission, this red emitter has the shortness of low luminance efficiency (<2 cd/A)^[4], and its luminance drops at high level of doping because of concentration quenching^[5]. The double emitting layers had been used to realize white emission^[6], and also in blue phosphorescent OLEDs to improve device efficiency^[7,8]. Up to now, C₅₄₅T is a widely used green dopant because of its superior performance in devices. A green device structured: Glass/ITO/2T-NATA/NPB/Alq₃:C₅₄₅T/Alq₃/LiF/Al, exhibited a maximum brightness of 11 000 cd/m² at a voltage of 9 V and a current efficiency of 11.66 cd/A at a voltage of 6 V^[9], this data showed that green device with dopant C₅₄₅T appears better characteristics in current efficiency and brightness.

In this paper, two dopants C₅₄₅T and DCJTb, doping into Alq₃ to form a double-emitting layers respectively, were introduced to take advantage of the superiority of C₅₄₅T and the double-emitting structure. Although the green emitter will surely lead to a decrease in color purity of red device, the investigation on double structure can reveal some informations about efficiency enhancement of devices like bilayers phosphorescent

OLEDs. The performance of prepared devices were tested and compared in terms of the variation of dopant concentration.

2 Experiments

Indium Tin Oxide(ITO) coated glass with a sheet resistance of 20 $\Omega/\square$ was used as the anode, ITO glass was cleaned by detergent, acetone, anhydrous ethanol successively. After the plasma treatment procedure, 2T-NATA was evaporated on the ITO thin films to inject hole, and NPB and Alq₃ were used as hole-transporting and electron-transporting materials respectively. A composite cathode LiF/Al was prepared outside the electron transporting layer. The OLED devices are structured: glass/ITO/2T-NATA (15 nm)/NPB(25 nm)/Alq₃:(y%)DCJTb(20 nm)/Alq₃:(x%)C₅₄₅T(20 nm)/Alq₃(10 nm)/LiF(1 nm)/Al(100 nm); Two structures (A and B), Emitter A [Alq₃:(1%)DCJTb/Alq₃:(x%)C₅₄₅T] with the concentration of C₅₄₅T varied from 1% to 5% with a step of 1% (mass fraction) and Emitter B [Alq₃:(y%)DCJTb/Alq₃:(2.5%)C₅₄₅T] with the concentration of DCJTb varied among values (about 1%, 1.5%, 2.5%, 3.5% mass fraction), were prepared in order to find out a appropriate proportion for red emitting devices. All the organics were evaporated with the rate in the range 0.1~0.3 nm/s under high vacuum ($\leq 3 \times 10^{-4}$ Pa), and the rate for metal cathode ranged 0.8~1 nm/s, the active area was about 210 mm².

Fig.1 shows the two structures (A, B) of OLED devices. All samples prepared were tested without typical glass encapsulation. The EL spectra was measured by the PMS-80 Spectral Testing System (from EVERFINE PHOTO-E-

INFO CO., LTD), the voltage-current-brightness characteristics was tested at the room temperature and in ambient atmosphere.

Al(100 nm)
LiF(1 nm)
Alq ₃ (10 nm)
Alq ₃ :(x%)C ₅₄₅ T(20 nm)
Alq ₃ :(1%)DCJTB(20 nm)
NPB(25 nm)
2T-NATA(15 nm)
ITO
Glass

Structure A

Al(100 nm)
LiF(1 nm)
Alq ₃ (10 nm)
Alq ₃ :(2.5%)C ₅₄₅ T(20 nm)
Alq ₃ :(y%)DCJTB(20 nm)
NPB(25 nm)
2T-NATA(15 nm)
ITO
Glass

Structure B

Fig. 1 Glass/ITO/2T-NATA/NPB/Alq₃:(y%)DCJTB/Alq₃:(x%)C₅₄₅T/Alq₃/LiF/Al

3 Results and Discussions

I-V-L characteristics of Structure A was shown in Fig. 2 and Fig. 3, it can be seen that the forward current raises with the increase of bias voltage and the curves has the same trend of a typical diode. The turn-on voltage of the five doped devices varied from 3 ~ 5 V, the 5% (mass fraction) doped devices had the lowest turn-on voltage but its brightness was not high and easily thermal-breakdown; the 3% (mass fraction) doped device was much more stable than any other devices and its maximum luminance reached 4 230 cd/m² that was the maximum value among other doping; the 2% and 3% (mass fraction) doped devices had similar *V-I* characteristics, but their brightness apparently differed from each other. Here we designed the Structure B with 2.5% (mass fraction) of C₅₄₅T to find out a better doping proportion of DCJTB,

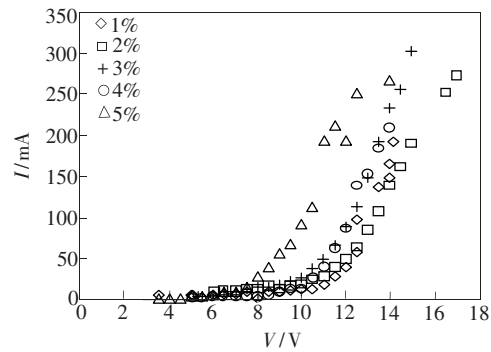


Fig. 2 Current vs. voltage of Structure A

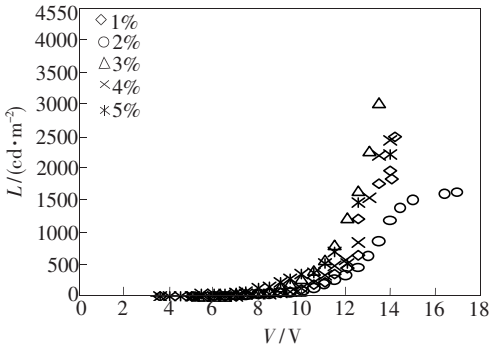


Fig. 3 Brightness vs. voltage of Structure A

for the closeness of the 2% and 3% (mass fraction) concentration of C₅₄₅T in Structure A.

I-V-L characteristics of Structure B can be seen in Fig. 4 and Fig. 5 below. The curves showed the same characteristic of a typical diode as well. We can see from Fig. 4 that 1% (mass fraction) doped device exhibited the lowest current and that of other devices raised when dopant concentration increased. In Fig. 5, the 1.5% (mass fraction) DCJTB device obtained the maximum luminance about 6 830 cd/m², and 1% device reached its maximum value about 5 500 cd/m², and other doping were much lower than that of the two doping concentration mentioned above.

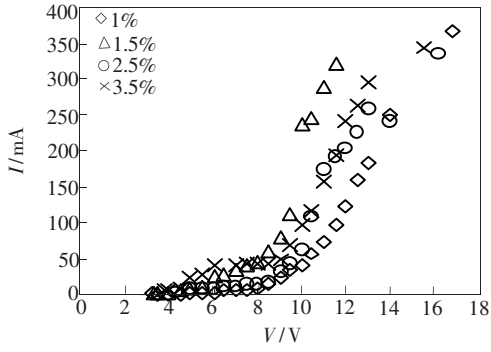


Fig. 4 Current vs. voltage of Structure B

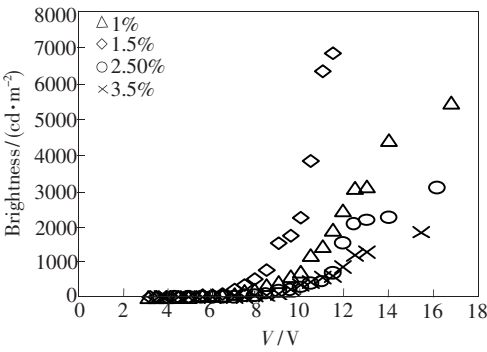


Fig. 5 Brightness *vs.* voltage of Structure B

Comparing to the 1% DCJTB device, the current of 1.5% (mass fraction) device is much higher, so the 1.5% (mass fraction) doped device must easily breakdown due to heat when the voltage applied increased.

The brightness of 4%, 5% (mass fraction) C₅₄₅T devices dropped dramatically in Structure A, that may due to excitons quenching effect as a result of high dopant concentration in the emitting layer Alq₃:C₅₄₅T and as for the Structure B, the DCJTB 1.5% (mass fraction) doped device displays better luminance because the carriers may be well balanced in the emitting layer. And the characteristics of Structure A with 3% (mass fraction) of C₅₄₅T exhibited medium current and higher brightness than any other doping.

Here characteristics of the two doping proportions which included 1% (mass fraction) DCJTB plus 3% (mass fraction) C₅₄₅T (Emitter1) and 1.5% (mass fraction) DCJTB plus 2.5% (mass fraction) C₅₄₅T (Emitter 2) were showed in Fig. 6 and Fig. 7, additionally another two devices with single emitting layer Alq₃:DCJTB (1%) (Emitter 3) and single emitting layer Alq₃:C₅₄₅T (3%) (Emitter 4) were prepared for references (C, B related to Current, Brightness respectively).

In Fig. 6, it is obvious that current of Emitter 2 (C2) is much higher than that of Emitter 1 (C1) (10 V for example), Emitter 2 (B2) is superior to Emitter 1 (B1) in brightness as well.

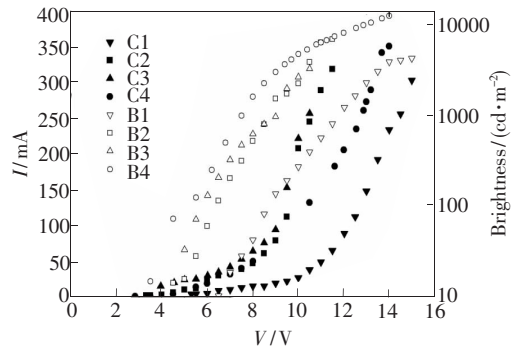


Fig. 6 Current-voltage-brightness curves of 4 Emitters

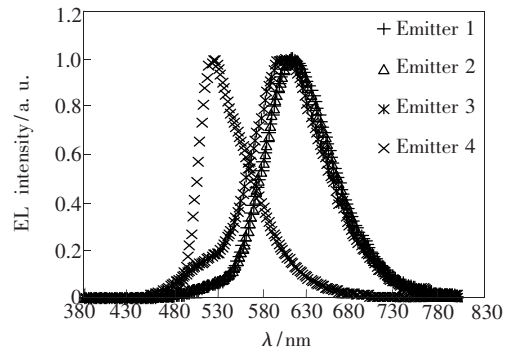


Fig. 7 EL spectra comparison of 4 Emitters

Emitter 2 is alike to Emitter 3 in current-brightness-voltage characteristics. In Fig. 7, it can be seen that the EL curve for Emitter 1 nearly coincided with that of Emitter 2, spectra of Emitter 3 slightly depart from the two coincided spectra above, and Emitter 4 is far way. The spectra of Emitter1 and Emitter 2 revealed that most of energy was transferred to dopant DCJTB rather than C₅₄₅T, not well balanced in the two emitters, this may due to the trap effect of Alq₃:DCJTB system^[10], the intensity distinction of Emitter 2 and Emitter 1 showed the trap effect may be increased as doping more DCJTB into Alq₃, thus it is easier to understand why the double-structured sample appear orange red, not yellow, meanwhile, it is worthy to note that the double structure emitters(1,2) have a little red shift.

Additionally, other parameters of the 4 devices were given in Table 1. Emitter 1 and Emitter 2 appear similar CIE coordinates, but Emitter 1 display higher turn-on voltage than Emitter 2

and its maximum brightness is much lower than that of the Emitter 2. Current efficiency of Emitter 1 and Emitter 2 are much better than that of Emitter 3, this shows the enhancement

of red emission in a double emitting structure as the expectation and there may be stronger enhancement if some other strategies are used in this double structure (discussed below).

Table 1 Parameters of 4 Emitters

	Turn-on voltage(V)	CIE(<i>x</i> , <i>y</i>)	<i>B</i> (cd/m ²) at 8 V	<i>B</i> _{max} (cd/m ²)	<i>I</i> at 8 V	η _{lax} (cd/A)
Emitter 1	5.30	(0.595 6,0.399 0)	42.5	4 230	15	3.47
Emitter 2	3.30	(0.593 5,0.399 3)	520.0	6 830	47	4.59
Emitter 3	3.95	(0.5428,0.435 7)	621.0	3 250	64	2.65
Emitter 4	2.83	(0.323 2,0.631 7)	1 600.0	12 418	50	8.67

Compared to the Emitter 3, Emitter 2 exhibited a better performance in brightness and current efficiency. Although few investigations have been performed in orange emission, it have been applied in realizing white lighting^[11,12]. In the double structure: Alq₃:DCJTB/Alq₃:C₅₄₅T, the Alq₃:C₅₄₅T layer may have trap as well, this is same to the effect of Alq₃:DCJTB, for the investigation of traps in Alq₃ have been demonstrated and discussed^[13], thus we tentatively assume that the trap effect was also raised as increase of C₅₄₅T concentration, the holes trapped formed a positive electrical barrier and inhibited hole transportation to cathode, hence the electrical barrier functioned like a hole blocking layer. In order to impressively improve the efficiency of devices, the approach of doping hole transporting materials into the emitting layer may be effective,for the means have been used in balancing

the carriers and improving efficiency in a single emitting layer OLED^[14,15], also two types of host may be helpful to ease this trouble^[16,17].

4 Conclusions

From the experiments and discussions above, two conclusions can be drawn:

(1) Red emission was indeed enhanced by the green emitter as comparing with the single emitting layer red organic light emitting devices, and further improvement is in need for a better performance;

(2) The optimal doping proportion for green emitter enhanced red device is [Alq₃: (1.5%)DCJTB]/[Alq₃: (2.5%)C₅₄₅T] (mass fraction), which exhibited a maximum brightness of 6 830 cd/m² at a voltage of 11.5 V, a maximum current efficiency of 4.59 cd/A at a voltage of 11 V.

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