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Blue Organic Light-Emitting Diodes Containing Anthracene Derivatives With End-Capping Phenyl Group

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We have synthesized and characterized new blue host materials for OLEDs; 9,10-di-o-tolylanthracene (1), 2-tert-butyl-9,10-diphenylanthracene (2), 10,10'-diphenyl-9,9'-bianthracene (3), and 1,4-bis(10-phenylanthracen-9-yl)benzene (4). To explore electro-luminescent properties of these materials, multilayered OLEDs with the configuration of ITO/NPB (50 nm)/Blue emitters (1–4) (30 nm)/LiQ (2 nm)/Al (100 nm) were fabricated. Among those non-doped devices, the device 4a employing 4 as an emitter showed high efficiencies of 4.11 cd/A, 3.31 lm/W, and 2.35%, respectively. The device 2b employing 2 as host material for PFVtPh blue dopant material exhibited excellent efficiencies with 5.64 cd/A, 4.14 lm/W, and 4.54%.

Keywords Blue fluorescent materials; deep blue emitting materials; diphenylanthracene; electroluminescence; OLEDs

Introduction

Since the pioneering report of Tang et al., organic light emitting devices (OLEDs) have attracted enormous interest because of their high efficiency, pure color reproduction, fast response, and wide viewing angle [1]. For full-color display application, efficient blue, green, and red emitters are required. Highly efficient and stable green OLEDs have already been realized [2]. To date, a number of π -conjugated materials have been reported to exhibit electroluminescence (EL) ranging from red to green and blue. In particular, it is difficult to generate high-performance blue emissions because the intrinsically wide band-gap makes it hard to inject charges into blue emitters. As a result, the electroluminescence (EL) performance of blue light-emitting devices is generally inferior to those of green- and red-EL. Thus, the development of novel blue light-emitting materials is of current concern [3]. Recently, various blue emitting materials, such as anthracene [4], di(styryl)arylene [5], and tetra(phenyl)silyl derivatives [6] have been developed.

Anthracene derivatives commonly possess excellent photoluminescence (PL) and electroluminescence (EL) properties [7–9]. Among those, 9,10-Diphenylanthracene (DPA) is a good candidate for blue host material for OLEDs because it has the suitable band-gap

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($E = 3.2$ eV) and excellent luminescent quantum yield ($\Phi = 0.90$) in dilute solution [10]. However, the self-aggregation between DPA reduces greatly the EL performances of solid state OLEDs. Furthermore, it tends to be crystallized in thin films, thereby limiting its OLEDs applications. For example, crystal formation deconstructs film homogeneity and raises the resistance of the sample, ultimately leading to device failure [11–13].

In order to prevent these problems, we have synthesized new host materials; 9,10-di-o-tolylanthracene (**1**), 2-*tert*-butyl-9,10-diphenylanthracene (**2**), 10,10'-diphenyl-9,9'-bianthracene (**3**), and 1,4-bis(10-phenylanthracen-9-yl)benzene (**4**) (Scheme 1). All compounds (**1–4**) are designed for reducing the intermolecular interaction and preventing the self-aggregation in solid state devices to improve EL performances [9]. In addition, we have investigated their optical and electroluminescent properties. Multilayered OLED are fabricated by using these host materials as the emitting layer (non-doped) and the host material for **PFVtPh** [14] and **PCVtPh** [15] (doped).

Experimental

Synthesis

o-Bromotoluene, bromobenzene, anthraquinone, 2-*tert*-butylanthraquinone, phenyl boronic acid, and 1,4-dibromobenzene were used as received from Aldrich or TCI. 9-Phenyl-10-anthracene boronic acid [16], 10,10'-dibromobiphenyl [17], 4'-[2-(2-Diphenylamino-9,9-diethyl-9H-fluoren-7-yl)vinyl]-p-terphenyl (**PFVtPh**) [14], and 3-(N-phenylcarbazol)vinyl-p-*tert*-phenyl (**PCVtPh**) [15] were synthesized as reported previously. The solvent were dried using standard procedures. All reagents were used as received from commercial sources, unless otherwise stated. All reactions were performed under N₂ atmosphere.

9,10-Di-o-tolylanthracene (**1**): To 1-bromotoluene (1.22 g, 7.13 mmol) dissolved in THF (10 mL) was added 4.6 mL of n-butyllithium (1.6 M in hexane) slowly at -78°C . To the suspension, anthraquinone (0.5 g, 2.37 mmol) in THF (10 mL) was added dropwise at -78°C . The mixture was left to reach room temperature. The water was added and the organic phase separated. The water phase was extracted with diethyl ether. The combined organic fractions were dried over magnesium sulfate and the volatiles removed in vacuo to deliver a foamy residue. To this residue were added potassium iodide (2.04 g, 12.29 mmol), sodium hypophosphite monohydrate (2.04 g, 23.19 mmol), and acetic acid (25 mL), and the mixture was heated under reflux for 3 h. After cooling, the crude solid was filtered, washed with water, and recrystallized from CH₂Cl₂/EtOH, afforded **1** (1.45 g, 81.0%). ¹H-NMR (300 MHz, CDCl₃) [δ ppm]: 7.56 (dd, $J = 3.3, 6.6$ Hz, 4H), 7.48–7.46 (m, 4H), 7.43–7.38 (m, 4H), 7.32 (dd, $J = 3.6, 6.8$ Hz, 6H), 1.93 (s, 6H). ¹³C-NMR (75 MHz, CDCl₃) [δ ppm]: 138.7, 138.1, 136.5, 131.6, 131.5, 130.3, 129.9, 128.1, 127.0, 126.1, 126.0, 125.4, 20.0. FT-IR [ATR]: ν 3708, 3680, 2981, 2972, 1738, 1371, 1055, 771, 752 cm⁻¹. MS(EI⁺) m/z 358 (M⁺). Anal. calcd for C₂₈H₂₂: C 93.81, H 6.19; found: C 93.11, H 6.39.

2-*tert*-Butyl-9,10-diphenylanthracene (**2**): To 1-bromobenzene (0.89 g, 5.67 mmol) dissolved in THF (10 mL) was added 3.54 mL of n-butyllithium (1.6 M in hexane) slowly at -78°C . To the suspension, 2-*tert*-butylanthraquinone (1.38 g, 5.0 mmol) in THF (10 mL) was added dropwise at -78°C . The mixture was left to reach room temperature. The distilled water was added and the organic phase separated. The water phase was extracted with diethyl ether. The combined organic fractions were dried over magnesium sulfate and the volatiles removed in vacuo to deliver a foamy residue. To this residue were added

potassium iodide (2.77 g, 16.69 mmol), sodium hypophosphite monohydrate (2.77 g, 31.53 mmol), and acetic acid (22 mL), and the mixture was heated under reflux for 3 h. After cooling, the precipitate was collected, washed with plenty of distilled water, and dried. Concentration of the CH_2Cl_2 solution, followed by column chromatography on silica gel with CH_2Cl_2 /hexane, afforded **2** (1.58 g, 89.0%). $^1\text{H-NMR}$ (300 MHz, CDCl_3) [δ ppm]: 7.71–7.67 (m, 3H), 7.64–7.54 (m, 7H), 7.50–7.45 (m, 4H), 7.42 (s, 1H), 7.32–7.28 (m, 2H), 1.26 (s, 9H). $^{13}\text{C-NMR}$ (75 MHz, CDCl_3) [δ ppm]: 147.5, 139.5, 137.1, 136.9, 131.6, 130.3, 129.8, 128.7, 128.6, 128.5, 127.6, 127.2, 126.9, 125.1, 124.9, 124.8, 121.4, 35.2, 31.0. FT-IR [ATR]: ν 3709, 3680, 2981, 2971, 1738, 1365, 1055, 700 cm^{-1} MS(EI^+) m/z 386 (M^+). Anal. calcd for $\text{C}_{30}\text{H}_{26}$: C 93.22, H 6.78; found: C 92.67, H 7.03.

10,10'-Diphenyl-9,9'-bianthryl (**3**): 10,10'-dibromo-9,9'-bianthryl (1.2 g, 2.34 mmol) and phenyl boronic acid (0.85 g, 7.02 mmol), $\text{Pd}(\text{PPh}_3)_4$ (0.41 g, 0.35 mmol), aqueous 2.0 M Na_2CO_3 (2.48 g, 22.8 mmol), and toluene (24 mL) were mixed in a flask. The mixture was refluxed for 4 h. When the reaction was completed, water was added to quench the reaction. After cooling, the crude solid was collected by filtration, washed with water, and ethanol. The product was recrystallized from CH_2Cl_2 /EtOH, afforded **3** (0.8 g, 67.8%). $^1\text{H-NMR}$ (300 MHz, CDCl_3) [δ ppm]: 7.82 (d, $J = 8.7\text{ Hz}$, 4H), 7.69–7.59 (m, 10H), 7.32 (td, $J = 1.2, 7.7\text{ Hz}$, 4H), 7.25 (d, $J = 8.4\text{ Hz}$, 4H), 7.17–7.12 (m, 4H). $^{13}\text{C-NMR}$ (75 MHz, CDCl_3) [δ ppm]: 139.3, 138.1, 133.7, 131.7, 131.6, 130.4, 128.7, 127.8, 127.5, 127.4, 125.8, 125.5. FT-IR [ATR]: ν 3062, 1739, 1441, 1363, 768, 706 cm^{-1} MS(EI^+) m/z 506 (M^+). Anal. calcd for $\text{C}_{40}\text{H}_{26}$: C 94.83, H 5.17; found: C 93.40, H 5.30.

1,4-Bis(10-phenylanthracen-9-yl)benzene (**4**): 1,4-dibromobenzene (1 g, 4.23 mmol) and 10-phenylanthracen-9-yl boronic acid (2.7 g, 9.32 mmol), $\text{Pd}(\text{PPh}_3)_4$ (0.20 g, 0.17 mmol), aqueous 2.0 M Na_2CO_3 (4.49 g, 42.39 mmol), ethanol (21 mL) and toluene (42 mL) were mixed in a flask. The mixture was refluxed for 3 h. When the reaction was completed, water was added to quench the reaction. After cooling, the crude solid was collected by filtration, washed with water, and ethanol. The product was recrystallized from CH_2Cl_2 /EtOH, afforded **4** (2.1 g, 85.4%). $^1\text{H-NMR}$ (300 MHz, CDCl_3) [δ ppm]: 7.99 (d, $J = 8.7\text{ Hz}$, 4H), 7.76 (t, $J = 8.7\text{ Hz}$, 2H), 7.74 (s, 4H), 7.68–7.59 (m, 8H), 7.55 (dd, $J = 1.5, 8.0\text{ Hz}$, 4H), 7.50–7.48 (m, 4H), 7.44–7.39 (m, 4H). FT-IR [ATR]: ν 3061, 2360, 2341, 1736, 1440, 1368, 764, 702 cm^{-1} MS(EI^+) m/z 582 (M^+). HRMS-TOF ($\text{M}^+ + \text{H}$) Anal. calcd for $\text{C}_{48}\text{H}_{32}\text{N}$ 583.242576; found: 583.23936. Anal. calcd for $\text{C}_{46}\text{H}_{30}$: C 94.81, H 5.19; found: C 93.58, H 5.29.

Fabrication of OLED

OLEDs using red-light-emitting molecules were fabricated by vacuum (10^{-6} torr) thermal evaporation onto pre-cleaned ITO coated glass substrates. All processes were carefully produced. The indium tin oxide (ITO) was first cleaned with acetone, methyl alcohol, distilled water, and kept in isopropyl alcohol for 48 h and dried by N_2 gas. The substrates were treated by O_2 plasma under 2.0×10^{-2} torr at 125 W for 2 min [18]. All organic materials and metals were deposited under high vacuum (5×10^{-7} torr). The OLEDs were fabricated in the following sequence: ITO/4,4'-Bis(N-(1-naphthyl)-N-phenylamino)biphenyl (NPB) (50 nm)/Blue emitting materials (**1–4**) (30 nm)/4,7-Diphenyl-1,10-phenanthroline (Bphen) (30 nm)/Lithium quinolate (Liq) (2 nm)/Al (100 nm), NPB as the hole-transporting layer, Bphen as the electron-transporting layer, and Liq:Al as the composite cathode. The current density (J), luminance (L), luminous efficiency (LE), and CIE chromaticity coordinates of

the OLEDs were measured with a Keithly 2400, Chroma meter CS-1000A. Electroluminescence was measured using a Roper Scientific Pro 300i.

Measurements

^1H - and ^{13}C -NMR were recorded on a Varian Unity Inova 300Nb spectrometer. FT-IR spectra were recorded using a Bruker VERTEX70 FT-IR spectrometer. Elemental analysis (EA) was measured using a EA 1108 spectrometer. Low- and high- resolution mass spectra were measured using a Jeol JMS-600 spectrometer in the EI mode and a JMS-T100TD (AccuTOF-TLC) in the positive ion mode.

The UV-Vis absorption spectra were measured in CH_2Cl_2 solution (10^{-5} M) using a Shimadzu UV-1650PC. The photoluminescence were obtained in CH_2Cl_2 solution (10^{-5} M) and thin film using an Amincobrowman series 2 luminescence spectrometer. The fluorescent quantum yields were determined in the CH_2Cl_2 solution at 293 K against the host ($\Phi_{\text{DPA}} = 0.90$) as a standard. The energy levels were measured with a low-energy photo-electron spectrometer (Riken-Keiki, AC-2). Thermal property was measured using thermogravimetric analysis (TGA) (DTA-TGA, TA-4000) under N_2 at a heating rate of $10^\circ/\text{min}$.

Results and Discussion

The thermal property of **1–4** was thermally stable up to $276\text{--}402^\circ\text{C}$, as shown by its decomposition temperature (T_d ; corresponding to 5% weight loss) determined from its Thermogravimetric Analyzer (TGA) measurement. The thermal data of the **1–4** were also listed in Table 1.

The HOMO energy levels of **1–4** were measured by a low-energy photo-electron spectrometer (Riken-Keiki AC-2). Their HOMO/LUMO energy levels were $-5.85/-2.67$, $-5.76/-2.64$, $-5.75/-2.68$, and $-5.71/-2.61$, respectively. Also, the optical energy band gaps (E_g) of **1–4** were 3.18, 3.14, 3.07, and 3.10 eV, respectively, as determined from the absorption spectra. All compounds have higher energy band gaps (≥ 3.07 eV) than those of **PFVtPh** (2.82 eV) and **PCVtPh** (3.10 eV). Thus, it is possible that the efficient Förster energy transfer occur from **1–4** to **PFVtPh** and **PCVtPh**.

Figure 1 (a) showed that the emission spectra of the host materials (**1–4**) overlap with the absorption spectra of dopant materials (**PFVtPh** and **PCVtPh**), respectively.

Table 1. Optical properties of new host materials

Compound	T_d^a [$^\circ$]	UV_{max}^b [nm]	PL_{max}^b [nm]	PL_{max}^c [nm]	FWHM ^d [nm]	HOMO/LUMO [eV]	E_g [eV]	Φ^e
1	276	375	403	432	40	$-5.85/-2.67$	3.18	0.85
2	274	375	419	445	53	$-5.76/-2.64$	3.14	0.96
3	374	402	452	464	80	$-5.75/-2.68$	3.07	0.52
4	402	398	417	446	48	$-5.71/-2.61$	3.10	0.85
MADN	397^f	398^f	436^f	447^f	60^f	$-5.50^f/-2.50^f$	3.0^f	0.54

[a] The decomposition temperature (5% loss weight). [b] CH_2Cl_2 solution (10^{-5} M). [c] Thin film. [d] FWHM in thin film. [e] Using 9,10-diphenylanthracene as a standard; $\lambda_{\text{ex}} = 360$ nm ($\Phi = 0.90$ in CH_2Cl_2). [f.] Ref. 21.

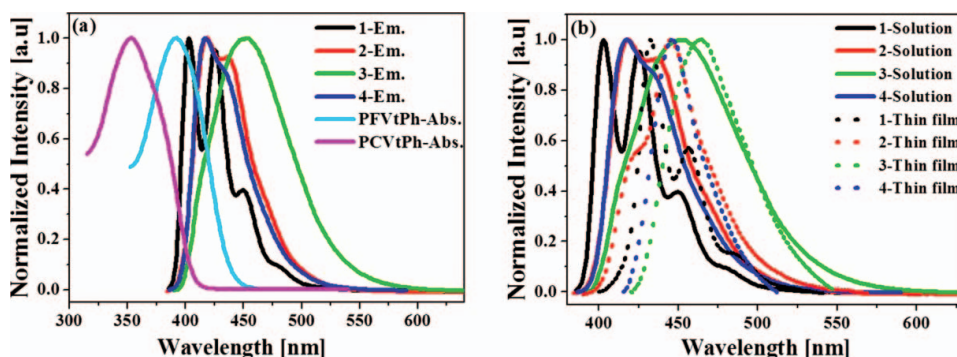


Figure 1. (a) The emission spectra of the host materials (**1-4**) and absorption spectra of dopant materials (**PFVtPh** and **PCVtPh**) in CH_2Cl_2 solution, and (b) the emission spectra of **1-4** in solution and thin film.

Presumably, **PFVtPh** (2.82 eV) can effectively accept energy from the host materials (**1-4**) through Förster-type energy transfer than **PCVtPh** (3.10 eV). The maximum emission peaks for **1-4** in CH_2Cl_2 solution ranged from 403 to 452 nm in the deep-blue region. In particular, **1** is the shorter emission peak (403 nm) than the others in PL spectra. This result indicates that the introduction of ortho-methyl groups in 9,10-diphenylanthracene can prevent π -conjugation between anthracene and phenyl moieties through the steric hindrance. Interestingly, compared to the PL spectrum of **2** and **4**, that of **3** shows a red shift (ca. 35 nm). Their full width at half maximum (FWHM), and the overall quantum yields of all compounds with the exception of **3** are narrow bandwidth (ca. 40–53 nm) and high values ($\Phi = 0.85$ –0.96). As shown in Fig. 1 (b), the emission spectra in thin films of **1-4** are red-shifted compared with those in CH_2Cl_2 solution owing to the solid-state effect [19].

The energy band diagrams of the devices **1a-4a** are depicted in Fig. 2. The EL properties of the devices **1a-4a** are summarized in Table 2. As shown in Fig. 3, the devices **2a-4a** emit blue region at 441–446 nm. Also, their full-width at half maximum (FWHM) are narrow (56–68 nm). In the case of the device **1a**, neither the light nor current is nearly occurred. Assumedly, the current leakage or catastrophic device failure in the device **1a** is generated, due to the formation of pin-hole or rough surface in thin film [12–14]. Fig. 4 shows the luminance-voltage-current density (L - V - J), luminous efficiencies (LE), power efficiencies (PE), and external quantum efficiency (EQE) of the devices **1a-4a**, respectively. Devices **2a-4a** reveal low turn-on voltages no greater than 4.0 V. The device **4a** displays the excellent EL performances; its luminous efficiency (LE), power efficiency (PE), and external quantum efficiency (EQE) reach 4.11 cd/A, 3.31 lm/W, and 2.36% (3.16 cd/A, 1.60 lm/W, and 1.80% at 20 mA/cm²), respectively. According to the energy diagrams in Fig. 2, we attribute high efficiencies of the device **4a** to the smaller barrier (0.31 eV) for hole injection from HTL (NPB) to the EML (**4**). In the case of **4a** having a little difference between the HOMO values of HTL and EML, the holes from NPB were easily transferred to EML. This result could be attributed the more balanced charge-transporting properties within the emissive layer achieved by better charge injection and confinement provided by HTL(NPB). Although the EL efficiencies are the highest in the device **4a**, it appears at sky-blue region with the CIE coordinates (0.232, 0.237) at 7.0 V because it seems that the excimer or exciplex formation is taken place in device **4a** as shown in the EL spectra.

Table 2. EL performance characteristic of the devices **1a–4a** (non-doped)

Device	V_{on}^{a} [V]	$\lambda_{\text{max}}^{\text{EL}}$, FWHM ^b [nm]	L^{c} [cd/m ²]	J^{c} [mA/cm ²]	$\text{LE}^{\text{d/e}}$ [cd/A]	$\text{PE}^{\text{d/e}}$ [lm/W]	$\text{EQE}^{\text{d/e}}$ [%]	CIE^{f} (x,y)
1a	—	—	—	1.2	0.25/—	0.18/—	0.35/—	—
2a	3.8	441, 56	541	155	1.70/0.65	1.41/0.31	2.67/0.96	(0.157,0.078)
3a	3.6	446, 56	788	196	2.11/1.45	1.74/0.76	1.90/1.32	(0.165,0.123)
4a	3.6	444, 63	2082	150	4.11/3.16	3.31/1.60	2.35/1.80	(0.232,0.237)
MADN	4.0	442, 55	954	154	1.35/1.08	1.01/0.48	1.45/0.98	(0.153,0.080)

[a] Turn-on voltage at 1 cd/m². [b] Emission maximum and FWHM of EL emission spectra. [c] Maximum luminance and current density. [d] Maximum values.
[e] At 20 mA/cm². [f] Commission Internationale d'Éclairage (CIE) at 7.0 V.

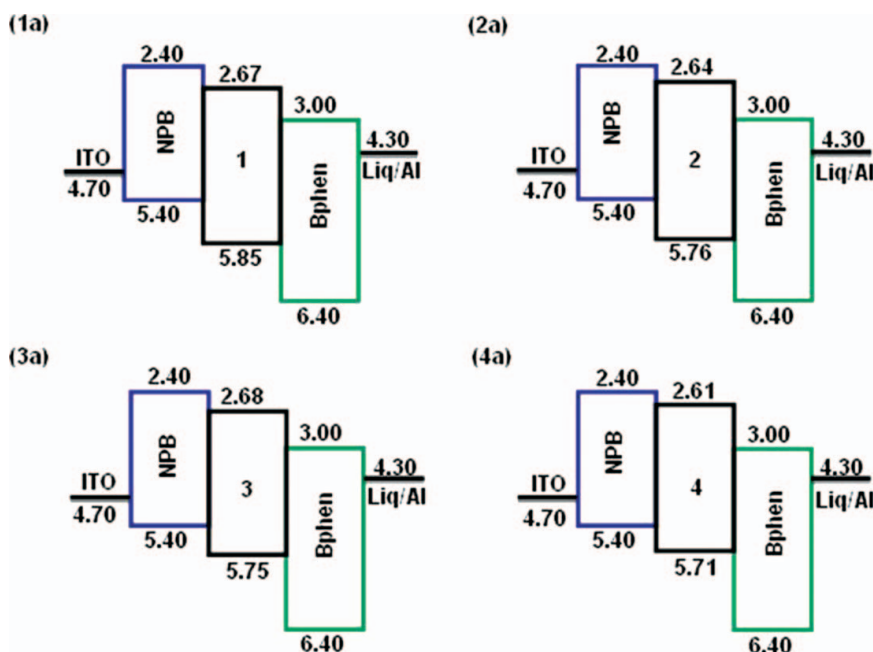


Figure 2. Energy diagrams of non-doped devices **1a–4a**.

In addition, in order to improve the efficiencies, we doped these host materials (**1–4**) with blue dopant materials (**PFVtPh** and **PCVtPh**) in the concentration of 8% in the same architecture, respectively. Figure 5 shows the EL spectra of the devices **b** (**PFVtPh**-doped) and devices **c** (**PCVtPh**-doped) and there are summarized in Table 3. The maximum wavelength (λ_{\max}) of the devices **1b–4c** appear at 442–498 nm. Interestingly, the phenomenon such as excimer and exciplex isn't observed in the doped-devices using compound **4** as host material. The luminance-voltage (L - V), luminous efficiencies (LE), and external quantum efficiency (EQE) of doped devices (**1b–4c**) are shown in Figs 6 and 7, respectively.

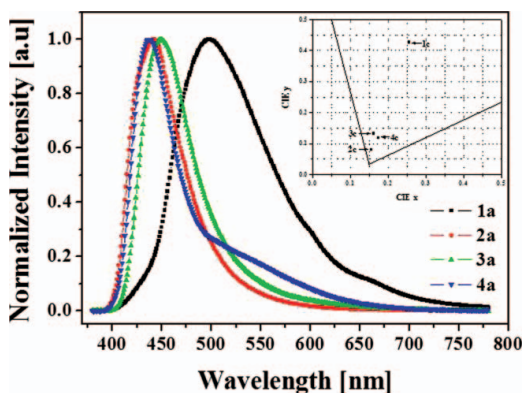


Figure 3. EL spectra and the CIE coordinates at 7.0 V of the non-doped devices **1a–4a**.

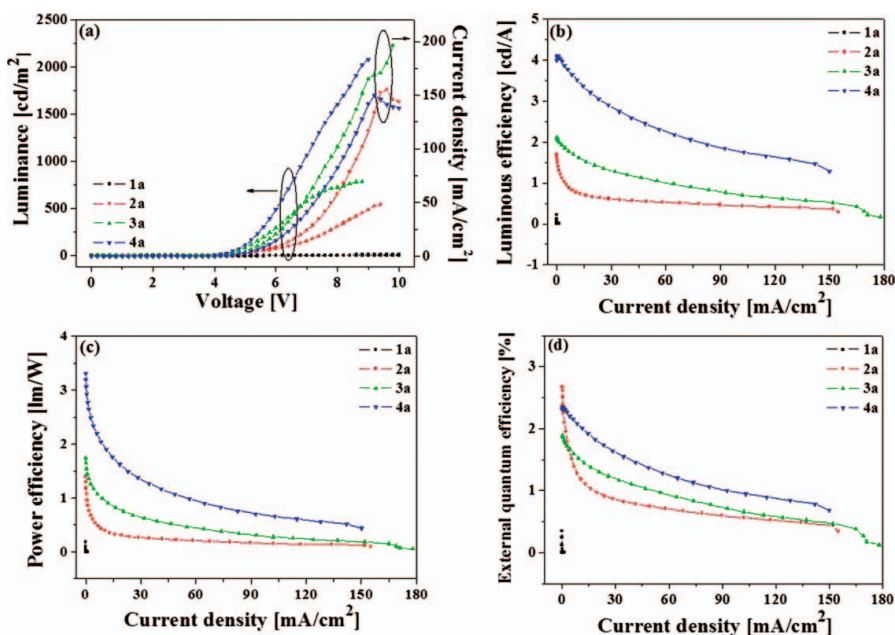


Figure 4. (a) L - V - J characteristics, (b) the luminous efficiencies, (c) power efficiencies, and (d) external quantum efficiencies as a function of current density for the devices **1a–4a**.

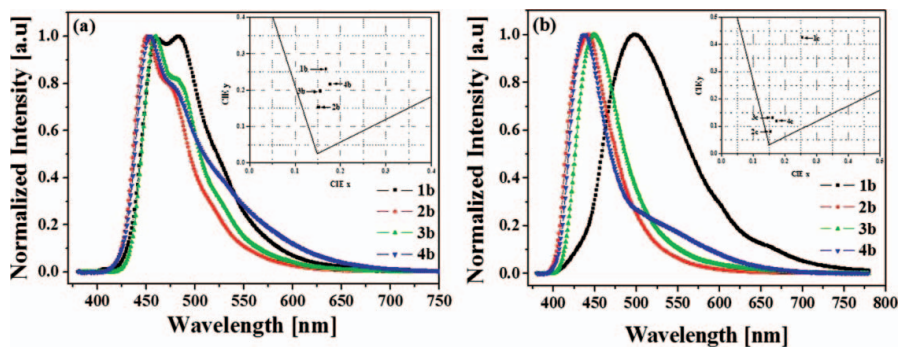


Figure 5. EL spectra and the CIE coordinates at 7.0 V of the doped devices; (a) **1b–4b**, and (b) **1c–4c**.

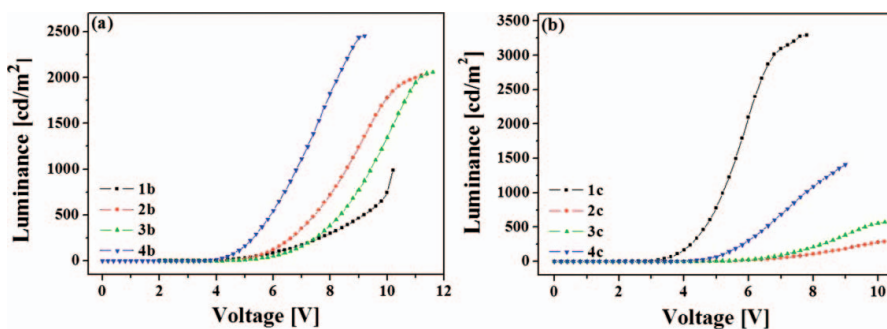


Figure 6. L - V characteristics of the doped devices; (a) **1b–4b**, and (b) **1c–4c**.

Table 3. EL performance characteristic of the devices **1b–4c** (doped)

Device	V_{on}^a [V]	$\lambda_{max}^{EL},$ FWHM ^b [nm]	L^c [cd/m ²]	J^c [mA/cm ²]	$LE^{d/e}$ [cd/A]	$PE^{d/e}$ [lm/W]	$EQE^{d/e}$ [%]	$CIE^f(x,y)$
1b	3.2	483, 78	988	333	3.38/2.37	3.32/0.43	1.83/1.60	(0.168,0.258)
2b	2.7	451, 58	2023	160	5.64/3.92	4.14/1.51	4.54/3.06	(0.152,0.153)
3b	3.9	459, 60	2059	97	5.18/4.25	3.72/1.46	3.52/2.79	(0.156,0.197)
4b	4.5	454, 71	2454	171	4.95/3.86	4.10/1.90	3.07/2.36	(0.178,0.216)
1c	4.0	498, 108	3291	378	2.30/1.20	2.02/1.61	2.62/0.55	(0.256,0.426)
2c	4.2	442, 62	300	152	3.10/0.71	1.05/0.26	1.05/0.25	(0.156,0.080)
3c	3.3	449, 60	603	159	1.54/1.12	2.33/0.44	2.33/0.44	(0.162,0.131)
4c	3.6	437, 51	1410	186	2.37/2.20	2.71/1.09	2.71/1.10	(0.175,0.118)

[a] Turn-on voltage at 1 cd/m². [b] Emission maximum and FWHM of EL emission spectra. [c] Maximum luminance and current density. [d] Maximum values.
[e] At 20 mA/cm². [f] Commission Internationale d'Enclaire (CIE) at 7.

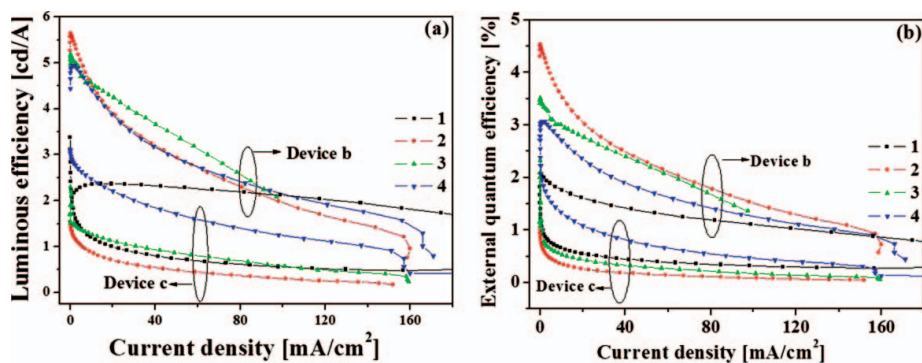
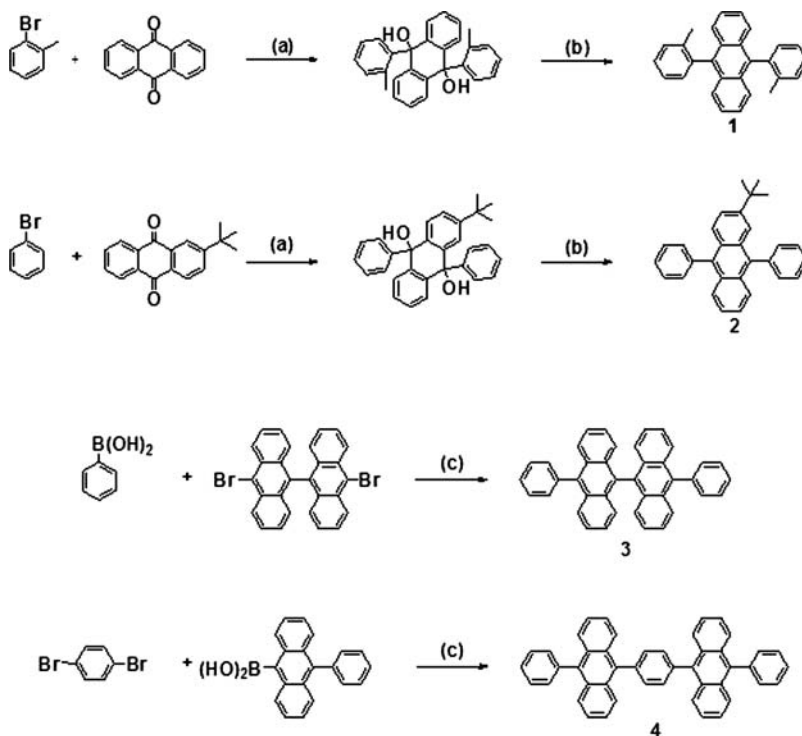


Figure 7. (a) The luminous efficiencies, and (b) external quantum efficiencies as a function of current density for the doped devices (**1b–4c**).

Regardless of the lowest efficiencies in non-doped device employing compound **2**, the device **2b** (**PFVtPh**-doped) has the highest efficiencies; its luminous efficiency (LE), power efficiency (PE), and external quantum efficiency (EQE) reach 5.64 cd/A, 4.14 lm/W, and 4.54% (3.92 cd/A, 1.51 lm/W, and 3.06% at 20 mA/cm²), respectively. We conjecture that compound **2** is the appropriate host material for **PFVtPh** blue dopant material. Notably,



Scheme 1. Synthesis of new host materials (**1–4**). *Conditions:* (a) *n*-BuLi, THF, –78°C, 3 h; (b) KI, NaHPO₃, Acetic acid, reflux, 3 h; (c) Pd(PPh₃)₄, 2M Na₂CO₃, Toluene/EtOH, reflux, 4 h.

the device **1c** is larger red shift than the others. Furthermore, it significantly reveals high luminance and current density (3291 cd/m^2 , and 378 mA/cm^2) among the devices **1c–4c**.

The **PFVtPh**-doped devices totally show higher EL efficiencies than those of **PCVtPh**-doped devices, because of good overlap between the absorption of dopant material (**PFVtPh**) and the emission of host materials (**1–4**). Hence, the devices (**PFVtPh**-doped) are more effective energy transfer (Förster-type energy transfer from host to dopant) or direct charge trapping in dopant [20,21]. The more effective hole trapping in the **PFVtPh**-doped devices imply that prevent hole leakage from emitting layer to ETL layer. Thus more efficient exciton formation at devices could contribute to the improved EL efficiencies. Thus, **PFVtPh** is more appropriate dopant material for these host materials.

Conclusion

We successfully synthesized A series of new blue emitting materials (**1–4**) based on diphenylanthracene via reductive coupling or Suzuki cross-coupling reaction. Their electroluminescent properties were investigated by fabrication of multilayered OLEDs. The device **4a** (non-doped device) shows the high luminous efficiency (LE), power efficiency (PE), and external quantum efficiency (EQE) reach 4.11 cd/A , 3.31 lm/W , and 2.36% (3.16 cd/A , 1.60 lm/W , and 1.80% at 20 mA/cm^2), respectively. Moreover, the device **2b** (**PFVtPh**-doped device) exhibits the high efficiencies with 5.63 cd/A , 4.13 lm/W , and 4.49% (3.92 cd/A , 1.50 lm/W , and 3.04% at 20 mA/cm^2). Furthermore, this device shows blue emission color with the CIE coordinates of (0.152, 0.153) at 7.0 V. This study clearly suggests that diphenylanthracene derivatives have sufficient potential for display or lighting applications.

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References

- [1] Wee, K. R., Han, W. S., Kim, J. E., Kim, A. L., Kwon, S. N., & Kang, S. O. (2011). *J. Mater. Chem.*, *21*, 1115.
- [2] Lee, K. H., Kang, L. K., Kwon, Y. S., Lee, J. Y., Kang, S., Kim, G. Y., Seo, J. H., Kim, Y. K., & Yoon, S. S. (2010). *Thin Solid Films.*, *518*, 5091.
- [3] Hosokawa, C., Higashi, H., Nakamura, H., & Kusumoto, T. (1997). *Synth. Met.*, *91*, 3.
- [4] Kim, Y. H., Shin, D. C., Kim, S. H., Ko, C. H., Yu, H. S., Chae, Y. D., & Kwon, S. K. (2001). *Adv. Mater.*, *13*, 1690.
- [5] Hosokawa, C., Higashi, H., Nakamura, H., & Kusumoto, T. (1995). *Appl. Phys. Lett.*, *67*, 3853.
- [6] Lee, K. H., Kang, L. K., Lee, J. Y., Kang, S., Jeon, S. O., Yook, K. S., Lee, J. Y., & Yoon, S. S. (2010). *Adv. Func. Mater.*, *20*, 1345.
- [7] Park, J. K., Lee, K. H., Kang, S., Lee, J. Y., Park, J. S., Seo, J. H., Kim, Y. K., & Yoon, S. S. (2010). *Org. Electron.*, *11*, 905.
- [8] Daniel, K., Huang, T.-H., Lin, J. T., Tao, Y.-T., & Chuen, C. H. (2002). *Chem. Mater.*, *14*, 3860.
- [9] Shen, W.-J., Dodda, R., Wu, C.-C., Wu, F.-I., Liu, T.-S., Chen, H.-H., Chen, C. H., & Shu, C.-F. (2004). *Chem. Mater.*, *16*, 930.
- [10] Berlan, I. B. (1971). *Handbook of Fluorescence Spectra of Aromatic Molecules*, 2nd ed.; Academic Press: New York.
- [11] Balaganesan, B., Shen, W. J., & Chen, C. H. (2003). *Tetrahedron Lett.*, *44*, 5747.

- [12] Kim, Y. H., Kwon, S. K., Yoo, D. S., Rubner, M. F., & Wrighton, M. S. (1997). *Chem. Mater.*, 9, 2699.
- [13] Shin, H. T., Lin, C. H., Shin, H. H., & Cheng, C. H. (2002). *Adv. Mater.*, 14, 1409
- [14] Kwon, Y. S., Lee, K. H., Kim, G. Y., Seo, J. H., Kim, Y. K., & Yoon, S. S. (2011). *J. Nanosci. Nanotechnol.*, 11, 4488.
- [15] Lee, K. H., Kwon, Y. S., Kang, L. K., Kim, G. Y., Seo, J. H., Kim, Y. K., & Yoon, S. S. (2009). *Synth. Met.*, 159, 2603.
- [16] Park, Y.-I., Son, J.-H., Kang, J.-S., Kim, S.-K., Lee, J.-H., & Park, J.-W. (2008). *Chem. Mater.*, 2143.
- [17] Müller, U., & Baumgarten, M. *J. Am. Chem. Soc.*, (1995). 117, 5840.
- [18] Li, C. L., S. Shieh, J., Lin, S. C., & Liu, R. S. (2003). *Org. Lett.*, 5, 1131.
- [19] Salbeck, J., Weissörtel, F., Yu, N., Baner, J., & Bestgen, H. (1997). *Synth. Met.*, 91, 209.
- [20] Lee, S. J., Park, J. S., Yoon, K. J., Kim, Y. I., Jin, S. H., Kang, S. K., Gal, Y. S., Kang, S. W., Lee, J. Y., Kang, J. W., Lee, S. H., Park, H. D., & Kim, J. J. (2008). *Adv. Funct. Mater.*, 18, 3922.
- [21] Littman, J., & Martic, P. (1992). *J. Appl. Phys. Lett.*, 72, 3610.