

## Supporting Information – Multi-colour Electrochromic

### Materials Based on Polyaromatic Esters with Low Driving

#### Voltage

Pengfei Zhang,<sup>a</sup> Xing Xing,<sup>b</sup> Yueyi Wang,<sup>a</sup> Imran Murtaza,<sup>c</sup> Yaowu He,<sup>a</sup> Joseph Cameron,<sup>d</sup> Ahmed Shuja,<sup>e</sup> Peter J. Skabara<sup>d</sup> and Hong Meng<sup>\*a</sup>

<sup>a</sup>School of Advanced Materials, Peking University Shenzhen Graduate School, Shenzhen, 518055, China.

<sup>b</sup>Research & Development Institute of Northwestern Polytechnical University (Shenzhen), Northwestern Polytechnical University, Shenzhen 518057, China

<sup>c</sup>Department of Physics, International Islamic University, Islamabad 44000, Pakistan.

<sup>d</sup>University of Glasgow, School of Chemistry, Joseph Black Building, University Place, Glasgow, G12 8QQ, United Kingdom.

<sup>e</sup>Centre for Advanced Electronics & Photovoltaic Engineering (CAEPE), International Islamic University, Islamabad 44000, Pakistan

<sup>1</sup>H NMR and <sup>13</sup>C NMR spectra were recorded on a (Bruker, AVANCE 500 MHz) spectrometer. High resolution mass spectra of new compounds were obtained using a Thermo, Q-Exactive spectrometer at Korea Basic Science Institute (Daegu). The UV-visible spectra were recorded using Lambda 750 spectrophotometer. Electrochemical measurements were performed using a CHI620E electrochemical workstation.

Conventional three electrodes assembly was used under nitrogen to record cyclic voltammogram. The working electrode was a glassy carbon electrode. The counter electrode was a platinum wire and Ag/AgNO<sub>3</sub> (Ag/Ag<sup>+</sup>) was used as the reference electrode. The scan rate was 100 mV/s. The 0.15 M anhydrous tetrabutylammonium hexafluorophosphate (TBAPF<sub>6</sub>) solution in the anhydrous N,N'-dimethylformamide (DMF) was used as a supporting electrolyte. The 0.1 mM solutions of each compound were used for measurements.

Spectroelectrochemistry measurements were carried out using platinum-gauze working electrode, Ag wire quasi-reference electrode and platinum wire counter electrode. The scan rate was 100 mV/s. Tetra-n-butylammonium perchlorate was

used as the electrolyte (5 mM) with each compound prepared at a concentration of 0.1 mM in anhydrous DMF. The applied potentials for spectroelectrochemistry have not been adjusted to an external reference.

Chemicals and instrumentation:

All chemicals were purchased from Sigma Aldrich. Absolute ethanol was used without further purification and deionized water was used where required.

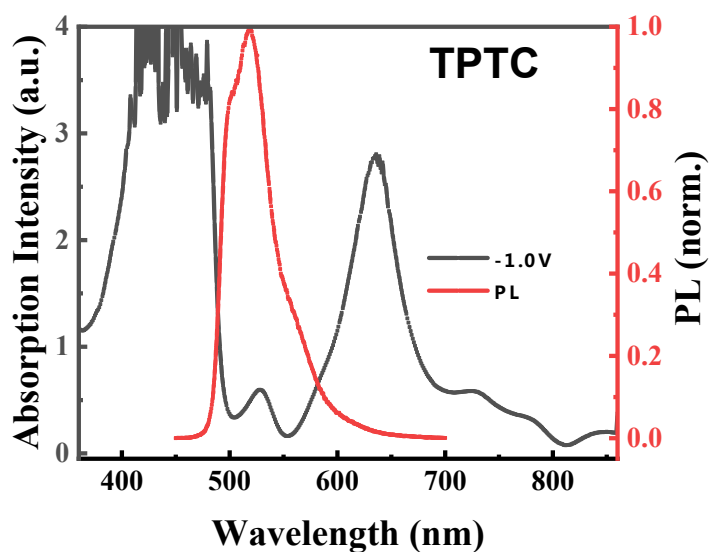


Figure S1. Absorption spectra of TPTC at -1.0 V (1mM TPTC and 5 mM TPAP in anhydrous DMF solution), PL spectrum of TPTC. (1 mM TPTC and 5 mM TPAP in anhydrous DMF solution) (UV-Vis spectra were taken for TPAP (5 mM) in anhydrous DMF solution as background)

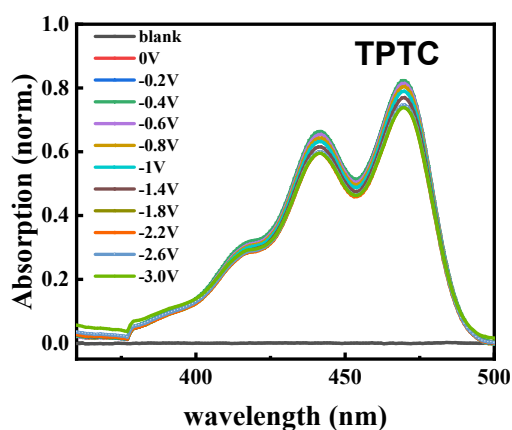


Figure S2. Spectroelectrochemistry of TPTC in anhydrous DMF solution (TPTC ( $10 \mu\text{M}$ ), TPAP (5 mM)). Three-electrode system: WE-Pt-mesh; CE-Pt wire; RE-Ag wire. (Uv-Vis spectra were taken TPAP (5 mM) in anhydrous DMF solution as background for all tests)

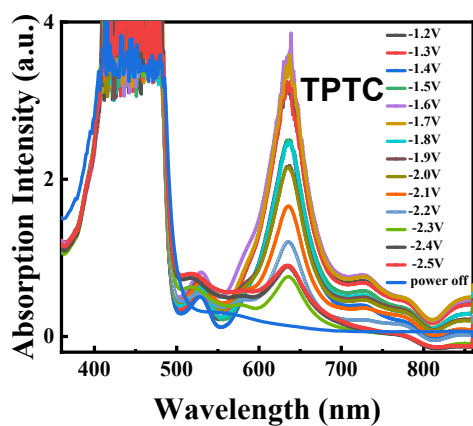


Figure S3. Spectroelectrochemistry of TPTC in anhydrous DMF solution (TPTC ( $10 \mu\text{M}$ ), TPAP (5 mM)) from -1.2 V to -2.5 V. Three-electrode system: WE-Pt-mesh; CE-Pt wire; RE-Ag wire. (Uv-Vis spectra were taken TPAP (5 mM) in anhydrous DMF solution as background for all tests)

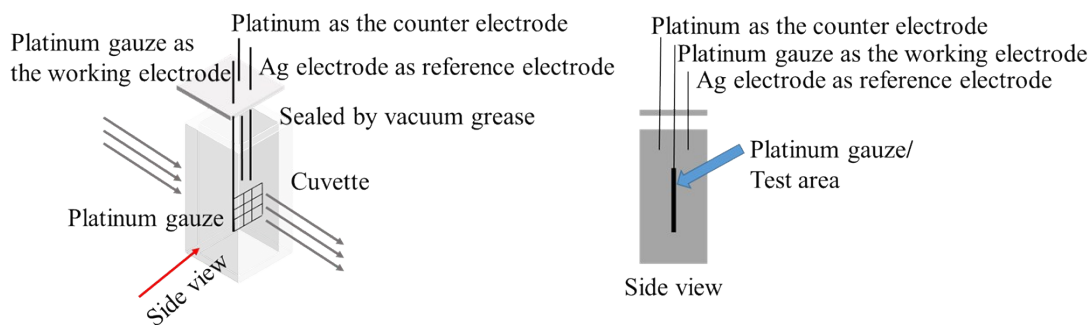


Figure S4. Schematic diagram of the solution testing of the electrochromic material. Platinum gauze was used as the working electrode, Ag wire as reference electrode, platinum wire as the counter electrode.

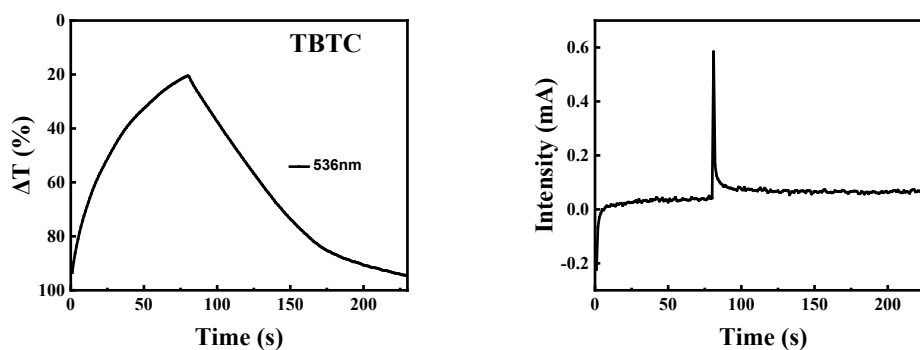


Figure S5. Representative switching cycles of TBTC (1 mM) (5 mM TPAP in anhydrous DMF solution) showing  $\Delta T\%$  as a function of time. TBTC were measured for transmittance at wavelengths of 536 nm. The switching pulse sequence is  $V_{on}(-1.2\text{ V}, 80\text{ s})/ V_{off}(0\text{ V}, 150\text{ s})$ .

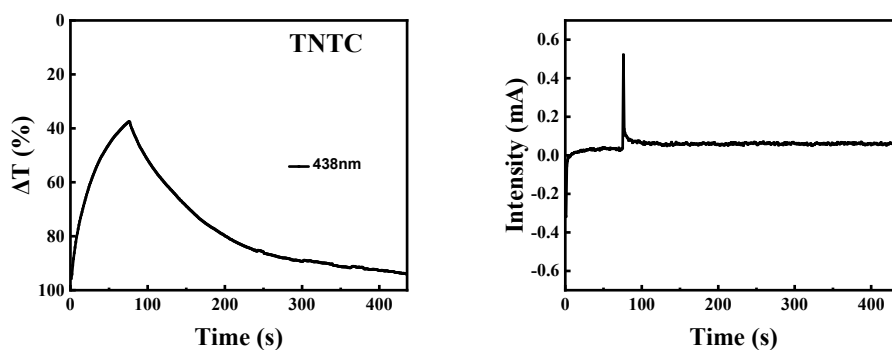


Figure S6. Representative switching cycles of TNTC (1 mM) (5 mM TPAP in anhydrous DMF solution) showing  $\Delta T\%$  as a function of time. TNTC were measured for transmittance at

wavelengths of 438 nm. The switching pulse sequence is  $V_{\text{on}}(-1.4 \text{ V}, 75 \text{ s})/V_{\text{off}}(0 \text{ V}, 360 \text{ s})$ .

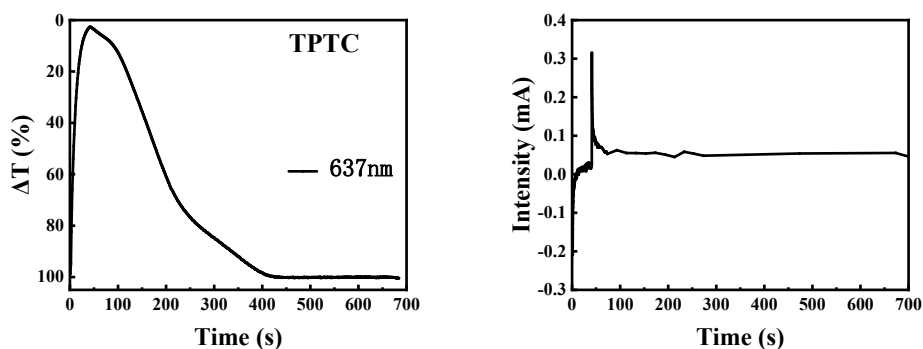


Figure S7. Representative switching cycles of TPTC (1 mM) (5 mM TPAP in anhydrous DMF solution) showing  $\Delta T\%$  as a function of time. TPTC were measured for transmittance at wavelengths of 637 nm. The switching pulse sequence is  $V_{\text{on}}(-0.8\text{V}, 40\text{s}) / V_{\text{off}}(0\text{V}, 660\text{s})$

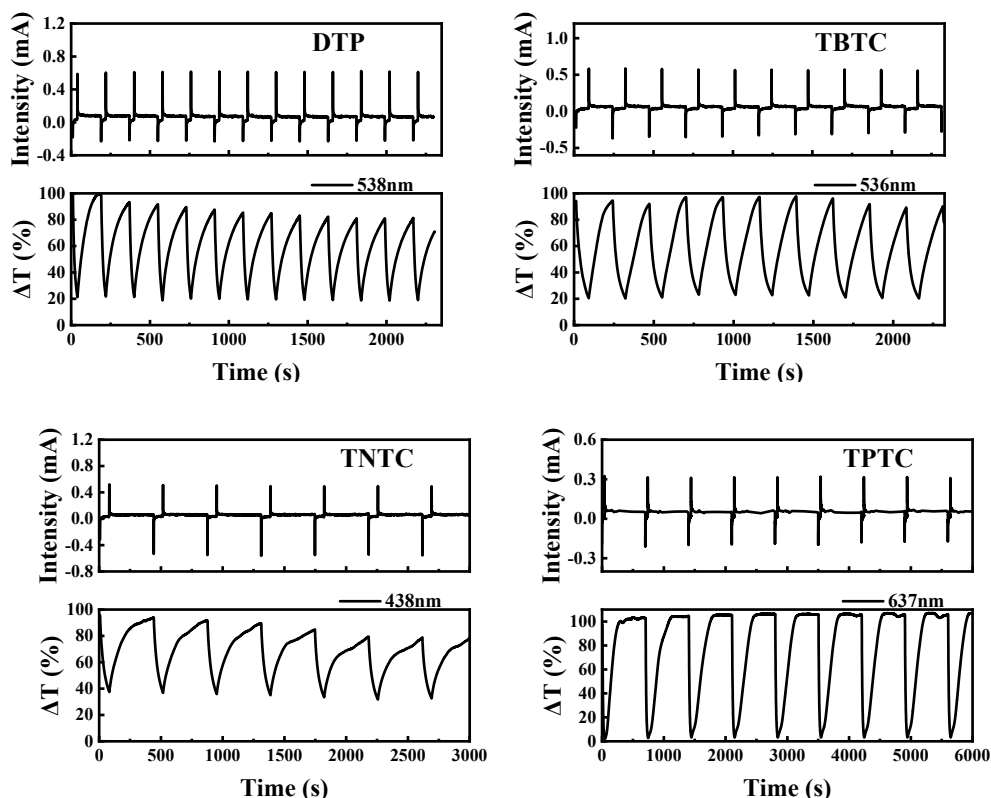


Figure S8. Switching behaviour of DTP, TBTC, TNTC and TPTC(1 mM and 5 mM TPAP) in anhydrous DMF solution showing transmittance ( $\Delta T\%$ ) and current

intensity as a function of time, measured in the air. The transmittance and current intensities for DTP, TBTC, TNTC, and TPTC were measured at the wavelengths of 538 nm, 536 nm, 438 nm, and 637 nm, respectively. The switching pulse sequence is  $V_{\text{on}}(-1.5 \text{ V}, 30 \text{ s})/V_{\text{off}}(0 \text{ V}, 150 \text{ s})$ ;  $V_{\text{on}}(-1.2 \text{ V}, 80 \text{ s})/V_{\text{off}}(0 \text{ V}, 150 \text{ s})$ ;  $V_{\text{on}}(-1.4 \text{ V}, 75 \text{ s})/V_{\text{off}}(0 \text{ V}, 360 \text{ s})$ ;  $V_{\text{on}}(-0.8 \text{ V}, 40 \text{ s})/V_{\text{off}}(0 \text{ V}, 660 \text{ s})$

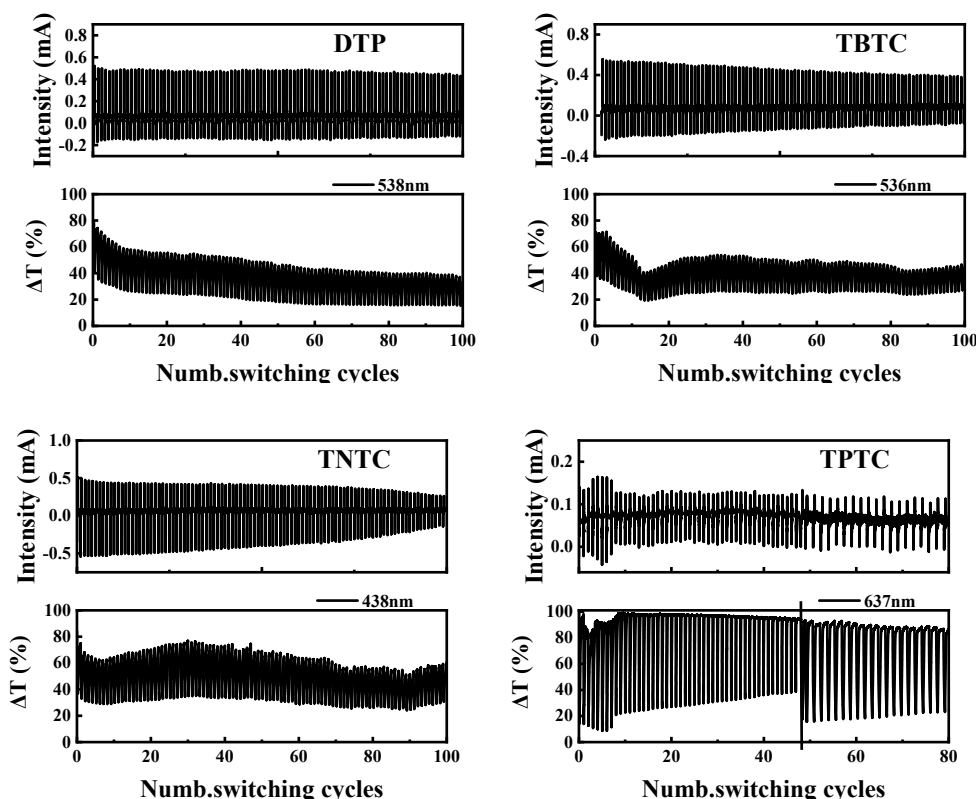
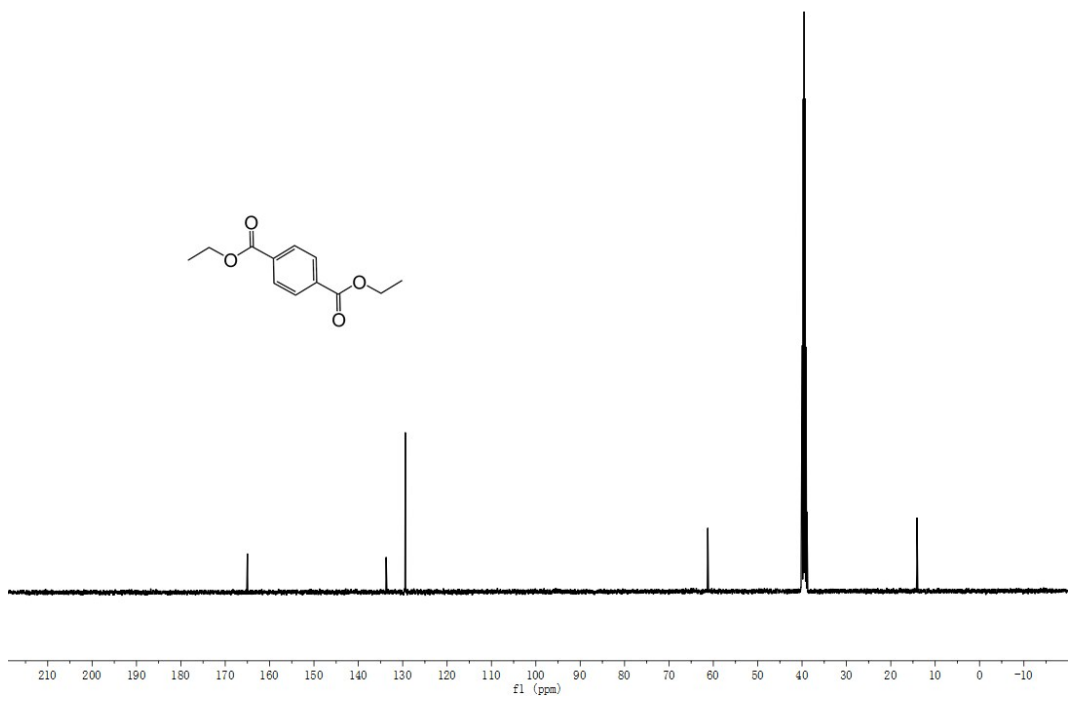
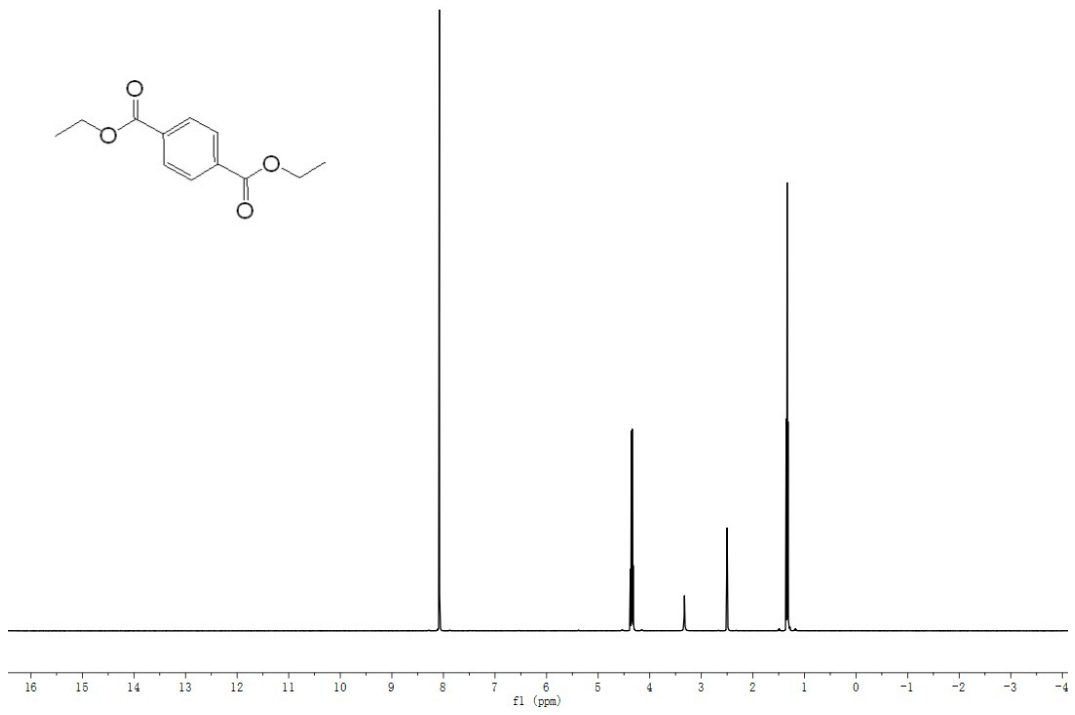
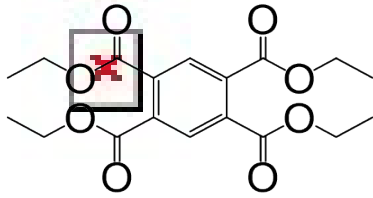
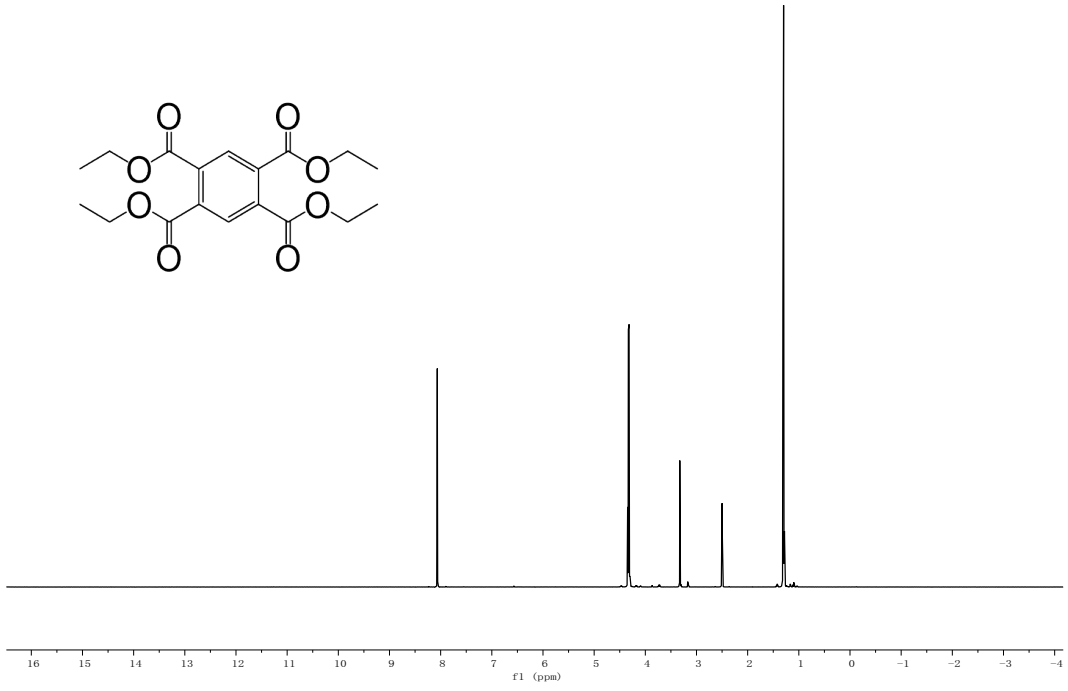
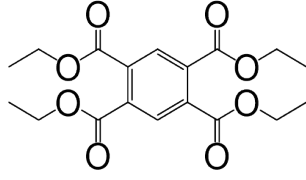


Figure S9. Stability of DTP, TBTC, TNTC and TPTC (1 mM and 5 mM TPAP) in anhydrous DMF solution showing transmittance ( $\Delta T\%$ ) and current intensity as a function of time. The transmittance and current intensities for DTP, TBTC, TNTC, and TPTC were measured in the air at the wavelengths of 538 nm, 536 nm, 438 nm and 637 nm, respectively. The switching pulse sequence is  $V_{\text{on}}(-1.5 \text{ V}, 20 \text{ s})/V_{\text{off}}(0 \text{ V}, 80 \text{ s})$ ;  $V_{\text{on}}(-1.2 \text{ V}, 30 \text{ s})/V_{\text{off}}(0 \text{ V}, 80 \text{ s})$ ;  $V_{\text{on}}(-1.4 \text{ V}, 60 \text{ s})/V_{\text{off}}(0 \text{ V}, 200 \text{ s})$  ,  $V_{\text{on}}(-0.8 \text{ V}, 40 \text{ s})/V_{\text{off}}(0 \text{ V}, 660 \text{ s})$  ( $V_{\text{on}}(-0.8 \text{ V}, 100 \text{ s})/V_{\text{off}}(0 \text{ V}, 200 \text{ s})$ )

# DTP

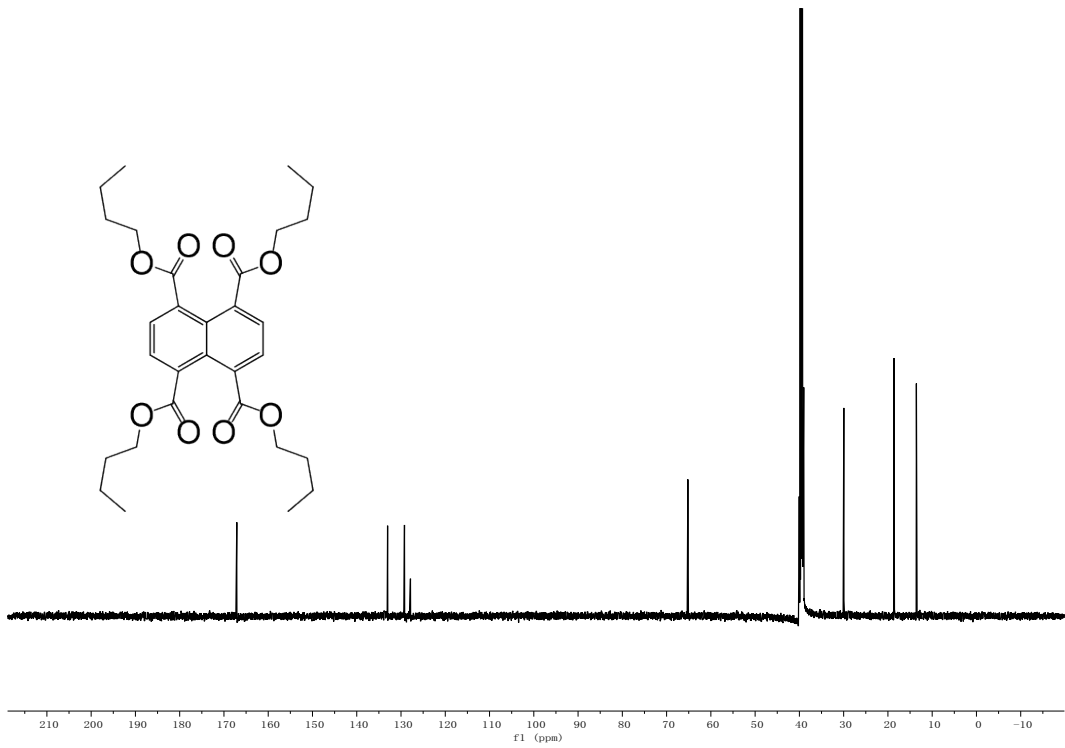
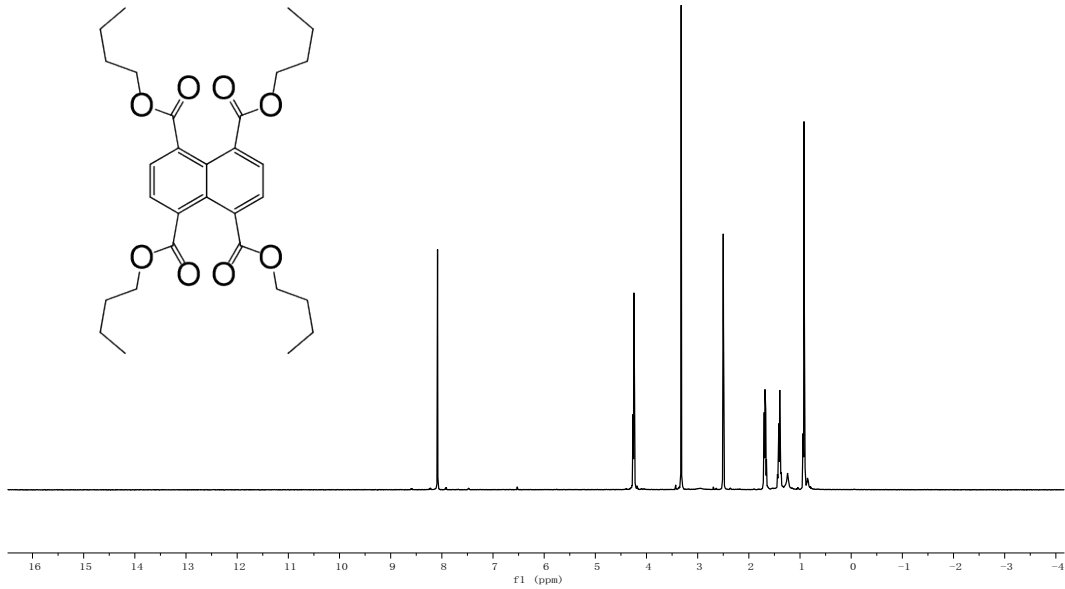


# TBTC





# TNTC



# TPTC

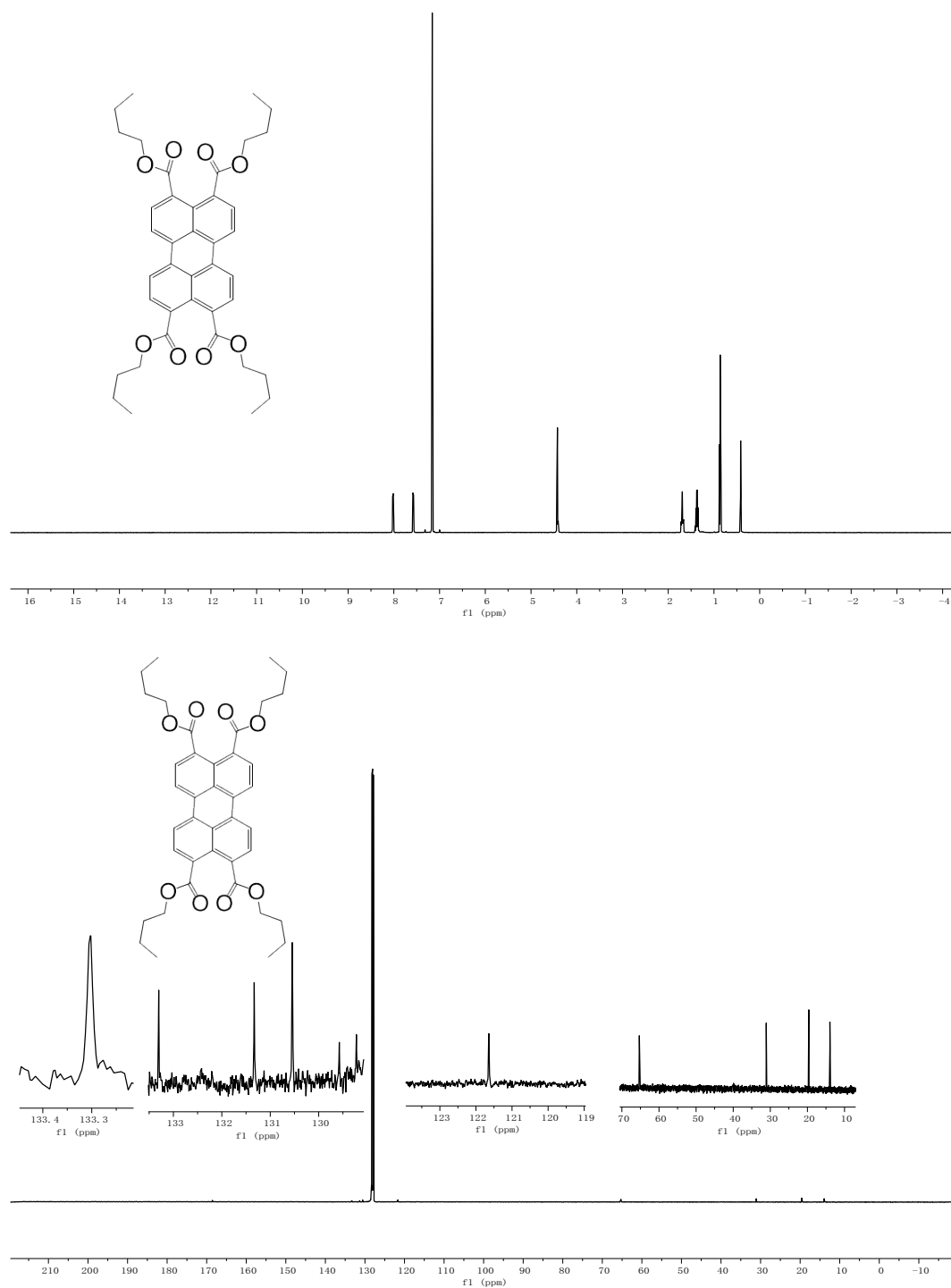


Figure S8. <sup>1</sup>H NMR and <sup>13</sup>C NMR spectra of novel compounds.

Table S1. Redox potentials of isophthalate-based compounds in cyclic voltammetry compared with this work

Compounds	Redox potential <sup>a</sup> vs Ag/Ag <sup>+</sup> (V)	Reference
<b>M1</b>	<b>2.68</b>	<b>Ref.1</b>
<b>M2</b>	<b>2.55</b>	<b>Ref.1</b>
<b>M3</b>	<b>2.58</b>	<b>Ref.1</b>
<b>M4</b>	<b>2.62</b>	<b>Ref.1</b>
<b>M5</b>	<b>2.57</b>	<b>Ref.1</b>
<b>M6</b>	<b>2.63</b>	<b>Ref.1</b>
<b>M7</b>	<b>2.72</b>	<b>Ref.1</b>
<b>M8</b>	<b>2.61</b>	<b>Ref.1</b>
<b>M9</b>	<b>1.88, 2.71, 2.81</b>	<b>Ref.1</b>
<b>IS1</b>	<b>-2.24,-2.48</b>	<b>Ref.2</b>
<b>IS2</b>	<b>-2.46</b>	<b>Ref.2</b>
<b>IS3</b>	<b>-2.36</b>	<b>Ref.2</b>
<b>IS4</b>	<b>-2.06, -2.36</b>	<b>Ref.2</b>
<b>IS5</b>	<b>-2.18, -2.49</b>	<b>Ref.2</b>
<b>IS6</b>	<b>-2.36</b>	<b>Ref.2</b>
<b>DTP</b>	<b>-2.19, -2.80</b>	<b>This work</b>
<b>TBTC</b>	<b>-1.81, -2.36</b>	<b>This work</b>
<b>TNTC</b>	<b>-1.86, -2.31</b>	<b>This work</b>
<b>TPTC</b>	<b>-1.44, -1.78</b>	<b>This work</b>

a) Redox potential vs. Ag/Ag<sup>+</sup>(reference electrode) determined in a conventional three electrodes cell by using 0.2 M tetrabutylammonium hexafluorophosphate as the supporting electrolyte in g-butyrolactone (Ref.1) or N-methylpyrrolidone (Ref.2) ITO glass as the working electrode, and platinum as the counter electrode.

Table S2. Transmittance changes and colouring efficiencies for DTP, TBTC, TNTC and TPTC, calculated from figures S3, S4, S5 and S6

	$\Delta\%T^a \pm \sigma$
<b>DTP</b>	<b>69.42 <math>\pm</math> 5.34</b>
<b>TBTC</b>	<b>74.94 <math>\pm</math> 2.13</b>
<b>TNTC</b>	<b>53.93 <math>\pm</math> 4.31</b>
<b>TPTC</b>	<b>96.43 <math>\pm</math> 1.15</b>

The transmittance contrast ( $\Delta\%T$ ) is defined as the difference between the transmittance in on and off states.

#### Reference:

- [1] W. Sharmoukh, K. C. Ko, J. H. Ko, H. J. Nam, D.-Y. Jung, C. Noh, J. Y. Lee and S. U. Son, *J. Mater. Chem.*, 2008, **18**, 4408-4413.
- [2] W. Sharmoukh, K. C. Ko, S. Y. Park, J. H. Ko, J. M. Lee, C. Noh, J. Y. Lee and S. U. Son, *Org. Lett.*, 2008, **10**, 5365-5368.