Supporting Information

Propeller-shaped small molecule acceptors containing a 9,9'-spirobifluorene

core with imide-linked perylene diimides for non-fullerene organic solar cells

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I. Experimental section.

1. Materials and Methods:

Materials All reagents and chemicals were purchased from commercial sources and used without further purification. All anhydrous organic solvents for the synthesis, characterization, and device fabrication steps, including tetrahydrofuran (THF), chloroform, and chlorobenzene (CB) were purchased from Sigma-Aldrich. PTB7-Th and 2,2'-diamino-9,9'-spirobi[9H-fluorene] were purchased from Solarmer and Lumtec, respectively. 1-Hexylheptylamine,^[1] *N*,*N'*-bis(1-hexylheptyl)perylene-3,4,9,10-tetracarboxylbisimide,^[1] *N*-(1-hexylheptyl)perylene-3,4,9,10-tetracarboxyl-3,4-anhydride-9,10-imide,^[2] 2,2',7,7'-tetranitro-9,9'-spirobi[9H-fluorene]^[4] were synthesized using modified literature procedure.

Characterizations of compounds ¹H and ¹³C NMR spectra of intermediate monomers, SF-iPDI2 and SF-iPDI4 were recorded on a Bruker ASCEMD 600 MHz NMR spectrometer. Mass spectra were obtained using a Bruker Reflex III Matrix-Assisted LASER Desorption Ionization - Time of Flight Mass Spectrometer (MALDI-TOF) using α -Cyano-4-hydroxycinnamic acid (α -CCA) as a matrix^[5] recorded in a (+)-reflector mode. Elemental analysis was performed using Vario MICRO. TGA plots were measured using TA Instruments, Inc., TGA 2050 under a nitrogen atmosphere at heating and cooling rates of 10 °C·min⁻¹. Differential scanning calorimetry (DSC) analysis was performed on a TA Instruments Q100 under flowing N₂ at a heating rate of 10 °C·min⁻¹. Atomic force microscopy (AFM) was performed using a MultiMode 8 Scanning Probe Microscope VEECO Instruments Inc.

Electrochemical characterizations Electrochemical cyclic voltammetry (CV) was conducted on a PowerLab/AD instrument model system with glassy carbon disk, Pt wire, and Ag/Ag+ electrode as the working electrode, counter electrode, and reference electrode, respectively in a 0.1 M tetrabutylammonium hexafluorophosphate (*n*-Bu₄NPF₆) anhydrous acetonitrile solution at a potential scan rate of 50 mV·s⁻¹. Thin films of samples were deposited onto the glassy carbon working electrode from a 1.0 mg·mL⁻¹ chloroform solution. The electrochemical onsets were determined at the position where the current started to differ from the baseline. The potential of Ag/AgCl reference electrode was internally calibrated using the ferrocene/ferrocenium redox couple (Fc/Fc⁺). The electrochemical energy levels were estimated using the empirical formula: $E_{HOMO} = -$ (4.80

+ $E_{onset, ox}$) and $E_{LUMO} = -(4.80 + E_{onset, red})$.^[6] UV-vis spectra were recorded on a Varian CARY-5000 UV-vis spectrophotometer. For the measurements of thin films, materials were spun coated onto precleaned glass substrates from chloroform solutions (10 mg·mL⁻¹). Optical band gap (E_g^{opt}) was determined from the absorption edge of thin film sample.

Computational studies Density functional theory (DFT) calculations were performed using the Gaussian 09 software package^[7] to facilitate an in-depth understanding of the electronic structure of the PDI molecules. Hybrid three-parameter B3LYP functional combined with 6-31G(d) basis set was used to obtain the optimized structures at the singlet ground state.^[8] For simplicity, the alkyl chains were trimmed with methyl chains. The highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) energy levels were analyzed using minimized singlet geometries to approximate the ground state.

Grazing incidence wide angle X-ray scattering (GIWAXS) analysis GIWAXS measurements were performed on Beamline 9A at the Pohang Accelerator Laboratory (PAL). The photon energy is 11.075 keV (λ = 1.1195 Å). The GIWAXS images shown were normalized with respect to exposure time.

Fabrication and characterization of organic solar cell (OSC) devices The inverted structure of the OSC devices was fabricated with stack glass / ITO (110 nm) / ZnO (40 nm) /polymer:acceptor (85-90 nm) / V_2O_5 (2 nm) / Ag (80 nm).^[9] ITO-coated glass substrates were cleaned by sequential sonications with detergent, distilled water, acetone, and isopropyl alcohol for 15 min each. After UV/ozone treatment for 30 min, a ZnO electron transport layer^[10] was prepared by spin-coating at 4000 rpm and then baked at 120 °C for 30 min on a hot plate in ambient conditions. Active layer solutions were prepared in CB (polymer concentration: 8 mg·mL⁻¹) and stirred on a hotplate at 80 °C for 12 h. Active layers were spin-coated from the warm polymer solution on the prepared ITO/glass substrate in a N₂-filled glovebox at 1800 rpm, and then the films were annealed at 100 °C for 5 min in N₂ atmosphere. To deposit the electrodes, the samples were transferred into a vacuum chamber (pressure < 4×10^{-6} Torr), and then V₂O₅ (2 nm)/Ag (80 nm) were deposited sequentially on top of the active layer by thermal evaporation. The electrical characteristics were measured using a source/measure unit (Keithley 4200) under 100 mW·cm⁻² AM1.5 solar illumination in a N₂-filled glove box. Light was generated by an Oriel 1-kW solar simulator referenced using a Reference Cell PVM 132 calibrated at the US National Renewable Energy

Laboratory. A photomodulation spectroscopic set-up (model Merlin, Oriel) was used to measure the incident photon-to-current conversion efficiency as a function of light wavelength. The device area was 0.0555 cm².

SCLC measurement The mobility data were extracted from the dark *J–V* characteristics of hole-only devices, ITO/PEDOT:PSS/PTB7-Th:PDIs/Au, and electron-only devices ITO/ZnO/PTB7-Th:SF-iPDIs/Ca/AI devices. The electrical characteristics were measured using a source/measure unit (Keithley 4200) in a N₂-filled glove box. The dark *J–V* curves were fitted by using the Mott-Gurney equation (eq. 1), where *J* is the dark current density, ε_0 is the vacuum permittivity, ε_r is the relative dielectric constant, μ_0 is the zero-field mobility, γ is the disorder parameter, *V* is the effective voltage and *L* is the film thickness. For the case of hole-only devices the built in voltage (*V*_{bi}) value of 0V and for electron only devices *V*_{bi} = 1.5 V was used. ^[11]

$$J(V) = \frac{9}{8} \varepsilon_0 \varepsilon_r \mu_0 exp(0.89\gamma \sqrt{V/L}) \frac{V^2}{L^3} \qquad (1)$$

Low temperature characterization For low-temperature measurements, hole-only devices were hold on a standard sample holder in a liquid-nitrogen cryostat (JANIS VPF-100). Low temperature (210-298K) for devices was controlled by connecting the cryostat to a Lake Shore, 335 temperature controller unit and dark J-V characteristics were measured using a Keithley 2636 source meter.



Scheme S1 Synthesis procedure of 3.

1-hexylheptylamine (1): A mixture of 7-tridecanone (10.0 g, 50.4 mmol), NH₄OAc (40.0 g, 519 mmol), and NaBH₃CN (2.24 g, 35.7 mmol) in MeOH (150 mL) was stirred at room temperature for 60 h. The mixture was quenched by adding concentrated HCl dropwise (~4 mL) and concentrated under reduced pressure. The resulting white solid was taken up in 300 mL distilled water, stirred, taken to pH ~ 10 using solid KOH, then extracted with 100 mL CHCl₃ three times. The organic layer was combined and concentrated *in vacuo* to afford the product as pale yellow oil (8.7 g, 87%). ¹H NMR (600 MHz, CDCl₃, ppm): δ 2.67 (quint, 1H), 1.38 (m, 4H), 1.30– 0.18 (m, 16H), 0.88 (t, 6H).

N,N'-bis(1-hexylheptyl)perylene-3,4,9,10-tetracarboxylbisimide (2): A mixture of compound 1 (5.0 g, 25.0 mmol) and perylene-3,4,9,10-tetracarboxylicdianhydride (3.94 g, 10.0 mmol) in 35 g imidazole were stirred at 140 °C for 3 h. The reaction mixture was cooled to room temperature, taken up in 150 mL ethanol, treated with 300 mL 2 N diluted HCl solution, and stirred overnight. The dark red precipitate was filtered and washed thoroughly with distilled water, and dried *in vacuo*. The compound was purified by silica gel column chromatography (n-hexane:chloroform = 1:3) to afford the product as red solid (6.5 g, 86%) ¹H NMR (600 MHz, CDCl₃, ppm): δ 8.64 (m, 8H), 5.19 (m, 2H), 2.25 (m, 4H), 1.87 (m, 4H), 1.30–1.18 (m, 32H), 0.83 (t, 12H).

N-(1-hexylheptyl)perylene-3,4,9,10-tetracarboxyl-3,4-anhydride-9,10-imide (3): A mixture of compound 2 (4 g, 5.3 mmol) and KOH (13 g) in isopropyl alcohol (160 mL) and distilled water (20 mL) was stirred at reflux for 60 min. After cooled to 0 °C in an ice bath, then concentrated HCl (20 mL) was slowly added and stirred vigorously for 1 h. The reaction mixture was concentrated under reduced pressure and the precipitate was filtered, washed with distilled water and dried *in vacuo*. The recovered solid was dissolved in chloroform and poured into 1 N HCl in methanol. The precipitate was filtered and dried *in vacuo*. The compound was purified by silica gel column chromatography (0.5% methanol in chloroform) to afford the product as red soild (1.8 g, 59%) ¹H NMR (600 MHz, CDCl₃, ppm): δ 8.67 (m, 8H), 5.18 (m, 1H), 2.23 (m, 2H), 1.86 (m, 2H), 1.32-1.19 (m, 16H), 0.82 (t, 6H).



Scheme S2. Synthesis procedure of SF-4NH2.

2,2',7,7'-Tetranitro-9,9'-spirobi[9H-fluorene] (4): 9,9'-spiro[9H-fluorene] (1 g, 3.16 mmol) was added to fuming nitric acid (10 mL) at 0 °C. The reaction mixture was kept at 0 °C for 1 h, then a mixture of acetic anhydride (4 mL) and acetic acid (6 mL) was slowly added. The precipitate was filtered, washed abundantly with acetic acid and water, then dried *in vacuo* to afford the product as a light yellow solid (1.2 g, 76%). ¹H NMR (600 MHz, DMSO- d_6 , ppm): δ 8.58 (d, 4H), 8.45 (dd, 4H), 7.63 (d, 4H).

2,2',7,7'-Tetramino-9,9'-spirobi[9H-fluorene] (5): Hydrazine monohydrate (3.2 g, 64.5 mmol) and Raney nickel (~20 g) were added slowly to compound 4 (2.0 g, 4.03 mmol) in THF (100 mL) and refluxed for 3 h. The mixture was hot filtered and washed with ethanol. Solvent was evaporated and the residue was washed with ethanol and dried *in vacuo*. (1.3 g, 84%) ¹H NMR (600 MHz, DMSO-d₆, ppm): δ 7.30 (d, 4H), 6.45 (dd, 4H), 5.85 (d, 4H), 4.79 (bs, 8H).



Scheme S3. Synthesis procedure of SF-iPDI2 & SF-iPDI4.

SF-iPDI2 (6): A mixture of compound 3 (828 mg, 1.44 mmol), 2,2'-diamino-9,9'-spirobi[9H-fluorene] (200 mg, 0.577 mmol) and a small amount of anhydrous $Zn(OAc)_2$ in quinoline (25 mL) was heated to 180 °C for 50 h. The reaction mixture was poured into 200 ml 2 N diluted HCl solution and stirred overnight. The resulting precipitate was filtered, washed thoroughly with distilled water and dried *in vacuo*. The compound was purified by silica gel column chromatography (1.5% methanol in chloroform) to afford the product as red solid (480 mg, 57%) ¹H NMR (600 MHz, CDCl₃, ppm): δ 8.62-8.53 (m, 16H), 8.00 (d, 2H), 7.86 (d, 2H), 7.39 (m, 4H), 7.21 (t, 2H), 6.94 (d, 2H), 6.90 (d, 2H), 5.18 (m, 2H), 2.25 (m, 4H), 1.88 (m, 4H), 1.33-1.213 (m, 32H), 0.93-0.80 (m, 12H), MS (MALDI-TOF): m/z (M⁺) = Calcd for C₉₉H₈₄N₄O₈: 1456.6; found 1458.1. Elem. Anal. Calcd for C₉₉H₈₄N₄O₈: C, 81.57; H, 5.81; N, 3.84. Found: C, 80.50; H, 6.10; N, 3.58.

SF-iPDI4 (7): A mixture of compound 3 (3,429 mg, 5.98 mmol), compound 5 (500 mg, 1.33 mmol) and a small amount of anhydrous Zn(OAc)2 in quinoline (50 mL) was heated to 180 °C for 50 h. The reaction mixture was poured into 300 ml 2 N diluted HCl solution and stirred overnight. The resulting precipitate was filtered, washed with distilled water and dried *in vacuo*. The compound was purified by silica gel column chromatography (1.5% methanol in chloroform) to afford the product as red solid (1,250 mg, 36%) ¹H NMR (600 MHz, CDCl₃, ppm): δ 8.68-8.57 (m, 32H), 8.04 (m, 4H), 7.44 (m, 4H), 7.14 (m, 4H), 5.21 (m, 4H), 2.27 (m, 8H), 1.90 (m, 8H), 1.35-1.25 (m, 64H), 0.85-0.83 (m, 24H), MS (MALDI-TOF): *m/z* (M⁺) = Calcd for C₁₇₃H₁₅₂N₈O₁₆: 2597.1; found 2598.3. Elem. Anal. Calcd for C₁₇₃H₁₅₂N₈O₁₆: C, 79.94; H, 5.89; N, 4.31. Found: C, 79.03; H, 5.82; N, 4.26.



Fig. S1. ¹H NMR (600 MHz, chloroform-d) spectra of (a) 2 and (b) 3 in Scheme S1.



Fig. S2. ¹H NMR (400 MHz, DMSO-d₆) spectra of (a) SF-4NO₂ (**4** in Scheme S2) and (400 MHz, chloroform-d) spectra of (b) SF-4NH₂ (**5** in Scheme S2).



Fig. S3. ¹H NMR (400 MHz, chloroform-d) spectra of (a) SF-iPDI2 (**6** in Scheme S3) and (b) SF-iPID4 (**7** in Scheme S3).



Fig. S4. Elemental analysis of (a) SF-iPDI2 and (b) SF-iPDI4.

[sec.]



Fig. S5. Thermogravimetric analysis plots of SF-iPDI2 and SF-iPDI4.



Fig. S6. Differential scanning calorimetry of SF-iPDI2 and SF-iPDI4.



Fig. S7. Optimized geometries of SF-iPDI4 (left) and SF-PDI4 (right) measured by DFT calculation (B3LYP functional/6-31G* basis set). Methyl-trimmed alkyl chains were used for simplicity of computation.



Fig. S8. Frontier molecular orbitals of SF-iPDI2 measured by DFT calculation (B3LYP functional/6-31G* basis set). Methyl-trimmed alkyl chains were used for simplicity of computation.



Fig. S9. Frontier molecular orbitals of SF-iPDI4 measured by DFT calculation (B3LYP functional/6-31G* basis set). Methyl-trimmed alkyl chains were used for simplicity of computation.



Fig. S10. Normalized UV-vis absorption spectra of (a) SF-iPDI2 and (b) SF-iPDI4 in chloroform (CF) at a concentration of 0.025 g·L⁻¹ for 25 °C and spin-coated thin films prepared by CF. (c) Absorption coefficient of the SF-iPDI2 and SF-iPDI4 pristine films prepared by CF.

Table S1.	Properties	of SF-iPDI2	and SF-iPDI4.
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Material	T_{d}	$\lambda_{\max}(\varepsilon)^{ m solution}$	$E_{g}^{solution}$	$\lambda_{max}\left(\epsilon ight) ^{film}$	$E_{\rm g}^{\rm film}$	E _{HOMO} CV	E _{LUMO} CV	<i>E</i> _{LUMO} ^{opt}
	[°C]ª	[nm] ^b	[eV] ^c	[nm] ^d	[eV] ^e	[eV] ^f	[eV] ^f	[eV] ^g
SF-iPDI2	399	459, 491, 526	2.28	466, 496, 534	2.18	-5.99	-3.82	-3.81
SF-iPDI4	396	460, 491, 525	2.28	465, 496, 534	2.19	-6.01	-3.85	-3.82

a) Thermal decomposition temperature T_d that caused 5% weight loss was determined using TGA. b) In chloroform at concentration of 0.025 g·L⁻¹ for 25 °C. c) Optical band gaps, calculated from the absorption edges in solution. d) From thin films on glass substrates. e) Optical band gaps, calculated from the absorption edges on thin films. f) Calculated from the onsets of oxidation and reduction potential measured by CV. g) The LUMO energy levels were estimated from the HOMO energy levels (CV) and the optical band gaps (UV-vis) in the solid state by using the following equation: $E_{LUMO} = E_g^{opt} + E_{HOMO}$.^[7]



Fig. S11. Energy level diagram of the inverted device structure with the three photoactive materials, interlayers, and electrodes used in our study of the photovoltaic characteristics.



Fig. S12. Normalized UV-vis absorption spectra of (a) PTB7-Th:SF-iPDI2 and (b) PTB7-Th:SF-iPDI4 prepared by CB and CB:DIO. (C) Comparison of UV-vis absorption spectra of PTB7-Th:SF-iPDI2 and PTB7-Th:SF-iPDI4 prepared by CB:DIO.

D:A	Ratio	DIO [vol%]	V _{oc} [V]	J _{sc} [mA∙cm⁻²]	FF [%]	PCE [%]
	1:0.8	-	0.84 ± 0.005	8.71 ± 0.11	38.6 ± 0.51	2.84 ± 0.09
PTB7-Th: SF-iPDI2	1:1	-	0.84 ± 0.003	9.32 ± 0.17	41.2 ± 1.15	3.16± 0.12
	1:1.2	-	0.84 ± 0.001	9.75 ± 0.12	48.1 ± 0.14	3.94 ± 0.09
	1:1.4	-	0.84 ± 0.001	10.28 ± 0.07	52.9 ± 0.65	4.47 ± 0.06
	1:1.6	-	0.84 ± 0.001	10.11 ± 0.07	49.3 ± 0.13	4.21 ± 0.12
	1:2	-	0.82 ± 0.001	8.87 ± 0.09	44.1 ± 0.17	3.19 ± 0.013
	1:1.4	0.5	0.84 ± 0.004	10.53 ± 0.12	59.9 ± 0.13	5.22± 0.09
PTB7-Th:	1:1.4	1	0.84 ± 0.001	9.64 ± 0.12	58.5 ± 0.13	4.72 ± 0.06
SF-iPDI2	1:1.4	2	0.84 ± 0.003	8.74 ± 0.07	56.1 ± 0.08	4.11 ± 0.03
	1:1.4	3	0.84 ± 0.003	7.97 ± 0.06	53.4 ± 0.08	3.58 ± 0.07
	1:0.6	_	0.82 ± 0.003	10.31 ± 0.07	44.2 ± 1.11	3.79 ± 0.13
PTB7-Th: SF-iPDI4	1:0.8	-	0.82 ± 0.005	10.73 ± 0.09	48.1 ± 1.02	4.19 ± 0.06
	1:0.9	-	0.82 ± 0.01	9.77 ± 0.09	47.6 ± 1.12	3.85 ± 0.11
	1:1	-	0.83 ± 0.003	9.50 ± 0.07	47.5 ± 1.02	3.76 ± 0.06
	1:1.1	-	0.83 ± 0.002	9.48 ± 0.16	47.2 ± 0.86	3.74 ± 0.05
	1:1.2	_	0.84 ± 0.01	8.67 ± 0.10	46.7 ± 1.01	3.40 ± 0.04
	1:0.8	0.5	0.82 ± 0.003	10.74 ± 0.04	48.4 ± 0.31	4.27 ± 0.05
PTB7-Th: SF-iPDI4	1:0.8	1	0.82 ± 0.002	11.36 ± 0.07	50.1 ± 0.66	4.61 ± 0.07
SF-IPUI4	1:0.8	2	0.82 ± 0.002	10.16 ± 0.05	47.6 ± 0.17	3.95 ± 0.09

Table S2. The detailed photovoltaic performances of the solar cells based on PTB7-Th:SF-iPDI2 and PTB7-Th:SF-iPDI4 with different D:A ratios and DIO vol%.



Fig. S13. Dark current density versus effective voltage characteristics of a) electron-only devices and b) hole-only devices, with photoactive layers PTB7-Th:SF-iPDI2 and PTB7-Th:SF-iPDI4 without and with DIO. Dotted lines: fits based on equation (1). In the case of electron-only devices $V_{\rm bi} = 1.5$ V is used.

D:A	DIO [vol %]	μ _e [cm ² ·V ⁻¹ ·s ⁻¹]	μ _h [cm²·V ⁻¹ ·s ⁻¹]	$\mu_{ m e}/\mu_{ m h}$
PTB7-Th:SF-iPDI2	-	6.45 × 10 ⁻⁵	3.61 × 10 ⁻⁶	17.8
	0.5	7.72 × 10 ⁻⁵	3.32 × 10 ⁻⁵	2.32
PTB7-Th:SF-iPDI4	-	2.26 × 10 ⁻⁵	1.99×10^{-6}	11.4
	1.0	2.38 × 10⁻⁵	1.96×10^{-6}	12.1

Table S3. Mobility results of space charge limited current (SCLC) devices based on PTB7-Th:SF-iPDI2 and PTB7-Th:SF-iPDI4 without and with DIO.



Fig. S14. Atomic force microscopy (AFM) of blend films based on PTB7-Th:SF-iPDI2 (a) without and (b) with DIO, and PTB7-Th:SF-iPDI4 (c) without and (d) with DIO.



Fig. S15. Atomic force microscopy (AFM) of neat films based on SF-iPDI2, SF-iPDI4, and PTB7-Th (a-c) without and (d-f) with DIO.



Fig. S16. Photoluminescence (PL) of blend films based on (a) PTB7-Th:SF-iPDI2 without and with DIO and (b) PTB7-Th:SF-iPDI4 without and with DIO at 635 nm, and (c) PTB7-Th:SF-iPDI2 without and with DIO and (d) PTB7-Th:SF-iPDI4 without and with DIO at 496 nm.



Fig. S17. 2D GIWAXS images (a) and 1D GIWAXS profiles (b) for the pristine and blend films.

DIO [vol %]		q _{ху} (100)	<i>q</i> z ^a (010)
	q value	0.22748	-
-	d-spacing	27.6	-
	q value	0.20152	1.56357
-	d-spacing	31.2	4.0
0.5	q value	0.18297	1.56186
	d-spacing	34.3	4.0
	q value	0.17926	-
-	d-spacing	35.05	-
	q value	0.25158	1.55611
-	d-spacing	24.97	4.0
1.0	q value	0.24972	1.55724
1.0	d-spacing	25.16	4.0
	DIO [vol %] - 0.5 - - 1.0	$\begin{array}{c} \textbf{DIO} \\ [vol \%] \end{array} \\ \hline $ \\ \hline \\ \hline \end{array} \\ \hline \\ \hline \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array} \\ \hline \\ \hline \\ \hline \end{array} \\ \hline \\ \hline	$ \begin{array}{c} \textbf{DIO} \\ [vol \%] \end{array} & \begin{array}{c} q_{xy} \\ (100) \end{array} \\ \hline \bigg \\ \hline \end{array} \\ \hline \bigg $ \\ \hline \bigg \\ \hline \bigg \\ \hline \bigg \\ \hline \bigg \\ \hline \bigg \\ \hline \bigg \\ \\ \hline \bigg \\ \Biggl \\ \end{aligned} \\ \end{aligned} \\ \end{aligned} \\ \Biggl \\ \Biggl \\ \Biggl \\ \Biggr \\ \bigg \\ \bigg \\ \bigg \\ \bigg \\ \Biggr \\ \bigg \\

Table S4. GIWAXS results and fit parameters for the pristine and blend films.

a) is q_z value of PTB7-Th marked with the asterisks in Fig. S17a.



Fig. S18. Transmission electron microscopy (TEM) of blend films based on (a & e) PTB7-Th:SF-iPDI2 (b & f) PTB7-Th:SF-iPDI2 w/ DIO (c & g) PTB7-Th:SF-iPDI4 and (d & h) PTB7-Th:SF-iPDI4 w/ DIO.



Fig. S19. Hole mobility as a function of temperature for PTB7-Th:SF-iPDI2 (open Square), PTB7-Th:SF-iPDI2 with DIO (filled square), PTB7-Th:SF-iPDI4 (open circle) and PTB7-Th:SF-iPDI4 with DIO (filled circle) based electron only devices. Dotted lines represent the fitting lines with Arrhenius equation ^[12] (inset equation) to calculate the activation energy (E_a). Temperature was varied from 210 – 298 K.

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