### ARTICLE

## Novel efficient green electroluminescent conjugated polymers based on fluorene and triarylpyrazoline for light-emitting diodes<sup>†</sup>

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A series of novel light-emitting conjugated polymers based on fluorene and triarylpyrazoline were synthesized in good yields through Suzuki coupling reactions. The resulting polymers were characterized by NMR, FT-IR, elemental analysis, DSC, TGA and GPC. These polymers possess excellent thermal stability with glass transition temperatures ( $T_g$ ) of 80–162 °C and onset decomposition temperatures ( $T_d$ ) of 376–387 °C. Cyclic voltammetry studies revealed that these polymers have good hole and electron transporting properties with LUMO energy levels of -2.97 to -2.98 eV and HOMO energy levels of -5.71 to -5.81 eV. All the polymers emit green fluorescence with very high photoluminescence (PL) quantum yields of 45–59%. Polymer light-emitting diodes (PLEDs) with the configuration ITO/PEDOT/polymer/Ba/Al were fabricated. All these devices showed bright green emission peaking at 494–500 nm with high maximum external quantum efficiencies of 0.6-2.53% and low turn-on bias voltages. The good light-emitting properties indicate that these polymers are new and promising candidates for electroluminescent materials that can be used to fabricate efficient polymer light-emitting diodes.

### Introduction

Since the discovery of polymer light-emitting diodes (PLEDs) by the Cambridge group,<sup>1</sup> great progress has been made in developing all kinds of conjugated polymers in order to obtain three primary (RGB) colors for large-area flat panel displays. Among these polymers, polyfluorene (PF) derivatives show interesting and unique chemical and physical properties because they contain a rigid planar biphenyl unit and facile substitution at the remote C-9 position can improve the solubility and processability of polymers without significantly increasing the steric interactions in the polymer backbone.<sup>2</sup> As a result, fluorene-based conjugated polymers have emerged as the most promising blue light-emitting materials because of their high quantum yield, good film-forming and excellent thermal stability.3-14 Color-tuning in these polymers can be achieved by incorporating other moieties, such as benzodithiazole, oxadiazole, quinoline and quinoxaline units, into the polymer backbone.<sup>15–22</sup> However, most of these moieties are electron-deficient units, which can easily form trapping centers that reduce the quantum efficiencies of the polymers. On the other hand, fluorene-based polymers often suffer from serious aggregation formation, which leads to enhanced excimer emission in the EL process and reduced quantum efficiency.<sup>23,24</sup> So modification of polyfluorene and their derivatives are still receiving considerable interest.

Triarylpyrazoline compounds have been widely used as fluorescent dyes in the textile industry because of their very high fluorescence yield. These compounds exhibit twisted intramolecular charge transfer (TICT).<sup>25</sup> Upon excitation, molecules with TICT will twist and form an electron donor–accepter system. Therefore, these compounds with nonplanar structure can be used as carrier-transporting as well as emitting materials.<sup>26–28</sup> However, pyrazoline compounds tend to recrystallize easily leading to device degradation. From the chemical viewpoint, this problem may be avoided by incorporating these moieties into the polymer main chain by chemical doping.

Herein, we present a series of novel fluorene-based conjugated polymers containing the triarylpyrazoline moiety in the main chain. The twisted triarylpyrazoline unit is introduced to avoid the aggregation of PFs and to increase their quantum yield. On the other hand, the often-observed recrystallization of small molecular pyrazoline compounds can be resolved in polymer films. The resulting polymer can emit green light with very high absolute PL quantum efficiency and an EL maximum external quantum efficiency in solid films. To our knowledge, this work will be the first report of pyrazoline-based conjugated polymers used in polymer lightemitting diodes.

### **Experimental**

### Chemicals

All the chemicals were purchased from Aldrich and Acros chemical company and were used without any further purification. All the solvents such as toluene and DMF were dried with appropriate drying agents, then distilled under reduced pressure, and stored over 4 Å molecular sieves. The catalyst tetrakis(triphenylphosphine)palladium  $Pd(PPh_3)_4^{29}$  and 9,9-dihexylfluorene-2,7-bis(trimethylene boronates) (8)<sup>8</sup>

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<sup>†</sup> Electronic supplementary information (ESI) available: The detailed synthesis procedures and characterization data of intermediate compounds 2, 3, 5–7. See http://www.rsc.org/suppdata/jm/b3/ b313160b/



Scheme 1 Synthetic route to the monomers and polymers.

were synthesized according to the literature. The detailed synthesis procedures and characterization data of intermediate compounds 2, 3, 5–7 (Scheme 1) are given in the electronic supplementary information (ESI) section.<sup>†</sup>

### Instrumentation

<sup>1</sup>H NMR and <sup>13</sup>C NMR spectra were performed on a Varian Unity INOVA-400. FT-IR spectra were recorded on a Perkin-Elmer 2000 spectrometer as KBr pellets. Elemental analysis studies were carried out with a Carlo Erba 116 Elemental Analyzer. UV-Vis spectra of the polymers in solution and as thin films were taken on a Shimadzu UV2100 UV-Vis recording spectrophotometer. Photoluminescence (PL) spectra of the polymers in solutions and thin films were measured on a Hitachi 850 fluorescence spectrophotometer. The PL quantum yields in neat films were measured in an integrating sphere at room temperature. Thermal gravimetric analysis (TGA) measurements were performed on Perkin-Elmer series 7 thermal analysis system under N<sub>2</sub> at a heating rate of 10 °C min<sup>-1</sup>. Differential scanning calorimetry (DSC) measurements were performed on a Perkin-Elmer DSC 7 under  $N_2$  at a heating rate of 10 °C min<sup>-1</sup>. The weight-average molecular weights  $(M_w)$  and polydispersity indices  $(M_w/M_n)$ of the polymers were measured on a PL-GPC model 210 chromatograph at 25 °C, using THF as the eluent and standard polystyrene as the reference. The cyclic voltammograms were recorded on a computer-controlled EG&G potential/galvanostat model 283. The thicknesses of the films were measured with a Dektak surface profilometer.

# Poly{(9,9-dihexyl-9*H*-fluoren-2,7-ylene)-*alt*-[3,5-bis(1,4-phenylene)-4,5-dihydro-1-phenyl-1*H*-pyrazole]} (PFPZ1)

To a mixture of 8 (502.3 mg, 1.0 mmol), 3 (456.2 mg, 1.0 mmol) and  $Pd(PPh_3)_4$  (12 mg, 1.0 mol%) was added a mixture of toluene (5 mL) and aqueous 2 M potassium carbonate (5 mL). The mixture was vigorously stirred at 85-90 °C for 48 h. After the mixture was cooled down to room temperature, it was poured into 200 mL of methanol and deionized water (10:1). A fibrous solid was obtained by filtration, the solid was washed with methanol, water and then methanol. After washing for 24 h in a Soxhlet apparatus with acetone, the resulting polymer PFPZ1 was obtained as a bright yellow powder with a yield of 85% after drying under a vacuum. <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz, δ/ppm): 8.27–7.97 (m, 4 H), 7.85–7.05 (m, 13 H), 7.00–6.80 (m, 2 H), 5.38 (m, 1 H), 3.91 (m, 2 H), 2.05 (br, 4 H), 1.95–0.74 (m, 22 H). <sup>13</sup>C NMR (CDCl<sub>3</sub>, 400 MHz, δ/ppm): 151.78, 146.46, 144.76, 144.41, 141.57, 140.90, 140.54, 139.79, 132.07, 131.97, 131.36, 130.53, 129.06, 128.93, 128.73, 128.48, 128.26, 127.78, 127.36, 127.13, 126.38, 126.21, 125.94, 125.58, 125.39, 125.24, 121.50, 121.26, 121.10, 119.20, 113.47, 64.26, 55.33, 43.57, 40.40, 31.40, 29.64, 23.77, 22.51, 13.94. FT-IR (KBr, v/cm<sup>-</sup> 3070, 3028, 2922, 2852, 1633, 1595, 1495, 1460, 1384, 1262, 1098, 1066, 1024, 872, 742, 689. Anal. Calcd for  $(C_{48}H_{48}N_2)_n$ : C, 87.85; H, 7.69; N, 4.45. Found: C, 86.12; H, 7.76; N, 4.49%.

# Poly{(9,9-dihexyl-9*H*-fluoren-2,7-ylene)-*alt*-[3-(2-hexyloxy-1,5-phenylene)-5-(1,4-phenylene)-4,5-dihydro-1-phenyl-1*H*-pyrazole]} (PFPZ2)

PFPZ2 was obtained as a bright yellow powder with a yield of 80% from the reaction of 7a with 8 according to the procedure described for the synthesis of polymer PFPZ1. <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz, δ/ppm): 8.33-8.00 (m, 4 H), 7.79-7.11 (m, 12 H), 7.01-6.81 (m, 2 H), 5.60 (m, 1 H), 4.29-4.20 (m, 2 H), 3.82–3.80 (m, 2 H), 2.05 (br, 4 H), 1.95–0.74 (m, 33 H). <sup>13</sup>C NMR (CDCl<sub>3</sub>, 400 MHz, δ/ppm): 151.75, 151.60, 151.53, 147.22, 147.04, 145.08, 144.25, 143.62, 141.70, 141.62, 141.08, 139.76, 139.44, 139.19, 139.10, 135.82, 134.11, 131.82, 131.73, 131.63, 130.07, 128.93, 128.74, 128.70, 128.39, 128.27, 127.32, 127.14, 126.10, 125.89, 125.57, 124.08, 121.49, 121.20, 121.07, 120.01, 119.80, 118.93, 113.44, 111.71, 68.45, 68.23, 55.26, 55.11, 42.09, 40.39, 40.25, 36.99, 31.54, 31.39, 29.65, 29.33, 29.09, 28.77, 25.95, 25.86, 25.52, 23.75, 22.66, 22.53, 21.98, 14.07, 13.96. FT-IR (KBr, v/cm<sup>-1</sup>): 3073, 3030, 2927, 2855, 1598, 1571, 1499, 1465, 1391, 1324, 1248, 1118, 1070, 999, 872, 816, 746, 724, 692, 542. Anal. Calcd for (C<sub>52</sub>H<sub>60</sub>N<sub>2</sub>O)<sub>n</sub>: C, 85.67; H, 8.30; N, 3.84. Found: C, 85.09; H, 8.41; N, 3.88%.

# Poly{(9,9-dihexyl-9*H*-fluorene-2,7-ylene-*alt*-[3-(2-dodecyloxy-1,5-phenylene)-5-(4-phenylene)-4,5-dihydro-1-phenyl-1*H*-pyrazole]} (PFPZ3)

PFPZ3 was obtained as a bright yellow powder with a yield of 81% from the reaction of 7b with 8 according to the procedure described above. <sup>1</sup>H NMR (CDCl<sub>3</sub>, 400 MHz, δ/ppm): 8.32-8.01 (m, 4 H), 7.79-7.13 (m, 12 H), 7.02-6.85 (m, 2 H), 5.60 (m, 1 H), 4.21 (m, 2 H), 3.82-3.78 (m, 2 H), 2.05 (br, 4 H), 1.94-0.74 (m, 45 H). <sup>13</sup>C NMR (CDCl<sub>3</sub>, 400 MHz, δ/ppm): 151.75, 151.61, 147.24, 145.09, 141.64, 140.09, 139.76, 139.45, 133.44, 131.89, 131.87, 131.74, 130.49, 130.10, 128.94, 128.86, 128.75, 128.71, 128.62, 128.42, 128.30, 127.43, 127.16, 126.73, 126.11, 125.91, 125.56, 124.49, 121.50, 121.20, 120.01, 119.81, 118.96, 113.45, 111.72, 68.48, 68.26, 55.27, 55.11, 42.10, 40.40, 31.89, 31.40, 29.65, 29.35, 29.14, 28.82, 26.30, 26.20, 25.90, 23.77, 22.66, 22.55, 14.11, 13.96. FT-IR (KBr, v/cm<sup>-1</sup>): 3071, 3029, 2925, 2853, 1637, 1598, 1499, 1464, 1389, 1326, 1250, 1117, 1069, 877, 815, 747, 693, 540. Anal. Calcd for (C<sub>58</sub>H<sub>72</sub>N<sub>2</sub>O)<sub>n</sub>: C, 85.66; H, 8.92; N, 3.44. Found: C, 85.12; H, 8.83; N, 3.49%.

#### EL device fabrications

For the fabrication of the devices, glass substrates coated with indium-tin oxide (ITO) with a sheet resistance of 30  $\Omega \gamma^{-1}$ (CSG Co. Ltd.) were cleaned sequentially in ultrasonic baths of aqueous ionic detergent, acetone and anhydrous ethanol. A thin film layer of PEDOT (Baytron P 4083) (90 nm) (PEDOT is poly(ethylenedioxythiophene) doped with polystyrene sulfonic acid) and the polymers (60 nm) (from a 10 mg mL<sup>-1</sup> solution of the polymers in toluene solution) were spin-coated on the ITO surface at 1500 rpm for 30 s, after which a thin layer of Ba (4 nm)/Al (170 nm) was deposited on the polymer film by thermal evaporation under a vacuum of  $10^{-6}$  Torr. The active area of the device was about  $0.15 \text{ cm}^2$ . The applied dc bias voltages for EL devices were in a forward direction (ITO, positive; Ba/Al, negative). The current-voltage characteristics were measured on a voltmeter and an amperometer, respectively. The EL efficiency and brightness measurements were carried out with a calibrated silicon photodiode. All the measurements of the EL devices were carried out in air at room temperature.

### **Results and discussion**

The resulting polymers readily dissolve in solvents, e.g., THF, CH<sub>2</sub>Cl<sub>2</sub>, CHCl<sub>3</sub>, toluene and xylene. This is partially due to the hexyl side chain attaching to the fluorene moiety and *n*-alkyl

Table 1 Molecular weights and thermal properties of the polymers

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Polymers	Yield (%)	$M_{ m w}{}^a$	$M_{\rm w}/M_{\rm n}^{\ a}$	$T_{\rm d}^{\ b}/^{\circ}{\rm C}$	$T_{g}^{c}/^{\circ}C$	
PFPZ1	85	39100	2.33	387	162	
PFPZ2	80	33200	1.53	376	111	
PFPZ3	81	37100	1.45	380	80	
<sup><i>a</i></sup> Molecular	r weights and	polydispe	rsity indices	were deter	nined by	

GPC in THF using polystyrene as the standard. <sup>*b*</sup> Onset decomposition temperature measured by TGA under  $N_2$ . <sup>*c*</sup> Glass transition temperature measured by DSC under  $N_2$ .

side chain linked to the triarylpyrazoline unit. Uniform and transparent films on substrates, such as ITO-coated glasses and microslides, can be obtained by spin-casting the solutions in toluene (1%) at a spin rate of 1500 rpm. Their molecular weights were determined by gel permeation chromatography (GPC) using polystyrene as the standard. The results are listed in Table 1. These copolymers have weight-average molecular weights  $(M_w)$  of 33200–39100 with polydispersity indices  $(M_w/$  $M_{\rm n}$ ) of 1.45–2.33. From GPC results, **PFPZ2** and **PFPZ3** have a relative narrow polydispersity index. The reason may be that these two polymers have a better solubility in the reaction system due to the long alkyl side chain linked to the triarylpyrazoline unit. Thus, the reagents can react with each other enough and equably to afford a narrow molecular distribution. The thermal properties of the polymers were investigated by differential scanning calorimetry (DSC: heating at 10  $^{\circ}$ C min<sup>-1</sup> in nitrogen) and thermogravimetric analysis (TGA: heating at 10  $^{\circ}$ C min<sup>-1</sup> in nitrogen). As shown in Table 1 and Fig. 1, all these polymers possess excellent thermal stability with high onset decomposition temperatures  $(T_d)$  in the range of 376 °C to 387 °C, and no weight loss was observed at lower temperatures. The glass transition temperatures  $(T_g)$ of the polymers range from 80 °C to 162 °C. These  $T_{\rm g}$  values are higher than those of poly(9,9-dioctylfluorene) (POF)  $(\sim 51 \text{ °C})^{30}$  and poly(9,9-dihexylfluorene) (PHF) (~55 °C),<sup>31</sup> in which each repeating fluorene unit contains two flexible n-octyl or n-hexyl chains at C-9. It is evident that the incorporation of triarylpyrazoline units in the main chain can increase the  $T_{g}$  of fluorene-based polymers. This is very important for such polymers used as emissive materials in PLEDs.<sup>32</sup>

The UV-Vis absorption and photoluminescence (PL) spectra of the polymers in films (spun-cast from the corresponding polymers in toluene at a concentration of 10 mg mL<sup>-1</sup>) on microslides are shown in Fig. 2 and 3. As shown in Fig. 2, the absorption onsets occur at 454, 457, 458 nm for **PFPZ1**, **PFPZ2**, **PFPZ3**, and give two peaks at 339, 395 nm, 337, 399 nm and 336, 398 nm for these three polymers, respectively. The absorbances are attributed to the  $\pi$ - $\pi$ \* transitions of these polymers. From the onset wavelengths, the optical band gaps can be estimated to be 2.71–2.73 eV. All these films emit green



**Fig. 1** Thermal gravimetric analysis (TGA) curves of the polymers (under a nitrogen atmosphere at a heating rate of 10  $^{\circ}$ C min<sup>-1</sup>).



Fig. 2 Absorption spectra of the polymers in solid state films spincoated on quartz plates.



Fig. 3 PL spectra of the polymers in films.

fluorescence when they are exposed to UV light. The PL spectra exhibit maxima at around 508–509 nm. The absolute PL quantum yields of the neat polymer films were about 45%, 56% and 59% for **PFPZ1**, **PFPZ2** and **PFPZ3** as measured in an integrating sphere at room temperature in air using a HeCd laser line of 405 nm as the excitation source according to the procedure described by Greenham *et al.*<sup>33</sup> From above, the PL efficiencies of **PFPZ2** and **PFPZ3** are very high. The main features of these spectra are summarized in Table 2 and Fig. 2 and 3.

The electrochemical behavior of the polymers was investigated by cyclic voltammetry (CV). CV was performed on a thin film of the polymer coated onto a platinum plate electrode (about 6 mm<sup>-2</sup>) in a 0.1 mol L<sup>-1</sup> tetrabutylammonium perchlorate (Bu<sub>4</sub>NClO<sub>4</sub>) solution in acetonitrile with a scan rate of 50 mV s<sup>-1</sup> at room temperature. A platinum wire was used as the counter electrode, and Ag/AgNO<sub>3</sub> (0.10 M) was employed as the reference electrode. As shown by the cyclic voltammograms in Fig. 4, all these polymers showed reversible n-doping and p-doping processes. In the anodic scan, the oxidation (p-doping) started at about 1.41, 1.34 and 1.31 V and gave two corresponding oxidation peaks at 1.61, 2.40 V, 1.71, 2.49 V and 1.78, 2.46 V for **PFPZ1**, **PFPZ2** and **PFPZ3**,

Table 2 Absorption and emission data for the polymers

Polymers	Absorption (film) $\lambda_{max}/nm$	Band gap/eV	PL (film) $\lambda_{max}/nm$	Quantum yield, $\phi_{PL}$ (%)	fwhm <sup>a</sup> / nm
PFPZ1	339, 395	2.73	512	45	105
PFPZ2	337, 399	2.71	508	56	95
PFPZ3	336, 398	2.71	509	59	96
<sup>a</sup> Full wid	th at half-maxin	num of t	he film PL	spectra.	



**Fig. 4** Cyclic voltammograms of the polymers recorded from thin films deposited on platinum plate electrodes at a scan rate of  $50 \text{ mV s}^{-1}$ . The potentials were measured relative to Ag/AgNO<sub>3</sub>.

respectively. The corresponding re-reduction peaks appeared at 1.47, 1.66 and 1.63 V. On sweeping the polymer cathodically, the reduction (n-doping) began at -1.42, -1.42 and -1.47 V with the cathodic current increasing quickly and produced cathodic peaks at -2.12, -1.76 and -1.80 V for PFPZ1, PFPZ2 and PFPZ3, respectively. The corresponding reoxidation peaks occurred at -1.52, -1.58 and -1.58 V. The electrochemically measured gaps are 2.83, 2.76 and 2.78 V for PFPZ1, PFPZ2 and PFPZ3, which are close to the optical band gaps determined from the absorption onsets. According to the equations,<sup>34,35</sup> IP =  $-([E_{onset}]^{0x} + 4.4)$  eV and EA =  $-([E_{onset}]^{red} + 4.4)$  eV, where  $[E_{onset}]^{ox}$  and  $[E_{onset}]^{red}$  are the onset potentials for oxidation and reduction of the polymer vs. the reference electrode, the LUMO and HOMO of the polymers were estimated to be -2.98, -2.98, -2.93 eV and -5.81, -5.74 and -5.71 eV for PFPZ1, PFPZ2 and PFPZ3, respectively, and therefore the HOMO and LUMO energy levels of these polymers are quite similar. The electrochemical data of these polymers are summarized in Table 3.

Light-emitting devices with the configuration of ITO/ PEDOT (90 nm)/polymer (60 nm)/Ba (4 nm)/Al (170 nm) were fabricated in a glove box under a nitrogen atmosphere. Poly(3,4-ethylenedioxythiophene) (PEDOT) doped with poly-(styrenesulfonic acid) (PSS) (Baytron P 4083) was used as the hole injection/transporting layer. A thin layer of Ba was employed as the cathode because it normally renders devices with longer lifetime due to its larger atomic size and mass as compared with Ca or Mg.<sup>36</sup> The active area of the devices was about 0.15 cm<sup>2</sup>. Fig. 6 show current (I) and luminance (L) as a function of the applied voltage (V) for these devices. A typical device with the configuration of ITO/PEDOT (90 nm)/PFPZ1 (60 nm)/Ba (4 nm)/Al (170 nm) emits visible green light starting at about 5.5 V and reaches a brightness of 543 cd  $m^{-2}$  at a bias of 9 V. The maximum external quantum efficiency was measured to be 0.60% (at 7.0 V with current indensity of 59.9 mA cm<sup>-2</sup> and brightness of 181 cd m<sup>-2</sup>). As shown in Fig. 6, the green emisssion from the device based on PFPZ2

 Table 3
 Electrochemical potentials and energy levels of the polymers

Polymer	$[E^a_{onset}]^{red}/V$	$[E^b_{onset}]^{ox}$ / V	$E_{\rm LUMO}^{c}$ / eV	$E_{\rm HOMO}^{d}$ / eV	Eg <sup>e</sup> /eV
PFPZ1	-1.42	1.41	-2.98	-5.81	2.83
PFPZ2	-1.42	1.34	-2.98	-5.74	2.76
PFPZ3	-1.47	1.31	-2.93	-5.71	2.78

<sup>*a*</sup> Onset reduction potentials measured by cyclic voltammetry. <sup>*b*</sup> Onset oxidation potentials measured by cyclic voltammetry. <sup>*c*</sup> Calculated from the reduction potentials. <sup>*d*</sup> Calculated from the oxidation potentials. <sup>*e*</sup> Calculated from the LUMO and HOMO energy levels.



Fig. 5 EL spectra of devices with the configuration of ITO/PEDOT/ polymer/Ba/Al.



Fig. 6 Current-voltage (I-V) and luminance-voltage (L-V) curves of an ITO/PEDOT/polymer/Ba/Al device. The curves of a and d were recorded from the device based on PFPZ1, b and e were from the device based on PFPZ2, c and f were from the device based on PFPZ3, respectively.

starts at about 3.9 V and reaches a brightness of 1859 cd  $m^{-2}$  at a bias of 8.3 V. The maximum external quantum efficiency was measured to be 1.56% (at 5.9 V with a current indensity of 37.4 mA cm<sup>-2</sup> and brightness of 337 cd m<sup>-2</sup>). The device with the configuration of ITO/PEDOT (90 nm)/PFPZ3 (60 nm)/ Ba (4 nm)/Al (170 nm) also emits visible green light at the lower forward bias of about 3.7 V and reaches a brightness of 2378 cd m<sup>-2</sup> at a bias of 7.9 V. The maximum external quantum efficiency was measured to be 2.53% (at 5 V with a current indensity of 17 mA cm<sup>-2</sup> and brightness of 248 cd m<sup>-2</sup>). Compared with the above two devices, the device based on PFPZ3 exhibits much higher maximum external quantum efficiency. The EL spectra of these polymers with maxima at 500, 497 and 495 nm are very similar to the corresponding PL spectra. The similarity of the PL and EL spectra indicates that the same excitations are involved in both cases. From the EL and PL spectra, no emission band appears between 600-700 nm, which indicates that the aggregation is efficiently suppressed in these solid films of these polymers. This may be caused by the incorporation of twisted triarylpyrazoline units into the polymer backbones. So further improvements could be expected after optimization.

### Conclusion

We have synthesized a series of novel efficient light-emitting polymers based on fluorene and triarylpyrazoline through palladium-catalyzed Suzuki coupling polymerization. These polymers show satisfactory thermal stability and excellent

green emission with high PL quantum efficiencies. Doublelayer polymer light-emitting diodes (PLEDs) were fabricated using these polymers as the emitting layers and Ba as cathodes. All these devices show bright green emission with high maximum external quantum efficiencies of 0.60-2.53% and low turn-on bias voltages of 3.7-5.5 V. The results show that these polymers are new and promising candidates for emissive materials that can be used to fabricate efficient polymer lightemitting diodes.

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