

## High Efficiency Blue TADF OLED with EQE of 35.8%

Yi-Zhen Li<sup>1</sup>, Hsuan-Chi Liang<sup>1</sup>, Chia-Hsun Chen<sup>1,2</sup>, Ching-Huang Chiu<sup>2</sup>, Lian-Chun Huang<sup>2</sup>, Kuan-Wei Chen<sup>2</sup>, Yi-Ting Lee<sup>3</sup>, Yi-Chung Dzung<sup>4</sup>, Chi Chen<sup>4</sup>, Bo-Yen Lin<sup>5</sup>, Jiun-Haw Lee<sup>2</sup>, Tien-Lung Chiu<sup>6,\*</sup>, Man-kit Leung<sup>1,7</sup>

<sup>1</sup>Department of Chemistry, National Taiwan University, Taipei, Taiwan

<sup>2</sup>Graduate Institute of Photonics and Optoelectronics and Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan

<sup>3</sup>Department of Chemistry, Soochow University, Taipei, Taiwan

<sup>4</sup>Research Center for Applied Sciences, Academia Sinica, Taipei, Taiwan

<sup>5</sup>Department of Opto-Electronic Engineering, National Dong Hwa University, Hualien, Taiwan

<sup>6</sup>Department of Electrical Engineering, Yuan Ze University, Chungli, Taoyuan, Taiwan

<sup>7</sup>Advanced Research Center for Green Materials Science and Technology, National Taiwan University, Taipei, Taiwan

\*e-mail: [tlchiu@saturn.yzu.edu.tw](mailto:tlchiu@saturn.yzu.edu.tw)

### Abstract

Blue TADF OLED with EQE= 35.8% and CIE= (0.14, 0.25) was demonstrated by using 4TCzBN emitter in a host consisting of electron donor and acceptor moieties which showed high PLQY= 98.6% and high light extraction ratio of 36.3%.

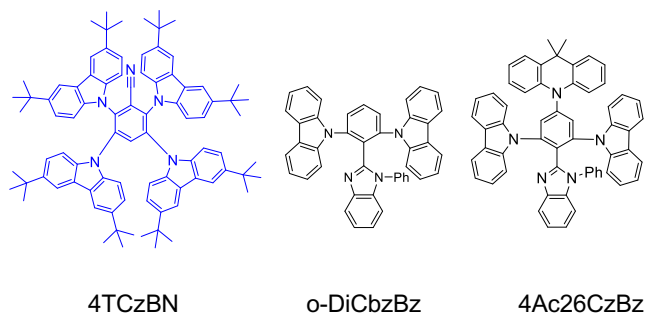
### Keywords

blue TADF OLED, high efficiency, molecular packing

### Introduction

Using thermally activated delayed fluorescence (TADF) emitter in an organic light-emitting diode (OLED) has attracted lots of attentions due to the advantages of fully utilization of triplet excitons for light emission, no heavy atoms, and flexible molecular design [1]. A TADF molecule consists of electron donor and acceptor units to reduce the energy difference between singlet and triplet state and hence triplet exciton can be upconverted to singlet for light emission through reverse intersystem crossing (RISC) process. By using carbazole and cyano moieties as the electron donor and acceptor units, respectively, and centered with a phenyl ring, different donor/acceptor configurations showed the capability to tune the emission wavelength of TADF molecules from blue to red region [1]. Fig. 1 shows the molecular structure of 2,3,5,6-tetrakis(3,6-di-*tert*-butyl-9*H*-carbazol-9-yl)benzotrile (4TCzBN), which is a blue TADF emitter, consisting of four carbazole and one cyano units centered with a phenyl ring. *Tert*-butyl substituents were introduced to the carbazoles for reducing concentration quenching and increasing the operation lifetime. However, maximum external quantum efficiency (EQE) of blue TADF OLED with 4TCzBN emitter was less than 25%, because of no appropriate host material [2]. Typically, requirements of host material for a wide-bandgap blue TADF emitter include: (1) high triplet energy to avoid back energy transfer from dopant to host, (2) large spectral overlap between host emission and dopant absorption for high photoluminescence quantum yield (PLQY), (3) suitable highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) for efficient carrier transport and recombination, (4) high carrier mobilities to reduce

driving voltage, and (5) suitable molecular packing to improve light extraction.



**Figure 1** Molecular structures of blue TADF dopant, 4TCzBN, and two hosts, o-DiCbzBz and 4Ac26CzBz.

In this paper, we have demonstrated two bipolar host materials based on molecular configuration similar to 4TCzBN, which is electron donor and acceptor units centered with a phenyl ring, for improving EQE of blue TADF-OLED based on 4TCzBN emitter. For the first material, o-DiCbzBz, as shown in Fig. 1, benzimidazole (which is a weaker acceptor unit compared to cyano unit) was introduced between two carbazole units connected to the meta position of phenyl ring [3]. Maximum EQE of blue TADF-OLED based on 4TCzBN doped in o-DiCbzBz as the emitting layer (EML) achieved 32.5%. For the second molecule, 4Ac26CzBz, one more acridian moiety (which served as a stronger donor compared to carbazole) was introduced, as shown in Fig. 1. Blue OLED based on 4TCzBN: 4Ac26CzBz was as high as 35.8%, which is also the highest EQE value, to our best knowledge, based on 4TCzBN emitter [4].

### Experiments

In our OLED fabrication, patterned indium-tin-oxide (ITO) on the glass substrate was used as the transparent anode. Oxygen plasma was employed on the glass substrate to clean the surface and improve the workfunction of ITO. Encapsulation process was done

in a nitrogen glove box after thin film deposition with another cover glass substrate and UV sealant. Device structure of the OLEDs was: ITO/ TAPC (50 nm)/ mCP (10 nm)/ EML (30 nm)/ DPPS (55 nm)/ LiF (1 nm)/ Al (100 nm). Here, TAPC, mCP, and DPPS were abbreviations of cyclohexylidenebis[N,N-bis(4-methylphenyl)benzenamine], N, N-dicarbazolyl-3, 5-benzene, and diphenylbis(4-(pyridin-3-yl) phenyl)silane, respectively, which served as the hole transporting layer (HTL), exciton blocking layer (EBL), and electron transporting layer (ETL) materials. LiF and Al were electron injection layer (EIL) material and cathode, respectively. EML consists of 40% of 4TCzBN in o-DiCbzBz and 4Ac26CzBz. Luminance, current density and voltage (L-J-V) characteristics were obtained through Keithley 2400 source meter and Minolta CS-1000 spectrometer. Angular-dependent photoluminescence and grazing-incident wide-angle x-ray scattering (GIWAXS) were used to understand the molecular packing in the EML.

### Result

Fig. 2 shows the absorption and emission spectra of o-DiCbzBz and 4Ac26CzBz thin films, while Table 1 summarizes important characteristics. Consisting of two weak electron donor and one weak electron acceptor, carbazole and benzimidazole units, respectively, o-DiCbzBz exhibited high singlet and triplet energy (3.5 and 3.1 eV, respectively) which can be used as the host of blue phosphorescent OLED [3]. For 4Ac26CzBz, singlet and triplet energy were reduced 3.2 and 3.0 eV with introduction of one more acridian unit, which resulted in better spectral overlap between host emission and dopant absorption for higher photoluminescence quantum yield (PLQY) from 93.1% to 98.6%.

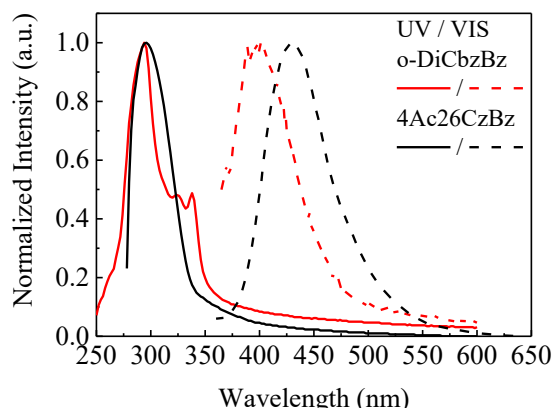


Figure 2 UV-vis spectra of o-DiCbzBz and 4Ac26CzBz thin films.

Table 1 Photophysical properties of o-DiCbzBz and 4Ac26CzBz thin films.

	$\lambda_{\text{onset}}^{\text{abs}}$ [nm]	$\lambda_{\text{onset}}^{\text{FL}}$ [nm]	$S_1$ [eV]	$T_1$ [eV]	HOMO [eV]	LUMO [eV]	PLQY (%)
o-DiCbzBz	354	341	3.5	3.1	-5.8	-2.2	93.1
4Ac26CzBz	340	382	3.2	3.0	-5.4	-2.4	98.6

Fig. 3 (a) shows the current density and luminance with different driving voltage of blue TADF-OLED by using o-DiCbzBz and 4Ac26CzBz hosts doped with 4TCzBN. Current density of both OLEDs were similar. Table 2 is the summary of

important device performances for blue TADF OLED. As shown in Fig. 3 (b), (c), and (d), current efficiency, power efficiency, and EQE of 4Ac26CzBz-based OLED all showed superior performances than o-DiCbzBz one. The maximum EQE of blue TADF OLEDs with 4Ac26CzBz and o-DiCbzBz hosts achieved 35.8% and 32.5%, respectively, which are the highest value based on 4TCzBN-emitter. Fig. 3 (e) shows the electroluminescence (EL) spectra, which shows typical 4TCzBN emission with the CIE coordinates of (0.14, 0.25) and (0.14, 0.23) for 4Ac26CzBz and o-DiCbzBz based OLEDs, respectively.

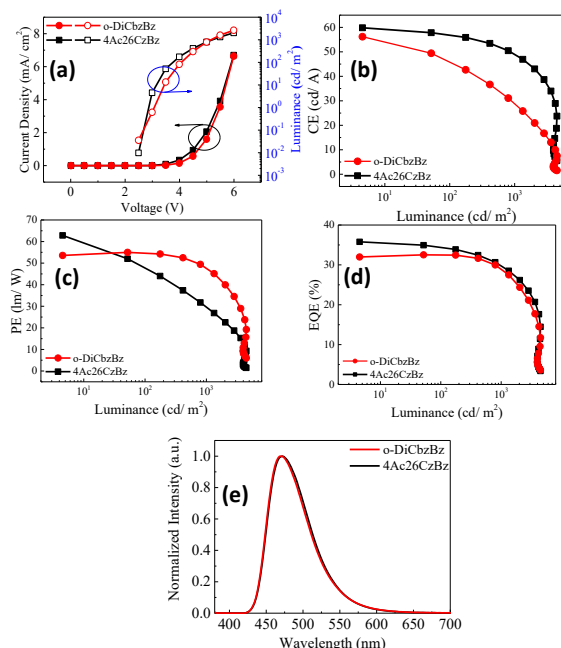


Figure 3 Device performances of blue TADF-OLED with o-DiCbzBz and 4Ac26CzBz hosts: (a) current density (J)-luminance (L)-voltage (V) curve, (b) CE, (c) PE, and (d) EQE (%) - versus different luminances, and (e) normalized EL spectra.

Table 2 EL performance of blue TADF OLED with o-DiCbzBz and 4Ac26CzBz hosts.

	Voltage@1 cd/m <sup>2</sup> [V]	CE <sub>max</sub> (cd/A)	PE <sub>max</sub> (lm/W)	EQE <sub>max</sub> (%)	CIE	Horizontal dipole ratio (%)
o-DiCbzBz	3.0	49.4	55.0	32.5	(0.14, 0.23)	81
4Ac26CzBz	2.9	59.8	62.8	35.8	(0.14, 0.25)	88

EQE of an OLED can be described by

$$\eta_{EQE} = \chi \times \gamma \times \Phi \times \eta_{LE} \quad (1)$$

where  $\eta_{EQE}$ ,  $\eta_{LE}$ ,  $\chi$ ,  $\gamma$ , and  $\Phi$  PLQY are EQE value, light extraction efficiency, exciton utilization ratio, charge recombination efficiency, and PLQY, respectively. In a TADF OLED, exciton utilization ratio is 100%. And the device was optimized for 100% recombination efficiency. As shown in Table 1, PLQY of the EML was as high as 93.1% and 98.6% For understanding the light extraction efficiency, ADPL and GIWAXS were performed to study the horizontal dipole of the EML and the molecular packing of host materials. As shown in Fig. 4 (a) and (b), horizontal dipole ratio of the thin films of o-DiCbzBz and 4Ac26CzBz doped with 4TCzBN achieved 81% and 88%, respectively. GIWAXS

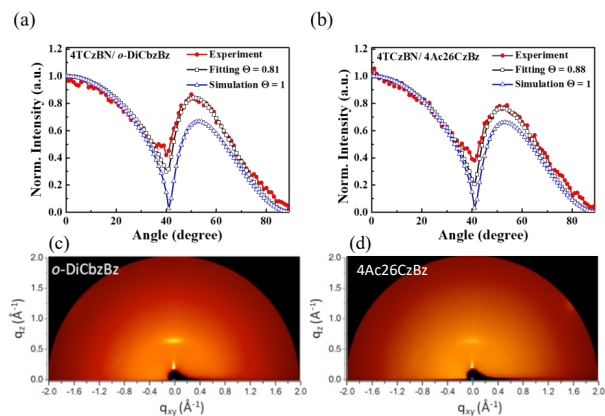
measurement also demonstrated that *o*-DiCzBz and 4Ac26CzBz formed crystallized packing which contributed to the light extraction ratio of 34.9% and 36.3%, respectively, accounting for the high EQE of 32.5%, 35.8%, for TADF OLED based on *o*-DiCzBz and 4Ac26CzBz hosts.

### Impact

Two organic materials, *o*-DiCzBz and 4Ac26CzBz, were used as the hosts in a TADF-OLED doped with blue emitter, 4TCzBN, which showed high EQE of 32.5% and 35.8%, respectively, due to high PLQY (93.1% and 98.6%) and horizontal dipole ratio (81% and 88%).

### References

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**Figure 4** (a) and (b) ADPL of *o*-DiCzBz and 4Ac26CzBz thin films doped with 4TCzBN. (c) and (d) GIWAXS of *o*-DiCzBz and 4Ac26CzBz thin films.