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A novel dimesitylboron-substituted indolo[3,2-b]carbazole derivative: Synthesis, electrochemical, photoluminescent and electroluminescent properties

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ABSTRACT

A novel indolo[3,2-b]carbazole derivative containing B(Mes)₂ groups, 5,11-dibutyl-2,8bis(dimesitylboryl) indolo[3,2-b]carbazole (**DBDMBICZ**), was synthesized and structurally characterized by elemental analysis, NMR, MS. The thermal, electrochemical and photophysical properties of **DBDMBICZ** were characterized by thermogravimetric analysis, electrochemical methods, UV-vis absorption spectroscopy and fluorescence spectroscopy. **DBDMBICZ** exhibited high fluorescence quantum yields ($\Phi_{max} = 0.76$) in solution and excellent thermal stability ($T_d = 290$ °C, $T_g = 170$ °C) and electrochemical stability. The multi-layered OLEDs devices with the configuration of ITO/NPB/CBP/light-emitting layer/ Bphen/LiF/Al are fabricated by using **DBDMBICZ** as light-emitting layer. The devices show the same pure blue emissions at different voltages and relative good electroluminescent performances. The results indicate that **DBDMBICZ** has potential applications as an excellent optoelectronic material in optical field.

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1. Introduction

Organic light emitting diodes (OLEDs) based on organic small molecules and polymers have attracted much attention since Tang and Van Slyke demonstrated that the use of hole transporting layers (HTLs) for hole injection from the anode into the light-emitting layer could provide significant improvement to the OLEDs device performance [1]. The OLEDs are in possession of a potential use in flat panel displays and lighting [2,3]. In order to improve the efficiency and stability of the OLEDs, great efforts have been made to develop high-performance materials with desirable properties and optimize device configuration. To date, many types of high-performance materials have been fabricated [4–6]. Among them, indolo[3,2-b]carbazole (ICZ) and its derivatives are the most popular ones.

ICZ with large planar and rigid conjugated structure is an important unit to synthesize various small molecules and polymers. The properties of ICZ derivatives could be greatly improved by the introduction of various functional groups into the 2,8-positions, 3,6-positions and/or 5,11positions of ICZ, such as better morphological stability and thermal durability as well as desirable charge-injecting and transporting properties [7–13]. Tao and co-workers designed and synthesized two triphenylaminesubstituted ICZ derivatives with excellent hole-transporting properties [14]. The double-layers electroluminescent devices made by using these ICZ derivatives as the HTLs





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exhibited the maximum luminance efficiency of 1.610 and 2.156 cd/A, respectively. Later, Tao and co-workers obtained two other luminescent ICZ derivatives, TPAP-ICZ and DBFP-ICZ, through peripheral substitutions at 6-position of ICZ [15]. The maximum luminance efficiency of electroluminescent devices with TPAP-ICZ and DBFP-ICZ as the emitting layers are 6.90 and 7.06 cd/A, respectively. Recently, Grigalevicius et al. synthesized and characterized three ICZ derivatives containing reactive oxetanyl groups [16]. They found the bilayer OLEDs using the derivative comprising phenyl groups as HTLs exhibited the best overall electroluminescent performance (turn-on voltage: \sim 5 V; maximum luminance efficiency: 3.64 cd/A; maximum brightness: 5700 cd/m^2). They also reported that multilayer OLEDs containing cross-linked layer of the derivative comprising phenyl groups shown maximum photometric efficiency of 2.8 cd/A. These results demonstrated that ICZ derivatives are very promising building blocks for the preparation of novel efficient electroluminescent materials.

Boron-containing π -conjugated derivatives have attracted a great deal of attention due to their intriguing electronic and photophysical properties as a result of overlap between the vacant p-orbital of the boron atom and the conjugated moieties such as high fluorescence quantum yields [17–27]. At present, many triarylboron-containing compounds have been synthesized and used as nonlinear optical materials and transporting and emissive materials in OLEDs and so on [28–35].

In view of the above-mentioned situation and the molecular design and synthesis of novel compounds need to be further developed by the structural modification in order to improve the properties and establish the relationship between structures and properties, we became interested in boron-containing π -conjugated compounds bearing boron groups as electron-acceptors and indo-lo[3,2-b]carbazole as electron-donor.

In this paper, a novel boron-containing indolo[3,2b]carbazole derivative, 5,11-dibutyl-2,8-bis(dimesitylboryl) indolo[3,2-b]carbazole (DBDMBICZ), was synthesized by using indolo[3,2-b]carbazole as the rigid core with two B(Mes)₂ groups linking to the core through the 2,8positions. DBDMBICZ is provided with the excellent properties of indolo[3,2-b]carbazole and boron-containing π conjugated molecule, containing a large π -conjugated indolo[3,2-b]carbazole as electron-donor and two $B(Mes)_2$ groups as electron-acceptors. To the best of our knowledge, the study on the boron-containing indolo[3,2-b]carbazole derivative have never been reported. The synthetic details are illustrated in Scheme 1. The structure of the compound **DBDMBICZ** was characterized by elemental analysis, ¹H NMR, ¹³C NMR and MS. The thermal, electrochemical, photoluminescent and electroluminescent properties are reported here.

2. Experimental section

2.1. Materials

1,4-Cyclohexanedione and 4-bromophenylhydrazine hydrochloride were purchased from Alfa Aesar and used

without further purifications. Dimesitylboron fluoride was purchased from TCI and other reagents were purchased from Beijing Chemical plants. Solvents were treated according to the standard methods used before. All reactions were carried out under an inert atmosphere of Nitrogen.

2.2. Synthesis of compounds

Cyclohexane-1,4-dione-bis(p-bromophenyl)-hydrazone (compound **1**), 2,8-dibromoindolo[3,2-b]carbazole (compound **2**) and 2,8-dibromo-5,11-dibutylindolo[3,2-b]carbazole (compound **3**) were prepared according the earlier reported procedure [36].

2.2.1. The synthesis of cyclohexane-1,4-dione-bis(p-bromophenyl)-hydrazone (compound 1)

The 1,4-cyclohexanedione (5.62 g, 50 mmol) dissolved absolute ethyl alcohol (100 mL) was added with stirring to a mixture of powdered 4-bromophenylhydrazine hydrochloride (22.4 g, 100 mmol), sodium acetate (8.2 g, 100 mmol) and absolute ethyl alcohol (200 mL) at room temperature. The mixture was quickly heated to 50 °C, and then cooled to 0 °C. Thus, a precipitate was obtained and filtered, washed carefully with water to give compound **1** with yield 66%.

2.2.2. The synthesis of 2,8-dibromoindolo[3,2-b]carbazole (compound **2**)

Compound **1** (10 g, 22 mmol) was added to a mixture of AcOH (130 mL) and H₂SO₄ (32 mL) at 0 °C and stirred for 5 min. The obtained mixture was heated up to 30 °C and kept stirring for 1 h and was then further risen up to 60–70 °C and stirred for another 1 h. Afterwards, it was cooled down to room temperature and poured into an ice water with stirring. The greenish solid was filtered off and washed with water and EtOH to neutral pH and dried finally. Thus a pure 2,8-dibromoindolo[3,2-b]carbazole (compound **2**) (4.88 g, yield 52.8%) was obtained. Mp > 300 °C. ¹H NMR (DMSO-*d*₆) δ 11.14 (2H, s, and N–H), and 7.1–8.24 (8H, m, and Ar–H).

2.2.3. The synthesis of 2,8-dibromo-5,11-dibutylindolo[3,2b]carbazole (compound **3**)

Compound **2** (2.0 g, 4.8 mmol) was added to a suspension of NaH (0.35 g, 14 mmol) in THF (50 mL) under N₂ flow. The mixture was stirred for 2 h at room temperature and then heated up slowly to 50 °C and kept for 4 h. After that, it was cooled to room temperature. 1-Bromobutane (1.91 g, 14 mmol) was added dropwise to the mixture with stirring continued for 50 min, and then the mixture was heated up to 50 °C and maintained for 24 h. Afterwards, the solvent was evaporated and solid left. The solid was washed with water and two or three times each with acetone to afford the desired compound **3** (2.01 g, yield 79.5%). Mp 271–274 °C. ¹H NMR (CDCl₃) δ 7.572–8.547 (8H, m, and Ar–H), 4.359–4.383 (4H, t, and –NCH₂–), 1.900–1.925 (4H, t, and –CH₂–), 1.440–1.537 (4H, t and –CH₂–), and 0.965–0.990 (6H, t, and –CH₃).



(c) NaH, THF, 1-Bromobutane, 50°C (d) n-BuLi, Dimesitylboron Fluoride, DMF, THF, -78°C

Scheme 1. The synthetic route of compound DBDMBICZ.

2.2.4. The synthesis of 2, 8-dimesitylboron-5,11-dibutylindolo [3,2-b]carbazole (**DBDMBICZ**)

2,8-dibromo-5,11-dibutylindolo[3,2-b]carbazole (compound 3) (0.44 g, 0.84 mmol) was dissolved in THF (50 mL), and the resulting solution was cooled to -78 °C. To this solution, butyllithium (0.8 mL, 2.5 M in hexanes) was added and the resulting solution was stirred for 20 min at -78 °C. Dimesitylboron Fluoride (0.67 g, 2.5 mmol) was dissolved in THF (20 mL) and then added to the stirred reaction mixture at -78 °C. The mixture was allowed to warm to room temperature with stirring overnight. Afterwards, the solvent was evaporated and solid left. The solid was washed with Et₂O and water to afford the desired 0.23 g (yield 31.8%) 2,8-Dimesitylboron-5,11dibutylindolo[3,2-b]carbazole (DBDMBICZ) as a white powder. Mp > 300 °C. ¹H NMR (CDCl₃) δ 7.321–8.457 (8H, m, and Ar-H), 6.882 (8H, s, and B-Ar-H), 4.377-4.402 (4H, t, and -NCH₂-), 2.082-2.360 (36H, m, and Ar-CH₃), 1.905-1.955 (4H, m, and -CH₂-), 1.473-1.511 (4H, m, and -CH₂-), and 0.958-0.983 (6H, t, and -CH₃). MS (*m*/*z*): 864.5814 (M+). Anal. Calcd. for C₆₂H₇₀B₂N₂: C, 86.10%; H, 8.16%; B, 2.50%; and N, 3.24%. Found: C, 86.15%; H, 8.03%; B, 2.47%; and N, 3.32%.

2.3. Measurement and characterization

Melting points were determined on an X-5 melting point detector. All NMR spectra were measured on a Bruker 600 MHz spectrometer. Thermogravimetric analysis were performed with a TGA 2050 thermogravimetric analyzer under nitrogen atmosphere with a heating rate of 10 °C/min from room temperature to 600 °C. Elemental analyses were performed with an Element Analysis System. Mass spectra were recorded with the LC-MS system consisted of a Waters 1525 pump and a Micromass ZQ4000 single quadrupole mass spectrometer detector. Cyclic voltammetry experiments were performed with a CHI-600C electrochemical analyzer, the measurements were carried out with a conventional three-electrode configuration consisting of a glassy carbon working electrode, a platinum-disk auxiliary electrode and a Ag/AgCl reference electrode, and the scan speed is 50 mV/s. UV-vis

was obtained on a shimadzu UV-2450 spectrophotometers. Fluorescence spectra were obtained on a F-4500 fluorophotometer. Fluorescence quantum yield was determined using quinine sulfate as the standard substance. All measurements were performed at room temperature.

2.4. Device fabrication and testing

The multilayer OLEDs were fabricated by vacuum-deposition method in this study. Organic layers were fabricated by high-vacuum (5 \times 10⁻⁴ Pa) thermal evaporation onto a glass $(3 \text{ cm} \times 3 \text{ cm})$ substrate precoated with an ITO layer. N,N-bis(naphthalen)-N, N-bis(phenyl)-benzidine (NPB) was used as the HTL, 4,4'-bis(N-carbazolyl)-1,1'-biphenyl (CBP) was used as the electron-blocking layer, DBDMBICZ was used as the emitting layer, 4,7-diphenyl-1,10-phenanthroline (Bphen) was used as the electron-transport laver (ETL) and LiF/Al was evaporated as cathode. All organic lavers were sequentially deposited. Thermal deposition rates for organic materials, LiF and Al were 0.5 Å/s, 0.5 Å/s and 1 Å/s, respectively. The active area of the devices is 9 mm². The electroluminescent spectra were measured on a Hitachi MPF-4 fluorescence spectrometer. The voltage-current density (V-J) characteristics of OLEDs were recorded on Keithley 2400 Source Meter. The characterization of brightness-current-voltage (B-I-V) were measured with a 3645 DC power supply combined with a 1980A spot photometer and were recorded simultaneously. All measurements were done at room temperature in the air.

2.5. Theoretical calculations

The ground-state geometry of the derivative (**DBDM-BICZ**) was optimized at B3LYP level with 6-31G (d,p) basis set [37–39]. The vibration frequencies and the frontier molecular orbital characteristics were analyzed on the optimized structure at the same level. The excited-state geometry of compound was optimized based on the ground state structures using DT-DFT method at B3LYP level with 6-31G (d,p) basis set. The absorption spectra and the emission spectra of compound were carried out using

time-dependent density functional theory (TD-DFT) method based on the optimized ground state structure and the lowest singlet excited state structure, respectively. Solvent effect was also taken into account by using the polarized continuum model (PCM) [40,41]. All calculations were carried out with the Gaussian 09 program package [42]. All the calculations were performed in supercomputing center of computer network information center of Chinese Academy of Sciences.

3. Results and discussion

3.1. Synthesis

In this paper, we described methods for the preparation of the indolo[3,2-b]carbazole derivative (**DBDMBICZ**). First, 2,8-dibromoindolo[3,2-b]carbazole was synthesized as the key intermediate for the whole procedure via a two step reaction as shown in Scheme 1. Then, 2,8-dibromo-5,11dibutylindolo[3,2-b]carbazole (compound **3**) was synthesized from the reaction between C₄H₉Br and compound **2** and NaH in THF. Finally, **DBDMBICZ** was resulted via lithiation with n-butyllithium and reaction with dimesitylboron fluoride. All of these new compounds were characterized by mass spectrometry and NMR spectroscopy. Further details are given in experimental section.

3.2. Thermal properties

The thermal properties of the **DBDMBICZ** were investigated by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). The TGA and DSC results of the **DBDMBICZ** show 5% weight loss temperature is higher than 290 °C and a glass transition temperature (T_g) of 170 °C, respectively. The results were collected in Table 1. These results indicate that the **DBDMBICZ** has good thermal stability and high glass transition temperature, which is very important in device fabrication process and other kinds of applications.

3.3. Molecular simulation

The molecular structure of **DBDMBICZ** contains one indolo[3,2-b]carbazole unit as the rigid core and two dimesitylboron units as the terminals. Its geometry in the ground state was optimized using the DFT/B3LYP/6-31G (d,p) method. As can be seen from the optimized geometry, indolo[3,2-b]carbazole moiety is planar conformation. Two mesityl groups form propeller-like conformations originate from the trigonal boron center.

The distribution of the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) of **DBDMBICZ** was also investigated at the DFT/ B3LYP/6-31G (d,p) level for the geometry optimizations. The isodensity surface plots of HOMO and LUMO were exhibited in Fig. 1. It can be seen from Fig. 1 that the election density of HOMO is mainly localized on the indolo[3,2-b]carbazole backbone. On the other hand, the election density of LUMO is mainly situates on the boron-indolo[3,2-b]carbazole-boron moiety with little contribution from the mesityl groups. The electron transition from the ground state to the excited state is mainly about the electron flowing from the indolo[3,2-b]carbazole moiety to two dimesitylboron moieties. The electron density distribution of HOMO and LUMO suggests that **DBDMBICZ** might possess beneficial electron injection and transport properties with the incorporation of electron-withdrawing dimesityl boron groups. The structure of two **DBDMBICZ** molecules in the closest distance in gas state was optimized at B3LYP level with 6-31G (d,p) basis set. The opti-

mized at B3LYP level with 6-31G (d,p) basis set. The optimized geometry was shown in Fig. S1 (in ESI). Fig. S1 shows the aggregation of two **DBDMBICZ** molecules was largely hindered by trigonal dimesityl groups. The plane distance is 7.12 A between two indolo[3,2-b]carbazole rings. This result indicates the absence of intermolecular π - π interactions owing to bulky mesityl groups, inferring the molecules can form stable amorphous thin film via vacuum deposition.

3.4. Photophysical properties

The UV–vis absorption spectra of **DBDMBICZ** were measured in several solvents $(1.0 \times 10^{-5} \text{ M})$. The spectral data in THF solvent was collected in Table 1. The spectra are shown in Fig. 2. As shown in Fig. 2, the absorption spectra of **DBDMBICZ** exhibit three absorption bands at 300–330, 330–360 and 370–440 nm due to π – π * electronic transitions. The low-energy broad band at 370–440 nm is assigned to an intramolecular charge transfer (CT) band from the indolo[3,2-b]carbazole core to two dimesitylboron terminals and show almost identical maxima in the different solvents meaning the slightly solvent-dependence. This indicates that the structural and electronic characteristics of the ground are not significant difference with a change in solvent polarity.

In order to elaborate the nature of the UV–vis absorption of **DBDMBICZ** observed experimentally, we computed singlet–singlet electronic transition based on the optimized geometry of the ground state of **DBDMBICZ** using time-dependent DFT method at the B3LYP/6-31G (d,p) level in THF solvent. The excitation energy, oscillator strength and main configuration for the most relevant absorption bands were listed in Table S1 (in ESI). Owing to the lowest-energy electronic transition HOMO \rightarrow LUMO, which mostly consists of the intramolecular charge transfer, an absorption band occurs around 398 nm. The other two absorption band of the indolo[3,2-b]carbazole occurs around 343 nm and 322 nm, mainly consisting of HOMO-

Table 1	
Physical properties of compound DBDMBICZ .	

λ_{abs} (nm)	λ_{PL} (nm)	Φ	HOMO (eV)	LUMO (eV)	E_g (eV)	T_g (°C)	T_d (°C)
317/348/390	452	0.76	-5.17	-2.32	2.85	170	290



Fig. 1. HOMO and LUMO diagrams of compound DBDMBICZ.



Fig. 2. The UV-vis absorption spectra of DBDMBICZ.

 $1 \rightarrow$ LUMO vertical transition and HOMO-1 \rightarrow LUMO + 2 vertical transition, respectively. The calculated results are in good agreement with the experimental absorption spectra.

The steady-state fluorescence spectra of **DBDMBICZ** were measured in several solvents $(1.0 \times 10^{-5} \text{ M})$. The spectral data in THF solvent was collected in Table 1. The spectra are shown in Fig. 3. As shown in Fig. 3, the emission spectra of **DBDMBICZ** consist of one broad band. With the increasing polarity of the solvents, a bathochromic shift of 75 nm ranging from 418 nm (in hexane) to 493 nm (in



Fig. 3. The steady-state fluorescence spectra of DBDMBICZ.

DMSO) was observed. Such a distinct solvatochromism indicated that intramolecular charge transfer from the indolo[3,2-b]carbazole core to two dimesitylboron terminals takes place during the excitation process.

In order to further understand the nature of the fluorescence emission observed for DBDMBICZ, the geometry of the first excited singlet state (S₁) was optimized for **DBDM-**BICZ. We can see DBDMBICZ possess similar molecular structure in the first excited state and in the ground state. The optimized geometry of **DBDMBICZ** in the first excited state (S₁) was used as input to calculate singlet-singlet electronic transition using time-dependent DFT method at the B3LYP/6-31G (d,p) level in THF solvent, yielding the vertical electronic transition energy of $S_1 \rightarrow S_0$. The computed data are collected in Table S2 (in ESI). As it can be seen in Table S2, the electronic transitions are of the π - π^* type. The calculated $S_1 \rightarrow S_0$ emission energy and oscillator strength of the compound in THF solvent are 2.707 eV and 0.451, respectively. The calculated results are in relatively good agreement with the experimental fluorescence spectra of the compound.

The fluorescence quantum yields of **DBDMBICZ** were measured in several solvents $(1.0 \times 10^{-6} \text{ M})$ at room temperature by a relative method using quinine bisulfate in 0.1 M sulfuric acid as a standard [43]. The fluorescence quantum yield (Φ) in THF solvent was collected in Table 1. As shown in Table 1, compound **DBDMBICZ** exhibited high fluorescence quantum yields ($\Phi_{\text{max}} = 0.76$) in THF solvent.

The solid fluorescence spectrum of **DBDMBICZ** was obtained by measuring that of its solid film and shown in Fig. S2. The spectrum shows the emission maximum of **DBDMBICZ** is at 440 nm in the solid film state, displaying that it can emit blue light. The photoluminescent properties of **DBDMBICZ** in solutions and solid film state indicate it could be used as an excellent optoelectronic material with blue light emission in OLEDs.

3.5. Electrochemical properties

The electrochemical properties of **DBDMBICZ** were investigated by cyclic voltammetry measurements. The measurement was performed with 1×10^{-3} mol/L solution of the samples under argon in a three electrode cell using 0.1 mol/L tetrabutylammonium perchlorate in anhydrous CH₃CN as the supporting electrolyte. The cyclic voltammogram (CV) of **DBDMBICZ** was shown in Fig. S3 (in ESI). The CV curves remained unchanged under multiple successive potential scans, indicating its excellent stability against electrochemical oxidation. The HOMO can be calculated by using the empirical equation HOMO = $-(E_{ox} + 4.40)$ eV, where E_{ox} stand for the onset potentials for oxidation[44]. Therefore, the HOMO levels of **DBDMBICZ** were estimated by using the onset potentials for oxidation (0.77 V) and were found to be -5.17 eV. From the absorption edges of the UV-vis spectra, optical band gap (E_g) was estimated as 2.85 eV. The LUMO energy level, which derived from the relationship E_g = HOMO-LUMO, was calculated to be -2.32 eV. The low HOMO energy level of **DBDMBICZ** suggests that the compound has high oxidative stability and potential application for charge transport material in OLEDs [45].

3.6. Electroluminescent property

In order to demonstrate the potential of **DBDMBICZ** as emission material in device, with the configuration of ITO/NPB/CBP/**DBDMBICZ**/Bphen/LiF/Al (device I) was fabricated. On top of indium-tin-oxide (ITO), the 40 nm thick layer of N,N'-di-[(1-naphthalenyl)-N,N'-diphenyl]-(1,10biphenyl)-4,4'-diamine (NPB) was used as the hole-transporting layer. The 10 nm thick layer of 4,4'-bis(N-carbazolyl)-1,1'-biphenyl (CBP) followed as the electron-blocking layer. The 20 nm thick layer of **DBDMBICZ** was used as the emitting layer. The 40 nm thick layer of 4,7-diphenyl-1,10-phenanthroline (Bphen) was used as the electrontransporting layer. The devices were finalized by deposition of a LiF (1 nm)/Al (180 nm) cathode.

The electroluminescence spectra of the device I measured at different voltages were shown in Fig. S4. As shown in Fig. S4, the electroluminescence spectra of the device I at different voltages are the same and identical to the photoluminescence spectrum of the solid film as well. The spectra show the pure blue emission of **DBDMBICZ** with a maximum at 440 nm and CIE coordinates of x = 0.1581and y = 0.0914. The current density–voltage–luminance curve and luminance efficiency-current density curve of the device I were shown in Figs. 4 and 5, respectively. The characteristics of the device I are summarized in Table 2. As shown in Table 2, the device I exhibits the turn-



Fig. 4. Current density-voltage-luminance curves of the devices.



Fig. 5. Current density-luminance efficiency curves of the devices.

 Table 2

 Electroluminescent characteristics of devices.

Device	$\lambda_{\rm EL} ({\rm nm})$	Von	$L_{\rm max}~({\rm cd}/{\rm m}^{-2})$	$\eta_{L,\max} (\mathrm{cd}/\mathrm{A}^{-1})$
I	440	3.6	1455	0.52
II	440	3.6	5342	1.67

 V_{on} = turn-on voltage at 1 cd m⁻², L_{max} = maximum luminance, and η_{L-max} = maximum luminance efficiency.

on voltage of 3.6 V and a maximum luminance efficiency of 0.52 cd/A and a maximum luminance of 1455 cd/m^2 .

The doped system can decrease the concentration of singlet exactions, inhibit the singlet-singlet quenching and improve the performance of the device. Therefore, we adopted a doped device (device II). The ITO/NPB/CBP/ CBP: DBDMBICZ (1%)/Bphen/LiF/Al device (device II) exhibited the same electroluminescence spectra as that of the device I at different voltages. The current densityvoltage-luminance curve and luminance efficiency-current density curve of the device II were also shown in Figs. 4 and 5, respectively. The electroluminescent performances of device II is also summarized in Table 2. The device II displayed a turn-on voltage of 3.6 V and a maximum luminance efficiency of 1.67 cd/A and a maximum luminance of 5342 cd/m². It is obviously that the device efficiency has been improved. It should be pointed out that the electroluminescent performances were obtained in a non-optimized test device under ordinary laboratory conditions. The device performances may be further improved by an optimization of the laver thicknesses and processing conditions [46]. The study on further improving device performances is currently in progress.

4. Conclusions

In this paper, a novel boron-containing indolo[3,2b]carbazole derivative, 5,11-dibutyl-2,8-bis(dimesitylboryl) indolo[3,2-b]carbazole (**DBDMBICZ**), was synthesized and characterized by elemental analysis, NMR, MS and thermogravimetric analysis. The electrochemical measurements indicate the compound possesses excellent stability against electrochemical oxidation. The calculated absorption and emission wavelengths are well coincident with the measured data. The lowest-lying absorption spectra can be mainly attributed to ICT character, and the fluorescence spectra can be mainly described as originating from an excited state with ICT character. **DBDMBICZ** exhibited excellent thermal stability ($T_d = 290$ °C, $T_g = 170$ °C) and high fluorescence quantum yields ($\Phi_{max} = 0.76$) in solution. Efficient OLEDs using **DBDMBICZ** as light-emitting layer are fabricated, showing relative good electroluminescent performances. The device performances may be further improved by an optimization of the layer thicknesses and processing conditions. All the results indicate **DBDMBICZ** has potential applications as an excellent optoelectronic material in optical field.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.orgel.2012.12.028.

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