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### Synthesis and characterization of carbazole-based dendrimers as bipolar host materials for green phosphorescent organic light emitting diodes

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#### ABSTRACT

A group of novel, carbazole-based dendrimers comprised of the electron-accepting dibenzothiophene core and the electron-donating oligo-carbazole dendrons, namely G1SF and G2SF, are synthesized utilizing the Ullmann C–N coupling reaction. The dendrimers are designed in such a way to show good solubility in common organic solvents, excellent thermochemical stability with decomposition temperatures ( $T_d$ ) up to 430 °C, and high HOMO levels in a range from -5.45 eV to -5.37 eV. Results of density functional theory calculations (DFT) indicate G2SF has an almost complete separation of HOMO and LUMO levels at the holeand electron-transporting moieties; while G1SF exhibits only partial separation of the HOMO and LUMO levels possibly due to intramolecular charge transfer. Green phosphorescent OLEDs were fabricated by the spin coating method with the dendrimers as hosts and traditional green iridium phosphor as doped emitter. Under ambient conditions, a maximum luminance efficiency ( $\eta_L$ ) of 19.83 cd A<sup>-1</sup> and a maximum external quantum efficiency of 5.85% are achieved for G1SF, and 15.50 cd A<sup>-1</sup> and 4.57% for G2SF. © 2016 Chinese Chemical Society and Institute of Materia Medica, Chinese Academy of Medical Sciences.

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### 1. Introduction

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Since the report of organic light-emitting diodes (OLED) based on phosphorescent emitters, there has been intensive interest in these devices because they can harvest both singlet and triplet excitons for emission, providing the opportunity to realize internal quantum efficiency close to 100% [1]. Until now, most of the efficient phosphorescent organic light-emitting diodes (PHOLEDs) have been fabricated through vacuum thermal evaporation which allows for complicated vertical device architectures and delivers excellent devices with high efficiencies [2,3], but requires complicated technological processes and, consequently, is much more costly. It is generally believed that solution-based processes, such as spincoating or ink-jet printing, are relatively inexpensive and can be utilized for the preparation of large-area displays [4]. To date, solution-processed PHOLEDs are mainly focused on polymeric materials by incorporation of heavy metal complexes through physical blending in polymer hosts like polyvinylcarbazole (PVK) [5] and polyfluorene (PFO) [6] or chemical bonding on polymer chains

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[7]. However, the applicability of polymeric materials is greatly 28 hampered by intrinsic disadvantages, such as the uncertain 29 molecular structure and difficulty in purification, while the purity 30 of materials has a great influence on electroluminescence perfor-31 mance. In contrast, conjugated dendrimers have emerged as a new 32 type of light-emitting organic materials for application in OLEDs [8]. 33 They combine the advantages of both small molecules and polymeric 34 35 materials, for example, repeatable monodispersity and high levels of purity of small molecules, and good solubility and film-formation 36 ability by wet methods of polymers [9,10]. Therefore, dendritic 37 molecules with good solubility and excellent thermal stability, either 38 39 as hosts or doped emitters for solution-processible phosphorescent 40 light-emitting devices, have been investigated [11,12].

Due to the relatively long excited state lifetimes of triplet 41 emitters, the heavy metal complexes are usually doped into host 42 materials to reduce the self-quenching and triplet-triplet annihi-43 lation [13]. By the combination of both hole and electron 44 transporting moieties in one molecule, bipolar molecules in the 45 quest for highly efficient PHOLEDs have aroused considerable 46 interest because they enable a balanced density of charge and 47 simplified device structures [14,15]. One of the most important 48 core structures of bipolar host molecules is the carbazole moiety 49 due to its large triplet energy and good hole-transport property 50

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[16-21]. To achieve bipolarity in the molecular designs based on 51 52 carbazole, various moieties capable of accepting electrons were 53 incorporated to give novel bipolar hosts [22-24]. For example, 54 Yang et al. reported a bipolar dendrimer with carbazole units as 55 hole-transporting units and oxadiazole units as electron-trans-56 porting units with maximum efficiencies of 16.8 cd A<sup>-1</sup> and 5.7% 57 obtained for solution-processed green PHOLEDs by using Ir(ppy)<sub>3</sub> 58 as guests [23]. Most recently, Li et al. reported a carbazole-based 59 molecule as a universal bipolar host material by attaching 3.6-60 bis(3,6-di-tert-butyl-carbazol-9-yl)-carbazole and pyrazole to the 61 dimethylbiphenyl core, achieving high luminance efficiencies of 35 cd  $A^{-1}$  and 39 cd  $A^{-1}$  for green and red electrophosphorescence, 62 63 respectively, by incorporating electron-transporting 2,2'-(1,3-64 phenylene)bis[5-(4-tert-butylphenyl)-1,3,4-oxadiazole] (OXD-7) 65 in the emitting layer as a mixed host [24].

66 In this paper, we report the synthesis and characterization of two 67 novel carbazole-based dendrimers, namely G1SF and G2SF, for 68 potential application as bipolar host materials. The electron-69 accepting dibenzothiophene was selected as the core, and the 70 well-known electron-donating oligo-carbazole dendrons were 71 attached at both terminals of the dibenzothiophene. Furthermore, 72 tert-butyl groups are introduced into the dendrimers surface to 73 enhance the solubility of these dendrimers. The dendrimers designed 74 in this way are observed to exhibit excellent thermal stability, to 75 possess relatively shallow, highest occupied, molecular orbital 76 (HOMO) levels, and to have the spatial separation of the HOMO 77 and LUMO energy levels. The green PHOLEDs using G1SF or G2SF, as a 78 host material by the spin-coating method with traditional  $Ir(ppy)_3$  as doped emitter, show the maximum luminance efficiency  $(\eta_l)$  of 79 80 19.83 cd  $A^{-1}$  and a maximum external guantum efficiency of 5.85%.

### 81 2. Experimental

### 82 2.1. Materials and methods

83 Chemicals, reagents and solvents from commercial sources are 84 of analytical, or spectroscopy grade and used as received without 85 further purification. The <sup>1</sup>H NMR spectra were recorded on an 86 AVANCE-400 NMR spectrometer (400 MHz). Mass spectra were 87 recorded on a gas chromatograph-time of flight (GC-TOF) mass 88 spectrometer (Micromass, UK) for EI-TOF-MS and a MALDI micro 89 MX (Waters, USA) for matrix-assisted laser desorption time of 90 flight (MALDI-TOF) mass spectra. Thermogravimetry analyses 91 (TGA) were carried out using a Pyris1 TGA (PerkinElmer Corp., USA) at a heating rate of 10 °C min<sup>-1</sup> under a nitrogen atmosphere. The 92 93 fluorescence and UV-vis absorption spectra measurements were 94 performed on a Hitachi F-4600 spectrofluorophotometer and a UV-95 265 spectrophotometer, respectively. Electrochemical measure-96 ments were made by using a conventional three-electrode 97 configuration and an EG & G PAR 283 potentiostatic instrument at a scan rate of 100 mV s<sup>-1</sup>. A glassy carbon working electrode, a 98 99 Pt-wire counter electrode, and a saturated calomel electrode (SCE) 100 as reference electrode were used. All measurements were made at 101 r.t. on samples dissolved in dichloromethane, with 0.1 mol  $L^{-1}$ tetra-*n*-butyl ammonium hexafluorophosphate (Bu<sub>4</sub>NPF<sub>6</sub>) as the 102 103 electrolyte, and ferrocene as the internal standard [25]. Density 104 functional theory (DFT) calculations using B3LYP functional were 105 performed. The basis set used for C, H, N atoms was 6-31G. There 106 are no imaginary frequencies for both optimized structures. All 107 these calculations were performed with Gaussian 09 [26].

108The patterned ITO substrates were cleaned by successive109ultrasonications in detergent, deionized water, ethanol, and110dichloromethane, followed by treatment with UV-ozone for11120 min. A 40 nm thick PEDOT:PSS film was first spin-coated on112pre-treated ITO substrates from an aqueous dispersion and baked113at 120 °C for 40 min in air. Subsequently, blends of host: Ir(ppy)<sub>3</sub> in

chlorobenzene were filtered through a 0.45 µm PTFE filter and 114 spin-coated on PEDOT/PSS film, the thickness of which was 115 controlled at 40 nm by adjusting the spin rate. The substrate was 116 transferred into a vacuum chamber to deposit the TPBI layer at a 117 base pressure less than  $10^{-6}$  Torr. Finally, the device fabrication 118 was completed through thermal deposition of LiF (1 nm) and then 119 capping with Al metal (100 nm) as cathode. The EL spectra, CIE 120 coordinates, and current density-voltage-luminance relationships 121 of devices were measured by the IY SPEX CCD 3000 photometer 122 and a Keithley 237 instrument. All the measurements were carried 123 out in ambient condition at r.t. 124

#### 2.2. Synthesis and characterization

The carbazole dendrons D1 and D2 were synthesized and characterized according to literature methods [27].

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Synthesis of compound 1: To a solution of dibenzothiophene (940 mg, 5.5 mmol), iodine (1.34 g, 5.2 mmol), iodic acid (1.58 g, 9.0 mmol), acetic acid (5 mL) and chloroform (5 mL), was added water (0.5 mL) and concentrated sulfuric acid (0.5 mL, 98%). The mixture was stirred at 50 °C for 18 h, and then 10 mL water was added. The organic layer was separated and washed with diluted HCl and brine, then dried over anhydrous MgSO<sub>4</sub>. The solvent was removed under vacuum and the residue was recrystallized from a mixed solvent of chloroform/ethanol (v/v = 3:1) to give 1 as a light-yellow crystal (1.83 g, 75% yield). EI-TOF-MS (m/z): 435.84 [M<sup>+</sup>].

Synthesis of G1SF: A mixture of compound 1 (100 mg, 138 0.23 mmol), D1 (154 mg, 0.55 mmol), CuI (5 mg, 0.03 mol), and 139 K<sub>2</sub>CO<sub>3</sub> (20 mg, 0.15 mmol) were added to a 50 mL 2-neck flask, and 140 then 18-crown-6 (5 mg, 0.02 mmol) and o-dichlorobenzene 141 (20 mL) were added under a nitrogen atmosphere. After stirring 142 for 12 h at 160 °C, the reaction mixture was cooled to r.t. The 143 solvent was removed under reduced pressure, dichloromethane 144 and water were added. The organic layer was separated and 145 washed with diluted HCl and brine, then dried over anhydrous 146 MgSO<sub>4</sub>. The solvent was removed to dryness and the residue was 147 purified by column chromatography over silica gel with petroleum 148 ether/dichloromethane (4:1) as the eluent to give G1SF as a white 149 solid (224 mg, 60% yield). Confirmation data: <sup>1</sup>H NMR (400 MHz, 150 CDCl<sub>3</sub>): δ 8.28 (d, 2H, ArH), 8.15 (d, 4H, ArH), 8.10 (s, 1H, ArH), 8.08 151 (s, 1H, ArH), 7.71–7.69 (m, 2H, ArH), 7.46–7.43 (m, 4H, ArH), 7.37 152 (s, 2H, ArH), 7.34 (s, 2H, ArH), 1.45 (s, 36H, CH<sub>3</sub>); MALDI-TOF-MS 153 (*m*/*z*): calcd. for C<sub>52</sub>H<sub>54</sub>N<sub>2</sub>S, 738.4008; found, 738.3795 [M<sup>+</sup>]. 154

Synthesis of G2SF: A mixture of compound 1 (100 mg, 155 0.23 mmol), **D2** (400 mg, 0.55 mmol), CuI (5 mg, 0.03 mmol), 156 and K<sub>2</sub>CO<sub>3</sub> (20 mg, 0.15 mmol) were added to a 50 mL 2-neck flask, 157 and then 1,10-phenanthroline monohydrate (10 mg, 0.05 mmol) 158 and toluene (20 mL) were added under a nitrogen atmosphere. 159 After stirring for 48 h at 110 °C, the solvent was removed under 160 reduced pressure. Water was added and the mixture was extracted 161 with dichloromethane. The organic layer was separated and 162 washed with diluted HCl and brine, then dried over anhydrous 163 MgSO<sub>4</sub>. The solvent was removed to dryness and the residue was 164 purified by column chromatography over silica gel with petroleum 165 ether/dichloromethane (4:1) as the eluent to give G2SF as a white 166 solid (58 mg, 35% yield). Confirmation data: <sup>1</sup>H NMR (400 MHz, 167 CDCl<sub>3</sub>):  $\delta$  8.56 (s, 2H, ArH), 8.29–8.24 (m, 6H, ArH), 8.13 (s, 8H, 168 ArH), 7.92–7.89 (m, 2H, ArH), 7.64–7.57 (m, 8H, ArH), 7.43–7.41 169 (m, 8H, ArH), 7.32 (d, 8H, ArH), 1.45 (s, 72H, CH<sub>3</sub>); MALDI-TOF-MS 170 (m/z): calcd. for C<sub>116</sub>H<sub>114</sub>N<sub>6</sub>S, 1624.2516; found, 1624.0037 [M<sup>+</sup>]. 171

### 3. Results and discussion

The synthetic routes for the target dendrimers (G1SF, G2SF) are173shown in Scheme 1. First, the important intermediates including174the carbazole dendrons (D1, D2) were synthesized according to175

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Scheme 1. Structures and synthetic routes of G1SF and G2SF.

176 literature methods [27], as detailed in Scheme 1. The 3,6-177 diiododibenzothiophene (1) was then obtained at a high yield of 178 75% by iodination of benzothiophene in presence of iodic acid at 179 50 °C. It is found that use of the traditional periodic acid often resulted in mono-iodinated byproducts. Finally, the target 180 compounds G1SF and G2SF were then prepared at a moderate 181 yield of 35% and 60% by the Ullmann C-N coupling reaction 182 between the bis-iodinated dibenzothiophene 1 with an excess 183 184 molar ratio of carbazole dendrons D1 and D2, respectively. They 185 have good solubility in common organic solvents such as dichloromethane, tetrahydrofuran and ethyl acetate, so they can 186 187 be easily purified by column chromatography and recrystallized to 188 high purity for spectroscopic characterization and OLEDs applica-189 tion. Their chemical structures were confirmed by <sup>1</sup>H NMR 190 spectroscopy, MALDI-TOF mass spectrometry.

191The thermal stability of the studied dendrimers was investi-192gated by means of thermogravimetric analysis (TGA) at a scanning193rate of 10 °C min<sup>-1</sup> and the data are listed in Table 1. As shown by194the TGA curves in Fig. 1, G1SF and G2SF exhibit high thermochem-195ical stability with decomposition temperatures ( $T_d$ , corresponding

Table 1				
Summary of physica	l data o	of the	dendrimer	S

Sammary of physical data of the denaminers.							
Comp.	$\lambda_{abs}$ $(nm)^a$	λ <sub>em</sub> (nm) <sup>a</sup>	<i>T</i> <sub>d</sub> (°C)	HOMO (eV) <sup>b</sup>	Eg (eV) <sup>c</sup>	LUMO (eV)	
G1SF G2SF	297, 347 297, 348	403 401	432 451	-5.45 -5.37	3.20 3.10	-2.25 -2.27	

<sup>a</sup> Measured in CH<sub>2</sub>Cl<sub>2</sub> solution.

<sup>b</sup> Calculated with reference to ferrocene (4.8 eV).

<sup>c</sup> The optical band gap, calculated by the absorption edge technique.

to 5% weight loss) up to 430 °C. This is an essential feature for<br/>organic light-emitting materials especially when they are used at<br/>high temperature. The thermal stability is attributed to the<br/>presence of carbazole dendrons, which are known for their<br/>excellent thermal and chemical stabilities [28].196<br/>198<br/>199<br/>200

The photophysical properties of these dendrimers were 201 investigated by means of electronic absorption and steady state 202 photoluminescence (PL) measurements of dilute solutions in 203 dichloromethane. The pertinent data are summarized in Table 1. As 204 shown in Fig. 2, both dendrimers exhibit two major absorption 205 bands in the ultra-violet region. The absorption around 297 nm 206 could be assigned to the  $\pi$ - $\pi^*$  local electron transition of the 207 carbazole dendrons at the terminal ends, and the longer 208 wavelength ranging from 310 nm to 370 nm could be attributed 209 to the  $\pi - \pi^*$  electron transition of the entire conjugated backbone. 210 Upon photoexcitation at the absorption maxima, both the 211 dendrimers exhibit deep-blue emission in dichloromethane 212 solutions with emission peaks at 403 and 401 nm for G1SF and 213 G2SF. Furthermore, there is little overlap between the absorption 214 and emission spectra for these two molecules, thus self-absorption 215 can be dramatically eliminated, which is a very important attribute 216 for materials used in optoelectronic devices. 217

The electrochemical behavior of these dendrimers was investi-218 gated by the cyclic voltammetry method in a nitrogen atmosphere, 219 as shown in the cyclic voltammograms in Fig. 3. Upon the anodic 220 sweep, G1SF and G2SF show one and two reversible oxidation 221 processes, respectively, with the first oxidation wave of G2SF 222 shifting to less positive potentials than that of G1SF. This implies 223 that the removal of the first electron from these dendritic 224 molecules become easier with increasing dendron generation. 225

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Fig. 1. TGA traces of (a) G1SF and (b) G2SF.

This is inconsistent with the previous observation that the electron density increasingly gathers on the outmost carbazole rings with increasing carbazole dendron generation [29]. The onset potential  $(E_{ox}^{onset})$  of the first oxidation wave is in the range of 0.65 ~ 0.57 V relative to ferrocene for these materials. The HOMO energy levels were estimated from the onset potentials to be -5.45 and -5.37 eV for G1SF and G2SF, respectively, according to the equation of HOMO



**Fig. 2.** Absorption and fluorescence spectra of G1SF and G2SF in dilute dichloromethane solutions.



Fig. 3. Cyclic voltammograms of G1SF and G2SF measured in  $\rm CH_2Cl_2$  at a scan rate of 100 mV s  $^{-1}.$ 

 $(eV) = -(E_{ox}^{onset} + 4.8 eV)$  [24]. Apparently the HOMO levels of these 233 carbazole-based dendrimers are higher than those of both CBP 234 (-5.69 eV) and PVK(-5.8 eV) and quite close to the work function of 235 the widely-used hole injecting material PEDOT:PSS (-5.2 eV) [30], 236 237 implying that efficient hole injection into the emitting layer could be expected when these dendrimers are used as host materials in the 238 emitting layer of PHOLEDs. Because no clear reduction wave was 239 observed within the potential window of the cyclic voltammograms, 240 the LUMO energy levels were deduced from HOMO energy levels 241 and the optical band gaps determined by the onset of absorption 242 [24]. The deduced LUMO levels are -2.25 eV and -2.27 eV for G1SF 243 and G2SF, respectively. The detailed electrochemical and electronic 244 data of these molecules are listed in Table 1. 245

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In order to gain insight into the electronic properties of these dendrimers, the spatial distribution of HOMO and LUMO was calculated with the Gaussian 03 package at the B3LYP/6-31G(d) level, using the Density Function Theory (DFT) for the geometry optimization [21]. Fig. 4 illustrates the HOMO and LUMO distribution for both G1SF and G2SF. It is obvious that, G1SF exhibits only a partial separation of the HOMO and LUMO levels, possibly due to intramolecular charge transfer. The HOMO of G1SF spreads over the whole molecular skeleton with major contributions from the two carbazole rings, while the LUMO is mainly located on the benzothiophene moiety. But for G2SF, it is observed that the HOMO orbital is mainly located on the electron-donating carbazole dendron moiety, while the LUMO orbital delocalize on the electron-accepting benzothiophene moiety. The separation between HOMO and LUMO levels is preferable for efficient holeand electron-transporting properties (bipolar) and the prevention of reverse energy transfer, and thus to benefit to the EL performance of the PHOLEDs.

In order to evaluate the capability of G1SF and G2SF as host 264 materials in PHOLEDs, the green-light emitting devices with the 265 configuration of ITO/PEDOT:PSS (40 nm)/G1SF (device A) or G2SF 266 (device B): Ir(ppy)<sub>3</sub> (6 wt%, 40 nm)/TPBI (30 nm)/LiF (1 nm)/Al 267 (100 nm) was fabricated. In these devices, PEDOT:PSS [poly(3,4-268 ethylenedioxythiophene):poly(styrene sulfonate)] is used as the 269 hole-injecting layer. The Ir(ppy)<sub>3</sub> doped emitting layer was 270 fabricated by spin coating the mixed solution of the host and 271 dopant on top of the PEDOT:PSS layer. The doping concentration 272 was carefully tuned in order to reach as good a performance as 273 possible. TPBI {1,3,5-tris[*N*-(phenyl)benzimidazole]-benzene} is 274 275 then deposited by vacuum thermal evaporation on top of the 276 emitting layer to act as the electron-transporting and hole-277 blocking layer. Both devices show typical green emission at around 512 nm originating from the guest  $Ir(ppy)_3$ , as show by the EL 278 279 spectra in Fig. 5. The absence of any residual emission from the dendrimer hosts or TPBI layer even at high current densities 280

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Fig. 4. Frontier molecular orbitals (HOMO and LUMO) distribution for G1SF and G2SF calculated with DFT on a B3LYP/6-31G(d) level.

281 suggests a complete energy transfer from these dendrimer hosts to 282 the iridium dopant and the effective hole-blocking function of TPBI layer in addition to its electron transporting role.

283 layer in addition to its electron-transporting role.



Fig. 5. EL spectra of the green devices A and B at 10 V.

The current density-voltage-brightness (*I*-V-L) characteristics 284 and efficiencies versus current density curves of the devices are 285 shown in Fig. 6. The G2SF based device B has a lower turn-on 286 voltage (4.9 V, corresponding to 1 cd  $m^{-2}$ ) than that (6.0 V) for 287 G1SF based device A. It is also evident that the current density of 288 device B was higher than that of the corresponding device A in spite 289 of the identical device configuration, presumably because of the 290 facilitated hole injection and transportation in device B. According 291 to the energy level diagram in Fig. 7, the HOMO level of G2SF 292 (-5.37 eV) is slightly higher than that of G1SF (-5.45 eV). Thus the 293 slightly smaller hole injection barrier at the ITO/dendrimer 294 interface in G2SF based device B should be responsible for its 295 lower driving voltages. In addition, the possible high hole-296 transporting mobility in the bulky layer of dendrimer G2SF due 297 to high density of hole-transporting carbazole groups is probably 298 another reason for the relatively high current in G2SF based device 299 B. The G1SF based device A exhibited a maximum luminance of 300 8837 cd m<sup>-2</sup> at 16 V, and a maximum luminance efficiency  $\eta_L$  of 301 15.50 cd  $A^{-1}$ , corresponding to a peak power efficiency  $\eta_p$  of 302 5.03 lm W<sup>-1</sup> and forward-viewing external quantum efficiency 303  $\eta_{\text{ext}}$  of 4.57%. The G2SF based device B achieved the maximum 304 efficiencies of 19.83 cd  $A^{-1}$ , 6.78 lm  $W^{-1}$  and 5.85%. Apparently, 305 the efficiencies of the present devices exceed the best literature 306



Fig. 6. (a) Voltage-current density-luminance (V-J-L) characteristics and (b) the luminance efficiency and external quantum efficiency curves for the green-emitting devices A and B.

2.25

ITO/

PEDOT

5.2

2 27

G2SF

5.37

5.45

27

TPBI

6.2

LiF

4.3

Ir(ppy)3

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- Ir(ppy)<sub>3</sub>

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Fig. 7. Energy level diagram for the OLEDs. Insert: chemical structures of Ir(ppy)<sub>3</sub>.

Device	V <sub>turn-on</sub> (V)	$L_{\rm max}$ (cd m <sup>-2</sup> , V)	$\eta_{L(\max)}$ (cd A <sup>-1</sup> , V)	$\eta_{p(\max)}$ (lm W <sup>-1</sup> , V)	$\lambda_{max}$ (nm)	CIE ( <i>x</i> , <i>y</i> )
A B	6 4.9	8837, 16 10.480, 16	15.50, 10 19.83, 10	5.03, 9 6.78, 9	4.57 5.85	0.29, 0.63 0.28, 0.63
			,			

data (15 cd A<sup>-1</sup>) of the partially solution-processed phosphores-307 308 cent device with  $PVK:Ir(ppy)_3$  emitting layer [31]. The detailed performances of these devices are summarized in Table 2. 309

#### 4. Conclusion 310

311 In summary, novel carbazole-based dendrimers have been 312 developed by attaching oligo-carbazole dendrons at both 313 terminals of the dibenzothiophene core through Ullmann 314 coupling reactions. The thermochemical and electrochemical 315 studies revealed that these compounds have high thermal 316 stability with  $T_d$  values of over 430 °C and excellent electro-317 chemical reversibility. More importantly, these molecules have 318 the spatial separation of the HOMO and LUMO energy levels at 319 the electron donor and acceptor moieties. The solution-320 processed green electrophosphorescent devices by using these 321 dendritic hosts and iridium complex dopant exhibited good performance with the maximum luminance efficiency  $(\eta_L)$  of 322 323 19.83 cd A<sup>-1</sup> and a maximum external quantum efficiency of 324 5.85%. The present study demonstrated that these carbazole-325 based dendrimers may find potential applications as bipolar 326 host materials for solution-processed PHOLEDs.

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