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Unsymmetrically amorphous 9,10-disubstituted anthracene derivatives for high-efficiency blue organic electroluminescence devices

Jinhai Huang^a, Bo Xu^a, Mei-Ki Lam^b, Kok-Wai Cheah^b, Chin H. Chen^{b,c}, Jian-Hua Su^{a,*}

^a Key Laboratory for Advanced Materials and Institute of Fine Chemicals, East China University of Science & Technology, Shanghai 200237, PR China ^b Centre for Advanced Luminescence Materials, Department of Physics, Hong Kong Baptist University, Kowloon Tong, Hong Kong, PR China ^c Displays & Lighting Centre, SEIEE, Shanghai Jiao Tong University, Shanghai 200240, PR China

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1. Introduction

Organic light-emitting diodes (OLEDs) have drawn great scientific and commercial attention, due to their potential applications in full-color, flat-displays as well as solid-state lighting [1–3]. Despite many efforts to improve the device performance, compared to the efficient and stable red and green device, sufficiently wide band gap of highly efficient and stable blue luminescent materials are still rare [4,5]. The thermal stability is one very important factor for the device operation efficiency and lifetime, because the morphological change of the organic layers caused by Joule heat during device operation limits the device durability [6,7]. Therefore, amorphous materials with high glass transition temperature (T_g) are significantly required to effectively suppress formation of grain boundaries [8–13].

Most of the recent studies have been devoted to optimize the morphological stability and photophysical properties of the blue emitters [10–16]. However, most synthesized stable blue-emitting materials are still far from commercial application because of the insufficient efficiency and the complicated synthesis routes, as well as excessively expensive cost.

ABSTRACT

Two unsymmetrically amorphous 9,10-disubstituted anthracene derivatives have been synthesized and characterized. They emit the light in the blue region and possess glass transition temperature of 132.5 °C and 133.8 °C. The scanning electron microscope (SEM) was employed in studying the thin-film morphological stability of the two unsymmetrical isomers. These two compounds were fabricated into typical trilayers devices with pure blue lighting performance. In addition, a series of highly efficient and stable sky blue devices doped with a sky blue dopant BUBD-1 have been fabricated by using these two isomers as the host.

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Anthracene has been intensively studied as an attractive building block and starting material in OLEDs, due to its unusual photoluminescence and electroluminescence properties and excellent electrochemical properties, as well as easier modification [15,17–23]. Moreover, the fluorescence spectral color of anthracene can be easily tuned from blue to green by introducing the different bulks at the C-9 and 10 positions [24]. Among these anthracene derivatives, the 9,10-di(2-naphthyl)anthrance (ADN) was firstly reported as blue host and 2,5,8,11-tetra (t-butyl)-perylene (TBP) as dopant to achieve an EL efficiency of around 3.5 cd/A with a blue emission $CIE_{(x,y)}$ of (0.154,0.232) and a half-time of 4000 h at an initial light output of 700 cd/m² [25]. However, the film morphology of ADN was found to be unstable and easily tend to crystallize after long operation [26]. Compounds with an unsymmetrical structure have less tendency to crystallize and favor amorphous morphology, thus yielding higher stability over that of the symmetric structures [11, 27]. 2-Methyl-9,10-di-(2-naphthyl) anthracene (MADN), a wellknown and deeply investigated blue emitter, was engineered based on ADN. The methyl substituent at C-2 position was introduced into the anthracene unit for slightly disrupting the symmetry of ADN, which can effectively suppress the problematic crystallization to fabricate the stable and amorphous film [28,29]. But a moderate T_{g} and a low luminance efficiency are the key problems for its widespread commercial use [30]. Thus, blue light-emitting materials with

^{*} Corresponding author. Tel./fax: +86 21 64252288. *E-mail address:* bbsjh@ecust.edu.cn (I.-H. Su).

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high efficiency, excellent morphological and thermal stability, as well as simple synthetic routes should be persistently investigated for the full-color displays and solid-lighting.

In this study, we sought to pursue two new high performance blue light-emitting amorphous materials from MADN based on the relationship between the molecular structures and the morphological stability. 2-methyl-9-(2-naphthyl)-10-(4-biphenyl) anthracene (MNBPA) and 2-methyl-9-(4-biphenyl)-10-(2-naphthyl) anthracene (MBPNA) were easily synthesized with good yield by using biphenyl moiety instead of one of the naphthyl moiety in the MADN structure. The slight change with the unsymmetrical substituent at C-9 and -10 positions of anthracene, not only efficiently improved the efficiency, but also strengthened amorphous morphological stability.

2. Experimental

2.1. General information

Unless otherwise specified, all reactions and manipulations were performed under nitrogen atmosphere using standard Schlenk techniques. All chemical reagents were used as received from commercial sources without further purification. And the solvents were dried using standard procedures. ¹H and ¹³C NMR spectra were recorded on Brüker AV-400, spectrometer tetramethylsilane (TMS) as the internal standard. The film morphologies were recorded using an LEO1530 FE-SEM. High-resolution mass spectrometric measurements were carried out using a Brüker autoflex MALDI-TOF mass spectrometer. UV-vis spectra were obtained on a Varian Cary 200 spectrophotometer. Fluorescence spectra were obtained on a Perkin Elmer LS55 luminescence spectrometer with the excitation at 380 nm. The concentration was adjusted so that the absorbance of the solution would be lower than 0.1.The differential scanning calorimetry (DSC) analysis was performed under a nitrogen atmosphere on a TA Instruments DSC 2920 with a heating and cooling scan rate of 20 °C/min. Thermogravimetric analysis (TGA) was undertaken using a TGA instrument under a nitrogen atmosphere with a heating scan rate of 20 °C/min. The quantum yield of 2-methyl-9,10-di(2-naphthyl)anthracene was set as 100% in CH₂Cl₂ as standard [27]. Cyclic voltammetric (CV) measurements were carried out in a conventional three electrode cell using a Pt button working electrode of 2 mm in diameter, a platinum wire counter electrode, and an SCE reference electrode on a computer-controlled EG&G Potentiostat/Galvanostat model 283 at room temperature. Reduction CV of all compounds was performed in dichloromethane containing Bu_4NPF_6 (0.1 M) as the supporting electrolyte. The $E_{1/2}$ values were determined by $(E_{pa} + E_{pc})/2$, where E_{pa} and E_{pc} are the anodic and cathodic peak potentials, respectively. Ferrocene was used as an external standard. Electrochemistry was done at a scan rate of 100 mV/s.

2.2. Device fabrication

Prior to the deposition of organic materials, indium–tin-oxide (ITO)/glass was cleaned with a routine cleaning procedure and pretreated with oxygen plasma, and then coated with a polymerized fluorocarbon (CF_x) film. Devices were fabricated under about 10^{-6} Torr base vacuum in a thin-film evaporation coater. The current–voltage–luminance characteristics were measured with a diode array rapid scan system using a Photo Research PR650 spectrophotometer and a computer-controlled, programmable, direct-current (DC) source. All measurements were carried out in ambient atmosphere at room temperature.

2.3. Synthesis

2.3.1. 2-Methyl-9-(2-naphthyl)anthracene (MNA)

2-Methyl-9-bromoanthracene (2 g, 7.38 mmol) and 2-nathphyl boronic acid (1.53 g, 8.89 mmol) were mixed in 10 ml of THF. K₂CO₃ (2.0 M. 10 ml) was added, and the mixture was stirred with magnetic stirring. Then tetrakis(triphenylphsosphine) palladium (100 mg. 0.075 mmol) was added to the mixture. The reaction solution was heated to reflux for 12 h under the atmosphere of nitrogen. After the mixture cooled, the solvent was evaporated and the product was extracted with dichloromethane. The organic was washed with brine and water, and then dried by anhydrous MgSO₄. The solvent was evaporated, and the residue was purified by using column chromatography with DCM: n-Hexane = 1:3 eluent to afford a white solid (2.1 g, 89.7%). ¹H NMR: (400 MHz, CDCl₃, δ): 8.45 (s, 1H), 7.94-8.04 (m, 4H), 7.87-7.89 (m, 2H), 7.51-7.61 (m, 4H), 7.38-7.41 (m, 2H), 7.24–7.29 (m, 2H), 2.34 (s, 3H). ¹³C NMR (400 MHz, CDCl₃, δ): 22.23, 124.73, 124.93, 125.33, 126.15, 126.34, 126.48, 126.77, 127.91, 127.93, 128.04, 128.15, 128.28, 128.40, 129.64, 130.05, 130.11, 130.58, 130.90, 132.74, 133.45, 135.17, 135.74, 136.59. HRMS (m/z) calculated for C₂₅H₁₈: 318.1409, Found [M⁺]: 318.1404.

2.3.2. 2-Methyl-9-(2-naphthyl)-10-bromoanthracene (MNBA)

2-Methy-9-(2-naphthyl)anthracence (1.45 g, 4.68 mmol) was mixed in 10 ml of dehydrated dimethylformamide (DMF). After the material was dissolved, N-bromosuccinimide (NBS) (0.92 g, 5.15 mmol) was added at 50 °C, and the resultant mixture was stirred with magnetic stirring for 10 h. After the reaction was completed, the reaction solution was poured into purified water, and formed crystals were separated by filtration. The separated crystals were recrystallized from THF and ethanol to afford a yellow solid (1.58 g, 85.4%). ¹H NMR: (400 MHz, CDCl₃, δ): 8.58–8.60 (d, 1H, *J* = 8.8 Hz), 8.51–8.53 (d, 1H, *J* = 9.2 Hz), 8.00–8.05 (m, 2H), 7.88–7.90 (d, 1H, *J* = 6.8 Hz), 7.49–7.62 (m, 5H), 7.39–7.43 (m, 2H), 7.28–732 (m, 1H), 2.36 (s, 3H). ¹³C NMR (400 MHz, CDCl₃, δ): 21.86, 122.75, 125.48, 125.54, 126.34, 126.52, 126.55, 127.32, 127.80, 127.87, 127.94, 128.06, 128.15, 128.98, 129.36, 129.72, 129.85, 130.10, 131.38, 132.81, 133.35, 135.48, 136.14, 136.51. HRMS (*m*/*z*) calculated for C₂₅H₁₇Br: 396.0514, Found [M⁺]: 396.0502.

2.3.3. 2-Methyl-9-(2-naphthyl)-10-(4-biphenyl)anthracene (MNBPA)

MNBPA was prepared from MNBA and 4-biphenyl boronic acid as described for MNBA. To afford a yellow solid (90.3%). ¹H NMR: (400 MHz, CDCl₃, δ): 8.07–8.09 (d, 1H, J = 8.4 Hz), 8.02–8.04 (m, 1H), 7.98 (s, 1H), 7.92–7.94 (m, 1H), 7.83–7.85 (d, 2H, J = 6.8 Hz), 7.71–7.73 (d, 1H, J = 8.4 Hz), 7.66–7.68 (m, 2 H), 7.53–7.63 (m, 7 H), 7.51 (s, 1H), 7.40–7.46 (m, 1H), 7.27–7.34 (m, 2H), 7.19–7.21 (d, 1H, J = 9.2 Hz), 2.35 (s, 3H). ¹³C NMR (400 MHz, CDCl₃, δ): 21.99, 124.69, 125.03, 125.12, 126.15, 126.35, 126.92, 127.01, 127.08, 127.18, 127.36, 127.43, 127.54, 127.91, 127.90, 128.15, 128.59, 128.82, 128.90, 129.45, 129.69, 130.21, 130.28, 131.79, 132.75, 133.47, 134.84, 135.91, 136.73, 136.84, 138.18, 140.22, 140.88. HRMS (m/z) calculated for C₃₇H₂₆: 470.2035, Found [M⁺]: 470.2032.

2.3.4. 2-Methyl-9-(4-biphenyl)anthracene (MBPA)

MBPA was prepared from 2-methyl-9-bromoanthracene and 4-biphenyl boronic acid as described for MNA. To afford a white solid (88.6%). ¹H NMR: (400 MHz, CDCl₃, δ): 8.44 (s, 1 H), 8.00–8.02 (d, 1H, *J* = 8.0 Hz), 7.37–7.60 (d, 1H, *J* = 8.8 Hz), 7.75–7.81 (m, 4H), 7.67–7.69 (d, 1H, *J* = 8.8 Hz), 7.46–7.52 (m, 5H), 7.37–7.45 (m, 2H), 7.28–7.37 (m, 2H), 2.41 (s, 3H). ¹³C NMR (400 MHz, CDCl₃, δ): 22.29, 124.73, 124.88, 125.30, 126.41, 126.74, 127.06, 127.17, 127.43, 128.02, 128.26, 128.38, 128.92, 130.05, 130.44, 130.89, 131.74, 135.11, 135.59, 137.98, 140.07, 140.88. HRMS (*m*/*z*) calculated for C₂₇H₂₀: 344.1565, Found [M⁺]: 344.1565.

2.3.5. 2-Methyl-9-(4-biphenyl)-10-bromoanthracene (MBPBA)

MBPBA was prepared from MBPA as described for MNBA. To afford a yellow solid (85.4%). ¹H NMR: (400 MHz, CDCl₃, δ): 8.57–8.60 (d, 1H, *J* = 9.2 Hz), 8.50–8.53 (m, 3H), 7.76–7.82 (m, 4H), 7.67–7.70 (d, 1H, *J* = 8.8 Hz), 7.50–7.58 (m, 3H), 7.34–7.47 (m, 6H), 2.43 (s, 3H). ¹³C NMR (400 MHz, CDCl₃, δ): 21.93, 122.70, 125.42, 125.51, 126.55, 127.12, 127.17, 127.28, 127.39, 127.54, 127.79, 127.86, 128.95, 129.71, 129.84, 131.25, 131.63, 135.43, 136.36, 137.55, 140.37, 140.72. HRMS (*m*/*z*) calculated for C₂₇H₁₉Br: 424.0650, Found [M⁺]: 424.0635.

2.3.6. 2-Methyl-9-(4-biphenyl)-10-(2-naphthyl)anthracene (MBPNA)

MBPNA was prepared from MBPBA and 2-naphtyl boronic acid as described for MNA. To afford a yellow solid (92.2%). ¹H NMR: (400 MHz, CDCl₃, δ): 8.05–8.06 (d, 1H, *J* = 8.0 Hz), 7.97–8.02 (m, 2H), 7.89–7.91 (m, 1H), 7.84–7.86 (d, 1H, *J* = 8.4 Hz), 7.75–7.78 (m, 1H), 7.69–7.71 (d, 1H, *J* = 8.4 Hz), 7.50–7.65 (m, 9H), 7.39–7.43 (t, 1H, *J* = 7.6 Hz), 7.25–7.34 (m, 2H), 7.14–7.16 (d, 1H, *J* = 8.8 Hz), 2.39 (s, 3 H). ¹³C NMR (400 MHz, CDCl₃, δ): 22.03, 124.72, 125.00, 125.07, 126.17,

MBA

MNA

B(OH)

Br

B(OH)₂

i)

126.39, 126.90, 126.94, 127.03, 127.09, 127.15, 127.42, 127.89, 127.91, 127.98, 128.08, 128.72, 128.90, 129.58, 130.14, 130.15, 130.20, 131.82, 132.73, 133.41, 134.78, 135.83, 136.71, 136.79, 138.25, 140.10, 140.86. HRMS (m/z) calculated for C₃₇H₂₆: 470.2035, Found [M⁺]: 470.2052.

3. Results and discussion

3.1. Synthesis

MNA

The synthetic routes to the two new compounds are shown in Scheme 1. 2-Methyl-9-bromoanthracene, naphthyl boronic acid, 4-biphenly boronic acid were provided by e-Ray Optoelectronics Technology Co., Ltd. Suzuki aryl–aryl coupling reactions and bromination reactions were employed in all the synthesis with a good yield. All compounds were availably purified with the silica column chromatographic method or recrystallization because of good solubility in the common solvents. Further purification was readily accomplished by train sublimation in vacuum (10^{-6} Torr). The compounds were verified by ¹H NMR, ¹³C NMR, high-resolution mass spectrometry.

Br

MBPBA

MNBA

MNBA Br_{+} $Br_{$



i) Pd(PPh₃)₄, K₂CO₃, THF; ii) NBS, DMF

Scheme 1. Synthetic routes to MNBPA and MBPNA.

Table 1

DI1	1	c	41	
Physical	data	IOL	tne	compounds.

	UV _{max} (nm) in CH ₂ Cl ₂	PL _{max} (nm) in CH ₂ Cl ₂	PL _{max} ^a (nm) in film	Quantum yield ^b $\Phi_{\rm f}$	HOMO/LUMO (eV)	$E_{g}(eV)$	<i>T</i> _d (°C)	$T_{\rm m}(^{\circ}{\rm C})$	$T_{g}(^{\circ}C)$
MADN	400, 262	431	448	1	5.5 ^c /2.5 ^c	3.0 ^c	397 ^c	255 ^c	120 ^c
MNBPA	400, 263	432	452	1.13	5.58/2.60	2.98	401.8	236.5	132.5
MBPNA	400, 263	431	452	1.10	5.58/2.60	2.98	412.1	265.2	133.8

^a Film on quartz plate (40 nm).

^b In CH₂Cl₂ solution, Ref. [30].

^c Ref. [26].

3.2. Thermal properties

The thermal properties of the new compounds were determined by differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) measurements (Table 1). The two isomers, MNBPA and MBPNA, possess thermal decomposition temperatures (T_d ; 5% weight loss) as high as 402 °C and 412 °C, and exhibit the melting temperatures (T_m) at 236.5 °C and 265.2 °C. Moreover, MNBPA and MBPNA have a similar T_g values, 132.5 °C and 133.8 °C, respectively, both of which are higher than that of MADN (120 °C) [26]. This is because the unsymmetrical nature of the two new hosts with biphenyl group instead of one naphthyl group may dramatically hampers the facile packing of the molecules and enhances the T_g value [12].

For further confirming the intrinsic amorphous characteristics, thin-film morphology of these unsymmetrical isomers and MADN were investigated to unveil the morphological stability by scanning electron microscope (SEM). There is no morphological change on the MNBPA film after annealing at 80 °C for 1 h under air atmosphere shown in Fig. 1(a). Moreover, we also cannot find the MBPNA film surface crystalline as shown in Fig. 1(b), when we improve the annealing temperature to 110 °C for 1 h under a vacuum atmosphere. In contrast, the film of MADN induced considerable crystallization after annealing at 80 °C for 1 h under air atmosphere as shown in Fig. 1(c). As we know, crystallization is a serious problem for molecular π -conjugated materials. The boundary of crystalline regions in OLEDs layers usually act as traps for mobile electrons or holes as they move past [31]. Hence, the two amorphous unsymmetrical isomers with a high $T_{\rm g}$ can efficiently hinder crystallization to promote the device lifetime.

3.3. Photophysical and electrochemical properties

Fig. 2 shows the absorption and PL spectra of the unsymmetrical isomers and MADN in dilute dichloromethane solution as well as in solid thin films deposited on quartz plates. The similar absorption and PL spectra in solution of the two isomers exhibit the characteristic vibrational structure of the anthracene moiety, which are identical to them of MADN. They have similar absorption peaks in the range from 350 to 400 nm, and these characteristic vibronic bands are assigned to the π - π * transitions of the anthracene core.

The HOMO and LUMO energy levels of the isomers were also listed in Table 1. The HOMO energies of the anthracene derivatives are -5.58 eV, which were determined by cyclic voltammetry (CV) analyses. The wide optical energy band gaps (E_g) were found about 2.98 eV, determined from the threshold of UV–vis absorption spectra. The LUMO values are -2.60 eV, calculated based on the HOMO energy levels and energy band gaps.

3.4. Electroluminescent properties

To study the electroluminescent performance of the two asymmetrical isomers, we fabricated six devices (1-6), with the following device configurations: ITO/CF_x/NPB (60 nm)/Host $(40 \text{ nm})/\text{Alg}_3$ (15 nm)/LiF (1 nm)/Al (device 1: Host = MBPNA; device **2**: Host = MNBPA); ITO/ $CF_x/2$ -TNATA (60 nm)/NPB (10 nm)/ Host: 3% BUBD-1(40 nm)/TPBI (20 nm)/LiF (1 nm)/Al (device 3: Host = MBPNA; device **4**: Host = MNBPA); ITO/CF_x/EHI (60 nm)/ NPB (10 nm)/Host: 3% BUBD-1 (40 nm)/Alq3 (20 nm)/LiF (1 nm)/Al (device 5: Host = MBPNA; device 6: Host = MNBPA), where indium tin oxide (ITO) was used as the anode, polymerized fluorocarbon (CF_x) and 4,4',4''-tris[N- (1-naphthyl)-N-phenylamino] triphenylamine (2-TNATA) were the hole-injection layer, 4,4'-bis[N-(1naphthyl)-N-phenyl-l-amino]biphenyl (NPB) was used as the hole transporting layer, Alq₃ or TPBI was used as the electron transporting layer, and LiF was used as the electron injecting layer, EHI is a new hole-injection material. The detailed device structures are shown in Fig. 3. Devices 1 and 2 were the typical trilayer non-doped

Table 2					
Detailed o	lata o	f the EL	performance	for the	compounds.

Device	Turn-on voltage (V) ^a	Max brightness (cd/m ²)	Max quantum efficiency (%)	Max power efficiency (lm/W)	Max current efficiency (cd/A)	Max EL spectra ^b (nm)	$\operatorname{CIE}_{(x,y)}^{c}$
1	3.6	3157	0.72	0.59	0.92	452	(0.164,0.156)
2	3.9	3740	0.82	0.70	1.07	456	(0.162,0.160)
3	2.9	12090	6.34	6.46	10.22	464	(0.152,0.222)
4	2.8	8057	4.07	3.82	6.7	460	(0.153,0.231)
5	3.5	14060	4.75	4.38	7.85	464	(0.148,0.236)
6	3.5	12890	3.15	3.01	5.32	464	(0.154,0.244)

^a At 1 cd/m².

^b The maximum EL spectra for devices 1-4 at 20 mA/m² and devices 5-6 at 6 V.

^c The $CIE_{(x,y)}$ for devices **1–4** at 20 mA/m² and devices **5–6** at 6 V.



Fig. 1. SEM images of (a) MNBPA, (b) MBPNA, (c) MADN.



Fig. 2. (a) The absorption and PL spectra of MADN, MNBPA, MBPNA in dichloromethane solution. (b) The film PL spectra of the compounds.

devices. Also, the highly efficient sky blue dopant BUBD-1 was employed in the devices 3-6 with a common concentration of 3%.

The current density-voltage-luminance (I-V-L) characteristics for the devices 1-6 are shown in Fig. 4. The devices with MBPNA as host emitting material present better performance than the devices with MNBPA in both the current density and luminance at the same applied voltage. They are attributed to the better film spectra performance of the MBPNA. After doping 3% BUBD-1, the luminance was significantly improved. For instance, the maximum luminance for the devices 3-6 were 12090 cd/m² (at 13.2 V), 8057 cd/m^2 (at 13.9 V), 14060 cd/m² (at 8.5 V), 12890 cd/m² (at 9.5 V), respectively, while those for devices 1-2 were 3157 cd/ m^{2} (at 11.7 V) and 3740 cd/m² (at 11.8 V). However, the devices **5–6** with a new hole injection material indicate the best current density characteristics in the three device types. The different current densities are attributed to the different hole injections, electron transporting materials and the thickness. Moreover, as shown in Fig. 4, the good hole injection material (EHI) and a doped system (BUBD-1) will be helpful to improve the OLEDs performance.

Fig. 5(a) shows the current density-current efficiency characteristics for the six devices. The current efficiencies of doped devices are several times higher than the non-doped system. In the pure blue devices 1 and 2, these two devices indicate the mostly identical current efficiency. In the doped devices, the MBPNA-based devices display a higher efficiency than the MNBPA-based devices. Moreover, device 3 reveals a better efficiency than device 5, and the same cases were happened in the MNBPA-based devices. The maximum current efficiency of the devices **3–6** are 10.22 cd/A (at 6.53 V), 6.7 cd/A (at 9.07 V), 7.85 cd/A (at 7 V), and 5.32 cd/A (at 8 V), respectively, which are several times higher than those of the non-doped devices 1-2 (0.92 cd/A and 1.07 cd/A, respectively). Meanwhile, for the devices 1, 2, 5 and 6, the EL efficiency rises sharply to a maximum value and then displays a nearly flat response from 10 mA/cm^2 to 200 mA/cm^2 . Although the current efficiency slightly decreases as the current density increases, the efficiencies of devices **3** and **4** at 200 mA/cm² are 6.04 cd/A and 4.02 cd/A,

Al	Al	Al	
LiF (1 nm)	LiF (1 nm)	LiF (1 nm)	
Alq ₃ (15 nm)	TPBI (20 nm)	Alq ₃ (20 nm)	
Host (40 nm)	Host:BUBD-1(40nm)	Host:BUBD-1(40 nm)	
NPB (70 nm)	NPB (10 nm)	NPB (10 nm)	
ITO	2-TNATA (60 nm)	EHI (60 nm)	
	ITO	ITO	
device 1 , 2	device 3 , 4	device 5 , 6	

respectively, which are still very efficient. These results suggest that the two isomers are stable in the device and can be the promising candidates for blue host materials in OLEDs. Fig. 5(b) reveals the dependence of the power efficiency and current density characteristics for the devices. The power efficiency drop down sharply as the current density rises for devices **3** and **4** compared with those for devices **5** and **6**. That is attributed to the higher applied voltage at the same current density in the devices **3** and **4**. The detailed data are summarized in Table 2.

EL spectra for the devices **1–4** at 20 mA/cm² and for the devices 5-6 at 6 V are displayed in Fig. 6. The spectrum peaks of the nondoped devices based on MBPNA and MNBPA at 20 mA/cm² are 452 nm (0.164, 0.156) with a full with at half maximum of 76 nm and 456 nm (0.162, 0.160) with a full with at half maximum of 76 nm, both of which are similar to the film PL spectra, indicating that all of the emissions originate from the emitting layer. The BUBD-1 doped devices exhibit the almost identical spectra with a dominating peak at around 456 nm with a similar full with at half maximum of 60 nm and a shoulder peak at around 490 nm. In comparison with the non-doped devices, the emission from the host materials are totally quenched, according to the doped spectra, suggesting the Förster energy transfer form the host to the dopant is very efficient which is beneficial to improve the EL performance. Moreover, there is almost no EL color shift for all devices with varying driving current density and voltage. For example, the $CIE_{(x,y)}$ color coordinates of device **3** only shifted from (0.152, 0.225) at 0.1 mA/cm² to (0.161,0.226) at 250 mA/cm² with $\triangle CIE_{(x,y)} = (0.01, 0.001)$.



Fig. 4. Current density-voltage-luminance (I-V-L) characteristics for the devices.



Fig. 5. (a) Current density-current efficiency characteristics for the devices. (b) The power efficiency-current density characteristics for the devices.



Fig. 6. EL spectra for the devices 1–4 at 20 mA/cm² and for the devices 5–6 at 6 V.

4. Conclusion

In summary, we have synthesized two anthracene derivatives isomers with a blue-emitting characteristic. The bipheny moiety was introduced to anthracene core instead of the naphthyl moiety to enhance the thermal and morphological stabilities. The pure blue OLED devices were obtained in the non-doped system with a $CIE_{(x,y)}$ of (0.164,0.156) for MBPNA and (0.162,0.160) for MNBPA at 20 mA/cm² in devices **1** and **2**, respectively. Moreover, the Förster energy transfer from the host to the dopant is very efficient which is beneficial to improve the EL performance. A high luminance of 14060 cd/m² (at 8.5 V) for device **5** and a high maximum current efficiency of 10.22 cd/ A (at 6.5 V) for device **3** in a sky blue dopant system are achieved.

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