

Electronic Supplementary Information for

A tetrathiafulvalene vinylogue-based double-layer polymer thin film as a highly sensitive and selective TNT sensor

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1. Experimental

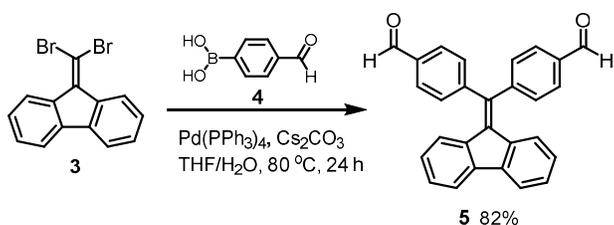
1.1 General

Chemicals were purchased from commercial suppliers and used directly without purification. All reactions were conducted in standard, dry glassware. Evaporation and concentration were carried out with a rotary evaporator. Flash column chromatography was performed with 240-400 mesh silica gel, and thin-layer chromatography (TLC) was carried out with silica gel F254 covered on plastic sheets and visualized by UV light. Melting points (m.p.) were measured using an SRS OptiMelt melting point apparatus and are uncorrected. ^1H and ^{13}C NMR spectra were measured on a Bruker Avance III 300 MHz multinuclear spectrometer. Chemical shifts (δ) are reported in ppm downfield relative to the signals of the internal reference SiMe_4 or residual solvents (CHCl_3 : $\delta_{\text{H}} = 7.24$ ppm, $\delta_{\text{C}} = 77.2$ ppm; CH_2Cl_2 : $\delta_{\text{H}} = 5.32$ ppm, $\delta_{\text{C}} = 54.0$ ppm). Coupling constants (J) are given in Hz. Infrared spectra (IR) were recorded on a Bruker Alfa spectrometer. MALDI-TOF MS analysis was performed on Bruker 9.4T Apex-Qe FTICR system. High-resolution APPI-TOF MS analysis was done on a GCT premier Micromass Technologies instrument. UV-Vis absorption spectra were measured on a Cary 6000i spectrophotometer. Surface topography of polymer thin films was visualized by using a New View 8000 3D optical surface profiler (Zygo Corporation) and FEI MLA 650F scanning electron microscope (SEM). Samples for SEM imaging were subjected to Au sputter coating before analysis.

Cyclic voltammetric (CV) and differential pulse voltammetric (DPV) analyses were carried out in a standard three-electrode setup controlled by a BASi Epsilon potentiostat. Experimental conditions were set up as follows. CV analysis: glassy carbon or indium tin oxide (ITO) coated glass as the working electrode, Pt wire as the counter electrode, Ag/AgCl as the reference electrode, scan rate = 100 mV/s. DPV analysis: glassy carbon as the working electrode, Pt wire as the counter electrode, Ag/AgCl as the reference electrode, step E = 4 mV, pulse width = 50 ms, pulse period = 200 ms, scan rate = 20 mV/s. All samples were measured in CH_2Cl_2 using Bu_4NBF_4 as electrolyte.

1.2 Synthetic procedures

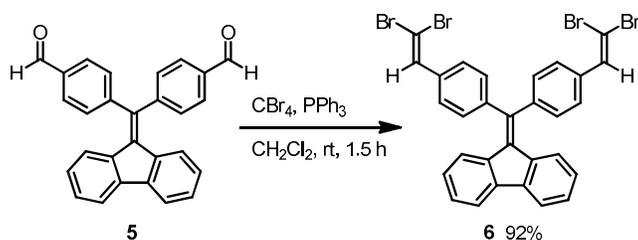
4,4'-((9H-Fluoren-9-ylidene)methylene)dibenzaldehyde (**5**)



9-(Dibromomethylene)-9H-fluorene (**3**) (0.500 g, 1.489 mmol), 4-formylphenylboronic acid (**4**) (0.665 g, 4.46 mmol), cesium carbonate (2.418 g, 7.440 mmol), THF (25 mL), and deionized water (10 mL) were added to 50 mL round-bottomed flask. The mixture was bubbled with N_2 flow for 5 min, and then $\text{Pd}(\text{PPh}_3)_4$ (0.172 g, 0.148 mmol) was added. The reaction mixture was stirred under N_2 and heated at reflux 24 h. The reaction mixture was next cooled down to room temperature, poured into a separatory funnel including water, and extracted twice with CH_2Cl_2 .

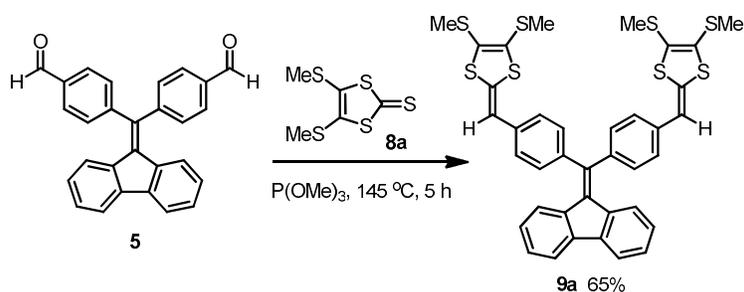
The organic layers were combined and dried over MgSO₄. After filtration and concentration under gentle heating and reduced pressure, the resulting residue was subjected to silica gel column chromatography (hexanes/EtOAc, 9:1) to give pure compound **5** (0.471 g, 1.219 mmol, 82%) as a yellow crystalline solid. m.p.: 199–202 °C; IR (neat): 3054, 2833, 2735, 1692, 1596, 1562, 1432, 1202, 1164 cm⁻¹; ¹H NMR (300 MHz, CD₂Cl₂): δ 10.07 (s, 2H), 7.95 (d, *J* = 8.4 Hz, 4H), 7.72–7.67 (m, 2H), 7.57 (d, *J* = 8.1 Hz, 4H), 7.27 (td, *J* = 7.5, 1.0 Hz, 2H), 6.95 – 6.88 (m, 2H), 6.58 (dt, *J* = 7.9, 0.8 Hz, 2H) ppm; ¹³C NMR (75 MHz, CD₂Cl₂): δ 192.02, 148.53, 142.04, 141.25, 138.23, 136.57, 136.41, 130.77, 130.67, 128.99, 127.15, 125.44, 119.94 ppm; HRMS (APPI-TOF, positive mode): *m/z* calcd for C₂₈H₁₈O₂ [M]⁺ 386.1307, found 386.1295. X-ray.

9-(Bis(4-(2,2-dibromovinyl)phenyl)methylene)-9H-fluorene (**6**)



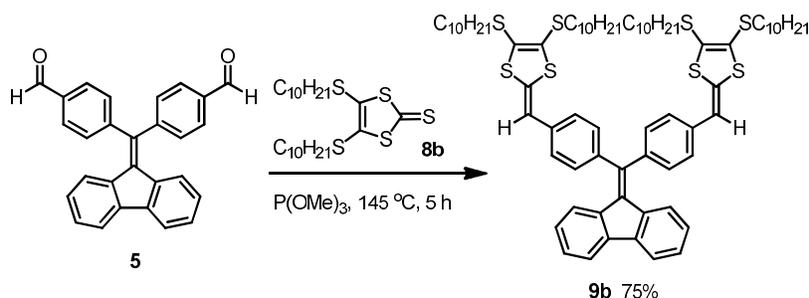
Compound **5** (1.043 g, 2.699 mmol), CBr₄ (4.470 g, 13.51 mmol), PPh₃ (5.663 g, 21.62 mmol), CH₂Cl (50 mL) were added to a 100 mL round-bottomed flask. The reaction mixture was stirred at room temperature for 1.5 hours and then subjected to vacuum filtration. The solids collected were extracted with CH₂Cl₂ and the organic layers were combined and concentrated under reduced pressure. The resulting residue was subjected to silica gel column chromatography (hexanes/CH₂Cl₂, 4:1) to give pure compound **6** (1.734 g, 2.484 mmol, 92%) as a pale yellow solid. m.p.: 213–216 °C; IR (neat): 3019, 1595, 1500, 1439, 1402, 1256, 1113, 1018, 785, 765 cm⁻¹; ¹H NMR (300 MHz, CDCl₃): δ 7.72 (d, *J* = 7.5 Hz, 2H), 7.65 (d, *J* = 8.2 Hz, 4H), 7.57 (s, 2H), 7.40 (d, *J* = 8.3 Hz, 4H), 7.32–7.24 (m, 2H), 7.00–6.93 (m, 2H), 6.70 (d, *J* = 7.9 Hz, 2H) ppm; ¹³C NMR (75 MHz, CDCl₃): δ 143.68, 142.86, 140.75, 138.51, 136.50, 135.36, 135.23, 130.22, 129.03, 128.14, 126.68, 125.01, 119.54, 90.31 ppm; HRMS (APPI-TOF, positive mode): *m/z* calcd for C₄₈H₂₉Br₈ [M + H]⁺ 693.8123, found 693.8142.

2,2'-((((9H-fluoren-9-ylidene)methylene)bis(4,1-phenylene))bis(methaneylylidene))bis(4,5-bis(methylthio)-1,3-dithiole) (**9a**)



Compound **5** (0.151 g, 0.391 mmol), 4,5-bis(methylthio)-1,3-dithiole-2-thione (**8a**) (0.265 g, 1.173 mmol), and P(OMe)₃ (15 mL) were added to a 100 mL round-bottomed flask. The flask was placed in an oil bath heated at 145 °C and kept in it for 5 h. After that, the reaction mixture was subjected to under vacuum distillation at the same temperature to remove unreacted P(OMe)₃. The residue was subjected to silica gel column chromatography (hexanes/EtOAc, 7:3) to give pure compound **9a** (0.189 g, 0.254 mmol, 65%) as a deep-orange oil. Caution: the product is quite sensitive to air and light, and it needs to be stored in a fridge immediately after purification to prevent significant decomposition. IR (neat): 3054, 3021, 2990, 2918, 2852, 1567, 1540, 1502, 1443, 1314, 1184 cm⁻¹; ¹H NMR (300 MHz, CD₂Cl₂): δ 7.71 (d, *J* = 7.3 Hz, 2H), 7.38–7.32 (m, 4H), 7.30–7.21 (m, 6H), 6.94 (td, *J* = 7.7, 1.2 Hz, 2H), 6.77 (d, *J* = 7.9 Hz, 2H), 6.57 (s, 2H), 2.45 (s, 6H), 2.43 (s, 6H) ppm; ¹³C NMR (75 MHz, CD₂Cl₂): δ 145.45, 140.84, 140.69, 139.32, 136.91, 134.77, 133.98, 131.08, 128.11, 128.01, 127.51, 126.94, 125.33, 125.00, 119.79, 114.48, 19.40, 19.31 ppm; HRMS (APPI-TOF, positive mode): *m/z* calcd for C₇₄H₁₀2S₈ [M]⁺ 1246.5747, found 1246.5708.

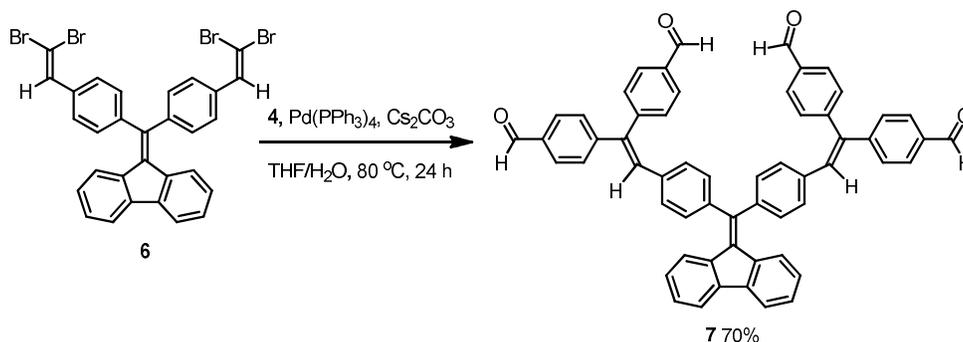
2,2'-((((9*H*-fluoren-9-ylidene)methylene)bis(4,1-phenylene))bis(methaneylylidene))bis(4,5-bis(decylthio)-1,3-dithiole) (9b**)**



Compound **5** (0.151 g, 0.391 mmol), 4,5-bis(decylthio)-1,3-dithiole-2-thione (**8b**) (0.561 g, 1.173 mmol), and P(OMe)₃ (15 mL) were added to a 100 mL round-bottomed flask. The flask was placed in an oil bath heated at 145 °C and kept in it for 5 h. After that, the reaction mixture was subjected to under vacuum distillation at the same temperature to remove unreacted P(OMe)₃. The residue was subjected to silica gel column chromatography (hexanes/EtOAc,

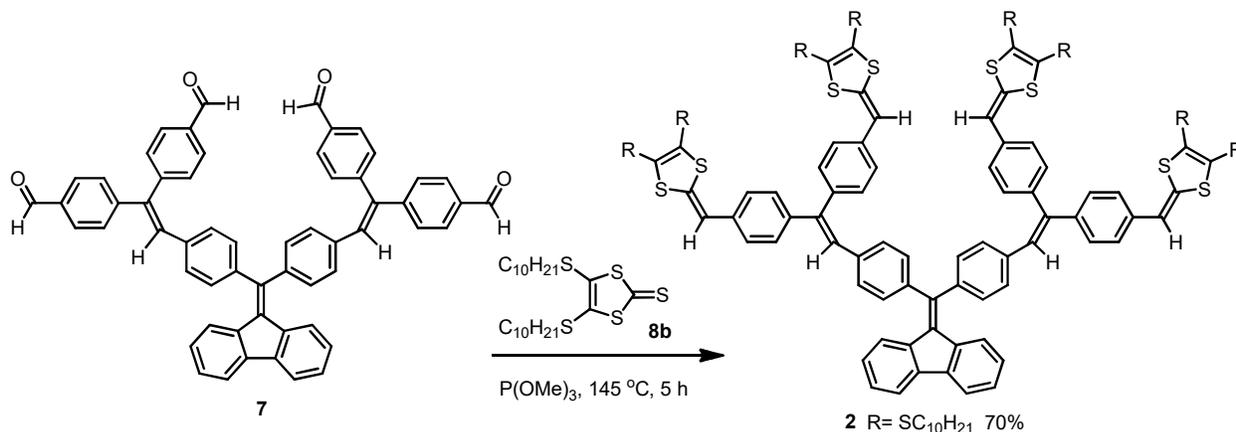
98:2) to give pure compound **9b** (0.366 g, 0.293 mmol, 75%) as a deep-orange oil. Caution: the product is quite sensitive to air and light, and it needs to be stored in a fridge immediately after purification to prevent significant decomposition. IR (neat): 3054, 3021, 2920, 2850, 1566, 1540, 1501, 1442, 1184 cm^{-1} ; ^1H NMR (300 MHz, CD_2Cl_2): δ 7.72 (d, $J = 7.5$ Hz, 2H), 7.35 (d, $J = 8.4$ Hz, 4H), 7.32–7.20 (m, 6H), 6.97–6.90 (m, 2H), 6.79 (d, $J = 7.9$ Hz, 2H), 6.56 (s, 2H), 2.85 (td, $J = 7.3, 2.5$ Hz, 8H), 1.72–1.59 (m, 8H), 1.36–1.19 (m, 56H), 0.96–0.81 (m, 12H) ppm; ^{13}C NMR (75 MHz, CD_2Cl_2) δ 145.17, 140.52, 140.24, 139.02, 136.66, 134.42, 134.02, 130.81, 127.94, 127.75, 127.13, 126.59, 125.22, 125.02, 119.45, 113.70, 36.35, 36.27, 32.19, 32.17, 29.84, 29.82, 29.61, 29.60, 29.42, 22.97, 22.96, 14.19 ppm; HRMS (APPI-TOF, positive mode): m/z calcd for $\text{C}_{74}\text{H}_{102}\text{S}_8$ $[\text{M}]^+$ 1246.5747, found 1246.5708.

4,4',4'',4'''-(((9*H*-fluoren-9-ylidene)methylene)bis(4,1-phenylene))bis(ethene-2,1,1-riyl))tetrabenzaldehyde (7**)**



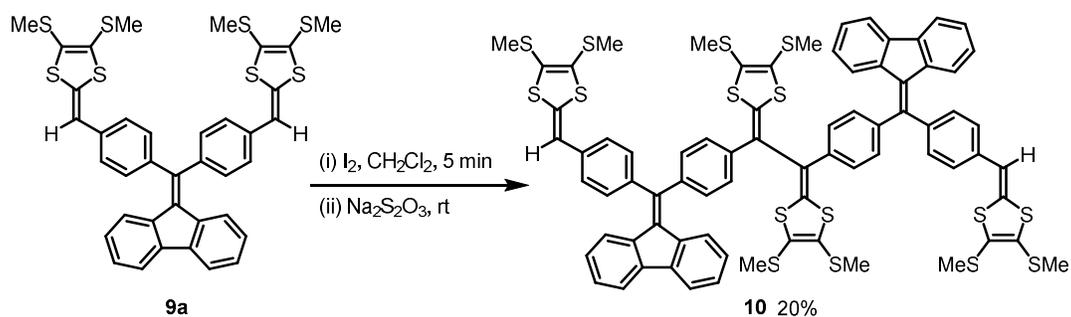
Compound **6** (0.642 g, 0.919 mmol), 4-formylphenylboronic acid (**4**) (0.685 g, 4.599 mmol), cesium carbonate (2.989 g, 9.197 mmol), THF (50 mL), and deionized water (15 mL) were added to 250 mL round-bottomed flask. The mixture was bubbled with N_2 flow for 5 min and then $\text{Pd}(\text{PPh}_3)_4$ (0.212 g, 0.184 mmol) was added. The reaction mixture was stirred under N_2 and heated at reflux 24 h. The mixture was next cooled down to room temperature, poured into a separatory funnel including water, and extracted twice with CH_2Cl_2 . The organic layers were combined and dried over MgSO_4 . After filtration and concentration under gentle heating and reduced pressure, the resulting residue was subjected to silica gel column chromatography (hexanes/ EtOAc , 4:1) to give pure compound **7** (0.514 g, 0.643 mmol, 70%) as a yellow crystalline solid. m.p.: 255 °C (dec.); IR (neat): 3043, 3023, 2922, 2823, 2733, 1694, 1598, 1562, 1385, 1303, 1205, 1164 cm^{-1} ; ^1H NMR (300 MHz, CD_2Cl_2): δ 10.02 (s, 2H), 10.01 (s, 2H), 7.90–7.83 (m, 8H), 7.67 (d, $J = 7.3$ Hz, 2H), 7.50–7.43 (m, 8H), 7.27–7.22 (m, 4H), 7.15–7.07 (m, 8H), 6.97–6.92 (m, 2H), 6.60 (d, $J = 7.9$ Hz, 2H) ppm; ^{13}C NMR (75 MHz, CD_2Cl_2): δ 192.17, 192.07, 148.68, 146.67, 144.62, 142.52, 141.74, 140.97, 138.94, 137.11, 136.47, 136.28, 135.24, 131.80, 131.73, 130.75, 130.68, 130.27, 130.23, 128.65, 128.42, 126.87, 125.35, 119.86 ppm; HRMS (APPI-TOF, positive mode): m/z calcd for $\text{C}_{58}\text{H}_{38}\text{O}_4$ $[\text{M}]^+$ 798.2770, found 798.2743.

2,2',2'',2'''-((((9*H*-fluoren-9-ylidene)methylene)bis(4,1-phenylene))bis(ethene-2,1,1-triyl))tetrakis(benzene-4,1-diyl))tetrakis(methaneylylidene))tetrakis(4,5-bis(decylthio)-1,3-dithiole) (2)



Compound **7** (0.103 g, 0.129 mmol), **8b** (0.370 g, 0.774 mmol), and P(OMe)₃ (6 mL) were added to a 50 mL round-bottomed flask. The flask was placed in an oil bath heated at 145 °C and kept in it for 5 h. After that, the reaction mixture was subjected to under vacuum distillation at the same temperature to remove unreacted P(OMe)₃. The residue was subjected to silica gel column chromatography (hexanes/EtOAc, 98:2) to give pure compound **2** (0.228 g, 0.090 mmol, 70%) as a deep-orange oil. Caution: the product is quite sensitive to air and light, and it needs to be stored in a fridge immediately after purification to prevent significant decomposition. IR (neat): 3022, 2920, 2850, 1567, 1542, 1504, 1462, 1412, 1018 cm⁻¹; ¹H NMR (300 MHz, CD₂Cl₂): δ 7.67 (d, *J* = 7.5 Hz, 2H), 7.34 (d, *J* = 8.5 Hz, 4H), 7.27–7.15 (m, 14H), 7.12–7.04 (m, 10H), 7.00–6.93 (m, 2H), 6.67 (d, *J* = 7.9 Hz, 2H), 6.48 (s, 4H), 2.89–2.73 (m, 16H), 1.62 (dq, *J* = 16.8, 9.1, 8.2 Hz, 16H), 1.25 (d, *J* = 14.1 Hz, 112H), 0.91–0.84 (m, 24H) ppm; ¹³C NMR (75 MHz, CD₂Cl₂): δ 145.42, 143.01, 141.49, 140.71, 139.01, 138.17, 137.87, 136.17, 136.07, 134.57, 133.30, 133.25, 131.10, 130.31, 129.94, 128.20, 128.14, 127.99, 127.82, 127.37, 126.98, 126.74, 125.30, 125.19, 119.57, 114.12, 36.51, 36.44, 32.35, 30.31, 30.29, 30.18, 30.13, 30.01, 29.98, 29.77, 29.58, 28.98, 28.95, 28.92, 23.13, 14.35 ppm; MS (MALDI-TOF, positive mode, DCTB as matrix): *m/z* calcd for C₁₅₀H₂₀₆S₁₆O [M + O]⁺ 2535.16, found 2535.15.

1,2-Bis(4,5-bis(methylthio)-1,3-dithiol-2-ylidene)-1,2-bis(4-(((4,5-bis(methylthio)-1,3-dithiol-2-ylidene)methyl)phenyl)(9*H*-fluoren-9-ylidene)methyl)phenyl)ethane (10)



Compound **9a** (0.050 g, 0.067 mmol), iodine (0.051 g, 0.20 mmol), and CH₂Cl₂ (10 mL) were added to a 100 mL round-bottom flask. The reaction mixture was stirred under N₂ at room temperature for 5 min. Then 60 mL of the aqueous solution of saturated Na₂S₂O₃ was added to the reaction and the mixture was kept stirring for another 15 min. The mixture was poured into a separatory funnel, and the aqueous layer was separated and extracted with CH₂Cl₂ twice. The organic layers were combined and dried over MgSO₄. After filtration and concentration under gentle heating and reduced pressure, the resulting residue was subjected to silica gel column chromatography (hexanes/CH₂Cl₂, 7:3) to give compound **10** (0.019 g, 0.013 mmol, 20%) as a red semi-solid. IR (neat): 3054, 3022, 2918, 2851, 1565, 1537, 1501, 1443, 1427, 1185, 967 cm⁻¹; ¹H NMR (300 MHz, CD₂Cl₂): δ 7.72–7.68 (m, 4H), 7.56–7.51 (m, 3H), 7.39–7.34 (m, 8H), 7.31–7.16 (m, 10H), 6.98–6.91 (m, 3H), 6.89–6.81 (m, 2H), 6.78 (d, *J* = 7.9 Hz, 2H), 6.66 (d, *J* = 7.9 Hz, 2H), 6.57 (s, 2H), 2.45 (s, 6H), 2.44 (s, 6H), 2.42 (s, 6H), 2.41 (s, 6H) ppm; HRMS (APPI-TOF, positive mode): *m/z* calcd for C₇₆H₅₈S₁₆ [M]⁺ 1482.0070, found 1482.0091.

2. NMR Spectra for New Compounds

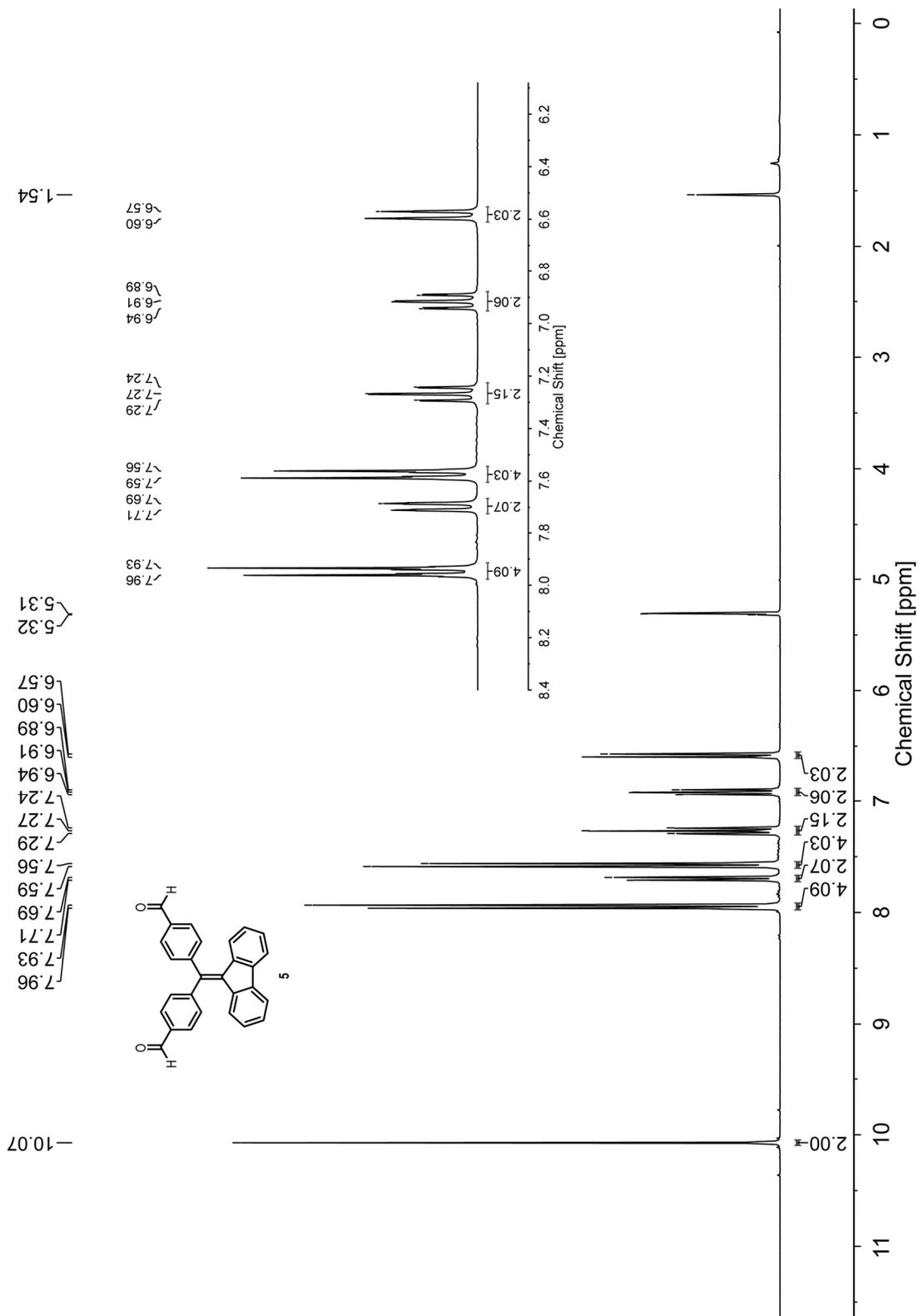


Fig. S-1 ¹H NMR (300 MHz, CD₂Cl₂) spectrum of compound 5.

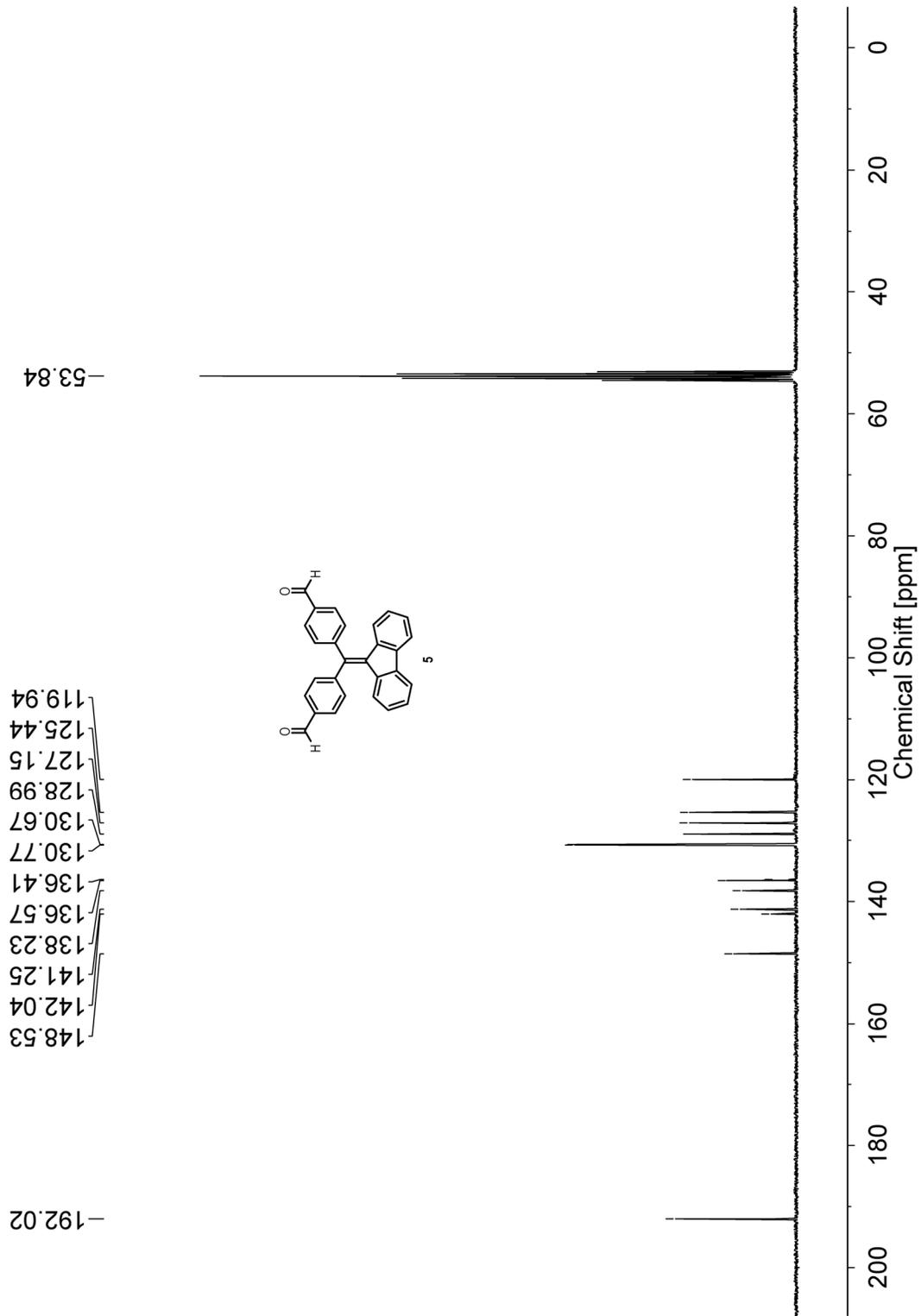


Fig. S-2 ¹³C NMR (75 MHz, CD₂Cl₂) spectrum of compound 5.

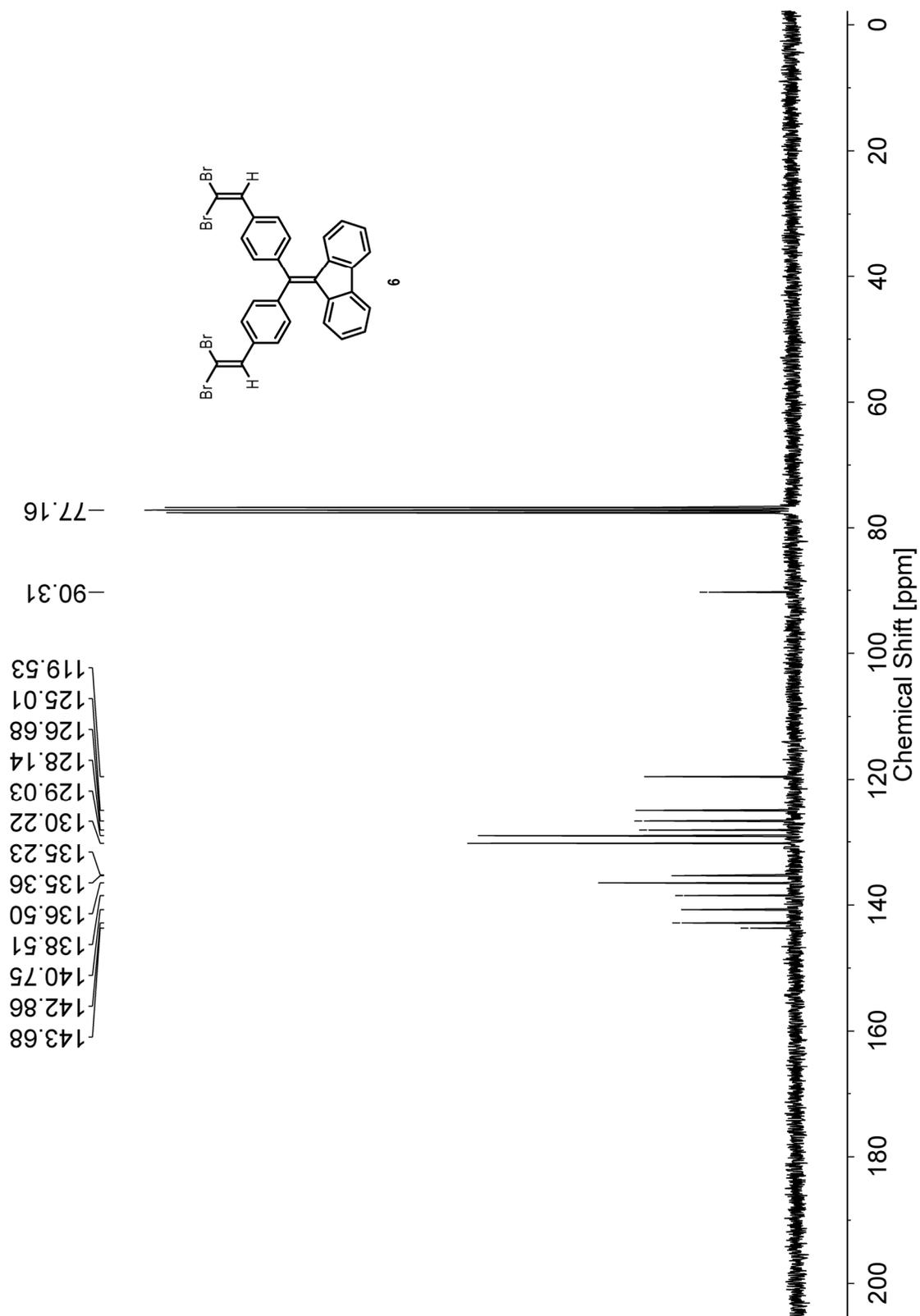


Fig. S-4 ¹³C NMR (75 MHz, CDCl₃) spectrum of compound 6.

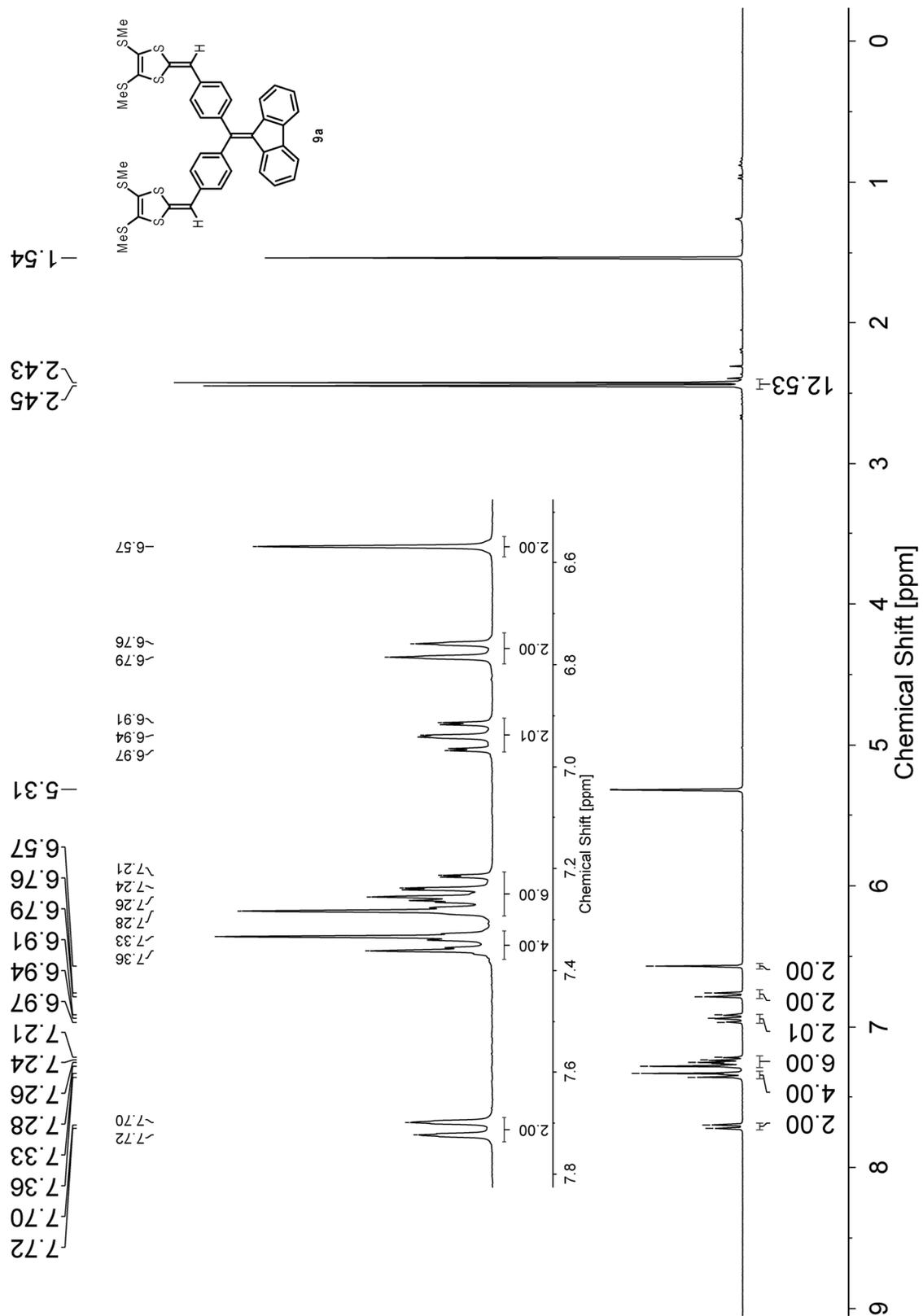


Fig. S-5 $^1\text{H NMR}$ (300 MHz, CD_2Cl_2) spectrum of compound **9a**.

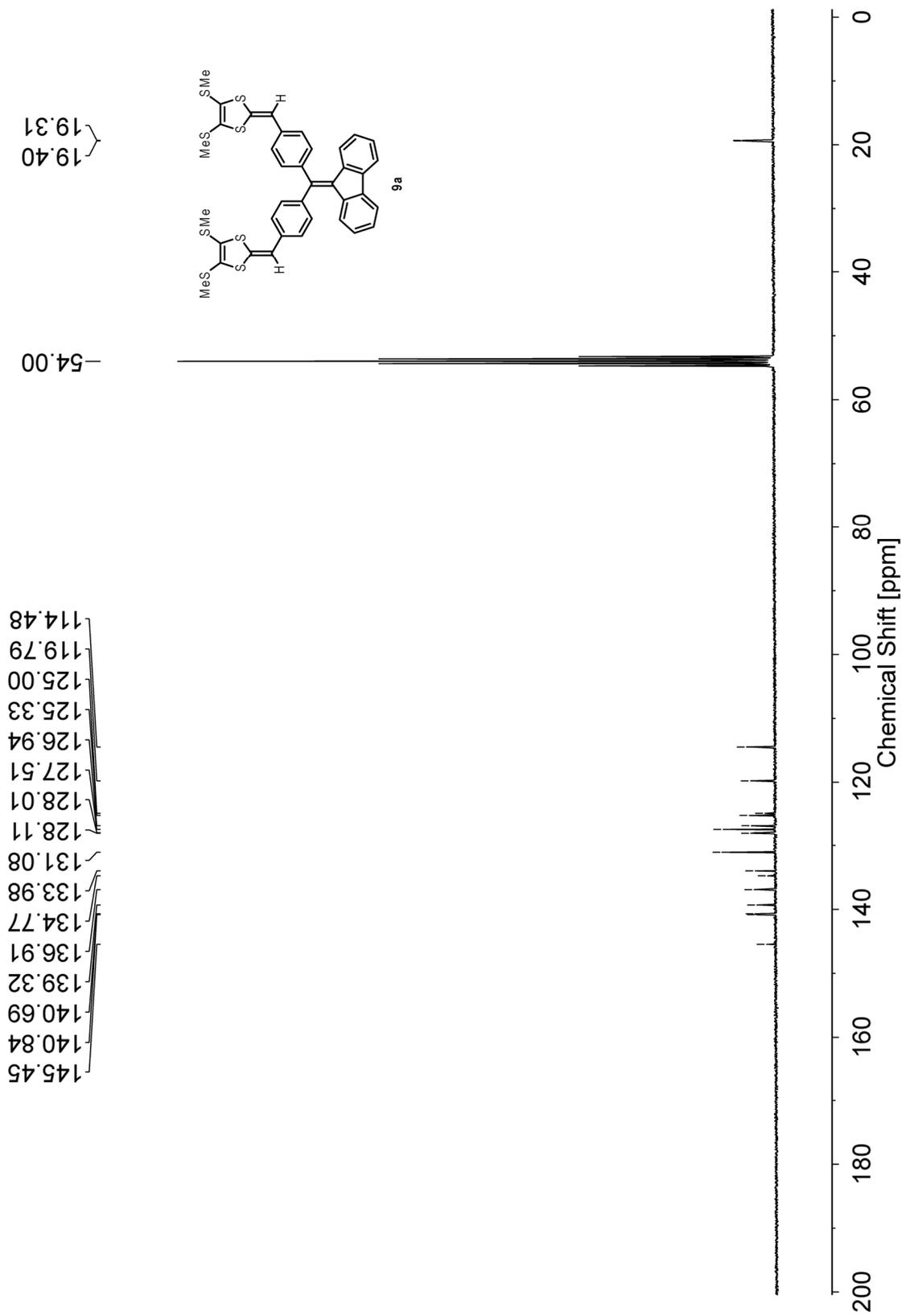


Fig. S-6 ^{13}C NMR (75 MHz, CD_2Cl_2) spectrum of compound **9a**.

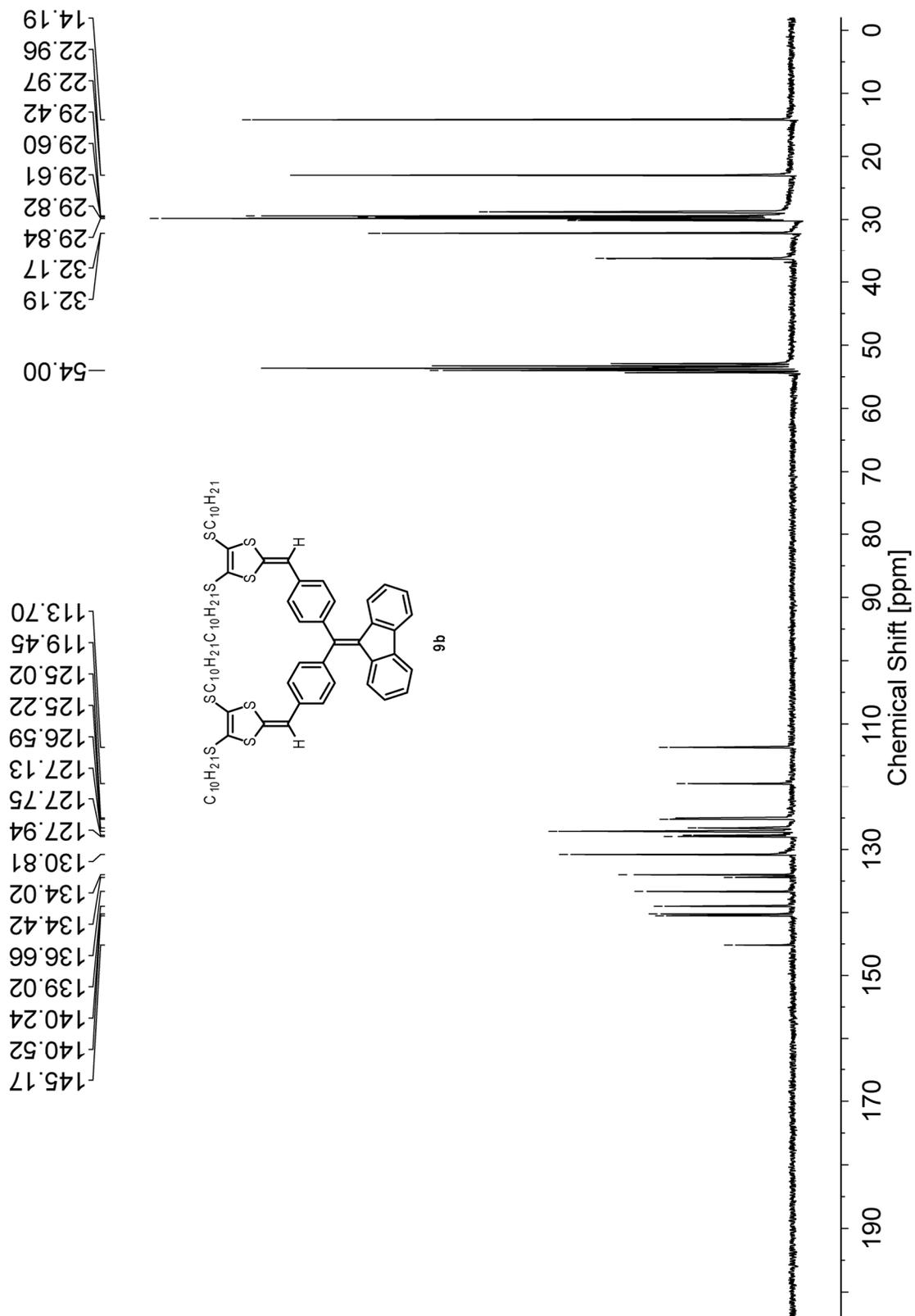


Fig. S-8 ^{13}C NMR (75 MHz, CD_2Cl_2) spectrum of compound **9b**.

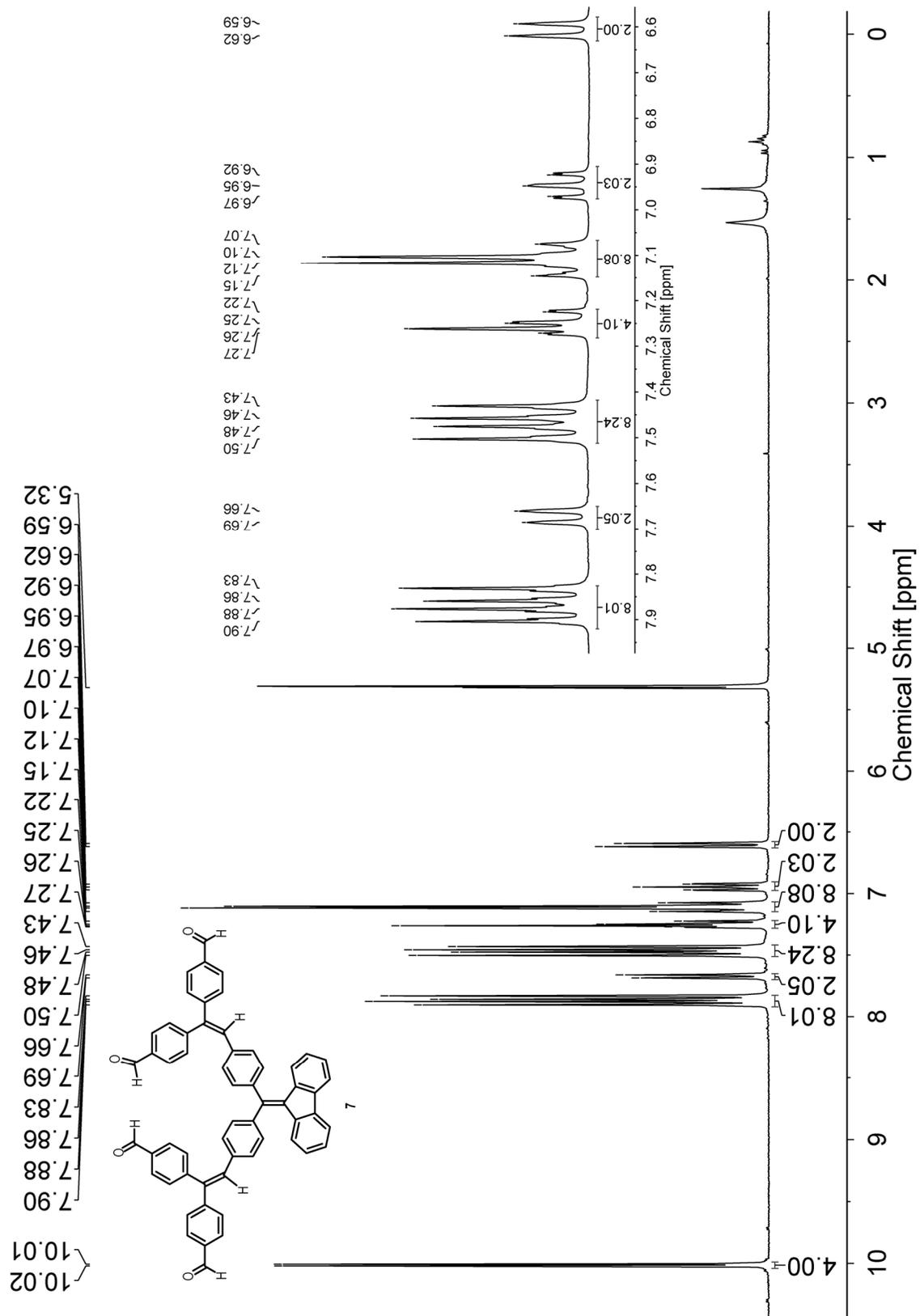


Fig. S-9 ¹H NMR (300 MHz, CD₂Cl₂) spectrum of compound 7.

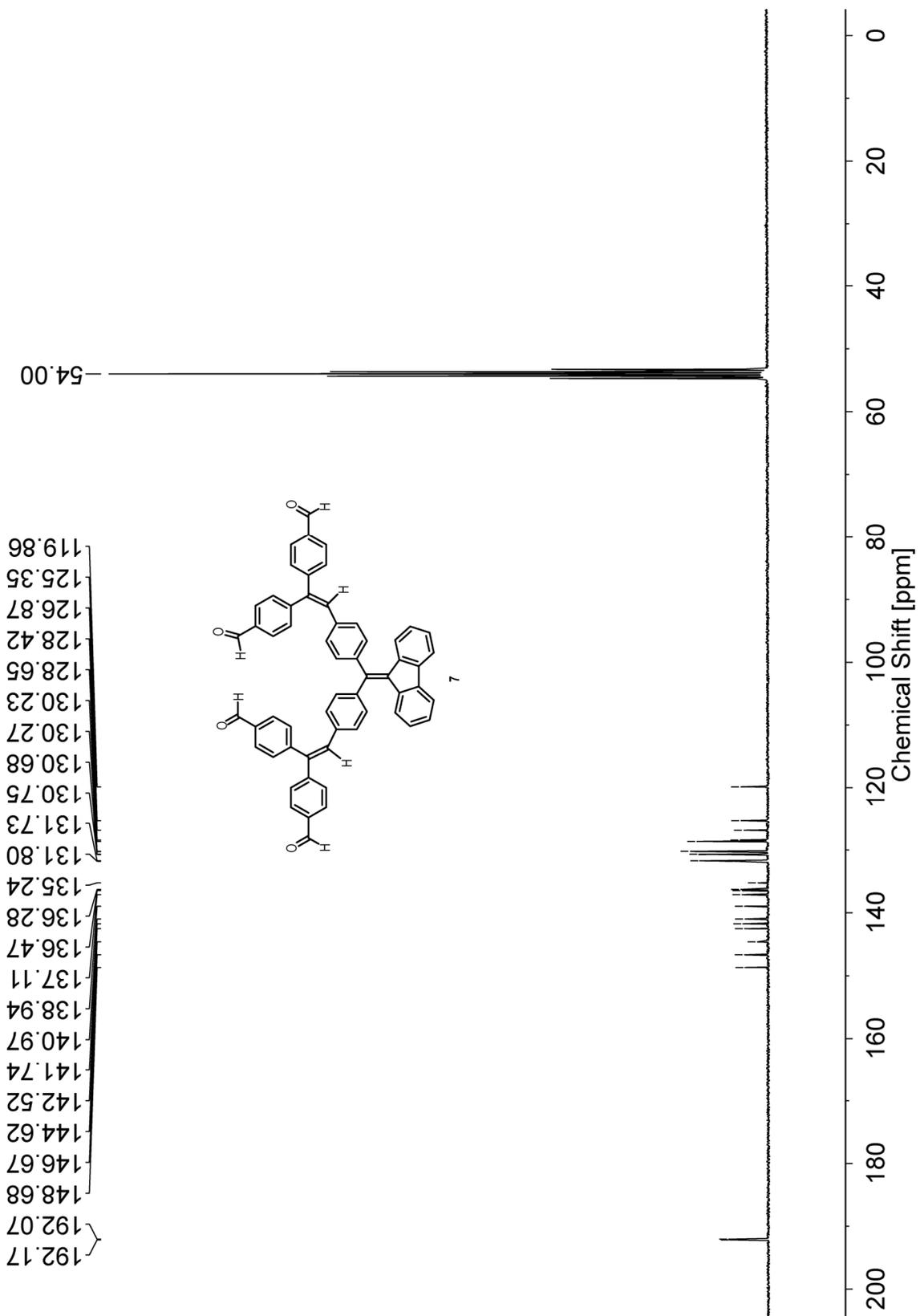


Fig. S-10 ^{13}C NMR (75 MHz, CD_2Cl_2) spectrum of compound 7.

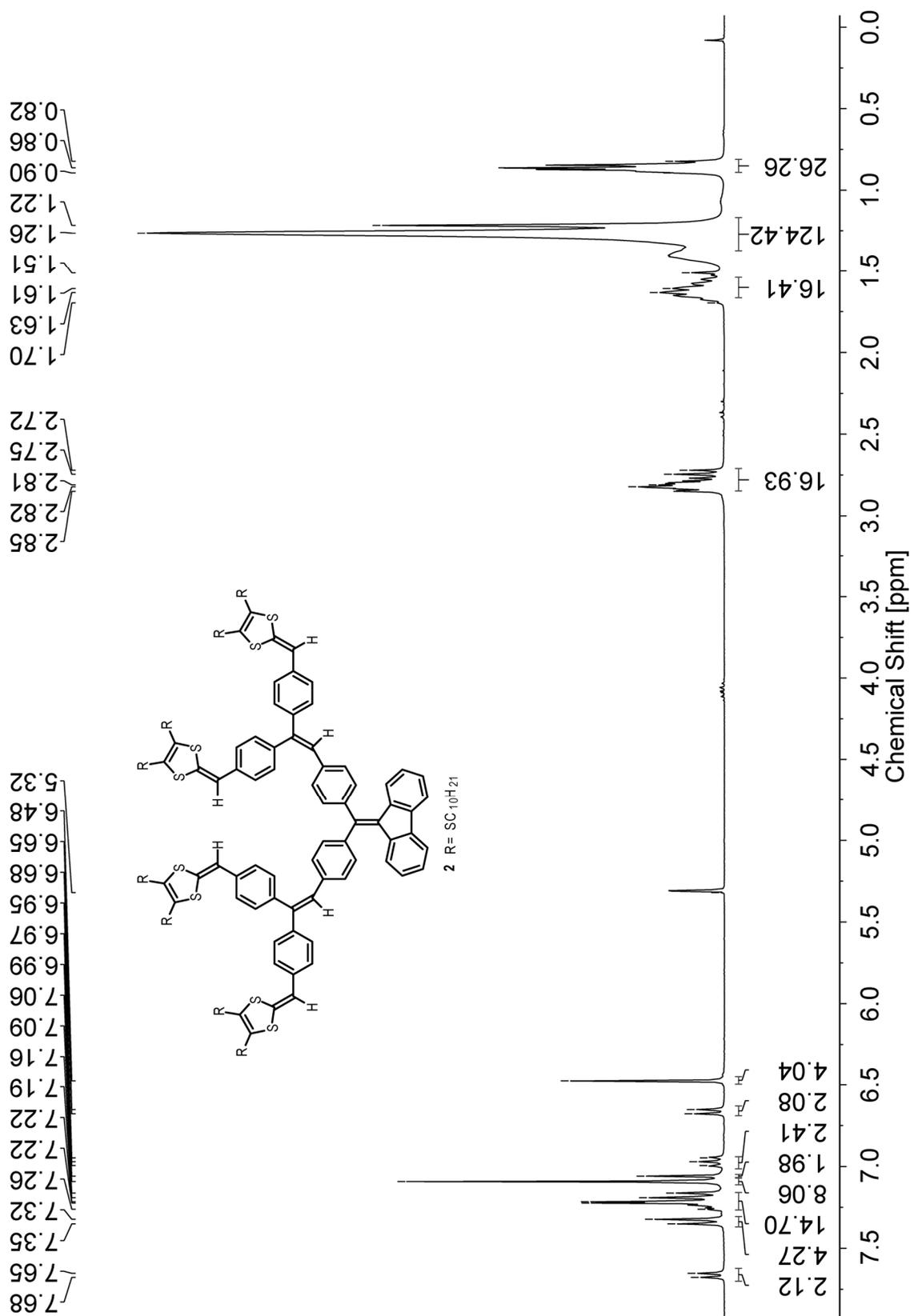


Fig. S-11 ¹H NMR (300 MHz, CD₂Cl₂) spectrum of compound 2.

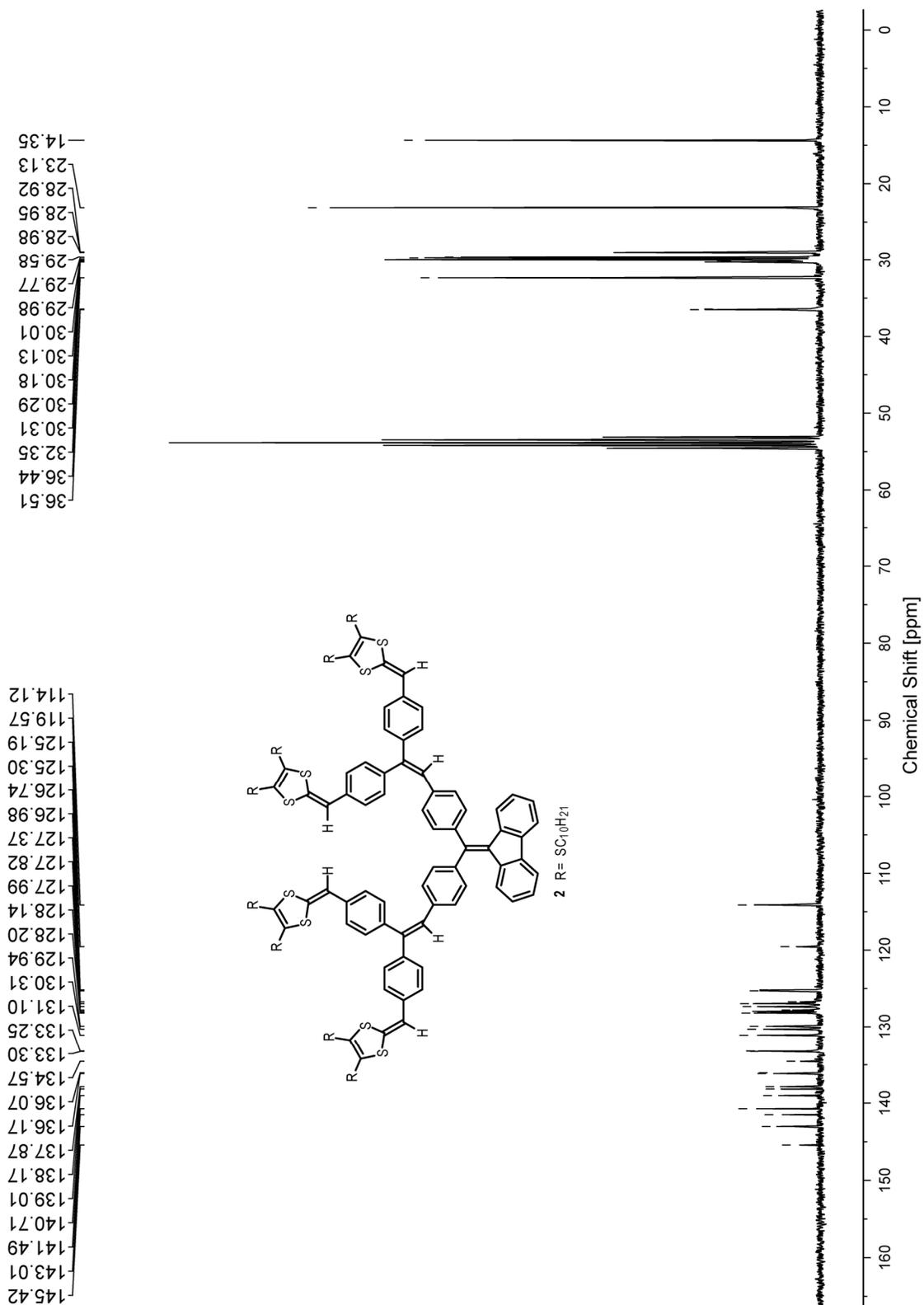


Fig. S-12 ¹³C NMR (75 MHz, CD₂Cl₂) spectrum of compound 2.

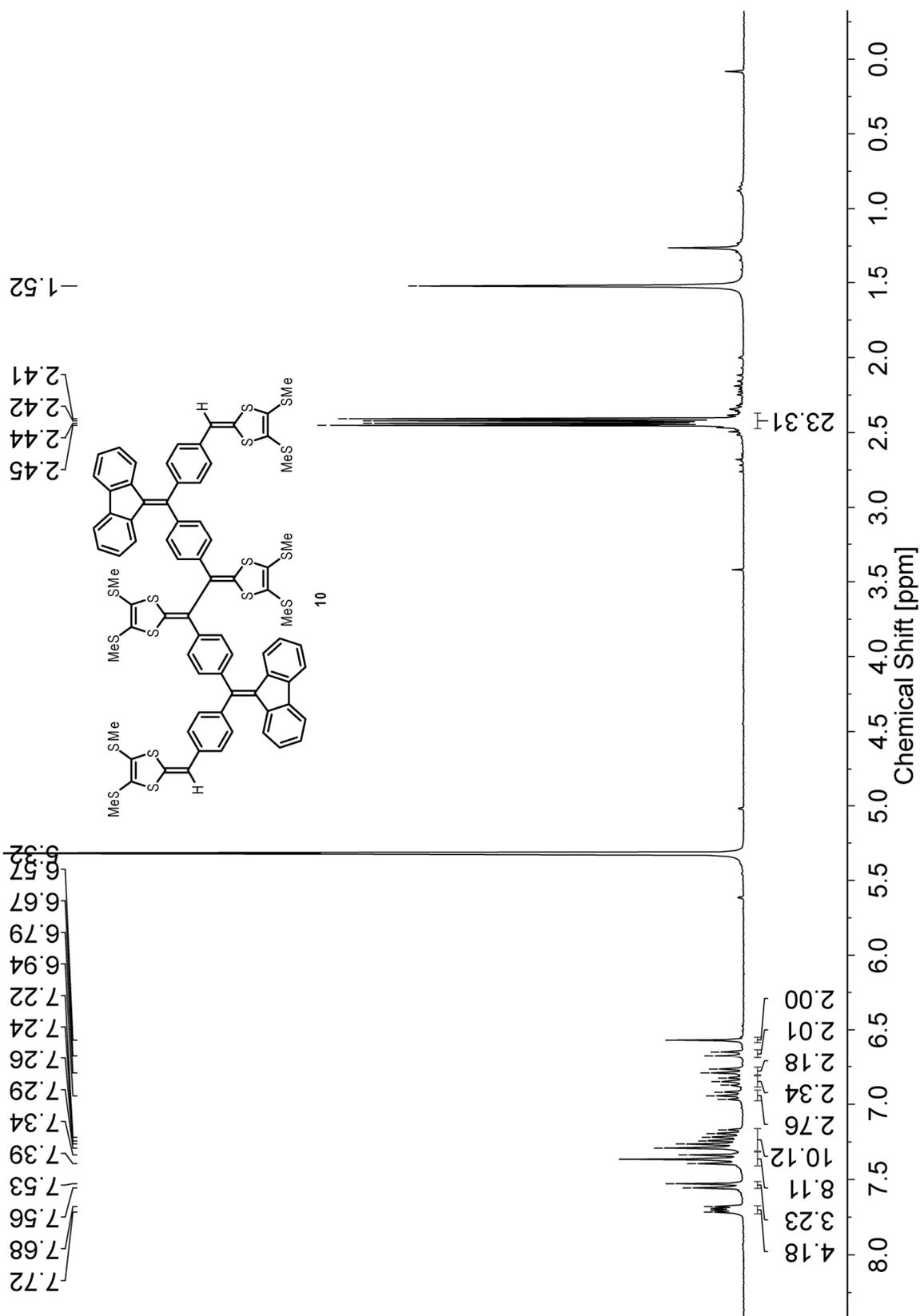


Fig. S-13 $^1\text{H NMR}$ (300 MHz, CD_2Cl_2) spectrum of compound 10.

3. Detailed Results of UV-Vis Titration Experiments

Solutions of compounds **9a** and **2** in CHCl_3 were subjected to titrations with nitrobenzene, 2,4-dinitrobenzene (DNT), and 2,4,6-trinitrobenzene (TNT), respectively. Detailed results are summarized in the following figure. Attempts to extract binding constants from the titration data, however, were not successful due to poor spectral fitting.

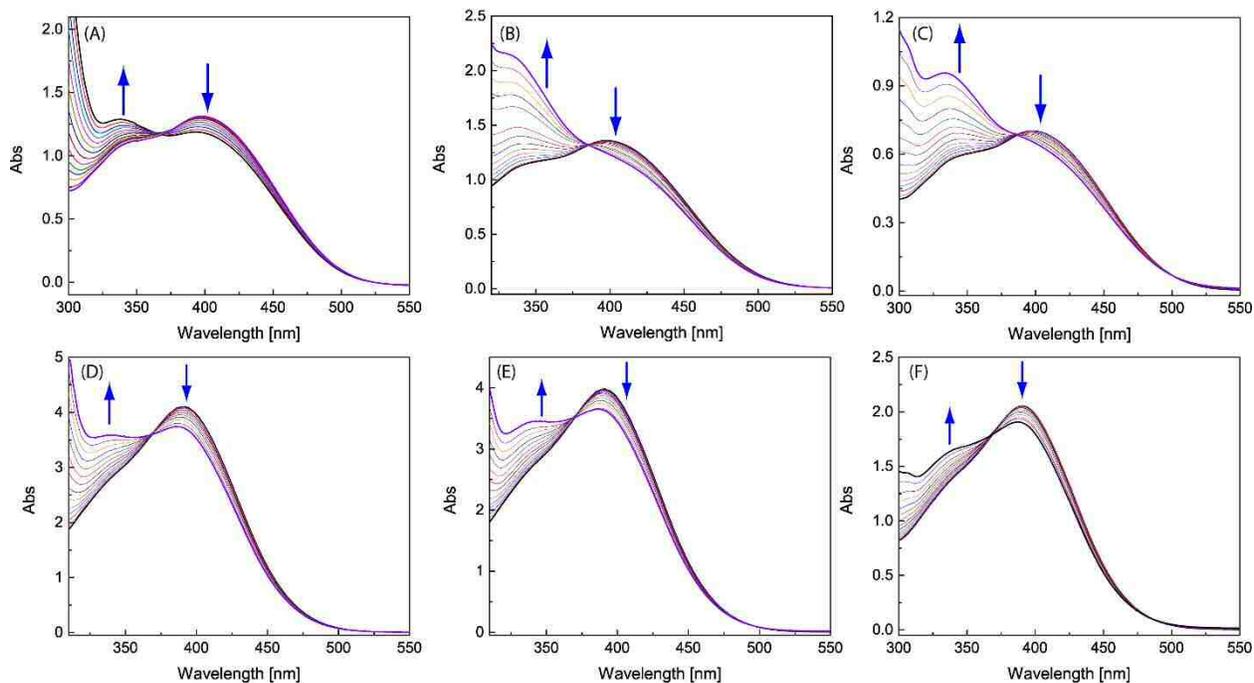


Fig. S-14 (A) UV-Vis titration results of compound **9b** (4.00×10^{-5} M in CHCl_3 , 298 K) with nitrobenzene (from 0 to 27.4 molar equiv). (B) UV-Vis titration results of compound **9b** (4.00×10^{-5} M in CHCl_3 , 298 K) with 2,4-dinitrotoluene (from 0 to 11.6 molar equiv). (C) UV-Vis titration results of compound **9b** (2.00×10^{-5} M in CHCl_3 , 298 K) with 2,4,6-trinitrotoluene (from 0 to 7.43 molar equiv). (D) UV-Vis titration results of compound **2** (3.97×10^{-5} M in CHCl_3 , 298 K) with nitrobenzene (from 0 to 27.1 molar equiv). (E) UV-Vis titration results of compound **2** (3.97×10^{-5} M in CHCl_3 , 298 K) 2,4-dinitrotoluene (from 0 to 11.7 molar equiv). (F) UV-Vis titration results of compound **2** (1.98×10^{-5} M in CHCl_3 , 298 K) 2,4,6-trinitrotoluene (from 0 to 7.5 molar equiv).

4. Detailed Results of Differential Pulse Voltammetric Titrations

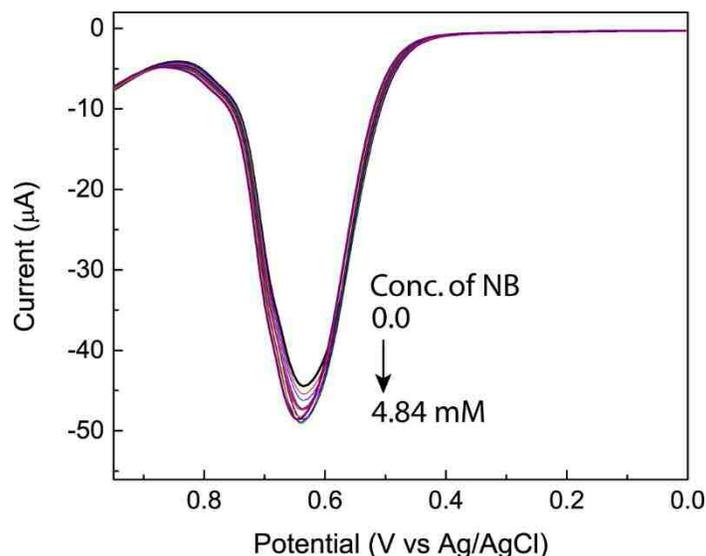


Fig. S-15 DPV profiles showing the responses of **poly-1** thin film (deposited on glassy carbon) to nitrobenzene (NB) at varied concentrations. Experimental conditions: solvent: CH_2Cl_2 ; electrolyte: Bu_4NBF_4 (0.1 M); reference electrode: Ag/AgCl; counter electrode: Pt wire. Step E: 4 ms; pulse with: 50 ms; pulse amplitude: 50 mV; pulse period: 200 ms; scan rate: 20 mV s^{-1} .

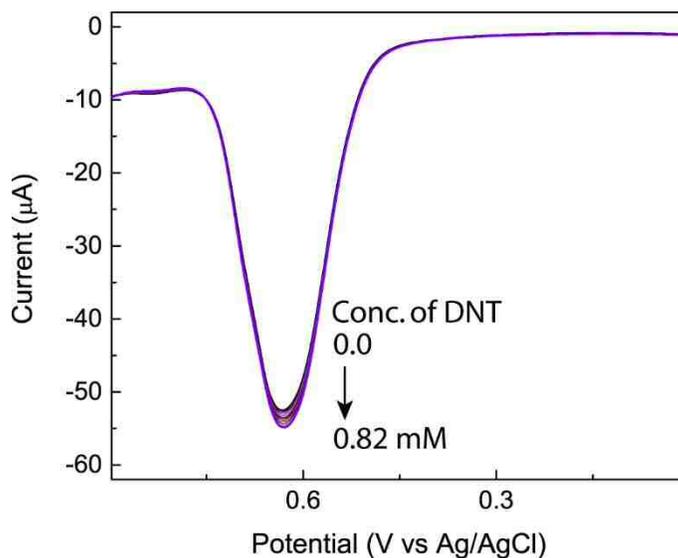


Fig. S-16 DPV profiles showing the responses of **poly-1** thin film (deposited on glassy carbon) to 2,4-dinitrobenzene (DNT) at varied concentrations. Experimental conditions: solvent: CH_2Cl_2 ; electrolyte: Bu_4NBF_4 (0.1 M); reference electrode: Ag/AgCl; counter electrode: Pt wire. Step E: 4 ms; pulse with: 50 ms; pulse amplitude: 50 mV; pulse period: 200 ms; scan rate: 20 mV s^{-1} .

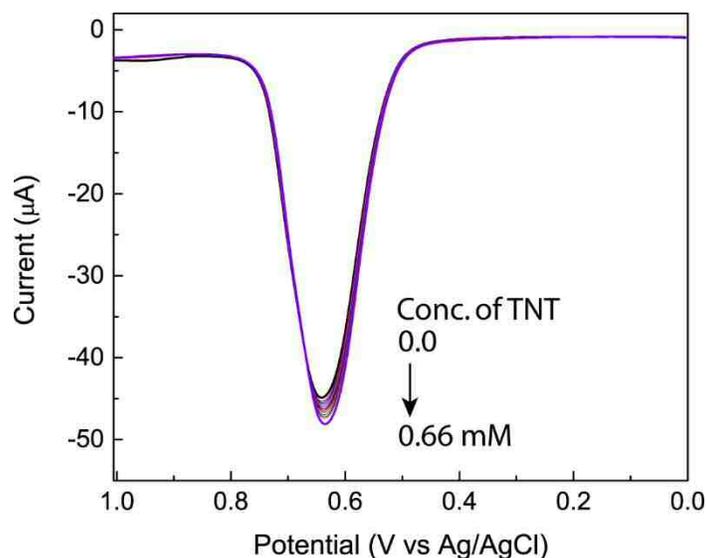


Fig. S-17 DPV profiles showing the responses of **poly-1** thin film (deposited on glassy carbon) to 2,4,6-trinitrobenzene (TNT) at varied concentrations. Experimental conditions: solvent: CH_2Cl_2 ; electrolyte: Bu_4NBF_4 (0.1 M); reference electrode: Ag/AgCl; counter electrode: Pt wire. Step E: 4 ms; pulse with: 50 ms; pulse amplitude: 50 mV; pulse period: 200 ms; scan rate: 20 mV s^{-1} .

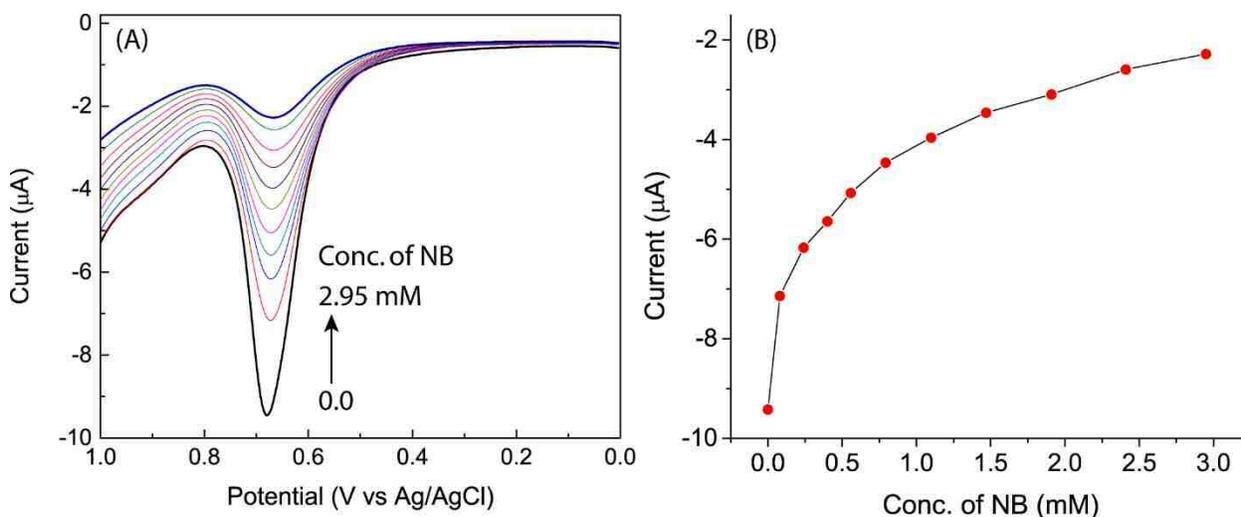


Fig. S-18 (A) DPV profiles showing the responses of **poly-2** thin film (deposited on glassy carbon) to nitrobenzene (NB) at varied concentrations. Experimental conditions: solvent: CH_2Cl_2 ; electrolyte: Bu_4NBF_4 (0.1 M); reference electrode: Ag/AgCl; counter electrode: Pt wire. Step E: 4 ms; pulse with: 50 ms; pulse amplitude: 50 mV; pulse period: 200 ms; scan rate: 20 mV s^{-1} . (B) Plot of DPV peak current against the concentration of nitrobenzene (NB).

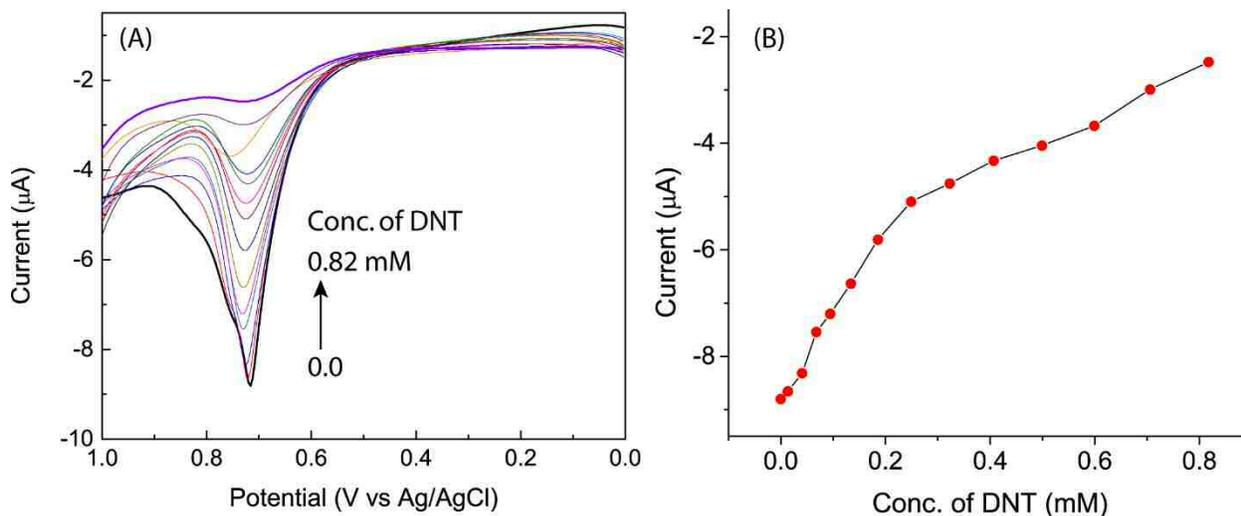


Fig. S-19 (A) DPV profiles showing the responses of **poly-2** thin film (deposited on glassy carbon) to 2,4-dinitrobenzene (DNT) at varied concentrations. Experimental conditions: solvent: CH_2Cl_2 ; electrolyte: Bu_4NBF_4 (0.1 M); reference electrode: Ag/AgCl; counter electrode: Pt wire. Step E: 4 ms; pulse with: 50 ms; pulse amplitude: 50 mV; pulse period: 200 ms; scan rate: 20 mV s^{-1} . (B) Plot of DPV peak current against the concentration of 2,4-dinitrobenzene (DNT).

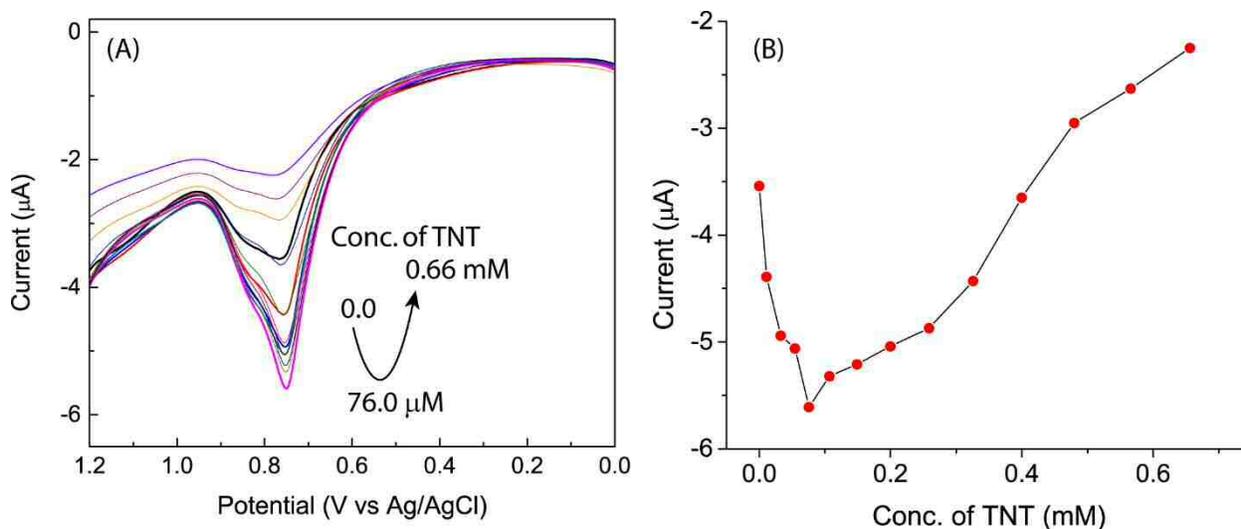


Fig. S-20 (A) DPV profiles showing the responses of **poly-2** thin film (deposited on glassy carbon) to 2,4,6-trinitrobenzene (TNT) at varied concentrations. Experimental conditions: solvent: CH_2Cl_2 ; electrolyte: Bu_4NBF_4 (0.1 M); reference electrode: Ag/AgCl; counter electrode: Pt wire. Step E: 4 ms; pulse with: 50 ms; pulse amplitude: 50 mV; pulse period: 200 ms; scan rate: 20 mV s^{-1} . (B) Plot of DPV peak current against the concentration of 2,4,6-trinitrobenzene (TNT).

5. Optical Profiling and SEM Images of Polymer Films

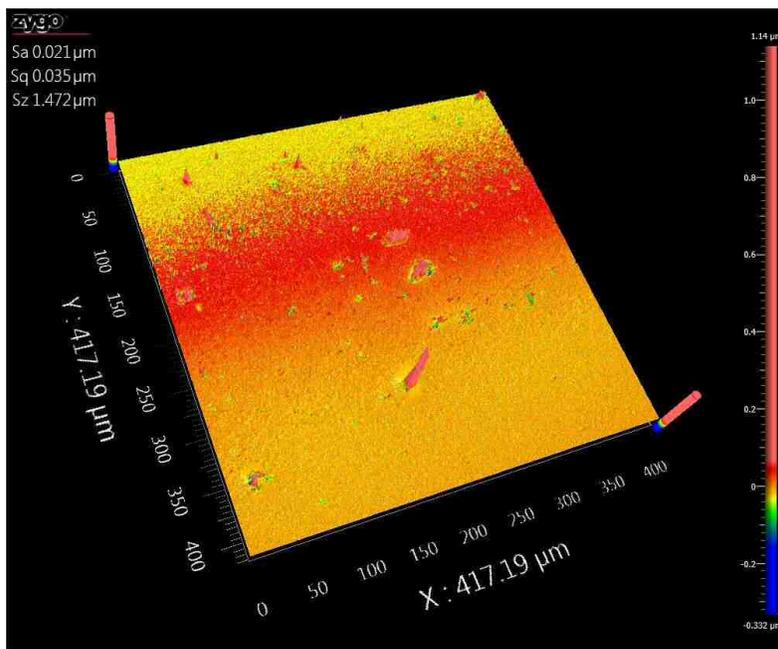


Fig. S-21 Surface morphology of the thin film of **poly-1** electrochemically deposited on an ITO substrate.

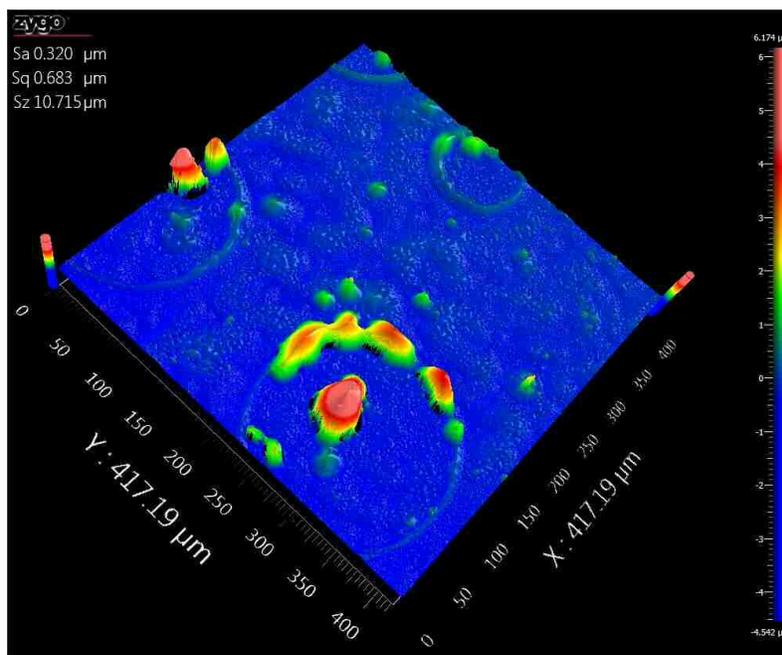
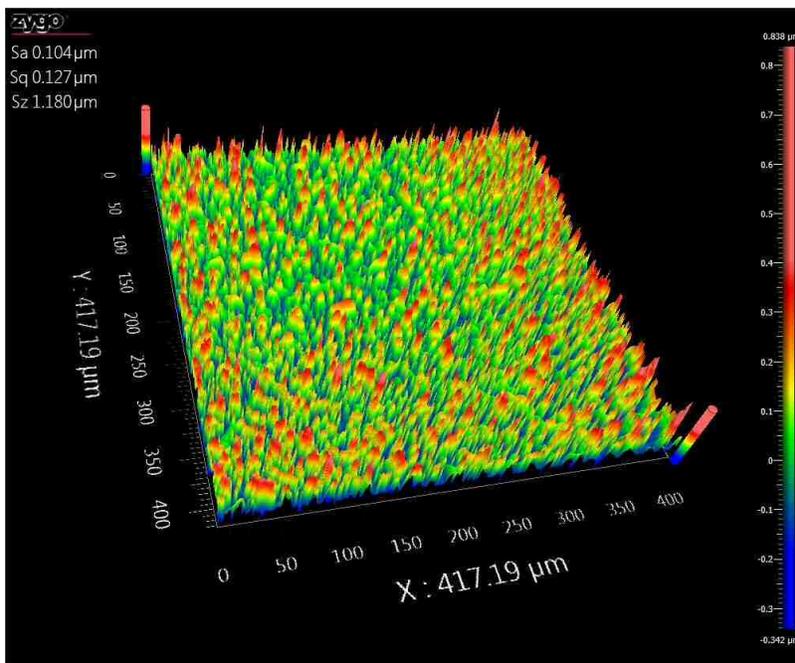
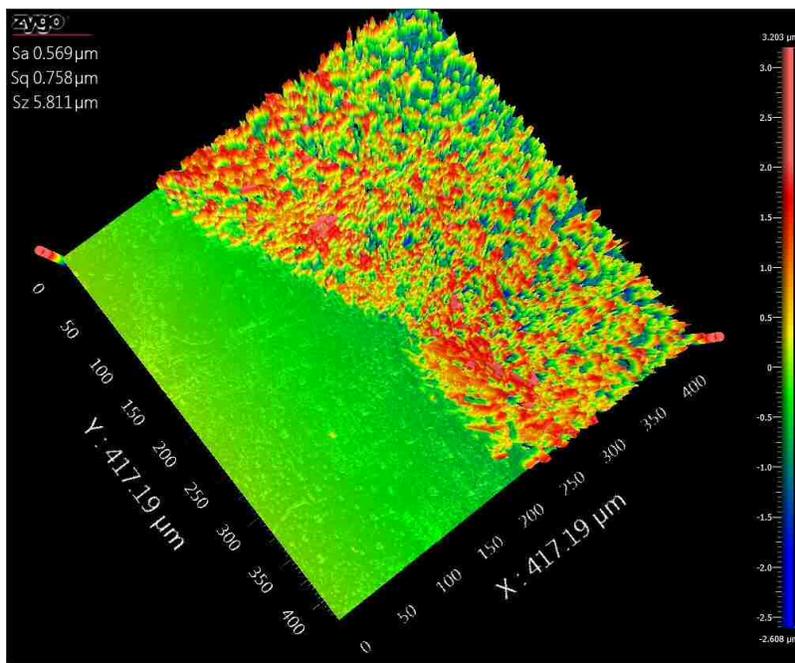


Fig. S-22 Surface morphology of the thin film of **poly-2** electrochemically deposited on an ITO substrate.



(A)



(B)

Fig. S-23 Optical profiling images for the surface morphology of the double-layer thin film of **poly-2|poly-1** on an ITO substrate. (A) Scanned in the central area of the film, and (B) scanned on the edge of the film.

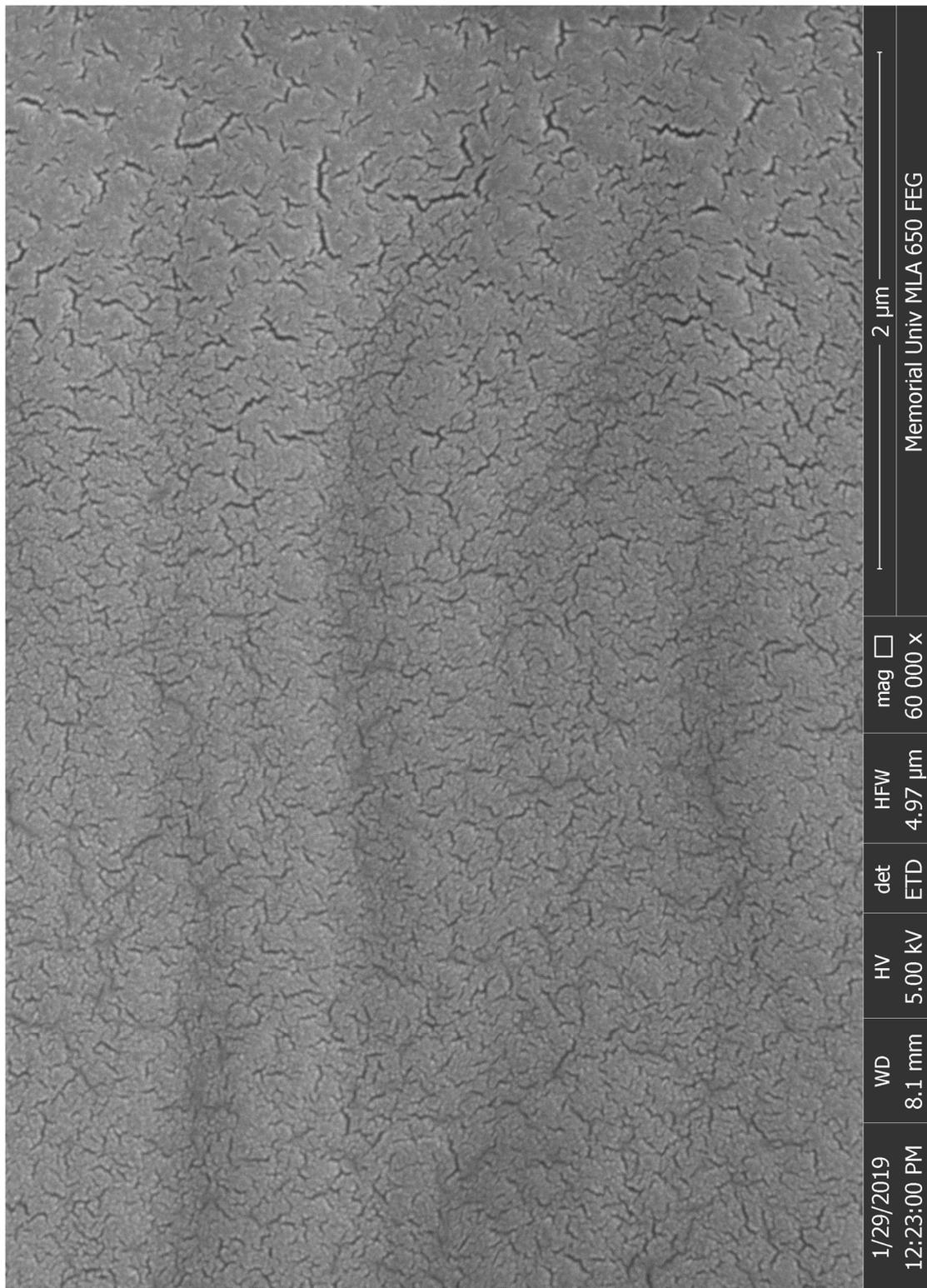


Fig. S-24 SEM image of the surface of the double-layer thin film of **poly-2|poly-1** on an ITO substrate.