Supporting information

Fine-Tuned Asymmetric Blue Multiple Resonance Thermally Activated Delayed Fluorescence Emitters with High Efficiency and Narrow Emission Band

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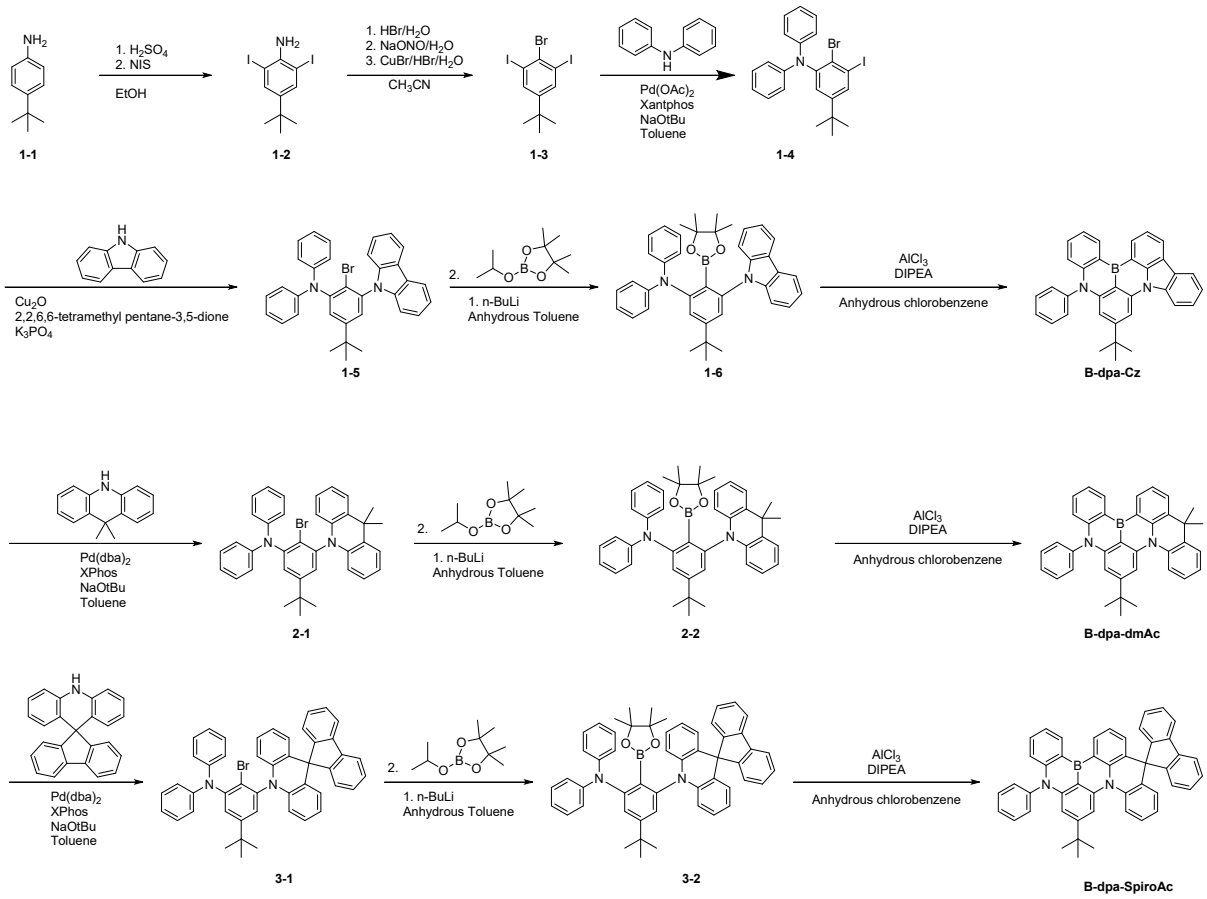
Experimental

General information

All chemical compounds were commercially available. All materials and solvents were used in the synthesis without further purification. Solvents for the nuclear magnetic resonance (NMR) analysis were chlroform-d ($CDCl_3$) and dichloromethane-d_2 (CD_2Cl_2). The NMR spectra were measured on a Avance-500 spectrometer (Bruker). The ultraviolet-visible (UV-vis) spectra were obtained using UV-vis spectrophotometer (JASCO, V-730), and the photoluminescence (PL) spectra were measured on a fluorescence spectrophotometer (PerkinElmer, LS-55). The HOMO levels were estimated using a cyclic voltammetry (Ivium Tech., Iviumstat). The mass spectra were measured using an Advion, Expression-L compact mass spectrometer (CMS) in APCI mode and a JMS-700 (JEOL) with high resolution fast

atom bombardment (FAB) mode. Thermogravimetric anaysis was measured using Seiko Exstar 6000 (TG/DTA 6100).

Synthesis



Scheme S1. Synthesis of B-dpa-Cz, B-dpa-dmAc and B-dpa-SpiroAc.

2-Bromo-5-(tert-butyl)-1,3-diiodobenzene (1-3)

2-Bromo-5-(tert-butyl)-1,3-diiodobenzene was synthesized according to the synthetic method from literature procedure.[1]

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.82 (s, 2H), 1.26 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 153.7, 137.8, 132.7, 99.8, 34.4, 31.0. MS (APCI) m/z 464.7 [$(M+H)^+$].

2-Bromo-5-(tert-butyl)-3-iodo-N,N-diphenylaniline (1-4)

2-Bromo-5-(tert-butyl)-1,3-diiodobenzene (**1-3**, 8.92 g, 19.2 mmol), diphenylamine (2.5 g, 14.8 mmol), $Pd(OAc)_2$ (0.1 g, 0.44 mmol), Xantphos (0.51 g, 0.89 mmol) and NaOtBu (2.63 g, 27.3 mmol) were dissolved in toluene (70 mL). And stirred under reflux for 8 hours under a nitrogen atmosphere. After completion of the reaction, the organic layer was extracted with distilled water and MC. After drying with $MgSO_4$, filterd and the solvent was evaporated. After column chromatography using MC:n-hexane (1:8) eluent, the titled compound was obtained by recrystallization from methanol as a white powder (4.86 g, yield 65.0%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.78 (d, J = 2.2 Hz, 1H), 7.24 – 7.19 (m, 5H), 6.96 (t, J = 8.8 Hz, 6H), 1.23 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 153.7, 146.6, 145.8, 135.5, 129.1, 128.3, 122.1, 121.8, 103.7, 34.6, 31.0. MS (APCI) m/z 506.1 [$(M+H)^+$].

2-Bromo-5-(tert-butyl)-3-(9H-carbazol-9-yl)-N,N-diphenylaniline (1-5)

2-Bromo-5-(tert-butyl)-3-iodo-N,N-diphenylaniline (**1-4,** 2.2 g, 4.35 mmol), 9H-carbazole (1.02 g, 6.08 mmol), Copper(I) oxide (0.12 g, 0.87 mmol), 2,2,6,6-tetramethyl-3,5-heptanedione (0.36 mL, 1.74 mmol), and potassium phosphate (1.85 g, 8.69 mmol) were dissolved in DMF (22 mL). And stirred at 110°C for 2 days under a nitrogen atmosphere. After completion of the reaction, the organic layer was extracted with distilled water and MC. After drying with $MgSO_4$, filterd and the solvent was evaporated. After column chromatography using MC:n-hexane (1:8) eluent, the titled compound was obtained by recrystallization from methanol as a white powder (1.49 g, yield 63.0%).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.14 (d, J = 7.7 Hz, 2H), 7.45 – 7.37 (m, 4H), 7.28 (t, J = 7.8 Hz, 6H), 7.08 (t, J = 8.1 Hz, 6H), 7.01 (t, J = 7.3 Hz, 2H), 1.28 (s, 9H). MS (APCI) m/z 545.3 [$(M+H)^+$].

5-(tert-butyl)-3-(9H-carbazol-9-yl)-N,N-diphenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (1-6)

2-Bromo-5-(tert-butyl)-3-(9H-carbazol-9-yl)-N,N-diphenylaniline (**1-5**, 1.0 g, 1.83 mmol) was placed in a reaction flask and vacuum dried. Under a nitrogen atmosphere, anhydrous toluene (18 mL) was added to the flask, and the flask was cooled to -20 °C. 2.5 M n-BuLi (1.47 mL, 3.67 mmol) was slowly added, followed by stirring at -20°C for 1 hour. The reaction flask was maintained at -20 °C, and 2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.50 mL, 7.33 mmol) was slowly added. After stirring at room temperature for 1 hour, the organic layer was extracted with distilled water and MC. After drying with $MgSO_4$, filtered and the solvent was evaporated. After column chromatography using MC/n-hexane (1:4) eluent, the title compound was obtained through recrystallization from methanol as a white powder (0.76 g, yield 65.0%)

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.09 (d, *J* = 7.6 Hz, 2H), 7.44 – 7.35 (m, 2H), 7.23 (ddd, *J* = 16.9, 5.8, 1.8 Hz, 10H), 7.14 – 7.08 (m, 4H), 6.92 (t, *J* = 7.3 Hz, 2H), 1.24 (s, 9H), 0.34 (s, 12H). MS (APCI) m/z 593.5 [$(M+H)^+$].

7-(Tert-butyl)-5-phenyl-5H-5,8b-diaza-15b-borabenzo[a]naphtho[1,2,3-hi]aceanthrylene (B-dpa-Cz)

5-(Tert-butyl)-3-(9H-carbazol-9-yl)-N,N-diphenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (**1-6**, 0.55 g, 0.93 mmol) and $AlCl_3$ (0.62 g, 4.64 mmol) were placed in a reaction flask, dried under vacuum and then filled with a nitrogen gas. Anhydrous chlorobenzene (10 mL) and DIPEA (0.32 mL, 1.86 mmol) were added to the flask, and the mixture was stirred at 110 ° C for 2 hours. After completion of the reaction, the organic layer was extracted with distilled water and MC. It was dried over $MgSO_4$, filtered and the solvent was evaporated. After column chromatography using MC/n-hexane (1:4) eluent, the title compound was

obtained through recrystallization from methanol as a yellow powder (0.25 g, yield 56.8%). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.03 (dd, *J* = 7.7, 1.3 Hz, 1H), 8.92 (d, *J* = 7.4 Hz, 1H), 8.43 (d, *J* = 8.4 Hz, 1H), 8.35 (d, *J* = 7.5 Hz, 1H), 8.26 (d, *J* = 7.6 Hz, 1H), 8.16 (d, *J* = 0.9 Hz, 1H), 7.74 (t, *J* = 7.7 Hz, 2H), 7.70 – 7.58 (m, 3H), 7.53 – 7.38 (m, 4H), 7.30 (dd, *J* = 10.8, 3.7 Hz, 1H), 6.81 (d, *J* = 8.6 Hz, 1H), 6.48 (d, *J* = 1.0 Hz, 1H), 1.33 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 156.3, 147.7, 147.5, 143.4, 142.9, 142.3, 139.8, 135.7, 132.8, 131.6, 131.2, 130.6, 128.8, 127.0, 126.8, 123.4, 122.7, 121.9, 121.9, 121.0, 120.1, 117.3, 114.2, 106.6, 103.2, 35.9, 31.4. MS (HR-FAB) m/z : Found 474.2267 [$(M)^+$]. Calculated for $C_{34}H_{27}BN_2$ 474.2268.

2-Bromo-5-(tert-butyl)-3-(9,9-dimethylacridin-10(9H)-yl)-N,N-diphenylaniline (2-1)

2-Bromo-5-(tert-butyl)-3-iodo-N,N-diphenylaniline (**1-4**, 1.25 g, 2.47 mmol), 9,9-Dimethyl-9,10-dihydroacridine (0.43 g, 2.05 mmol), bis(dibenzylideneacetone)-palladium(0) (0.04 g, 0.62 mmol), 2-dicyclohexylphosphino-2',4',6'-triisopropylbiphenyl (Xphos, 0.06 g, 0.12 mmol) and sodium tert-butoxide (0.59 g, 6.18 mmol) were dissolved in toluene (25 mL). The reaction mixture was stirred under reflux for 4 hours under a nitrogen atmosphere. After completion of the reaction, the mixture was extracted with distilled water and MC. After drying with $MgSO_4$, filtered and the solvent was evaporated. After column chromatography using MC/n-hexane (1:8) eluent, the title compound was obtained through recrystallization from methanol as a white powder (0.96 g, yield 79.3%).

^{1}H NMR (500 MHz, CD_2Cl_2) δ 7.41 – 7.36 (m, 1H), 7.25 (d, *J* = 2.3 Hz, 3H), 7.25 (d, 1H) 7.18 (t, *J* = 7.9 Hz, 4H), 6.97 – 6.88 (m, 8H), 6.85 (t, *J* = 7.5 Hz, 2H), 6.09 (d, *J* = 8.2 Hz, 2H), 1.65 (s, 3H), 1.54 (s, 3H), 1.20 (s, 9H). MS (APCI) m/z 557.3 [$(M+H)^+$].

5-(Tert-butyl)-3-(9,9-dimethylacridin-10(9H)-yl)-N,N-diphenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (2-2)

The title compound was synthesized using same snynthetic method of 5-(tert-butyl)-3-(9H-carbazol-9-yl)-N,N-diphenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (**1-6**). 2-bromo-5-(tert-butyl)-3-(9,9-dimethylacridin-10(9H)-yl)-N,N-diphenylaniline (**2-1,** 0.74 g, 1.26 mmol), n-BuLi (1.26 mL, 3.15 mmol), 2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.16 mL, 5.67 mmol) and anhydrous toluene (15 mL) were used. A white powder was obtained as a product (0.67 g, yield 83.5%)

^{1}H NMR (500 MHz, CD_2Cl_2) δ 7.32 (dd, *J* = 7.7, 1.5 Hz, 2H), 7.16 – 7.11 (m, 4H), 7.10 (d, *J* = 1.7 Hz, 1H), 7.01 (dd, *J* = 8.6, 1.0 Hz, 3H), 6.98 (d, *J* = 1.7 Hz, 1H), 6.89 (ddd, *J* = 8.5, 7.3, 1.5 Hz, 2H), 6.83 (t, *J* = 7.3 Hz, 2H), 6.79 – 6.73 (m, 2H), 6.14 (dd, *J* = 8.3, 1.1 Hz, 2H), 3.34 (d, *J* = 5.5 Hz, 1H), 1.59 (t, *J* = 6.9 Hz, 6H), 1.45 (s, 12H), 1.13 (d, *J* = 9.5 Hz, 9H). MS (APCI) m/z 635.4 [$(M+H)^+$].

6-(Tert-butyl)-16,16-dimethyl-8-phenyl-8,16-dihydro-4b,8-diaza-12b-boradibenzo[a,j]perylene (B-dpa-dmAc)

The title compound was synthesized using same snynthetic method of 7-(tert-butyl)-5-phenyl-5H-5,8b-diaza-15b-borabenzo[a]naphtho[1,2,3-hi]aceanthrylene (**B-dpa-Cz**). 5-(tert-butyl)-3-(9,9-dimethylacridin-10(9H)-yl)-N,N-diphenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (**2-2,** 0.34 g, 0.54 mmol), $AlCl_3$ (0.22 g, 1.62 mmol), DIPEA (0.09 mL, 0.54 mmol) and anhydrous toluene (20 mL) were used. A yellow powder was obtained as a product (0.08 g, yield 25.2 %)

^{1}H NMR (500 MHz, CD_2Cl_2) δ 7.65 – 7.61 (m, 2H), 7.51 – 7.47 (m, 2H), 7.46 – 7.41 (m, 3H), 7.38 – 7.29 (m, 4H), 7.28 – 7.20 (m, 2H), 7.20 – 7.14 (m, 2H), 7.09 – 7.04 (m, 2H), 1.50 (s, 6H), 1.18 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.2, 148.0, 146.4, 144.1, 143.9, 142.2,

141.2, 138.2, 135.3, 135.2, 132.8, 131.3, 128.7, 125.9, 125.4, 124.2, 123.9, 122.4, 112.0, 119.6, 117.1, 107.0, 104.9, 37.3, 35.7, 31.2, 31.0, 23.2. MS (HR-FAB) m/z : Found 516.2737 [$(M)^+$]. Calculated for $C_{37}H_{33}BN_2$ 516.2740.

2-Bromo-5-(tert-butyl)-N,N-diphenyl-3-(10H-spiro[acridine-9,9'-fluoren]-10-yl)aniline (3-1)

The title compound was synthesized using same snynthetic method of 2-bromo-5-(tert-butyl)-3-(9,9-dimethylacridin-10(9H)-yl)-N,N-diphenylaniline (**2-1**). 2-bromo-5-(tert-butyl)-3-iodo-N,N-diphenylaniline (**1-4**, 1.1 g, 2.17 mmol), 10H-spiro[acridine-9-9'-fluorene] (0.79 g, 2.39 mmol), bis(dibenzylideneacetone)-palladium(0) (0.04 g, 0.7 mmol), 2-dicyclohexylphosphino-2',4',6'-triisopropylbiphenyl (Xphos, 0.06 g, 0.13 mmol), sodium tert-butoxide (0.42 g, 4.35 mmol) and toluene (20 mL) were used. A white powder was abtained as a product (0.85 g, yield 55.2%).

^{1}H NMR (500 MHz, CD_2Cl_2) δ 7.77 (d, *J* = 7.6 Hz, 1H), 7.73 (d, *J* = 7.5 Hz, 1H), 7.42 (dd, *J* = 9.7, 2.1 Hz, 2H), 7.37 – 7.18 (m, 9H), 7.07 (t, *J* = 7.5 Hz, 1H), 7.00 (d, *J* = 8.3 Hz, 4H), 6.95 – 6.86 (m, 4H), 6.48 (t, *J* = 7.4 Hz, 2H), 6.21 (dd, *J* = 16.6, 8.1 Hz, 4H), 1.26 (s, 9H). MS (APCI) m/z 709.3 [$(M+H)^+$].

5-(Tert-butyl)-N,N-diphenyl-3-(10H-spiro[acridine-9,9'-fluoren]-10-yl)-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (3-2)

The title compound was synthesized using same snynthetic method of 5-(tert-butyl)-3-(9H-carbazol-9-yl)-N,N-diphenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (**1-6**). 2-bromo-5-(tert-butyl)-N,N-diphenyl-3-(10H-spiro[acridine-9,9'-fluoren]-10-yl)aniline (**3-1,** 0.75 g, 1.13 mmol), n-BuLi (1.13 mL, 3.15 mmol), 2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-

dioxaborolane (1.50 mL, 5.64 mmol) and anhydrous toluene (11 mL) were used. A white powder was obtained as a product (0.35 g, yield 43.8%)

^{1}H NMR (500 MHz, CD_2Cl_2) δ 7.78 (d, *J* = 7.6 Hz, 1H), 7.70 (d, *J* = 7.5 Hz, 1H), 7.37 (td, *J* = 7.6, 1.3 Hz, 1H), 7.31 (d, *J* = 7.5 Hz, 1H), 7.26 (d, *J* = 7.0 Hz, 1H), 7.24 – 7.20 (m, 2H), 7.17 (ddd, *J* = 7.1, 4.5, 1.8 Hz, 6H), 7.12 (td, *J* = 7.5, 1.0 Hz, 1H), 7.09 – 7.04 (m, 4H), 6.92 – 6.84 (m, 4H), 6.45 – 6.40 (m, 2H), 6.35 (dd, *J* = 8.4, 0.8 Hz, 2H), 6.21 (dd, *J* = 7.8, 1.5 Hz, 2H), 1.20 (s, 9H), 0.59 (s, 12H). MS (APCI) m/z 756.5 [$(M+H)^+$].

6-(Tert-butyl)-8-phenyl-8H-spiro[4b,8-diaza-12b-boradibenzo[a,j]perylene-16,9'-fluorene] (B-dpa-SpiroAc)

The title compound was synthesized using same snynthetic method of 7-(tert-butyl)-5-phenyl-5H-5,8b-diaza-15b-borabenzo[a]naphtho[1,2,3-hi]aceanthrylene (**B-dpa-Cz**). 5-(tert-butyl)-N,N-diphenyl-3-(10H-spiro[acridine-9,9'-fluoren]-10-yl)-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (**3-2,** 0.35 g, 0.46 mmol), $AlCl_3$ (0.31 g, 2.31 mmol), DIPEA (0.16 mL, 0.92 mmol) and anhydrous toluene (20 mL) were used. A yellow powder was obtained as a product (0.15 g, yield 50.0 %)

^{1}H NMR (500 MHz, CD_2Cl_2) δ 8.66 (d, *J* = 7.5 Hz, 1H), 8.41 (d, *J* = 7.4 Hz, 1H), 7.89 (d, *J* = 7.7 Hz, 1H), 7.75 (d, *J* = 8.3 Hz, 1H), 7.72 – 7.65 (m, 2H), 7.64 (s, 1H), 7.59 (t, *J* = 7.5 Hz, 1H), 7.54 (t, *J* = 7.4 Hz, 1H), 7.48 – 7.37 (m, 4H), 7.28 (s, 1H), 7.21 – 7.12 (m, 2H), 7.09 (t, *J* = 7.1 Hz, 1H), 7.01 (t, *J* = 7.5 Hz, 1H), 6.88 – 6.75 (m, 4H), 6.66 (d, *J* = 7.8 Hz, 1H), 6.36 (s, 1H), 1.13 (s, 9H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 155.5, 153.6, 149.5, 148.0, 146.4, 144.3, 142.9, 142.1, 141.1, 137.5, 135.2, 134.3, 134.0, 131.4, 131.1, 128.8, 128.4, 128.2, 127.7, 126.8, 126.6, 124.1, 123.7, 122.4, 120.3, 120.2, 120.1, 112.0, 117.2, 107.0, 105.2, 58.5, 35.8, 31.2, 30.0. MS (HR-FAB) m/z : Found 638.2893 [$(M)^+$]. Calculated for $C_{47}H_{35}BN_2$ 638.2896.

Device fabrication and measurements

Device configuration is as follows : ITO (50 nm)/ PEDOT:PSS(40 nm)/ TAPC (5 nm)/ TCTA (5 nm)/ PCZAC (5 nm)/ mCBP:mCBP-CN:Emitters (50 :50 w%: x w%) (25 nm)/ TSPO1 (5 nm)/ TPBi (20 nm)/ LiF (1.5 nm)/ Al (200 nm). Here, ITO is indium tin oxide, PEDOT: PSS is poly(3,4-ethylenedioxythiophene): poly(styrene sulfonate), TAPC is 1,1-bis[(di-4-tolylamino)phenyl]-cyclohexane, TCTA is tris(4-carbazoyl-9-ylphenyl)amine, PCZAC is 1,3-di(9H-carbazol-9-yl)benzene, mCBP is 3,3'-di(9*H*-carbazol-9-yl)-1,1'-biphenyl, mCBP-CN is 3',5-di(9H-carbazol-9-yl)-[1,1'-biphenyl]-3-carbonitrile, TSPO1 is diphenyl(4-(triphenylsilyl) phenyl)phosphine oxide, and TPBi is 2,2′,2″-(1,3,5-benzinetriyl)-tris(1-phenyl-1H-benzimidazole. All fabrication processes of devices used vacuum thermal evaporation. Device performance measurements were made using encapsulated devices under ambient condition. Keithley 2400 and CS 1000 (Konica Minolta Inc.) were used to measure electrical and optical properites.

Figure S1. Emission spectra of (a) B-dpa-Cz, (b) B-dpa-dmAc and (c) B-dpa-SpiroAc in different solvents.

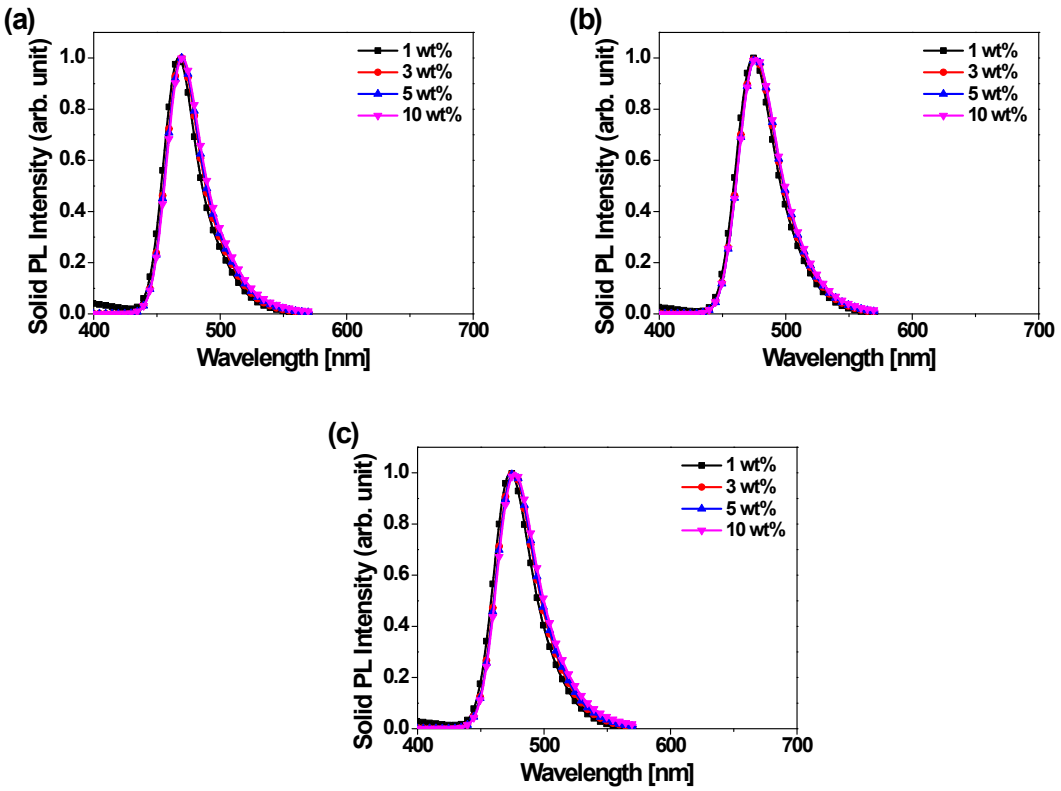


Figure S2. Emission spectra of 1, 3, 5, 10 wt% of (a) B-dpa-Cz, (b) B-dpa-dmAc and (c) B-dpa-SpiroAc doped in mCBP films.

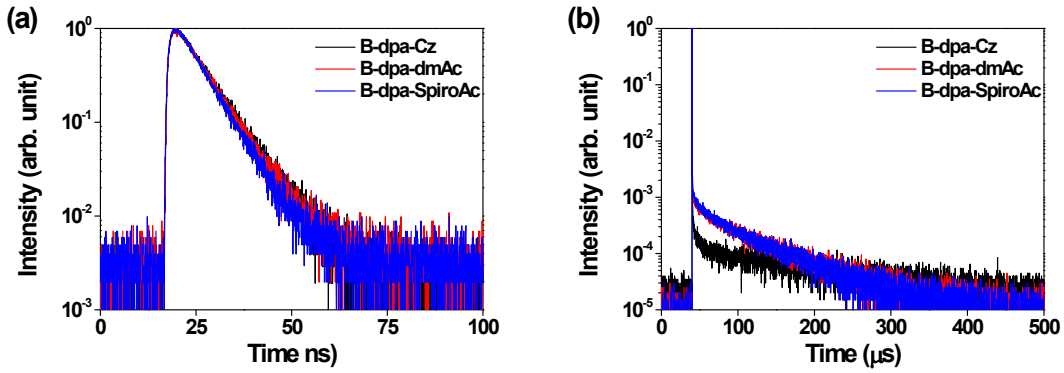


Figure S3. Transient photoluminescence decay cures of 3 wt% B-dpa-Cz, B-dpa-dmAc and B-dpa-SpiroAc doped mCBP films.

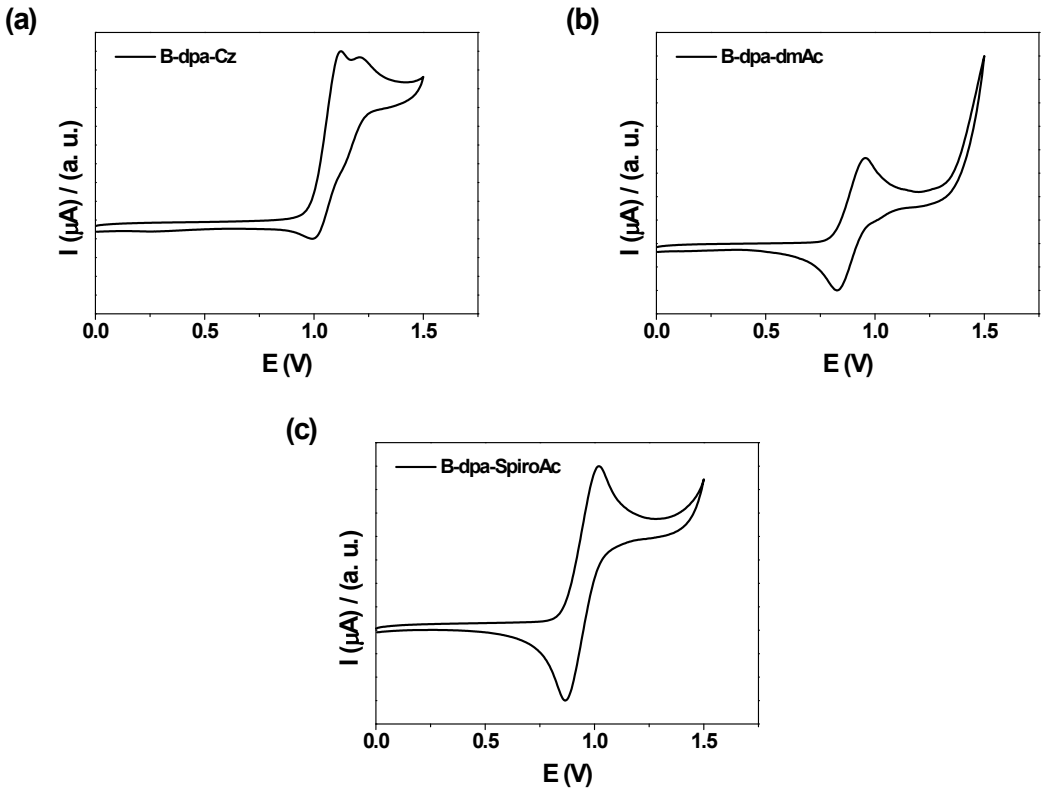


Figure S4. Cyclic voltammetry data for the oxidation of (a) B-dpa-Cz, (b) B-dpa-dmAc and (c) B-dpa-SpiroAc.

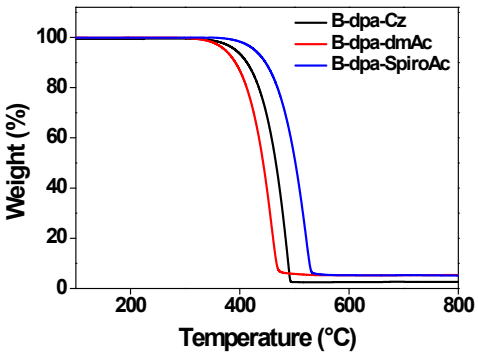


Figure S5. Thermogravimetric analysis data of B-dpa-Cz, B-dpa-dmAc and B-dpa-SpiroAc.

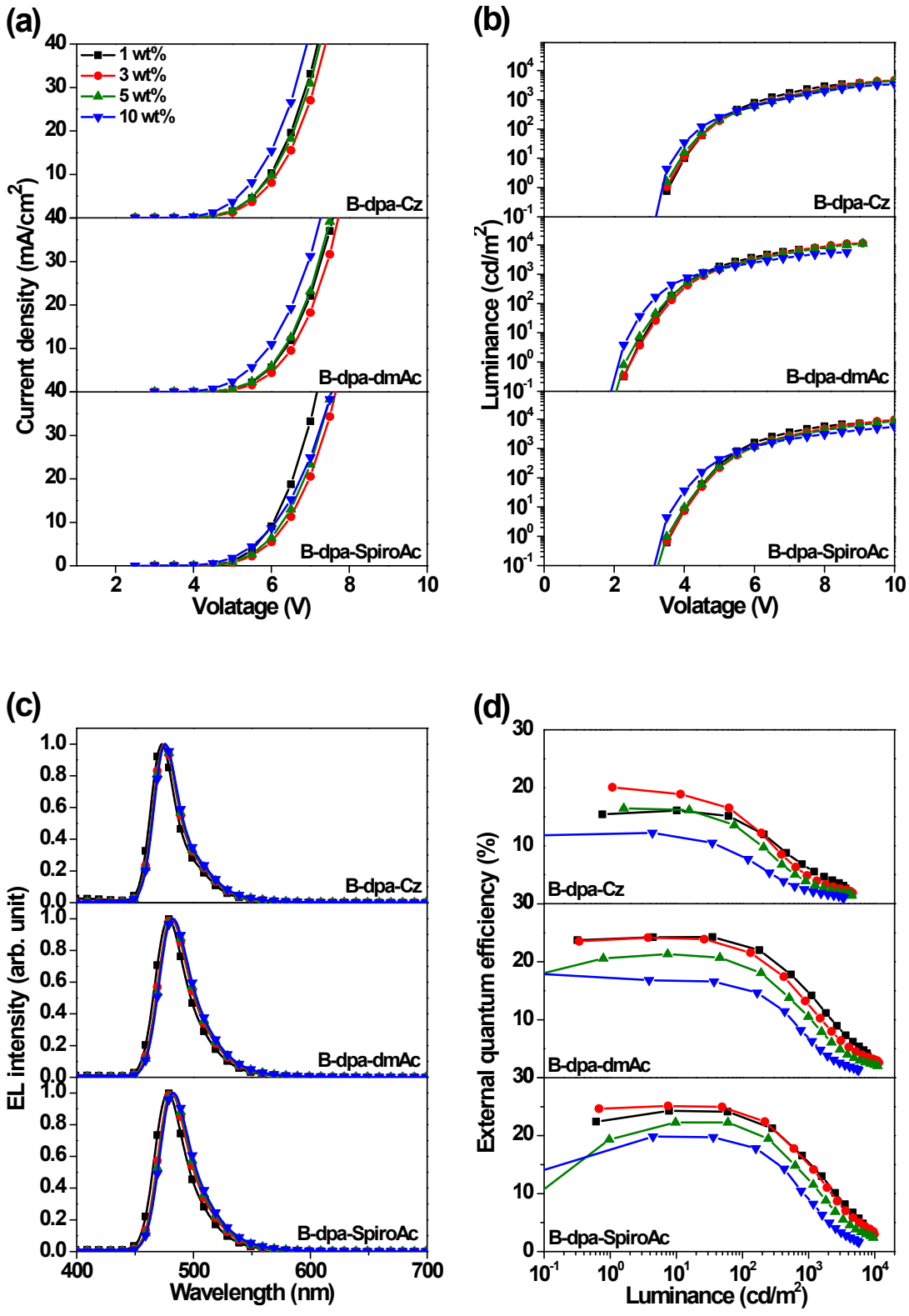


Figure S6. EL characteristics of 1 to 10 wt% doping concentration of emitters. (a) Current (*J*)-voltage (*V*) characteristics, (b) Current (*J*)-luminance (*L*) characteristics, (c) EL spectra and (d) External quantum efficiency-luminance (EQE-*L*) data.

Table S1. Summarized emission peak and FWHM of B-dpa-Cz, B-dpa-dmAc and B-dpa-SpiroAc in different solvents.

Compund	n-hexane / FWHM (nm)	toluene / FWHM (nm)	THF / FWHM (nm)	MC / FWHM (nm)
B-dpa-Cz	455 / 22	466 / 27	458 / 28	474 / 32
B-dpa-dmAc	463 / 29	472 / 31	473 / 33	483 / 39
B-dpa-SpiroAc	464 / 29	472 / 31	474 / 33	483 / 38

Table S2. Summarized emission peak and FWHM of 1, 3, 5, 10 wt% of B-dpa-Cz, B-dpa-dmAc and B-dpa-SpiroAc doped in mCBP films.

Compund	1wt% / FWHM (nm)	3 wt% / FWHM (nm)	5 wt% / FWHM (nm)	10 wt% / FWHM (nm)
B-dpa-Cz	468/32	469/33	470/34	470/34
B-dpa-dmAc	475/37	476/38	477/38	477/39
B-dpa-SpiroAc	474/37	476/38	476/38	477/39

Table S3. Absolute PLQY and rate constant calculations for B-dpa-Cz, B-dpa-dmAc and B-dpa-SpiroAc.

Compund	Φ_{total}[a] (%)	Φ_p[b] (%)	Φ_d[b] (%)	τ_p[c] (ns)	τ_d[d] (μs)	k_r[e] (10^7 s^{-1})	k_{nr}[f] (10^3 s^{-1})	k_{ISC}[g] (10^7 s^{-1})	k_{RISC}[h] (10^4 s^{-1})
B-dpa-Cz	0.94	0.42	0.52	7.0	78	6.00	1.33	8.29	2.74
B-dpa-dmAc	0.98	0.36	0.62	6.8	60	5.29	0.52	9.41	4.48
B-dpa-SpiroAc	0.92	0.34	0.58	6.3	52	5.40	2.33	10.5	4.97

[a] Absolute photoluminescence quantum yield.

[b] Prompt and delayed components.

[c] Prompt decay lifetime.

[d] Delayed fluorescence lifetime.

[e] Radiative decay rate constant.

[f] Non-radiative decay rate constant.

[g] Intersystem crossing rate constant from S_1 to T_1.

[h] Reverse intersystem crossing rate constant.

Reference

1. J. Park, J. Lim, J. H. Lee, B. Jang, J. H. Han, S. S. Yoon and J. Y. Lee, *ACS Appl. Mater. Interfaces*, 2021, **13**, 45798-45805.