Blue organic light-emitting device with low driving voltage and high current efficiency

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ABSTRACT

In this paper, we report a high efficiency organic light-emitting device (OLED) with a high electron mobility electron transport layer (ETL) material and high efficiency blue dopant material. Typically, the mobility of a hole transport layer (HTL) material is much higher than that of an electron transport layer (ETL) material. Here we used the bis(10-hydroxyben-zo[h]quinolinato)beryllium (Bebq2) as the ETL material that exhibits superior electron mobility. It effectively reduced the driving voltage and increased the power efficiency. The blue dopant material was 4,4'-bis[2-(4-(N,N-diphenylamino)phenyl)vinyl]biphenyl (DPAVBi) in the 9,10-bis(2'-naphthyl) anthracene (BNA), that was the host material of the emitting layer (EML). At 100 cd/m^2, the current efficiencies with different dopant concentration can be as high as 19.2 cd/A with the CIE coordinate at (0.154, 0.238). Driving voltage at 20mA/cm^2 was 4.94 V of this device. With increasing the doping concentration, the drive voltage variation did not vary much and was within 0.6 V at 20 mA/cm^2. The emitting mechanism in such a device may be mainly due to energy transfer rather than carrier trapping. CIE coordinate of such a device shifted toward blue with increasing current density due to intense light emission from the host material of the EML. The highest efficiency was achieved when doping concentration is 3%.

Keywords: OLED, balanced charge transport

1. INTRODUCTION

Since the discovery of organic light emitting diode (OLED) by Tang and VanSlyke in Kodak at 1987 [1], many researches focused on the electroluminescence phenomenon of organic materials began. There are many advantages in OLED such as flexibility [2], light-weight, self-emitting, wide view-angle and the potential of low cost due to its simple device structure with stacks of amorphous organic materials thermal-evaporated on indium tin oxide (ITO) glass substrate.

For effective blue OLEDs, host materials such as distyrylarylene derivatives and styrylamine are commonly used. With suitable dopant materials, devices show high efficiency, brightness and good color saturation [3-5]. However, lifetime issue is still one of the major concerns in such a device [6-8]. Here, we propose a new combination of blue host and dopant to achieve an ultra-high efficiency and low driving voltage. Typically, the mobility of a hole transport layer (HTL) material is much higher than that of an electron transport layer (ETL) material. Such unbalance mobility between HTL and ETL materials results in low device efficiency and shortens the operation lifetime. Here we used the bis(10-hydroxyben-zo[h]quinolinato)beryllium (Bebq2) as the ETL material that exhibits the electron mobility of about two orders of magnitude higher than that of the typically used ETL material, tris-(8-hydroxyquinoline) aluminum (Alq3). The molecular structures of these two materials are shown in the figure 1. It effectively reduced the driving voltage and increased the power efficiency.

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The blue dopant material was 4,4'-bis[2-(4-(N,N-diphenylamino)phenyl)vinyl]biphenyl (DPAVBi) with the concentration 0, 1, 2, 3, 4, 6, 8, and 10% in the 9,10-bis(2’-naphthyl) anthracene (BNA), that was the host material of the emitting layer (EML). The molecular structures of these two materials are also shown in the figure 1. Hole transport material we used was N^4,$N^{4'}$-Di-naphthalen-2-yl-N^4,$N^{4'}$-di-naphthalen-1-yl-biphenyl-4,4’-diamine (TNB). The structure of the devices were ITO /HTL (40nm)/EML (45nm)/ETL (15nm)/ LiF(1.2nm)/Al (100nm) that was optimized with combinational experiments and optical simulation. The recipes are listed in table 1.

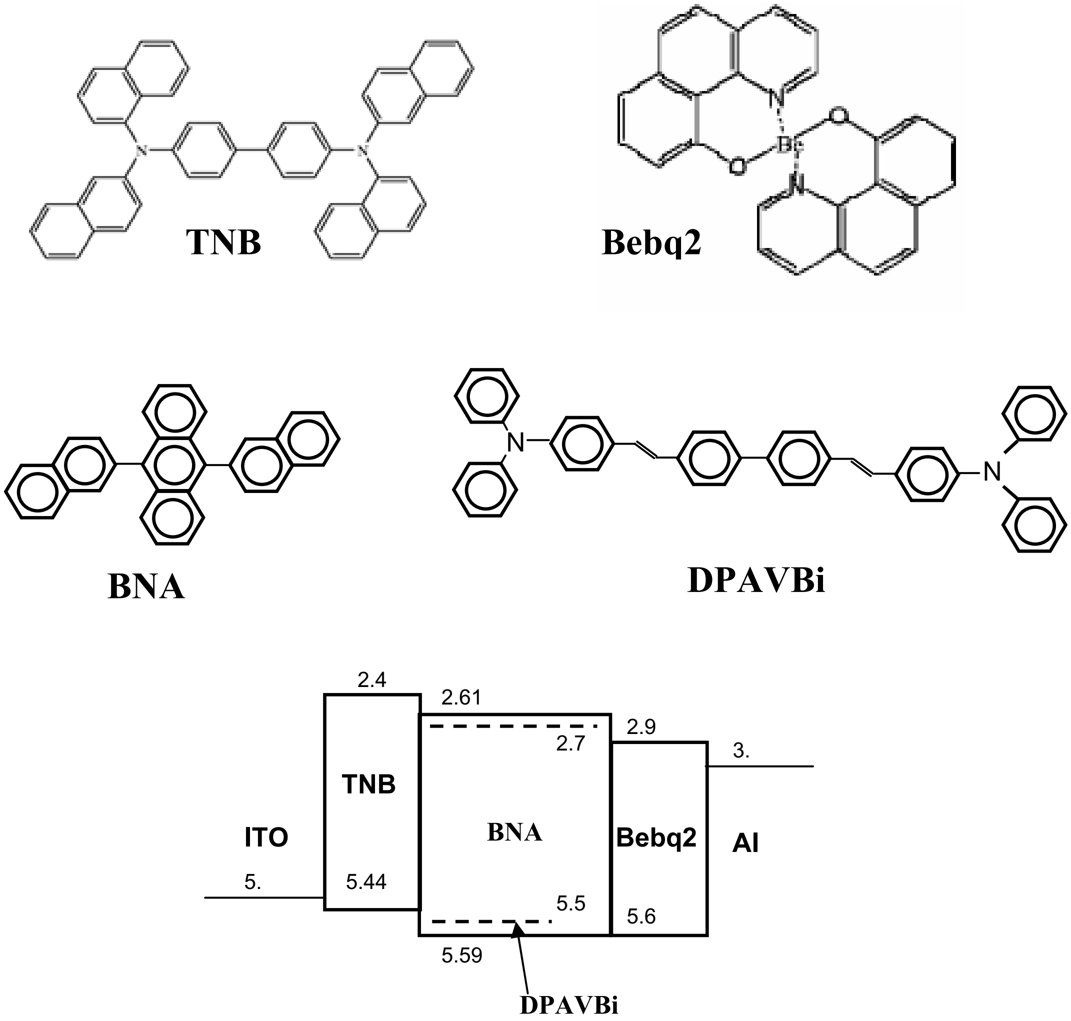

Fig. 1 (a) The molecular structures of TNB, Bebq2 , DPAVBi, and BNA. (b) The energy band diagram.

Device	Substrate	HTL	EML		ETL	EIL	Cathode
			Host	Dopant			
		TNB	BNA	DPAVBi	Bebq2	LiF	Al
1	ITO glass	400	450	0%	150	12	1000
2				1%			
3				2%			
4				3%			
5				4%			
6				6%			
7				8%			
8				10%			

Table 1 Device structure (unit: Å)

2. EXPERIMENTS

The experimental devices in this paper are fabricated in multi-chamber cluster evaporator under the pressure about 1 x 10^{-7} torr. The substrate is indium-tin-oxide (ITO) glass with sheet resistance 10 Ohm/sqr. O_2 plasma treatment was used to clean the ITO substrate surface and to improve the ITO work function before the deposition. The deposition rates of organic materials are typically 0.1 nm/sec. After evaporative deposition in the vacuum chamber, the devices were transported to the glove box with O_2 and H_2O concentration below 1 ppm. Encapsulation was completed in the glove box. Desiccant was used to absorb moisture that leak into the device.

The active pixel size of a device is 0.5 mm x 0.5 mm. We used Keithley 2400 source meter I-V characteristics. Minolta CS-1000 photometer was used to measure the luminance, the spectrum, and the CIE coordinate of the device. Lifetime was measured under the DC constant current of the initial brightness of 10000 cd/m^2 and recorded every 5 minutes. All these measuring instruments were connected to the personal computer and controlled by Labview programs.

3. RESULTS AND DISCUSSIONS

The resulting current density versus drive voltage plot of the experimental devices is shown in Figure 2. Here we can see that how the dopant concentration variation affects the electrical property of the device. The current density is large when there is no dopant doped in the device. Such a phenomenon is ascribed to the charge carrier trapping effect of the fluorescence dopant [9] [10]. Therefore, at the same drive voltage, device 1 has the largest current density compared with other doped devices, as shown in figure 2.

Figure 3 shows the voltage variation of the eight experimental devices at the same current density 20, 100 and 500 mA/cm^2, respectively. Although the concentration of DPAVBi varies, the drive voltage does not deviate very much as can be seen from the figure. Hence we deduce that the charge trapping effect of the dopant DPAVBi is not very serious.

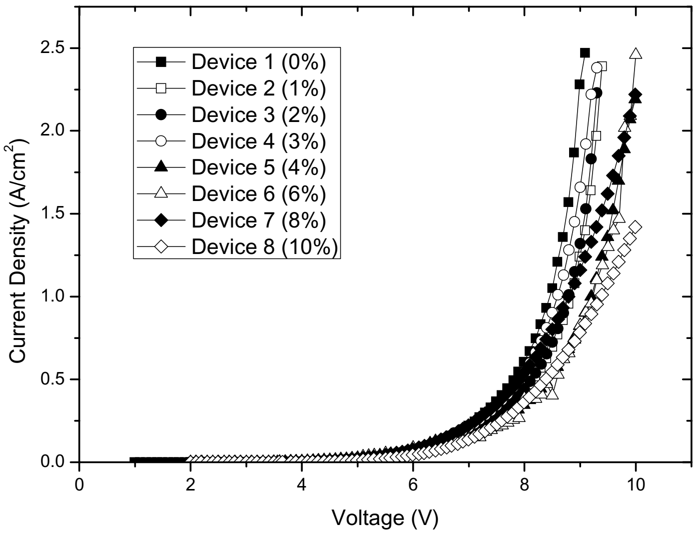

Fig. 2 Current density-Drive voltage curves of the different devices.

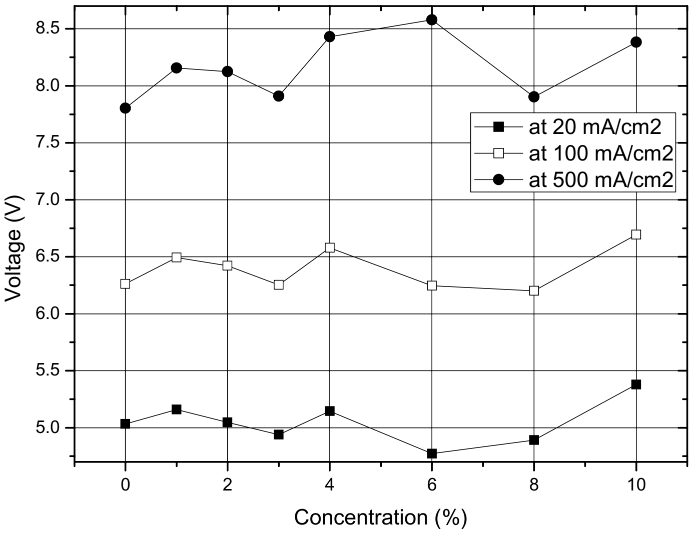

Fig. 3 Drive voltage-DPAVBi concentration curves at different current density.

The resulting luminance versus drive voltage plot of the experimental devices is shown in figure 4. From this figure we can note that device 4, which is doped 3% DPAVBi, has the best luminance performance. When the dopant concentration is above 3%, the luminance drops gradually.

Figure 5 shows the current efficiency versus the current density. It indicates that the efficiency is highest when the dopant DPAVBi concentration reaches 3%. The current efficiency drops when the concentration increases above 3%.

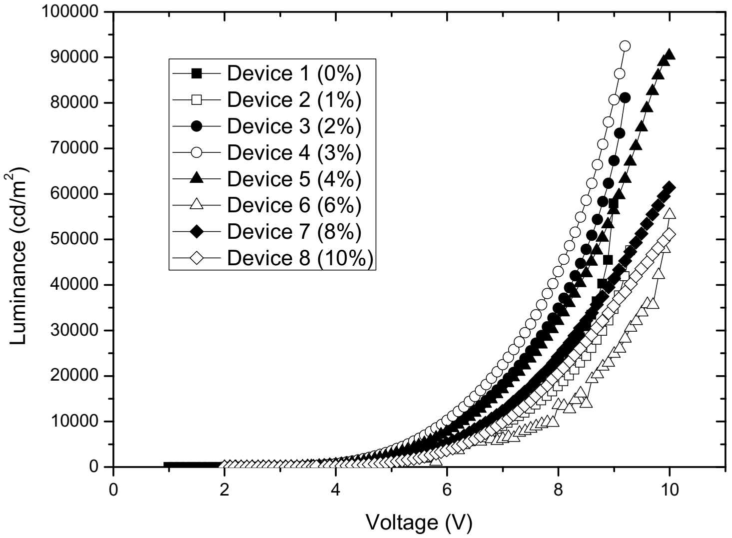

Fig. 4 Luminance versus drive voltage plot of the eight devices.

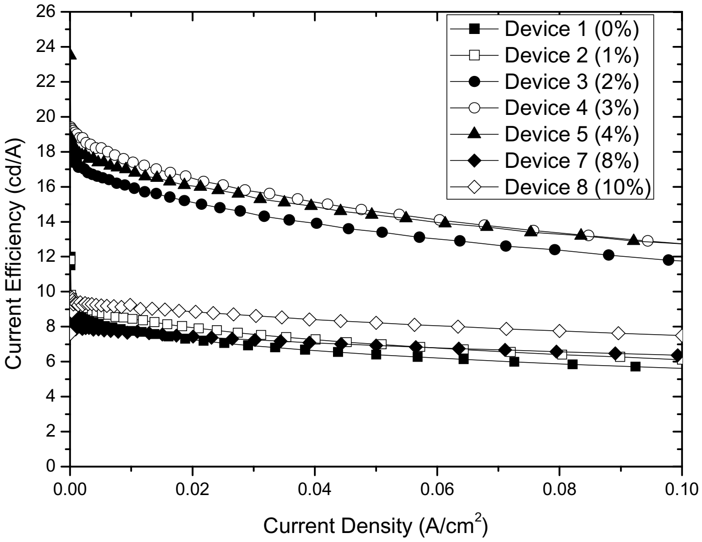

Fig. 5 Current efficiency versus current density plot of the eight devices.

From the Fig. 3, 4 and 5, we can conclude that adding the dopant can really help to increase the radiative recombination and therefore increase the brightness and efficiency. It does not affect the electrical property, very much, such as the current density the drive voltage. At 100 cd/m^2, the current efficiencies with different dopant concentration were 8.5, 9.3, 17.6, 19.2, 18.3, 5.2, 8.0, 9.3 cd/A, respectively. CIE coordinate of devices were (0.178, 0.213), (0.175, 0.220), (0.159, 0.238), (0.154, 0.238), (0.154, 0.242), (0.161, 0.248), (0.160, 0.270) and (0.159, 0.275), respectively. Driving voltage at 20mA/cm^2 were 5.03, 5.16, 5.05, 4.94, 5.14, 4.77, 4.89, and 5.38 V, respectively. The energy difference of HOMO (highest occupied molecular orbital) and LUMO (lowest unoccupied molecular orbital) between the host and dopant materials of EML is small. The good energy transfer from the emitting host material BNA to the high efficiency emitting dopant material DPAVBi contributes the high current efficiency. With increasing the doping concentration, the drive voltage variation did not vary much and was within 0.6 V at 20 mA/cm^2. The emitting mechanism in such a device may be mainly due to energy transfer rather than carrier trapping. CIE coordinate of such a device shifted toward blue with increasing current density due to intense light emission from the host material of the EML. The highest efficiency was achieved when doping concentration is 3%. Higher doping concentration leads to concentration quench and reduces the efficiency.

With increasing the dopant concentration, the x-value of CIE coordinates decreased then increased and the y-value increased monotonically, as shown in Fig. 6, which marks the x and y value of the eight experimental devices at current density 10 mA/cm^2. The initial blue shift results from the more efficient energy transfer from the host to the dopant with increasing dopant concentration. However, such a dopant material, DPAVBi, was reported to have a hole-transport characteristic. When the dopant concentration exceeds 6%, the holes inject into the EML and recombination zone shifts towards the cathode. Such an optical interference induced the anomalous x-value increase that was also confirmed by the optical simulation model.

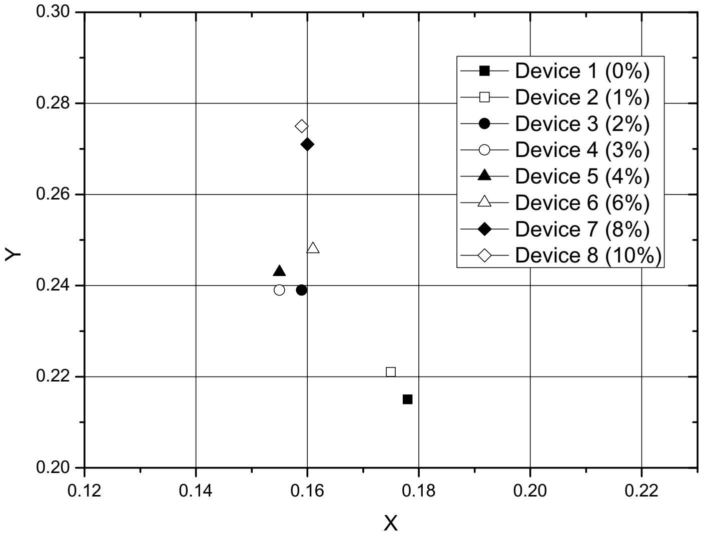

Fig. 6 CIE 1931 coordinate of the devices at constant current density 10 mA/cm^2.

4. CONCLUSIONS

In the end, we conclude that a fluorescence blue organic light emitting device was fabricated with high efficiency and low driving voltage. When the dopant concentration is 3%, there is a high current efficiency of 19.2 cd/A at 100 cd/m^2. The lifetime of device 4 (3% DPAVBi) is approximately 20 hours under the accelerated lifetime test with initial luminance 10000 cd/m^2.

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