Available online at www.sciencedirect.com

ScienceDirect

Tetrahedron Letters 49 (2008) 1593–1597

Tetrahedron Letters

Two types of rhodium-catalyzed CS/CS metathesis reactions: formation of CS/CS bonds and CC/SS bonds

Mieko Arisawa[a], Yoko Tagami[a], Masahiko Yamaguchi[a,b,*]

[a] *Department of Organic Chemistry, Graduate School of Pharmaceutical Sciences, Tohoku University, Aoba, Sendai 980-8578, Japan*
[b] *WPI Advanced Institute for Material Research, Tohoku University, Aoba, Sendai, Japan*

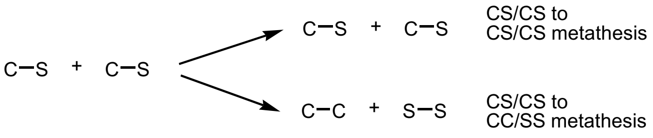
Received 3 December 2007; revised 26 December 2007; accepted 10 January 2008
Available online 15 January 2008

Abstract

A rhodium complex catalyzes two types of single bond metathesis reactions of two CS bonds depending on the added ligand: CS/CS to CS/CS metathesis and CS/CS to CC/SS metathesis. In the presence of a catalytic amount of $RhH(PPh_3)_4$ and 1,1′-bis(diphenylphosphino)ferrocene (dppf), two 1-alkylthioalkynes exchange alkylthio groups to give equilibrium mixtures of four 1-alkylthioalkynes. When tris(*p*-methoxyphenyl)phosphine or diphenylmethylphosphine is used, 1,3-butadiynes are obtained.

We propose the use of transition metal catalyzed reactions, in particular single bond metathesis reactions, for the efficient synthesis of organosulfur compounds.[1] Several such reactions have been developed: SS/SS metathesis for disulfide exchange;[2] CH/SS metathesis of 1-alkynes to give 1-alkylthioalkynes;[3] CS/SS metathesis for the alkylthio exchange of 1-alkylthioalkynes;[3] SS/HH metathesis to reduce disulfides to thiols;[4] PP/SS metathesis to give thiophosphinates;[5] PS/SS metathesis for the alkylthio exchange of thiophosphinates.[5] In order for such reactions to proceed effectively, the catalyst must be able to cleave two single bonds and to exchange the combination of the groups.

The above reactions using organic disulfides for one of the substrates give products of a single metathesis mode. In contrast, the single bond metathesis of CS/CS bond can undergo two modes of the reaction, CS/CS to CS/CS metathesis and CS/CS to CC/SS metathesis. Control of the reaction mode using a single metal complex is an interesting subject, which leads to the understanding on the properties of the catalysts, and provides novel synthetic method for the CC bond formation. Described herein is that a rhodium complex in the presence of different phosphine ligands catalyzes either the alkylthio exchange reaction of 1-alkylthioalkynes or the coupling reaction to give 1,3-butadiyne, which are CS/CS to CS/CS metathesis and CS/CS to CC/SS metathesis, respectively (Scheme 1). Although symmetrical 1,3-butadiynes are readily prepared from 1-alkynes by copper catalyzed oxidation reaction,[6] a notable aspect of the present reaction is to provide a method for catalytic CC bond formation using organosulfur compounds liberating disulfides. The change of single bond formation mode by ligand in the transition metal reaction has a few precedents in the reductive elimination of palladium(IV) complex.[7] For example, depending on the ligand and substituent, $PdBrMe_2(CH_2Ar)(L_2)$ complexes give ethane or arylethane. Its application to catalytic reaction as indicated in this study may be important.



Scheme 1.

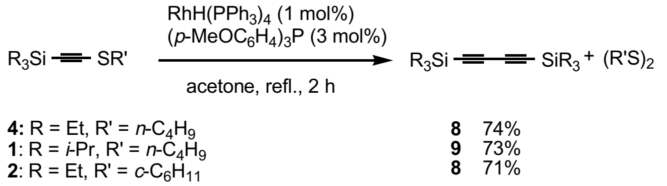
---

[*] Corresponding author. Tel.: +81 22 795 6812; fax: +81 22 795 6811.
E-mail address: yama@mail.pharm.tohoku.ac.jp (M. Yamaguchi).

0040-4039/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2008.01.040

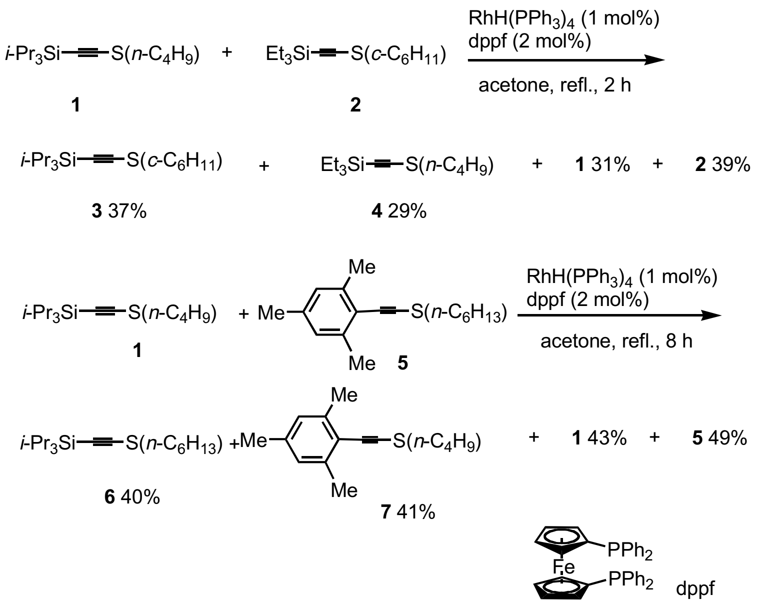
It was previously found in our laboratory that a rhodium complex derived from RhH(PPh$_3$)$_4$ and 1,1′-bis(diphenylphosphino)ferrocene (dppf) was capable to cleave CS bond of 1-alkylthioalkynes:[3] the reaction of a 1-alkylthioalkyne and a thiol gave a 1-alkyne and an alkylthio exchanged 1-alkylthioalkyne; the reaction of a 1-alkylthioalkyne and a disulfide gave an alkylthio exchanged 1-alkylthioalkyne. It was therefore considered that alkylthio exchange of 1-alkylthioalkynes could take place by the treatment of two 1-alkylthioalkynes in the presence of the rhodium complex. When a mixture of 1-butylthio–2-triisopropylsilylethyne **1**, and 1-cyclohexylthio–2-triethylsilylethyne **2** in acetone was heated at reflux for 2 h in the presence of RhH(PPh$_3$)$_4$ (1 mol %) and dppf (2 mol %), a mixture of 1-cyclohexylthio–2-triisopropylsilylethyne **3** (37%), 1-butylthio-2-triethylsilylethyne **4** (29%), **1** (31%), and **2** (39%) was formed (Scheme 2). The ligand dppf is essential in the alkylthio exchange reaction, and no reaction occurs in its absence. This is an equilibrium giving comparable amounts of the possible products. The alkylthio exchange reaction of 1-hexylthio-2-(2,4,6-trimethylphenyl)ethyne **5** and **1** was slower, and a mixture of 1-alkylthioalkynes containing 1-hexylthio-2-triisopropylsilylethyne **6** (40%), 1-butylthio-2-(2,4,6-trimethylphenyl)ethyne **7** (41%), **1** (43%), and **5** (49%) was formed after 8 h. It is shown that RhH(PPh$_3$)$_4$ and dppf catalyze the cleavage of two CS bonds and alkylthio exchange reaction, CS/CS to CS/CS metathesis.

Next examined was the other mode of the metathesis, CS/CS to CC/SS metathesis. The reaction of 1-butylthio-2-triethylsilylethyne **4** in refluxing acetone with RhH(PPh$_3$)$_4$ (1 mol %) and (p-MeOC$_6$H$_4$)$_3$P (3 mol %) for 2 h gave 1,4-bis(triethylsilyl)-1,3-butadiyne **8** in 74% yield, which was accompanied by dibutyl disulfide in 54% (Scheme 3). Analogously, **1** was converted to the corresponding diyne **9** in 73% yield. The alkylthio group could be secondary cyclohexyl as shown by the example of **2** to give **8**. The use of electron-rich monodentate phosphine was essential, and the use of dppf (4%), dppe (not detected), and dppb (trace) gave a very small amount of dimer **8**. Monodentate phosphine ligands, Ph$_3$P (51%) and (p-ClC$_6$H$_4$)$_3$P (43%), were less effective.

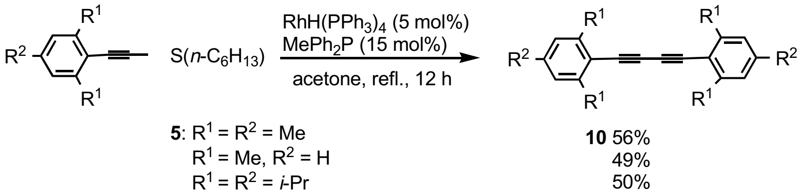


Scheme 3.

The ligand effect in the dimerization of aryl substituted 1-alkylthioalkynes is slightly different from the silylalkynes. When 1-hexylthio-2-(2,4,6-trimethylphenyl)ethyne **5** was treated with RhH(PPh$_3$)$_4$ (5 mol %) and MePh$_2$P (15 mol %) in refluxing acetone for 12 h, dimer **10** was obtained in 56% yield (Scheme 4). The ligand effect follows: (p-MeOC$_6$H$_4$)$_3$P, 40% (reaction time, 9 h); {2,4,6-(MeO)$_3$C$_6$H$_2$}$_3$P, 30% (9 h); (p-ClC$_6$H$_4$)$_3$P, 9% (2 h); EtPPh$_2$, 57% (12 h); Me$_2$PPh, 8% (12 h); Bu$_3$P, 22% (9 h); (2-furyl)$_3$P, 7% (9 h); without phosphine, 16% (12 h). The 1-alkylthioalkynes required bulky aromatic groups for effective dimerization, and the reaction of 1-hexylthio-2-phenylethyne gave various products without forming 1,4-diphenyl-1,3-butadiyne. The bulky substituents may be retarding the oligomerization of alkynes. It was confirmed that this reaction was not reversible, and the reaction of **10** and dioctyl disulfide in the presence of RhH(PPh$_3$)$_4$



Scheme 2.



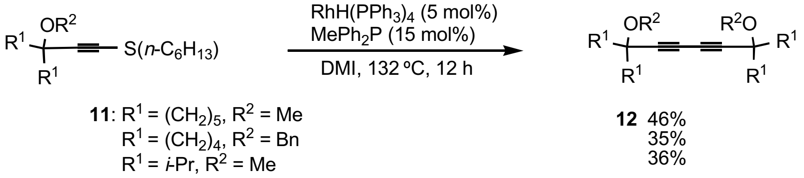
Scheme 4.

(5 mol %) and $MePPh_2$ (15 mol %) in 1,3-dimethyl-2-imidazolidinone (DMI) at 132 °C for 12 h resulted in the recovery of **10** in 93% yield. The irreversibility was further confirmed by the lack of crossover in the reaction of **8** and **10** under the conditions.

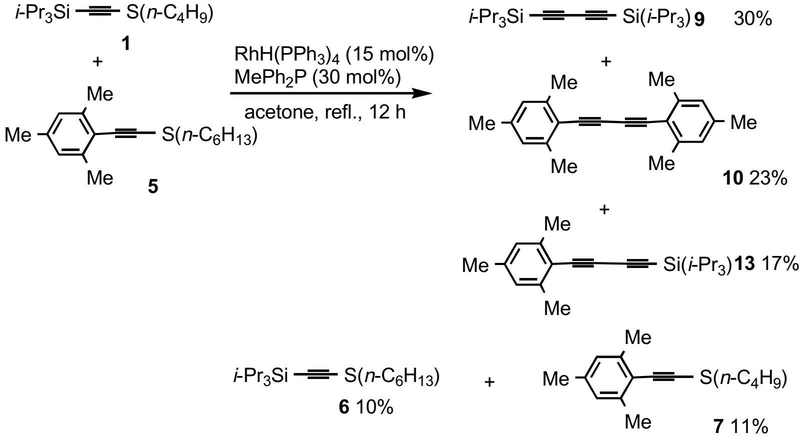
The dimerization of alkyl substituted 1-alkylthioalkynes required higher temperatures. When 1-hexylthio-2-(1-methoxycyclohexyl)ethyne **11** was treated with $RhH(PPh_3)_4$ (5 mol %) and $MePPh_2$ (15 mol %) in DMI at 132 °C for 12 h, dimer **12** was obtained in 46% yield (Scheme 5). This reaction competed with catalyst deactivation. The reaction in refluxing acetone gave only 4% yield of **12**. As for the substrate, the tertiary ether structure was critical for the effective reaction, and 1-butylthio-3,3-dimethyl-1-butyne was recovered unchanged under the conditions.

To know the difference in the reactivity of the substrate, cross-coupling experiments were conducted (Scheme 6). The reaction of **1** and **5** in the presence of $RhH(PPh_3)_4$ (5 mol %) and $MePh_2P$ (15 mol %) in refluxing acetone for 12 h gave homodimers **9** (30%) and **10** (23%), which was accompanied by the cross-coupling product **13** (17%). The result indicated a comparable efficiency in the homo- and cross-coupling, and appreciable difference in the reactivity of **1** and **5** was not observed in the coupling. The alkylthio exchange products **6** (10%) and **7** (11%) were formed as well as the starting materials **1** and **5**, which indicated that $RhH(PPh_3)_4$-$MePh_2P$ complex catalyzed both CS/CS to CS/CS metathesis and CS/CS to CC/SS metathesis. The attempt of the cross-coupling of the less reactive alkyl substituted 1-alkylthioalkyne **11** and reactive **1** in refluxing acetone gave only a small amount of **9** without forming the unsymmetrical butadiyne. Thus, the facility of the CS bond cleavage appears to be an important factor in the present reaction.

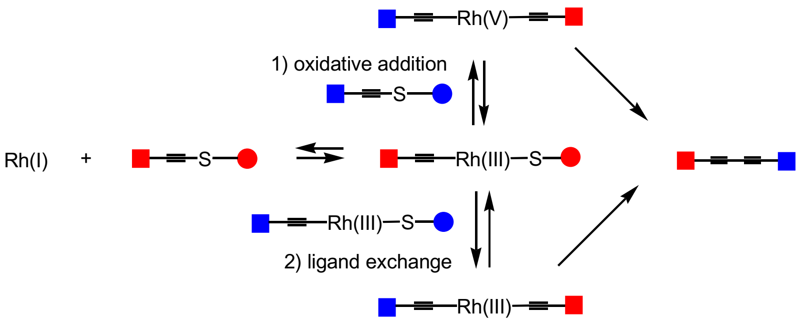
Mechanistically, it may be acceptable that the initial step is the oxidative addition of a 1-alkylthioalkyne with rhodium(I) complex to form alkynylrhodium(III) complex (Scheme 7). The direct metathesis reaction of CRh and CS bonds to form either CC or CS bonds for the next step



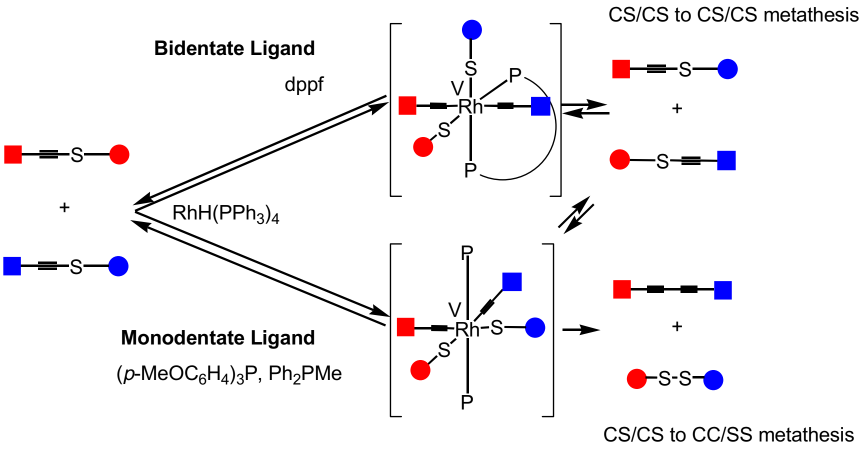
Scheme 5.



Scheme 6.



Scheme 7.



Scheme 8.

may not be likely, since an alkynylrhodium(III) would not possess such reactivity to attack carbon or sulfur atom of another 1-alkylthioalkyne. Rather, ligand coupling on rhodium metal may be probable, and the next possible pathways will be either (1) oxidative addition of thioalkyne to form rhodium(V) complex, or (2) ligand exchange between the rhodium(III) complex.

A possible explanation of the ligand effect can be provided based on the Rh(V) mechanism (Scheme 8).[8] Two thioalkynes subsequently undergo oxidative addition with rhodium(I) intermediate to give octahedral rhodium(V) species possessing two alkynyl and two alkylthio ligands. The dppf ligand occupies the cis-configuration and the trans-configuration of alkylthio and phosphine group assuming the trans-effect of phosphorous and sulfur groups. Here, two alkynyl groups possessing the trans-configuration do not undergo reductive elimination to form butadiyne, and only alkylthio exchange proceeds (CS/CS to CS/CS metathesis). In case of monophosphine complex, two phosphines take the trans-configuration, and reductive elimination to form either butadiyne or alkylthio exchanged products take place (CS/CS to CS/CS metathesis and CS/CS to CC/SS metathesis).

It is shown that a rhodium complex in the presence of different phosphine ligand catalyzes single bond metathesis reactions of CS and CS bonds to form either CS/CS bond or CC/SS bond. It is an interesting method to probe the reactivity of rhodium complex possessing C–Rh–S structure, which plays important roles in the single bond metathesis reactions of organosulfur compounds. It should also be noted that the present work provides a possibility to develop catalyzed coupling reaction of organosulfur compounds.

Acknowledgments

This work was supported by JSPS (Nos. 16109001 and 17689001). M.A. expresses her thanks to the Grant-in-Aid for Scientific Research on Priority Areas, ‘Advanced Molecular Transformations of Carbon Resources’ from MEXT (Nos. 18037005 and 19020008).

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2008.01.040.

References and notes

1. (a) Arisawa, M.; Yamaguchi, M. *Pure Appl. Chem.*, in press; (b) Arisawa, M.; Yamaguchi, M. *J. Synth. Org. Chem. Jpn.* **2007**, *65*, 1213.

2. (a) Arisawa, M.; Yamaguchi, M. *J. Am. Chem. Soc.* **2003**, *125*, 6624; (b) Arisawa, M.; Tanaka, K.; Yamaguchi, M. *Tetrahedron Lett.* **2005**, *46*, 4797; (c) Arisawa, M.; Suwa, A.; Yamaguchi, M. *J. Organomet. Chem.* **2006**, *691*, 1159.
3. Arisawa, M.; Fujimoto, K.; Morinaka, S.; Yamaguchi, M. *J. Am. Chem. Soc.* **2005**, *127*, 12226.
4. Arisawa, M.; Sugata, C.; Yamaguchi, M. *Tetrahedron Lett.* **2005**, *46*, 6097.
5. Arisawa, M.; Ono, T.; Yamaguchi, M. *Tetrahedron Lett.* **2005**, *46*, 5669.
6. For example: Sonogashira, K. Coupling Reactions Between *sp* Carbon Centers. In *Comprehensive Organic Synthesis*; Trost, B. M., Ed.; Pergamon Press: Oxford, 1991; Vol. 3, p 551.
7. For example. (a) Canty, A. J. *Acc. Chem. Res.* **1992**, *25*, 83; (b) Aye, K.-T.; Canty, A. J.; Crespo, M.; Puddephatt, R. J.; Scott, J. D.; Watson, A. A. *Organometallics* **1989**, *8*, 1518; (c) de Graaf, W.; Boersma, J.; van Koten, G. *Organometallics* **1990**, *9*, 1479; (d) Byers, P. K.; Canty, A. J.; Skelton, B. W.; Traill, P. R.; Watson, A. A.; White, A. H. *Organometallics* **1990**, *9*, 3080; (e) Kruis, D.; Markies, B. A.; Canty, A. J.; Boersma, J.; van Koten, G. *J. Organomet. Chem.* **1997**, *532*, 235.
8. (a) Fernandez, M.-J.; Maitlis, P. M. *J. Chem. Soc., Chem. Commun.* **1982**, 310; (b) Gómez, M.; Robinson, D. J.; Maitlis, P. M. *J. Chem. Soc., Chem. Commun.* **1983**, 825; (c) Fernandez, M.-J.; Bailey, P. M.; Bentz, P. O.; Ricci, J. S.; Koetzle, T. F.; Maitlis, P. M. *J. Am. Chem. Soc.* **1984**, *106*, 5458.