Journal of Physics and Chemistry of Solids 70 (2009) 765–768

Contents lists available at ScienceDirect

Journal of Physics and Chemistry of Solids

journal homepage: www.elsevier.com/locate/jpcs

The mechanism of efficiency enhancement with proper thickness of DPVBi layer for blue organic light-emitting devices (BOLED)

Chien-Jung Huang [a,*], Teen-Hang Meen [b], Kuo-Chien Liao [c], Yan-Kuin Su [c,d]

[a] Department of Applied Physics, National University of Kaohsiung, #700 Kaohsiung University Road, Nanzih, Kaohsiung 811, Taiwan
[b] Department of Electronic Engineering, National Formosa University, 64, Wen-Hwa Road, Hu-Wei, Yunlin 632, Taiwan
[c] Institute of Electro-Optical Engineering, National Sun Yat-Sen University, #70 Lien-hai Road, Kaohsiung 804, Taiwan
[d] Institute of Microelectronics and Department of Electrical Engineering, National Cheng Kung University, Tainan 701, Taiwan

ARTICLE INFO

Article history:
Received 7 December 2008
Received in revised form
12 February 2009
Accepted 26 March 2009

Keywords:
A. Thin film
D. Luminescence

ABSTRACT

We report on the fabrication of blue organic light-emitting devices (BOLEDs) with structure: ITO/NPB/DPVBi/Alq_3/LiF/Al. The hole-blocking effect in NPB/DPVBi interface was indirectly demonstrated and deduced by inserting DCJTB layer. In addition, the effect of the device with better *J–V* characteristics because of the extra DCJTB layer is discussed as well. However, the performance of devices was investigated with various thicknesses of DPVBi layer. The result shows that the device with proper thickness of DPVBi layer generating better electron injection enhances efficiency and luminance for BOLED.

1. Introduction

It is widely known that hole mobility in hole-transporting layer (HTL) is higher than electron mobility in electron-transporting layer (ETL). Unbalanced charge carriers result in lower efficiency of organic light-emitting devices (OLEDs). Thus, it is important to balance charge carriers [1,2]. In general, a buffer layer is inserted between the indium-tin oxide (ITO) and the organic layer, enhancing the efficiency of OLED [3–5]. In addition, hole-blocking layer (HBL) in emission layer (EL)/ETL interface is usually used to confine holes. It is believed that HBL with lower highest occupied molecule orbital (HOMO) value is beneficial to block holes effectively. HBL materials, for example 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP; 6.7 eV) [6–9] and 4,7-diphenyl-1,10-phenanthroline (BPhen; 6.4 eV) [10,11], are with lower HOMO values, resulting in excitons being confined in EL to improve color purity.

To realize charge carriers distribution and generated excitons information are important for obtaining optimal OLED. Besides, choosing proper thickness of organic layer is crucial to balance charge carriers [12,13]. Towards this goal, a series of data are generated for particular purposes in our experiment, including current density–voltage (*J–V*) characteristics with changing thicknesses of organic layer, the study of hole-blocking effect by inserting a red organic material, and the variations for the balance of charge carriers with various thicknesses of organic layer. In this study, a BOLED has been fabricated with a structure: indium-tin oxide/N,N′-diphenyl-N,N′-(2-napthyl)-(1,1′-phenyl)-4,4′-diamine (NPB)/4,4-Bis(2,2-diphenyl-ethen-1-yl)-biphenyl (DPVBi)/tris (8-quinolinolato) aluminum (Alq_3)/lithium fluorine (LiF)/aluminum (Al). Although there is no ordinary material of HBL in our structure, the hole-blocking effect still exists in NPB/DPVBi interface of device. Thus, a thin 4-(Dicyanomethylene)-2-tert-butyl-6-(1,1,7,7-tetramethyljulolidin-4-yl-vinyl)-4H-pyran(DCJTB) layer is inserted in NPB/DPVBi interface to prove that hole-blocking effect occurs in NPB/DPVBi interface. Optimal OLED with high efficiency is generated by tuning proper thickness of DPVBi layer. However, the mechanism of hole blocking in NPB/DPVBi interface and the effect of electron injection with various thicknesses of DPVBi layer are demonstrated and discussed.

2. Experimental

The device structure was fabricated as follows: ITO/NPB/DPVBi/Alq_3/LiF/Al. All the organic layers were deposited by thermal evaporation onto the ITO coated glass substrate in a vacuum chamber ($<10^{-6}$ Torr). The sheet resistance of ITO is about 50 Ω/□. The deposition rate and thicknesses of evaporated layers were monitored by an oscillating quartz thickness monitor (Sigma, SID-142). The deposition rates were about 0.5~1.5 Å/s for organic layers and 2 Å/s for Al. Commission International de l'Eclairage (CIE) coordinates, electroluminescence (EL) spectra and luminance, were measured by the photospectrometer (Kollmorgen Instrument PR655; USA) and the current–voltage characteristics

* Corresponding author. Fax: +886 7 5919357.
E-mail address: chien@nuk.edu.tw (C.-J. Huang).

0022-3697/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jpcs.2009.03.010

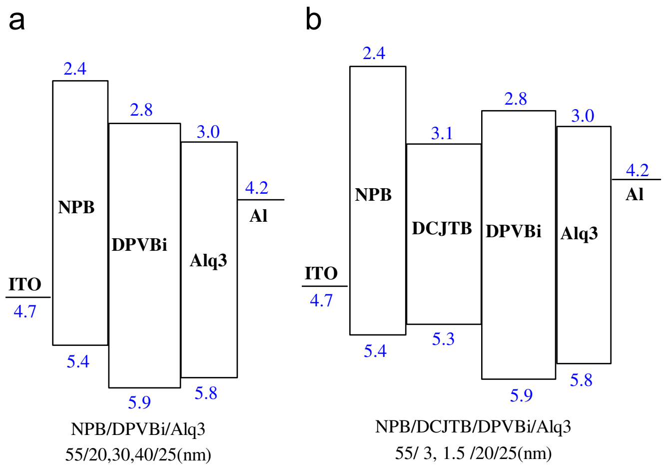

Fig. 1. (a) The energy level diagram of devices 1–3 for the structure of NPB/DPVBi/Alq_3 and (b) the energy level diagram of devices 4–5 for the structure of NPB/DCJTB/DPVBi/Alq_3.

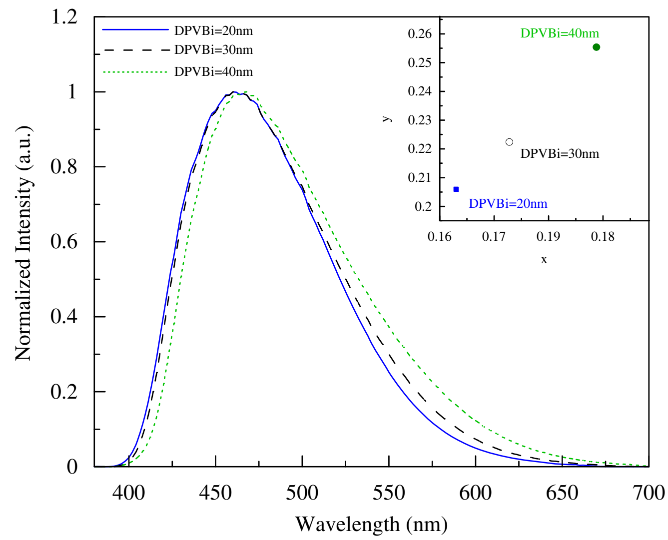

Fig. 2. The normalized EL spectra of devices with structure: ITO/NPB (55 nm)/DPVBi (20, 30, 40 nm)/Alq_3 (25 nm)/LiF (0.5 nm)/Al at 15 V. Inset, CIE coordinates of devices with different thickness of DPVBi (20/30/40 nm) at 15 V.

were simultaneously measured by the programmable power source (Keithley SourceMeter 2400; USA), controlled using computer software (Chief I-V-L system; Taiwan). All measurements were carried out at room temperature under ambient. The structure of this device was: ITO/NPB(550 Å)/DPVBi (x nm)/Alq_3(250 Å)/LiF(5 Å)/Al, where $x = 20$, 30 and 40, and the corresponding devices are named 1, 2 and 3. In order to demonstrate the mechanism for hole in NPB/DPVBi interface of OLED, device 4 and device 5 were presented. The structure of this device was: ITO/NPB (550 Å)/DCJTB (y nm)/DPVBi (20 Å)/Alq_3 (250 Å)/LiF (5 Å)/Al, where $y = 3$ nm and 1.5 nm, and corresponding devices are named 4 and 5, respectively. The schematic energy band diagram of devices 4 and 5 are shown in Fig. 1(b). In our devices, NPB is used as a hole transport layer; DPVBi and Alq_3 layers are used as blue-emitting and electron-transport layers, respectively. LiF is used as an electron injecting layer, and Al as cathode electrode. DCJTB was selected as red-emitting layer; moreover, it demonstrated indirectly that the mechanism for hole in NPB/DPVBi interface.

3. Results and discussions

The energy level diagram of the devices 1–3 are shown in Fig. 1(a). There is a band-gap (0.5 eV) for hole in the NPB/DPVBi interface, so some holes were blocked in this interface. As electrons were injected into the DPVBi layer, electrons continuously pass through the DPVBi layer without recombining with holes and then move into NPB layer. Thus, the DCJTB layer is inserted in between the NPB layer and DPVBi layer to prove whether the hole is blocked in the NPB/DPVBi interface or not. The energy level diagram of the devices 4–5 are shown in Fig. 1(b). Fig. 2 shows the performance of devices 1–3 with various DPVBi thicknesses. It can be seen in Fig. 2 that color-mixing phenomenon of devices 1–3 is composed of blue and green emission because the spectrum has a broad peak. Furthermore, we could see that the EL spectra of devices 1 and 2 are almost the same (EL peak: 460 nm of devices 1 and 2). The EL spectrum of device 3 has a little red shift compared with device 1 (EL peak: 468 nm of device 3). That is to say, the difference in EL peak between device 1 and 3 is 8 nm. It can be seen that the green Alq_3 emission increased with increasing DPVBi thickness. In other words, the blue emission increases as DPVBi thickness decreases. It is observed that the CIE coordinates shifted significantly with different DPVBi thickness. The CIE coordinates were gradually close to blue region with

Table 1
Comparisons of devices 1–3.

	Max current efficiency (cd/A)	CIE coordinates (x, y) for max current efficiency	Max luminance (cd/m^2)	CIE coordinates (x, y) for max luminance
Device 1	4.16 at 10 V	(0.162, 0.208)	3938 at 16 V	(0.163, 0.204)
Device 2	2.62 at 10 V	(0.171, 0.225)	3752 at 16 V	(0.174, 0.222)
Device 3	1.66 at 10 V	(0.189, 0.257)	1297 at 16 V	(0.189, 0.252)

decreasing DPVBi thickness. This is due to the fact that more electrons move across the DPVBi layer and recombined with holes blocked in the NPB/DPVBi interface, i.e., more excitons are generated in the NPB/DPVBi interface with much blue emission. Thus, CIE coordinates of device 1 were close to blue region as compared with other devices, as shown in the inset of Fig. 2. For device 3 with the thickest DPVBi layer, electrons scarcely passed through DPVBi layer and hardly recombined with holes blocked in the NPB/DPVBi interface. EL spectrum with red shift of device 3 could be attributed to few excitons generated in the NPB/DPVBi interface. These results are summarized in Table 1. The current efficiency of devices 1–3 is 4.16, 2.62 and 1.66 cd/A at 10 V, respectively. The luminance of devices 1–3 is 3938, 3752 and 1297 cd/m^2 at 16 V, respectively. It is obvious that the device with a 20 nm DPVBi layer has the highest current efficiency and luminance. In addition, the current efficiency and luminance of devices increase with decreasing DPVBi layer. Fig. 3 shows EL spectrum and CIE coordinates of device 1 at various voltages. The EL spectrum of device 1 at 15 V has slight blue shift as compared with device 1 at 12 V (EL peak: 462 nm at 12 V, 460 nm at 15 V). The variation is usually attributed to the change of recombination zone with different applied voltages. There is a band-gap (0.2 eV) in Fig. 1(a) for electron injection in DPVBi/Alq_3 interface, thus few electrons were blocked in the interface. With higher applied voltage, electrons were easily injected into the DPVBi layer and recombined with holes in DPVBi layer to generate blue emission. Therefore, slight blue shift occurred with higher applied voltage.