F-6-04 (Late News)

Highly efficient deep-blue OLED with a novel carbazole based fluorescent emitter

Snehasis Sahoo,[1] Meenu Singh,[1] Vellaichamy Joseph,[2] K. R. Justin Thomas,[2] Jwo-Huei Jou,[1]*
[1]Department of Materials Science and Engineering, National Tsing-Hua University, Hsin-Chu, Taiwan, 30013, ROC
[2]Organic Materials Laboratory, Department of Chemistry, Indian Institute of Technology Roorkee, Roorkee, India
Corresponding author: jjou@mx.nthu.edu.tw

Abstract

We demonstrate here a highly efficient deep-blue OLED using a carbazole based fluorescent emitter. At 100 cd m^{-2}, the resultant device shows an external quantum efficiency of 4.1% with CIE coordinates (0.15, 0.06). The high efficiency may be attributed to the suitable device architecture facilitating balanced carrier injection and low doping concentration preventing concentration quenching.

1. Introduction

A highly efficient deep-blue emitter with wet-process feasibility is important to realize low cost, roll-to-roll fabrication of large area and high performance white organic light emitting diodes (OLEDs). To fabricate energy-saving and long-lifetime full color displays, the primary chromaticity components, red, green, and blue emitters are required to be highly efficient. In the past years, high-efficiency red and green OLEDs with excellent color purity had already been reported[1], while deep-blue OLEDs still suffer from poor carrier injection into the emitting layer due to their intrinsically wide bandgap[2]. Consequently, an appropriate emitter with a reasonably high efficiency is yet to be developed. In addition, such emitters can successfully reduce the power consumption of an OLED device and can be used to generate emission of other colors by energy cascade to a suitable emissive dopant[3]. Therefore, continuous efforts have been devoted to the design and synthesis of high performance deep-blue emitters.

The development of deep-blue emitters is critical because it can significantly enhance the gamut area and enable high color saturation in full color displays[4]. Deep-blue color is determined as the EL emission with a Commission International de L'Eclairage (CIE) coordinate of $y < 0.08$[5]. Fluorescent emitters can realize deep-blue emission, while phosphorescent ones can only, to the moment, generate blue or sky-blue emission, but with higher efficiency[6,7]. Thermally activated delayed fluorescence (TADF) emitters can exhibit deep-blue emission with reasonably high device efficiencies[8]. However, fluorescent emitters can generate even deeper blue emission with a CIEy as low as 0.04[9], resulting in higher color saturation than that of TADF counterparts. Moreover, fluorescent emitters exhibit higher device efficiency than TADF especially at elevated brightness[9]. It is hence worthy to devise new fluorescent emitters to achieve deeper blue emission with higher efficiency.

2. Device fabrication:

Fig. 1 shows all the studied OLED device structures and their corresponding energy levels. The devices are composed of a 125 nm indium tin oxide (ITO) anode layer, followed by a 35 nm poly(3,4-ethylene-dioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS) hole injection layer (HIL), a 20 nm single emissive layer (EML) with the deep-blue emitter, JV234 doped in 4,4′-bis(N-carbazolyl)-1,1′-biphenyl (CBP) host via spin-coating, a 32 nm 1,3,5-tris(N-phenyl-benzimidazol-2-yl)benzene (TPBi) electron transporting layer (ETL), a 1 nm lithium fluoride (LiF) layer, and a 100 nm aluminum (Al) cathode layer. Besides the CBP host, two other hosts, 2,7-bis(carbazol-9-yl)-9,9-ditolylfluorene (Spiro-2CBP) and 4,4′,4″-tri(N-carbazolyl)triphenylamine (TCTA) are also studied herein.

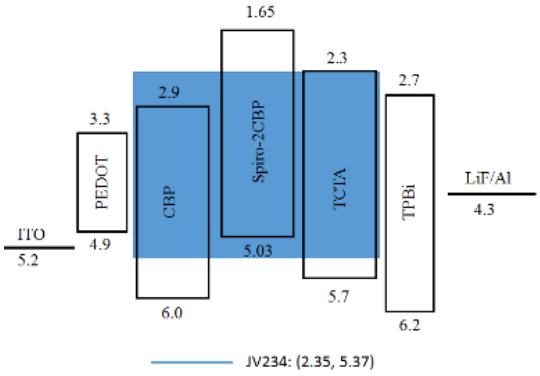

Fig. 1. Schematic diagram of the energy levels of the OLED devices containing the blue emitter JV234 with three different hosts: CBP, Spiro-2CBP and TCTA.

3. Results and discussion:

We demonstrate here a highly efficient deep-blue organic light emitting diode using a carbazole based fluorescent emitter, JV234. When doped in CBP, the resultant device shows a deep-blue emission of CIE (0.15, 0.06) with an external quantum efficiency (EQE) of 4.1% at 100 cd m-2. Besides, it shows an EQE of 3.0 % with a CIE (0.16, 0.07) while doped in Spiro-2CBP and an EQE of 1.5% and a CIE (0.16, 0.08) with the host TCTA. The emitter's behavior with different hosts can be explained in following ways.

Figure 1 demonstrates that, CBP host in the device structure possesses the most favorable electron injection pathway from TPBi (electron transport layer) with a -0.2 eV electron trap. Whereas, it is 1.05 and 0.4 eV for Spiro-2CBP and TCTA, respectively. The electron trapping character would hence facilitate higher amount of excitons generation on the CBP host comparing with other two hosts, resulting in higher device efficiency for the CBP based OLED device. In the TCTA based device, JV234 emitter and TCTA host have almost similar LUMO energy barrier to TPBi. However, holes will favorably travel form PEDOT:PSS (hole injection layer) to the emitter due to having 0.35 eV less hole transport barrier than that of the TCTA host. Therefore, most of the recombination will occur in emitter, resulting in very less device efficiency.

Fig. 2(a) shows EL spectra of the devices containing 3 wt% emitter in the CBP, Spiro-2CBP and TCTA hosts. The peaks of EL spectra prove the emission from all the devices are in deep-blue region. However, the emission spectrum becomes broader as the spectra moves from CBP to Spiro-2CBP and TCTA based devices. CBP shows narrowest FWHM of 58.3, while the respective values for Spiro-2CBP and TCTA are 58.9 and 61.8. This shows deep-blue emission from the resultant CBP based device is of highest color purity resulting in very high color saturation.

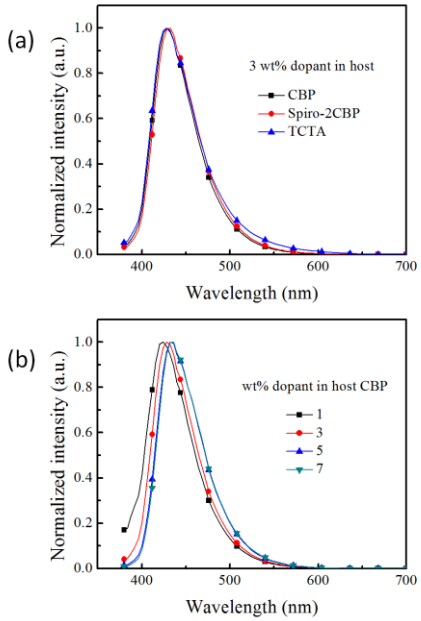

Fig. 2. (a) Host and (b) concentration effects on the electroluminescence (EL) spectra of the devices containing the deep blue emitter, JV234.

Fig. 2(b) indicates the reason why the resulting device shows an extremely marked blue shift, which may be attributed to the effective emitter dispersion. The employed host can be utilized to disperse the dopant to prevent the bathochromic-shift caused by emitter aggregation. The dispersion is more effective when the dopant is more diluted[10], as indicated by the main emission peak which is blue-shifted from 436 nm to 424 nm as the concentration of the JV234 emitter is diluted from 7 to 1 wt%.

4. Conclusion:

To conclude, we demonstrate in this report the electroluminescence behavior of a carbazole based deep-blue emitter, JV234, with wet-process feasibility. By employing the highly electroluminescence-active dopant in the CBP host, deep-blue OLEDs with high device efficiency with high color purity have been realized. The reported deep-blue dye can be a promising candidate in realizing high-quality displays and solid state lighting, coupled with the energy-saving character via the wet-process.

Acknowledgements:

The authors would like to acknowledge the support from the Energy Fund of Ministry of Economics Affairs and Ministry of Science and Technology, Taiwan. This work was financially supported in part by Grants MEA 104-EC-17-A-07-S3-012, MOST 105-2119- M-007- 012.

References:

[1] S. Lee, K.-H. Kim, D. Limbach, Y.-S. Park and J.-J. Kim, Adv. Funct. Mater., 23, 4105, 2013.

[2] A. W. Grice, D. D. C. Bradley, M. T. Bernius, M. Inbasekaran, W. W. Wu and E. P. Woo, Appl. Phys. Lett., 1998, 73, 629.

[3] M. T. Lee, C. H. Liao, C. H. Tsai, and C. H. Chen, Adv. Mater., 2005, 17, 2493–2497.

[4] M. T. Lee, H. H. Chen, C.H. Liao, C. H. Tsai and C. H. Chen, Appl. Phys. Lett., 2004, 85, 3301.

[5] Y. Yu, Z. Wu, Z. Li, B. Jiao, L. Li, L. Ma, D. Wang, G. Zhou and X. Hou, J. Mater. Chem. C, 2013, 1, 8117.

[6] D. Kumar, K. R. J. Thomas, C.-C. Lin and J.-H. Jou, Chem. Asian J., 2013, 8, 2111.

[7] S. O. Jeon, S. E. Jang, H. S. Son and J. Y. Lee, Adv. Mater., 2011, 23, 1436.

[8] Q. Zhang, J. Li, K. Shizu, S. Huang, S. Hirata, H. Miyazaki and C. Adachi, J. Am. Chem. Soc., 2012, 134, 14706.

[9] J. H. Jou, S. Kumar, P. H. Fang, A. Venkateswararao, K. R. J. Thomas, J. J. Shyue, Y. C. Wang, T. H. Lia and H. H. Yu, J. Mater. Chem. C, 2015, 3, 2182.

[10] V. Bulovic, R. Deshpande, M. E. Thompson and S. R. Forrest, Chem. Phys. Lett., 1999, 308, 317.