Supporting Information

Highly Efficient and Stable Deep-blue OLEDs Based on Narrowband Emitters Featuring Orthogonal Spiro-configured Indolo[3,2,1-*de*]acridine Structure

Guoyun Meng, Dongdong Zhang, Jinbei Wei, Yuewei Zhang, Tianyu Huang, Ziyang Liu, Chen Yin, Xiangchen Hong, Xiang Wang, Xuan Zeng, Dezhi Yang, Dongge Ma, Guomeng Li, and Lian Duan

Table of Contents

- 1. Experimental Section
 - **1.1 General Information**
 - **1.2** Computational methods
 - **1.3 Measurement of absorption and emission characteristics**
 - **1.4 Electrochemical measurements**
 - 1.5 Calculation of rate constants of FET and DET
 - 1.6 Single crystal analysis
 - **1.7 Device fabrication and measurement of EL characteristics**

1.8 Synthesis

- 2. Supplementary figures and tables
- 3. References

1. Experimental Section

1.1 General Information. All commercially available reagents were used as received unless otherwise stated. All reactions were carried out using Schlenk techniques under a nitrogen atmosphere. 600 MHz ¹H-NMR and ¹³C-NMR spectra were measured by a JEOL JNM-ECS600 spectrometer at room temperature in deuterated dichloromethane and chloroform respectively with tetramethyl silane as the internal standard. MALDI-TOF-MS data was performed on a Shimadzu AXIMA Performance MALDI-TOF instrument in positive detection modes. Elemental analysis was obtained with a CE-440 Elemental Analyzer.

1.2 Computational methods. The calculations were performed with the Gaussian 09 package, using the density functional theory (DFT) and time-dependent density functional theory (TD-DFT) method with the B3LYP hybrid functional.^[1-3] The structures were optimized using DFT/single-crystal (S_0 state) or TD-DFT (S_1 and T_1 state) methods with a 6-31G(d) basis set. Franck-Condon analyses of the absorption/emission spectra were performed according to the literature ^[4] using the Gaussian 16 package.

1.3 Measurement of absorption and emission characteristics. The solution of 1×10^{-5} M were prepared with 100 mL volumetric flask for all the solution measurements. UV-vis absorption and PL spectra were measured using UV-2600 (Shimadzu) and FluoroMax-4P (Horiba) instruments at 77 and 298 K. The PLQYs were obtained with an absolute photoluminescence quantum yield measurement system Hamamatsu C9920-03G in an integrating sphere. The solution sample was bubbled with nitrogen for 10 minutes before measurement while the films were measured in air. The transient spectra were collected on an Edinburgh Fluorescence Spectroscopy FLS920 equipped with a R928P photomultiplier tube and a Hamamatsu R5509 near infrared photomultiplier tube. Transient spectra for prompt part were collected with a 365 nm picosecond pulsed LED.

1.4 Electrochemical measurements. Cyclic voltammetry was performed on a CHI 660 instrument, using a platinum (Pt) electrode as the working electrode, a Pt wire as the auxiliary electrode and an Ag/Ag^+ electrode as the reference electrode. The oxidation/reduction potentials were measured in dry dichloromethane/DMF solutions with 0.1 M of TBAPF₆ (tetrabutylammonium hexafluorophosphate) as a supporting electrolyte at a scan rate of 100 mV s⁻¹.

 $E_{HOMO} = -(E_{[onset, ox vs. Fc^+/Fc]} + 4.8) (eV)$

 $E_{LUMO} = -(E_{[onset, red vs. Fc]} + 4.8) (eV)$

1.5 Calculation of the rate constants FET and DET: The k_{FET} and k_{DET} can be calculated by^[5,6]:

$$k_{PF} = \frac{1}{\tau_{PF}} (S-1);$$

$$k_{DF} = \frac{1}{\tau_{DF}} (S-2);$$

$$k_{FET,x wt\%} = \frac{1}{\tau_{PF,x wt\%}} - \frac{1}{\tau_{PF,0 wt\%}} (S-3);$$

$$k_{DET,x wt\%} = \frac{1}{\tau_{DF,x wt\%}} - \frac{1}{\tau_{DF,0 wt\%}} + k_{RISC} k_{ISC} * (\tau_{PF,x wt\%} - \tau_{PF,0 wt\%}) (S-4);$$

Commonly, the FET radii (R_0), defined as an intermolecular distance at which the energy transfer rate constant k_{ET} is equal to the total decay rate constant of the donor in absence of the acceptor, is used to quantify the ability of FET process. Based on Equation (S-5), the R_0 can be expressed as:

$$R_0^6 = \Phi_D k^2 \left(\frac{9000(ln10)}{128\pi^5 N_A n^4} \right) \int_0^\infty F_D(\lambda) \varepsilon_A(\lambda) \lambda^4 d\lambda$$
(S-5).

where R_F is critical intermolecular distance between donor and acceptor where energy transfer is occurred 50%. Φ_D stands for the PLQY of donor without acceptor, and k^2 represents the dipole orientation and assumed to 2/3, while n is refractive index (1.8). $F_D(\lambda)$ is the normalized emission spectra of the donor to an area of 1 and $\varepsilon_A(\lambda)$ is the molar absorption coefficient of the acceptor.

1.6 Single crystal analysis. Single-crystal X-ray diffraction data were recorded on a Bruker D8 Venture X-ray single-crystal diffractometer using Mo K α radiation ($\lambda = 0.71073$ Å) at 180 K for all compounds. Data were processed on a PC with the aid of the Bruker SHELXTL software package and corrected for absorption effects. All non-hydrogen atoms were refined anisotropically. The positions of hydrogen atoms were calculated and refined isotropically. Full crystallographic information in CIF format has been deposited at the Cambridge Crystallographic Data Center (CCDC) under deposition number 2107659 (**pSFIAc**).

1.7 Device fabrication and measurement. All OLEDs were fabricated on glass substrates coated with a patterned transparent ITO (indium tin oxide) conductive layer. The ITO glasses were cleaned by successively sonicating in a detergent solution and distilled water in an ultrasonic bath. Subsequently, the ITO substrates were dried for 2 hours in an oven at 70 °C. After 10 min ozone plasma treatment, the substrates were loaded into a deposition chamber. The vacuum-deposited OLEDs were fabricated under the pressure of $< 5.0 \times 10^{-4}$ Pa in a

Fangsheng OMV-FS450 vacuum deposition system. All organic materials were thermally evaporated at a deposition rate of 1.0 Å s⁻¹. After the organic film deposition, 0.5 nm of LiF and 150 nm of aluminum were thermally evaporated onto the organic surface with the rate of 0.1 and 2.5 Å s⁻¹, respectively. The EL spectra, the luminance–voltage–current density characteristics of the OLEDs were measured by a Photo Research PR-650 spectrophotometer and a Keithley 2400 Source Meter and they are recorded simultaneously. The OLED characteristics of all fabricated devices with encapsulation were evaluated at ambient laboratory conditions.

1.8 Synthesis.



Synthesis of 5,11-bis(2-bromo-4-methylphenyl)-5,11-dihydroindolo[3,2-b] carbazole (1a).

A mixture of 5,11-dihydroindolo[3,2-b]carbazole (5.00 g, 19.51 mmol), 2-bromo-1-fluoro-4-methylbenzene (7.34 mL, 58.52 mmol) and Cesium carbonate (25.4 g, 77.96 mmol) in 100 mL DMF under argon was heated at 140 °C for 24 h. After the solvent was removed under reduce pressure, the reaction mixture was purified by flash chromatography on silica gel with petroleum ether / CH₂Cl₂(5:1, v/v) as eluent to give a white powder (6.5 g, 56%). ¹H NMR (600 MHz, CDCl₃, δ): 8.09 (d, *J* = 7.3 Hz, 2H), 7.78 – 7.69 (m, 4H), 7.45 (dd, *J* = 21.2, 7.8 Hz, 2H), 7.38 (t, *J* = 7.2 Hz, 4H), 7.22 (t, *J* = 7.3 Hz, 2H), 7.06 (dd, *J* = 8.0, 3.0 Hz, 2H), 2.54 (s, 6H). ¹³C NMR (151 MHz, CDCl₃, δ): 142.20, 140.64, 140.58, 137.33, 137.24, 134.80, 134.77, 134.71, 134.60, 131.17, 131.03, 130.88, 129.91, 129.74, 126.05, 123.83, 123.45, 123.40, 123.34, 123.27, 120.43, 120.35, 119.41, 119.24, 110.04, 109.87, 109.77, 100.31, 21.20, 21.10. MALDI-TOF: Calculated: 594.0129, Found: 594.0470.

Synthesis of 5,11-bis(2-bromo-4-methylphenyl)-2,8-di-tert-butyl-5,11dihydroindolo[3,2-b]carbazole (**1b**). Compound **1b** was synthesized according to the same procedure described above for the synthesis of 1a. Using 2,8-di-tert-butyl-5,11dihydroindolo[3,2-b]carbazole (3.0 g, 8.14 mmol), 2-bromo-1-fluoro-4-methylbenzene (3.06 mL, 24.42 mmol) and Cesium carbonate (10.61 g, 32.56 mmol) in 100 mL DMF, yielding 1b as a faint yellow solid (yield 60%). ¹H NMR (600 MHz, CDCl₃, δ): 8.08 (s, 2H), 7.79–7.73 (m, 2H), 7.68 (s, 2H), 7.47–7.35 (m, 6H), 6.98 (dd, *J* = 8.5, 2.2 Hz, 2H), 2.54 (s, 6H), 1.42 (s, 18H). MALDI-TOF: calcd for 706.1381; found, 706.1372.

Synthesis of 2',12'-dimethyldispiro[fluorene-9,10'-dibenzo[2,3:5,6]indolizino [1,8-ab]indolo[3,2,1-de]acridine-20',9''-fluorene] (**pSFIAc1**).

In a two-neck flask, 5,11-bis(2-bromo-4-methylphenyl)-5,11-dihydroindolo[3,2-b] carbazole (1a) (2.05 g, 3.45 mmol) was dissolved in 30 mL dehydrated THF under nitrogen atmosphere. The mixture was cooled to -78 °C for 10 minutes. Then 1.6 M n-BuLi (4.3 mL, 6.9 mmol) was added drop by drop in 10 minutes and the mixture was stirring at -78 °C for 1 h. After that, 9H-fluoren-9-one (1.37 g, 7.59 mmol) was added and the mixture was stirred under room temperature overnight. Then the reaction was quenched with water, after the removal of the solvent in vacuo, the residue was extracted with CH₂Cl₂ and water. After the organic phase was dried over anhydrous Na₂SO₄, the solvent was removed in vacuo and the residue was recrystallized by petroleum ether. After filtration, the residue was dissolved in 30 mL CH₃COOH and then 1 mL HCl was added. The mixture was stirred at 110 °C for 5 h. After cooling to room temperature, the mixture was poured into 100 mL ice water and filtered to get crude product. The crude product was purified by column chromatography on silica gel using petroleum/CH₂Cl₂ (10:1) to get target compounds as faint yellow powder (1.83 g, 70%). ¹H NMR (600 MHz, CD_2Cl_2 , δ): 8.09 (t, *J* = 7.9 Hz, 6H), 7.99 (d, *J* = 8.4 Hz, 2H), 7.52 – 7.47 (m, 4H), 7.33 – 7.28 (m, 2H), 7.19 (d, *J* = 7.4 Hz, 4H), 7.16 - 7.12 (m, 4H), 7.07 - 7.03 (m, 2H), 6.69 (t, J = 7.7 Hz, 2H), 6.49 (d, J = 7.7 Hz, 2H), 78.1 Hz, 2H), 6.30 (d, J = 1.6 Hz, 2H), 2.03 (s, 6H); ¹³C NMR (151 MHz, CD₂Cl₂, δ): 153.51, 140.52, 138.57, 137.48, 133.19, 132.47, 130.91, 128.61, 128.41, 128.02, 127.93, 125.52, 125.30, 124.57, 120.77, 119.77, 119.45, 116.50, 114.19, 112.57, 20.61. MALDI-TOF: calcd for 760.2878; found, 760.2886. Anal. Calcd for C₅₈H₃₆N₂: C 91.55, H 4.77, N 3.68; found, C 91.65, H 4.62, N 3.73.

Synthesisof8',18'-di-tert-butyl-2',12'-dimethyldispiro[fluorene-9,10'-dibenzo[2,3:5,6]indolizino[1,8-ab]indolo[3,2,1-de]acridine-20',9"-fluorene](**pSFIAc2**):Compound pSFIAc2 was synthesized according to the same procedure described above for thesynthesisofpSFIAc1.Using5,11-bis(2-bromo-4-methylphenyl)-2,8-di-tert-butyl-5,11-dihydroindolo[3,2-b]carbazole (2.0 g, 2.83 mmol), 1.6 M n-BuLi (3.5 mL, 5.66 mmol) and9H-fluoren-9-one (1.02 g, 5.66 mmol), yielding pSFIAc2 as a faint yellow solid (yield 80%).

¹H NMR (600 MHz, CD₂Cl₂, δ): 8.06 (d, *J* = 7.6 Hz, 4H), 7.93 (d, 8.2 Hz, 4H), 7.43 (t, *J* = 7.3 Hz, 4H), 7.33 (d, *J* = 7.0 Hz, 2H), 7.15 – 7.11 (m, 7.0 Hz, 8H), 6.97 (d, *J* = 8.0 Hz, 2H), 6.77 – 6.66 (m, 2H), 6.11 (s, 2H), 1.96 (s, 6H), 1.09 (s, 18H); ¹³C NMR (151 MHz, CD₂Cl₂, δ): 154.05, 143.04, 140.23, 137.73, 136.72, 133.06, 132.08, 130.64 128.69, 128.54, 128.08, 127.98, 127.87, 125.15, 124.99, 124.68, 123.36, 123.24, 122.35, 121.62, 119.52, 116.04, 114.05, 112.00, 34.86, 31.65, 20.67. MALDI-TOF: calcd for 872.4130; found, 872.4166. Anal. calcd for C₆₆H₅₂N₂: C 90.79, H 6.00, N 3.21; found, C 90.82, H 6.03, N 3.15. MALDI-TOF: calcd for 872.4130; found, 872.4166. Anal. calcd for C₆₆H₅₂N₂: C 90.79, H 6.00, N 3.21; found, C 90.82, H 6.03, N 3.15. MALDI-TOF: calcd for 872.4130; found, 872.4166. Anal. calcd for C₆₆H₅₂N₂: C 90.79, H 6.00, N 3.21; found, C 90.82, H 6.03, N 3.15. MALDI-TOF: calcd for 872.4130; found, 872.4166. Anal. calcd for C₆₆H₅₂N₂: C 90.79, H 6.00, N 3.21; found, C 90.82, H 6.03, N 3.15. MALDI-TOF: calcd for 872.4130; found, 872.4166. Anal. calcd for C₆₆H₅₂N₂: C 90.79, H 6.00, N 3.21; found, C 90.82, H 6.03, N 3.15. MALDI-TOF: calcd for 872.4130; found, N 3.21; found, C 90.82, H 6.03, N 3.15. MALDI-TOF: calcd for 872.4130; found, 872.4166. Anal. calcd for C₆₆H₅₂N₂: C 90.79, H 6.00, N 3.21; found, C 90.82, H 6.03, N 3.15. MALDI-TOF: calcd for 872.4130; found, 872.4166. Anal. calcd for C₆₆H₅₂N₂: C 90.79, H 6.00, N 3.21; found, C 90.82, H 6.03, N 3.15.

Synthesis of 2,12-di-tert-butyl-5,9-bis(4-(tert-butyl)phenyl)-7-(3,6-di-tert-butyl-9H-carbazol-9-yl)-5,9-dihydro-5,9-diaza-13b-boranaphtho[3,2,1-de]anthracene (**TBN-TPA**) followed the reported procedures⁷: ¹H NMR (600 MHz, CD₂Cl₂, δ): 9.04 (s, 2H), 7.97 (s, 2H), 7.69 (d, *J* = 8.1 Hz, 4H), 7.54 (d, *J* = 7.0 Hz, 2H), 7.35 (d, *J* = 8.1 Hz, 4H), 7.30 – 7.19 (m, 4H), 6.87 (d, *J* = 8.9 Hz, 2H), 6.30 (s, 2H), 1.49 (s, 18H), 1.36 (d, *J* = 5.4 Hz, 36H); ¹³C NMR (151 MHz, CD₂Cl₂, δ): 148.30, 145.90, 142.32, 139.65, 138.13, 130.86, 129.63, 128.79, 128.08, 123.94, 123.50, 117.02, 115.87, 109.91, 101.65, 34.79, 34.54, 34.37, 31.67, 31.56, 31.18. MALDI-TOF: calcd for 921.6132; found, 921.8433. Anal. calcd for C₆₆H₇₆BN₃: C 85.96, H 8.31, B 1.17, N 4.56; found, C 85.82, H 8.45, B 1.01, N 4.68.



2. Supplementary figures and tables

Scheme S1. Summary of FWHM values versus emission wavelength for PL (solution, fill) and EL (hollow) of the representative blue MR-emitters (FWHM≤30 nm).

LUMO+5	LUMO+4	LUMO+3	LUMO+2
LUMO+1	LUMO	НОМО	HOMO-1
HOMO-2	HOMO-3	HOMO-4	HOMO-5

Table S1. Primary orbitals which contribute to the calculated transitions of pSFIAc1 (iso = 0.03).

Table S2. Primary orbitals which contribute to the calculated transitions of **pSFIAc2** (iso = 0.03).

LUMO+5	LUMO+4	LUMO+3	LUMO+2



Table S3. Summary of TD-DFT calculation for **pSFIAc1** and **pSFIAc2** at the S_0 , S_1 , and T_1 structures at the B3LYP/6-31G(d) level.

compound	Optimized structure	transition	Wavelengt h (nm)	Energ y (eV)	Oscillator strength	coefficient of HOMO- LUMO
pSFIAc1	\mathbf{S}_{0}	S_0-S_1	414.62	2.9903	0.1271	0.69846
		S_0-T_1	495.61	2.5017	0.0000	0.66734
	S ₁	S ₁ -S ₀	445.37	2.7839	0.1220	0.69988
pSFIAc2	S ₀	S_0-S_1	422.96	2.9314	0.1166	0.69889
		S ₀ -T ₁	506.07	2.4499	0.0000	0.66951
	S ₁	S ₁ -S ₀	451.76	2.7445	0.1135	0.70012





Figure S1. (a, b) Emission spectra measured in toluene solution (purple) and simulated by Franck-Condon analysis (B3LYP/6-31G(d)) on the S_1 - S_0 transition in toluene (yellow). The final spectrum is got from Gaussian broadening with a half width at half-maximum of 300 cm⁻¹. (c, d) Schematic potential energy diagram of the single point energies (*E*) and reorganization energy (λ). E^{S0}(S₁) is the energy of the S₀ state with the optimized S₁ geometry, E^{S0}(S₀) is the energy of the S₀ states with the optimized S₀ geometry, E^{S1}(S₀) is the energy of S₁ states with the optimized S₀ geometry, and E^{S1}(S₁) is the energy of S₁ state with the optimized S₁ geometry. The single point energy was calculated at B3LYP level with 6-31G (d, p) basis set.

compound	transition	frequency	Relative	line	dipole strength
	$(S_1 \rightarrow S_0)$	(cm^{-1})	frequency	density	(a.u.)
			(cm^{-1})		
pSFIAc1	$0 \rightarrow 0$	22212.1069	0	1.810	0.002914
	$0 \rightarrow 1^2$	22188.9446	-23.1623	15.81	0.02556
	$0 \rightarrow 1^3$	22177.3635	-34.7434	20.46	0.03315
	$0 \rightarrow 1^4$	22165.7842	-46.3245	18.82	0.03055
	$0 \to 3^{1}, 1^{3}$	22159.9852	-52.1217	18.20	0.02959
	$0 \to 3^{1}, 1^{4}$	22148.4041	-63.7028	16.41	0.02672
pSFIAc2	$0 \rightarrow 0$	21867.5192	0	24.23	0.04152
	$0 \rightarrow 2^1$	21850.4986	-17.0206	38.99	0.06706
	$0 \rightarrow 2^2$	21833.4780	-34.0412	32.35	0.05581
	$0 \rightarrow 2^3$	21816.4574	-51.0618	18.14	0.03188

Table S4. Summary of Franck-Condon analysis on the S_1 - S_0 transition of pSFIAc1 andpSFIAc2 at the (TD) B3LYP/6-31G(d) level.



Figure S2. The stacking patterns of pSFIAc1 in stick style.



Figure S3. (a) Decomposition temperature (T_d) with 5% weight loss for pSFIAc1 and pSFIAc2.



Figure S4. Cyclic voltammograms (CV) for **pSFIAc1**. The CV curves were measured at room temperature with 0.1 M solution of n-Bu₄NPF₆ in dichloromethane for the reduction (a) and oxidation (b) scan (vs Fc/Fc⁺); HOMO and LUMO energies obtained from electrochemical data.



re S5. Cyclic voltammograms (CV) for **pSFIAc2**. The CV curves were measured at room temperature with 0.1 M solution of n-Bu₄NPF₆ in dichloromethane for the reduction (a) and oxidation (b) scan (vs Fc/Fc⁺); HOMO and LUMO energies obtained from electrochemical data.



Figure S6. PL spectra of pSFIAc1 (a) and pSFIAc2 (b) in different solvents with various polarities.



Figure S7. PL transient spectrum pSFIAc1 (a) and pSFIAc2 (b) in degassed toluene.



Figure S8. (a) The PL spectra and (b) transient PL curves of the doped films of α - β -ADN: x wt% **pSFIAc1** (x = 1, 3, 5, 10, 15) and the neat film.



Figure S9. (a) The PL spectra and (b) transient PL curves of the doped films of α - β -

ADN: x wt% **pSFIAc2** (x = 1, 3, 5, 10, 15) and the neat film.



Figure S10. The PL spectra of pSFIAc1 and pSFIAc2 neat film.

AND: xwt% pSFIAc	λ _{em} [nm]	FWHM [nm/eV]	$arPhi_{ ext{PL}} \ [\%]$	$ au_{ m PF}$ [ns]	$k_{ m r} = [10^7 { m s}^{-1}]$
1	448	19.2/0.12	81	4.10	19.5
3	448	19.0/0.12	80	2.53	29.6
5	448	19.0/0.12	78	2.23	30.5
10	449	18.8/0.11	76	1.84	28.3
15	449	18.8/0.11	72	1.45	27.6
neat film	449	20.8/0.13	26	1.10	23.6

Table S5. Photophysical properties of α , β -ADN: x wt% **pSFIAc1** films.

Table S6. Photophysical properties of α , β -ADN: x wt% pSFIAc2 films.

AND: xwt%	λ_{em}	FWHM	$arPsi_{ ext{PL}}$	$ au_{ m PF}$	$k_{ m r}$
pSFIAc	[nm]	[nm/eV]	[%]	[ns]	$[10^7 \text{s}^{-1}]$
1	455	19.2/0.11	83	4.14	20.0
3	455	18.6/0.11	81	4.01	20.3

5	455	18.8/0.11	80	3.81	21.0
10	455	18.8/0.11	77	3.52	21.8
15	455	18.8/0.11	76	3.40	22.3
neat film	454	20.0/0.13	30	0.96	31.2

 Table S7. Photophysical properties of mCBP: x wt% pSFIAc1 films.

mCBP: xwt% pSFIAc	λ _{em} [nm]	FWHM [nm/eV]	$\Phi_{ ext{PL}}$ [%]	$ au_{ m PF}$ [ns]	$k_{ m r} \ [10^7 { m s}^{-1}]$
1	447	20.2/0.12	83	7.71	10.8
3	448	20.2/0.12	80	7.52	10.6
5	449	20.4/0.12	79	6.83	11.6
10	449	20.6/0.13	79	5.64	14.0
15	449	20.6/0.13	70	4.67	15.0

Table S8. Photophysical properties of DPEPO: x wt% pSFIAc1 films.

_						
	DPEPO: xwt% pSFIAc	λ _{em} [nm]	FWHM [nm/eV]	$arPhi_{ ext{PL}} \ [\%]$	τ _{PF} [ns]	$k_{ m r} \ [10^7 { m s}^{-1}]$
	1	447	20.8/0.13	84	8.53	9.8
	3	447	21.0/0.13	84	8.24	10.2
	5	448	21.2/0.13	82	7.15	11.5
	10	448	21.4/0.13	80	6.24	12.8
	15	449	21.6/0.13	80	6.07	13.2

Table S9. Photophysical properties of mCBP: x wt% pSFIAc2 films.

mCBP: xwt% pSFIAc	λ _{em} [nm]	FWHM [nm/eV]	$\Phi_{ ext{PL}}$ [%]	$ au_{ m PF}$ [ns]	$k_{ m r} = [10^7 { m s}^{-1}]$
1	454	19.0/0.11	85	8.31	10.2
3	454	19.0/0.11	81	6.87	11.8
5	454	19.4/0.11	80	5.67	14.1

10	454	19.2/0.11	80	3.70	21.6
15	455	19.2/0.11	73	2.31	29.1

 Table S10. Photophysical properties of DPEPO: x wt% pSFIAc2 films.

DPEPO: xwt% pSFIAc	λ _{em} [nm]	FWHM [nm/eV]	$\Phi_{ ext{PL}}$ [%]	$ au_{ m PF}$ [ns]	$k_{ m r} = [10^7 { m s}^{-1}]$
1	454	20.6/0.12	87	9.30	9.4
3	454	19.6/0.12	85	9.01	9.4
5	454	19.6/0.12	83	8.17	10.2
10	454	19.8/0.12	81	7.51	10.8
15	454	19.8/0.12	80	6.34	12.6



Figure S11. Schematic illustration of triplet triplet fusion (TTF), Förster energy transfer (FET) and Dexter energy transfer (DET) process in the devices.



Figure S12. (a) The EL spectra of the devices recorded at 1000 cd cm⁻². (b) The EQE versus brightness characters for devices based on **pSFIAc1**. (c), (d) The J-V-L characters.



Figure S13. (a) The EL spectra of the devices recorded at 1000 cd cm⁻². (b) The EQE versus brightness characters for devices based on **pSFIAc2**. (c), (d) The J-V-L characters.



Figure S14. (a) The power efficiency and (b) current efficiency versus brightness characters for devices based on pSFIAc1.



Figure S15. (a) The power efficiency and (b) current efficiency versus brightness characters for devices based on pSFIAc2.



Figure S16. The EL spectra of **pSFIAc1** based devices at (a) 1.0 wt% and (b) 15.0 wt% under different brightness.



Figure S17. The EL spectra of **pSFIAc2** based devices at (a) 1.0 wt% and (b) 15.0 wt% under different brightness.



Figure S18. (a, b) EL transient spectra of devices **A** and **B** in varied voltage. (c) EL transient spectra of devices **A**, **B** and **C** under the voltage of 4 V.



Figure S19. The EL operational stability of pSFIAc1 and pSFIAc2 in the 3 wt% doped devices under a constant current density with an initial luminance of 2000 cd/m².



Figure S20. (a) The absorption (left axis), fluorescence and phosphorescence (right axis) spectra of **TBN-TPA** in toluene (10⁻⁵ M). (b) The PL spectra of TBN-TPA in toluene (10⁻⁵ M) and the doped film of TBN-TPA in α , β -AND at a doping concentration of 1 wt%.



Figure S21. (a) The EL spectra of devices A, B and C were recorded at 1000 cd/m². (b) The EQE versus luminance curves of the devices A, B and C. (c) The power efficiency and current efficiency versus brightness characters. (d) The J-V-L characters.



Figure S22. The PL spectra of the doped films of mCBP: 1 wt% pSFIAc1 and pSFIAc2; mCBP:30 wt% m4TCzPhBN: 1–3 wt% **pSFIAc1** and **pSFIAc2**.



Figure S23. The PL transient spectra of the doped films of mCBP: 30 wt% m4TCzPhBN; mCBP:30 wt% m4TCzPhBN: 1–3 wt% **pSFIAc1** and **pSFIAc2**.







HATCN





mCP





PPF

mCBP





m4TCzPhBN



Figure S24. (a) The molecular structures of the materials used in devices. (b) Device structures and energy-level diagrams.



Figure S25. (a) The EL spectra of TSF-devices **A6–A8** were recorded at 1000 cd/m². (b) The EL spectra of device **A6** at 1.0 wt% under different brightness. (c) The EQE and power efficiency versus brightness characters. (d) The J-V-L characters.



Figure S26. (a) The EL spectra of TSF-devices **B6-B8** were recorded at 1000 cd/m². (b) The EL spectra of device **B6** at 1.0 wt% under different brightness. (c) The EQE and power efficiency versus brightness characters. (d) The J-V-L characters.



Figure S27. Experimentally obtained angle-dependent PL emission of pSFIAc1 and pSFIAc2 in PPF films, respectively on silica substrate (circle) compared to the simulated curves (lines) with a different ratios of horizontal dipoles (Θ) (blue line for $\Theta = 100\%$ (fully horizontal), black line for $\Theta = 71\%$ and 72% for pSFIAc1 and pSFIAc2, respectively, and red line for $\Theta = 66.7\%$ (isotropic)).



Figure S28. The device luminance versus lifetime curves of TSF-OLEDs using **pSFIAc1** and **pSFIAc2** measured under 1000 cd/m².



Figure S29. (a) The EL spectra, (b) the EQE versus brightness and (c) the J-V-L characters for 2 wt% doped pSFIAc1/pSFIAc2 devices. Based on a device structure of ITO/ TAPC (30 nm)/ TCTA (5 nm)/ mCP (5 nm)/ mCBP: 2 wt% pSFIAc1/pSFIAc2 (30 nm)/ PPF (5 nm)/ Bphen (30 nm)/ LiF (0.5 nm)/ Al (150 nm).



Figure S30. (a) The EQE versus brightness, (b) the EL spectra and (c) the J-V-L character of device with sensitizer (m4TCzPhBN) as emitter.



Figure S31. (a) The EQE versus brightness, (b) the EL spectra and (c) the J-V-L character of devices with TBN-TPA as emitter. Based on a device structure of ITO/ TAPC (30 nm)/ TCTA (5 nm)/ mCP (5 nm)/ mCBP: 30 wt% m4TCzPhBN: 1–3 wt% TBN-TPA (30 nm)/ PPF (5 nm)/ Bphen (30 nm)/ LiF (0.5 nm)/ Al (150 nm).

 Table S11. Summary of the TTA-/TSF-device performances based pSFIAc1.

Device type	x wt%	$\lambda_{\rm EL}{}^{a)}$ [nm]	FWHM ^{b)} [nm/eV]	V _{on} ^{c)} [V]	$L_{max}^{d)}$ [cd/m ²]	PE _{max} ^{e)} [lm/W]	EQE ^{f)} [%]	CIE (x,y) ^{a)}
-------------	-------	--------------------------------	-------------------------------	--------------------------------------	--	---	--------------------------	-------------------------

Device A1	1	448	19.0 (0.12 eV)	2.6	14040	4.6	8.9/8.2/7.3	(0.147, 0.054)
Device A2	3	448	19.0 (0.12 eV)	2.7	13210	4.0	7.8/7.3/6.9	(0.147, 0.054)
Device A3	5	448	18.8 (0.12 eV)	2.7	13490	4.0	7.7/7.2/6.4	(0.148, 0.053)
Device A4	10	448	18.8 (0.12 eV)	2.7	11490	4.0	7.4/6.7/6.2	(0.148, 0.053)
Device A5	15	448	18.8 (0.12 eV)	2.7	10710	3.8	7.4/6.5/5.5	(0.148, 0.053)
Device A6	1	446	21.1 (0.13 eV)	3.4	2002	14.9	24.9/4.1/3.2	(0.148, 0.058)
Device A7	2	446	21.0 (0.13 eV)	3.4	1870	13.8	19.8/3.4/2.8	(0.148, 0.058)
Device A8	3	446	21.0 (0.13 eV)	3.4	1333	11.2	18.4/3.1/2.4	(0.148, 0.056)

^{a)}Value recorded at a luminance around 1000 cd/cm²; ^{b)}Full width at half maximum of electroluminescence; ^{c)}Turn-on voltage at the luminance of 1 cd/m²; ^{d)}Maximum luminescence (L); ^{e)}Maximum power efficiency (PE); ^{f)}Maximum external quantum efficiency (EQE) value, value at 1000 and 5000 cd/cm² for A1–A5, and maximum efficiency value, value at 500 and 1000 cd/cm² for A6–A8.

Table S12. Summary of the TTA-/TSF-device performances based pSFIAc2.

Device type	x wt%	$\lambda_{EL}{}^{a)}$ [nm]	FWHM ^{b)} [nm/eV]	V _{on} ^{c)} [V]	$\begin{array}{c} L_{max} ^{d)} \\ [cd/m^2] \end{array}$	PE _{max} ^{e)} [lm/W]	EQE ^{f)} [%]	CIE (x,y) ^{a)}
Device B1	1	453	19.1 (0.12 eV)	2.7	16250	5.2	9.1/8.7/8.2	(0.142, 0.066)
Device B2	3	453	19.0 (0.12 eV)	2.7	19660	5.1	8.6/8.4/7.9	(0.142, 0.066)
Device B3	5	453	19.0 (0.12 eV)	2.7	17390	5.1	8.4/8.3/7.4	(0.142, 0.066)
Device B4	10	453	18.9 (0.12 eV)	2.7	17130	5.1	8.1/7.8/7.1	(0.141, 0.067)
Device B5	15	453	18.8 (0.12 eV)	2.7	15850	5.1	7.9/7.5/6.5	(0.141, 0.067)
Device B6	1	451	21.0 (0.13 eV)	3.5	2253	23.0	31.4/5.6/4.3	(0.146, 0.078)
Device B7	2	451	21.0 (0.13 eV)	3.6	1844	22.1	21.8/4.5/3.5	(0.146, 0.078)
Device B8	3	451	21.1 (0.13 eV)	3.6	1462	12.3	19.9/3.7/2.7	(0.144, 0.077)

^{a)}Value recorded at a luminance around 1000 cd/cm²; ^{b)}Full width at half maximum of electroluminescence; ^{c)}Turn-on voltage at the luminance of 1 cd/m²; ^{d)}Maximum luminescence (L); ^{e)}Maximum power efficiency (PE) ; ^{f)}Maximum external quantum efficiency (EQE) value, value at 1000 and 5000 cd/cm² for B1–B5, and maximum efficiency value, value at 500 and 1000 cd/cm² for B6–B8.

Table S13. Summary of the maximum EQE versus FWHMs and CIE_y color coordinates based on the reported deep-blue OLEDs.

Emitter	λ_{PL} (nm)	FWHM _{PL} (nm)	PLQY (%)	λ_{EL} (nm)	FWHM _{EL} (nm)	EQE (%)	CIEy	Refs.
pSFIAc1	443 (in Tol)	18 (in Tol)	81 (in film)	446	21	24.9	0.058	This work
pSFIAc2	450 (in Tol)	18 (in Tol)	83 (in film)	453	21	31.4	0.078	This work
TDBA-Ac	458 (in Tol)	50 (in Tol)	93 (in film)	445	48	21.5	0.06	8
DMACN-B	430 (in Tol)	44 (in Tol)	90 (in film)	444	44	10.0	0.045	9
TB-tPCz	422 (in THF) 445 (in film)	46.3 (in Tol)	51.9 (in film)	420	43.5	14.1	0.05	10

tPBisICz	445 (in DCM) 450 (in film)	27 (in DCM)	91 (in film)	452	21	23.1	0.05	11
tBuOBOtSAc	446 (in Tol) 450 (in film)	48 (in Tol)	90 (in film)	448	48	28.2	0.061	12
B-O-dpa	433 (in Tol)	28(in Tol)	86 (in film)	443	32	16.3	0.05	13
PyAnTPh	437 (in THF) 441 (in film)	-	80 (in film)	440	52	8.44	0.07	14
DCzBN3	424 (in film)	-	76 (in film)	428	65	10.3	0.06	15
sAC-sDBB	453 (in Tol) 444 (in film)	51 (in Tol) 55 (in film)	96 (in Tol)	444	49	25.4	0.058	16
BD3	422 (in Tol)	-	82 (in film)	432	45	12.0	0.06	17
CNICCz	-	-	46 (in film)	449	56	12.4	0.08	18
3tPAB	456 (in Tol) 458 (in film)	23 (in Tol)	75 (in Tol)	460	26	19.3	0.076	19
2M-ph- pCzAnBzt	428 (in DCM)	55 (in DCM) 63 (in film)	65 (in film)	450	57	10.44	0.057	20
BOBO-Z	441 (in Tol) 445 (in film)	15 (in Tol) 18 (in film)	76 (in Tol)	445	18	9.8	0.04	21
BOBS-Z	453 (in Tol) 457 (in film)	21 (in Tol) 24 (in film)	94 (in Tol)	456	23	24.0	0.06	21
BSBS-Z	460 (in Tol) 464 (in film)	20 (in Tol) 22 (in film)	93 (in Tol)	463	22	24.0	0.08	21
4F-v-DABNA	457 (in Tol)	14 (in Tol)	90.2 (in film)	464	18	35.8	0.08	าา
4F-m-v- DABNA	455 (in Tol)	14 (in Tol)	88.9 (in film)	461	18	33.7	0.06	
TDBA-PAS	427 (in Tol)	50 (in Tol)	92 (in film)	435	50	22.3	0.042	23

Table S14.	Summary	of the	reports	on	high-efficiency	and	long-lifetime	deep-blue	OLEDs
with CIEy b	elow 0.15.								

Emitter	EQE (%) ^a	FWHM (nm)	C	IE	L0 (nit)	x	LTx (hr)	Refs.
α,β-ADN/pSFIAc1	8.9/-/8.2	19	0.147	0.054	2,000 100	80	96 ^b 18,900	This
m4TCzPhBN/pSFIAc1	24.9/4.1/3.2	21	0.148	0.058	1,000	50	13	work
α,β-ADN/pSFIAc2	9.1/-/8.7	19	0.142	0.066	2,000	80	230 ^b	

					100		43,470	
m4TCzPhBN/pSFIAc2	31.4/5.6/4.3	21	0.146	0.078	1,000	50	20	
α,β-ADN/TBN-TPA	8.4/-/8.0	23	0.142	0.054	2,000	80	70	
HDT-1/v-DABNA	27/24/20	18	0.15	0.20	1,000	95	11	
HDT-1/v-DABNA (two-unit-stacked)	41/39/32	19	0.13	0.16	1,000	95	18	24
PPCzTrz/v-DABNA	33.0/25.2/-	19	0.13	0.20	1,000 100	50	151 ° 9,500	
PCzTrz/v-DABNA	33.5/23.8/-	19	0.12	0.18	1,000 100	50	113 ° 7,100	
PPCzTrz/v-DABNA (top-emission)	29.3/21.4/-	-	0.12	0.09	1,000 100	50	117° 9,500	25
PCzTrz/v-DABNA (top-emission)	34.4/21.9/-	-	0.12	0.09	1,000 100	50	97° 7,400	
v-DABNA	33.2/17.7/-	-	0.13	0.14	1,000 100	50	41 ° 6,100	
DMAC-DPS/t-DABNA	31.4/27.2/19.8	31	0.13	0.15	100	50	32	26
t-DABNA	22.8/4.5/-	27	0.129	0.108	200	50	17	27
Ir(cb) ₃ /t-DABNA	24.6/-/19.4	27	0.132	0.115	200	50	293	21
p4TCzPhBN/t-DABNA	32.5/26.4/23.2	29	0.13	0.12	1,000 100	80	60 ^b 3,000	28
v-DABNA	23.4/-/22.4	18	0.13	0.12	1,000	50	259	29
PtON7-dtb/v-DABNA	32.2/-/25.4	20	0.111	0.141	1,000	50	117	
PtON7-dtb/TBPDP	16.9/-/14.3	51	0.128	0.271	1,000	50	339.2	
PtON7-dtb/v-DABNA (top-emission)	-	17	0.109	0.134	1,000	50	253.8	30
PtON7-dtb/TBPDP (top-emission)	-	25	0.115	0.091	1,000	50	192.2	
DABNA-NP-TB	19.5/17.5/12.0	33	0.14	0.11	100	80	19	31
Cz2DABNA-NP-M/TB	21.8/20.4/14.9	27	0.11	0.23	100	80	91	51
v-DABNA	34.4/32.8/26.0	18	0.12	0.11	100	50	31	32
t-DABNA	7.6/-/7.0	24.7	0.126	0.098	200	90	608	
DABNA	5.4/-/4.9	25	0.135	0.072	200	90	203	33
PyCN	5.0/-/3.4	-	0.140	0.088	200	90	33	
pMDBA-DI/t-Bu-v- DABNA	37.6/-/33.9	19	0.13	0.19	1,000	50	440	34
mMDBA-DI/t-Bu-v- DABNA	32.8/-/28.4	19	0.14	0.23	1,000	50	133	51

oCBP:CNmCBPCN/B	26 4/25 0/22 7	20	0.122	0.147	1 000	70	175	
D-02	20.4/23.0/23.7	38	0.132	0.147	1,000	/0	47.5	35
SiCzCz:SiTrzCz2/BD-	25 4/24 6/22 4	12	0.141	0.107	1 000	70	1 1 1 2	
02	23.4/24.0/23.4	43	0.141	0.197	1,000	/0	1,115	

^a EQE maximum value, EQE value at 100 cd/m^2 and EQE value at $1,000 \text{ cd/m}^2$. ^b The lifetime can be tranformed into 100 cd/m^2 of initial luminance using an acceleration factor of 1.75 and 1.8 c.



Figure S27. ¹H NMR spectrum of 1a in CDCl₃.





160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 f1 (ppm) Figure S31. ¹³C NMR spectrum of **pSFIAc1** in CD₂Cl₂.









Sample	pSFIAc
Empirical formula	$C_{58}H_{36}N_2$
Formula weight	760.28
Temperature	296(2) K
Wavelength	0.71073 Å
Crystal system	triclinic
Space group	P-1
Unit cell dimensions	a = 8.4867(18) Å, b = 12.972(3) Å, c = 18.128(4) Å; α = 105.478(7)°; β = 90.206(7)°; γ = 96.312(8)°
Volume	1910.6(7) Å ³
Z	4
Density (calculated)	1.323 g/m^3
Absorption coefficient	0.076 mm ⁻¹
F(000)	796
Theta range for data collection	3.28 to 56.878°
Index ranges	-11<=h<=11, -17<=k<=17, -24<=1<=24
Reflections collected	23393
Independent reflections	9486 [R(int) = 0.0393]
Completeness to theta = 25.242°	100.0 %
Absorption correction	Semi-empirical from equivalents
Refinement method	Full-matrix least-squares on F ²
Data/restraints/parameters	9486 / 3 / 549
Goodness-of-fit on F ²	1.003
Final R indices [I>2sigma(I)]	R1 = 0.0555, WR2 = 0.1304
R indices (all data)	R1 = 0.1028, WR2 = 0.1530
Extinction coefficient	n/a
Largest diff. peak and hole (e.Å ⁻³)	0.33 and -0.24

Table S15. X-Ray crystallographic data and structure refinement for pSFIAc1.

 Table S16. Bond lengths [Å] and angles [°] for pSFIAc1.

Atom	Atom L	.ength/Å	Atom Atom Length/Å
N1	C33	1.391(2)	C16 C17 1.387(2)
N1	C10	1.395(2)	C16 C15 1.414(2)
N1	C6	1.410(2)	C6 C5 1.390(2)
N2	C16	1.389(2)	C15 C20 1.396(2)
N2	C13	1.393(2)	C26 C25 1.388(3)
N2	C53	1.416(2)	C26 C27 1.465(3)
C11	C12	1.408(2)	C39 C40 1.392(3)
C11	C10	1.428(2)	C33 C35 1.385(3)
C11	C34	1.451(2)	C47 C48 1.388(2)
C10	C9	1.392(2)	C47 C43 1.470(2)
C13	C12	1.391(2)	C50 C51 1.392(3)
C13	C14	1.422(2)	C27 C28 1.390(3)
C9	C14	1.410(2)	C57 C56 1.381(3)
C9	C8	1.537(2)	C43 C42 1.386(2)

C12	C45	1.539(2)	C38 C37	1.366(3)
C8	C32	1.531(2)	C31 C30	1.388(3)
C8	C21	1.532(2)	C22 C23	1.383(3)
C8	C7	1.541(2)	C2 C3	1.375(2)
C44	C39	1.375(2)	C17 C18	1.366(3)
C44	C43	1.397(2)	C51 C49	1.380(3)
C44	C45	1.525(2)	C54 C55	1.376(3)
C14	C15	1.461(2)	C3 C4	1.368(3)
C32	C31	1.378(2)	C3 C1	1.505(3)
C32	C27	1.389(2)	C56 C55	1.381(3)
C45	C46	1.537(2)	C56 C58	1.518(3)
C45	C52	1.549(2)	C48 C49	1.379(3)
C21	C22	1.377(3)	C25 C24	1.370(3)
C21	C26	1.395(2)	C20 C19	1.378(3)
C46	C50	1.381(2)	C42 C41	1.382(3)
C46	C47	1.389(2)	C37 C36	1.372(3)
C53	C52	1.388(2)	C40 C41	1.377(3)
C53	C54	1.396(2)	C5 C4	1.381(3)
C7	C6	1.385(2)	C23 C24	1.384(3)
C7	C2	1.401(2)	C28 C29	1.384(3)
C52	C57	1.399(2)	C18 C19	1.384(3)
C34	C38	1.394(2)	C30 C29	1.379(3)
C34	C33	1.414(2)	C35 C36	1.372(3)



The ORTEP diagram showing the structure of **pSFIAc1** with labeling schemes

3. References

- [1] J.-D. Chai and M. H.-Gordon, Phys. Chem. Chem. Phys., 2008, 10, 6615-6620.
- [2] L. Kronik, T. Stein, S. Refaely-Abramson, R. Baer, J. Chem. Theory Comput., 2012, 8, 1515–1531
- [3] H. Sun, C. Zhong, J. L. Brédas, J. Chem. Theory. Comput., 2015, 11, 3851–3858.
- [4] F. Santoro, A. Lami, R. Improta, J. Bloino, and V. Barone. J. Chem. Phys., 2008, 128, 224311.
- [5] K. Masui, H. Nakanotani, C. Adachi, Org. Electron. 2013, 14, 2721.
- [6] N. Aizawa, S. Shikita, T. Yasuda, Chem. Mater. 2017, 29, 7014.
- [7] S. Oda, W. Kumano, T. Hama, R. Kawasumi, K. Yoshiura, T. Hatakeyama, *Angew. Chem. Int. Ed.* **2021**, *60*, 2882.
- [8] D. H. Ahn, S. W. Kim, H. Lee, I. J. Ko, D. Karthik, J. Y. Lee, J. H. Kwon, *Nat. Photonics* 2019, 13, 540.
- [9] A. Khan, X. Tang, C. Zhong, Q. Wang, S. Y. Yang, F. C. Kong, S. Yuan, A. S. D. Sandanayaka, C. Adachi, Z. Q. Jiang, L. S. Liao, *Adv. Funct. Mater.* 2021, 31, 2009488.
- [10] H. J. Kim, H. Kang, J. E. Jeong, S. H. Park, C. W. Koh, C. W. Kim, H. Y. Woo, M. J. Cho, S. Park, D. H. Choi, *Adv. Funct. Mater.* 2021, *31*, 2102588.
- [11] V. V. Patil, H. L. Lee, I. Kim, K. H. Lee, W. J. Chung, J. Kim, S. Park, H. Choi, W. J. Son, S. O. Jeon, J. Y. Lee, Adv. Sci. 2021, 2101137.
- [12] Y. Lee, J. I. Hong, Adv. Opt. Mater. 2021, 9, 2100406.
- [13] X. Li, Y. Z. Shi, K. Wang, M. Zhang, C. J. Zheng, D. M. Sun, G. L. Dai, X. C. Fan, D. Q. Wang, W. Liu, Y. Q. Li, J. Yu, X. M. Ou, C. Adachi, X. H. Zhang, ACS Appl. Mater. Interfaces 2019, 11, 13472.
- [14] F. Liu, Z. Cheng, L. Wan, L. Gao, Z. Yan, D. Hu, L. Ying, P. Lu, Y. Ma, Chem. Eng. J. 2021, 426, 131351.
- [15] C. Y. Chan, L. S. Cui, J. U. Kim, H. Nakanotani, C. Adachi, Adv. Funct. Mater. 2018, 28, 1706023.
- [16] G. Xia, C. Qu, Y. Zhu, J. Ye, K. Ye, Z. Zhang, Y. Wang, Angew. Chem. Int. Ed. 2021, 60, 9598.
- [17] J.-Y. Hu, Y.-J. Pu, F. Satoh, S. Kawata, H. Katagiri, H. Sasabe, J. Kido, Adv. Funct. Mater. 2014, 24, 2064.
- [18] Y. Im, S. H. Han, J. Y. Lee, J. Mater. Chem. C 2018, 6, 5012-5017.
- [19] Y. Wang, Y. Duan, R. Guo, S. Ye, K. Di, W. Zhang, S. Zhuang, L. Wang, Org. Electron. 2021, 97, 106275.
- [20] R. Guo, W. Liu, S. Ying, Y. Xu, Y. Wen, Y. Wang, D. Hu, X. Qiao, B. Yang, D. Ma, L. Wang, Sci. Bull. 2021, 66, 2090-2098.
- [21] I. S. Park, M. Yang, H. Shibata, N. Amanokura, T. Yasuda, Adv. Mater. 2021, e2107951.
- [22] K. Rayappa Naveen, H. Lee, R. Braveenth, K. Joon Yang, S. Jae Hwang, J. Hyuk Kwon, *Chem. Eng. J.* **2022**, *432*, 134381.
- [23] H.-J. Tan, G.-X. Yang, Y.-L. Deng, C. Cao, J.-H. Tan, Z.-L. Zhu, W.-C. Chen, Y. Xiong, J.-X. Jian, C.-S. Lee, Q.-X. Tong. Adv. Mater. 2022. doi:10.1002/adma.202200537.
- [24] C.-Y. Chan, M. Tanaka, Y.-T. Lee, Y.-W. Wong, H. Nakanotani, T. Hatakeyama, C. Adachi, Nat. Photonics 2021, 15, 203.
- [25] S. O. Jeon, K. H. Lee, J. S. Kim, S.-G. Ihn, Y. S. Chung, J. W. Kim, H. Lee, S. Kim, H. Choi, J. Y. Lee, *Nat. Photonics* 2021, 15, 208.
- [26] S. H. Han, J. H. Jeong, J. W. Yoo, J. Y. Lee. J. Mater. Chem. C, 2019, 7, 3082.
- [27] K. Hyung Lee, J. Y. Lee. J. Mater. Chem. C, 2019, 7, 8562.
- [28] D. Zhang, X. Song, A. J. Gillett, B. H. Drummond, S. T. E. Jones, G. Li, H. He, M. Cai, D. Credgington, L. Duan, *Adv. Mater.* **2020**, *32*, 1908355.

- [29] K. W. Lo, G. S. M. Tong, G. Cheng, K. H. Low, C. M. Che, Angew. Chem. Int. Ed. 2021., DOI:10.1002/anie.202115515.
- [30] S. Nam, J. W. Kim, H. J. Bae, Y. M. Maruyama, D. Jeong, J. Kim, J. S. Kim, W. J. Son, H. Jeong, J. Lee, S. G. Ihn, H. Choi, *Adv. Sci.* 2021, *8*, e2100586.
- [31] S. Oda, W. Kumano, T. Hama, R. Kawasumi, K. Yoshiura, T. Hatakeyama, *Angew. Chem. Int. Ed.* **2021**, *60*, 2882.
- [32] Y. Kondo, K. Yoshiura, S. Kitera, H. Nishi, S. Oda, H. Gotoh, Y. Sasada, M. Yanai, T. Hatakeyama, *Nat. Photonics* **2019**, *13*, 678.
- [33] K. H. Lee, J. Y. Lee. Org. Electron. 2019, 75, 105377.
- [34] K. R. Naveen, H. Lee, R. Braveenth, D. Karthik, K. J. Yang, S. J. Hwang, J.H. Kwon. *Adv. Funct. Mater.* **2021**, 2110356.
- [35] J. Sun, H. Ahn, S. Kang, S.-B. Ko, D. Song, H. A. Um, S. Kim, Y. Lee, P. Jeon, S.-H. Hwang, Y. You, C. Chu, S. Kim, *Nat. Photonics* 2022. doi.org/10.1038/s41566-022-00958-4.