Supplementary Material (ESI) for Chemical Communications

Synthetic Method for Multifunctionalized Oligoarenes Using Pinacol Esters of Hydroxyphenylboronic Acids

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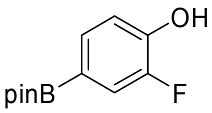
Supplementary Information

Table of Contents

Experimental

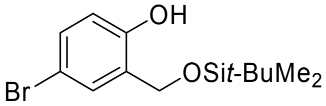
General: Melting points were uncorrected. $CDCl_3$ was used as a solvent for ^1H and ^{13}C NMR spectra. For ^1H NMR, tetramethylsilane (TMS) ($\delta = 0$) in $CDCl_3$ served as an internal standard. For ^{13}C NMR, $CDCl_3$ ($\delta = 77.00$) served as an internal standard. Preparative thin-layer chromatography (TLC) was carried out using silica gel 60 F_{254}, 0.5 mm coated glass plates (Merck). FAB-MS spectra were measured using 3-nitrobenzyl alcohol as the matrix. THF (dry) was purchased from Kanto. Distilled water was used as a solvent for aqueous reactions. All reaction solvents were bubbled with Ar before use, and THF/H_2O (4/1) solution was prepared by mixing 6 mL of THF and 1.5 mL of H_2O before adding to the reaction vessel.

Synthesis of Pinacol Esters of Boronic Acids



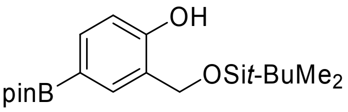
2-Fluoro-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol: *t*-BuLi (1.59 M in pentane, 12.0 mL, 19.1 mmol) was slowly added to a solution of 4-bromo-2-fluorophenol (1.11 g, 5.81 mmol) in Et_2O (12.0 mL) at –78 ˚C for 8 min, and the whole was stirred for 30 min. 2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.42 mL, 6.96 mmol) was added for 2 min. After stirring at –78 ˚C for 35 min, the mixture was allowed to warm to rt and then stirred at rt for 80 min. After addition of 5% aq. HCl (20 mL), the organic products were extracted with EtOAc (40 mL), washed with brine, dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, EtOAc/hexane = 1/15 to 1/5) gave the desired product as colorless fine plates in 52% yield (0.72 g).

Mp 99.3-100.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.33 (12H, s), 5.42 (12H, s), 6.99 (1H, t, *J* = 8.0 Hz), 7.48-7.51 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.81, 83.90, 116.75, 121.33 (d, *J* = 15.6 Hz), 131.84 (d, *J* = 4.1 Hz), 146.25 (d, *J* = 14.8 Hz), 150.72 (d, *J* = 236.1 Hz) (one carbon signal (C-B) was not observed due to broadening); IR (ATR) 3253, 2979, 1616, 1348, 1217, 1138 cm^{-1}; MS (FAB) m/z 238 (M^+); Anal. calcd. for $C_{12}H_{16}BFO_3$: C, 60.54; H, 6.77, found: C, 60.36; H, 6.87.

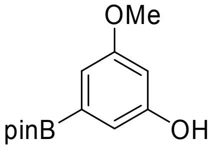


4-Bromo-2-(*t*-butyldimethylsilyloxymethyl)phenol: To a solution of 4-bromo-2-hydroxymethylphenol (2.04 g, 10.0 mmol), 4-dimethylaminopyridine (49.1 mg, 0.402 mmol), and triethylamine (1.68 mL, 12.1 mmol) in CH_2Cl_2 (10.0 mL) was added *t*-butyldimethylsilyl chloride (1.67 g, 11.1 mmol) at rt, and the whole was stirred for 18 h. EtOAc (40 mL) was added, the mixture was washed with 5% aq. HCl, water, satd. aq. $NaHCO_3$, and brine, dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, CH_2Cl_2/hexane = 1/2) gave the desired product as a colorless oil in 68% yield (2.16 g).

^{1}H NMR (400 MHz, $CDCl_3$) δ 0.14 (6H, s), 0.93 (9H, s), 4.85 (2H, s), 6.75 (1H, d, *J* = 8.4 Hz), 7.07 (1H, d, *J* = 2.4 Hz), 7.26 (1H, dd, *J* = 8.4, 2.4 Hz), 8.09 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ -5.57, 18.09, 25.66, 65.29, 111.36, 118.51, 126.00, 129.23, 131.58, 155.78; IR (neat) 3349, 2954, 2930, 2858, 1486, 1242, 1056, 835 cm^{-1}; MS (FAB) m/z 316, 318 (M^+); Anal. calcd. for $C_{13}H_{21}BrO_2Si$: C, 49.21; H, 6.67, found: C, 48.96; H, 6.50.

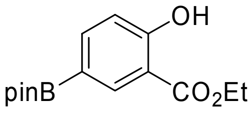


2-(*t*-Butyldimethylsilyloxymethyl)-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol: *t*-BuLi (1.59 M in pentane, 6.9 mL, 11.0 mmol) was slowly added to a solution of 4-bromo-2-(*t*-butyldimethylsilyloxymethyl)phenol (1.05 g, 3.31 mmol) in Et_2O (7.0 mL) at –78 ˚C for 6 min, and the whole was stirred for 30 min. 2-Isopropoxy-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.35 mL, 6.62 mmol) was added for 5 min. After stirring at –78 ˚C for 30 min, the mixture was allowed to warm to 0 ˚C. After 90 min, 5% aq. HCl (10 mL) was added, and the organic products were extracted with EtOAc (40 mL), washed with satd. aq. $NaHCO_3$ and brine, dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, CH_2Cl_2/hexane = 1/2 to 2/1 and then EtOAc/CH_2Cl_2 = 1/20 to 1/10) gave the desired product as a white solid in 51% yield (0.62 g). Mp 73.6-76.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.13 (6H, s), 0.92 (9H, s), 1.33 (12H, s), 4.93 (2H, s), 6.87 (1H, d, J = 8.4 Hz), 7.40 (1H, s), 7.65 (1H, d, J = 8.4 Hz), 8.46 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ -5.58, 18.09, 24.84, 25.70, 66.01, 83.53, 116.24, 123.29, 133.42, 136.01, 159.72 (one carbon signal (C-B) was not observed due to broadening); IR (ATR) 3336, 2927, 1352, 1246, 837, 777 cm^{-1}; HRMS (FAB) m/z calcd for $C_{19}H_{33}BO_4Si$ (M^+): 364.2241; found: 364.2231.



3-Methoxy-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol: 3-Methoxyphenol (336 mg, 2.70 mmol), bis(pinacolato)diboron (687 mg, 2.70 mmol), 4,4'-di-*t*-butyl-2,2'-bipyridine (21.7 mg, 0.0809 mmol), and $[Ir(OMe)(cod)]_2$ (26.7 mg, 0.0403 mmol) were placed in a flask, and the whole was heated at 80 ˚C for 21 h. After cooling to rt, the mixture was dissolved in EtOAc (30 mL), washed with water (10 mL x 2) and brine, dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, EtOAc/CH_2Cl_2 = 1/50 to 1/20) gave the desired product as a pale yellow solid in 33% yield (225 mg).

Mp 97.0-99.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.34 (12H, s), 3.80 (3H, s), 4.84 (1H, s), 6.52 (1H, s), 6.85 (1H, s), 6.92 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 24.82, 55.40, 83.94, 105.07, 111.47, 113.76, 156.23, 160.62 (one carbon signal (C-B) was not observed due to broadening); IR (ATR) 3330, 2970, 1738, 1375, 1140 cm^{-1}; MS (FAB) m/z 250 (M^+); Anal. calcd. for $C_{13}H_{19}BO_4$: C, 62.43; H, 7.66, found: C, 62.40; H, 7.77.

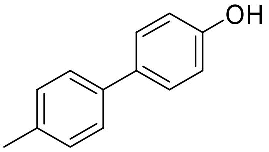


Ethyl 5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)salicylate: To a suspension of ethyl 5-iodosalicylate (3.07 g, 10.5 mmol), $PdCl_2(dppf) \bullet CH_2Cl_2$ (0.26 g, 0.318 mmol), and triethylamine (5.90 mL, 42.3 mmol) was added pinacolborane (3.80 mL, 26.2 mmol) at rt for 1 min. The mixture was heated under reflux for 2 h. After cooling to 0 ˚C, water (30 mL) was slowly added, and EtOAc (100 mL) and 10% aq. HCl (30 mL) were also added. The organic layer was washed with water and brine, dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, EtOAc/hexane = 1/15 and then silica gel, CH_2Cl_2/hexane = 1/2 to 1/0 and then EtOAc/CH_2Cl_2 = 1/10) gave the desired product as a white solid in 39% yield (1.20 g).

Mp 98.1-101.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.34 (12H, s), 1.43 (3H, t, *J* = 7.2 Hz), 4.42 (2H, q, *J* = 7.2 Hz), 6.96 (1H, d, *J* = 8.0 Hz), 7.88 (1H, d, *J* = 8.0 Hz), 8.30 (1H, s), 11.15 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.28, 24.82, 61.43, 83.83, 112.31, 117.03, 137.17, 141.90, 164.13, 170.36 (one carbon signal (C-B) was not observed due to broadening); IR (ATR) 2979, 1670, 1591, 1356, 1286 cm^{-1}; MS (FAB) m/z 292 (M^+); Anal. calcd. for $C_{15}H_{21}BO_5$: C, 61.67; H, 7.25, found: C, 61.72; H, 7.17.

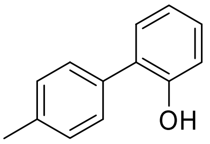
Optimization of Cross-Coupling Conditions (Table 1)

p-Tolyl trifluoromethanesulfonate (**1**) (120 mg, 0.500 mmol), **2** (0.600 mmol), base (1.65 mmol or 1.20 mmol), $Pd(OAc)_2$ (2.2 mg, 0.0100 mmol), and ligand (0.0120 mmol) were placed in a flask, and then evacuated and backfilled with argon. Solvents (0.50 mL) were added, and the whole was stirred at rt for the indicated amount of time. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. The yield of the desired product was determined by crude NMR using durene as an internal standard. Isolation of the desired product was possible by preparative TLC (silica gel, CH_2Cl_2).



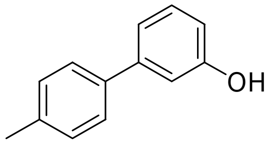
4'-methylbiphenyl-4-ol:[1] ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.38 (3H, s), 5.01 (1H, brs), 6.88 (2H, d, *J* = 8.4 Hz), 7.22 (2H, d, *J* = 8.0 Hz), 7.43 (2H, d, *J* = 8.0 Hz), 7.45 (2H, d, *J* = 8.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.01, 115.57, 126.53, 128.16, 129.41, 133.93, 136.38, 137.86, 154.80.

Cross-Coupling of Various Substrates (Table 2)



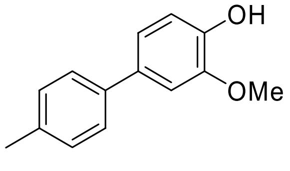
4'-Methylbiphenyl-2-ol:[1] *p*-Tolyl trifluoromethanesulfonate (124 mg, 0.515 mmol), 2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol (149 mg, 0.670 mmol), LiOH•H_2O (51.9 mg, 1.24 mmol), $Pd(OAc)_2$ (2.3 mg, 10.3 μmol), and **6** (4.3 mg, 12.4 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.52 mL) was added, and the whole was stirred at rt for 2 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, EtOAc/hexane = 1/5) gave the desired product as a colorless oil in 97% yield (91.7 mg).

^{1}H NMR (400 MHz, $CDCl_3$) δ 2.39 (3H, s), 5.27 (1H, brs), 6.95 (1H, d, *J* = 7.6 Hz), 6.95-6.99 (1H, m), 7.22 (1H, d, *J* = 7.8 Hz), 7.21-7.25 (1H, m), 7.27 (2H, d, *J* = 8.0 Hz), 7.34 (2H, d, *J* = 8.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.15, 115.68, 120.74, 128.06, 128.90, 129.92, 129.95, 130.16, 134.00, 137.65, 152.44.



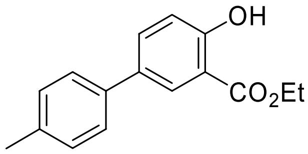
4'-Methylbiphenyl-3-ol: *p*-Tolyl trifluoromethanesulfonate (117 mg, 0.488 mmol), 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol (140 mg, 0.635 mmol), LiOH•H_2O (49.2 mg, 1.17 mmol), $Pd(OAc)_2$ (2.2 mg, 9.77 μmol), and **6** (4.1 mg, 11.7 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.49 mL) was added, and the whole was stirred at rt for 4 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, CH_2Cl_2/EtOAc = 20/1) gave the desired product as a white solid in 96% yield (86.4 mg).

Mp 75.2-75.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.39 (3H, s), 4.87 (1H, brs), 6.79 (1H, ddd, *J* = 8.0, 2.4, 0.8 Hz), 7.04 (1H, t, *J* = 2.4 Hz), 7.15 (1H, dt, *J* = 8.0, 0.8), 7.23 (2H, d, *J* = 8.0 Hz), 7.28 (1H, t, *J* = 8.0 Hz), 7.46 (2H, d, *J* = 8.0 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 21.09, 113.87, 119.58, 126.92, 129.46, 129.92, 137.29, 137.80, 142.93, 155.75 (one peak is overlapped); IR (KBr) 3301, 1588, 1478, 1300, 1192 cm^{-1}; MS (ESI) m/z 185 (M+H$^+$); Anal. calcd. for $C_{13}H_{12}O$: C, 84.75; H, 6.57, found: C, 84.51; H, 6.81.



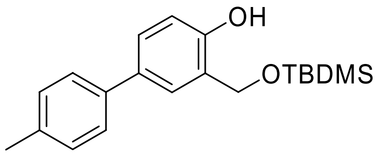
3-Methoxy-4'-methylbiphenyl-4-ol: *p*-Tolyl trifluoromethanesulfonate (108 mg, 0.451 mmol), 2-methoxy-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol (147 mg, 0.587 mmol), LiOH•H_2O (45.4 mg, 1.08 mmol), $Pd(OAc)_2$ (2.0 mg, 9.03 μmol), and **6** (3.8 mg, 10.8 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.45 mL) was added, and the whole was stirred at rt for 4 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, CH_2Cl_2/hexane = 1/1, and EtOAc/hexane = 1/3) gave the desired product as a white solid in 98% yield (94.5 mg).

Mp 76.2-76.6 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.35 (3H, s), 3.86 (3H, s), 5.74 (1H, brs), 6.96 (1H, d, J = 7.8 Hz), 7.03 (1H, d, J = 2.0 Hz), 7.06 (1H, dd, J = 7.8, 2.0 Hz), 7.18 (2H, d, J = 8.3 Hz), 7.41 (2H, d, J = 8.3 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.95, 55.88, 109.67, 114.79, 119.98, 126.70, 129.49, 133.77, 136.49, 138.40, 145.10, 146.83; IR (ATR) 3408, 1498, 1207, 806 cm^{-1}; MS (FAB) m/z 214 (M^+); Anal. calcd. for $C_{14}H_{14}O_2$: C, 78.48; H, 6.59, found: C, 78.30; H, 6.62.



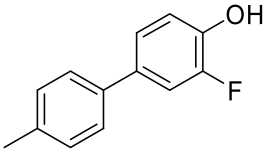
Ethyl 4-hydroxy-4'-methylbiphenyl-3-carboxylate: *p*-Tolyl trifluoromethanesulfonate (92.4 mg, 0.385 mmol), ethyl 5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)salicylate (146 mg, 0.500 mmol), LiOH•H_2O (38.7 mg, 0.923 mmol), Pd$(OAc)_2$ (1.7 mg, 7.69 μmol), and **6** (3.2 mg, 9.23 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.38 mL) was added, and the whole was stirred at rt for 6 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, CH_2Cl_2/hexane = 1/3) gave the desired product as a colorless oil in 93% yield (91.4 mg).

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.43 (3H, t, J = 7.2 Hz), 2.39 (3H, s), 4.44 (2H, q, J = 7.2 Hz), 7.04 (1H, d, J = 8.8 Hz), 7.24 (2H, d, J = 8.0 Hz), 7.44 (2H, d, J = 8.0 Hz), 7.67 (1H, dd, J = 2.4, 8.8 Hz), 8.04 (1H, d, J = 2.4 Hz), 10.84 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.23, 21.04, 61.52, 112.69, 117.92, 126.49, 127.89, 129.51, 132.37, 134.20, 136.78, 137.12, 160.85, 170.20; IR (neat) 3160, 2983, 1676, 1482, 1333, 1207, 1093, 814 cm^{-1}; MS (FAB) m/z 256 (M^+); Anal. calcd. for $C_{16}H_{16}O_3$: C, 74.98; H, 6.29, found: C, 74.95; H, 6.30.



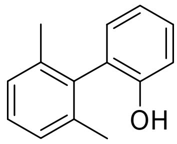
3-*t*-Butyldimethylsilyloxymethyl-4'-methylbiphenyl-4-ol: *p*-Tolyl trifluoromethanesulfonate (81.1 mg, 0.338 mmol), 2-*t*-Butyldimethylsilyloxymethyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol (160 mg, 0.439 mmol), LiOH•H_2O (34.0 mg, 0.810 mmol), $Pd(OAc)_2$ (1.5 mg, 6.75 μmol), and **6** (2.8 mg, 8.10 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.34 mL) was added, and the whole was stirred at rt for 8 h. After adding H_2O (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, CH_2Cl_2/hexane = 1/2) gave the desired product as a yellow oil in 84% yield (92.7 mg).

^{1}H NMR (400 MHz, $CDCl_3$) δ 0.16 (6H, s), 0.94 (9H, s), 2.37 (3H, s), 4.96 (2H, s), 6.93 (1H, d, J = 8.4 Hz), 7.16 (1H, d, J = 2.4 Hz), 7.21 (2H, d, J = 8.0 Hz), 7.40 (1H, dd, J = 2.4, 8.4 Hz), 7.42 (2H, d, J = 8.0 Hz), 8.10 (1H, s); ^{13}C NMR (100 MHz, $CDCl_3$) δ -5.53, 18.13, 21.02, 25.71, 66.06, 116.97, 124.19, 125.16, 126.48, 127.38, 129.39, 132.75, 136.27, 137.95, 156.00; IR (neat) 3358, 2954, 2929, 2858, 1495, 1260, 1057, 1038, 836, 812 cm^{-1}; MS (FAB) m/z 328 (M^+); Anal. calcd. for $C_{20}H_{28}O_2Si$: C, 73.12; H, 8.59, found: C, 73.19; H, 8.60.



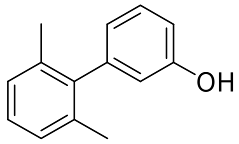
3-Fluoro-4'-methylbiphenyl-4-ol: *p*-Tolyl trifluoromethanesulfonate (102 mg, 0.424 mmol), 2-fluoro-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol (131 mg, 0.552 mmol), LiOH•H_2O (42.7 mg, 1.02 mmol), $Pd(OAc)_2$ (1.9 mg, 8.48 μmol), and **6** (3.6 mg, 10.2 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.42 mL) was added, and the whole was stirred at rt for 2 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, CH_2Cl_2/hexane = 2/1) gave the desired product as a white solid in 98% yield (85.1 mg).

Mp 115.5-116.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.38 (3H, s), 5.05 (1H, d, J = 4.4 Hz), 7.04 (1H, dd, J = 8.0, 8.2 Hz), 7.22 (2H, d, J = 8.0 Hz), 7.25 (1H, dd, J = 2.4, 8.0 Hz), 7.30 (1H, dd, J = 2.4, 11.6 Hz), 7.41 (2H, d, J = 8.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.04, 113.90 (d, J = 18.2 Hz), 117.38, 123.12 (d, J = 3.3 Hz), 126.51, 129.52, 134.52 (d, J = 4.9 Hz), 136.86, 136.99, 142.56 (d, J = 14.9 Hz), 151.14 (d, J = 238 Hz); IR (ATR) 3379, 1500, 806, 781 cm^{-1}; MS (FAB) m/z 202 (M^+); Anal. calcd. for $C_{13}H_{11}FO$: C, 77.21; H, 5.48, found: C, 77.28; H, 5.48.



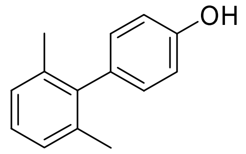
2',6'-Dimethylbiphenyl-2-ol: 2,6-Dimethylphenyl trifluoromethanesulfonate[2] (124 mg, 0.487 mmol), 2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol (139 mg, 0.633 mmol), $LiOH•H_2O$ (49.0 mg, 1.17 mmol), $Pd(OAc)_2$ (2.2 mg, 9.74 μmol), and **6** (4.1 mg, 11.7 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.49 mL) was added, and the whole was stirred at rt for 2 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, EtOAc/hexane = 1/5) gave the desired product as a colorless oil in 90% yield (87.3 mg).

^1H NMR (400 MHz, $CDCl_3$) δ 2.03 (6H, s), 4.64 (1H, brs), 6.95-7.01 (3H, m), 7.12-7.21 (3H, m), 7.27 (1H, ddd, J = 2.2, 6.4, 8.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.27, 115.26, 120.74, 126.33, 127.84, 128.32, 128.98, 129.72, 134.79, 137.95, 152.23; IR (neat) 3489, 3426, 1489, 1466, 1224, 756 cm^{-1}; MS (FAB) m/z 198 (M^+); Anal. calcd. for $C_{14}H_{14}O$: C, 84.81; H, 7.12, found: C, 84.43; H, 7.19.



2',6'-Dimethylbiphenyl-3-ol: 2,6-Dimethylphenyl trifluoromethanesulfonate (111 mg, 0.438 mmol), 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol (125 mg, 0.569 mmol), $LiOH•H_2O$ (44.1 mg, 1.05 mmol), $Pd(OAc)_2$ (2.0 mg, 8.76 μmol), and **6** (3.7 mg, 10.5 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.44 mL) was added, and the whole was stirred at rt for 2 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, EtOAc/hexane = 1/5) gave the desired product as a colorless oil in 99% yield (86.1 mg).

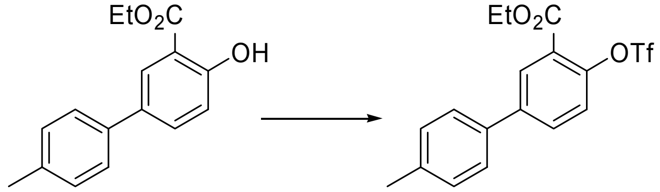
^1H NMR (400 MHz, $CDCl_3$) δ 2.03 (6H, s), 5.12 (1H, brs), 6.61 (1H, dd, J = 1.2, 2.4 z), 6.70 (1H, dt, J = 8.0, 1.2 Hz), 6.79 (1H, ddd, J = 1.2, 2.4, 8.0 Hz), 7.07-7.17 (3H, m), 7.27 (1H, t, J = 8.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.68, 113.55, 115.88, 121.64, 127.05, 127.20, 129.70, 135.94, 141.34, 142.77, 155.40; IR (neat) 3348, 3061, 2921, 1583, 1445, 1289, 1190, 882, 771 cm^{-1}; MS (FAB) m/z 198 (M$^+$); Anal. calcd. for $C_{14}H_{14}O$: C, 84.81; H, 7.12, found: C, 84.50; H, 7.05.



2',6'-Dimethylbiphenyl-4-ol: 2,6-Dimethylphenyl trifluoromethanesulfonate (124 mg, 0.486 mmol), 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenol (139 mg, 0.632 mmol), LiOH•H_2O (48.9 mg, 1.17 mmol), Pd(OAc)$_2$ (2.2 mg, 9.72 μmol), and **6** (4.1 mg, 11.7 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.49 mL) was added, and the whole was stirred at rt for 2 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, EtOAc/hexane = 1/5) gave the desired product as a white solid in 97% yield (93.7 mg).

Mp 95.4-96.2 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.04 (6H, s), 4.72 (1H, brs), 6.89 (2H, d, *J* = 8.8 Hz), 7.01 (2H, d, *J* = 8.8 Hz), 7.08-7.17 (3H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.86, 115.29, 126.89, 127.22, 130.25, 133.50, 136.48, 141.37, 154.09; MS (FAB) m/z 198 (M$^+$); IR (ATR) 3302, 1225, 831, 769 cm^{-1}; Anal. calcd. for $C_{14}H_{14}O$: C, 84.81; H, 7.12, found: C, 84.49; H, 7.25.

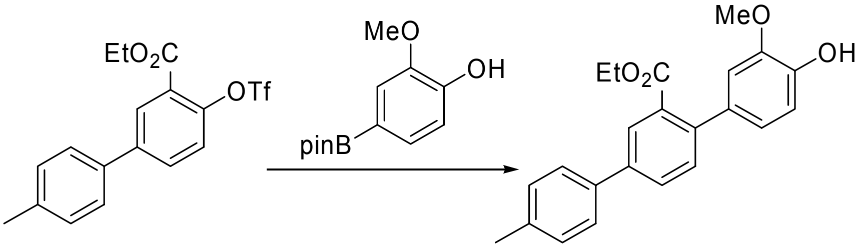
Synthesis of Multifunctionalized Oligoarene (Scheme 1)



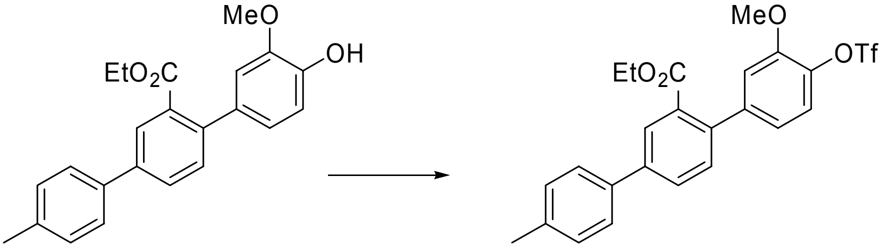
Trifluoromethanesulfonic anhydride (0.36 mL, 2.13 mmol) was added slowly to a solution of the phenol (454 g, 1.77 mmol) and pyridine (215 μL, 2.66 mmol) in CH_2Cl_2 (1.77 mL) at 0 °C. After 5 min, the ice-bath was removed and the mixture was stirred for an additional 55 min at rt. After adding 10% aq. HCl (10 mL), the product was extracted with EtOAc (30 mL). The organic layer was washed with water (10 mL x 2) and brine (10 mL) successively, dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, EtOAc/hexane = 1/30) gave the desired product as a white solid in 98% yield (675 mg).

Mp 55.5-56.7 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.43 (3H, t, *J* = 7.2 Hz), 2.40 (3H, s), 4.47 (2H, q, *J* = 7.2 Hz), 7.28 (2H, d, *J* = 8.2 Hz), 7.33 (1H, d, *J* = 8.0 Hz), 7.48 (2H, d, *J* = 8.2 Hz), 7.76

(1H, dd, $J = 2.4, 8.0$ Hz), 8.25 (1H, d, $J = 2.4$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.03, 21.08, 62.21, 118.7 (q, $J = 322$ Hz), 122.94, 124.95, 126.96, 129.79, 130.89, 132.02, 135.35, 138.47, 141.60, 147.14, 163.85; IR (ATR) 1714, 1211, 1134, 812 cm^{-1}; MS (FAB) m/z 388 (M^+); Anal. calcd. for $C_{17}H_{15}F_3O_5S$: C, 52.58; H, 3.89, found: C, 52.61; H, 4.13.

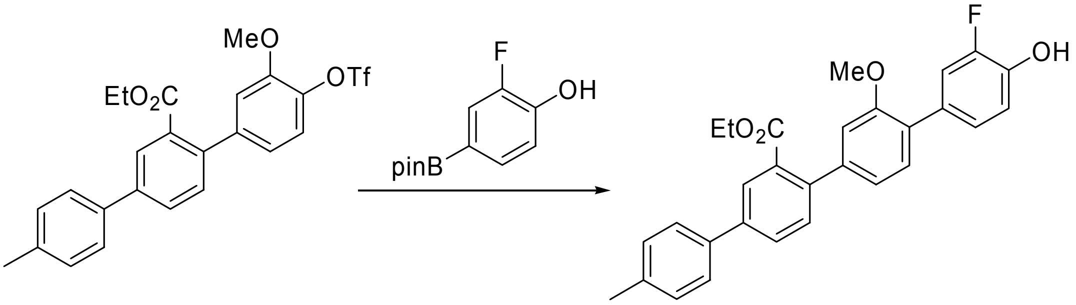


The triflate (519 mg, 1.34 mmol), the boronic ester (435 mg, 1.74 mmol), LiOH•H_2O (135 mg, 3.21 mmol), $Pd(OAc)_2$ (6.0 mg, 26.7 μmol), and **6** (11.2 mg, 32.1 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (1.34 mL) was added, and the whole was stirred at rt for 4 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, EtOAc/hexane 1/4) gave two fractions. The first fraction contained the mixture and the second fraction contained only the desired product (247 mg). Further purification of the former fraction by preparative TLC (silica gel, EtOAc/hexane = 1/3) gave the desired product (216 mg). Thus, the desired product was obtained as a white solid in 96% yield (463 mg).
Mp 116.8-119.4 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.08 (3H, t, $J = 7.2$ Hz), 2.40 (3H, s), 3.89 (3H, s), 4.15 (2H, q, $J = 7.2$ Hz), 5.69 (1H, brs), 6.86 (1H, dd, $J = 2.0, 8.4$ Hz), 6.87 (1H, d, $J = 2.0$ Hz), 6.96 (1H, d, $J = 8.4$ Hz), 7.27 (2H, d, $J = 8.2$ Hz), 7.43 (1H, d, $J = 7.8$ Hz), 7.54 (2H, d, $J = 8.2$ Hz), 7.70 (1H, dd, $J = 2.0, 7.8$ Hz), 7.97 (1H, d, $J = 2.0$ Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.83, 21.09, 55.91, 61.04, 111.08, 114.15, 121.44, 126.84, 127.81, 129.19, 129.59, 130.92, 131.94, 133.16, 136.83, 137.54, 139.76, 140.42, 145.07, 146.12, 169.26; IR (ATR) 3469, 2920, 1716, 1234, 1084, 814 cm^{-1}; MS (FAB) m/z 362 (M^+); Anal. calcd. for $C_{23}H_{22}O_4$: C, 76.22; H, 6.12, found: C, 75.84; H, 6.30.



Trifluoromethanesulfonic anhydride (0.24 mL, 1.41 mmol) was added slowly to a solution of the phenol (427 mg, 1.18 mmol) and pyridine (0.14 mL, 1.77 mmol) in CH_2Cl_2 (1.18 mL) at 0 °C, and the whole was stirred for 20 min. After adding 10% aq. HCl (10 mL), the product was extracted with EtOAc (30 mL). The organic layer was washed with water (10 mL x 2) and brine (10 mL) successively, dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, EtOAc/hexane = 1/5) gave the desired product as a white solid in 98% yield (571 mg).

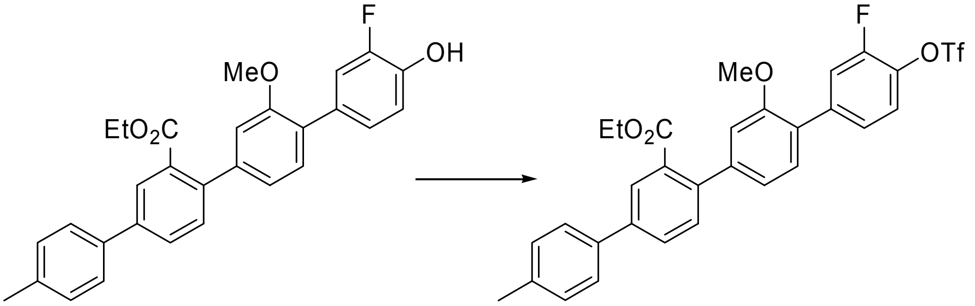
Mp 84.2-85.1 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.02 (3H, t, *J* = 7.2 Hz), 2.41 (3H, s), 3.92 (3H, s), 4.11 (2H, q, *J* = 7.2 Hz), 6.94 (1H, dd, *J* = 2.0, 8.2 Hz), 7.00 (1H, d, *J* = 2.0 Hz), 7.24 (1H, d, *J* = 8.2 Hz), 7.29 (2H, d, *J* = 8.0 Hz), 7.41 (1H, d, *J* = 8.2 Hz), 7.55 (2H, d, *J* = 8.0 Hz), 7.75 (1H, dd, *J* = 1.6, 8.2 Hz), 8.07 (1H, d, *J* = 1.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.55. 21.11. 56.22. 61.22. 113.41. 118.74 (q, *J* = 320 Hz), 120.85, 121.92, 126.89, 128.32, 129.51, 129.69, 130.77, 131.60, 136.48, 137.91, 139.18, 140.91, 142.82, 150.83, 168.37 (one peak is overlapped); IR (ATR) 1714, 1417, 1230, 1196, 1130, 1103, 816 cm^{-1}; MS (FAB) m/z 494 (M^+); Anal. calcd. for $C_{24}H_{21}F_3O_6S$: C, 58.29; H, 4.28, found: C, 58.29; H, 4.16.



The triflate (602 mg, 1.22 mmol), the boronic ester (377 mg, 1.58 mmol), LiOH•H_2O (123 mg, 2.92 mmol), $Pd(OAc)_2$ (5.5 mg, 24.3 μmol), and **6** (10.2 mg, 29.2 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (1.22 mL) was added, and the whole was stirred at rt for 2 h. After adding 10% aq. HCl (20 mL), the product was extracted with EtOAc (20 mL x 3). The combined organic layers were washed with brine (20 mL), dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, EtOAc/hexane 1/4) gave the desired product as a white solid in 93% yield (518 mg).

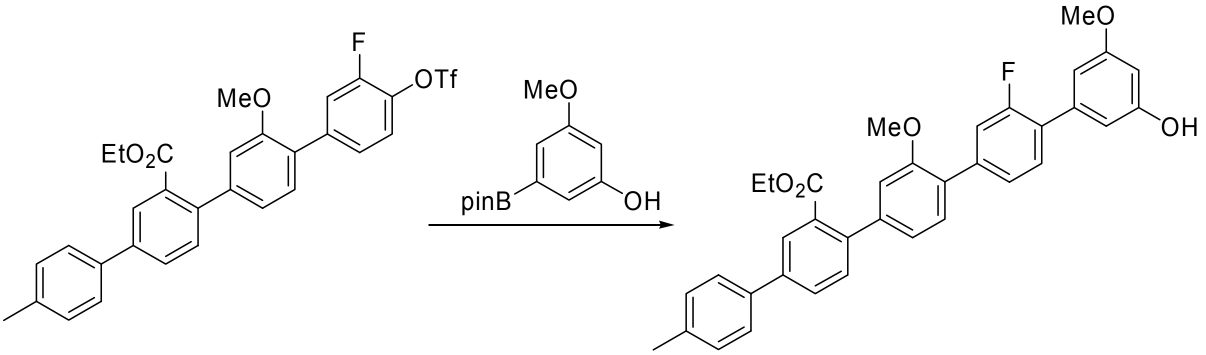
Mp 160.2-162.0 °C (dec); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.07 (3H, t, *J* = 7.2 Hz), 2.42 (3H, s), 3.84 (3H, s), 4.17 (2H, q, *J* = 7.2 Hz), 5.14 (1H, d, *J* = 4.4 Hz), 6.96 (1H, d, *J* = 2.0 Hz), 7.01 (1H, dd, *J* = 2.0, 7.8 Hz), 7.05 (1H, t, *J* = 8.8 Hz), 7.24-7.33 (1H, m), 7.29 (2H, d, *J* = 8.4 Hz), 7.32 (1H, d, *J* = 7.8 Hz), 7.37 (1H, dd, *J* = 2.0, 12.0 Hz), 7.50 (1H, d, *J* = 7.8 Hz), 7.56 (2H, d, *J* = 8.4 Hz), 7.75 (1H, dd, *J* = 2.0, 7.8 Hz), 8.03 (1H, d, *J* = 2.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.73, 21.11, 55.58, 61.20, 111.54, 116.68 (d, *J* = 11.5 Hz), 116.78 (d, *J* = 5.0 Hz), 121.00, 125.79 (d, *J* = 3.3 Hz), 126.89, 127.98, 128.03, 129.41, 129.64, 130.13, 130.87, 131.02 (d, *J* = 6.6 Hz), 131.76, 136.73, 137.70, 140.30, 140.35, 141.60, 142.58 (d, *J* = 14.9 Hz), 150.49

(d, J = 236 Hz), 155.92, 169.13; IR (ATR) 3342, 1691, 1306, 1246, 1099, 812 cm^{-1}; MS (FAB) m/z 456 (M$^+$); Anal. calcd. for $C_{29}H_{25}FO_4$: C, 76.30; H, 5.52, found: C, 76.27; H, 5.29.



Trifluoromethanesulfonic anhydride (62 μL, 0.370 mmol) was added slowly to a solution of the phenol (141 mg, 0.309 mmol) and pyridine (37 μL, 0.463 mmol) in CH_2Cl_2 (0.31 mL) at 0 °C. After 5 min, the ice-bath was removed and the mixture was stirred for an additional 55 min at rt. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (20 mL). The organic layer was washed with water (5 mL x 2) and brine (5 mL) successively, dried over Na_2SO_4, and concentrated. Purification by column chromatography (silica gel, EtOAc/hexane = 1/4, dried *in vacuo* at 100 °C for 5 h) gave the desired product as a white solid in 97% yield (176 mg).

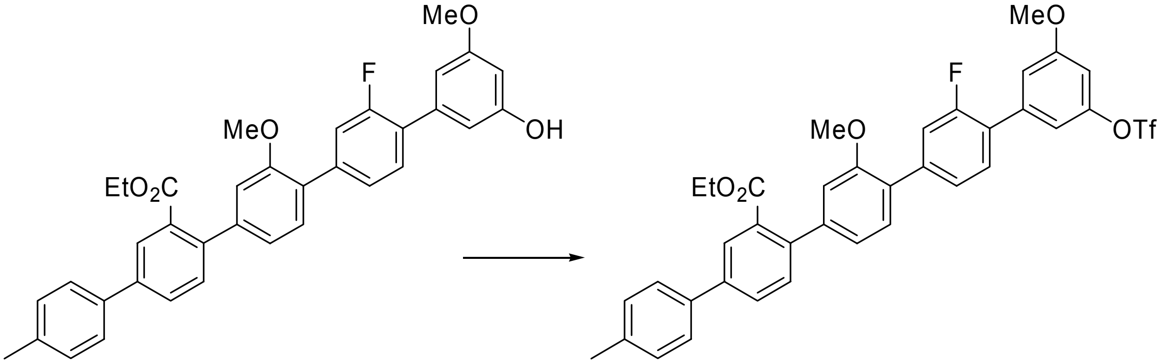
Mp 100.6-101.5 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (3H, t, J = 7.0 Hz), 2.42 (3H, s), 3.85 (3H, s), 4.18 (2H, q, J = 7.0 Hz), 6.99 (1H, d, J = 1.4 Hz), 7.04 (1H, dd, J = 1.4, 7.8 Hz), 7.29 (2H, d, J = 8.2 Hz), 7.32-7.38 (2H, m), 7.40 (1H, dd, J = 2.0, 8.8 Hz), 7.48 (1H, d, J = 8.0 Hz), 7.53 (1H, dd, J = 2.0, 11.8 Hz), 7.56 (2H, d, J = 8.2 Hz), 7.76 (1H, dd, J = 2.0, 8.0 Hz), 8.06 (1H, d, J = 2.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.80, 21.12, 55.59, 61.12, 111.70, 118.65 (d, J = 18.2 Hz), 118.71 (q, J = 321 Hz), 121.21, 122.79, 125.90 (d, J = 3.2 Hz), 126.35, 126.91, 128.17, 129.47, 129.69, 130.16, 130.87, 131.71, 135.46 (d, J = 13.3 Hz), 136.68, 137.82, 140.10, 140.37 (d, J = 8.3 Hz), 140.58, 143.11, 153.02 (d, J = 251 Hz), 155.88, 168.63; IR (ATR) 1722, 1431, 1215, 1138, 876, 812 cm^{-1}; MS (FAB) m/z 588 (M$^+$); Anal. calcd. for $C_{30}H_{24}F_4O_6S$: C, 61.22; H, 4.11, found: C, 61.16; H, 4.30.



The triflate (253 mg, 0.431 mmol), the boronic ester (140 mg, 0.560 mmol), LiOH•H_2O (43.4

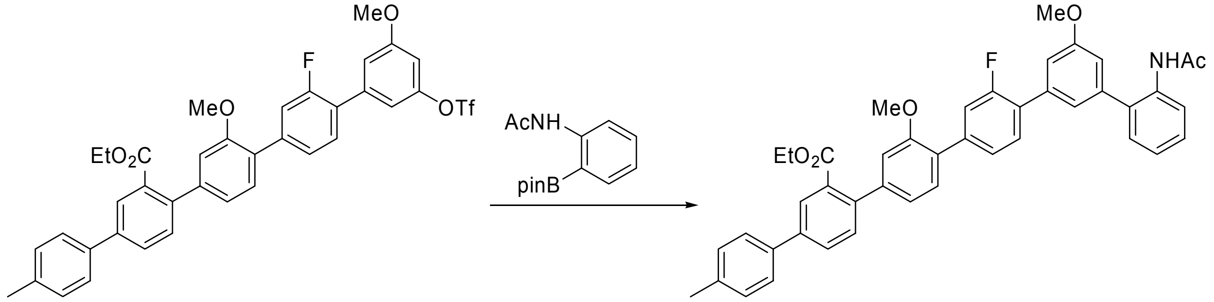
mg, 1.03 mmol), Pd(OAc)$_2$ (1.9 mg, 8.61 μmol), and **6** (3.6 mg, 10.3 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.43 mL) was added, and the whole was stirred at rt for 5 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 3). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, EtOAc/hexane = 1/3) and then column chromatography (silica gel, EtOAc/CH_2Cl_2 = 1/30, dried *in vacuo* at 100 °C for 4 h) gave the desired product as a white solid in 84% yield (203 mg).

Mp 156.4-158.8 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.08 (3H, t, *J* = 7.0 Hz), 2.41 (3H, s), 3.81 (3H, s), 3.84 (3H, s), 4.19 (2H, q, *J* = 7.0 Hz), 5.48 (1H, brs), 6.44 (1H, t, *J* = 2.2 Hz), 6.67 (1H, s), 6.73 (1H, s), 6.99 (1H, d, *J* = 1.6 Hz), 7.04 (1H, dd, *J* = 1.6, 8.0 Hz), 7.28 (2H, d, *J* = 8.2 Hz), 7.36-7.46 (4H, m), 7.47 (1H, d, *J* = 7.6 Hz), 7.56 (2H, d, *J* = 8.2 Hz), 7.75 (1H, dd, *J* = 1.8, 7.6 Hz), 8.05 (1H, d, *J* = 1.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.40, 20.79, 55.03, 55.30, 60.97, 100.53, 107.01, 108.38 (d, *J* = 3.3 Hz), 111.29, 116.82 (d, *J* = 23.1 Hz), 120.77, 125.00 (d, *J* = 3.2 Hz), 126.58, 126.71 (d, *J* = 13.3 Hz), 127.40, 127.75, 129.16, 129.34, 129.70 (d, *J* = 3.3 Hz), 129.92, 130.56, 131.40, 136.37, 137.42, 137.50, 139.12 (d, *J* = 8.2 Hz), 139.99, 140.10, 141.91, 155.73, 156.38, 158.89 (d, *J* = 248 Hz), 160.44, 168.90; IR (ATR) 3365, 1678, 1597, 1394, 1308, 1255, 1192, 1153, 810 cm^{-1}; MS (FAB) m/z 562 (M^+); Anal. calcd. for $C_{36}H_{31}FO_5$: C, 76.85; H, 5.55, found: C, 76.88; H, 5.60.



Trifluoromethanesulfonic anhydride (65 μL, 0.385 mmol) was added slowly to a solution of the phenol (181 mg, 0.321 mmol) and pyridine (39 μL, 0.482 mmol) in CH_2Cl_2 (0.32 mL) at 0 °C, and the whole was stirred for 20 min. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (20 mL). The organic layer was washed with water (5 mL x 2) and brine (5 mL) successively, dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, EtOAc/hexane = 1/5, dried *in vacuo* at 100 °C for 4 h) gave the desired product as a colorless, amorphous solid in 94% yield (209 mg).

Mp 47.9-90.7 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.10 (3H, t, *J* = 7.0 Hz), 2.42 (3H, s), 3.87 (3H, s), 3.88 (3H, s), 4.19 (2H, q, *J* = 7.0 Hz), 6.83 (1H, t, *J* = 2.2 Hz), 7.01 (1H, d, *J* = 1.6 Hz), 7.06 (1H, dd, *J* = 1.6, 8.0 Hz), 7.12 (1H, s), 7.17 (1H, s), 7.29 (2H, d, *J* = 8.0 Hz), 7.39 (1H, d, *J* = 8.0 Hz), 7.44-7.49 (m, 3H), 7.50 (1H, d, *J* = 8.0 Hz), 7.57 (2H, d, *J* = 8.0 Hz), 7.76 (1H, dd, *J* = 2.0, 8.0 Hz), 8.06 (1H, d, *J* = 2.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.78, 21.11, 55.64, 55.81, 61.12, 106.54, 111.67, 113.97 (d, *J* = 3.3 Hz), 114.76 (d, *J* = 3.3 Hz), 117.39 (d, *J* = 24.7 Hz), 118.7 (q, *J* = 320 Hz), 121.16, 125.33 (d, *J* = 13.3 Hz), 125.66 (d, *J* = 3.3 Hz), 126.89, 127.38, 128.11, 129.42, 129.67, 129.85 (d, *J* = 3.2 Hz), 130.18, 130.87, 131.79 136.71, 137.77, 138.62, 140.23, 140.46, 140.58 (d, *J* = 9.9 Hz), 142.60, 150.11, 156.05, 159.14 (d, *J* = 248 Hz), 160.62, 168.78; IR (ATR) 1716, 1612, 1419, 1209, 1138, 1043, 953, 808 cm^{-1}; MS (FAB) m/z 694 (M^+); Anal. calcd. for $C_{37}H_{30}F_4O_7S$: C, 63.97; H, 4.35, found: C, 63.93; H, 4.49.



The triflate (178 mg, 0.256 mmol), the boronic ester (86.8 mg, 0.332 mmol), $LiOH•H_2O$ (25.7 mg, 0.613 mmol), $Pd(OAc)_2$ (1.1 mg, 5.11 μmol), and **6** (2.2 mg, 6.13 μmol) were placed in a flask, and then evacuated and backfilled with argon. A THF/H_2O (4/1) solution (0.26 mL) was added, and the whole was stirred at rt for 6 h. After adding 10% aq. HCl (5 mL), the product was extracted with EtOAc (5 mL x 6). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4, and concentrated. Purification by preparative TLC (silica gel, EtOAc/hexane = 1/1 and then $EtOAc/CH_2Cl_2$ = 1/3, dried *in vacuo* at 100 °C for 5 h) gave the desired product as a colorless, amorphous solid in 90% yield (157 mg).

Mp 97.3-157.3 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (3H, t, *J* = 7.2 Hz), 2.09 (3H, s), 2.41 (3H, s), 3.87 (3H, s), 3.89 (3H, s), 4.18 (2H, q, *J* = 7.2 Hz), 6.93 (1H, s), 7.00 (1H, d, *J* = 1.4 Hz), 7.05 (1H, dd, *J* = 1.4, 8.0 Hz), 7.18-7.53 (9H, m), 7.29 (2H, d, *J* = 8.4 Hz), 7.40 (1H, d, *J* = 8.0 Hz), 7.50 (1H, d, *J* = 8.0 Hz), 7.57 (2H, d, *J* = 8.4 Hz), 7.76 (1H, dd, *J* = 2.0, 8.0 Hz), 8.05 (1H, d, *J* = 2.0 Hz), 8.34 (1H, d, *J* = 7.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.77, 21.09, 24.64, 55.45, 55.63, 61.09, 111.62, 114.02, 114.17, 117.21 (d, *J* = 23.1 Hz), 121.11, 121.46, 122.18 (d, *J* = 3.3 Hz), 124.19, 125.56 (d, *J* = 3.3 Hz), 126.63 (d, *J* = 13.3 Hz), 126.87, 127.50, 128.06, 128.54, 129.39, 129.64, 129.93, 130.01 (d, *J* = 4.9 Hz), 130.18, 130.84, 131.55, 131.78, 134.79, 136.68, 137.67, 137.72, 139.41, 139.89 (d, *J* = 9.8 Hz), 140.22, 140.40, 142.42, 156.01, 159.26 (d, *J* = 246 Hz), 160.31, 168.39, 168.78; IR (ATR) 3415, 1697, 1589, 1516, 1392, 1304, 1236, 1020, 812 cm^{-1}; HRMS (FAB) m/z calcd for $C_{44}H_{39}FNO_5$ ($M+H^+$) 680.2812; found: 680.2832;

Anal. calcd. for $C_{44}H_{38}FNO_5$: C, 77.74; H, 5.63; N, 2.06, found: C, 77.74; H, 5.69; N, 2.01.

References

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