J|A|C|S
COMMUNICATIONS

# Copper-Catalyzed $\gamma$-Selective and Stereospecific Substitution Reaction of Allylic Carbonates with Diboron: Efficient Route to Chiral Allylboron Compounds

Hajime Ito,* Chika Kawakami, and Masaya Sawamura*

*Division of Chemistry, Graduate School of Science, Hokkaido University, and PRESTO, JST,
Sapporo 060-0810, Japan*

Received September 5, 2005; E-mail: hajito@sci.hokudai.ac.jp; sawamura@sci.hokudai.ac.jp

Allylboron compounds are useful reagents for the stereoselective synthesis of homoallylic alcohols.[1] A desirable but unprecedented method for the preparation of the boron reagent would be the *$\gamma$-selective and stereospecific* substitution reaction of an allyl alcohol derivative with a boron reagent.[2−6] This would allow easy access to functionalized[7] or optically active[8−10] allylboron compounds. Herein, we report that a Cu(I) complex coordinated with the Xantphos[11] ligand can catalyze the $\gamma$-selective substitution reaction of allylic carbonates with bis(pinacolato)diboron to afford the corresponding allylboronates. The reaction of the optically active allylic carbonates with an α-stereogenic center underwent α-to-$\gamma$ chirality transfer with *anti*-stereochemistry, leading to chiral allylboronates with a boron-substituted stereogenic center.

During our continued investigations of group 11 metal-catalyzed reactions, we observed that a chelating phosphine (Xantphos) featuring a large natural bite-angle produced a remarkable rate-acceleration for copper-catalyzed hydrosilane alcoholysis.[12] This outcome suggested that the large bite-angle ligand would activate Cu(I)−OR for $\sigma$-bond metathesis with an H−Si bond of the hydrosilane to form a monomeric, highly active copper hydride, Cu(I)−H. Drawing an analogy between H−Si and B−B, it was hoped that Xantphos-ligated Cu−OR would react with a diboron reagent to form a Cu−B species useful as a "formal boryl nucleophile".[5,13] Formal $S_N2'$ attack of the Cu−B species on an allylic carbonate would allow $\gamma$-selective formation of an allylboron compound along with a copper carbonate that would undergo decarboxylation to regenerate the Cu−OR. The reaction of allylic carbonate **1a** and bis(pinacolato)diboron **2** in the presence of Cu(O-*t*-Bu)−Xantphos catalyst (5 mol %) proceeded at room temperature to give the corresponding allylboronate in a quantitative yield with high regio- (**3a**:**3b** = 99:1) and *E*/*Z*- (*E*-**3a**:*Z*-**3a** = 97:3) selectivities (Table 1, entry 1). The use of a monophosphine (PPh$_3$) or other diphosphines (dppe, dppp, dppf), however, resulted in decreased catalytic activities (entries 2−6). In the case of dppe (entry 2), the product was obtained in a low yield with poor *E*/*Z* selectivity. Although the dppp (entry 3) and dppf (entry 4) complexes possessed higher activities and exhibited high regio- and *E*/*Z*-selectivities, their activities were still significantly lower than that of the Xantphos complex. The PPh$_3$ complex (entry 5) was nearly inactive. Furthermore, CuOTf-PBu$_3$[6,13] (entry 6) and the stoichiometric CuCl−KOAc−LiCl system[5,6] (entry 7), which have been reported to catalyze the borylation of α,$\beta$-unsaturated compounds and allyl chloride, were ineffective for the reaction of **1a**. Low-valent palladium complex Pd(dba)$_2$ (entry 8) catalyzed the conversion, but afforded a mixture of **3a** and **3b** in a ratio of 57:43; the low regioselectivity is attributable to the loss of regiochemical information of substrate **1a** upon formation of a ($\pi$-allyl)palladium(II) complex intermediate.[2]

*Scheme 1.* Expected Catalytic Cycle

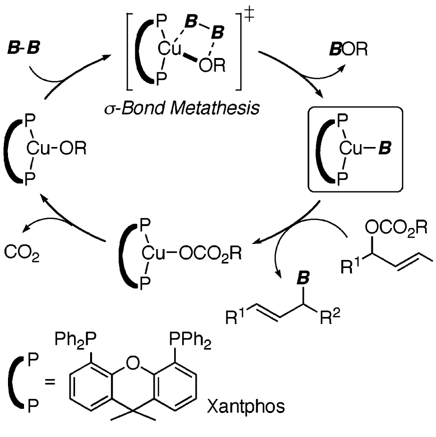
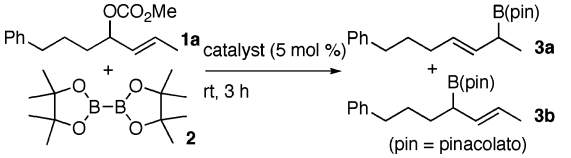


*Table 1.* Reaction of Allylic Carbonates with Diboron **2**[a]



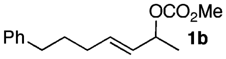
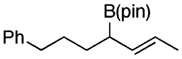
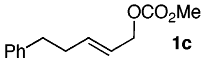
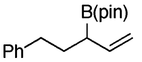
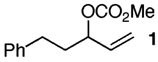
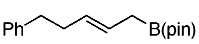
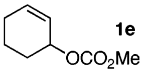
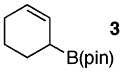
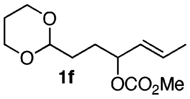
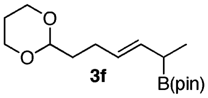
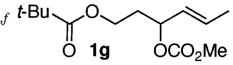
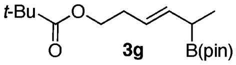
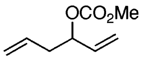
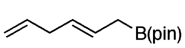
| entry | catalyst | solvent | yield[b] (%) | Selectivity[c] 3a/3b | Selectivity[c] *E*/*Z* (3a)[d] |
|---|---|---|---|---|---|
| 1 | Cu(O-*t*-Bu)−Xantphos | THF | 100 | 99:1 | 97:3 |
| 2 | Cu(O-*t*-Bu)-dppe | THF | 11 | >99:<1 | 62:38 |
| 3 | Cu(O-*t*-Bu)-dppp | THF | 44 | >99:<1 | 97:3 |
| 4 | Cu(O-*t*-Bu)-dppf | THF | 37 | >99:<1 | 96:4 |
| 5 | Cu(O-*t*-Bu)-PPh$_3$ | THF | 2 | nd | nd |
| 6 | CuOTf-PBu$_3$ | DMF | 0 | nd | nd |
| 7[e,f] | CuCl−KOAc−LiCl | DMF | 0 | nd | nd |
| 8[f] | Pd(dba)$_2$ | DMSO | 96 | 57:43 | 98:2 |

[a] Conditions: catalyst (5 mol %), allylic carbonates **1a** (0.25 mmol), diboron **2** (0.5 mmol), and solvent (0.25 mL). [b] Yield of all allylboronates was determined by GC. [c] Ratio of regio- and *E*/*Z*-isomers was determined by GC. [d] The *Z*-isomer of **3b** was not detected. [e] Catalyst (110 mol %) was used. [f] Compound **2** (0.28 mmol) and 1.5 mL of the solvent were used.

A series of allylboronates was synthesized from allylic carbonates using the Cu(I)−Xantphos catalyst (Table 2). The Cu(I)-catalyzed reaction converted allylic carbonates **1a** (Table 1, entry 1) and **1b** (Table 2, entry 1) into **3a** and **3b**, respectively, as major products. As shown in entries 2 and 3, high $\gamma$-selectivity was retained even when the allylic systems are located at the terminal of the carbon chain. Accordingly, carbonates **1c** and **1d** were converted into the branched (**3c**) and linear (**3d**) boronates, respectively. The reaction was applicable to cyclic carbonate **1e** (entry 4). Allylboronates containing acetal, ester, and isolated alkene were also obtained in high yields (entries 5−7, respectively).

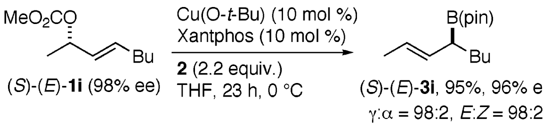
10.1021/ja056099x CCC: $30.25 © 2005 American Chemical Society

***Table 2.*** Cu(I)−Xantphos-Catalyzed Reaction of Allylic Carbonates with Diboron **2**[a]

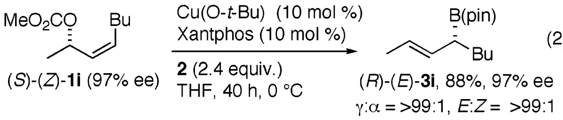
| entry | allylic carbonate | allylboronate | time (h) | yield[b] (%) |
|---|---|---|---|---|
| 1[c] |  **1b** |  **3b** | 1.5 | 96<br>(92)[d] |
| 2[e,f] |  **1c** |  **3c** | 2 | 75 |
| 3[e] |  **1d** |  **3d** | 1.5 | 98 |
| 4[g] |  **1e** |  **3e** | 47 | 74 |
| 5[e] |  **1f** |  **3f** | 3.5 | 88 |
| 6[e,f] |  **1g** |  **3g** | 6 | 86 |
| 7[e] |  **1h** |  **3h** | 1 | 87 |

[a] Conditions: catalyst (5 mol %), allylic carbonates **1a** (0.50 mmol), diboron **2** (1.0 mmol), and THF (0.5 mL) at room temperature. [b] Isolated yield of all allylboronates. [c] Isomeric ratio (**3a**:**3b** = 2:98, *E*:*Z* (for **3b**) = 97:3) was determined by GC. [d] Yield on a 5 mmol scale (reaction time: 3 h). [e] Isomeric purity of allylboronates was determined to be >97% by GC. [f] Catalyst (10 mol %) and 1.1 mmol of **2** were used. [g] Catalyst (10 mol %) and 1.0 mmol of **2** were used at 50 °C in toluene.

The reaction also offers an expeditious and general route to optically active allylboronates that have a stereogenic carbon with a boryl substituent.[14] The reaction of (*S*)-(*E*)-**1i** (98% ee) with **2** in the presence of Cu(I)−Xantphos catalyst (10 mol %) at 0 °C underwent an α-to-γ chirality transfer accompanied by only a slight loss of enantiomeric purity to afford (*S*)-(*E*)-**3i** (96% ee) along with a small amount of the α-substituted *E*-isomer and γ-*Z*-isomer (eq 1). On the other hand, the reaction of (*S*)-(*Z*)-**1i** (97% ee), the *Z*-isomer with the same configuration at the chiral center as (*S*)-(*E*)-**1i**, afforded (*R*)-(*E*)-**3i** (97% ee), the antipode of the product derived from (*S*)-(*E*)-**1i**, with complete chirality transfer and γ-selectivity (eq 2). The observed stereochemical outcome can be explained by the *anti*-attack of the borylcopper to an allyl carbonate in a conformation that avoids an allylic 1,3-strain.[15]



(1)



(2)

In conclusion, the γ-selective and stereospecific copper-catalyzed substitution of allylic carbonates with a diboron reagent offers a convenient and powerful method for the synthesis of allylboronates. Investigations into the asymmetric synthesis of allylboronates based upon displacements of prochiral allyl alcohol derivatives in the presence of an optically active copper catalyst are currently underway.

**Supporting Information Available:** Experimental procedures and compound characterization data (PDF). This material is available free of charge via the Internet at http://pubs.acs.org.

---

## References

(1) (a) Hoffmann, R. W. In *Stereocontrolled Organic Synthesis*; Trost, B. M., Ed.; Blackwell Scientific Publications: Oxford, 1994; pp 259−274. (b) Matteson, D. S. *Stereodirected Synthesis with Organoboranes*; Springer: Berlin, 1995. (c) Roush, W. R. Allylboron Reagents. In *Stereoselective Synthesis*; Ahlbrecht, H., Helmchean, G., Arend, M., Herrmann, R., Eds.; Methods in Organic Chemistry E21b; Georg Thieme: Stuttgart, 1995; pp 1410−1485.

(2) Pd-catalyzed reactions of allylic compounds with diborons were reported, but they were not γ-selective. Both linear and branched allylic compounds led to a linear allylboronate. This is probably due to the formation of a (π-allyl)palladium(II) intermediate. See: (a) Ishiyama, T.; Ahiko, T.; Miyaura, N. *Tetrahedron Lett.* **1996**, *37*, 6889−6892. (b) Ahiko, T. A.; Ishiyama, T.; Miyaura, N. *Chem. Lett.* **1997**, 811−812. (c) Sebelius, S.; Wallner, O. A.; Szabó, K. J. *Org. Lett.* **2003**, *5*, 3065−3068.

(3) Very recently, palladium pincer complex-catalyzed reaction of allylic compounds with tetrahydroxydiboron was reported to be effective for the synthesis of functionalized allylboronic acids. Although it was proposed that this reaction proceeds without formation of a (π-allyl)palladium(II) complex, the regiospecificity was not demonstrated. Instead, only the reactions producing linear allylboronic acids were reported. See: Sebelius, S.; Olsson, V. J.; Szabó, K. J. *J. Am. Chem. Soc.* **2005**, *127*, 10478−10479.

(4) For Pt-catalyzed reaction of allyl halides with pinacolborane, see: Murata, M.; Watanabe, S.; Masuda, Y. *Tetrahedron Lett.* **2000**, *41*, 5877−5880.

(5) For Cu-mediated reaction of allyl chloride and a diboron, see: (a) Takahashi, K.; Takagi, J.; Ishiyama, T.; Miyaura, N. *Chem. Lett.* **2000**, 126−127. (b) Takahashi, K.; Ishiyama, T.; Miyaura, N. *J. Organomet. Chem.* **2001**, *625*, 47−53.

(6) For Cu-catalyzed reactions of allylic acetates activated by an electron-withdrawing group, see: Ramachandran, P. V.; Pratihar, D.; Biswas, D.; Srivastava, A.; Reddy, M. V. R. *Org. Lett.* **2004**, *6*, 481−484. See also refs 5 and 13.

(7) (a) Hoffmann, R. W.; Sander, T.; Hense, A. *Liebigs Ann. Chem.* **1993**, 771−775. (b) Kruger, J.; Hoffmann, R. W. *J. Am. Chem. Soc.* **1997**, *119*, 7499−7504. (c) Kennedy, J. W. J.; Hall, D. G. *J. Am. Chem. Soc.* **2002**, *124*, 898−899. (d) Yamamoto, Y.; Kurihara, K.; Yamada, A.; Takahashi, M.; Takahashi, Y.; Miyaura, N. *Tetrahedron* **2003**, *59*, 537−542. (e) Yamamoto, Y.; Takahashi, M.; Miyaura, N. *Synlett* **2002**, 128−130. (f) Goldberg, S. D.; Grubbs, R. H. *Angew. Chem., Int. Ed.* **2002**, *41*, 807−810. (g) Gao, X.; Hall, D. G. *J. Am. Chem. Soc.* **2003**, *125*, 9308−9309. (h) Pietruszka, J.; Schone, N. *Eur. J. Org. Chem.* **2004**, 5011−5019. (i) Flamme, E. M.; Roush, W. R. *Org. Lett.* **2005**, *7*, 1411−1414.

(8) For the synthesis of optically active allylboron compounds with an α-stereogenic center, see: (a) Midland, M. M.; Preston, S. B. *J. Am. Chem. Soc.* **1982**, *104*, 2330−2331. (b) Hoffmann, R. W.; Landmann, B. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 437−438. (c) Hoffmann, R. W.; Dresely, S. *Angew. Chem., Int. Ed. Engl.* **1986**, *25*, 189−190. (d) Sturmer, R. *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 59−60. (e) Roush, W. R.; Ando, K.; Powers, D. B.; Palkowitz, A. D.; Halterman, R. L. *J. Am. Chem. Soc.* **1990**, *112*, 6339−6348. (f) Beckmann, E.; Desai, V.; Hoppe, D. *Synlett* **2004**, 2275−2280. (g) Brown, H. C.; Narla, G. *J. Org. Chem.* **1995**, *60*, 4686−4687. (h) Flamme, E. M.; Roush, W. R. *J. Am. Chem. Soc.* **2002**, *124*, 13644−13645.

(9) For the synthesis of chiral allylboron compounds with chiral auxiliaries, see: (a) Herold, T.; Hoffmann, R. W. *Angew. Chem., Int. Ed. Engl.* **1978**, *17*, 768−769. (b) Yamamoto, Y.; Asao, N. *Chem. Rev.* **1993**, *93*, 2207−2293. (c) Ramachandran, P. V. *Aldrichimica Acta* **2002**, *35*, 23−35. See also ref 1.

(10) For asymmetric synthesis of β-boryl allylic boronates by diboration of allenes, see: Pelz, N. F.; Woodward, A. R.; Burks, H. E.; Sieber, J. D.; Morken, J. P. *J. Am. Chem. Soc.* **2004**, *126*, 16328−16329.

(11) Kranenburg, M.; Vanderburgt, Y. E. M.; Kamer, P. C. J.; van Leeuwen, P. W. N. M.; Goubitz, K.; Fraanje, J. *Organometallics* **1995**, *14*, 3081−3089.

(12) (a) Ito, H.; Watanabe, A.; Sawamura, M. *Org. Lett.* **2005**, *7*, 1869−1871. (b) Ito, H.; Takagi, K.; Miyahara, T.; Sawamura, M. *Org. Lett.* **2005**, *7*, 3001−3004.

(13) Ito, H.; Yamanaka, H.; Tateiwa, J.; Hosomi, A. *Tetrahedron Lett.* **2000**, *41*, 6821−6825.

(14) Optically active (*E*)-allylsilanes were synthesized from optically active allylic alcohols with highly efficient chirality transfer. See: Suginome, M.; Matsumoto, A.; Ito, Y. *J. Am. Chem. Soc.* **1996**, *118*, 3061−3062.

(15) Breit, B.; Demel, P. In *Modern Organocopper Chemistry*; Krause, N., Ed.; Wiley-VCH GmbH: Weinheim, Germany, 2002; pp 188−223.

JA056099X