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Nickel-Catalyzed Hydrosilylation/ Cyclization of Difluoro-Substituted 1,6-Enynes

Manabu Takachi and Naoto Chatani*

Department of Applied Chemistry, Faculty of Engineering, Osaka University, Suita, Osaka 565-0971, Japan

chatani@chem.eng.osaka-u.ac.jp

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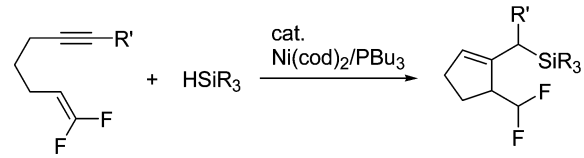
ABSTRACT



Ni-catalyzed hydrosilylative cyclization of difluoro-substituted 1,6-enynes can be carried out. The presence of a geminal-difluoromethylene group at an alkene terminus in enynes is essential for the reaction to proceed.

Catalytic hydrosilylation of unsaturated organic compounds is a process of substantial importance for the synthesis of organosilicon derivatives.[1] Numerous transition metal complexes are known to function as effective catalysts for hydrosilylation. Hydrosilylation of enynes is also an important method for the preparation of cyclic compounds bearing a C−Si bond.[2−4] In most cases, rhodium complexes were used as catalysts for hydrosilylation of enynes reported thus far.[2] Enynes that are applicable to the Rh-catalyzed hydrosilylation are limited to those having no substituents at the alkene moiety except one specific example.[2h] In contrast to the Rh-catalyzed hydrosilylation of enynes, which results in the formation of a C−Si bond at the alkyne carbon, palladium-[3] and yttrium-catalyzed hydrosilylation[4] of enynes yields hydrosilylative cyclization products, in which a C−Si bond forms at the alkene terminus carbon. To the best of our knowledge, there is no example of hydrosilylation of difluoro-substituted enynes, although the expected cyclic products would have both C−Si and C−F bonds that are useful in synthesis—the fluorine atom attached at an alkene is expected to put a unique reactivity to the alkene.[5] We have already reported that the Ni-catalyzed reaction of difluoro-substituted 1,6-enynes with organozinc reagents resulted in alkylative or reductive cyclization in which a trans-C−F bond is selectively substituted during cyclization.[6] We wish to report a new type of Ni-catalyzed hydrosilylative cyclization of difluoro-substituted 1,6-enynes in which the presence of a difluoromethylene group at the alkene carbon is essential for the reaction to proceed.

The reaction of **1** with $HSiMe_2Ph$ in the presence of $Ni(cod)_2/PBu_3$ as the catalyst in dioxane at 50 °C for 2 h gave **2a** as a single product in 75% isolated yield (Scheme 1). The product obtained was not the expected product, which

(1) Hiyama, T.; Kusumoto, T. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Elsevier: Oxford, U. K., 1991; Vol. 8, p 763. Ball, Z. In *Comprehensive Organometallic Chemistry III*; Crabtree, R. H., Mingos, M., Eds.; Elsevier: Oxford, U. K., 2007; Vol. 10, p 815. Roy, A. K. *Adv. Organomet. Chem.* **2008**, *44*, 1.

(2) (a) Ojima, I.; Donovan, R. J.; Shay, W. R. *J. Am. Chem. Soc.* **1992**, *114*, 6580. (b) Ojima, I.; Vu, A. T.; Lee, S.-Y.; McCullagh, J. V.; Moralee, A. C.; Fujiwara, M.; Hoang, T. H. *J. Am. Chem. Soc.* **2002**, *124*, 9164. (c) Chakrapani, H.; Liu, C.; Widenhoefer, R. A. *Org. Lett.* **2003**, *5*, 157. (d) Park, K. H.; Kim, S. Y.; Son, S. U.; Chung, Y. K. *Eur. J. Org. Chem.* **2003**, 4341. (e) Park, K. H.; Jung, I. G.; Kim, S. Y.; Chung, Y. K. *Org. Lett.* **2003**, *5*, 4967. (f) Maerten, E.; Delerue, H.; Queste, M.; Nowicki, A.; Suisse, I.; Agbossou-Niedercorn, F. *Tetrahedron: Asymmetry* **2004**, *15*, 3019. (g) Fan, B.-M.; Xie, J.-H.; Li, S.; Wang, L.-X.; Zhou, Q.-L. *Angew. Chem., Int. Ed.* **2007**, *46*, 1275. (h) Denmark, S. E.; Liu, H.-C. J. *J. Am. Chem. Soc.* **2007**, *129*, 3737.

(3) Wakayanagi, S.; Shimamoto, T.; Chimori, M.; Yamamoto, K. *Chem. Lett.* **2005**, *34*, 160.

(4) Molander, G. A.; Retsch, W. H. *J. Am. Chem. Soc.* **1997**, *119*, 8817.

(5) Amii, H.; Uneyama, K. *Chem. Rev.* **2009**, *109*, 2119.

(6) Takachi, M.; Kita, Y.; Tobisu, M.; Fukumoto, Y.; Chatani, N. *Angew. Chem., Int. Ed.*, in press.

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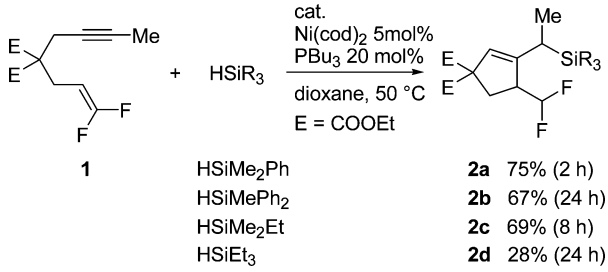
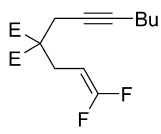
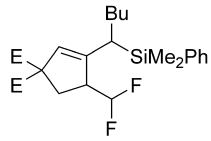
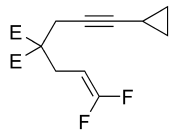
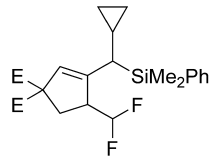
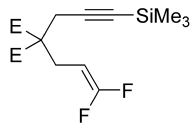
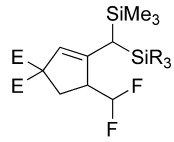
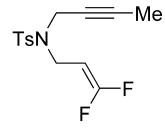
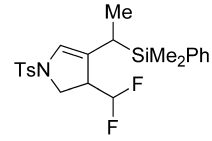
Scheme 1



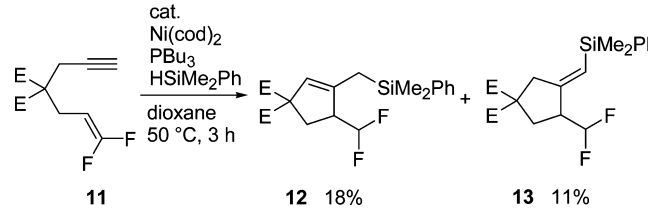
has an exosilylmethylene (vinylsilane) moiety, but instead has an allylsilane moiety[7] unlike reported examples of the Rh-catalyzed hydrosilylation of simple enynes.[2] In addition, the product has a difluoromethyl moiety, which is often used in the medicinal, agricultural, and material sciences.[8] Among the ligands examined, it was found that PBu_3 is the ligand of choice: PBu_3 (75%, 2 h), PPh_3 (56%, 2 h), PCy_3 (41%, 24 h), dppe (no reaction, 24 h). While other hydrosilanes also gave the corresponding cyclic allylsilanes, the reaction with $HSiMe_2Ph$ gave a better yield in a short reaction time. The reaction was significantly affected by steric factors of hydrosilanes ($HSiMe_2Ph$ > $HSiMePh_2$, $HSiMe_2Et$ > $HSiEt_3$).

Table 1. Ni-Catalyzed Hydrosilylation of Difluoro-Substituted Enynes[a]

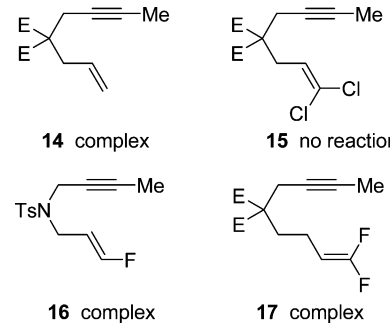
difluoro-enyne	product[b]
 **3**	 **4** 67% (24 h)
 **5**	 **6** 71% (4 h)
 **7**	 $HSiMe_2Ph$ **8a** 95% (6 h) $HSiMePh_2$ **8b** 94% (6 h) $HSiMe_2Et$ **8c** 94% (2 h) $HSiEt_3$ **8d** 90% (6 h) $HSi(OMe)_3$ **8e** 84% (6 h)
 **9**	 **10** 68% (24 h)

[a] Reaction conditions: enyne (0.3 mmol), $HSiR_3$ (0.60 mmol), $Ni(cod)_2$ (0.015 mmol), PBu_3 (0.06 mmol), dioxane (1.5 mL) at 50 °C. [b] Isolated yield.

Scheme 2



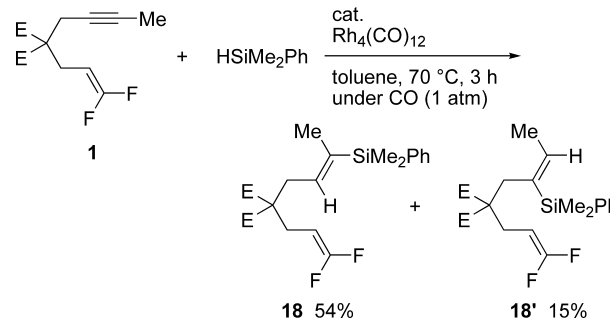
Scheme 3. Limitations



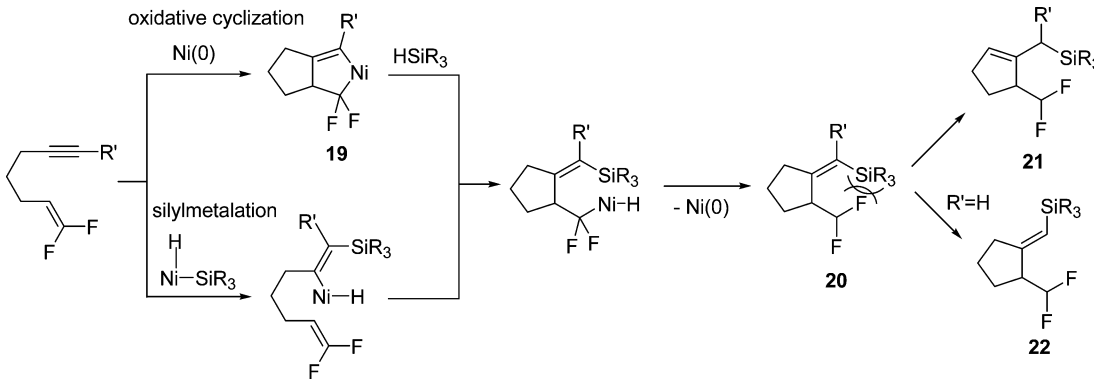
The results of the Ni-catalyzed hydrosilylation of difluoro-substituted 1,6-enynes are shown in Table 1. Various difluoro-substituted 1,6-enynes having an internal alkyne served as good substrates to give the corresponding cyclic allylsilanes. Curiously, an enyne having a trimethylsilyl group at the alkyne terminus, as in **7**, gave the corresponding products **8** in high yields, irrespective of the structure of the hydrosilanes.[9] An enyne with a nitrogen functional group, as in **9**, also gave the corresponding product **10** in a good yield.

In contrast to enynes having internal alkynes, the reaction of an enyne having a terminal alkyne moiety, as in **11**, gave a mixture of allylsilane **12** and vinylsilane **13** (Scheme 2).

Scheme 4. Rh-Catalyzed Hydrosilylation of **1**



Scheme 5. Reaction Mechanism



The presence of a difluoromethylene group at an alkene terminus in enynes was essential for the reaction to proceed (Scheme 3). The reaction of a simple enyne **14**, dichloro-substituted enyne **15**, and monosubstituted enyne **16** gave either complex mixtures or no reaction at all. The length in the tether was also an important factor. Thus, a complex mixture was obtained in the case of 1,7-difluoro-substituted enyne **17**.

Use of $Rh_4(CO)_{12}$ as the catalyst gave a regioisomeric mixture of hydrosilylation products **18**, in which the alkene moiety did not participate (Scheme 4).

The proposed reaction mechanism is shown in Scheme 5. One possibility would have the pathway via a nickelacycle **19** as a key intermediate, which is formed by the oxidative cyclization of an enyne and Ni(0).[10] Another possibility could be the silylmetalation pathway. Tamao and Ito reported the Ni-catalyzed hydrosilylation of diynes in which it was proposed that the reaction is initiated by silylmetalation.[11] Irrespective of the mechanism, an initial product was vinylsilane **20**, which isomerized to thermodynamically stable allylsilane **21** under the reaction conditions. When R′ = H, the isomerization of **20** to **22** also proceeded.

In summary, the first example of hydrosilylation of difluoro-substituted 1,6-enynes is described. A nickel complex showed high catalytic activity.

Acknowledgment. This work was supported, in part, by grants from Ministry of Education, Culture, Sports, Science and Technology, Japan. We wish to thank to Daikin Industries Ltd. for financial support.

Supporting Information Available: Experimental procedures and spectroscopic data for new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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(7) Masse, C. E.; Panek, J. S. *Chem. Rev.* **1995**, *95*, 1293. Fleming, I.; Barbero, A.; Walter, D. *Chem. Rev.* **1997**, *97*, 2063. Denmark, S. E.; Almstead, N. G. In *Modern Carbonyl Chemistry*; Otera, J., Ed.; Wiley-VCH: Weinheim, 2000; Chapter 10. Chabaud, L.; James, P.; Landais, Y. *Eur. J. Org. Chem.* **2004**, 3173.

(8) Welch, J. T.; Eswarakrishnan, S. *Fluorine in Bioorganic Chemistry*; John Wiley & Sons: New York, 1991. Filler, R., Kobayashi, Y., Yagupolskii, L. M., Eds. *Organofluorine Compounds in Medicinal Chemistry and Biomedical Applications; Studies in Organic Chemistry*; Elsevier Science Ltd.: Amsterdam, 1993; Vol. 48. Banks, R. E., Smart, B. E., Tatlow, J. C., Eds. *Organofluorine Chemistry: Principles and Commercial Applications; Topics in Applied Chemistry*; Plenum Publishing Corp: New York, 1994. Hiyama, T. *Organofluorine Compounds: Chemistry and Applications*; Springer-Verlag: Berlin, 2000. Kirsch, P. *Modern Fluoroorganic Chemistry: Synthesis, Reactivity, Applications*; Wiley-VCH: Weinheim, Germany, 2004. Hambers, R. D. *Fluorine in Organic Chemistry*; Blackwell: Oxford, 2004.

(9) Lautens, M.; Ben, R. N.; Delanghe, P. H. M. *Tetrahedron* **1996**, *52*, 7221. Princet, B.; Anselme, G.; Pornet, J. *Synth. Commun.* **1999**, *29*, 3329. Princet, B.; Anselme, G.; Pornet, J. *J. Organomet. Chem.* **1999**, *592*, 34. Princet, B.; Gardès-Gariglio, H.; Pornet, J. *J. Organomet. Chem.* **2000**, *604*, 186. Hodgson, D. M.; Barker, S. F.; Mace, L. H.; Moran, J. R. *Chem. Commun.* **2001**, 153. Williams, D. R.; Morales-Ramos, Á. I.; Williams, C. M. *Org. Lett.* **2006**, *8*, 4393.

(10) Kaschube, W.; Schröder, W.; Pörschke, K. R.; Angermund, K.; Krüger, C. *J. Organomet. Chem.* **1990**, *389*, 399. Bennett, M. A.; Glewis, M.; Hockless, D. C. R.; Wenger, E. *J. Chem. Soc., Dalton Trans.* **1997**, 3105.

(11) Tamao, K.; Kobayashi, K.; Ito, Y. *J. Am. Chem. Soc.* **1989**, *111*, 6478.