Supporting Information

Transmissive-to-black fast electrochromic switching from long conjugated pendant group and highly dispersed polymer/SWNT

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Materials

Pyrene, triphenylamine, N-bromosuccinimide (NBS), aniline, p-anisidine, 4-dodecylaniline, 1-bromo-4-iodobenzene, bis(dibenzylideneacetone)palladium(0) (Pd(dba)$_2$), 1‘1’-bis(diphenylphosphino)ferroocene (DPPF), sodium tert-butoxide, 9,9-dioctylfluorene-2,7-diboronic acid bis(1,3-propanediol) ester, tetrakis(triphenylphosphine)palladium(0) (Pd(PPh$_3$)$_4$), potassium carbonate (K$_2$CO$_3$), n-butyllithium solution (2.5M), 2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane and tetrabutylammonium perchlorate (TBAP) were purchased from Aldrich. 9,9-Dioctylfluorene-2,7-diboronic acid bis(1,3-propanediol) ester was used after recrystallization from hexane. Aniline, p-anisidine and 4-dodecylaniline were distilled under nitrogen before use. The other chemicals were used without purification. The solvents (analytical grade) were purchased from Merck. Tetrahydrofuran (THF) and toluene were distilled from sodium/benzophenone (deep purple) under nitrogen before use. Dimethylformamide (DMF) and acetonitrile (CH$_3$CN) were distilled from calcium hydride (stirring for 12 hours) under nitrogen before use. All other reagents were used as received. CoMoCAT single walled carbon nanotube (SWNT) was purchased from West Technology Limited.

Syntheses of monomers and polymers

Scheme S1. Synthetic route of monomers 1, 2 and polymer ECPblack (P1)

1-Bromopyrene$^1$ and tri(4-bromophenyl)amine$^2$ were synthesized according to the literatures.

N-phenylpyren-1-amine (1, Figure S1)

1-Bromopyrene (12.5 g, 44 mmol), aniline (8.9 g, 89 mmol), DPPF (490 mg, 0.9 mmol), Pd(dba)$_2$ (500 mg, 0.9 mmol), sodium tert-butoxide (6.4 g, 67 mmol), and toluene (100 mL) were placed in a 500 mL three-neck round-bottom flask equipped with a condenser. The mixture was heated and stirred at 110 °C for 24 h under nitrogen flow. After reaction, the reaction mixture was distilled at 55 °C under reduced pressure (50 torr). Residual aniline was removed by distilling under nitrogen flow at 110 °C with reduced pressure (0.1 torr). The crude product was washed by methanol then purified by silica gel column chromatography (n-hexane : dichloromethane (DCM) = 1 : 2) which was dried under reduced pressure then recrystallized with methanol to afford 4.56 g pure product (yield: 35%, mp = 156°C).$^1$H NMR (600 MHz, CDCl$_3$): $\delta$H (ppm): 5.40-6.75 (1H,
H15); 6.98-7.04 (1H, H19); 7.05-7.12 (2H, H17); 7.30-7.36 (2H, H18); 7.93-7.95 (1H, H13); 7.95-7.97 (1H, H12); 7.97-8.00 (1H, H7); 8.00-8.02 (1H, H6); 8.02-8.05 (1H, H5); 8.08-8.11 (2H, H3 and H9); 8.15-8.18 (2H, H9 and H10). 13C NMR (150 MHz, CDCl3), δC (ppm): 116.96 (C17), 118.99(C13), 118.99(C12), 120.61 (C19), 121.20 (C2), 121.20 (C10), 123.19(C14), 124.37 (C21), 124.72 (C8), 125.09(C1), 125.50 (C3), 125.90 (C11), 126.02(C5), 126.98 (C6), 127.31(C4), 129.40 (C18), 131.30 (C4), 131.64 (C8), 136.50 (C20), 144.80 (C16). IR (KBr): 3400 cm−1(NH strech); 3000 cm−1 & 2900 cm−1 (ArH); 1495 cm−1 (NH bend); 1600 cm−1 and 1475 cm−1 (CC aromatic strech); 1300 cm−1 (CN strech); 800 cm−1 (NH out of plane bending); 690 cm−1 & 750 cm−1 (monosubstitute out of plane bending). Anal. calcd for C22H15N: C 90.07%, H 5.15%, N 4.77%; found: C 91.04%, H 5.09%, N 5.17%. HRMS (ESI) m/z: [M] calcd for C22H15N, 293.12; found, 293.1199.

![Figure S1. Structure of monomer 1.](image)

_N,N-Bis(4-bromophenyl)-N’-phenyl-N’-(pyrene-1-yl)-1,4-phenylenediamine (2, Figure S2)_

Tris(4-bromophenyl)amine (6.7 g, 14 mmol), compound 1 (3.6 g, 9 mmol), Pd(dba)2 (115 mg, 0.2 mmol), DPPF (110 mg, 0.2 mmol), sodium tert-butoxide (1.78 g, 18.54 mmol) and toluene (70 mL) were charged in a 250 mL three-necked flask equipped with a condenser and kept under nitrogen flow. The mixture was heated to reflux for 24 h. After the completion of the reaction, the solvent was removed under vacuum and the residue was extracted with DCM and dried, and the residue was purified by silica gel column chromatography (n-hexane : DCM = 1 : 2). Then the product was recrystallized from a solvent mixture (n-hexane : DCM = 2 : 1), and 3.86 g of light yellow-green solid was obtained (yield: 60%). 1H NMR (600 MHz, CDCl3): δH (ppm)= 6.89-6.94 (2H, H16); 6.94-6.97 (4H, H26); 6.97-7.10 (2H, H22); 6.97-7.04 (2H, H23); 7.04-7.10 (1H, H18); 7.19-7.26 (2H, H17); 7.29-7.37(4H, H27); 7.96-7.98 (1H, H13); 7.98-8.00 (1H, H9); 8.00-8.03(1H, H7); 8.06-8.11 (2H, H2 and H3); 8.13-8.16 (1H, H10); 8.16-8.17 (1H, H5); 8.17-8.19(1H, H7); 8.17-8.19(1H, H10); 8.19-8.22(1H, H12). 13C NMR (150 MHz, CDCl3), δC (ppm): 114.93 (C25), 140.65 (C20),144.93 (C14), 146.54 (C19), 148.51 (C28), 121.63 (C18), 123.19(C7 and C3), 123.26 (C23 and C22), 124.81 (C16 and C26), 125.14(C10), 125.28 (C12),126.00 (C24), 126.08 (C21), 126.25 (C6), 126.36 (C11), 127.18 (C2 and C3), 127.59 (C9), 127.94 (C13), 129.18 (C17), 129.67 (C1), 131.03 (C4), 131.24 (C8), 132.23 (C27). IR (KBr) 1020 cm−1 (ArH strech); 1600 cm−1 & 1475 cm−1 (CC aromatic strech); 1320 cm−1 & 1270 cm−1 (CN strech); 510 cm−1 (CBr strech). Melting point (mp) is 223°C. Anal. calcd for C40H26Br2N2: C 69.18%, H 3.77%, N 4.03%; found: C 69.50%, H 3.84%, N 4.35%. HRMS (ESI) m/z: [M] calcd for C40H26Br2N2, 694.04; found, 694.0392.
Synthesis of Polymer ECPblack (P1, Figure S3)

To the 250 mL three-necked flask was added monomer 2 (386 mg, 0.93 mmol) with 9,9-dioctylfluorene-2,7-diboronic acid bis(1,3-propanediol) ester (519 mg, 0.93 mmol) for ECPblack (P1). The flask equipped with a condenser was evacuated and filled with nitrogen several times to remove traces of air, then the degassed toluene (5 mL) was added. Once the two monomers were dissolved, tetrakis(triphenylphosphine)palladium(0) (Pd(PPh3)4) (3 mg, 0.026 mmol) and potassium carbonate aqueous solution (10 ml, 3 M) was added and the mixture was stirred for 48 hrs at 100 °C under nitrogen flow. The reaction mixture was cooled to room temperature and the organic layer was separated, washed with water and precipitated into methanol. The green polymer sample was filtered and washed with excess methanol, then dried and purified by a Soxhlet extraction with acetone for 2 days, after which 729 mg (yield: 85%) of polymer was obtained. 1H NMR (600 MHz, C6D6Cl): δH (ppm)= 0.76-0.80 (3H, H23); 0.87-0.90 (2H, H37); 0.90-0.95(2H, H40); 0.95-1.01(2H, H38); 1.01-1.04 (m, 2H, H41); 1.04-1.10 (2H, H39); 1.10-1.15 (2H, H42); 2.10-2.25 (2H, H36); 6.86-6.91 (1H, H18); 6.91-6.93 (2H, H23); 6.93-6.95 (1H, H13); 6.95-6.97 (2H, H17); 6.97-7.20(2H, H16); 7.12-7.15 (2H, H22); 7.15-7.19 (1H, H12); 7.25-7.32 (4H, H26); 7.58-7.63 (1H, H5); 7.63-7.68 (4H, H27) 7.74-7.78 (1H, H7); 7.78-7.81 (1H, H6); 7.81-7.84 (1H, H10); 7.84-7.88 (2H, H30); 7.88-7.90(1H, H2); 7.90-7.94 (1H, H3); 7.98-8.00 (2H, H6); 8.00-8.03 (1H, H9); 8.31-8.35 (1H, H7). 13C NMR (150 MHz, C6D6Cl), δC (ppm): 138.16 (C25), 142.26 (C29), 142.48 (C32), 143.32 (C20), 149.55 (C28), 151.40 (C19), 154.40(C33), 121.34(C13), 122.73 (C7), 123.46(C10), 124.04 (C18), 124.09(C12), 125.60 (C17), 126.04 (C5), 126.44 (C28), 127.65(C3), 127.75 (C9), 128.09(C31), 128.25 (C6), 128.54 (C27), 128.67 (C11), 129.03 (C1), 129.70 (C2) 130.07 (C30), 130.38 (C15), 130.71(C5), 131.71 (C16), 131.83 (C23), 132.16 (C22), 133.64 (C8), 133.81 (C4), 136.48 (C24), 138.16 (C25), 16.53 (C43) 25.16 (C42), 26.63 (C37), 31.79(C40), 32.41 (C39), 32.71 (C41), 34.31 (C38), 43.13(C36), 57.88 (C35). IR (KBr) 3050 cm⁻¹ (sp² C-H strech); 2930 cm⁻¹& 2850 cm⁻¹ (sp³ C-H strech); 1600 cm⁻¹ & 1475 cm⁻¹(C=C aromatic strech) 1500 cm⁻¹ (C-H of CH2 bending) 1450 cm⁻¹ (C-H of CH bending) 1260 cm⁻¹ (C-N strech); 750 cm⁻¹ (Long alkane chain bend).

Anal. calcd for (C71H72N2)n: C 89.76%, H 7.21%, N 3.03%; found: C 89.26%, H 7.06%, N 2.96%.
Figure S3. Structure of polymer ECPblack (P1)
**Molecules Weight Characterization and Solubility**

GPC measurements were conducted to measure the molecular weight and polydispersity complex relative to the polystyrene standards. The results are summarized in Table S1. **ECPblack** has a number average molecular weight (Mn) of $2.08 \times 10^4$ g/mol and a weight average molecular weight (Mw) of $2.93 \times 10^4$ g/mol. **ECPblack** was highly soluble in DCM, toluene, chlorobenzene (CB), xylene, and benzene because it possessed the noncoplanar structure of triarylamine and fluorene, asymmetric structure of phenyl and pyrene units as well as alkyl chains as pendant groups, resulting in large spaces for solubility enhancement.
Thermal Properties

The rigid structure of triphenylamine can enhance the $T_g$ and thermal stability as studied in the literature. The thermal stability of ECPblack was determined by thermogravimetric analysis (TGA) and its phase transition behavior was evaluated with differential scanning calorimetry analysis (DSC) techniques. Results are summarized in Table S1. There are no melting endotherms up to the decomposition temperatures on the DSC thermograms. This supports the proposed amorphous nature of this triphenylamine-containing polymer. The glass transition temperature ($T_g$), 10% weight-loss temperatures ($T_{d10}$) in nitrogen and air, and char yield (CR) at 800 °C in nitrogen and air of ECPblack were 169 °C, 445 °C and 371 °C, 62% and 3% (Table S1), respectively.

![Figure S4. (a) and (b) TGA graphs of ECPblack in nitrogen and air. (c) DSC graph of ECPblack.](image-url)
Optical properties

The optical properties of ECPblack were investigated by UV-vis and photoluminescence (PL) spectroscopy when in solid state and in various solvents (ca. $1 \times 10^{-5}$ M) such as toluene, THF and NMP, as shown in Figure S5. The optical properties were summarized in Table S1. We ascribed the peak at 393 nm to a $\pi-\pi^*$ transition derived from the conjugated polymer backbone. The absorption wavelength of ECPblack in solid-state film causes a bathochromic shift of the low-energy transition band at 399 nm. This hypsochromic shift may be attributed to the more disordered morphology of the backbone, resulting from conformational fluctuations of the highly twisted and bulky propeller-shaped bi-triarylamine moiety. The optical bandgap was determined from the onset absorption of ECPblack in solid film form, with a bandgap of 2.7 eV for ECPblack. The normalized fluorescence emission spectra of the conjugated polymer ECPblack in various solvents exhibited a strong solvent polarity dependence and are also shown in Figure S5. The fluorescence emission spectra underwent remarkable bathochromic shifts with an increase of the solvent polarity, exhibiting maximum emission peaks at 514, 558, and 595 nm in toluene, THF, and NMP, respectively. The solvatochromism could be attributed to the fast intramolecular charge-transfer process resulting in a large change of dipole moment in the excited state. Therefore, the higher the polarity of the solvent, the lower the energy of the relaxed state and the larger red-shift of the emission spectrum. The fluorescent quantum yield of ECPblack was 45.1% in toluene solution.

![Normalized absorption and PL spectra of ECPblack](image-url)

**Figure S5.** Normalized absorption and PL spectra of ECPblack. The absorption of ECPblack film (1) and dissolved in toluene (2). The absorption of monomer 2 dissolved in toluene (3). The PL of ECPblack were measured when dissolved in toluene (4), THF (5) and NMP (6).
Electrochemical Properties

The electrochemical behavior of ECPblack was investigated by cyclic voltammetry (CV). The two reversible redox couples with the two $E_{1/2}$ values of 0.65 V and 0.98 V of conjugated polymer film on ITO-glass, which were in good agreement with the oxidation order of the two nitrogen atoms in the bi-triarylamine groups of ECPblack. The CV of ECPblack/graphene/PET showed weaker oxidation waves than ECPblack/ITO/Glass, due to the higher resistance of the graphene electrode. The two oxidation peaks do not appear in the same bias potential, so the first electron is removed from the HOMO of the molecule and the second electron was removed from the SOMO. From the oxidation potential relative to ferrocene/ferrocenium, which corresponds to -4.8 eV for ferrocene below the vacuum level, the HOMO of the ECPblack can be determined by the equation: HOMO = $-\left(E_{\text{onset \ ox}}^{\text{ox}} - E_{\text{onset \ Fc}}^{\text{Fc}}\right) - 4.8$. The LUMO and $E_g$ are found to be -2.3 eV and 2.7 eV, respectively. All the corresponding data are collected in Table S1.

![Cyclic voltammograms of the conjugated polymer ECPblack film. The CV of ECPblack was performed in acetonitrile solutions containing 0.1 M TBAP. ITO-coated glass and graphene-coated PET were used as electrode. Sweep rate = 100 mV/s. The optical bandgap and LUMO level of pristine ECPblack were calculated to be 2.7 eV and -2.3 eV, respectively. (See Table S1 for details)
Figure S7. Top-view (a) and cross-sectional (b) SEM images of pristine ECPblack on ITO.
Figure S8. (a) Structures of DIPHFL, NAPHFL and ECPblack. Absorption of (b) DIPHFL, (c) NAPHFL and (d) ECPblack.
Figure S9. Absorption spectral change of pristine ECPblack film on the flexible graphene-PET substrate with increasing of the applied voltage versus Ag/Ag⁺ couple as reference. The photo shows the color change of film at indicated applied voltages.
Table S1. Summary of the basic characterizations of ECPblack.

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<th>( T_{d10} ) in air (°C) \textsuperscript{c}</th>
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<th>( \lambda_{\text{max}} ) (nm, in toluene) \textsuperscript{e}</th>
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\textsuperscript{a} Determined by gel permeation chromatography (GPC) using THF as eluent and polystyrene standards.

\textsuperscript{b} Glass transition temperatures (\( T_g \))s were determined by DSC at a heating rate of 10 °C /min.

\textsuperscript{c} Decomposition temperatures at 10\% weight-loss (\( T_{d10} \)) were measured by TGA at a heating rate of 10 °C /min.

\textsuperscript{d} Residual weight percentage at 800 °C under nitrogen/air flow.

\textsuperscript{e} Polymer solution in toluene (ca. 1×10^{-5} M solution).

\textsuperscript{f} Calculated from the UV absorption spectrum of the polymer films by the equation: band gap (eV) = \( 1240/\lambda_{\text{onset}} \).

\textsuperscript{g} The oxidation potential versus Ag/Ag\(^+\) calculated from CV using ferrocene as an internal standard.

\textsuperscript{h} Calculated from the equation HOMO = \( -(E_{\text{onset}}^{\text{ox}} - E_{\text{Fc}}^{\text{Fas}}) - 4.8 \) and LUMO = HOMO + band gap.
4-Dodecy-\textit{N}, \textit{N}-bis(4-bromophenyl) aniline (3, Figure S10)

A mixture of 4-dodecylaniline (1 g, 3.8 mmole), 1-bromo-4-iodobenzene (2.7 g, 9.5 mmole), Pd(db\textsubscript{2}) (0.05 g, 0.1 mmole), DPPF (0.1 g, 0.2 mmole) and sodium tert-butoxide (1.47 g, 15.3 mmole) in dry toluene (50 ml) was degassed with nitrogen for 30 min while stirring. The mixture was heated and stirred to reflux under nitrogen for 24 hours. After the completion of reaction, 150 ml toluene and 100 ml distilled water were used in extraction. The toluene phase was separated, dried with MgSO\textsubscript{4}, filtered and evaporated to dryness. The crude product was purified by silica gel column chromatography using hexane as eluent to give monomer 3 (1.24 g, yield: 57%) as a colorless viscous liquid. \textsuperscript{1}H NMR (600 MHz, CDCl\textsubscript{3}): \(\delta\)H 7.32-7.34 (4H, m, H\textsubscript{15}), 7.08-7.10 (2H, m, H\textsubscript{13}), 6.97-7.00 (2H, m, H\textsubscript{14}), 6.92-6.94 (4H, m, H\textsubscript{13}), 2.56-2.59 (2H, t, H\textsubscript{12}), 1.59-1.64 (2H, m, H\textsubscript{11}) 1.28-1.35 (18H, m, H\textsubscript{2}, H\textsubscript{3}, H\textsubscript{4}, H\textsubscript{5}, H\textsubscript{6}, H\textsubscript{7}, H\textsubscript{8}, H\textsubscript{9}, H\textsubscript{10}), 0.89-0.91 (3H, t, H\textsubscript{1}); \textsuperscript{13}C NMR (150 MHz, CDCl\textsubscript{3}): \(\delta\)C 146.7 (C\textsubscript{19}), 144.4 (C\textsubscript{18}), 138.9 (C\textsubscript{17}), 132.2 (C\textsubscript{16}), 129.5 (C\textsubscript{13}), 125.0 (C\textsubscript{14}, C\textsubscript{15}), 115.0 (C\textsubscript{20}), 35.4 (C\textsubscript{12}), 31.9 (C\textsubscript{3}), 31.4 (C\textsubscript{11}), 29.7, 29.7, 29.7, 21.6, 29.5, 29.4, 29.4 (C\textsubscript{4}, C\textsubscript{5}, C\textsubscript{6}, C\textsubscript{7}, C\textsubscript{8}, C\textsubscript{9}, C\textsubscript{10}), 22.7 (C\textsubscript{2}), 14.1 (C\textsubscript{1}).

4,4,5,5-Tetramethyl-1,3,2-dioxaborolan-2-ylphenyl(p-methoxy)aniline were synthesized according to the literatures.\textsuperscript{7}

Synthesis of P2 (Figure S11)

In a 50 ml three-necked flask, 401 mg (0.75 mmole) of 3 and 434 mg (0.75 mmole) of \textit{N},\textit{N}-bis[4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl](p-methoxy)aniline were added. The flask was filled with 5 ml of the degassed toluene. Once the two monomers were dissolved, 3 mg Pd(PPh\textsubscript{3})\textsubscript{4} (0.03 mmole) and 10 ml of 2M K\textsubscript{2}CO\textsubscript{3} aqueous solution were added, and the mixture was stirred for 48 hours at 100\textdegreeC under nitrogen atmosphere. After completion of the reaction, the mixture was cooled to room temperature, and the organic
layer was separated, washed with water and precipitated using methanol. The light celadon fibrous polymer sample was filtered, washed with excess methanol, dried and purified by Soxhlet extraction with acetone for 48 hours to obtain P2 (0.43 g, yield: 83%) as a green solid. \(^1\)H NMR (600 MHz, CDCl\(_3\)): \(\delta\) \(H\) 7.46-7.60 (8H, H\(_{17}\) and H\(_{18}\)), 7.11-7.16 (14H, H\(_{14}\), H\(_{16}\), H\(_{19}\), H\(_{20}\), H\(_{21}\)), 6.89-6.90 (2H, H\(_{15}\)), 3.83 (3H, H\(_3\)), 2.59-2.61 (2H, H\(_{13}\)), 1.64-1.66 (2H, H\(_{12}\)), 1.30-1.37 (18H, H\(_3\), H\(_4\), H\(_5\), H\(_6\), H\(_7\), H\(_8\), H\(_9\), H\(_{10}\), H\(_{11}\)), 0.90-0.92 (3H, H\(_2\)); \(^{13}\)C NMR (150 MHz, CDCl\(_3\)): \(\delta\) c 156.3 (C\(_{22}\)), 146.8, 146.7 (C\(_{24}\) and C\(_{27}\)), 145.1 (C\(_{28}\)), 140.5 (C\(_{23}\)), 138.1 (C\(_{29}\)), 134.5, 134.1 (C\(_{25}\) and C\(_{26}\)), 129.2 (C\(_{21}\)), 127.4 (C\(_{14}\)), 127.2 (C\(_{17}\) and C\(_{18}\)), 124.9 (C\(_{20}\)), 123.8, 123.0 (C\(_{16}\) and C\(_{19}\)), 114.8 (C\(_{15}\)), 55.5 (C\(_1\)), 35.4 (C\(_{13}\)), 31.9 (C\(_4\)), 31.5 (C\(_{12}\)), 29.7, 29.6, 29.6, 29.5, 29.4 (C\(_5\), C\(_6\), C\(_7\), C\(_8\), C\(_9\), C\(_{10}\), C\(_{11}\)), 22.7 (C\(_3\)), 14.1 (C\(_2\)).

Figure S11. Structure of polymer P2.
**Figure S12.** Absorption of P3HT/SWNT and P2/SWNT films.
Figure S13. Absorption spectra of (a) P1/SWNT and (b) P2/SWNT dispersion.
Figure S14. TEM image of SWNT/P2.
Figure S15. Fitting of (a) ECPblack and (b) ECPblack/P2/SWNT film’s impedance behavior.
Figure S16. The CIE 1931 UCS (uniform chromaticity scale) diagrams of the luminance under (a) 5000 K and (b) 3000 K with \((u', v')\) coordinates points.

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Theoretical calculation

The theoretical calculations of ECPblack were carried out using the Gaussian 09 program package. We employed the B3LYP exchange correlation functional combined with the standard double-$\zeta$ plus polarization basis set, 6-31G*, to optimize the geometrical molecular structures of Mx, Mx$^+$ and Mx$^{2+}$ (Mx means M1, M2 or M3). There was no artificial symmetric or geometric constraint used during the optimization process. HF (Hartree–Fock) was used to calculate the energies and intensities of the 30 lowest-energy electronic transitions of all the Mx species. These were transformed, using the SWizard program, into simulated spectra as described before, using Gaussian functions with half-widths of 3000 cm$^{-1}$, as shown in the following Equation:

$$\varepsilon(\omega) = c \sum f \frac{\exp\left(-2.773 \frac{(\omega - \omega_0)^2}{\Delta_1/2}\right)}{\Delta_{1/2,1}}$$

where $\varepsilon$ is the molar extinction coefficient, given in units of M$^{-1}$·cm$^{-1}$; the energy $\omega$ of all allowed transitions included in the Equation, is expressed in cm$^{-1}$; $f$ and $\Delta_{1/2}$ are representing the oscillator strength and the half-bandwidths (3000 cm$^{-1}$), respectively.

By using these equations and the model compound, simulation of the oxidation states of ECPblack was carried out and the UV-vis spectra of neutral, 1st oxidation and 2nd oxidation states predicted, which are very similar to the experimental results. The difference may arise because the natural difference between the model compound and the polymer.

Figure S17. Theoretical calculation of ECPblack and oxidized ECPblack.
**Figure S18.** Lightness data of SWNT/P2/ECPblack at a different thickness.
Figure S19. Transmittance of SWNT/P2/ECPblack film at a thickness of 1.8 μm.
Figure S20. STEP of SWNT/P2/ECPblack.
**Figure S21.** Optical memory property of SWNT/P2/ECPblack film.
Reference:

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