OPTOELECTRONICS LETTERS Vol.4 No.3, 1 May 2008

White organic light-emitting devices based on fac tris(2-phenylpyridine) iridium sensitized 5,6,11,12-tetraphenylnap-hthacene*

DING Gui-ying, WANG Jin, JIANG Wen-long, WANG Jing, WANG Li-zhong, and CHANG Xi**

College of Information Technology, Jilin Normal University, Siping 136000, China

(Received 2 November 2007)

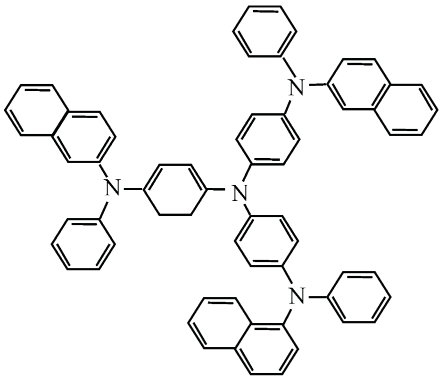
We have fabricated the white organic light-emitting devices (WOLEDs) based on 4,4′ -bis(2,2 -diphenyl vinyl)-1,1′ -biphenyl (DPVBi) and phosphorescence sensitized 5,6,11,12,-tetraphenylnaphthacene (rubrene). The device structure is ITO/2T-NATA (20 nm)/ NPBX (20 nm)/ CBP: x%$Ir(ppy)_3$:0.5% rubrene (8 nm)/ NPBX (5 nm)/DPVBi (30 nm)/ Alq(30 nm)/LiF(0.5 nm)/Al. In the devices, DPVBi acts as a blue light-emitting layer, the rubrene is sensitized by a phosphorescent material, fac tris (2-phenylpyridine) iridium [$Ir(ppy)_3$], acts as a yellow light-emitting layer, and N,N′ -bis- (1-naphthyl)-N,N′ –diphenyl -1, 1′ -biphenyl-4,4′ -diamine (NPBX) acts as a hole transporting and exciton blocker layer, respectively. When the concentration of Ir $(ppy)_3$ is 6wt%, the maximum luminance is 24960 cd/m^2 at an applied voltage of 15 V, and the maximum luminous efficiency is 5.17 cd/A at an applied voltage of 8 V.

CLC numbers: TN383 **Document code:** A **Article ID:** 1673-1905(2008)03-0205-4

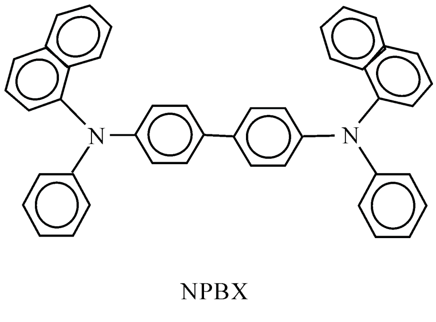
DOI 10.1007/s11801-008-7150-3

White organic light emitting devices (OLEDs) attract considerable interest from the research community due to their applications in solid state lighting, flat-panel displays and backlights for liquid crystal displays. so far, there are many methods to enhance the luminous efficiency of WOLEDs, such as using emission layer into which different fluorescent dyes are doped[1-4]. White light-emission is obtained using dyes doped[5-6], such as by mixing two complementary colors (e.g., blue/yellow, red). ZHENG Jia jin[7] has reported white organic light-emitting devices in z_n(BTZ)-doped. The device shows a maximum external quantum efficiency of 0.63%, a luminous efficiency of 4.05 cd/A, CIE coordinates of (0.341, 0.334), and a maximum luminance of 4048 cd/m^2 at an applied voltage of 20 V. WU Xiao-ming[8] reported a WOLED that is doped with an orange-red dye rubrene and a greenish-blue emitting layer z_n(BTZ)_2 with electron-transport characteristics. The device shows a maximum luminance of 1 600 cd/m^2(18 V), CIE coordinates of (0.310,0.330), and a maximum external quantum efficiency of 0.21%. Recently, many groups in the world have reported WOLEDs based on the phosphorescent sensitization and have gotten better achievements [9-12].

We have fabricated the white organic light-emitting de-



2T-NATA



NPBX

---

* This work was supported by the Ministry of Science and Technology of Jilin under Grant No. 20050523, the Grant for the Scientific Research from the educational office of Jilin (Project No.25, [2003]; 54, [2004]) and the Grant from the department of Science and Technology of Siping [Project No.2005007; 2006008]

* E-mail: gy-ding@163.com

vices (WOLEDs) based on 4,4′ -bis(2,2 -diphenyl vinyl)-1, 1′ -biphenyl (DPVBi) and phosphorescence sensitized 5,6, 11,12, -tetraphenylnaphthacene(rubrene). The device structure is ITO/2T-NATA (20 nm)/ NPBX (20 nm)/ CBP: *x*%Ir $(ppy)_3$:0.5%rubrene (8 nm)/ NPBX (5 nm)/DPVBi (30 nm)/ Alq (30 nm)/LiF (0.5 nm)/Al. In the devices, the doping concentration of $Ir(ppy)_3$ is 0 wt %, 2wt %, 4 wt %, 6 wt % and 8 wt %, respectively.

The chemical structures of the materials are shown in Fig.1. The structure and the schematic energy diagrams of the devices are shown in Fig.2. In this letter, we have fabricated the white organic light-emitting devices (WOLEDs) based on the phosphorescent sensitization. In the devices, 4,4',4'-{N'，－（2-naphthyl-N-phenylamino}-triphenylamine (2T-NATA) and tris-8- hydroxyquinoline aluminum (Alq3) are used as hole injection and electron transport layer, respectively. The NPBX is used as a hole transport and electro block layer. Blue emission comes from 4,4'-bis (2,2'-diphenylvinyl)-1,1'-biphenyl (DPVBi) layer. 5, 6, 11, 12-tetraphenylnaphthacene (rubrene) and fac tris (2-phenylpyridine) iridium $[Ir(ppy)_3]$ are co-doped into the host material, 4,4-N, N'-dicarbazole-biphenyl (CBP）, and this doping layer emits yellow light. The rubrene and $Ir(ppy)_3$ act as a fluorescent dye and a phosphorescent sensitizer, respectively.

The ITO-coated glass substrate is first immersed sequentially in ultrasonic baths of acetone, alcohol and deionized water for 10 min, respectively, and is then driven in an oven. The devices are fabricated in a multi source organic molecule gas deposition system. There are different materials in every sources, and the temperature of every source can be controlled independently. The different organic material layer is first deposited on the ITO-coated glass substrate according to the designed structure, and then a LiF buffer layer and an Al are deposited as a co-cathode under a pressure of $4x10^{-4}$ Pa or so. The area of active region is 5 mm^2. Electroluminescent (EL) spectra and commission international De L'Eclairage (CIE) coordination of these devices are measured by a PR650 spectra scan spectrometer. The luminance-current- voltage characteristics are recorded simultaneously with the measurement of the EL spectra by combining the spectrometer with a Keithly model 2 400 programmable voltage-current source. The layer thicknesses of the deposited materials are monitored in situ using a model FTM-V oscillating quartz thickness monitor made in Shanghai, China. All the measurements are carried out at room temperature under ambient conditions.

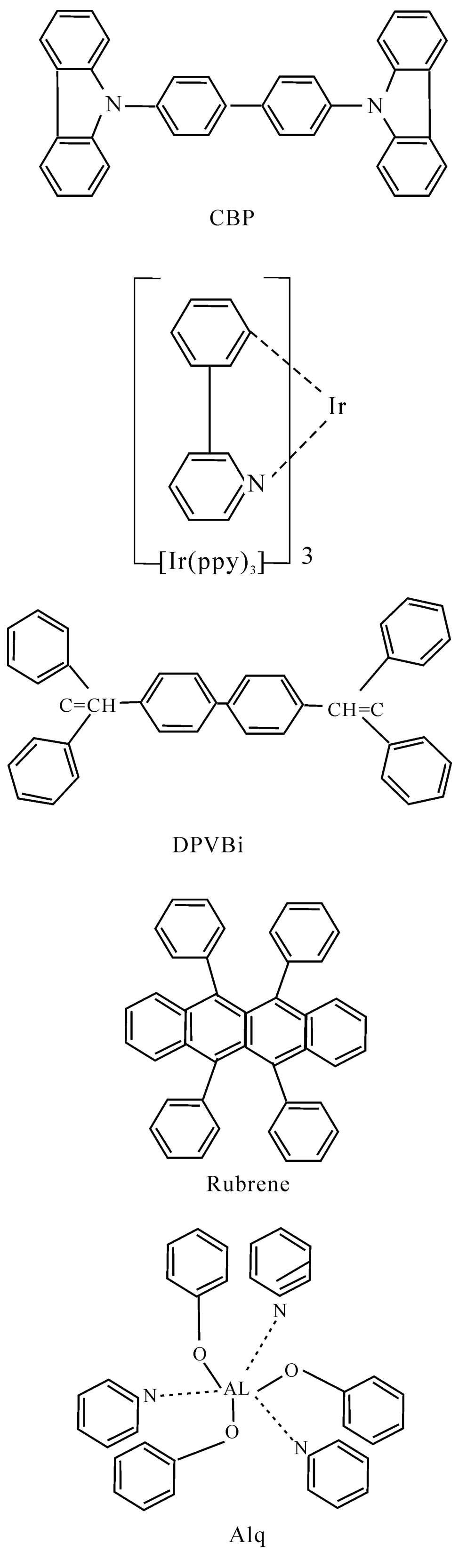
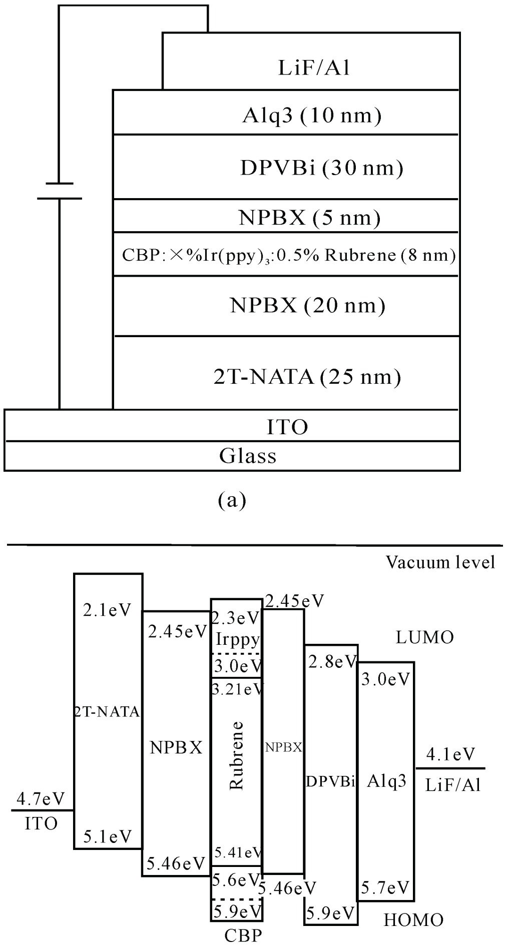


Fig.1 Chemical structure of the organic materials used



(a)

(b)

Fig.2 Structure and schematic energy diagrams of the device

Fig.3 shows the E-V characteristics of the devices with various concentrations of Ir(ppy)$_3$. The luminous efficiency of the devices is higher at a low voltage. The maximum luminous efficiency of the device with 4 wt% of Ir(ppy)$_3$ is 6. 85 cd/A, which is higher than the other devices at the same voltage. According to Tab.1 that shows the efficiencies, the luminance, and the CIE coordinates of the devices studied in this work, the efficiency of the device with 4% Ir(ppy)$_3$ is lower than that of 6% Ir(ppy)$_3$ device$_i$. The efficiency of the device non-doped Ir(ppy)$_3$ is much lower.

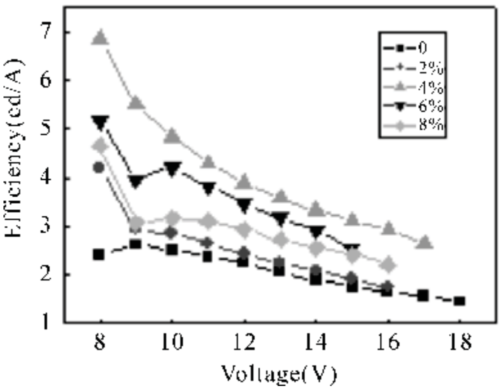


Fig.3 E-V characteristics of the devices with various concentration of Ir(ppy)$_3$.

Fig.4 shows the L-V characteristics of the devices with various concentration of Ir(ppy)$_3$. At the same voltage, a much higher luminance, 24960 cd/m^2 at 15 V, is obtained by increasing the doping Ir(ppy)$_3$ to 6 wt%.The luminance of the device non-doped Ir(ppy)$_3$ is much lower.

According to Tab.1 that shows the maximum efficiency, the maximum luminance, and the CIE coordinates of the devices studied in this work, the efficiency and the luminance of the device without doping Ir(ppy)$_3$ are much lower. The device with 6 wt% of Ir(ppy)$_3$ presents the highest efficiency. According to Tab.2 that shows the CIE coordinates of the devices within a wide region. Hence, the device with 6 wt% of Ir(ppy)$_3$ shows the best performance.

Tab.1 Characteristics of WOLEDs with various concentration of Ir(ppy)$_3$

Concentration	Max luminance	CIE(x, y)	Max efficiency	CIE (x, y)
of Ir(ppy)$_3$ (wt%)	(cd/m^2)	(Luminance)$_{max}$	(cd/A)	(efficiency)$_{max}$
0	13060	(0.29,0.30)	2.62	(0.33,0.35)
2	14810	(0.29,0.30)	4.20	(0.34,0.35)
4	19010	(0.33,0.35)	6.85	(0.35,0.38)
6	24960	(0.32,0.36)	5.17	(0.34,0.39)
8	18830	(0.37,0.41)	4.65	(0.41,0.45)

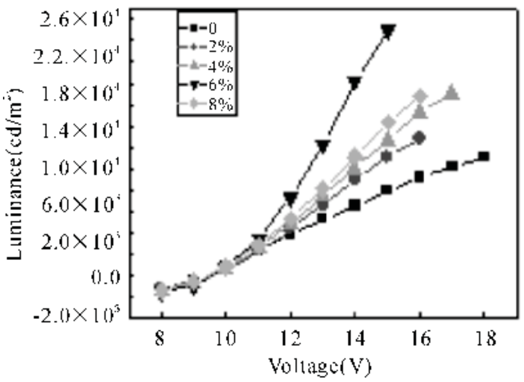


Fig.4 *L-V* characteristics of the devices with various concentration of Ir(ppy)$_3$

White emission could be realized by mixing the yellow fluorescent dyes rubrene with a blue fluorescent dyes DPVBi. Fig.2(b) shows that NPBX has an effect on the electron blocker because the LUMO barrier of 0.35 eV exists at the NPBX/DPVBi interface, and electrons and holes are injected and compounded into the DPVBi layer, which ensures the blue emission.

Tab.2 Characteristics of the device with 6 wt% Ir(ppy)$_3$

Voltage(V)	Luminance (cd/m^2)	CIE (x, y)	Efficiency (cd/A)
8	429.2	0.34,0.39	5.17
9	1048	0.33,0.38	3.96
10	2720	0.32,0.36	4.22
11	5366	0.32,0.37	3.81
12	9267	0.31,0.35	3.46
13	14320	0.31,0.35	3.17
14	20230	0.31,0.35	2.92
15	24960	0.32,0.36	2.53

To improve the white light emission intensity, it is necessary to ensure the yellow light emission intensity. We chose Ir(ppy)$_3$ and rubrene that are co-doped into CBP host. The excited triplet states energy of host transfer to the singlet states of fluorescent acceptor using phosphorescent sensitizer. Thus the yellow emissive intensity and efficiency can be improved greatly. We have fabricated the devices with 0.5 wt% rubrene and different doping concentrations of Ir(ppy)$_3$ in CBP layer based on the reported[13].The luminous efficiency of the device with less than 4 wt% of Ir(ppy)$_3$ is lower, because the energy transfer is not enough. When the doping concentration is higher than 4 wt% of Ir(ppy)$_3$, the result of concentration quenching effect can also lower the efficiency. When the doping concentration of Ir(ppy)$_3$ is 6 wt%, the luminance of the device is higher at the same drive voltage due to the efficient and balanced charge injection and the resonant energy transfer.

In this doped device, the energy of the excitation is first transferred from the host (donor) CBP to the guest materials (acceptor) Ir(ppy)$_3$, and then from the Ir(ppy)$_3$ to the rubrene. The expressions (1) and (2) describe the multi-energy transfer. After the mechanism of the energy transferring, the yellow emissive intensity and efficiency can be improved greatly.

$$\left.\begin{array}{l} {}^1\mathrm{D}^* + {}^1\mathrm{X} \rightarrow {}^1\mathrm{D} + {}^1\mathrm{X}^* \\ {}^1\mathrm{X}^* \rightarrow {}^3\mathrm{X}^* \\ {}^3\mathrm{X}^* + {}^1\mathrm{A}^* \rightarrow {}^1\mathrm{X} + {}^1\mathrm{A}^* \\ {}^1\mathrm{A}^* \rightarrow {}^1\mathrm{A} + \mathrm{hv} \end{array}\right\} \qquad (1)$$

$$\left.\begin{array}{l} {}^3\mathrm{D}^* + {}^1\mathrm{X} \rightarrow {}^1\mathrm{D} + {}^3\mathrm{X}^* \\ {}^3\mathrm{X}^* + {}^1\mathrm{A} \rightarrow {}^1\mathrm{X} + {}^1\mathrm{A}^* \\ {}^1\mathrm{A}^* \rightarrow {}^1\mathrm{A} + \mathrm{hv} \end{array}\right\} \qquad (2)$$

In Egs. (1) and (2), hv is the energy of photon, D, X and A and the donor, the sensitizer and the fluorescent acceptor, respectively, the left upside notation 3 and 1 indicate the triplet and singlet states, respectively, and the right upside notation * indicates the excitation states.

With increasing the drive voltage to enhance electron injection to balance the number of carriers for recombination, the luminance wiu be raised. With increasing the drive voltage, the carrier mobility and the electrode leak current increase, and thus the device efficiency is gradually reduced.

We have fabricated the white organic light-emitting devices (WOLEDs) based on the phosphorescent sensitization. The structure of the device is ITO/2 T-NATA (20 nm)/ NPBX (20 nm)/ CBP: x%Ir(ppy)$_3$:0.5% rubrene (8 nm)/ NPBX(5 nm)/DPVBi(30 nm)/ Alq(30 nm)/ LiF(0.5 nm)/Al. In the devices, when the doping concentration of Ir(ppy)$_3$ is 6wt%, the maximum luminance is 24960 cd/m^2 at an applied voltage of 15 V, and the maximum luminous efficiency is 5.17 cd/A at an applied voltage of 8 V. The CIE coordinate is within a region of white color.

References

[1] H. Murata, C.D Merritt, and Z.H Kafafi. Selected Topics in Quantum Electronics, IEEE Journal of , **4** (1998), 119.

[2] Zhou X, Pfeiffer M, and Blochwitz . Appl. Phys. Lett., **78** (2001), 410.

[3] Li G, and Shinar J. Appl. Phys. Lett, **83** (2003), 5359.

[4] Gao W B, Sun J X, and Yang K X, Optical and Quantum Electronics , **35(**2003**)**, 1149.

[5] Shizuo Tokito, Toshimitsu Tsuzuki, and Fumio Sato, Current Applied Physics, **5** (2005), 331.

[6] Cheng Gang,Zhang Yingfang, and Zhao Yi, Appl. Phys. Lett., **88** (2006), 083512-1.

[7] ZHENG Jia jin , HUA Yu lin ,and YIN Shou gen Chinese Science Bulletin, **49** (2004), 2426.(in Chinese).

[8] WU Xiao-ming, HUA Yu-lin, and WANG Zhao-qi, Journal of Optoelectronics·Laser,**17** (2006),1177.(in Chinese).

[9] Tokito S, Lijima T,and Tsuzuki T, Appl Phys Lett, **83**(2003), 2459.

[10] D'Andrade B. W., Thompson M. E., and Forrest S, R,.Adv. Mater , 14(2002), 147.

[11] Li F., Cheng G., and Zhao Y., Appl. Phys. Lett., **83**(2003), 4716.

[12] Yang X. H., and Neher D., Appl. Phys. Lett., **84** (2004), 2476.

[13] Zhang Yingfang,Cheng Gang, and Zhao Yi, Appl.Phys.Lett.,, **86** (2005), 011112-1.