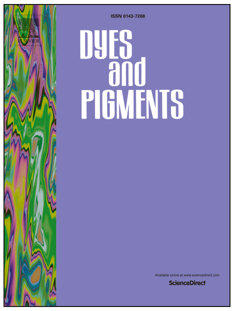

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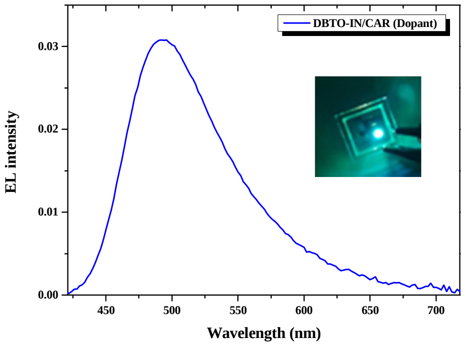
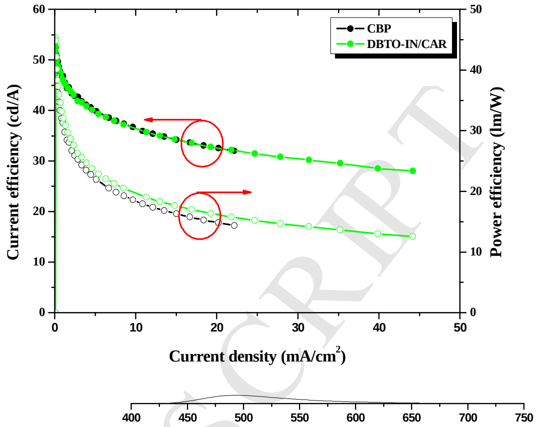
Graphical abstract





Dibenzothiophene-indolocarbazole-based bipolar material: Host for green phosphorescent OLEDs and non-doped fluorescent emitter

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[1] These authors contributed equally to this work

Abstract

Novel bipolar material 2-(5-phenylindolo[3,2-a]carbazol-12(5H)-yl)dibenzothiophene 5,5-dioxide (DBTO-IN/CAR) was designed and synthesized with a high yield of 64%. The synthesized material exhibited an excellent glass transition temperature of 156 °C, which manifests as a high thermal stability of DBTO-IN/CAR. We fabricated two different devices, namely a green phosphorescent OLED and a non-doped bipolar fluorescent emitter, with DBTO-IN/CAR as the bipolar material. The DBTO-IN/CAR host material based device exhibited excellent maximum power and current efficiencies of 45.36 lm/W and 51.98 cd/A, respectively. The efficiencies are higher than that of the reference CBP-based similar device, which exhibited a power efficiency of 42.01 lm/W. The DBTO-IN/CAR-based green phosphorescent device revealed a good external quantum efficiency of 19.03 %. Moreover, the non-doped DBTO-IN/CAR fluorescent emitter related device also exhibited better current and external quantum efficiencies of 4.30 cd/A and 2.47%, respectively, with the emission of cyan color.

Keywords: organic light-emitting diodes; bipolar host; green phosphorescent; fluorescent; indolocarbazole.

1. Introduction

Organic light emitting diode (OLED) based devices have been astonishingly successful in the commercial market, with a variety of display products such as mobile phones, television, flat panels, and flexible displays. This success is possible as a result of its high efficiencies compared to conventional devices. The development of thermally activated delayed fluorescence (TADF) and phosphorescence, organic light-emitting diodes in recent times has enabled harvesting of both triplet and singlet excitons to achieve 100% internal quantum efficiency through the inter system crossing (ISC) and reverse intersystem crossing (RISC) mechanisms [1-13]. A suitable host material, proper holes, and electron charge balance in the emission layer are essential requirements for high-performance OLEDs. The triplet energy of the host materials plays a major role in supplying energy to the dopant, while preventing energy flowback to the host. Along with triplet energy, the frontier molecular orbital energies (FMOs) of the host material are also important to enable proper charge transportation between adjacent layers [14-18]. Additionally, host materials avoid several triplet exciton quenching operations, such as triplet-triplet annihilation (TTA) and aggregation-caused quenching (ACQ) [19-24]. Three types of host material have been reported, namely hole-transporting (HT), electron-transporting (ET), and bipolar host materials [25-28]. HT host materials are constructed using electron-donating arylamine and carbazole moieties, whereas ET host materials use electron-withdrawing derivatives, such as the triazine, pyridine, pyrimidine, phosphine oxide, and cyano groups. 4,4′-Bis(9-carbazolyl)-1,1′-biphenyl (CBP) and 1,3-Di(9H-carbazol-9-yl)benzene (mCP) are well-known HT host materials. The triplet energies of CBP and mCP are 2.56 and 2.90 eV, respectively. Unfortunately, CBP has exhibited a low thermal stability which manifested as a low glass transition temperature of 62 °C [29-36]. Tris(8-hydroxyquinolinato)aluminum (Alq_3) was employed as an ET host material in an initial work [33]. Phosphine oxide based 2,8-bis(diphenylphosphine oxide)dibenzofuran (PODBF) exhibited a high triplet energy of 3.14 eV as an ET host material; its device applications are limited owing to its poor photo-oxidation stability of the furan ring which leads to air instability of the whole molecule [6, 37].

For HT and ET host materials, the charge recombination zone extends towards either the ET or HT layer. Thus, this nature causes an efficiency drop associated with the improper charge balance in the devices. To overcome these issues, a double emission layer with two types of hosts and a single emission layer with bipolar host materials were introduced to enhance the device efficiencies while improving the thermal stabilities. The bipolar host materials have both an electron donor and electron acceptor present in one molecule; this supports a good charge balance, charge transportation/movement, broad recombination area, as well as proper highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) energies with adjacent layers and stable thermal stabilities [38-40]. The molecular design is crucial for bipolar host materials to meet the aforementioned intrinsic requirements. However, it is slightly challenging to achieve a high triplet energy in bipolar molecules owing to the intra-molecular charge-transfer mechanism between the electron donor and acceptor moieties [41-46].

In our study, we designed and synthesized a bipolar host and fluorescent emitting material DBTO-IN/CAR by incorporating Dibenzothiophene 5,5-dioxide as the electron-withdrawing and indolocarbazole as the electron-donating derivatives in a single molecule. The experimental results show that DBTO-IN/CAR is a suitable candidate for green phosphorescence OLED as host material and non-doped bipolar fluorescence emitter. We fabricated two different OLED devices to investigate the device performance.

2. Materials and methods

2.1. Materials

All reagents and solvents were purchased from commercial sources. DBT and 1-bromo-2-nitrobenzene were obtained from Fisher Scientific Korea Ltd. (Seoul, Korea). 3-(2-nitrophenyl)-9-phenyl-9H-carbazole was collected from Green Guardee Technology Co., Ltd. (Beijing, China). Anhydrous toluene was made using sodium, benzophenone and toluene through a distillation process. Toluene, n-hexane, and dichloromethane were purchased from SK chemicals (Gyeonggi-do, Korea). *O*-dichlorobenzene was obtained from Samchun Pure Chemical Co., Ltd. (Gyeonggi-do, Korea). Triethyl phosphite and sodium tert-butoxide were purchased from Sigma Aldrich (Seoul, Korea). Palladium-based catalysts were acquired from TCI Chemicals (Seoul, Korea). Analytical thin-layer chromatography (TLC) was performed using aluminum-backed Merck Kieselgel 60 and silica gel with mesh size of 200–300 from Merck (Seoul, Korea). Deionized water was used for all cases.

2.2. Instrumentation

A JEON JNM-ECP FT-NMR spectrometer (Peabody, MA, USA) operating at 500 MHz was used to analyze the ^{1}H and ^{13}C NMR data. Mass spectrometry was evaluated using a Xevo TQ-S spectrometer (Waters, Milford, MA, USA). UV-absorption spectra were obtained using a SINCO S-4100 UV-Vis spectrophotometer (SINCO, Seoul, Korea). The band-gap (E_g) energy value was obtained from the onset wavelength of the UV-visible absorbance spectra. An HR800 spectrofluorometer (Horiba Jobin Yvon, Paris, France) was accessed to record the photoluminescence (PL) spectra. The triplet energy level (E_T) was calculated from the onset wavelength of the emission spectra in toluene. The HOMO level was recorded by a photoelectron spectrometer (RIKEN, Saitama, Japan). The LUMO level was estimated by adding the band-gap energy to the recorded HOMO energy value. Thermal gravimetric analysis (TGA) and differential scanning calorimetry (DSC) measurements were obtained by using SDT Q600 V20.9 Build 20 and DSC Q200 V24.9 Build 121 (TA Instruments, New Castle, DE, USA) instruments with a heating rate of 10 °C/min in a nitrogen atmosphere. OLED devices with a frontier molecular orbital distribution achieved using density functional theory in a Gaussian 09 program (Wallingford, CT, USA) were fabricated on an indium-tin-oxide (ITO) coated glass substrate using a thermal evaporating system (5×10^{-7} Torr pressure) (Sunicel plus 200, Seoul, Republic of Korea). Current density-voltage-luminescence (J-V-L) efficiencies were determined by an OLED I-V-L test system (Polaronix M6100, Suwon, Republic of Korea). The electroluminescence (EL) spectra analysis was conducted using a spectroradiometer (Konica Minolta CS-2000, Japan).

2.3. Synthesis procedure

The complete set of synthetic steps is displayed in Scheme 1.

2.3.1. Synthesis of 2-bromodibenzothiophene 5,5-dioxide (DBTO)

A mixture of 2-bromodibenzothiophene (**DBT**, 5.0 g, 19 mmol) and acetic acid (**AcOH**, 150 ml) was refluxed at 80 °C for 30 min in a two-neck round-bottom flask equipped with a condenser. After 30 min, 30% of hydrogen peroxide (**H_2O_2**, 100 ml) was added drop wisely through the top of the condenser, and the mixture was stirred continuously at 80 °C for a further two hours. Then, a white precipitate was filtered and washed with deionized water several times. Finally, the white solid was kept inside a vacuum oven for 8 h to obtain 4.6 g of the dried product **DBTO**.

2-bromodibenzothiophene 5,5-dioxide (DBTO)

Yield: 82%; White solid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.92 (S, 1H), 7.82-7.83 (d, *J*= 8 Hz, 1H), 7.75-7.76 (d, *J*= 8 Hz, 1H), 7.64-7.69 (m, 3H), 7.54-7.57 (t, *J*= 7.5, 1H); ^{13}C NMR (500 MHz, $CDCl_3$) δ 138.1, 136.5, 134.1, 133.6, 133.3, 131.1, 130.3, 128.7, 125.0, 123.5, 122.4, 121.8.

2.3.2. Synthesis of 3-(2-nitrophenyl)-9-phenyl-9H-carbazole (C)

A mixture of (9-phenyl-9H-carbazol-3-yl)boronic acid (**A**, 5.0 g, 17.41 mmol), 1-bromo-2-nitrobenzene (**B**, 3.9 g, 19.15 mmol), Tetrakis(triphenylphosphine)palladium(0) (**$Pd(PPh_3)_4$**, 0.02 g, 0.17 mmol), potassium carbonate (**K_2CO_3**, 2.0 M) in 50 ml water, 100 ml toluene, and 30 ml ethanol was refluxed at 110 °C under an inert condition while stirring for 12 h in a two-neck round-bottom flask equipped with a condenser. After completion of the reaction, the mixture was worked up using dichloromethane (100 ml) and water (70 ml). The organic layer was separated and dried over anhydrous sodium carbonate. After filtration, the organic layer was concentrated using the rotary evaporation method. The residues were separated using a silica column with a *n*-Hexane: dichloromethane (2:1) solvent system to obtain an intermediate **C** of 4.2 g.

3-(2-nitrophenyl)-9-phenyl-9H-carbazole (C)

Yield: 66.2 %; Yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.15-8.16 (d, *J*= 8 Hz, 2H), 7.87-7.88 (d, *J*= 8 Hz, 1H), 7.57-7.62 (m, 6H), 7.44-7.51 (m, 5H), 7.31-7.36 (m, 2H); ^{13}C NMR (500 MHz, $CDCl_3$) δ 149.8, 141.4, 140.7, 137.5, 137.0, 132.6, 132.2, 130.0, 129.1, 127.8, 127.7, 127.2, 126.5, 126.0, 124.1, 123.8, 123.2, 120.6, 120.3, 119.9, 110.2, 110.1.

2.3.3. Synthesis of 5,12-dihydroindolo[3,2-a]carbazole (IN/CAR)

3-(2-nitrophenyl)-9-phenyl-9H-carbazole (**C**, 4.0 g, 10.97 mmol), 40 ml of triethyl phosphite, and 40 ml of *o*-dichlorobenzene were vacuumed for 15 min. Then, a nitrogen atmosphere was generated through a nitrogen balloon. The mixture was refluxed at 180 °C for 24 h. After completion of the reaction, the crude mixture was evaporated using a rotary evaporator. The work-up was continued after concentration using water (150 ml) and dichloromethane (200 ml), and the organic layer dried over anhydrous magnesium sulfate. The crude residues were separated by a silica column with a gradient mobile system of *n*-hexane: dichloromethane. Finally, recrystallization (*n*-Hexane) was carried out to achieve an intermediate **IN/CAR** of 3.3 g.

Yield: 89 %; White solid ; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.66 (s, 1H), 8.22-8.23 (d, *J*= 7.5 Hz, 1H), 8.08-8.13 (m, 2H), 7.60-7.64 (m, 5H), 7.49-7.53 (m, 2H), 7.39-7.47 (m,3H), 7.28-7.36 (m, 2H); ^{13}C NMR (500 MHz, $CDCl_3$) δ 140.7, 140.3, 139.2, 137.9, 134.3, 130.0, 127.8, 127.6, 124.8, 124.3, 124.2, 122.1, 120.6, 120.2, 120.0, 119.9, 118.6, 116.6, 110.9, 110.2, 107.2, 103.1.

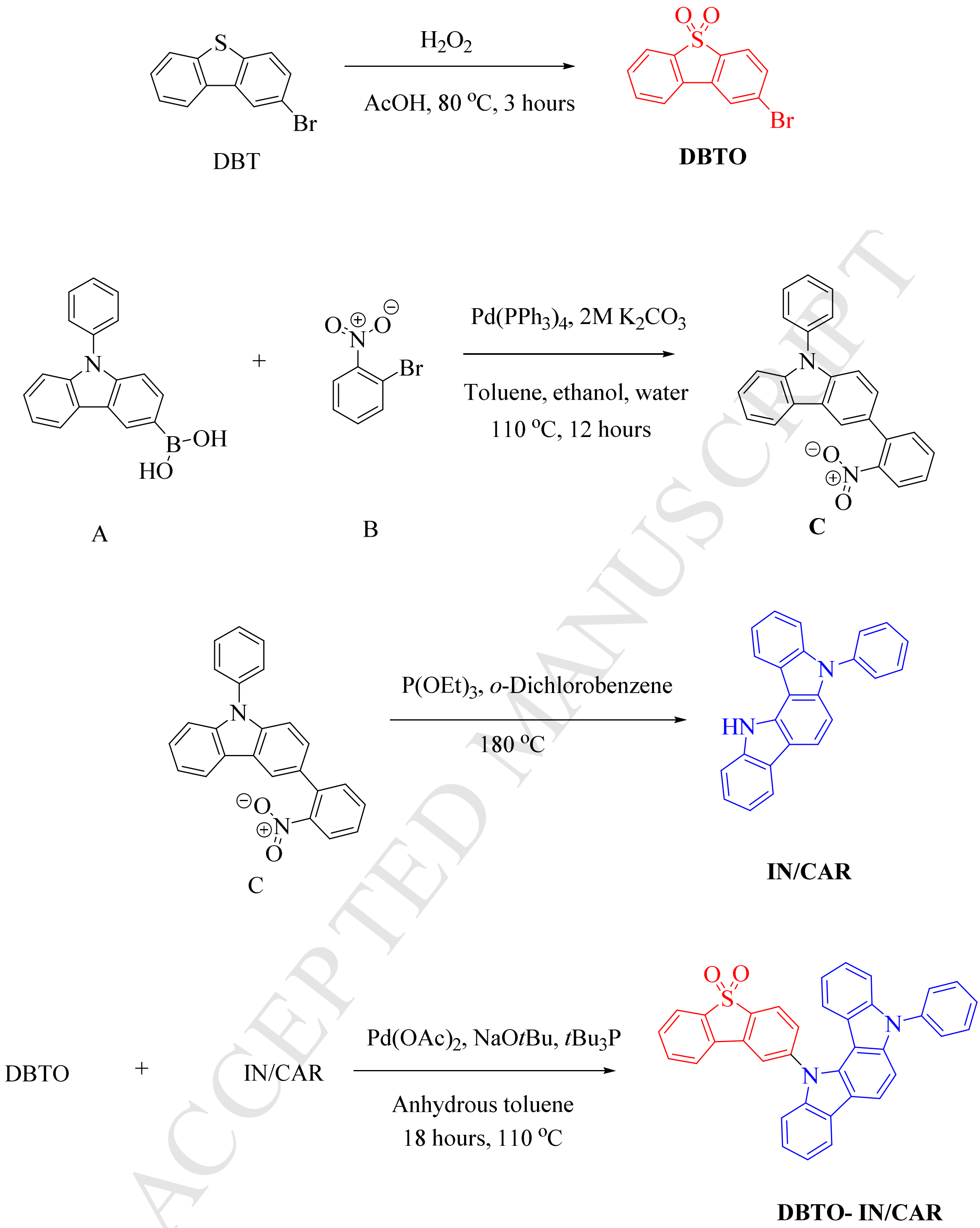
2.3.4. 2-(5-phenylindolo[3,2-a]carbazol-12(5H)-yl)dibenzothiophene 5,5-dioxide (DBTO-IN/CAR)

A mixture of 2-bromodibenzothiophene 5,5-dioxide (**DBTO**, 2.0 g, 6.77 mmol), 5-phenyl-5,12-dihydroindolo[3,2-a]carbazole (**IN/CAR**, 2.6 g, 7.79 mmol), $Pd(OAc)_2$ (0.05 g, 0.20 mmol), 10% *t*-Bu_3P in toluene (0.98 ml, 4.06 mmol), and 100 ml of anhydrous toluene was added in a two-neck round-bottom flask equipped with a condenser, and refluxed at 110 °C for 18 h in a nitrogen atmosphere while stirring. The crude residues were separated by a silica column and *n*-hexane- dichloromethane (2:1) solvent system to obtain the target molecule **DBTO-IN/CAR** as a yellow solid.

Yield: 64.3 %; Yellow solid; FT-IR (KBr pellet): υ_{max} 3052.8, 1595.2, 1500.6, 1474.2, 1442.3, 1421.5, 1368.9, 1308.4, 1243.9, 1218.0, 1167.7, 1119.8 and 1060.3 cm^{-1} ; ^1H NMR (500 MHz, $CDCl_3$) δ 8.14-8.17 (m, 2H), 8.10-8.11 (d, *J*= 8.0 Hz, 1H), 8.00-8.02 (m, 1H), 7.90-7.92 (m, 1H), 7.78-7.79 (d, *J*= 7.5 Hz, 1H), 7.64-7.67 (m, 3H), 7.53-7.59 (m, 5H), 7.36-7.44 (m, 4H), 7.30-7.31 (d, *J*= 8.0 Hz, 1H), 7.20-7.26 (m, 1H), 6.84-6.87 (t, *J*= 7.5 Hz, 1H), 6.28-6.29 (d, *J*= 8.5 Hz, 1H); ^{13}C NMR (500 MHz, $CDCl_3$) δ 145.8, 141.9, 141.3, 140.7, 138.6, 137.6, 137.0, 136.1, 134.0, 133.8, 131.1, 130.8, 130.3, 130.0, 128.2, 128.1, 127.1, 125.2, 124.9, 124.8, 123.8, 123.1, 122.4, 122.1, 121.6, 121.5, 120.8, 119.9, 119.3, 118.5, 118.2, 109.9, 109.6, 107.9, 104.7; MS (APCI) *m/z*: 546.76 for $C_{36}H_{22}N_2O_2S$ $[(M+H)^+]$. TOF MS (ES+) *m/z:* cal. For $C_{36}H_{22}N_2O_2S$ 546.14, found 546.14; Anal. Calcd for $C_{36}H_{22}N_2O_2S$ (%): C, 79.10; H, 4.06; O, 5.85; N, 5.12; S, 5.86. Found: C, 78.95; H, 4.03; O, 5.79; N, 5.08; S, 6.11.

2.4. OLED fabrication and characterization

To fabricate the OLEDs, indium-tin-oxide (ITO) coated glass substrates (150 nm) were cleaned in an ultrasonic bath with solvent isopropyl alcohol and deionized water for 10 and 20 min, respectively. The substrates were then dried using nitrogen gas and each subjected to a UV-ozone treatment for 6 min. All of the organic layers and the metal cathode were deposited on the pre-cleaned ITO glass under a pressure of ~5×10^{-7} Torr using a Sunic organic evaporator. Finally, all of the devices were encapsulated using a glass cover and all deposition processes were conducted inside a nitrogen-filled glove box. The OLED area was 2 mm^2 for all of the samples fabricated in this work.



Scheme 1. Synthetic route of target molecule DBTO- IN/CAR.

3. Results and discussion

The thermal properties of DBTO-IN/CAR were characterized by thermal gravimetric analysis (TGA) and differential scanning calorimetry (DSC). All measurements were reordered under a nitrogen atmosphere. The DSC data of

DBTO-IN/CAR is shown in Figure 1 and Table 1. We noticed that the glass transition temperature of DBTO-IN/CAR was 156 °C, which is higher than those of the CBP and mCP host materials [29-32]. The thermal decomposition of our material was recorded at approximately 435 °C for a 5% weight reduction. The melting point was noticed at 254 °C. These good thermal stabilities can enhance the morphological properties during device fabrication and operation.

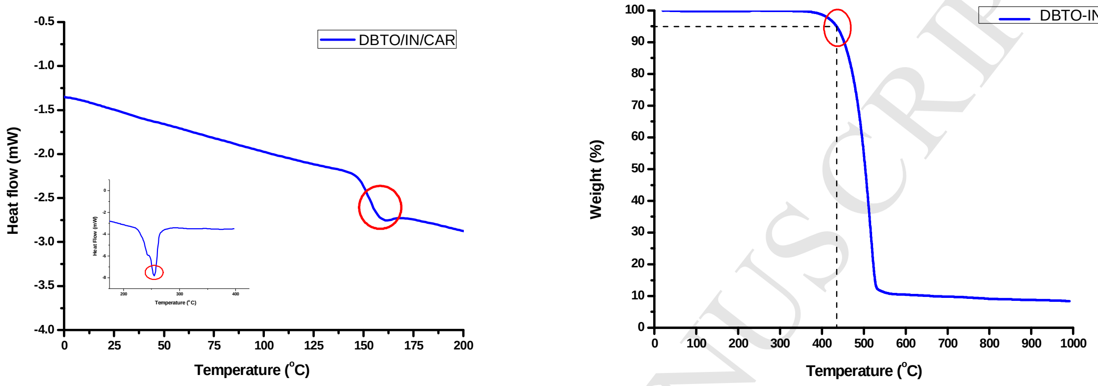


Figure 1. Differential scanning calorimetry and thermal gravimetric analysis curves of DBTO-IN/CAR.

Table 1. Thermal, photophysical, and electrochemical properties of DBTO-IN/CAR.

Material	**T_g [a] (°C)**	**T_d [b] (°C)**	**UV-Vis [c] (nm)**	**PL max [d] (nm)**	**HOMO [e] (eV)**	**LUMO [f] (eV)**	**E_g [g] (eV)**	**E_T [h] (eV)**
DBTO-IN/CAR	156	435	376	458	5.68	2.38	3.30	2.71

[a] Glass transition temperature

[b] Thermal decomposition temperature at 5% weight reduction

[c] Onset of UV-absorption wavelength

[d] Photoluminescent maximum emission

[e] Highest occupied molecular orbital energy

[f] Lowest unoccupied molecular orbital energy

[g] Energy band gap

[h] Triplet energy

Figure 2 shows the UV-vis absorption and photoluminescent (PL) spectra of DBTO-IN/CAR at room temperature. The absorption and emission data are summarized in Table 1. The absorption at approximately 300 nm attributed to the π- π* transition of the indolocarbazole (IN/CAR) moiety. The charge transfer (CT) absorption from the electron-donating IN/CAR to the electron-withdrawing DBTO was noticed at 340 nm. The band-gap energy of DBTO-IN/CAR was recorded at 3.30 eV, which relates to the onset absorption wavelength of 376 nm. The maximum PL emission was found at 458 nm, which relates to an energy of 2.71 eV. The energy value is suitable for a host material for green phosphorescent dopant because the host material is responsible for supplying energy to the dopant and preventing energy flow back from the dopant. The triplet energy of the CBP reference material is 2.58 eV; thus, we believed DBTO-IN/CAR will exhibit a greater efficiency improvement than CBP-based green phosphorescent OLED.

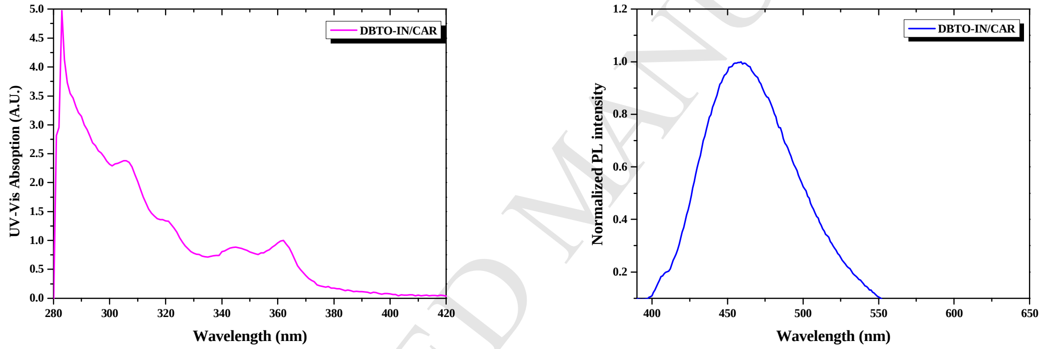


Figure 2. UV-Vis absorption and photoluminescence spectra of DBTO-IN/CAR.

The HOMO energy level was calculated as -5.68 eV using the AC2 photoelectron spectrometer. The LUMO energy level was achieved by adding the band-gap energy to the HOMO energy; this is summarized in Table 1. The LUMO value is -2.38 eV, which is higher than that of the green dopant (-2.90 eV). The proper frontier molecular orbital energy levels support the effective transportation of holes and electrons from the anode and cathode, respectively. Moreover, this can enhance the device efficiencies by providing a suitable environment for charge recombination. To understand the molecular orbital distribution, we calculated the density functional theory DFT using a Gaussian 09 program with the basic set of 6-31G. The HOMO-LUMO distributions are depicted in Figure 3. The HOMO is distributed over the electron-donating indolocarbazole moiety, whereas the LUMO is distributed over the electron-withdrawing DBTO group. We notice a small overlapping of the aromatic benzene of the donor and acceptor units. This explains the bipolar nature of the DBTO-IN/CAR molecule.

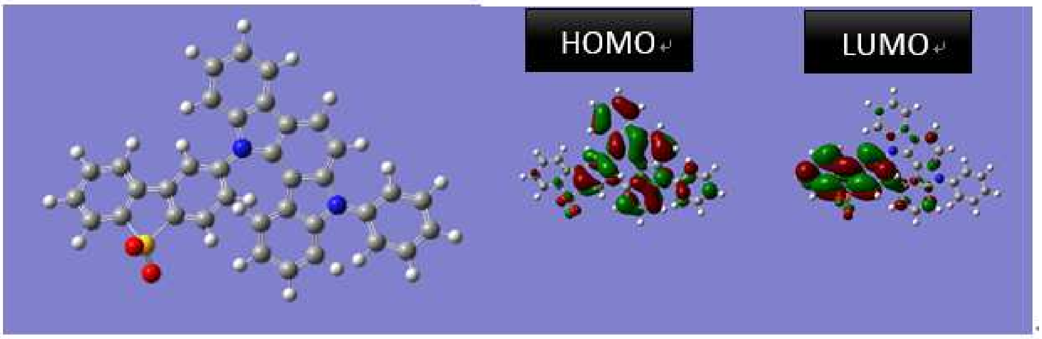


Figure 3. Frontier molecular orbital distribution of DBTO-IN/CAR.

To investigate the electroluminescent properties of our DBTO-IN/CAR, we fabricated OLED devices with green phosphorescent dopant Ir(ppy)$_3$. The device structure was indium tin oxide (ITO) (150 nm)/ 1,4,5,8,9,11-Hexaazatriphenylenehexacarbonitrile (HATCN) (7 nm)/ 4,4′-Cyclohexylidenebis[*N*,*N*-bis(4-methylphenyl)benzenamine] (TAPC) (43 nm)/ DBTO-IN/CAR: 5 wt % Tris[2-phenylpyridinato-C2,N]iridium(III) (Ir(ppy)$_3$) (20 nm)/ 1,3,5-Tri(m-pyridin-3-ylphenyl)benzene (TmPyPB) (35 nm)/ 8-Quinolinolato lithium (Liq) (1.5 nm)/ Aluminum (Al) (100 nm), and is shown in Figure 4. In the given configuration, ITO is the anode, Al the cathode, HATCN the hole-injecting layer (HIL), TAPC the hole-transporting layer (HTL), TmPyPB the electron-transporting layer (ETL), and Liq the electron-injecting layer (EIL) (Figure 4). We fabricated a similar device with CBP as the host material for our reference study, and compared the device efficiencies.

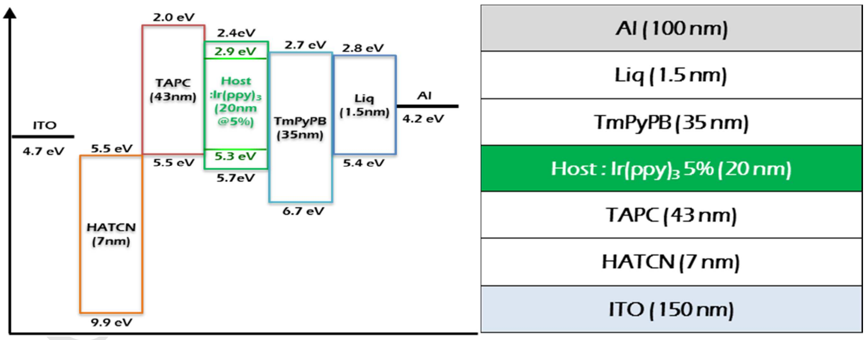


Figure 4. Green phosphorescent OLED device structure.

The current density-voltage (J-V) and luminescence-voltage (L-V) properties are shown in Figure 5 and summarized in Table 2. The turn-on voltage of the DBTO-IN/CAR-based device was 3.6 V, whereas the driving voltage was 4.9 V. These values are lower than those of the CBP-based reference device, which had turn-on and driving voltages of 3.8 and 5.2 V, respectively. The lower turn-on and driving voltages enhance the device efficiencies. The maximum current efficiency of the DBTO-IN/CAR-based device was 51.98 cd/A, which is higher than that of the reference-based device (50.81 cd/A) owing to its lower turn-on voltage. The power efficiency of the DBTO-IN/CAR-based device was determined as 45.36 lm/W at maximum and 27.56 lm/W at 1000 cd/m^2. Moreover, the power efficiency of the reference device was determined as 42.01 and 25.88 lm/W for the maximum and at 1000 cd/m^2, respectively. This indicates that better charge recombination occurred in the DBTO-IN/CAR-based device than in the reference CBP device. Consequently, the DBTO-IN/CAR host material supplied sufficient energy to the green dopant to prevent energy flow back to the host material. The DBTO-IN/CAR-based device exhibited a high external quantum efficiency (EQE) of 19.03%, but the CBP-based reference device exhibited a lower EQE of 17.72 % (Figure 6). The lower HOMO energy level of DBTO-IN/CAR attributed to the hole transportation and charge recombination into the emission layer. Additionally, the DBTO-IN/CAR material based green OLED revealed a slightly lower efficiency roll-off, which is an important phenomenon for long-operation devices.

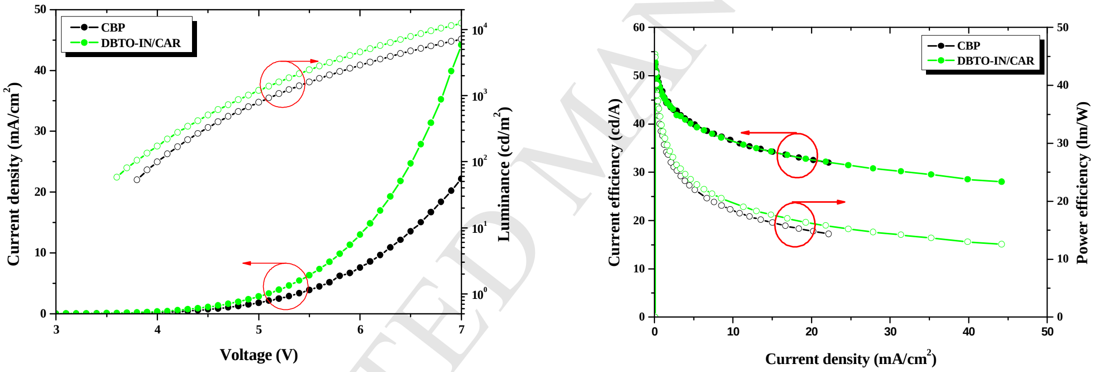


Figure 5. Current density-voltage (J-V) and luminescence-voltage (L-V) characteristics of DBTO-IN/CAR host material and reference CBP.

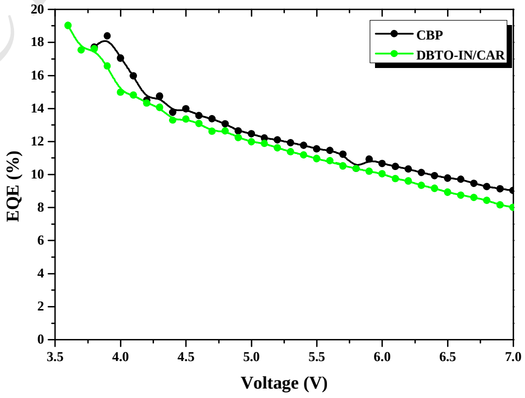


Figure 6. External quantum efficiencies of DBTO-IN/CAR and CBP based green PhOLEDs.

We fabricated another OLED device using DBTO-IN/CAR as a bipolar fluorescent emitting material without doping (Figure 7). The device structure was ITO (150 nm)/ MoO_3 (7 nm)/ NPB (80 nm)/ TCTA (5 nm)/ non-doped DBTO-IN/CAR (20 nm)/ TPBI (40 nm)/ Liq (1 nm)/ Al (100 nm). The turn-on voltage of the DBTO-IN/CAR bipolar emitter was 4.5 V. The maximum current efficiency was 4.3 cd/A, which is one of the higher values among non-doped fluorescent emitter-based OLEDs. The bipolar DBTO-IN/CAR fluorescent emitter revealed a good maximum power efficiency of 3.0 lm/W. Consequently, the fluorescent OLED device exhibited an excellent external quantum efficiency of 2.47%. These details are depicted in Figure 8.

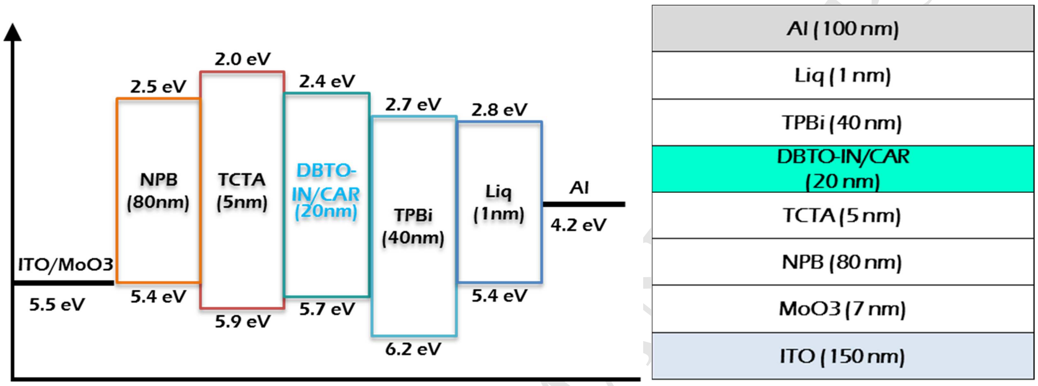


Figure 7. Device structure of DBTO-IN/CAR based non-doped fluorescent emitting OLED.

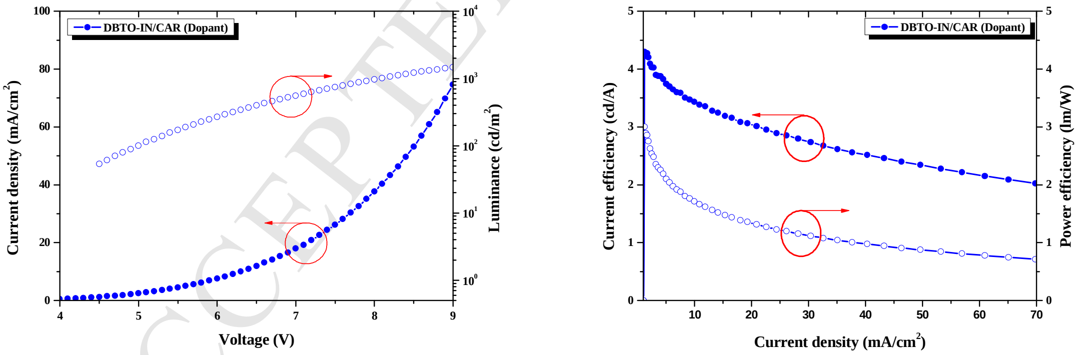
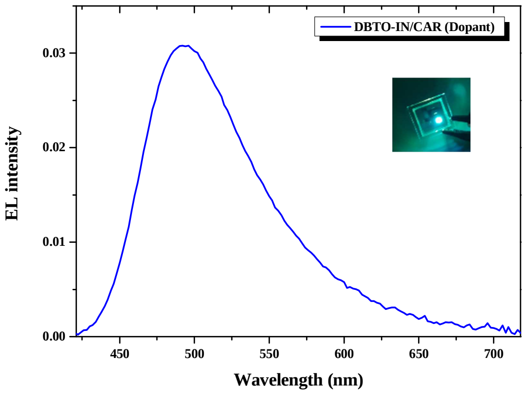


Figure 8. Current density-voltage (J-V) and luminescence-voltage (L-V) characteristics of DBTO-IN/CAR as non-doped fluorescent emitter.

The electroluminescent spectra of the DBTO-IN/CAR non-doped OLED device are shown in Figure 9. The maxima peak wavelength is 492 nm with CIE coordinate values of 0.23 and 0.41 for x and y, respectively.



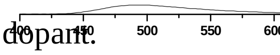


Figure 9. Electroluminescence (EL) spectra of non-doped DBTO-IN/CAR fluorescent dopant.

Table 2. Device characteristics of green phosphorescent and non-doped fluorescence OLEDs.

Characteristic	CBP (Reference Host)	DBTO-IN/CAR (Green Host)	DBTO-IN/CAR (Non-doped Emitter)
Turn-on voltage	3.8 V	3.6 V	4.5 V
Driving voltage [a]	5.2 V	4.9 V	8.1 V
Current density [b]	0.10 mA/cm^2	0.11 mA/cm^2	1.25 mA/cm^2
Current efficiency (Max)	50.81 cd/A	51.98 cd/A	4.30 cd/A
Power efficiency	42.01 lm/W	45.36 lm/W	3.00 lm/W
EQE (Max)	17.72 %	19.03 %	2.47 %
Luminescence [b]	52.89 cd/m^2	57.97 cd/m^2	53.63 cd/m^2
CIE color [b]	0.34, 0.61	0.36, 0.61	0.23, 0.41

[a] At 1000 cd/m^2

[b] At turn-on voltage

4. Conclusion

A bipolar host and fluorescent emitting DBTO-IN/CAR material was designed and synthesized using a 2-bromodibenzo[b,d]thiophene 5,5-dioxide withdrawing moiety and 5-phenyl-5,12-dihydroindolo[3,2-a]carbazole donor units. The DBTO-IN/CAR-based green phosphorescent OLED device exhibited a low turn-on voltage of 3.6 V with an excellent external quantum efficiency of 19.03%. The maximum current and power efficiencies were 51.98 cd/A and 45.36 lm/W, respectively. These efficiencies are higher than those of the CBP-based reference device, the external quantum and power efficiencies of which were noted as 17.72% and 42.01 lm/W, respectively. The DBTO-IN/CAR-based non-doped fluorescence emitting OLED device exhibited excellent power and current efficiencies of 3.0 lm/W and 4.30 cd/A, respectively. The maximum external quantum efficiency of the DBTO-IN/CAR fluorescence emitter was noted as 2.47%. The CIE color coordinate values were 0.03 and 0.41 (x,y) with an emission wavelength of 490 nm. The bipolar nature of DBTO-IN/CAR enhanced the green phosphorescence OLED as well as the non-doped fluorescent emitter.

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Highlights

- Current efficiency of bipolar host reached 51.98 cd/A
- Green phosphorescent OLED showed outstanding power efficiency of 45.36 lm/W
- Non-doped cyan emitting fluorescent OLED showed current efficiency of 4.30 cd/A
- OLED devices showed lower efficiency roll off