Supporting Information for

# *N*-acylation: an effective method for reducing the LUMO energy levels of conjugated polymers containing five-membered lactam units

Ping Deng, <sup>*a*</sup>Lu Liu, <sup>*b*</sup> Shendong Ren, <sup>*b*</sup> Hongxiang Li,<sup>\*, *b*</sup> Qing Zhang<sup>\*, *a*</sup>

<sup>a</sup> Department of Polymer Science and Engineering, School of Chemistry and Chemical Engineering, Shanghai Jiaotong University, Shanghai 200240, China.

<sup>b</sup> Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences, Shanghai, 200032, China.

# Contents

## **1.** Materials and Characterization

- **2.** Synthesis Procedures
- 3. OFET Device Fabrication and Characterization
- 4. The morphology of the polymer films
- 5. References

### 1. Materials and Characterization

1-(4-Bromophenyl)ethanone was obtained from Darui Chemical Co. Ltd., Shanghai, China. Other materials used in this work were purchased from Sigma-Aldrich Chemical Co., Alfa Aesar Chemical Company and Sinopharm Chemical Reagent Co. Ltd., China. Tetrahydrofuran (THF) and toluene were freshly distilled over sodium wire under nitrogen atmosphere prior to use. *N*-Methyl-2-pyrrolidone (NMP) was dried over potassium hydroxide and *N*,*N*-dimethylformamide (DMF) was dried over calcium hydride and was freshly distilled before used. All chromatographic separations were carried out on silica gel (200-300 mesh).

Nuclear magnetic resonance (NMR) spectra were recorded on a Mercury plus 400 MHz machine. Gel permeation chromatography (GPC) measurements were performed on a Waters 1515 series GPC coupled with UV-vis detector using tetrahydrofuran as eluent with polystyrenes as standards. Thermogravimetric analyses (TGA) were conducted with a TA Instruments QS000IR at a heating rate of 20 °C min<sup>-1</sup> under nitrogen gas flow. UV-vis absorption spectra were recorded on a Perkin-Elmer model  $\lambda$  20 UV-vis spectro-photometer.

Electrochemical measurements were conducted on a CHI 600 electrochemical analyzer with a three-electrode system under nitrogen atmosphere in a deoxygenated anhydrous acetonitrile solution of tetra-*n*-butylammonium hexafluorophosphate (0.1 M). A platinum electrode was used as a working electrode, a platinum-wire was used as the counter electrode, and an Ag/Ag<sup>+</sup> (0.01 M AgNO<sub>3</sub> in acetonitrile) electrode was used as the reference electrode. The sample films for electrochemical measurements were coated on the surface of platinum electrode. The CV curves were calibrated using the ferrocene/ferrocenium (Fc/Fc<sup>+</sup>) redox couple as an external standard which was measured under same condition before and after the measurement of samples. The energy level of Fc/Fc<sup>+</sup> was assumed at –4.8 eV to vacuum.<sup>1</sup> The half-wave potential of the ferrocene/ferrocenium (Fc/Fc<sup>+</sup>) redox couple ( $E_{1/2, Fc,Fc+}$ ) was estimated from  $E_{1/2, Fc,Fc+} = (E_{ap} + E_{cp})/2$ , where  $E_{ap}$  and  $E_{cp}$  are the anodic and cathodic peak potentials, respectively. The half-wave potential of Fc/Fc<sup>+</sup> was found to

be 0.05 V { $E_{1/2, Fc,Fc^+} = (E_{ap} + E_{cp})/2 = (0.01+0.09)/2 = 0.05$  V} related to the Ag/Ag<sup>+</sup> reference electrode. The LUMO energy levels of monomers and polymers were calculated using the equation:  $E_{LUMO} = -(4.8 - E_{1/2, Fc,Fc^+} + E_{red, onset}) = -(4.75 + E_{red, onset})$  eV, where  $E_{red, onset}$  is the onset reduction potential relative to the Ag/Ag<sup>+</sup> reference electrode.<sup>2</sup> The HOMO energy levels of monomers were calculated by subtracting the optical band gap value from the respective LUMO energy levels ( $E_{HOMO} = E_{LUMO} - E_{g, opt}$ ). The HOMO energy levels of polymers were estimated by equation:  $E_{HOMO} = -(4.8 - E_{1/2, Fc,Fc^+} + E_{ox, onset}) = -(4.75 + E_{ox, onset})$  eV, where  $E_{ox, onset}$  is the onset othe Ag/Ag<sup>+</sup> reference electrode.<sup>2</sup>

## 2. Synthetic Procedures

Compound **3** and Compound **4**, were synthesized according to procedures reported in the literatures.<sup>3</sup> The detail routes are displayed in Scheme S1. 2,6-Bis(trimethyltin)-4,8-di(2-octyldodecyloxy)benzo [1,2-b:4,5-b']dithiophene<sup>4</sup> and 2,5'-bis(trimethylstannyl)-thiophene<sup>5</sup> were prepared according to literature procedures. The routes for synthesis of polymers are shown in Scheme S2.



#### Scheme S1. Synthesis of the monomers





**Monomer M1.** To a solution of potassium *tert*-butoxide (0.60 g, 5.13 mmol) in anhydrous *N*-methyl-2-pyrrolidone (30.0 mL) was added compound **4** under nitrogen atmosphere. The mixture was slowly heated to 60 °C and 2-ethylhexyl bromide (2.70 g, 13.80 mmol) was added dropwise. After addition, the mixture was heated at 60 °C for 24 h, and then was poured into water. It was extracted with toluene. The organic layer was washed with water and saturated aqueous sodium chloride solution, and then was dried with anhydrous magnesium sulfate. After removing solvent, the crude product was purified by flash column chromatography (silica gel, dichloromethane: petroleum ether = 1:2) to afford the titled compound (0.415 g, 25%) as a brown solid. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>):  $\delta$  ppm 7.59 (m, 8H), 6.29 (s, 2H), 3.51 (dd, *J* = 9.8, 7.4 Hz, 4H), 1.72 (m, 2H), 1.25 (br, 16H), 0.98 -0.79 (m,12H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  ppm 169.80, 144.50, 134.71, 132.25, 131.15, 130.22, 126.58, 123.81, 97.38, 43.81, 38.63, 31.00, 29.91, 29.11, 24.37, 23.24, 14.30, 10.95.



**Monomer M2**. Dodecanoyl chloride (2.20 g, 10.00 mmol) was added slowly to a suspension of compound **3** (1.00 g, 2.00 mmol) in pyridine (20.0 mL). The mixture was heated at reflux for 8 h, and then was cooled to room temperature. It was poured into ice-cold aqueous hydrochloric acid solution (2.0 M). The precipitate was collected by filtration and was washed with ethanol. After removing solvent, it was purified by flash column chromatography (silica gel, dichloromethane: petroleum ether = 1:2). The purified product was dried in air at 80 °C overnight to obtain the titled compound (0.541 g, 31%) as a red brown solid. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>):  $\delta$  ppm 8.11 (s, 2H), 7.68-7.65 (m, 4H), 7.58-7.55 (m, 4H), 3.10-3.07 (m, 4H), 1.68-1.74 (m, 4H), 1.25 (br, 32H), 0.87 (t, *J* = 6.9 Hz, 6H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  ppm 173.96, 168.34, 140.30, 137.27, 132.57, 131.47, 128.64, 128.06, 124.93, 106.96, 38.33, 32.12, 29.84, 29.71, 29.62, 29.55, 29.36, 24.42, 22.90, 14.33. MS-EI (m/z): calcd for C<sub>46</sub>H<sub>56</sub>Br<sub>2</sub>N<sub>2</sub>O<sub>4</sub>: 860.26 Found: 860.30



**Monomer M3**. To a solution of potassium *tert*-butoxide (1.23 g, 11.00 mmol) in anhydrous *N*,*N*-dimethylformamide (60.0 mL) was added compound **4** (2.48 g, 5.00 mmol) under nitrogen atmosphere. The mixture was slowly heated to 80 °C and 9-(bromomethyl)nonadecane (10.85 g, 30.00 mmol) was added dropwise. The mixture was heated at 80 °C for 24 h and then was poured into water. It was extracted with toluene. The organic layer was washed with water, saturated aqueous sodium chloride solution, and then was dried with anhydrous magnesium sulfate. After removing solvent, the crude product was purified by flash column chromatography (silica gel, dichloromethane: petroleum ether = 1:2) to afford the titled compound (2.45 g, 45%) as a brown solid. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  ppm 7.58 (m, 8H), 6.29 (s, 2H), 3.49 (d, *J* = 7.2 Hz, 4H), 1.78-1.59 (m, 2H), 1.35-1.16 (m, 62H), 0.86 (t, *J* = 6.9 Hz, 12H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  169.77, 144.52, 134.70, 132.26, 131.14, 130.24, 126.54, 123.81, 97.38, 44.24, 37.32, 32.11, 31.97, 30.22, 29.87, 29.82, 29.57, 29.54, 26.90, 22.89, 14.34.



**Monomer M4.** A solution of *N*,*N*-dimethylaminopyridine (DMAP) (6.11 g, 50.00 mmol) in anhydrous tetrahydrofuran (8.0 mL) was added to a suspension of Compound **3** (2.00 g, 4.00 mmol) in anhydrous THF (20.0 mL). The reaction mixture was stirred for 15 min at room temperature, and then 2-heptylundecanoyl chloride (7.58 g, 25.00 mmol) was added dropwise. The mixture was stirred for 48 h at room temperature, and then was poured into iced-cold aqueous hydrochloric acid solution (0.5 M). The mixture was extracted with dichloromethane. The organic layer was washed with water, saturated sodium bicarbonate solution and sodium chloride solution. It was dried with anhydrous magnesium sulfate. After removing solvent, the crude product was purified by flash column chromatography (silica gel, dichloromethane: petroleum ether = 1:10). The purified product was dried in air at 60 °C overnight to obtain the titled compound (1.07 g, 26%) as a red brown solid. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  ppm 8.11 (s, 2H), 7.68 (d, *J* = 8.6 Hz, 4H), 7.58 (d, *J* = 8.4 Hz, 4H), 3.93 (t, *J* = 5.9 Hz, 2H), 1.80-1.71 (m, 4H), 1.54-1.48 (m, 4H), 1.36-1.22 (m, 48H), 0.85 (t, *J* = 6.8 Hz, 12H). <sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>)  $\delta$  ppm 177.86, 168.27, 140.70, 137.37, 132.59, 131.57, 128.70, 128.13, 124.88, 107.13, 45.51, 32.82, 32.44, 32.09, 32.03, 31.56, 29.96, 29.76, 29.70, 29.51, 29.37, 27.54, 22.86, 14.31.

Scheme S2. Synthesis of the polymers



2.2 Synthesis of the polymers



**Polymer P1. M1** (0.2160 g, 0.3000 mmol), 2,6-bis(trimethyltin)-4,8-di(2-octyldodecyloxy)benzo-[1,2-b:4,5-b']dithiophene (0.3330 g, 0.3000 mmol),  $Pd_2(dba)_3$  (0.0055 g, 0.0060 mmol),  $P(o-toly)_3$  (0.0073 g, 0.0240 mmol) and degassed toluene (10.0 mL) were added to a Schlenk tube. The solution was subjected to three cycles of evacuation and admission of nitrogen and was stirred for 48 h at 110 °C. The reaction mixture was allowed to cool to room temperature and was poured into methanol. The

product was collected by filtration. It was washed with methanol, hexane and acetone in a Soxhlet extractor for 24 h each. It was extracted with hot chloroform in an extractor for 24 h. The chloroform solution of the product was concentrated, and then was added dropwise to methanol. The precipitate was collected and was dried under vacuum to afford the titled polymer (0.342 g, 85%) as a blue solid with metallic luster. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  ppm 7.63-7.86 (br, 8H), 7.32-7.44 (br, 2H), 5.78-6.05 (br, 2H),4.06-4.14 (br, 4H), 3.54-3.60 (br, 4H), 1.55-1.84 (m, 8H), 1.14-1.42 (m, 76H), 0.85-0.93 (br, 24H).



**Polymer P2. M2** (0.2160 g, 0.2500 mmol), 2,6-bis(trimethyltin)-4,8-di(2-octyldodecyloxy)benzo[1,2-b:4,5-b'] dithiophene (0.3050 g, 0.2500 mmol),  $Pd_2(dba)_3$  (0.0046 g, 0.0050 mmol),  $P(o-toly)_3$  (0.0060 g, 0.0200 mmol) and degassed toluene (8.0 mL) were added to a Schlenk tube. The solution was subjected to three cycles of evacuation and admission of nitrogen and was stirred for 48 h at 110 °C. The reaction mixture was allowed to cool to room temperature and was poured into methanol. The product was collected by filtration. It was washed with methanol, hexane and acetone in a Soxhlet extractor for 24 h each. It was extracted with hot chloroform in an extractor for 24 h. The chloroform solution of the product was concentrated, and then was added dropwise to methanol. The precipitate was collected and was dried under vacuum to afford the titled polymer (0.3370 g, 91%) as a dark blue solid with metallic luster. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  ppm 7.64- 7.85 (br, 8H), 7.45-7.55 (br, 4H), 4.02-4.21 (m, 4H), 3.15-3.30 (m, 4H), 1.61-1.96 (m, 10H), 1.18-1.53 (m, 92H), 0.82-0.93 (br, 18H).



**Polymer P3. M3** (0.5280 g, 0.5000 mmol), 2,5'-bis(trimethylstannyl)-thiophene (0.2050 g, 0.5000 mmol),  $Pd_2(dba)_3$  (0.0091 g, 0.0100 mmol) and P(o-toly)\_3 (0.0122 g, 0.0400 mmol) and degassed toluene (10.0 mL) were added to a Schlenk tube. The solution was subjected to three cycles of evacuation and admission of nitrogen and was stirred for 36 h at 110 °C. The reaction mixture was allowed to cool to room temperature and was poured into methanol. The product was collected by filtration. It was washed with methanol, hexane and chloroform in a Soxhlet extractor for 24 h each. It

was extracted with hot chlorobenzene in an extractor for 24 h. The chlorobenzene solution of the product was concentrated, and then was added dropwise to methanol. The precipitate was collected and was dried under vacuum to afford the titled polymer (0.3820 g, 78%) as a blue solid with metallic luster. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>)  $\delta$  ppm 7.62- 7.81 (br, 8H), 7.42-7.48 (br, 2H), 6.23-6.41 (br, 2H), 3.54 (br, 4H), 1.55-1.84 (m, 4H), 1.14-1.42 (m, 62H), 0.85-0.93 (br, 12H).



**Polymer P4. M4** (0.5145 g, 0.5000 mmol), 2,5'-bis(trimethylstannyl)-thiophene (0.2050 g, 0.5000 mmol),  $Pd_2(dba)_3$  (0.0091 g, 0.0100 mmol) and P(o-toly)\_3 (0.0122 g, 0.0400 mmol) and degassed toluene (10.0 mL) were added to a Schlenk tube. The solution was subjected to three cycles of evacuation and admission of nitrogen and was stirred for 36 h at 110 °C. The reaction mixture was allowed to cool to room temperature and was poured into methanol. The product was collected by filtration. It was washed with methanol, hexane and chloroform in a Soxhlet extractor for 24 h each. It was extracted with hot chlorobenzene in an extractor for 24 h. The chlorobenzene solution of the product was concentrated, and then was added dropwise to methanol. The precipitate was collected and was dried under vacuum to afford the titled polymer (0.3860 g, 81%) as a dark blue solid with metallic luster. <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) 8.24 (br, 2H), 7.74- 7.78 (br, 8H), 7.33-7.30 (br, 2H), 4.08-4.13 (br, 2H), 1.49-1.82 (br, 8H), 1.14-1.45 (br, 48H), 0.82-0.94 (br, 12H).

## 2.3 NMR spectra of the monomers and polymers



Figure S1. <sup>1</sup>H NMR spectrum of M1.



Figure S2. <sup>13</sup>C NMR spectrum of M1.



Figure S3. <sup>1</sup>H NMR spectrum of M2.



Figure S4. <sup>13</sup>C NMR spectrum of M2.



Figure S5. <sup>1</sup>H NMR spectrum of M3.



Figure S6. <sup>13</sup>C NMR spectrum of M3.



Figure S7. <sup>1</sup>H NMR spectrum of M4.



Figure S8. <sup>13</sup>C NMR spectrum of M4.



Figure S9. <sup>1</sup>H NMR spectrum of P1.



Figure S10. <sup>1</sup>H NMR spectrum of P2.



Figure S11. <sup>1</sup>H NMR spectrum of P3.



Figure S12. <sup>1</sup>H NMR spectrum of P4.

#### 2.4 The properties of the polymers



Figure S13. TGA curves of the polymers collected under nitrogen at a heating rate of 20 °C min<sup>-1</sup>.

#### 2.5 The UV-vis and CV data of the monomers and polymers



Figure S14. Absorption spectra of monomers in dilute chloroform solution (a) and as thin film (b).



**Figure S15.** Cyclic voltammograms of ferrocene in anhydrous acetonitrile solution of tetra-*n*-butylammonium hexafluorophosphate (0.1 M). The half-wave potential of the ferrocene/ ferrocenium (Fc/Fc<sup>+</sup>) redox couple ( $E_{1/2, Fc,Fc^+}$ ) was found to be 0.05 V relative to the Ag/Ag<sup>+</sup> reference electrode.

$\lambda_{max}$ (nm)							
monomer	solution	film	$\lambda_{onset}$ (nm) film	$E_{\rm g,  opt}({ m V})^a$	$E_{\text{rex,onset}}(\mathbf{V})^b$	$LUMO^{c}(eV)$	$HOMO^{d}(eV)$
M1	468	521	595	2.08	-1.23	-3.52	-5.60
M2	478	531	603	2.05	-0.93	-3.82	-5.87
M3	468	523	581	2.13	-1.18	-3.57	-5.70
M4	478	504, 555	620	2.00	-0.86	-3.89	-5.89

#### Table S1. The Optical and electrochemical properties of the monomers

<sup>*a*</sup> Estimated from the absorption edge. <sup>*b*</sup>*Vs*. Ag/Ag<sup>+</sup> in acetonitrile solution with 0.1 M *n*-Bu<sub>4</sub>NPF<sub>6</sub> as supporting electrolyte, at scan speed of 100 mV s<sup>-1</sup>,  $E_{1/2, Fc,Fc^+} = 0.05$  V). <sup>*c*</sup> Calculated based on  $E_{LUMO} = -(4.8 - E_{1/2, Fc,Fc^+} + E_{red, onset}) = -(4.75 + E_{red, onset}) = -(4.75 + E_{red, onset})$  eV. <sup>*d*</sup> Estimated from  $E_{HOMO} = E_{LUMO} - E_{g, opt}$ .

$\lambda_{max}$ (nm)									
polymer	solution	film	λ <sub>onset</sub> (nm) film	$E_{\rm g,opt}$ (V) <sup><i>a</i></sup>	$E_{\text{ox,onset}}$ (V) <sup>b</sup>	$E_{\text{rex},\text{onset}}$ (V) <sup>b</sup>	HOMO <sup>c</sup> (eV)	LUMO <sup>c</sup> (eV)	$E_{ m g,  ec}$ $\left({ m V} ight)^e$
P1	614	625	787	1.57	+0.63	-1.22	-5.38	-3.53	1.85
P2	633	668	867	1.43	+0.75	-0.91	-5.50	-3.84	1.66
Р3	621	632	795	1.56	+0.86	-1.18	-5.61	-3.57	2.04
P4	645	673	858	1.44	+0.87	-0.85	-5.62	-3.90	1.72

#### Table S2. The Optical and electrochemical properties of the polymers

<sup>*a*</sup> Estimated from the absorption edge. <sup>*b*</sup>*Vs.* Ag/Ag<sup>+</sup> in acetonitrile solution with 0.1 M *n*-Bu<sub>4</sub>NPF<sub>6</sub> as supporting electrolyte, at scan speed of 100 mV s<sup>-1</sup>,  $E_{1/2, Fc,Fc^+} = 0.05$  V). <sup>*c*</sup> Calculated based on  $E_{HOMO} = -(4.8 - E_{1/2, Fc,Fc^+} + E_{ox, onset})$  eV=  $-(4.75 + E_{ox, onset})$  eV=  $-(4.75 + E_{ox, onset})$  eV=  $-(4.75 + E_{rex, onset})$  eV. <sup>*c*</sup> Calculated based on  $E_{LUMO} = -(4.8 - E_{1/2, Fc,Fc^+} + E_{red, onset}) = -(4.75 + E_{rex, onset})$  eV. <sup>*c*</sup> Estimated from  $E_{g, ec} = E_{LUMO} - E_{HOMO}$ .

## **3. OFET Device Fabrication and Characterization**

The devices are top-contact/bottom-gate structure. A heavily n-doped Si wafer with a layer of SiO<sub>2</sub> (300 nm) was used as a gate electrode and gate dielectric layer. The substrates were cleaned in deionized water, and then were immerged into hot sulphuric acid (98%) and hydrogen peroxide solution (v/v = 2:1) for 15 min to remove organic compounds physically absorbed on the substrates. The substrates were successively cleaned with deionized water, *iso*-propyl alcohol and acetone, and then were dried with nitrogen. The octadecyltrichlorosilane (OTS) modification was carried out by vapour-deposition for about 5 h. After modification, the substrates were rinsed with chloroform, *n*-hexane, *iso*-propyl alcohol and acetone. The substrates were dried under nitrogen flow.

Thin films (80 nm) were prepared by spin-coating of a hot chlorobenzene solution of **P3** or **P4** (5 mg/mL, 80 °C) on the substrates (the temperature of the substrate was kept at 80 °C). The thin films were annealed at 240 °C for 1 h. The Au layers (50 nm) were deposited through shadow masks to pattern the drain and source electrodes. The characteristics of the OFETs were measured using a Keithley 4200 semiconductor parameter analyzer under nitrogen atmosphere.



Figure S16. Typical output (a) and transfer (b) curves of thin film transistors based on polymer P3.

**Table S3.** The characteristics of OFETs based on polymers (P3 and P4) thin films after annealingat 240 °C

Compound	Contact	$\mu_e^{\ a}(\text{cm}^2\text{V}^{-1}\text{s}^{-1})$	Ion/Ioff	<i>V</i> <sub>T</sub> (V)	n <sup>b</sup>			
P3	Тор	0.000534 (0.0003)	$10^2 \sim 10^3$	35~39	18			
P4	Тор	0.012 (0.004)	$10^3 \sim 10^4$	31~44	40			
<sup><i>a</i></sup> The largest mobility value (average); <sup><i>b</i></sup> Numbers of devices tested.								

# 4. The morphology of the polymer films

The films for AFM and XRD studies and for fabrication of the OFET devices were deposited in the same substrate under the same experimental conditions. The AFM and XRD results showed **P3** and **P4** both formed continuous and amorphous films on the OTS modified SiO<sub>2</sub> substrates. (Figure S17~S20)



Figure S17. The AFM image (2  $\mu$ m × 2  $\mu$ m) of polymer P3 thin film on OTS-treated substrates after annealing at 240 °C.



**Figure S18.** The X-Ray diffraction (XRD) pattern of spin-coated polymer **P3** thin film on OTS-treated substrates after annealing at 240 °C.



Figure S19. The AFM image (2  $\mu$ m × 2  $\mu$ m) of polymer P4 thin film on OTS-treated substrates after annealing at 240 °C.

19 / 20



Figure S20. The X-Ray diffraction (XRD) pattern of spin-coated polymer P4 thin film on OTS-treated substrates after annealing at 240 °C.

## 5. References

- 1. Y. Liu, M. S. Liu and A. K.-Y. Jen, Acta Polym., 1999, 50, 105-108.
- (a) J.-H. Tsai, W.-Y. Lee, W.-C. Chen, C.-Y. Yu, G.-W. Hwang and C. Ting, *Chem. Mater.*, 2010, 22, 3290–3299; (b) C. Lu, H. C. Wu, Y. C. Chiu, W. Y. Lee and W. C. Chen, *Macromolecules*, 2012, 45, 3047–3056.
- 3. C. W. Greenhalgh, J. L. Carey and D. F. Newton, Dyes Pigm., 1980, 1, 103–120.
- T. Yamamoto, T. Ikai, M. Kuzuba, T. Kuwabara, K. Maeda, K. Takahashi and S. Kanoh, *Macromolecules*, 2011, 44, 6659–6662.
- 5. G. Zhang, Y. Fu, Z. Xie and Q. Zhang, *Macromolecules*, 2011, 44, 1414–1420.