Naphthalene diimide-difluorobenzene-based polymer acceptors for all-polymer solar cells

Ping Deng
Fuzhou University

Carr Hoi Yi Ho
Hong Kong Baptist University

Yong Lu
Hong Kong Baptist University

Ho-Wa Li
City University of Hong Kong

Sai-Wing Tsang
City University of Hong Kong

See next page for additional authors

This document is the authors' final version of the published article.
Link to published article: http://dx.doi.org/10.1039/c6cc09724c

Recommended Citation
Deng, Ping, Carr Hoi Yi Ho, Yong Lu, Ho-Wa Li, Sai-Wing Tsang, Shu Kong So, and Beng S. Ong. "Naphthalene diimide-difluorobenzene-based polymer acceptors for all-polymer solar cells." Chemical Communications 53.22 (2017): 3249-3252.
Naphthalene Diimide-difluorobenzene-based Polymer Acceptors for All-polymer Solar Cells

Ping Deng a,b,c, Carr Hoi Yi Ho c,d, Yong Lu b, Ho-Wa Li d, Sai-Wing Tsang d, Shu Kong So e and Beng S. Ong f

A regio-random (P1) and -regular (P2) difluorobenzene-naphthalene-containing polymer acceptors were developed for bulk-heterojunction all-polymer solar cells (all-PSCs). P2 exhibited significantly higher crystallinity in thin films, affording highly spectral absorptivity and electron mobility than P1. When used in all-PSC devices, P2 afforded a respectably higher power conversion efficiency of over 5%.

All-polymer solar cells (all-PSCs) comprising organic polymer donor and non-fullerene polymer acceptors have attracted considerable attention in recent years. This stems from realization that replacing fullerene acceptor components in the active layers of organic solar cells (OSCs) with polymer acceptors may provide several advantages including light absorption tenability, ease of molecular orbital energy matching, better mechanical and thermal properties as well as potentially lower acceptor costs. Despite these perceived attributes, progress toward realization of All-PSCs with performance characteristics comparable to those of fullerene-based PSCs has been slow. Major challenges in developing an efficient PCBM replacement persist, and current power conversion efficiencies (PCEs) of all-PSCs are comparatively much lower at about 1-8%. 2a,b,3-S

Among polymer acceptors, naphthalene diimide (NDI)-based polymers a,b have been shown to be promising alternative acceptors for fullerene derivatives. In theory, the electron transport, frontier molecular orbital energy levels and spectral absorption properties of NDI-based polymers can be appositely tuned to improve the PCE of corresponding All-OSCs. This may be accomplished via incorporation of suitable donor or acceptor moieties into the NDI polymer structure as well as controlling its structural regioregularity. To capitalize on these attributes, appropriately functionalized donor or acceptor precursors would have to be readily accessible and that their incorporation into the polymer acceptor structure would not negatively impact polymerization in achieving higher molecular weights and that the solution processability of the resulting polymer would not be compromised. High molecular weight and solution processability are two important parameters for achieving optimal PCE. Likewise, it is also important that the resulting polymer acceptor possesses reasonable compatibility with the polymer donor component of all-PSC devices.

Fluorine atom, when incorporated into the acceptor moiety of polymer acceptors, has been particularly effective in simultaneously lowering their lowest unoccupied molecular orbital (HOMO) and highest occupied molecular orbital (LUMO) energy levels. When appositely positioned on the repeating units on the polymer backbone, it can also help attain polymer structural coplanarity for low band-gap properties by locking-up neighboring moieties via C-F...S, C-F...H and C-F...π interactions. It may also facilitate charge separation and help reduce charge recombination leading to enhanced charge carrier mobility. Accordingly, we have witnessed a variety of fluorine-containing donor polymers been developed and...
utilized in single-junction PSCs, providing PCEs in excess of 11%.11 Despite significant achievements in fluorine-containing polymer donors, not many fluorine-containing acceptor polymers have hitherto been reported.12 It is thus of great interest to explore properly constructed fluorine-containing acceptor polymers systems with random and regioregular backbone structures for all-OSCs. We report herein the synthesis of two difluorobenzene-containing NDI polymers, one structurally random (P1) and one regioregular (P2) isomers, and the studies of the structural effects on their electrical and photovoltaic performance as polymer acceptors in all-PSC devices.

The synthetic schemes for both random and regioregular polymer acceptors, P1 and P2, are summarized in Scheme 1. The polycondensation was carried out via Stille cross-coupling reaction using tris(dibenzylidene-acetone)dipalladium as the catalyst and tri-o-tolylphosphine as the ligand. P1 was synthesized from the coupling reaction of 2,5-bis(trimethylstannyl)thiophene with 1,4-dibromo-2,5-difluorobenzene and 4,9-dibromo-2,7-bis(2-octyldodecyl)benzo[llmn][3,8]-phenanthroline-1,3,6,8(2H,7H)-tetraone. On the other hand, P2, was obtained from the reaction of 4,9-dibromo-2,7-bis(2-octyldodecyl)benzo[llmn][3,8]-phenanthroline-1,3,6,8(2H,7H)tetraone with [(2,5-difluoro-1,4-phenylene)-bis(thiophene-5,2-diyl)]bis(trimethylstannane). Both polycondensations were conducted 90 °C for 20 h. The crude polymer products were isolated by precipitation from stirring methanol and collected by filtration. Subsequently, they were subjected to sequential Soxhlet extractions with methanol, hexane, ethyl acetate and chloroform to remove low molecular weight materials and isolated by extraction with chlorobenzene from the extraction residue. Both polymers displayed reasonably good solubility in hot chlorinated solvents such as chlorobenzene, dichlorobenzene, etc. As both the solutions of both polymers displayed a tendency to aggregate at room temperature, their molecular weights were thus measured by high-temperature GPC at 160 °C using 1,2,4-trichlorobenzene as eluent against polystyrene standards (See ES†, Table S1). The number-average molecular weights (Mn) for P1 and P2 are 22.3 kDa (PDI: 4.57) and 44.8 kDa (PDI: 6.38), respectively. Both polymers exhibited good thermal stability as thermogravimetric analysis (TGA) showed their decomposition temperatures to be above 400 °C (5% weight loss) in inert atmosphere (Fig. S1 and Table S1).

The UV-vis absorption spectra of P1 and P2 are depicted in Fig. 1a and 1b, and their spectral properties are tabulated in Table S2. In dilute solutions and in thin films, both polymers displayed broad, somewhat featureless dual-band absorptions typical of NDI-based D-A polymers: a short-wavelength band arising from localized π-π* transition (300–450 nm) and a long-wavelength band (500–750 nm) attributable to intramolecular charge transfer (ICT).13 From their dilute solution to thin-film spectra, both P1 and P2 exhibited bathochromic shifts of about 30-35 nm in their long-wavelength absorptions, while only P2 simultaneously experienced a bathochromic shift of 18 nm in its short-wavelength absorption (Table S2). This may be attributed to significantly higher molecular ordering of P2 in the thin film state by virtue of its structural regioregularity.

As expected on the basis of structural regioregularity, P1 exhibited significantly much higher absorptivity than P2. Fig. 1c shows the thin-film spectral absorptivity of the two polymers, with P1 displaying absorption coefficients of 5.30×10⁴ cm⁻¹ at λmax, 388 nm, and 4.19×10⁴ cm⁻¹ at λmax, 600 nm, and P2, 1.06×10⁵ cm⁻¹ at λmax, 388 nm and 5.67×10⁴ cm⁻¹ at λmax, 620 nm. The substantially higher spectral absorptivity of P2 lends unequivocal support to a significantly enhanced π-conjugated system of P2 as a result of its relative backbone coplanarity enabled by structural regioregularity.

The electrochemical properties of the polymers were investigated by cyclic voltammetry (Fig. 1d). The voltammograms was calibrated using the ferrocene/ferrocenium (Fc/Fc⁺) redox couple (energy level assumed to be −4.8 eV relative to vacuum)14, and the reduction potential was estimated from the onset of reduction. The LUMO energy levels were calculated according to the equation LUMO = (−Ered(onset) + E1/2(Fc/Fc+) + 4.8) eV15 = (−Ered(onset) + 4.36) eV, where the half-wave potential of Fe/Fc⁺(E1/2(Fc/Fc⁺)) was found to be 0.44 V relative to the Ag/AgCl reference electrode. Both polymer displayed similar LUMO energy levels of about −3.90 eV. Their HOMO energy

![Fig. 1 UV-vis absorption spectra (a,b), thin-film absorptivity (c), and cyclic voltammogram (d) of P1 and P2.](image1)

![Fig. 2 Thickness-adjusted X-ray diffraction patterns of thin films of P1 and P2 on silicon wafer substrates.](image2)
levels as calculated from their LUMO energy levels and optical band gaps were about ~5.64 and ~5.61 eV for P1 and P2 respectively. The HOMO and LUMO levels of these polymer acceptors (Table S2) would match well with those of widely-used donor polymer PTB7-Th (Fig. S2), leading to favorable energetic offset and driving forces sufficient for charge transfer.

As molecular ordering and surface morphological properties of active layer have decisive influence over photovoltaic properties, we accordingly engaged X-ray diffraction (XRD) and atomic force microscopic (AFM) measurements to gain insights into the bulk crystalline nature and surface morphology of P1 and P2 in their thin film states. Fig. 2 shows the thickness-adjusted XRD diffraction patterns of thin films of P1 and P2 spin cast from their solutions in o-dichlorobenzene (o-DCB). Both P1 and P2 displayed diffraction peaks arising from lamellar interlayer and π-π stacking orderings in their thin-film XRD diffraction patterns. It was noteworthy that the second-order (200) diffraction peak was also visible in the diffraction pattern of P2. The diffraction signals of P2, particularly (100) interlayer ordering, were significantly more intense than those of P1. In addition, the second-order (200) diffraction peak (2θ = 8.2°) was also visible in the diffraction pattern of P2. These results strongly support a higher degree of molecular ordering in the thin film of P2. The latter exhibited lamellar interlayer (100) peak at 2θ = 4.1° and π-π stacking (010) peak at 2θ = 23.0°, corresponding to d-spacing of 21.5Å and 3.86Å, respectively. On the other hand, the interlayer (100) and π-π stacking (010) peaks of P1 were at 2θ = 3.9° and 2θ = 21.0°, corresponding to respective d-spacing of 22.6 Å and 4.22 Å. The observed much closer π-π stacking distance of P2 was also a strong manifestation of substantially higher molecular ordering of P2 in the solid state. Stronger π-π stacking should be conducive to charge transport leading to enhanced photovoltaic properties.

Fig. 3 shows the AFM topographic images of composite films of P1 and P2 with PTB7-Th (acceptor:PTB7-Th composition ratio of 1.0:1.5 by weight) processed with and without DIO processing additive. We observed that the surface morphologies of P1:PTB7-Th films did not show any noticeable changes when fabricated from o-DCB solutions with or without DIO processing additive (Fig. 3a and 3b). In sharp contrast, visibly observable morphological changes occurred when the P2:PTB7-Th films were fabricated in the presence of 1 vol % of DIO additive. In the absence of DIO additive, the P2:PTB7-Th film still displayed a somewhat rougher surface morphology than those of P1:PTB7-Th films, with the root-mean-square (RMS) roughness of 1.1 nm (Fig. 3c). With 1 vol % of DIO additive, the resulting P2:PTB7-Th film exhibited substantially rougher surface morphology with the RMS roughness of 3.4 nm (Fig. 3d). Distinctly discernable nanofibrillar network structure could be clearly observed in this P2:PTB7-Th film. This interconnected nanofibrillar network structure would be beneficial to charge transport, and thus enhanced photovoltaic performance.

The bulk-heterojunction photovoltaic properties of P1 and P2 as acceptor polymers with donor polymer, PTB7-Th, for all-OSC devices were evaluated using an OSC device configuration of ITO/PEDOT:PSS/P1 or P2:PTB7-Th:LiF/Al under 100 mW cm⁻² AM 1.5 G illumination. The composition of the active layer (P1 or P2:PTB7-Th) was adjusted from 1:2 to 2:1 by weight, and 1~5 vol % of DIO was used as a processing additive to optimize photovoltaic performance. Optimization conditions are summarized Fig. S3 and S4 in ESI†, and the optimized photovoltaic performance properties are summarized in Fig. 4 and Table 1.

As can be noted, the optimized P1:PTB7-Th device (1:1.5, w/w; 1 vol % DIO) gave a PCE of 1.30% with a Voc of 0.78 V, a short-circuit current density (Jsc) of 4.80 mA cm⁻² and a fill factor (FF) of 0.34. On the other hand, the corresponding P2:PTB7-Th (1:1.5, w/w; 1 vol % DIO) afforded a significantly

![AFM height images of polymer acceptor:polymer donor films fabricated from o-DCB solutions: P1:PTB7-Th films fabricated without DIO (a) and with DIO (b); P2:PTB7-Th films fabricated without DIO (c) and with DIO (d).](image_url)

**Table 1.** Performance characteristics of all-PSCs with active layers of P1: PTB7-Th and P2:PTB7-Th (1:1.5, w/w; with 1 vol % DIO) (under Standard Solar Illumination Conditions)

<table>
<thead>
<tr>
<th>Polymer acceptor</th>
<th>Voc (V)</th>
<th>Jsc (mA/cm²)</th>
<th>FF (%)</th>
<th>PCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.78</td>
<td>4.80</td>
<td>34</td>
<td>1.30 (1.11)</td>
</tr>
<tr>
<td>P2</td>
<td>0.80</td>
<td>14.3</td>
<td>44</td>
<td>5.20 (5.13)</td>
</tr>
</tbody>
</table>

*Average PCEs given in parentheses.
much higher PCE of 5.20% with a $V_{oc}$ of 0.80 V, a short-circuit current density ($J_{sc}$) of 14.3 mA cm$^{-2}$ and a fill factor (FF) of 0.44. The P2 devices also exhibited much higher $J_{sc}$ than those of P1, in strong agreement their much higher external quantum efficiency (EQE) values (Fig. 4b).

The higher short-circuit current density of P2 devices is primarily linked to its higher electron mobility than that of P1 by virtue of its structural regioregularity. The charge carrier mobilities of P1:PTB7-Th and P2:PTB7-Th active layers were evaluated by space-charge-limited current (SCLC) method using electron-only and hole-only devices (Fig. 5 and Table S3). The electron mobility ($\mu_e$) and hole mobility ($\mu_h$) of P1:PTB7-Th layer were estimated to be $1.3\times10^{-3}$ cm$^2$V$^{-1}$s$^{-1}$ and $7.3\times10^{-5}$ cm$^2$V$^{-1}$s$^{-1}$, respectively while those of P2:PTB7-Th layer, respectively $2.1\times10^{-3}$ cm$^2$V$^{-1}$s$^{-1}$ and $1.6\times10^{-4}$ cm$^2$V$^{-1}$s$^{-1}$. The fact that P2:PTB7-Th layer had a higher electron mobility, which was comparable in magnitude to its hole mobility (Table S3), had clearly contributed to the overall much better performance of P2 as a polymer acceptor in all OSCs.

Two new difluorobenzene-naphthalene diimide polymer acceptors, one random and one regioregular structurally, were developed to study the structural effects on their electronic, morphological, electrical and photovoltaic properties as polymer acceptors in all-PSC devices. Being structurally regioregular, P2 presumably possessing significantly higher efficacy in molecular self-assembly than its random counterpart, P1, leading to formation of extensively interconnected nanofibrillar network structure in thin films processed with suitable amount of DIO additive. This was supported by long-wavelength spectral absorption and substantially stronger absorption coefficients as well as higher crystallinity reflected in its XRD properties. As a result, P2 exhibited much higher electron mobility and a more balanced electron and hole mobility in its composite film with polymer donor, PTB7-Th. This explains for the significantly enhanced $J_{sc}$ and photovoltaic performance than its random counterpart, P1, when used as a polymer acceptor with PTB7-Th donor in All-PSC devices. The P2:PTB7-Th device afforded a respectively high PCE over 5% for all-PSC devices. We believe that proper structural modification of polymer acceptor with appositely designed fluorinated moiety as well as processing optimization would lead to enhance active layer composition for all-PSCs.

**Acknowledgements**

This work was financially supported by a Strategic Development Fund (SDF13-0531-A02) of HK Baptist University, a Collaborative Research Fund (C5015-15GP) from HK Research Grants Council, Hung Hin Shiu Charitable Foundation, and Shenzhen Science and Technology Innovation Grant (KQTD2014063011033934).

**Notes and references**


Supporting Information for

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Ping Deng\textsuperscript{a,b,†}, Carr Hoi Yi Ho \textsuperscript{c,†}, Yong Lu\textsuperscript{b}, Ho-Wa Li\textsuperscript{d}, Sai-Wing Tsang\textsuperscript{d}, Shu Kong So\textsuperscript{e}, Beng S. Ong\textsuperscript{b,*}

\textsuperscript{a}College of Materials Science and Engineering, Fuzhou University, Fuzhou, China.

\textsuperscript{b}Research Centre of Excellence, Institute of Creativity and Department of Chemistry, Hong Kong Baptist University, Hong Kong SAR, China.

\textsuperscript{c}Department of Physics and Institute of Advanced Materials, Hong Kong Baptist University, Kowloon, Hong Kong SAR, China.

\textsuperscript{d}Department of Physics and Materials Science, City University of Hong Kong, Kowloon Tong, Hong Kong SAR, China.

(†These two authors contributed equally to this work)

\* Corresponding author. Tel.: +852 6221 4519; fax: +852 3411 7348.

E-mail address: bong@hkbu.edu.hk (B.S. Ong)
1. Experimental section

Materials and instruments
All chemicals and reagents were purchased from Aldrich and used without further purification. (2,5-difluoro-1,4-phenylene)bis(thiophene-5,2-diyl)bis(trimethyl-stannane)\(^{[1]}\) and 4,9-dibromo-2,7-bis(2-octyldodecyl)benzo[lnn][3,8]phenanthroline-1,3,6,8-(2H,7H)-tetrone\(^{[2]}\) were prepared according to reported procedures. All the reactions were conducted under nitrogen atmosphere.

Nuclear magnetic resonance (NMR) spectra were measured on a Bruker Ultrashield 400 Plus NMR spectrometer. Thermogravimetric analyses (TGA) were recorded on a TA instrument Q5000IR at a heating rate of 20 °C min\(^{-1}\) under nitrogen atmosphere. Gel permeation chromatography (GPC) were conducted on a ShimadzuSIL-20A liquid chromatography instrument using 1,2,4-trichlorobenzene as eluent at 160 °C with polystyrene as standards. UV-vis spectra were recorded on a Perkin Elmer Lambda 20 UV-vis spectrophotometer. Cyclic voltammetry (CV) measurements were carried out on a CHI 600 electrochemical analyzer with a three-electrode cell in a deoxygenated anhydrous acetonitrile solution of tetra-n-butylammonium-hexafluorophosphate (0.1 M) under nitrogen atmosphere. A platinum disk electrode, platinum wire, and Ag/AgCl electrode were used as a working electrode, a counter electrode, and a reference electrode, respectively, with the polymer thin film for evaluation coated on the surface of platinum disk electrode. The CV curves were calibrated using ferrocene/ferrocenium (Fc/Fc\(^{+}\)) redox couple as an external standard, which was measured under the same condition before and after the measurement of samples.

Polymer Acceptor Synthesis

Structurally Random Polymer Acceptor, \(P1\). A mixture of 2,5-bis(trimethylstannyl)thiophene (0.123 g, 0.3000 mmol), 1,4-dibromo-2,5-difluorobenzene (0.041 g, 0.1500 mmol), 4,9-dibromo-2,7-bis(2-octyldodecyl)benzo[lnn][3,8]phenanthroline-1,3,6,8-(2H,7H)-tetrone (0.148 g, 0.1500 mmol), Pd\(_2\)(dba)\(_3\) (5.5 mg, 0.0060 mmol), and P(o-tolyl)\(_3\) (7.3 mg, 0.0120...
mmol) in anhydrous toluene (10 mL) in a Schlenk tube was subjected to three cycles of evacuation and admission of nitrogen and subsequently stirred at 90 °C for 20 h. After polymerization, the reaction mixture was allowed to cool to room temperature and poured into stirring methanol to precipitate the polymer product. The precipitate was collected by filtration and was further purified by sequential Soxhlet extractions with methanol, acetone, hexane and chloroform each for 24 h. The residue after Soxhlet extractions was then extracted with chlorobenzene. The combined chlorobenzene extracts were concentrated and added dropwise to methanol with vigorous stirring to precipitate the polymer product as a purple solid (134 mg, 81% yield). GPC analysis (160 °C, TCB): $M_n = 22.3$ kg/mol, PDI = 4.57; $T_d$ (5% loss) = 440 °C. The polymer could not be successfully characterized by NMR spectroscopy in common deuterated solvent even at high temperatures due to its limited solubility in common deuterated solvents.

*Structurally Regioregular Polymer Acceptor, P2.* P2 was prepared from a mixture of \(((2,5\text{-difluoro-1,4-phenylene})\text{bis(thiophene-5,2-diyl)})\text{bis(trimethylstannane)} \ (0.091 \text{ g, 0.1500 mmol})\), 4,9-dibromo-2,7-bis(2-octyldodecyl)benzo[lmn][3,8]phenanthroline-1,3,6,8(2H,7H)-tetrone (0.148 g, 0.1500 mmol), Pd$_2$(dba)$_3$ (5.5 mg, 0.0060 mmol), and P(o-tolyl)$_3$ (7.3 mg, 0.0120 mmol) in anhydrous toluene (10 mL) in a Schlenk tube and isolated in accordance with the procedure for P1 as before. The final purified polymer product was a purple solid (149 mg; 90% yield). GPC analysis (160 °C, TCB): $M_n = 44.8$ kg/mol, PDI = 6.38. $T_d$ (5% loss) = 480 °C. The polymer could not be successfully characterized by NMR spectroscopy in common deuterated solvent even at high temperatures due to its limited solubility in common deuterated solvents.

2. All-PSC Device Fabrication and Characterization

We used an all-PSC device structure of ITO/PEDOT:PSS/Polymer acceptor:polymer donor/LiF/Al. Patterned ITO glass substrate was firstly cleaned by deconex for 10 min at 120°C, and then cleaned with deionized water and acetone in an ultrasonic bath,
followed by UV-ozone treatment. PEDOT:PSS was spin coated on the UV-ozone-treated substrates as anode buffer layer followed by annealing at 140°C for 10 min in air, thus forming a 30 nm film. An active layer solution of P1 or P2 with PTB7-Th at appropriate stoichiometry with 1 vol% DIO in o-DCB was prepared at a solid concentration of 12 mg mL⁻¹. The solution was stirred at 80°C overnight before spin coated onto PEDOT:PSS-coated substrate in a glove box to form a ~100 nm active layer. The resulting active layer was annealed at 90°C for 30 minutes before LiF (1 nm) and Al (130 nm) were deposited on its surface under high vacuum thermal evaporation. The experimental all-PSC devices were characterized under 100 mW cm⁻² AM 1.5 G illumination conditions.

3. Electron and Hole Mobility Measurement by J-V measurements

The structure of the devices for mobility measurements was similar to the all-PSC devices. For the electron-only devices, the PEDOT:PSS layer is replaced with a 50 nm aluminum film which served as a hole blocking layer. For the hole-only devices, spiro-TPD:CuPc/Au was used as the top electrode. 10-nm Spiro-TPD:CuPc, prepared by thermal co-evaporation under high vacuum, was used as an electron blocking and trapping layer. A 130-nm thick gold layer was subsequently evaporated onto the Spiro-TPD:CuPc surface. After fabrication, the devices were put in an Oxford cryostat with a pressure of less than 20 mTorr for measurement.
4. Figures in ESI†

**Figure S1.** TGA plots of polymers at a heating rate of 10 °C min⁻¹ under N₂ atmosphere.

**Figure S2.** Chemical structures (a) and energy levels (b) of polymers PTB7-Th, P1 and P2
Figure S3. Current density-voltage curves and data of all-PSC devices with different P1:PTB7-Th weight ratios in the active layers (a) and devices of P1:PTB7-Th with different DIO loadings (b).
Figure S4. Current density-voltage curves and data of all-PSC devices with different P2:PTB7-Th weight ratios in the active layers (a) and devices of P2:PTB7-Th with different DIO loadings (b).
5. *Tables in ESI*†

**Table S1.** Molecular weight and thermal properties of polymer acceptors, P1 and P2

<table>
<thead>
<tr>
<th>Polymer</th>
<th>$M_n$ a[kDa]</th>
<th>$M_w$ a[kDa]</th>
<th>PDI</th>
<th>$T_d$ b[°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>22.3</td>
<td>285.9</td>
<td>4.57</td>
<td>440</td>
</tr>
<tr>
<td>P2</td>
<td>44.8</td>
<td>101.9</td>
<td>6.38</td>
<td>480</td>
</tr>
</tbody>
</table>

a Determined by GPC at 160 °C using 1,2,4-trichlorobenzene as an eluent against polystyrene standards. b 5% weight loss temperature measured by TGA under nitrogen atmosphere.

**Table S2.** Optical and electrochemical properties of polymers P1 and P2

<table>
<thead>
<tr>
<th>Polymer</th>
<th>$\lambda_{\text{max}}$ a (nm)</th>
<th>$\lambda_{\text{max}}$ b(e$^b$) (nm)/(cm)</th>
<th>$E_g$ optc (eV)</th>
<th>$E_{\text{ox}}$ onset/LUMO (V/eV)</th>
<th>HOMO d (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>388, 570</td>
<td>388 (5.30×10$^4$), 600 (4.19×10$^4$)</td>
<td>1.74</td>
<td>−0.44/−3.90</td>
<td>−5.64</td>
</tr>
<tr>
<td>P2</td>
<td>370, 585</td>
<td>388 (1.06×10$^5$), 620 (5.67×10$^4$)</td>
<td>1.71</td>
<td>−0.44/−3.90</td>
<td>−5.61</td>
</tr>
</tbody>
</table>

a Measured in chlorobenzene solution. b Measured as thin film. c Optical band gap, d Calculated from the LUMO energy level and optical band gap.

**Table S3.** The hole and electron mobilities of active blend layer (P1:PTB7-Th or P2:PTB7-Th blend (1:1.5, w(acceptor)/w(donor)) with 1 vol % DIO Additive) investigated by the space charge limited current (SCLC) method

<table>
<thead>
<tr>
<th>Active blend layer</th>
<th>$\mu_h$(cm$^2$V$^{-1}$s$^{-1}$)</th>
<th>$\mu_e$(cm$^2$V$^{-1}$s$^{-1}$)</th>
<th>$\mu_e$/$\mu_h$</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1:PTB7-Th</td>
<td>$1.3\times10^{-6}$</td>
<td>$7.3 \times 10^{-5}$</td>
<td>0.018</td>
</tr>
<tr>
<td>P2:PTB7-Th</td>
<td>$2.1\times10^{-4}$</td>
<td>$1.6 \times 10^{-4}$</td>
<td>1.313</td>
</tr>
</tbody>
</table>
Reference


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