



Supporting Information

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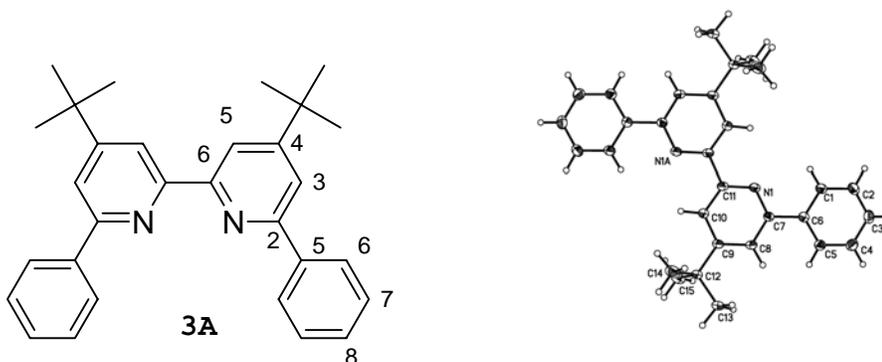
# Iridium-Catalysed Borylation of C-H Bonds in Nitrogen-Containing Heterocycles: Regioselectivity in the Synthesis of Heteroarylboronate Esters

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## Synthesis

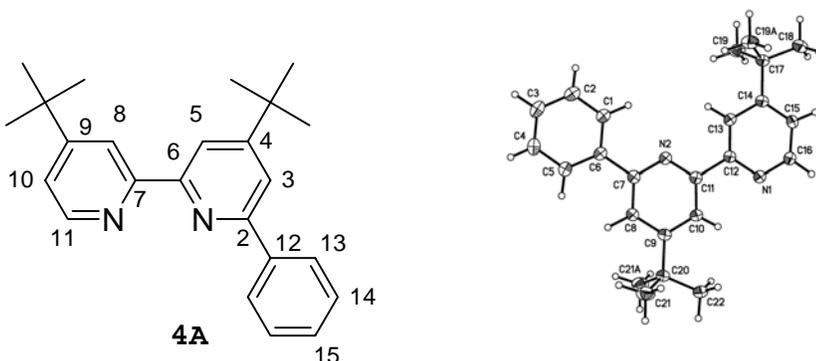
All reactions were carried out under a dry nitrogen atmosphere using standard Schlenk techniques or in an Innovative Technology Inc. System 1 double-length glove box. Glassware was oven dried before transfer into the glove box. Hexane was dried over sodium/benzophenone and distilled under nitrogen; 2-phenylpyridine and 2,3-dimethylpyrazine were dried over CaH<sub>2</sub>. [Ir(OMe)(COD)]<sub>2</sub> was synthesized by reported procedures [R. Usón, L. A. Oro, J. A. Cabeza, *Inorg. Synth.* 1985, **23**, 126]. All other compounds were obtained from Aldrich Chemical Company, tested for purity by GC/MS and used without further purification. NMR spectra were recorded at ambient temperature on Varian Inova 500 (<sup>1</sup>H, <sup>13</sup>C{<sup>1</sup>H}, HSQC), Varian C500 (<sup>1</sup>H, <sup>13</sup>C{<sup>1</sup>H}, HSQC), Varian Unity 300 (<sup>11</sup>B and <sup>11</sup>B{<sup>1</sup>H}) and Bruker AC200 (<sup>13</sup>C{<sup>1</sup>H}) instruments. Proton and carbon spectra were referenced to external SiMe<sub>4</sub> via residual protons in the deuterated solvents or solvent resonance

respectively. Elemental analyses were conducted in the Department of Chemistry at the University of Durham using an Exeter Analytical Inc. CE-440 Elemental Analyser. GC-MS analyses were performed on a Hewlett-Packard 5890 Series II gas chromatograph equipped with a 5971 mass selective detector and a 7673 autosampler. A fused silica capillary column (10 m or 12 m cross-linked 5% phenylmethylsilicone) was used, and the oven temperature was ramped from 50 °C to 280 °C at a rate of 20 °C/min. UHP grade helium was used as the carrier gas. The screw-cap autosampler vials used were supplied by Thermoquest Inc. and were fitted with Teflon/silicone/Teflon septa and 0.2 ml micro inserts.

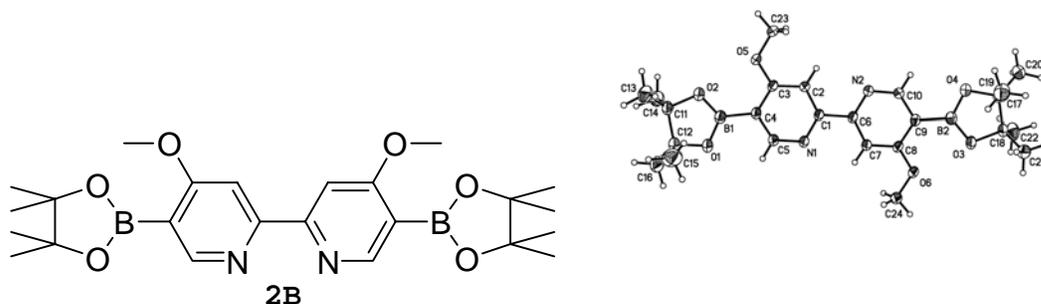


In a nitrogen-filled glove box, to a solution of [Ir(OMe)COD]<sub>2</sub> (6.2 mg, 5 mol%) and dtbpy (5 mg, 10 mol%) in 2 ml of hexane was added a mixture of B<sub>2</sub>pin<sub>2</sub> (95 mg, 2 equiv.) and dtbpy (0.187 mmol) in 3 ml of hexane (5 ml total volume). The mixture was shaken vigorously to ensure complete mixing, transferred to ampoules sealed with a

Teflon Young's tap and heated at 80 °C. After 16 h the mixture was analyzed by GC-MS. The solvent was removed *in vacuo*, followed by addition of PhI (114 mg, 3 equiv.), K<sub>3</sub>PO<sub>4</sub>·2H<sub>2</sub>O (185 mg, 4 equiv.), (dppf)PdCl<sub>2</sub> (15 mg, 10 mol%) and dry DMF (8 ml). The mixture was heated at 80 °C for 5 h. The product was extracted with hexane, dried (MgSO<sub>4</sub>), and chromatographed on silica gel (hexane:diethylether 9:1) to yield 52 mg (0.098 mmol, 67 %) of product; <sup>1</sup>H NMR (400 MHz, [D] CHCl<sub>3</sub>): δ = 1.47 (s, 9H; Me<sub>3</sub>), 7.45 (t, <sup>3</sup>J(H,H) = 7.6 Hz, 1H; 8), 7.53 (t, <sup>3</sup>J(H,H) = 7.6 Hz, 2H; 7), 7.78 (d, <sup>3</sup>J(H,H) = 1.5 Hz, 1H; 3), 8.17 (d, <sup>3</sup>J(H,H) = 7.6 Hz, 1H; 6), 8.61 (d, <sup>3</sup>J(H,H) = 1.5 Hz, 1H; 5). <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, [D] CHCl<sub>3</sub>, TMS): δ = 29.76 (s, Me<sub>3</sub>), 34.17 (s, CMe<sub>3</sub>), 116.89 (s, 3), 117.57 (s, 5), 127.07 (s, 8), 128.67, 128.70 (s, 6, 7), 139.14 (s, 5), 155.40 (s, 6, 2), 160 (s, 3); MS (EI) m/z: 420 [M<sup>+</sup>], 405 [M-Me]<sup>+</sup>; Anal. Calcd for C<sub>30</sub>H<sub>32</sub>N<sub>2</sub>: C 85.76, H 7.67, N 6.66; found C 85.61, H 7.66, N 6.55; m.p. 182–184 °C.

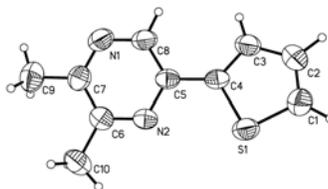
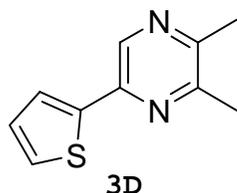


Borylated compound **2A** was prepared as above. The solvent was removed *in vacuo* followed by addition of PhI (45.7 mg (0.025 ml), 1.2 equiv.),  $K_3PO_4 \cdot 2H_2O$  (92.5 mg, 2 equiv.), (dppf)PdCl<sub>2</sub> (15 mg, 10 mol%) and dry DMF (8 ml). The reaction was heated at 80 °C for 5 h. The product was extracted with hexane, dried (MgSO<sub>4</sub>), and chromatographed on silica gel (hexane:diethylether 9:1) to give 20 mg (0.098 mmol, 31 %) of product; <sup>1</sup>H NMR (500 MHz, [D<sub>6</sub>] C<sub>6</sub>H<sub>6</sub>): δ = 1.17 (s, 9H; Me<sub>3</sub>), 1.20 (s, 9H; Me<sub>3</sub>), 6.96 (dd, <sup>3</sup>J(H,H) = 1.7, 5.2 Hz, 1H; 10), 7.23 (t, <sup>3</sup>J(H,H) = 7.3 Hz, 1H; 15), 7.35 (t, <sup>3</sup>J(H,H) = 7.3 Hz, 2H; 14), 7.71 (d, <sup>3</sup>J(H,H) = 1.7 Hz, 1H; 3), 8.31 (d, <sup>3</sup>J(H,H) = 7.3 Hz, 1H; 13), 8.66 (d, <sup>3</sup>J(H,H) = 5.2 Hz, 1H; 11), 9.01 (d, <sup>3</sup>J(H,H) = 1.7 Hz, 1H; 5), 9.08 (d, <sup>3</sup>J(H,H) = 1.4 Hz, 1H; 8). <sup>13</sup>C{<sup>1</sup>H} NMR (100 MHz, [D<sub>6</sub>] C<sub>6</sub>H<sub>6</sub>): δ = 30.32 (s, (Me)<sub>3</sub>), 30.40 (s, (Me)<sub>3</sub>), 34.60 (s, CMe<sub>3</sub>), 34.90 (s, CMe<sub>3</sub>), 117.26 (s, 3), 117.45 (s, 5), 118.25 (s, 8), 120.74 (s, 10), 127.36, 128.11, 128.75 (s, 13, 14, 15), 140.67 (s, 12), 149.25 (s, 11), 156.82, 157.1 (s, 6, 7, 2), 160.28 161.43 (4, 9); MS (EI) m/z: 344 [M<sup>+</sup>], 329 [M-Me]<sup>+</sup>; Anal. Calcd. for C<sub>24</sub>H<sub>28</sub>N<sub>2</sub>: C 83.68, H 8.19, N 8.13; found C 83.49, H 8.12, N 8.10; m.p. 107-109 °C



In a nitrogen-filled glove box, to a solution of  $[\text{Ir}(\text{OMe})\text{COD}]_2$  (8 mg, 5 mol%) and dtbpy (7 mg, 10 mol%) in 2 ml of hexane was added a mixture of  $\text{B}_2\text{pin}_2$  (118 mg, 2 equiv) and 4,4'- $\text{MeO}_2$ -2,2'-bipyridine (50 mg, 0.231 mmol) in 3 ml of hexane (5 ml total volume). The mixture was shaken vigorously to ensure complete mixing, transferred to ampoules sealed with a Teflon Young's tap and heated at 80 °C for 16 h. The mixture was analyzed by GC-MS. The solvent was removed *in vacuo*, and the residue was redissolved in 10 ml of hexane, then passed through a celite pad, and the solvent was evaporated. Single crystals were grown by slow evaporation of  $\text{CH}_2\text{Cl}_2$  solution.

$^1\text{H}$  NMR (400 MHz,  $[\text{D}] \text{C}_6\text{D}_6$ ):  $\delta$  = 1.10 (s, 12H; Bpin), 3.36 (s, 3H; Me), 8.49 (s, 5), 9.51 (s, 2);  $^{13}\text{C}\{^1\text{H}\}$  NMR (100 MHz,  $\text{CDCl}_3$ ):  $\delta$  24.57 (s,  $\text{BO}_2\text{C}_2(\text{CH}_3)_4$ ), 55.83 (s, OMe), 83.82 (s,  $\text{BO}_2\text{C}_2(\text{CH}_3)_4$ ), 111.11, 150.05, 156.70, 167.73 (s, Ar); MS (EI)  $m/z$ : 467  $[\text{M}^+]$ , 453  $[\text{M}-\text{CH}_2]^+$ .

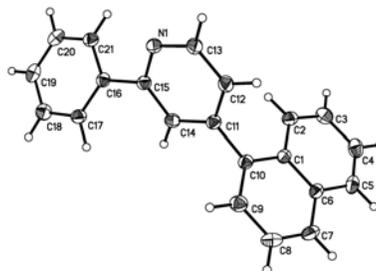
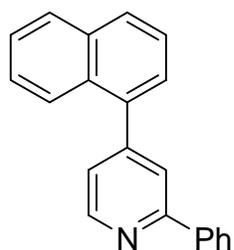


In a nitrogen-filled glove box, to a solution of  $[\text{Ir}(\text{OMe})\text{COD}]_2$  (30.7 mg, 2.5 mol%) and dtbpy (24.8 mg, 5 mol%) in 2 ml of hexane was added a mixture of  $\text{B}_2\text{pin}_2$  (470 mg, 1 equiv.) and 2,3-dimethyl-pyrazine (200 mg, 1.85 mmol) in 3 ml of hexane (5 ml total volume). The mixture was stirred at room temperature for 16 h. The solvent was removed *in vacuo* followed by addition of 2-bromothiophene (300 mg, 1 equiv.),  $\text{K}_3\text{PO}_4$  (aq.) (785 mg, 2 equiv.),  $(\text{PPh}_3)_2\text{PdCl}_2$  (65 mg, 5 mol%) and DMF (20 ml). The reaction mixture was transferred to a thick-walled glass microwave tube (20 ml volume), crimp sealed with a septum cap, and heated for 1 h at 150 °C. The product was extracted with ethylacetate, dried ( $\text{MgSO}_4$ ), and chromatographed on silica gel (hexane:ethylacetate 9:1) to yield: 120 mg of product (0.632 mmol, 34%).  $^1\text{H}$  NMR (400 MHz, [D]  $\text{CHCl}_3$ ):  $\delta$  = 2.52 (s, 3H; Me), 2.54 (s, 3H; Me), 7.10 (dd,  $^3J(\text{H},\text{H}) = 4.0, 5.1$  Hz, 1H; 9), 7.39 (dd,  $^3J(\text{H},\text{H}) = 5.1, ^4J(\text{H},\text{H}) = 1.0$  Hz, 1H; 8), 7.59 (dd,  $^3J(\text{H},\text{H}) = 4.0, ^4J(\text{H},\text{H}) = 1.0$  Hz, 1H; 10), 8.62 (s, 1H; 5);  $^{13}\text{C}\{^1\text{H}\}$  NMR (100 MHz, [D]  $\text{CHCl}_3$ ):  $\delta$  21.59 (s,

CH<sub>3</sub>), 21.98 (s, CH<sub>3</sub>), 124.63, 127.61, 128.15 (s, 8, 9, 10), 136.6 (s, 5), 141.82 (s, 7), 145 (s, 6) 150.15 (s, 3), 151.67 (s, 2); MS (EI) m/z: 190 [M<sup>+</sup>], 108 [M-C<sub>4</sub>H<sub>2</sub>S]<sup>+</sup>. m.p. 50-52 °C.

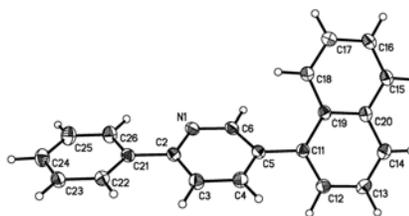
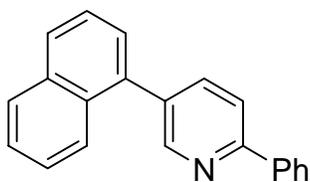
Synthesis of 2-Ph-4-(Bpin)-pyridine and 2-Ph-5-(Bpin)-pyridine.

In a nitrogen-filled glove box, to a solution of [Ir(OMe)COD]<sub>2</sub> (22 mg, 2.5 mol%) and dtbpy (18 mg, 5 mol%) in 2 ml of hexane was added a mixture of B<sub>2</sub>pin<sub>2</sub> (164 mg, 0.5 equiv) and 2-phenylpyridine (200 mg, 1.3 mmol) in 3 ml of hexane (5 ml total volume). The mixture was stirred at room temperature for 16 h. The solvent was removed *in vacuo* followed by addition of 1-iodonaphthalene (328 mg, 1 equiv.), K<sub>2</sub>CO<sub>3</sub> (aq.) (359 mg, 2 equiv.), (PPh<sub>3</sub>)<sub>2</sub>PdCl<sub>2</sub> (45.3 mg, 5 mol%) and 1,4-dioxane (20 ml). The mixture was transferred to a microwave tube (20 ml volume) as above, then sealed and heated for 1 h at 150 °C. The product was extracted with ethylacetate, dried (MgSO<sub>4</sub>), and chromatographed on silica gel (hexane:ethylacetate 95:5) to yield 220 mg of a mixture of the two isomers (0.783 mmol, 67%), with 55% selectivity for 2-Ph-5-(Bpin)-pyridine.



**3C(4)**

Yield: 100 mg (0.356 mmol, 61%);  $^1\text{H}$  NMR (500 MHz,  $[\text{D}_6]$   $\text{C}_6\text{H}_6$ ):  $\delta$  = 6.94 (dd,  $^3J_{\text{H,H}} = 4.9$ ,  $^4J_{\text{H,H}} = 1.5$  Hz, 1H), 7.02–7.07 (m, 3H), 7.23–7.28 (m, 4H), 7.65 (d,  $^3J_{\text{H,H}} = 8.3$  Hz, 1H), 7.67 (d,  $^3J_{\text{H,H}} = 7.8$  Hz, 1H), 7.69 (s, 1H), 7.76 (d,  $^3J_{\text{H,H}} = 8.3$  Hz, 1H), 8.19 (2 overlapped d,  $^3J_{\text{H,H}} = 6.8$  Hz, 2H), 8.67 (d,  $^3J_{\text{H,H}} = 4.9$  Hz, 1H).  $^{13}\text{C}\{^1\text{H}\}$  NMR (125 MHz,  $[\text{D}_6]$   $\text{C}_6\text{H}_6$ ):  $\delta$  = 119.50, 123.57, 125.52, 125.79, 126.34, 126.87, 127.04, 127.39, 128.72, 128.91, 128.94, 129.62, 131.53, 134.26, 138.36, 139.69, 149.42, 150.09, 157.70 (s); MS (EI)  $m/z$ : 281  $[\text{M}^+]$ ; Anal. Calcd. for  $\text{C}_{21}\text{H}_{15}\text{N}$ : C 89.65, H 5.37, N 4.89; found C 89.41, H 5.56, N 4.98; m.p. 80–82 °C.



**3C(5)**

Yield: 120 mg (0.427 mmol, 61 %);  $^1\text{H}$  NMR (500 MHz,  $[\text{D}_6]$   $\text{C}_6\text{H}_6$ ):  $\delta$  = 7.17-7.28 (m, 5H), 7.32 (m, 2H), 7.40-7.45 (m, 2H), 7.64 (d,  $^3\text{J}(\text{H},\text{H}) = 8.3$  Hz, 1H), 7.68 (d,  $^3\text{J}(\text{H},\text{H}) = 7.8$  Hz, 1H), 7.83 (d,  $^3\text{J}(\text{H},\text{H}) = 8.8$  Hz, 1H), 8.28 (2 overlapped d,  $^3\text{J}(\text{H},\text{H}) = 8.3$  Hz, 1H), 8.90 (s, 1H).  $^{13}\text{C}\{^1\text{H}\}$  NMR (125 MHz,  $[\text{D}_6]$   $\text{C}_6\text{H}_6$ ):  $\delta$  = 119.46, 125.66, 125.82, 126.26, 126.71, 127.27, 127.57, 128.55, 128.57, 128.74, 129, 129.25, 134.40, 134.92, 136.89, 137.95, 139.56, 150.82, 156.32 (s); MS (EI) m/z: 281  $[\text{M}^+]$ ; Anal. Calcd. for  $\text{C}_{21}\text{H}_{15}\text{N}$ : C 89.65, H 5.37, N 4.89; found C 89.42, H 5.52, N 4.79; m.p. 130-132  $^\circ\text{C}$ .