Efficient blue phosphorescent organic light-emitting diode with long triplet lifetime TADF host

Tien-Lung Chiu[1], Tse-Ying Chen[2], Yi-May Huang[3], Man-Kit Leung[3], Jiun-Haw Lee[4], Yu-Cheng Chiu[2]

[1]Department of Electrical Engineering, Yuan Ze University, Taiwan
[2]Graduate Institute of Chemical Engineering, National Taiwan University of Science and Technology, Taiwan
[3]Department of Chemistry, Institute of Polymer Science and Engineering, National Taiwan University, Taiwan
[4]Graduate Institute of Photonics and Optoelectronics and Department of Electrical Engineering, National Taiwan University, Taiwan
*Email: ycchiu@mail.ntust.edu.tw

Abstract

A new wide bandgap material, CbzBzCN, was successfully synthesized to be the host of an efficient blue phosphorescent light emitting diode (OLED), which also particularly performs a very long lifetime of triplet excitons reach approximate 2 msec. The OLED showed the maximum current efficiency and external quantum efficiency of 46.3 cd/A and 18.7%, respectively.

1. Introduction

Currently, organic light emitting diodes (OLEDs) have widely applied for the display and lighting industries, such as Samsung and Apple mobile phones and LG lighting panels, etc. Hence, the new organic materials for the improved properties are also the urgent demand for these industries. Right now, some high efficiency emission mechanism for the blue OLED are still caught the attentions, e.g. phosphorescence and thermal activated delay florescent (TADF) [1,2,3].

In this study, a new derivative was synthesized conjugating the carbazoles, benzene, cyano to be a wide band gap (3.0 eV) host, CbzBzCN. In addition, this CbzBzCN also possess a TADF behavior due to the high triplet energy of 2.82 eV. Particularly, in room temperature, the singlet energy easily transfers to the triplet energy through intersystem crossing. Hence, we doped a sky-blue phosphorescent emitter Bis[2-(4,6-difluorophenyl)pyridinato-C2,N] (picolinato)Iridium(III) (FIrpic) to energy transfer the triplet excitons to be the photons. Preliminarily, the OLED showed the maximum current efficiency (CE_{max}) and external quantum efficiency (EQE_{max}) of 46.3 cd/A and 18.7%, respectively.

2. Experiment

Here, the device structure was ITO/ di-[4-(N,N-di-p-tolyl-amino)-phenyl]cyclohexane (TAPC, 50 nm)/ 1,3-bis (N-carbazolyl)benzene (mCP, 10 nm)/ CbzBzCN: 0% and 15% FIrpic (30 nm)/ 3,3'-[(diphenylsilylene)di-4,1-phenylene]bispyridine (DPPS, 50 nm)/ LiF/ Al, which ITO was cleaned by O_2 plasma to raised its workfunction as anode, TAPC and mCP as hole transporting layer, CbzBzCN as host, FIrpic as emitter, DPPS as electron transporting layer, LiF as electron injection layer, and Al as cathode. Their highest occupied molecular orbital (HOMO) and lowest unoccupied molecular (LUMO) were in sequence 5.8, 5.9, 5.84, 5.7, 6.5 eV and 1.8, 2.4, 2.46, 3.1, 2.5 eV, respectively. These thin films were deposited by a thermal evaporator under ultrahigh vacuum

over 8×10^{-6} torr.

The device brightness-current-voltage (BIV) performances were measured using a system with a spectrometer (Minolta CS1000) and a multisource meter (Keithley 2400). In addition, the transient electroluminescence (TrEL) signal measurement was detected using a function generator (Agilent 33500B), a photomultiplier tube (Hamamatsu H6780-20) and an oscilloscope (Tektronix TDS2004C).

.

3. Result and discussion

Without FIrpic dopant, a pristine OLED with pure CbzBzCN emitting layer shows low CE_{max} and EQE_{max} of 5.4 cd/A and 2.2%. The emission peak was located at approximately 443 nm. The emission mechanism of this pristine OLED was belong to TADF behavior because there a slow decay in TrEL signal as shown in Fig. 1. In particular, this decay time implied that the lifetime of triplet excitons was very long to reach almost 2 msec. The energy was stored in triplet states and then transferred to the singlet state for quite a while through reverse intersystem crossing.

Hence, it can be forecasted that the efficient phosphorescence OLED is easily realized after the FIrpic emitters were doped into the emitting layer to efficiently energy transfer the triplet energy from CbzBzCN host to FIrpic emitter. With 15% FIrpic doping ratio in the emitting layer, the BIV performance of OLED are shown in Fig. 2. Fig. 2(a) describes the curves of current density versus voltage and luminance versus voltage. The driving voltage at 20 mA/cm^2 and 1000 cd/m^2 was 7.7 and 5.6 V, respectively. Fig. 2(b) exhibits the curves of efficiency versus current density. The CE_{max} and EQE_{max} are 46.3 cd/A and 18.7%, respectively. These preliminary results provide the evidence that energy transfer in triplet states did happen between CbzBzCN host and FIrpic emitter. The exciton lifetime in the TrEL signal of this OLED shorten to about 60 μsec as shown in Fig. 3.

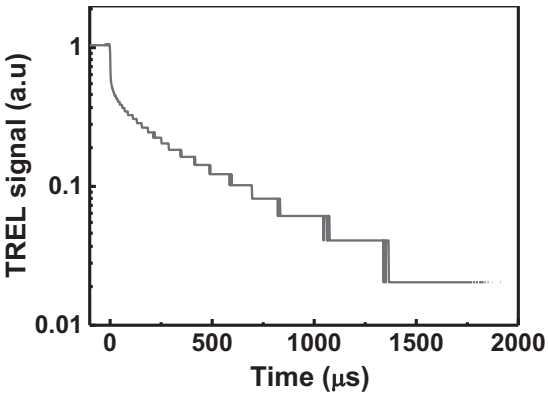

Figure 1. TrEL signal of pristine OLED with pure CbzBzCN in emitting layer.

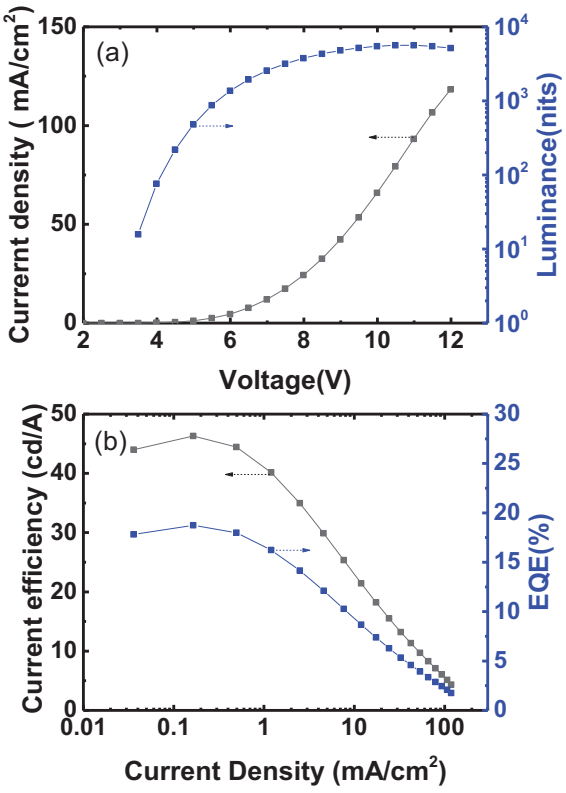

Figure 2. (a) current density and luminance versus voltage, (b) current efficient and external quantum efficiency versus current density of OLED with FIrpic emitter.

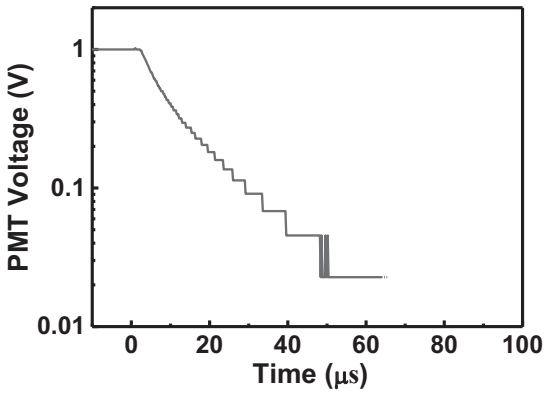

Figure 3. TrEL signal of OLED with FIrpic emitter and CbzBzCN host in emitting layer.

4. Conclusion

A TADF and wide bandgap material, CbzBzCN, was successfully demonstrated to be the host for an efficient blue phosphorescent light emitting diode (OLED) with FIrpic emitter. The OLED showed the maximum current efficiency and external quantum efficiency of 46.3 cd/A and 18.7%, respectively. In particular, the CbzBzCN material performed a very long lifetime of triplet excitons reach approximate 2 msec.

Acknowledgements

This work was supported by the Ministry of Science and Technology (MOST), Taiwan, under Grants MOST 105-2221-E-002-130-MY3, 106-2923-E-002-004-MY3, 107-2221-E-002-156-MY3,107-2221-E-155-027, 107-3113-E-155-001-CC2, 106-2221-E-155-036,106-3113-E-155-001-CC2, 106-2221-E-239-020, 107-2221-E-239-020-MY2, 107-2221-E-155-058-MY3, 106-2923-E-155-002-MY3, 107-3017-F-002-001, 107-2113-M002-020-MY3, 108-2221-E-155-051-MY3, and Ministry of Education, Taiwan (107L9006).

Reference

1. Jiun-Haw Lee, Chia-Hsun Chen, Pei-Hsi Lee, Hung-Yi Lin, Man-kit Leung, Tien-Lung Chiu, and Chi-Feng Lin, J. Mater. Chem. C, 7, 5874-5888 (April 2019).
2. Yi-Ting Lee, Po-Chen Tseng, Takeshi Komino, Masashi Mamada, Ruby Janet Ortiz, Man-Kit Leung, Tien-Lung Chiu, Chi-Feng Lin, Jiun-Haw Lee, Chihaya Adachi, Chao-Tsen Chen, and Chin-Ti Chen, ACS Appl. Mater. Interfaces, 10 (50), pp 43842–43849 (Dec. 2018).
3. Shu-yun Chang, Guan-Ting Lin, Yu-Chieh Cheng, Jau-Jiun Huang, Chiou-Ling Chang, Chi-Feng Lin, Jiun-Haw Lee, Tien-Lung Chiu, and Man-Kit Leung*, ACS Appl. Mater. Interfaces, 10 (49), pp 42723–42732 (Dec. 2018).