# Alkenyldimethyl(2-thienyl)silanes, Excellent Coupling Partner for the Palladium-Catalyzed Cross-Coupling Reaction

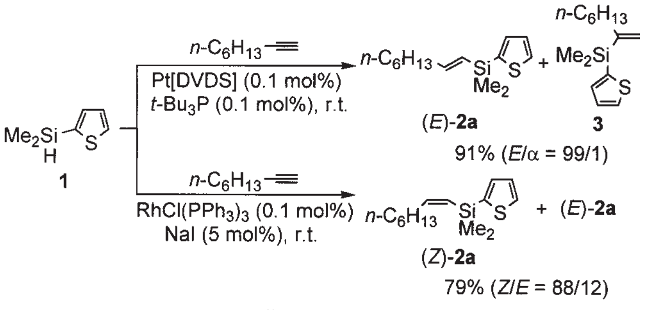
Kazushi Hosoi, Kyoko Nozaki, and Tamejiro Hiyama*
*Department of Material Chemistry, Graduate School of Engineering, Kyoto University, Yoshida, Sakyo-ku, Kyoto 606-8501*

(Received October 31, 2001; CL-011088)

Introduction of a 2-thienyl group to the silicon atom of alkenylsilanes promoted the cross-coupling reaction with aryl halides mediated by tetrabutylammonium fluoride and a palladium catalyst. The reaction proceeded under extremely mild conditions to afford arylalkenes in high yields.

---

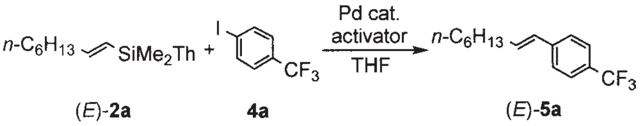
The transition metal-catalyzed cross-coupling reaction is today among the most important class of carbon-carbon bond forming reactions[1] useful in organic synthesis. Of the metals employed for the cross-coupling reaction, boron[2] and tin[3] have gained extensive use in combination with Pd catalysts. We have been studying the palladium catalyzed cross-coupling reaction of organohalosilanes (halogen = F, Cl) using a fluoride ion as an activator.[4] The success of the reaction depends on the activation of a less polar C-Si bond by forming a silicate anion. The existence of an electron-withdrawing hetero atom on the tetracoodinated silicon makes the silicon acidic enough to accept $F^-$.[5] Recently, cross-coupling reactions of organo-alkoxysilanes[6] or organosilanols[7,8] with organic halides are also documented. Thus, the presence of at least one hetero atom on the silicon of alkenylsilanes is essential for the reaction to proceed. Herein, we report that alkenyldimethyl(2-thienyl)silanes **2** efficiently act as a coupling partner with organic halides. The coupling reaction proceeds under extremely mild conditions ever reported for any organosilicon compounds. The advantage of the 2-thienyl group as an activating group as well as a dummy ligand is that alkenyl(2-thienyl)silanes **2** are much more stable against moisture, acid and base, compared to the corresponding halosilanes or other hetero atom substituted silanes. Alkenyldimethyl(2-thienyl)silanes **2** can be readily accessible by hydrosilylation of alkynes with dimethyl(2-thienyl)silane (**1**).



**Scheme 1.**

First, we prepared (*E*)- and (*Z*)-1-octenyldimethyl(2-thienyl)silanes as shown in Scheme 1. Treatment of chlorodimethylsilane with 2-thienyllithium gave dimethyl(2-thienyl)silane (**1**).[9] Hydrosilylation of 1-octyne with **1** in the presence of a Pt or Rh catalyst[10] afforded (*E*)- or (*Z*)-1-octenyldimethyl(2-thienyl)silanes ((*E*)- or (*Z*)-**2a**), respectively. The *E*/*Z* selectivity of hydrosilylation could be controlled by the catalyst to be employed. With $t\text{-}Bu_3P/Pt(CH_2=CHSiMe_2)_2O$ (Pt[DVDS]),[11] (*E*)-1-octenyldimethyl(2-thienyl)silane ((*E*)-**2a**) and $\alpha$-adduct **3** were obtained in a ratio of 99/1. On the other hand, (*Z*)-1-octenyldimethyl(2-thienyl)silane ((*Z*)-**2a**) and (*E*)-**2a** were produced in an 88/12 ratio with $NaI/RhCl(PPh_3)_3$.[12,13] Both (*E*)- and (*Z*)-**2a** are quite stable against moisture, acid (acetic acid, silica gel), and base (1 N NaOH aq., basic alumina).

Next, we optimized the conditions for the cross-coupling reaction of (*E*)-**2a** with 4-iodobenzotrifluoride (**4a**) using a palladium catalyst and tetrabutylammonium fluoride (TBAF, 1.0 M in THF solution ) as a fluoride source.



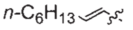
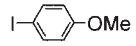
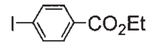
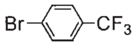
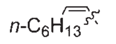
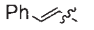
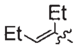
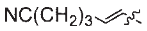
**Scheme 2.**

Cross-coupling of 1.2 equiv. of (*E*)-**2a** with **4a** in the presence of $Pd(PPh_3)_4$ (5 mol%) and 2.4 equiv. of TBAF took place at 60 °C to afford in 4 h the desired arylalkene (*E*)-**5a** in 72% yield. Using palladium(II) acetate, the reaction proceeded smoothly even at room temperature (25 °C) to give (*E*)-**5a** in quantitative yield in 1 h. Taking into account that the silicon-mediated cross-coupling reaction requires normally elevated temperatures,[14] the reactivity is enhanced significantly in this system. With $Pd_2(dba)_3$, the reaction proceeded more rapidly and was completed in 0.5 h to afford (*E*)-**5a** in quantitative yield. Because of the easiness of handling, we chose $Pd(OAc)_2$ as the catalyst. The reaction using an equimolar amount of TBAF to (*E*)-**2a** proceeded more slowly compared to the reaction with 2 equiv. Accordingly, TBAF was used in an amount of 2 equiv. to (*E*)-**2a**, or 2.4 equiv. to **4a**. When we introduced two 2-thienyl groups on silicon, the reactivity was enhanced further, and the reaction was completed in 0.5 h. Unlike TBAF, the use of anhydrous $[(Et_2N)_3S]^+[Me_3SiF_2]^-$ (TASF) or KF as a fluoride salt resulted in no reaction. Meanwhile with aqueous solution of KF or NaOH, the coupled product was obtained to a small extent. Also, the THF solution of TBAF contains water (water content ~5 wt.%, Aldrich).

Very recently, Yoshida reported the cross-coupling reaction of alkenyldimethyl(2-pyridyl)silanes.[15] The coupling reaction is considered to proceed through the silanol formation followed by transmetalation, pyridine being detected spectometrically. We also observed that thiophene was released gradually when the coupling of (*E*)-**2a** and **4a** was monitored by $^1H$ NMR. Thus, even under the conditions for (*E*)-**2a**, milder than those for 2-pyridylsilanes, the 2-thienyl group on Si appears to be cleaved. Direct transmetalation from penta-coodinated silicate, alkenyldimethyl(2-thienyl)(fluoro)silicate, remains to be another possibility though.

The scope of the coupling reaction was examined under the optimum conditions. Various types of alkenylsilanes and aryl halides are applicable to the coupling reaction (Table 1). Aryl iodides having an electron-donating group as well as an electron-withdrawing group (entry 1) are available. Second, the reaction is tolerant of such a functional group as ester (entry 2). An aryl bromide also couples with the alkenylsilane at room temperature (entry 3). The (*Z*)-isomer of **2a** (*Z/E* = 88/12) gave the corresponding arylalkene (*Z*)-**5a** maintaining the *Z*/*E* ratio of 89/11 (entry 4). Mono-substituted vinylsilane **2b**, di-substituted alkenylsilane **2c** coupled smoothly with **4a** (entries 5 and 6). Bissilylated alkene **2d** reacted completely at a dimethyl(2-thienyl)silyl moiety with a trimethylsilyl site being unaffected (entry 7). Also, tri-substituted alkenylsilane **2e** couples without any problem (entry 8). Chemoselectivity is as good as previous organosilicon-based coupling reactions.[4] For example, the reaction gives the coupled product without protecting a nitrile functional group (entry 9). Yields were still high and no other by-products were detected.

**Table 1.** Cross-Coupling of alkenydimethyl(2-thienyl)silanes **2** with halides **4**[a]

| entry | R (%) [b] | aryl halide | time (h) | yield (%) of **5** [c] |
|---|---|---|---|---|
| 1 |  <br>(*E*)-**2a** (*E*/α = 99/1) |  <br>**4b** | 0.5 | 97<br>(*E*/α = 99/1) |
| 2 | (*E*)-**2a** |  <br>**4c** | 0.5 | 94<br>(*E*/α = 99/1) |
| 3 | (*E*)-**2a** |  <br>**4d** | 5 | 96<br>(*E*/α = 97/3) |
| 4 |  <br>(*Z*)-**2a** (*Z*/*E* = 88/12) | **4a** | 1 | 98<br>(*Z*/*E* = 89/11) |
| 5 | <br>**2b** | **4a** | 0.5 | 90 |
| 6 |  (85)<br>**2c** (*E*/α = 99/1) | **4a** | 1 | 98<br>(*E*/α = 99/1) |
| 7 |  (72)<br>**2d** (*E*/α = 96/4) | **4a** | 1 | 95<br>(*E*/α = 96/4) |
| 8 |  (82)<br>**2e** | **4a** | 3 | 86 |
| 9 |  (77)<br>**2f** (*E*/α = 75/25) | **4a** | 1 | 90<br>(*E*/α = 81/19) |

[a] All the reaction was performed using alkenyl(2-thienyl)silane **2** (0.6 mmol), **4** (0.5 mmol), Pd(OAc)$_2$ (5 mol%), and TBAF (1.2 mmol) in THF at room temperature. [b] Yields and isomer ratios of the hydrosilylation are given. [c] Isolated yields. Ratios were determined by $^1$H and $^{19}$F NMR.

In conclusion, we have demonstrated alkenyldimethyl(2-thienyl)silanes are excellent coupling partners with aryl halide in the TBAF promoted palladium-catalyzed cross-coupling reactions. The 2-thienyl group acts as an activating group as well as a dummy ligand. The reaction proceeds under very mild conditions and can be tolerant of a variety of functional groups. Studies on applications as well as mechanistic details are currently undertaken.

We thank the Ministry of Education, Culture, Sports, Science and Technology, Japan, for the Grant-in-Aids for COE Research on Elements Science, No. 12CE2005.

This paper is dedicated to Professor Teruaki Mukaiyama on the occasion of his 75th birthday.

## References and Notes

1 "Metal-Catalyzed Cross-Coupling Reactions," ed. by F. Diederich and P. J. Stang, Wiley-VCH, Weinheim (1998).

2 a) N. Miyaura and A. Suzuki, *Chem. Rev.*, **95**, 2457 (1995). b) A. Suzuki, in "Metal-Catalyzed Cross-Coupling Reactions," ed. by F. Diederich and P. J. Stang, Wiley-VCH, Weinheim (1998), Chap. 2.

3 a) J. K. Stille, *Angew. Chem. Int. Ed. Engl.*, **25**, 508 (1986). b) T. N. Mitchell, in "Metal-Catalyzed Cross-Coupling Reactions," ed. by F. Diederich and P. J. Stang, Wiley-VCH, Weinheim (1998), Chapter 4.

4 a) Y. Hatanaka and T. Hiyama, *Synlett*, **1991**, 845. b) T. Hiyama, in "Metal-Catalyzed Cross-Coupling Reactions," ed. by F. Diederich and P. J. Stang, Wiley-VCH, Weinheim (1998), Chap. 10.

5 K. Tamao, *J. Syn. Org. Chem., Jpn.*, **48**, 457 (1990).

6 a) K. Shibata, K. Miyazawa, and Y. Goto, *Chem. Commun.*, **1997**, 1309. b) M. E. Mowery and P. DeShong, *J. Org. Chem.*, **64**, 1684 (1999).

7 K. Hirabayashi, J. Kawashima, Y. Nishihara, A. Mori, and T. Hiyama, *Org. Lett.*, **1**, 299 (1999).

8 a) S. E. Denmark and J. Y. Choi, *J. Am. Chem. Soc.*, **121**, 5821 (1999). b) S. E. Denmark and D. Wehrli, *Org. Lett.*, **2**, 565 (2000). c) S. E. Denmark and R. F. Sweis, *J. Am. Chem. Soc.*, **123**, 6439 (2001).

9 Dimethyl(2-thienyl)silane (**1**): Bp 45 °C (20 mmHg). $^1$H NMR (200 MHz, CDCl$_3$) $\delta$ 0.38 (s, 3H), 0.40 (s, 3H), 4.54–4.61 (m, 1H), 7.19 (dd, $J = 3.2$, 4.6 Hz, 1H), 7.32 (d, $J =$ 3.2,Hz, 1H), 7.61 (d, $J = 4.6$ Hz, 1H). $^{13}$C NMR (200 MHz, CDCl$_3$) $\delta$ 2.8, 111.1, 128.2, 131.0, 135.1. HRMS. Calcd for $C_6H_{10}SiS$: M, 142.0272; Found: $m/z$ 142.0261.

10 a) I. Ojima, in "The Chemistry of Organic Silicon Compounds," ed. by S. Patai and Z. Rappoport, Wiley, New York (1989), pp 1479–1526. b) T. Hiyama and T. Kusumoto, in "Comprehensive Organic Synthesis," ed. by B. M. Trost and I. Fleming, Pergamon, Oxford (1991), Vol. 8, pp 763–792.

11 a) G. Chandra, P. Y. Lo, P. B. Hitchcock, and M. F. Lappert, *Organometallics*, **6**, 191 (1987). b) K. Takahashi, T. Minami, Y. Ohara, and T. Hiyama, *Tetrahedron Lett.*, **34**, 8263 (1993).

12 I. Ojima, N. Clos, R. J. Donovan, and P. Ingallina, *Organometallics*, **9**, 3127 (1990).

13 a) A. Mori, E. Takahisa, H. Kajiro, K. Hirabayashi, Y. Nishihara, and T. Hiyama, *Chem. Lett.*, **1998**, 443. b) A. Mori, E. Takahisa, H. Kajiro, Y. Nishihara, and T. Hiyama, *Polyhedron*, **19**, 567 (2000).

14 Y. Hatanaka and T. Hiyama, *J. Org. Chem.*, **54**, 268 (1989).

15 a) K. Itami, T. Nokami, and J. Yoshida, *J. Am. Chem. Soc.*, **123**, 5600 (2001). b) K. Itami, T. Nokami, Y. Ishimura, K. Mitsudo, T. Kamei, and J. Yoshida, *J. Am. Chem. Soc.*, **123**, 11577 (2001).