Supplementary Information

Non-Fused Core Linked Star-Shaped Oligomer Acceptors for over 19% Efficiency and Stable Binary Organic Solar Cells

Cheng Sun,† Jianxiao Wang,† Fuzhen Bi, Huanxiang Jiang, Chunming Yang, Yonghai Li,* Junhao Chu, and Xichang Bao*

Dr. C. Sun, Dr. J. Wang, Dr. F. Bi, Dr. Y. Li, Prof. J. Chu, Prof. X. Bao Key Laboratory of Photoelectric Conversion and Utilization of Solar Energy, Qingdao Institute of Bioenergy and Bioprocess Technology, Chinese Academy of Sciences Qingdao 266101, China Email: liyh@qibebt.ac.cn; baoxc@qibebt.ac.cn

Dr. F. Bi, Dr. Y. Li, Prof. J. Chu, Prof. X. Bao Laboratory of Solar Energy, Shandong Energy Institute Qingdao 266101, China

Dr. F. Bi, Dr. Y. Li, Prof. J. Chu, Prof. X. Bao Qingdao New Energy Shandong Laboratory Qingdao 266101, China

Dr. H. Jiang College of Textiles and Clothing, State Key Laboratory of Bio-fibers and Eco-textiles, Qingdao University Qingdao 266071, China

C. Yang Shanghai Synchrotron Radiation Facility Shanghai Advanced Research Institute Chinese Academy of Sciences Shanghai 201204, China

[†] These authors contributed equally to this work.

Experimental Procedures

Materials and Characterization Techniques

Donor material PM6 were purchased from Solarmer Materials Inc. Other reagents were purchased from Alfa Aesar, Sigma-Aldrich, et al., which were utilized directly unless stated otherwise.

¹H NMR and ¹³C NMR spectra were recorded on Bruker AVANCE III 600 MHz spectrometer at 298 K. The absorption spectra were recorded using a Hitachi U-4100 UV-Vis scanning spectrophotometer. Cyclic voltammetry (CV) measurements were performed on a CHI660D electrochemical workstation, equipped with a three-electrode cell consisting of a platinum working electrode, a saturated calomel electrode (SCE) as reference electrode and a platinum wire counter electrode. CV measurements were carried out in anhydrous acetonitrile containing 0.1 M *n*-Bu₄NPF₆ as a supporting electrolyte under an argon atmosphere at a scan rate of 100 mV s⁻¹ assuming that the absolute energy level of Fc/Fc⁺ was -4.80 eV. Thin films of three acceptors were deposited from CHCl₃ solutions for the measurements of UV-vis absorption spectra. The theoretical simulations of molecular conformations were based on Gaussian at a B3LYP/6-31G(d,p) set. The thickness of films was measured using a Veeco Dektak 150 profilometer. In-situ absorptions were carried out from the in-situ dynamic spectrometer DU-300, with chloroform as the solvents. Time-of-flight mass was measured based on spectrometer Bruker Autoflex III.

In-situ absorptions were carried out from the dynamic spectrometer DU-300, with chloroform as the working solvents. Femtosecond transient spectroscopy (fs-TA) spectra were measured Excipolar Spinon Optoelectronics with a pump wavelength of 780 nm, pump energy of 200 nJ, and time delay ranges of 10 ps-7.6 ns.

Grazing incidence wide-angle X-ray scattering (GIWAXS) patterns were acquired from Shanghai Synchrotron Radiation Facility at the beam BL6B1. Differential scanning calorimetry (DSC) measurements were performed by NETZSCH DSC 200F3 at a heating rate of 10 °C min⁻¹ under N_2 atmosphere.

Transmission electron microscopy (TEM) images were obtained by using a HITACHI H-7650 electron microscope with an acceleration voltage of 100kV. Atomic force microscopy (AFM) images were obtained using Agilent 5400 scanning probe microscope in tapping mode with MikroMasch NSC-15 AFM tips. Kelvin probe force microscopy (KPFM) images were also obtained from Agilent 5400 scanning probe microscope.

The geometry optimization of the single 3BY/3QY and the PM6/3BY and PM6/3QY composite were comprehensively optimized by employing the B3LYP function with 6-31g(d,p) basis sets. The counterpoise correction (CP) method was used to account for the basis set superposition error (BSSE) when calculating the intermolecular interaction energy. The molecular electrostatic potential (ESP) and independent gradient model based on Hirshfeld partition (IGMH) analysis were implemented using Multiwfn 3.8 ^[1-2] and outputs are visualized using VMD 1.9.3. ^[3]

[1] Tian Lu, Feiwu Chen, Multiwfn: A Multifunctional Wavefunction Analyzer, J. Comput. Chem., 2012, **33**, 580-592.

[2] Tian Lu, Qinxue Chen, Independent gradient model based on Hirshfeld partition: A new method for visual study of interactions in chemical systems, *J. Comput. Chem.*, 2022, **43**, 539-555.

[3] W. Humphrey, A. Dalke, K. Schulten. J. Mol. Graphics, 1996, 14, 33-38.

Device Fabrication and Evaluations

All the solar cells were fabricated with a conventional device structure of ITO/PEDOT:PSS/active layer/PDINN/Ag. The patterned ITO glass (sheet resistance = 15Ω / square) was pre-cleaned in an ultrasonic bath of acetone and isopropyl alcohol and treated in an ultraviolet-ozone chamber (PREEN II-862) for 6 min. Then a thin layer (about 30 nm) of PEDOT:PSS was spin-coated onto the ITO glass at 4000 rpm and baked at 150 °C for 15 min. Solutions of active layers in chloroform (7.5 mg/mL for PM6) were stirred for 2.0 hrs at 50 °C before spin-coating on the PEDOT:PSS layer to form the active layer about 100±20 nm. The thickness of the active layer was measured using a Veeco Dektak 150 profilometer. Then PDINN (in CH₃OH, 1mg/mL) was spin-coating at 3000 rpm to form the electron transfer layer. Finally, Ag (60 nm) metal electrode was thermal evaporated under about 5×10^{-4} Pa and the device area was 0.1 cm² defined by shadow mask.

The current density–voltage (J-V) characteristics were recorded with a Keithley 2400 source measurement unit under simulated 100 mW cm⁻² irradiation from a Newport solar simulator.

The external quantum efficiencies (EQEs) were analyzed using a certified Newport incident photon conversion efficiency (IPCE) measurement system. The hole mobility and electron mobility were measured by space-charge-limited current (SCLC) method with a device configuration of ITO/PEDOT:PSS/active layer/MoO₃/Al and ITO/ZnO/active layer/PDINO/Al structure, respectively. The SCLC is described by the Mott–Gurney law:

$$J = 9\varepsilon\mu V^2/(8L^3)$$

where ε represents the dielectric constant of the metal, and μ is the carrier mobility, V is the voltage drop across the device and L is the thickness of the active layer.

The thermal stability was performed under 80 °C in a nitrogen filled glove box, which possesses oxygen content below 0.1 ppm, and water content below 0.1 ppm. The device was placed under dark, and the light was only turned on when measuring the J-V plots. Every data point was averaged from at least five independent devices.

Materials Synthesis

Synthesis of 3BT-Sn



To solution of 1,3,5-tri(thiophen-2-yl)benzene (300 mg, 0.92 mmol) in dry THF (20 mL), n-Butyllithium in THF(1M) (3.3 mL, 3.3 mmol) was added dropwise at -78 °C under nitrogen atmosphere. The mixture was stirred for 3 hours at -78 °C, and the solution of trimethyltin chloride solution (1 M) (4 mL, 4 mmol) was added dropwise; the low-temperature bath was removed, and the reaction was stirred at room temperature for 12 h. Then the mixture was quenched with water and extracted with diethyl ether. The organic phase was dried over anhydrous MgSO4 and concentrated. Wash the crude product by methanol to obtain 1,3,5-tris(5-(trimethylstannyl) thiophen-2-yl) benzene. (Yield: 680 mg, 91%). ¹H NMR (600 MHz, Chloroform-d) δ 7.74 (s, 3H), 7.51 (d, J = 3.3 Hz, 3H), 7.20 (d, J = 3.3 Hz, 3H), 0.42 (s, 27H). *Synthesis of 3QT-Sn*



To solution of 2,4,6-tri(thiophen-2-yl)-1,3,5-triazine (300 mg, 0.92 mmol) in dry THF (20 mL), n-Butyllithium in THF(1M) (3.3 mL, 3.3 mmol) was added dropwise at -78 °C under nitrogen atmosphere. The mixture was stirred for 3 hours at -78 °C, and the solution of trimethyltin chloride solution (1 M) (4 mL, 4 mmol) was added dropwise; the low-temperature bath was removed, and the reaction was stirred at room temperature for 12 h. Then the mixture was quenched with water and extracted with diethyl ether. The organic phase was dried over anhydrous MgSO4 and concentrated. Wash the crude product by methanol to obtain 1,3,5-tris(5-(trimethylstannyl) thiophen-2-yl) benzene. (Yield: 695 mg, 93%).¹H NMR (600 MHz, Chloroform-d) δ 8.34 (d, J = 3.4 Hz, 3H), 7.29 (d, J = 3.5 Hz, 3H), 0.44 (s, 27H).

Synthesis of 3BY



Y-2FBr (300 mg, 0.161 mmol), 3BT-Sn (52 mg, 0.065mmol), and Pd(pph₃)₄(3 mg, 0.0026 mmol) were combined in a 100 mL two-necked flask. Anhydrous toluene (30 mL) was added under the argon atmosphere. The mixture was reacted for 12 h at 110 °C. After removing residual solvents at low pressure (< 300 mbar) by a rotary evaporator, the product was purified by silica-gel column chromatography using chloroform as eluent to give 3BY as black solid (266 mg, 73%). ¹H NMR (600 MHz, Chloroform-d) δ 9.22 (s, 3H), 9.02 – 8.73 (m, 6H), 8.62 (dd, J = 9.4, 6.4 Hz, 3H), 7.94 – 7.33 (m, 18H), 4.97 (d, J = 51.8 Hz, 12H), 3.25 (s, 6H), 2.48 –

1.94 (m, 18H), 1.50 – 0.95 (m, 288H), 0.94 – 0.68 (m, 72H). MS (MALDI-TOF) m/z: $[M + H]^+$ calculated for $C_{342}H_{426}F_6N_{24}O_6S_{18}$, 5654.86, found: 5654.87.





Y-2FBr (300 mg, 0.161 mmol), 3QT-Sn (54 mg, 0.065mmol), and Pd(pph₃)₄ (3 mg, 0.0026 mmol) were combined in a 100 mL two-necked flask. Anhydrous toluene (30 mL) was added under the argon atmosphere. The mixture was reacted for 12 h at 110 °C. After removing residual solvents at low pressure (< 300 mbar) by a rotary evaporator, the product was purified by silica-gel column chromatography using chloroform as eluent to give 3QY as black solid (283 mg, 76%). ¹H NMR (600 MHz, Chloroform-d) δ 9.25 – 9.03 (m, 3H), 9.03 – 8.62 (m, 6H), 8.60 – 8.44 (m, 3H), 8.03 – 7.86 (m, 3H), 7.81 – 7.30 (m, 9H), 5.20 – 4.73 (m, 12H), 3.33 – 1.80 (m, 24H), 1.49 – 0.98 (m, 288H), 0.92 – 0.70 (m, 72H). MS (MALDI-TOF) m/z: [M + H]⁺ calculated for C₃₃₉H₄₂₃F₆N₂₇O₆S₁₈, 5657.85, found: 5657.85.

Supplementary Figures



Fig. S1 The optimized molecular configurations of 3BY and 3QY molecules.



Fig. S2 The distributions of electron could density and HOMO/LUMO energy levels based on the optimized molecular configurations of 3BY and 3QY molecules.



Fig. S3 The CV plots of 3BY and 3QY deposited on glassy carbon electrodes in 0.1 M $Bu_4NPF_6-CH_3CN$ at a scan rate of 100 mV s⁻¹.



Fig. S4 The PL spectra of 3BY, 3QY neat films and the blend films with excitation wavelength of 700 nm.



Fig. S5 The line-cut profiles of GIWAXS studies of 3BY and 3QY neat films.



Fig. S6 The SCLC curves of 3BY and 3QY based electron-only devices.



Fig. S7 The line-cut profiles of in-situ absorptions of neat 3BY and 3QY casted from chloroform solutions.

(R) Б 检验检测 报告 TEST REPORT No: 2024DMCS20115 ∎∦ 产品名称 有机太阳能电池 SAMPLE Organic Solar cells 4740 规格型号 有机太阳能电池 Organic Solar cells MODEL/TYPE 中国科学院青岛生物能源与过程研究所 Qingdao Institute of Bioenergy and 委托单位 Bioprocess Technology Chinese APPLICANT Matenv of F 研制有检验检测入位调算院 Wuxi Institute of Inspection, Testing and Certification 国家太阳能光伏产品质量检验检测中心 National Center of Inspection on Solar Photovoltaic Products Quality



	No:2024DMCS20115		共 5 页 第 2 页 检验检测结果 Test Results					
						of 5		
	序号 Clause	检验项目 Test item(s)	单位 Unit	技术要求 Technical requirements	结果 Results	单项评价 Verdict Pass/Fail		
	1	电流-电压特性的测量 (1#) Current-voltage characteristic measurement (1#)	_	在标准试验条件下(样品温度: 25℃,辐照度:1000W/m ² ,标准 太阳光谱辐照分布符合 IEC 60904-3 规定),测量样品随负荷 变化的电流-电压特性。 At STC (module temperature: 25℃, irradiance: 1000W/m ² , standard solar spectral irradiance distribution corresponds to IEC60904-3), measure the current-voltage characteristics of the cell with the variation of load.	_	- - r		
	1.1	开路电压 Voc Open-circuit voltage, Voc	v	_	0.9552	- AM		
	1.2	短路电流 Isc Short-circuit current, Isc	mA	_	2.585	- 🛉		
	1.3	最大功率 Pmax Maximum-power, Pmax	mW	_	1.867			
	1.4	最大功率点电压 Vmp Maximum-power voltage, Vmp	v	_	0.8079	-		
	1.5	最大功率点电流 Imp Maximum-power current, Imp	mA	_	2.311	_		
	1.6	填充因子 FF,% Fill factor FF, %	_	_	75.62			
	1.7	转换效率 η, % Conversion efficiency η, %	_	Pmax η=×100% 1000W/m ² ×S S 为样品面积/Sample area	18.80	_		

备注: 扫描方向从-0.2V~1V, 步进 0.012V, 步数 101; 样品面积 S 为有效区域面积, S=9.933mm² Remark: Sweep direction: -0.2V~1V, steeping: 0.012V, sweep steps: 101;Sample area S is determined by sample effective area, S=9.933mm²

e v



Fig. S8 The certification report of PM6:3QY device by CPVT.



Fig. S9 The comparison of EQE profiles and blend absorption spectra.



Fig. S10 The chemical structures of G-Trimer-C6C8 and G-Trimer-C8C10.



Fig. S11 The absorption spectra of neat 3BY and 3QY thin films upon different annealing temperatures.



Fig. S12 (a) J_{SC} vs light intensity and (b) V_{OC} vs light intensity of PM6:3BY and PM6:3QY solar cells.



Fig. S13 TA spectra of PM6:3BY blend film with indicated decay times.



Fig. S14 TA spectra of PM6:3QY blend film with indicated decay times.



Fig. S15 2D patterns of fs-TA spectra of 3BY neat film in the range of 430–760 nm and 840–1400 nm with pump at 780 nm.



Fig. S16 2D patterns of fs-TA spectra of 3QY neat film in the range of 430–760 nm and 840–1400 nm with pump at 780 nm.



Fig. S17 TA spectra of 3BY neat film with indicated decay times.



Fig. S18 TA spectra of 3QY neat film with indicated decay times.



Fig. S19 The phase images of PM6:3BY and PM6:3QY blend films based on AFM measurements.



Fig. S20 The 2D pattern and line-cut profiles of PM6 neat film based on GIWAXS measurements.



Fig. S21 The resolved (100) diffraction peaks in IP plane of the two blend films.



Fig. S22 SCLC curves of PM6:3BY and PM6:3QY based on (a) hole-only and (b) electrononly devices.



Fig. S23 The line-cut profiles of in-situ absorptions of PM6:3BY and PM6:3QY blend films casted from chloroform solutions.



Fig. S24 The optimized interaction configurations and interaction energies between 3BT or 3QT and PM6 at different regions.



Fig. S25 The ESP map of PM6 dimer based on optimized molecular configuration.



Fig. S26 The optimized interaction configurations and IGMH isosurfaces of PM6-BDT:3BT and PM6-BDT:3QT.

Supplementary Tables

		1	()		1	-	- (
		Pea	k 1				Peak 2	
	q_z	$d_{\pi-\pi}$	FWHM	CCL	q_{z}	$d_{\pi-\pi}$	FWHM	CCL
	(nm ⁻¹)	(Å)	(nm ⁻¹)	(nm)	(nm ⁻¹)	(Å)	(nm ⁻¹)	(nm)
3BY	17.38	3.62	6.10	1.03	16.40	3.83	2.86	2.19
3QY	17.32	3.63	6.09	1.03	16.54	3.80	2.78	2.26

Table S1. The parameters of π - π stacking spacing ($d_{\pi-\pi}$) and crystal coherence lengths (CCLs) for each resolved peak based on the (010) diffraction peaks of 3BY and 3QY neat films.

Table S2. The hole mobility (μ_h) and electron mobility (μ_e) of 3BY and 3QY neat films and the two optimal blend films.

Film	$\mu_{\rm h} ({\rm cm2~V^{-1}~s^{-1}})$	$\mu_e ({\rm cm2~V^{-1}~s^{-1}})$	$\mu_{ m h}/\mu_{e}$
3BY	-	0.59×10^{-4}	-
3QY	-	0.83×10^{-4}	-
PM6:3BY	2.87×10^{-4}	1.95×10^{-4}	1.47
PM6:3QY	3.69×10^{-4}	2.55×10^{-4}	1.44

Table S3. Photovoltaic parameters of the PM6:3BY and PM6:3QY based OSCs at different conditions.

Active layer	Additive	$V_{\rm OC}$ (V)	$J_{\rm SC}$ (mA cm ⁻²)	FF (%)	PCE (%)
PM6:3BY	As cast	0.971	23.11	75.62	16.97
	0.5% CN	0.969	23.43	77.15	17.52
	0.75% CN	0.969	23.92	76.59	17.75
	1% CN	0.966	23.14	75.52	16.88
PM6:3QY	As cast	0.954	25.46	75.45	18.32
	0.5% CN	0.954	25.80	76.00	18.71
	0.75% CN	0.951	26.36	76.86	19.27
	1% CN	0.942	26.27	76.76	19.01

Active layer	$V_{\rm OC}$ (V)	$J_{\rm SC} ({\rm mA \ cm^{-2}})$	FF (%)	PCE (%)	Ref.
PM6:2BTP-2F-T	0.911	25.50	78.28	18.19	1
PM6:DYT	0.940	24.08	76	17.30	2
PM6:DYTVT	0.95	24.62	74	17.68	2
PM6:DYV	0.930	25.02	78	18.60	2
PM6:DYBO	0.968	24.62	75.8	18.082	3
PM6:EV-i	0.897	26.60	76.56	18.27	4
PM6:TYT	0.964	25.07	75	18.15	5
PM6:DIBP3F-Se	0.917	25.92	76.1	18.09	6
D18:DYA-IO	0.948	24.29	76	17.54	7
D18:DYA-I	0.938	25.67	78	18.83	7
PM6 : Tri-Y6-OD	0.916	25.30	77.8	18.03	8
PM6:DYV	0.910	25.972	76.215	18.013	9
PM6:TDY-α	0.864	26.9	78.0	18.1	10
PM6:TDY-β	0.849	26.1	76.6	17.0	10
PM6: Dimer-2CF	0.900	26.39	80.03	19.02	11
PM6:DY-P2EH	0.905	24.03	78.58	17.09	12
PBQx-H-TF:dBTIC-yV-BO	0.91	24.52	76.58	17.14	13
D18:2Y-wing	0.850	27.66	75.4	17.73	14
PM6:Tet-1	0.919	24.53	76.8	17.32	15
PM6:T0	0.923	24.06	77.1	17.12	16
PM6:CH8-6	0.891	26.23	77.8	18.2	17
D18:DYF-E	0.938	24.23	75	17.02	18
PM6:Tri-Qx	0.935	25.28	77.5	18.33	19
PM6:TQT	0.944	25.78	76.1	18.52	19
PM6:DYSe-1	0.885	27.51	76.6	18.56	20
PM6:DYSe-2	0.884	27.45	75.2	18.22	20
PM6:Tri-V	0.909	26.13	77.8	18.48	21
PM6:Tri-BT	0.933	25.49	74.9	17.81	22
PM6:GT-l	0.960	25.61	77.42	19.03	23
D18:DYF-TF	0.939	25.82	75.30	18.26	24
PM6: BDY-α	0.869	26.09	76.38	17.38	25
PM6: BDY-β	0.881	26.49	77.67	18.12	25
DYBT-C4	0.96	24.03	77	18.26	26
PM6:DY2	0.87	26.60	76.85	17.85	27
PM6:DY3	0.87	26.20	76.21	17.33	27
PM6:CH8-1	0.923	24.89	74.2	17.05	28

Table S4. The comparison of photovoltaic parameters of high-performance OSCs (PCE≥17%) in previous literatures and this study based on oligomer acceptors.

PM6:CH8-4	0.894	26.5	75.5	17.58	29
PM6: G-Trimer-C6C8	0.899	25.32	79.34	18.07	30
PM6: G-Trimer-C8C10	0.911	25.40	79.49	18.39	30
PM6: G-Trimer-C8C10 ^a	0.896	26.75	79.30	19.01	30
D18:TYT-S	0.964	25.18	77	18.61	31
PM6:TBT	0.940	24.63	78.07	18.04	32
PM6:GTs	0.935	24.66	78.27	18.05	23
PM6:GT-s	0.968	23.98	75.75	17.58	23
PM6: BTY	0.864	27.06	78.01	18.24	25
PM6:3BY	0.969	23.92	76.59	17.75	This study
PM6:3QY	0.951	26.36	76.86	19.27	This study

^a 2PACZ as the hole transport layer.

Table S5. CCLs of PM6 and the acceptor in their blend films based on the resolved (100) diffraction peaks in IP plane.

Blend film	CCL_{PM6} (nm)	CCL _{acceptor} (nm)
PM6:3BY	10.47	7.66
PM6:3QY	11.42	7.95

Supplementary NMR spectra



¹H-NMR of 3QT-Sn in CDCl₃.



¹H-NMR of 3BY in CDCl₃.



¹H-NMR of 3QY in CDCl₃.

Supplementary MALDI-TOF spectra



MALDI-TOF-MS Result of 3B-Y.



MALDI-TOF-MS Result of 3Q-Y.

References:

- [S1] L. Zhang, Z. Zhang, D. Deng, H. Zhou, J. Zhang, Z. Wei, Adv. Sci. 2022, 9, 2202513.
- [S2] J.-W. Lee, C. Sun, C. Lee, Z. Tan, T. N.-L. Phan, H. Jeon, D. Jeong, S.-K. Kwon, Y.-H. Kim, B. J. Kim, ACS Energy Lett. 2023, 8, 1344-1353.
- [S3] C. Sun, J.-W. Lee, C. Lee, D. Lee, S. Cho, S.-K. Kwon, B. J. Kim, Y.-H. Kim, *Joule* 2023, 7, 416-430.
- [S4] H. Zhuo, X. Li, J. Zhang, S. Qin, J. Guo, R. Zhou, X. Jiang, X. Wu, Z. Chen, J. Li, Angew. Chem. Int. Ed. 2023, 62, e202303551.
- [S5] J.-W. Lee, C. Sun, T. N.-L. Phan, D. C. Lee, Z. Tan, H. Jeon, S. Cho, S.-K. Kwon, Y.-H. Kim, B. J. Kim, *Energy Environ. Sci.* 2023, 16, 3339-3349.
- [S6] J. Wu, Z. Ling, L. R. Franco, S. Y. Jeong, Z. Genene, J. Mena, S. Chen, C. Chen, C. M. Araujo, C. F. Marchiori, *Angew. Chem. Int. Ed.* 2023, *62*, e202302888.
- [S7] C. Sun, J. W. Lee, Z. Tan, T. N. L. Phan, D. Han, H. G. Lee, S. Lee, S. K. Kwon, B. J. Kim, Y. H. Kim, *Adv. Energy Mater.* 2023, *13*, 2301283.
- [S8] C. Zhang, J. Song, J. Xue, S. Wang, Z. Ge, Y. Man, W. Ma, Y. Sun, Angew. Chem. Int. Ed. 2023, 135, e202308595.
- [S9] H. Fu, M. Zhang, Y. Zhang, Q. Wang, Z. a. Xu, Q. Zhou, Z. Li, Y. Bai, Y. Li, Z. G. Zhang, Angew. Chem. Int. Ed. 2023, 62, e202306303.
- [S10] Y. Bai, Z. Zhang, Q. Zhou, H. Geng, Q. Chen, S. Kim, R. Zhang, C. Zhang, B. Chang, S. Li, *Nat. Commun.* 2023, 14, 2926.
- [S11] M. Lv, Q. Wang, J. Zhang, Y. Wang, Z. G. Zhang, T. Wang, H. Zhang, K. Lu, Z. Wei, D. Deng, Adv. Mater. 2024, 36, 2310046.
- [S12] M. Zhang, B. Chang, R. Zhang, S. Li, X. Liu, L. Zeng, Q. Chen, L. Wang, L. Yang, H. Wang, *Adv. Mater.* 2024, 36, 2308606.
- [S13] P. Tan, H. Chen, H. Wang, X. Lai, Y. Zhu, X. Shen, M. Pu, H. Lai, S. Zhang, W. Ma, Adv. Funct. Mater. 2024, 34, 2305608.
- [S14] F. Yi, M. Xiao, Y. Meng, H. Bai, W. Su, W. Gao, Z. F. Yao, G. Qi, Z. Liang, C. Jin, Angew. Chem. Int. Ed. Engl 2024, 63, e202319295.
- [S15] C. Zhang, J. Song, L. Ye, X. Li, M. H. Jee, H. Y. Woo, Y. Sun, Angew. Chem. Int. Ed. Engl 2024, 136, e202316295.
- [S16] Y. Li, L. Mei, Z. Ge, C. Liu, J. Song, Y. Man, J. Gao, J. Zhang, Z. Tang, X. K. Chen, Adv. Mater. 2024, 2403890.
- [S17] Z. Zhang, S. Yuan, T. Chen, J. Wang, B. Zhao, M. Li, Z. Yao, C. Li, X. Wan, G. Long, *Energy Environ. Sci.* 2024, 17, 5719-5729.
- [S18] S. Oh, D. Jeong, K. Bae, G. U. Kim, T. N. L. Phan, J. W. Lee, J. Park, D. Lee, S. Cho, B. J. Kim, *Adv. Funct. Mater.* 2024, 2406501.
- [S19] J. Liu, X. Duan, J. Song, C. Liu, J. Gao, M. H. Jee, Z. Tang, H. Y. Woo, Y. Sun, *Energy Environ. Sci.* 2024, 17, 3641-3650.
- [S20] Y. Bai, T. Chen, X. Ji, J. Wang, W. Zhao, S. Yuan, Y. Zhang, G. Long, Z. Zhang, X. Wan, Adv. Energy Mater., 2400938.
- [S21] J. Song, C. Zhang, C. Li, J. Qiao, J. Yu, J. Gao, X. Wang, X. Hao, Z. Tang, G. Lu, Angew. Chem. Int. Ed. Engl 2024, e202404297.
- [S22] J. Liu, X. Duan, J. Song, C. Liu, J. Gao, M. H. Jee, Z. Tang, H. Y. Woo, Y. Sun, *Energy Environ. Sci.* 2024, 17, 3641-3650.

- [S23] H. Zhuo, X. Li, S. Qin, J. Zhang, Y. Gong, Y. Wu, T. Zou, Z. Chen, K. Yin, M. Yuan, Adv. Funct. Mater. 2024, 2410092.
- [S24] X. Gu, Y. Wei, N. Yu, J. Qiao, Z. Han, Q. Lin, X. Han, J. Gao, C. Li, J. Zhang, CCS Chem 2023, 5, 2576-2588.
- [S25] B. Chang, Y. Zhang, C. Zhang, M. Zhang, Q. Wang, Z. a. Xu, Q. Chen, Y. Bai, H. Fu, S. Meng, Angew. Chem. Int. Ed. 2024, 136, e202400590.
- [S26] J.-W. Lee, C. Sun, S. Lee, D. J. Kim, E. S. Oh, T. N.-L. Phan, T. H.-Q. Nguyen, S. Seo, Z. Tan, M. J. Lee, *Nano Energy* 2024, 125, 109541.
- [S27] S. Li, R. Zhang, M. Zhang, J. Yao, Z. Peng, Q. Chen, C. Zhang, B. Chang, Y. Bai, H. Fu, Adv. Mater. 2023, 35, 2206563.
- [S28] H. Chen, Z. Zhang, P. Wang, Y. Zhang, K. Ma, Y. Lin, T. Duan, T. He, Z. Ma, G. Long, *Energy Environ. Sci.* 2023, 16, 1773-1782.
- [S29] H. Chen, B. Kan, P. Wang, W. Feng, L. Li, S. Zhang, T. Chen, Y. Yang, T. Duan, Z. Yao, Angew. Chem. Int. Ed. 2023, 62, e202307962.
- [S30] C. Wang, X. Ma, Y.-f. Shen, D. Deng, H. Zhang, T. Wang, J. Zhang, J. Li, R. Wang, L. Zhang, Joule 2023, 7, 2386-2401.
- [S31] J. W. Lee, C. Sun, J. Lee, D. J. Kim, W. J. Kang, S. Lee, D. Kim, J. Park, T. N. L. Phan, Z. Tan, Adv. Energy Mater. 2024, 14, 2303872.
- [S32] W. Liu, X. Xu, S. He, R. Sun, Q. Chen, J. Min, Z. Zhang, J. Yuan, Y. Li, Y. Zou, *Macromolecules* 2023, 56, 8623-8631.