Carbon−Carbon Bond Formation *via* the Transmetalation of an Alkenyl Group on Azazirconacyclopentene

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*Summary: The transmetalation of azazirconacyclopentene **1**, prepared by inserting alkyne **8** into azazirconacyclopropane **7**, was realized, and the zirconium−carbon bond of complex **1** was transformed to a carbon−carbon bond using a copper(I) salt. Thus, both allyl and formyl groups can be introduced into alkyne carbons in a highly stereoselective manner in a one-pot reaction.*

The transmetalation of an alkyl or alkenyl group from one metal to another metal is a useful tool in synthetic organic chemistry. Various carbon−carbon bond formations which involve transmetalation from an organozirconium complex to other metals have been reported.[1,2] Since these new carbon−carbon bonds are formed with a retention of configuration, highly stereocontrolled products are obtained. Lipshutz[2a] and Takahashi[2b,c] independently reported that the allyl group can be introduced into alkyl− and alkenyl−zirconium bonds in the presence of a copper(I) salt (Scheme 1).

Azazirconacyclopentene **1**, prepared by inserting an alkyne into azazirconacyclopropane **7**, has been useful in synthetic organic chemistry.[3,4] There are two types of transmetalations involving azazirconacyclopentene **1**. One is transmetalation of the zirconium−carbon bond into another metal−carbon bond (route a), and the other is transmetalation of the zirconium−nitrogen bond into another metal−nitrogen bond (route b). If the alkenyl group of azazirconacyclopentene **1** transmetalates from zirconium to copper, the alkenylcopper complex **2** (MX_{n-1} = Cu) is formed, which reacts with allyl halide to give the γ-allylated (α-silylallyl)amine **4** (R^3 = allyl) (Scheme 2). We previously reported a novel synthesis of azazirconacyclopentene **1** from η^2-iminosilaacylcomplex **6** by a one-pot reaction:[4a] the insertion of an isonitrile into the zirconium−silyl bond of silylzirconium complex **5**, which was prepared from Cp_2ZrCl_2 and silyllithium, gives η^2-iminosilaacylcomplex **6**. Treatment of **6** with LiEt$_3$BH in the presence of alkyne affords azazirconacyclepentene **1**. In this reaction, azazirconacyclopropane **7** is formed as an intermediate.

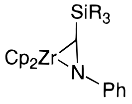

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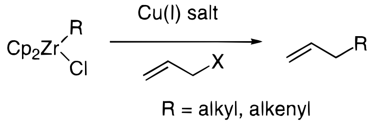
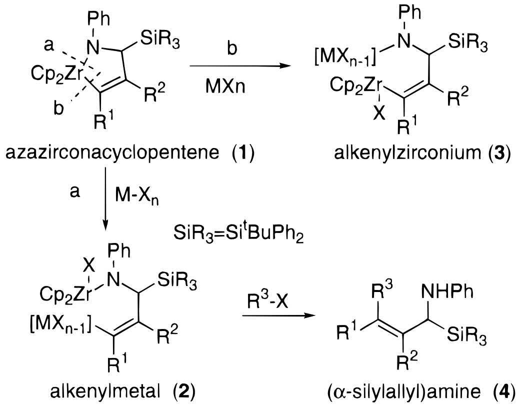
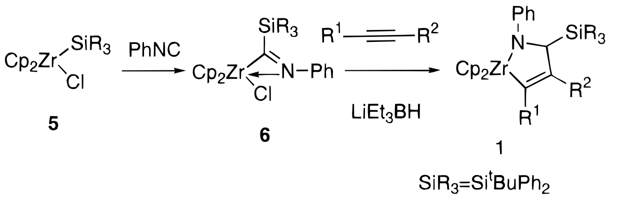
Figure 1.

Scheme 1



Scheme 2





We report here a novel carbon−carbon bond formation using the transmetalation of azazirconacyclopentene **1**.

An ethereal solution of complex **1**, prepared *in situ* from η^2-iminosilaacyl complex **6** and 4-octyne (**8a**; 2.0 equiv) in the presence of LiEt$_3$BH (2.0 equiv), was added to an ethereal solution of allyl chloride (2.0 equiv) in the presence of CuCl (2.0 equiv), and the solution was stirred at room temperature for 1 h. After an aqueous workup, the γ-allylated (α-silylallyl)amine **4a** was obtained in 75% yield (Scheme 3; Table 1, run 1).[5] The stereochemistry of compound **4a** was determined by NMR measurement (NOESY), and the results indicated

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(1) (a) Schwartz, J.; Loots, M. J.; Kosugi, H. *J. Am. Chem. Soc.* **1980**, *102*, 1333−1340. (b) Negishi, E.; Takahashi, T.; Baba, S.; Van Horn, D. E.; Okukado, N. *J. Am. Chem. Soc.* **1987**, *109*, 2393−2401. (c) Fagan, P. J.; Nugent, W. A.; Calabrese, J. C. *J. Am. Chem. Soc.* **1994**, *116*, 1880−1889. (d) Wipf. P. *Synthesis* **1993**, 537−557. (e) Wipf. P.; Xu, W. *Tetrahedron Lett.* **1994**, *35*, 5197−5200.

(2) (a) Venanzi, L. M.; Lehmann, R.; Keil, R.; Lipshutz, B. H. *Tetrahedron Lett.* **1992**, *33*, 5857−5860. (b) Takahashi, T.; Kotora, M.; Kasai, K.; Suzuki, N. *Tetrahedron Lett.* **1994**, *35,* 5685−5688. (c) Kasai, K.; Kotora, M.; Suzuki, N.; Takahashi, T. *J. Chem. Soc., Chem. Commun.* **1995**, 109−110. (d) Takahashi, T.; Hara, R.; Nishihara, Y.; Kotora, M. *J. Am. Chem. Soc.* **1996**, *118*, 5154. (e) Lipschutz, B.; Segi, M. *Tetrahedron* **1995**, *51*, 4407.

(3) (a) Jensen, M.; Livinghouse, T. *J. Am. Chem. Soc.* **1989**, *111*, 4495−4496. (b) Ito, H.; Taguchi, T.; Hanzawa, Y. *Tetrahedron Lett.* **1992**, *33*, 4469−4472. (c) Buchwald, S. L.; Wannamaker, M. W. *J. Am. Chem. Soc.* **1989**, *111*, 776−777. (d) Grossman, R. B.; Davis, M. W.; Buchwald, S. L. *J. Am. Chem. Soc.* **1991**, *113*, 2321−2322. (e) Davis, J. M.; Whitby, R. J.; Jaxa-Chamiec, A. *Tetrahedron Lett.* **1992**, *33*, 5655−5658. (f) Harris, M. C. J.; Whitby, R. J.; Blagg, J. *Tetrahedron Lett.* **1995**, *36*, 4289−4290.

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Scheme 3

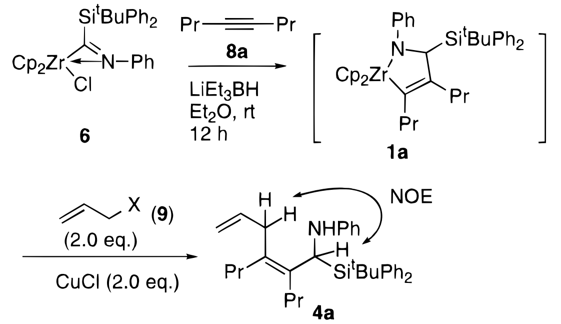
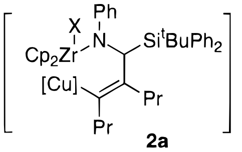


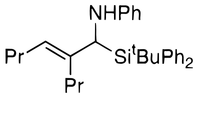
Table 1. Allylation of 1a in the Presence of CuCl

run	X		CuCl	reaction time	yield (%)	
					4a	**10**
1	Cl	**9a**	2.0 eq.	1 h	75	9
2	Cl	**9a**	0.3	23	86	7
3	Cl	**9a**	0	3	-	85
4	OP(O)(OEt)$_2$	**9b**	2.0	20	88	-
5	OAc	**9c**	2.0	15	-	<100

that the reaction proceeded in a highly regio- and stereoselective manner. When the same reaction was carried out in the presence of a catalytic amount of CuCl (0.3 equiv), allylation product **4a** was obtained in high yield (run 2, 86% yield). On the other hand, in the absence of CuCl, compound **4a** was not obtained (run 3) and (α-silylallyl)amine **10**, which is a hydrolyzed product of **1a**, was obtained in 85% yield. The use of allyl phosphate **9b** instead of allyl chloride **9a** gave the same product, **4a**, in 88% yield (run 4). However, allyl acetate **9c** did not give the desired product **4a** (run 5). These results indicate that the reaction proceeds *via* the alkenyl copper complex **2a** generated by transmetalation of the alkenyl group of complex **1a** from zirconium to copper.



2a



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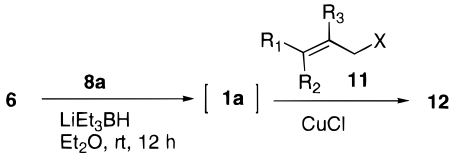
Complex **1a** was reacted with various allyl halides **11** in the presence of a catalytic amount of CuCl (0.3 equiv), and the results are shown in Table 2. Various γ-allylated (α-silylallyl)amines **12** were obtained in high yields. When 1-chloro-3-methyl-2-butene (**11c**) was used as the allyl halide, two regioisomers, **12c** and **12c′**, were obtained in a ratio of 1:2 (Table 2, run 3). The allylation of various azazirconacyclopentenes **1**, prepared *in situ* from alkynes **8** and η^2-iminosilaacyl complex **6**, was carried out in the presence of CuCl (Table 3). The (γ-allyl-α-silylallyl)amines **4** were obtained stereoselectively in good to moderate yields. The reaction of complex **1e**, prepared from complex **6** and alkyne **8e** in the presence of LiEt$_3$BH, with allyl chloride **9a** gave (γ-allyl-α-silyl)allylamine **4e** in good yield. The new carbon–carbon bond would be formed on the alkenyl carbon of **4e** by Suzuki–Miyaura coupling[6] of **4e** and an aryl or alkenyl halide in the presence of Pd(0).[7]

Table 2. Reaction of 1a with Various Allyl Halides in the Presence of CuCl (0.3 Equiv)



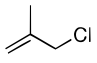
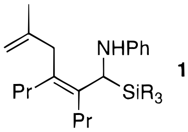
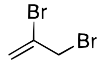
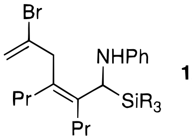
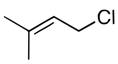
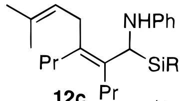
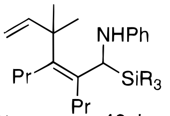
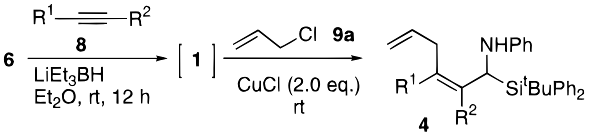
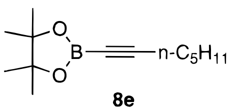
run	allyl halide (**11**)	**12** (SiR$_3$ = Si^{t}BuPh$_2$)	yield (%)
1	 **11a**	 **12a**	87
2	 **11b**	 **12b**	95
3	 **11c**	 **12c** (1 : 2)  **12c'**	91

Table 3. Allylation of Various Azazirconacyclopentenes 1b–g Prepared from 6 and Alkyne 8 in the Presence of LiEt$_3$BH

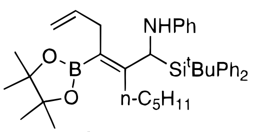


run	alkyne **8** R^1—≡—R^2		reaction time (hr)	product	yield (%)
1	R^1=Ph, R^2=n-C$_5$H$_{11}$	**8b**	9	**4b**	87
2	R^1=TMS, R^2=Me	**8c**	22	**4c**	87
3	R^1=TMS, R^2=n-C$_5$H$_{11}$	**8d**	22	**4d**	78
4	R^1=BR$_2$, R^2=n-C$_5$H$_{11}$	**8e**	24	**4e**	85
5	R^1=R^2=CH$_2$OBn	**8f**	2	**4f**	41[a]
6	R^1=R^2=(CH$_2$)$_3$OBn	**8g**	5	**4g**	53

[a] Allene **13** was obtained in 12% yield (Scheme 4).



8e



4e

Figure 2.

The reaction of **1f** with allyl chloride **9a** in the presence of CuCl (2.0 equiv) gave γ-allylated allylamine

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(5) Spectral data for **4a**: IR (neat) ν 3416, 1600, 1500 cm^{-1}; ^{1}H NMR (500 MHz, CDCl$_3$) δ 0.55 (t, J = 7.3 Hz, 3 H), 0.85 (t, J = 7.3 Hz, 3 H), 0.90–1.00 (m, 2 H), 1.10 (s, 9 H), 1.20–1.40 (m, 2 H), 1.63 (m, 1 H), 1.85–1.95 (m, 2 H), 1.98–2.07 (m, 1 H), 2.89 (dd, J = 15.2, 7.2 Hz, 1 H), 3.39 (dd, J = 15.2, 5.1 Hz, 1 H), 3.81 (d, J = 8.8 Hz, 1 H), 4.77 (d, J = 8.8 Hz, 1 H), 5.10–5.20 (m, 2 H), 5.79–5.90 (m, 1 H), 6.50 (d, J = 7.8 Hz, 2 H), 6.61 (t, J = 7.1 Hz, 1 H), 7.08 (t, J = 7.8 Hz, 2 H), 7.30–7.50 (m, 6 H), 7.62–7.66 (m, 2 H), 7.70–7.74 (m, 2 H); ^{13}C NMR (67.8 MHz, CDCl$_3$) δ 14.8, 18.9, 20.9, 23.3, 28.4, 33.7, 34.1, 35.6, 43.1, 113.1, 116.4, 116.7, 127.3, 127.6, 128.9, 129.3, 129.6, 131.9, 133.4, 133.7, 134.4, 136.6, 137.1, 137.1, 148.4; MS m/z 495 (M$^+$), 454, 345, 256 (bp); HRMS (EI) calcd for $C_{34}H_{45}NSi$ 495.3332, found 495.3307.

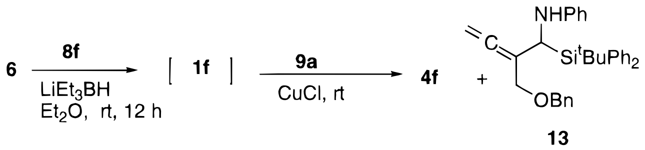
(6) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457–2483.

(7) Brown, S. D.; Armstrong, R. W. *J. Am. Chem. Soc.* **1996**, *118*, 6331.

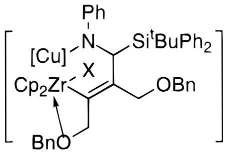
Table 4. Reaction of 1f with 9a

run	CuCl	**9a**	Time (h)	Yield of **4f**	Yield of **13**
1	2.0	2.0	2	41	12
2	0.5	2.0	10	27	32
3	1.5	-	19	-	50

Scheme 4



4f in 41% yield along with allene **13** in 12% yield (Table 3, run 5). The use of a catalytic amount of CuCl decreased the yield of **4f** and increased the yield of the allene **13** (Table 4, run 2). In the absence of allyl chloride, but in the presence of CuCl (1.5 eq.), allene **13** was obtained in 50% yield (Scheme 4). Allene **13** may be formed from alkenylzirconium complex **14** coordinated by the oxygen of the benzyloxy group. In this case, the amino group of **1f** ($R^1 = R^2 = CH_2OBn$) would transmetalate from zirconium to copper (Scheme 1, path b) to produce **14**. It means that azazirconacyclopentene **1** is in a state of equilibrium with alkylzirconium complex **3** and alkenylcopper complex **2** in the presence of CuCl.



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These results indicate that two functional groups, a formyl group and an allyl group, can be introduced onto alkyne carbons in high yield with high regio- and stereoselectivity, using a one-pot reaction.

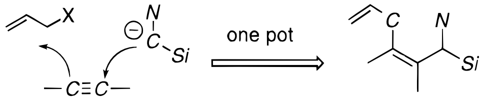

Figure 3.

Further studies are in progress.

Supporting Information Available: Text giving synthetic details and spectroscopic data for the compounds prepared in this paper (7 pages). Ordering information is given on any current masthead page.

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