Palladium-Catalyzed Cross-Coupling Reactions of 2-Iodo-4-(phenylchalcogenyl)-1-butenes

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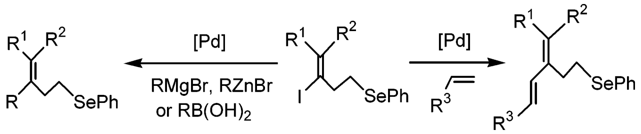

2-Iodo-4-(phenylchalcogenyl)-1-butenes **2** or **3**, which are derived from the ring-opening reaction of methylenecyclopropanes (MCPs) **1** by iodine, can be applied to some palladium-catalyzed cross-coupling reactions such as the Sonogashira, Heck, Kumada, Suzuki, and Negishi reactions under mild conditions to give the corresponding coupling products in good yields. These reactions proceeded smoothly at room temperature (20 °C) in most cases without any phosphine ligand and additive. The phenylchalcogenyl group plays an important role in the reactions and a plausible reaction mechanism has been proposed.

Introduction

Metal-catalyzed cross-coupling reactions are an extremely useful synthetic method in current organic chemistry and these reactions are primarily utilized for the formation of the carbon−carbon bond as well as the carbon−heteroatom bond.[1] Among these reactions, the Sonogashira, Heck, Kumada , Suzuki, and Negishi reactions have been extensively investigated and have found wide application in organic synthesis. On the other hand, methylenecyclopropanes (MCPs) **1** are highly strained but readily accessible molecules that have served as useful building blocks in organic synthesis.[2−4] Recently, we have successfully introduced some heteroatoms such as sulfur (S) and selenium (Se) atoms into the aromatic and/or aliphatic group substituted methylenecyclopropanes.[5] In fact, selenium- or sulfur-containing organic molecules are extremely useful compounds in synthetic organic chemistry,[6] and selenium- or sulfur-ligated Pd(II) complexes are active catalysts for some coupling reactions.[7] For example, previously, we reported the synthesis of 2-iodo-4-phenylchalcogenyl-1-butenes **2** (X

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(1) For recent reviews on metal-catalyzed cross-coupling reactions see: (a) Diederich, F.; Stang, P. J., Eds. *Metal-catalyzed Cross-coupling Reactions*; Wiley: New York, 1998. (b) de Meijere, A.; Diederich, F., Eds. *Metal-catalyzed Cross-coupling Reactions*, 2nd ed., 2 volumes; Wiley: Weinheim, Germany, 2004. (c) Miyaura, N., Eds. *Cross-coupling Reactions*, *A Practical Guide*; Top. Curr. Chem. Vol. 219*;* Springer: Berlin, Germany, 2002. (d) Negishi, E.; de Meijere, A., Eds. *Handbook of Organo-palladium Chemistry for Organic Synthesis*, 2 volumes; Wiley: New York, 2002. (e) Tsuji, J. *Palladium Reagents and Catalysts*; Wiley: Chichester, UK, 1995. (f) Tsuji, J. *Palladium Reagents and Catalysts*; Wiley: Chichester, UK, 2004.

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(4) For selected recent articles on MCPs, see: (a) Nakamura, I.; Oh, B. H.; Saito, S.; Yamamoto, Y. *Angew. Chem.*, *Int. Ed.* **2001**, *40*, 1298. (b) Oh, B. H.; Nakamura, I.; Saito, S.; Yamamoto, Y. *Tetrahedron Lett.* **2001**, *42*, 6203. (c) Yamago, S.; Nakamura, E. *J. Org. Chem.* **1990**, *55*, 5553. (d) Yamago, S.; Yanagawa, M.; Nakamura, E. *Chem. Lett.* **1999**, 879. (e) Camacho, D. H.; Nakamura, I.; Saito, S.; Yamamoto, Y. *J. Org. Chem.* **2001**, *66*, 270. (f) Nakamura, I.; Itagaki, H.; Yamamoto, Y. *J. Org. Chem.* **1998**, *63*, 6458. (g) Yamago, S.; Nakamura, E. *J. Org. Chem.* **1990**, *55*, 5553. (h) Yamago, S.; Yanagawa, M.; Nakamura, E. *Chem. Lett.* **1999**, 879. (i) Lautens, M.; Han, W.; Liu, J. H.-C. *J. Am. Chem. Soc.* **2003**, *125*, 4028. (j) Siriwardana, A. I.; Kamada, M.; Nakamura, I.; Yamamoto, Y. *J. Org. Chem.* **2005**, *70*, 5932. (k) Scott, M. E.; Lautens, M. *Org. Lett.* **2005**, *7*, 3045. (l) Scott, M. E.; Han, W.; Lautens, M. *Org. Lett.* **2004**, *6*, 3309. (m) Lautens, M.; Han, W. *J. Am. Chem. Soc.* **2002**, *124*, 6312. (n) Lautens, M.; Han, W.; Liu, J. H.-C. *J. Am. Chem. Soc.* **2003**, *125*, 4028.

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SCHEME 1. Synthesis and Enynylation of Compound 2 or 3 and Formation of Trienyne 6a

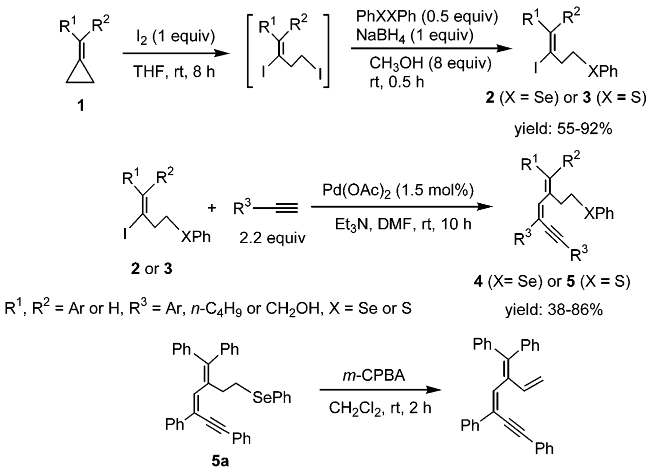
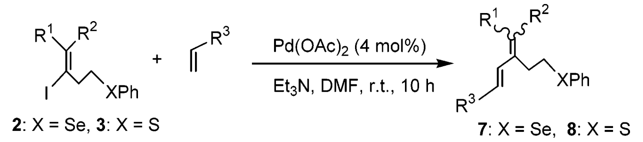


TABLE 1. Heck Reaction of Compounds 2 or 3 (0.3 mmol)



entry	R^1, R^2	R^3	X	yield, %[a] **7** or **8**	*E,Z*/*E,E*
1	C_6H_5, C_6H_5 **2a**	CO_2CH_3	Se	**7a**, 94	
2	*p*-MeC_6H_4, *p*-MeC_6H_4 **2b**	CO_2CH_3	Se	**7b**, 86	
3	*p*-$MeOC_6H_4$, *p*-$MeOC_6H_4$ **2c**	CO_2CH_3	Se	**7c**, 94	
4[c]	*p*-MeC_6H_4, *p*-MeC_6H_4 **2b**	CO_2CH_3	Se	**7d**, 85	
5[c]	*p*-FC_6H_4, *p*-FC_6H_4 **2e**	CO_2CH_3	Se	**7e**, 82	
6	*p*-$MeOC_6H_4$, H **2f**	CO_2CH_3	Se	**7f**, 90	1.1:1[b]
7	*o,m*-$(MeO)_2C_6H_3$, H **2g**	CO_2CH_3	Se	**7g**, 88	0.7:1[b]
8	*m,m,p*-$(MeO)_3C_6H_2$, H **2h**	CO_2CH_3	Se	**7h**, 86	1.7:1[b]
9	*p*-ClC_6H_4, H **2i**	CO_2CH_3	Se	**7i**, 84	1.8:1[d]
10	C_6H_5, C_6H_5 **3a**	CO_2CH_3	S	**8a**, 86	
11	*p*-MeC_6H_4, *p*-MeC_6H_4 **3b**	CO_2CH_3	S	**8b**, 82	
12	*p*-$MeOC_6H_4$, *p*-$MeOC_6H_4$ **3c**	CO_2CH_3	S	**8c**, 90	
13	C_6H_5, C_6H_5 **2a**	CO_2Ph	Se	**7j**, 86	
14	C_6H_5, C_6H_5 **2a**	$COCH_3$	Se	**7k**, 84	
15[c]	C_6H_5, C_6H_5 **2a**	CN	Se	**7*l***, 82	

[a] Isolated yields. [b] Determined by ^1H NMR spectroscopic data. [c] Conducted at 80 °C. [d] Determined by isolated yields.

= Se) or **3** (X = S) from MCPs **1** by a one-pot method and the subsequent enynylation with alkynes (Sonogashira reaction) to give the corresponding dienynes **4** (X = Se) or **5** (X = S) in good yields under mild conditions (room temperature). The conjugated dienyne **5a**, which was obtained unexpectedly in this coupling reaction, could be smoothly transformed to the corresponding conjugated trienyne **6a** in good yield (Scheme 1).[8] In addition, we further confirmed that the phenylchalcogenyl group plays an important role in this coupling reaction. A plausible mechanism has been proposed on the basis of the control experiments and ^{77}Se NMR spectroscopic investigation, indicating that the phenylchalcogenyl group might be an intramolecular ligand to the active Pd intermediate in the catalytic cycle.[9] Therefore, to extend the scope and limitations of this interesting intramolecular phenylchalcogenyl group chelation promoted coupling reaction, we attempted to further investigate several other typical cross-coupling reactions of 2-iodo-4-phenylchalcogenyl-1-butenes **2** (X = Se) or **3** (X = S) under similar conditions.

Herein, we wish to report the palladium-catalyzed cross-coupling reactions of 2-iodo-4-(phenylchalcogenyl)-1-butenes **2** or **3** with methyl acrylate (Heck reaction), phenylmagnesium bromide (Kumada reaction), phenylboronic acid (Suzuki reaction), and benzylzinc bromide (Negishi reaction) under mild conditions without any phosphine ligand and additive.

Results and Discussion

First of all, we examined the Heck reaction[10] of 2-iodo-4-(phenylchalcogenyl)-1-butenes **2** and **3** (0.3 mmol) with methyl acrylate (0.4 mmol) in dimethylformamide (DMF) with use of palladium acetate [$Pd(OAc)_2$] as a catalyst and triethylamine (Et_3N) as a base, typical Heck reaction conditions. Using 1,1-diphenyl-2-iodo-4-(phenylselenyl)-1-butene **2a** as substrate, we found that the corresponding coupling reaction product, methyl 5,5-diphenyl-4-(2-phenylselenyl)ethyl-2,4-dientanoate **7a**, was obtained in good yield at room temperature (20 °C) (Table 1, entry 1). Next, we carried out the reactions of a variety of compounds **2b**−**i** or **3a**−**c** with methyl acrylate (Table 1, entries 2−12) and other vinylic compounds such as phenyl acrylate, methyl vinyl ketone, and acrylonitrile (Table 1, entries 13−15) under the same conditions. As can be seen from Table 1, most of these reactions proceeded smoothly at room temperature without any phosphine ligand and other additive to give the corresponding coupling products **7** (X = Se) and **8** (X = S) in good to high yields.

For compounds **2d** and **2e** having an electron-withdrawing group on the benzene rings, the reactions proceeded slowly at room temperature. However, the

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(9) (a) Dupont, J.; Pfeffer, M.; Spencer, J. *Eur. J. Inorg. Chem.* **2001**, 1917. (b) Bedford, R. B. *Chem. Commun.* **2003**, 1787. (c) Bergbreiter, D. E.; Osburn, P. L.; Wilson, A.; Sink, E. M. *J. Am. Chem. Soc.* **2000**, *122*, 9058. There is a significant change of ^{77}Se NMR spectra between compound **2a** and the mixture of compound **2a** and $Pd(OAc)_2$. The ^{77}Se NMR spectra (95.44 MHz, $CDCl_3$) of PhSeSePh, compound **2a**, and compound **2a** mixed with 1 equiv of $Pd(OAc)_2$ were measured at 95.44 MHz on a BRUKER DRX 500 spectrometer at 300 K. Spectra were recorded in $CDCl_3$, with PhSeSePh as a ^{77}Se external reference at δ 462.2 ppm. Typical parameters were as follows: 1 μs pulse (30° flip angle) with a 2 s recycle time; spectral window of 1000 ppm; and line broadening equal to 1.0 Hz. For compound **2a**, δ 297.5 ppm; for a solution of compound **2a** and $Pd(OAc)_2$ (1:1 mol ratio) in $CDCl_3$, δ 347.5, 349.6, 353.1, 368.7 ppm (for detailed information see the Supporting Information).

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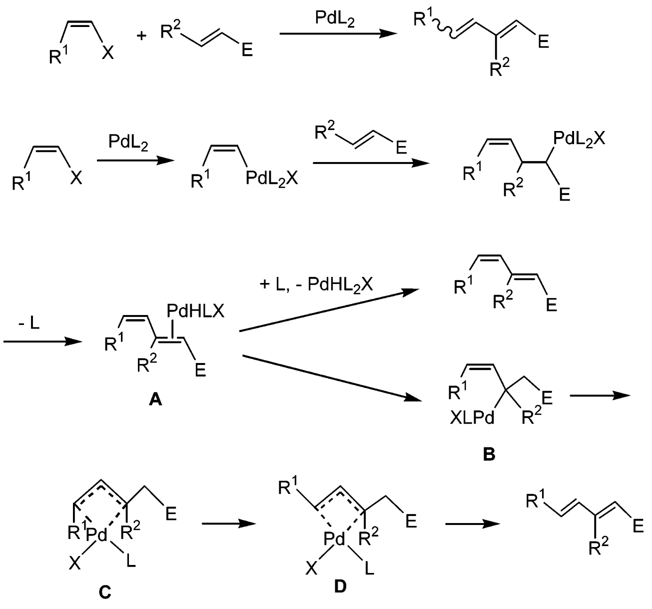
SCHEME 2. Mechanism for Isomerization of the Double Bond in the Coupling Products

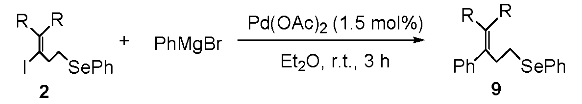


R^1, R^2 = H, alkyl; E = electron-withdrawing group; X = Br, I

corresponding coupling products **7d** and **7e** were obtained in good yields at higher temperature (80 °C) (Table 1, entries 4 and 5). According to the mechanism of oxidative addition of vinyl halides to metal complex,[11] the electron-withdrawing group on the benzene rings decreased the electron density of the carbon−carbon double bond, so that the rate of the oxidative addition was reduced relatively and a higher temperature was therefore required in the oxidative addition process. When acrylonitrile, a weak nucleophilic compound, was utilized in this reaction, higher temperature (80 °C) was also required to give the corresponding product **7*l*** in good yield (Table 1, entry 15).

For unsymmetrical compounds **2f**−**i**, which are the *Z*-isomers, the corresponding Heck reaction products **7f**−**i** were obtained as mixtures of *E*,*Z*- and *E*,*E*-isomers in different ratios (Table 1, entries 8−11). The products of *E*,*Z*- and *E*,*E*-isomeric mixtures of **7f**−**h** are inseparable by silica gel flash column chromatography although *E*,*Z*- and *E*,*E*-**7i** could be separated by silica gel flash column chromatography. The isomerization of the double bond might be induced by the rearrangement of a certain intermediate that has been proposed by Heck and coworkers before (Scheme 2).[12] The hydridopalladium halide π complex **A** may form an allylic, σ derivative **B**, which will go on to a π-allylic palladium complex **C** with the allylic double bond. The π-allylic complex **C**, unfortunately, rapidly equilibrates isomers **C** and **D** through rotating σ forms. This causes loss of stereochemistry and the product ultimately formed by the hydridopalladium halide elimination and dissociation process will be the isomer formed from the most stable π-allylic complex.

TABLE 2. Kumada Reaction of Compounds 2 (0.3 mmol)



entry	R	yield, %^{a}
1	C_6H_5 **2a**	**9a**, 84
2	*p*-$CH_3C_6H_4$ **2b**	**9b**, 87
3	*p*-$CH_3OC_6H_4$ **2c**	**9c**, 92
4	*p*-ClC_6H_4 **2d**	**9d**, 57
5	*p*-FC_6H_4 **2e**	**9e**, 72

^{a} Isolated yields.

As for the Heck reaction, it was usually performed at high temperature except when using phase-transfer catalyst at room temperature, known as Jeffery's conditions.[13] We believe that the phenylchalcogenyl group in compounds **2** or **3** contributes to this effective Heck reaction at room temperature in most cases via an intramolecular chelation promotion as we proposed in our previous work.[8]

Next, we also examined the palladium-catalyzed Kumada reaction[14] of 2-iodo-4-(phenylchalcogenyl)-1-butenes **2a**−**e** (0.3 mmol) with phenylmagnesium bromide (0.4 mmol) in diethyl ether at room temperature. In general, these reactions proceeded smoothly under mild conditions (room temperature) to afford the corresponding coupling products 2-phenyl-4-(phenylchalcogenyl)-1-butenes **9** in moderate or good to high yields in the presence of Pd(OAc)$_2$ (1.5 mol %) within 3 h. The results are summarized in Table 2.

In addition, using 1,1-diphenyl-2-iodo-4-(phenylselenyl)-1-butene **2a** (0.3 mmol) as substrate, we examined the Suzuki reaction[15] and the Negishi reaction[16] with phenylboronic acid (0.3 mmol) and benzylzinc bromide (0.4 mmol) in THF, respectively, and the results are

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(11) Rajaram, J.; Pearson, R. G.; Ibers, J. A. *J. Am. Chem. Soc.* **1974**, *96*, 2103.

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(15) (a) Miyaura, N.; Suzuki,A. *Chem. Rev.* **1995**, *95*, 2457. (b) Suzuki, A. *J. Organomet. Chem.* **1999**, *576*, 147. For some more recent related papers, please see: (c) LeBlond, C. R.; Andrews, A. T.; Sun, Y.; Sowa, J. R., Jr. *Org. Lett.* **2001**, *3*, 1555. (d) Collier, P. N.; Campbell, A. D.; Patel, I.; Raynham, T. M.; Taylor, R. J. K. *J. Org. Chem.* **2002**, *67*, 1802. (e) Urawa, Y.; Ogura, K. *Tetrahedron Lett.* **2003**, *44*, 271. (f) Byun, J.-W.; Lee, Y.-S. *Tetrahedron Lett.* **2004**, *45*, 1837. (g) Baleizão, C.; Corma, A.; García, H.; Leyva, A. *J. Org. Chem.* **2004**, *69*, 439. (h) Dubbaka, S. R.; Vogel, P. *Org. Lett.* **2004**, *6*, 95. (i) Dai, M.-J.; Liang, B.; Wang, C.-H.; Chen, J.-H.; Yang, Z. *Org. Lett.* **2004**, *6*, 221. (j) Bedford, R. B.; Hazelwood, S. L.; Horton, P. N.; Hursthouse, M. B. *Dalton Trans.* **2003**, 4164. (k) McLachlan, F.; Mathews, C. J.; Smith, P. J.; Welton, T. *Organometallics* **2003**, *22*, 5350. (l) Conlon, D. A.; Pipik, B.; Ferdinand, S.; LeBlond, C. R.; Sowa, J. R., Jr.; Izzo, B.; Collins, P.; Ho, G.-J.; Williams, J. M.; Shi, Y.-J.; Sun, Y.-K. *Adv. Synth. Catal.* **2003**, *345*, 931. (m) Wang, A.-E.; Zhong, J.; Xie, J.-H.; Li, K.; Zhou, Q.-L. *Adv. Synth. Catal.* **2004**, *346*, 595.

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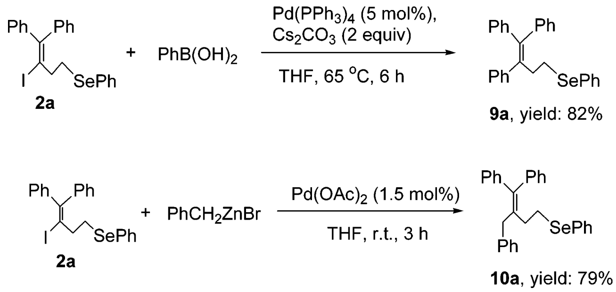
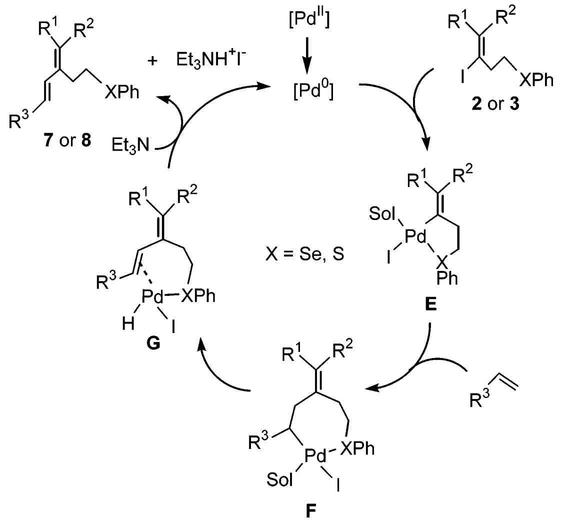
SCHEME 3. Suzuki and Negishi Reaction of Compound 2a (0.3 mmol)



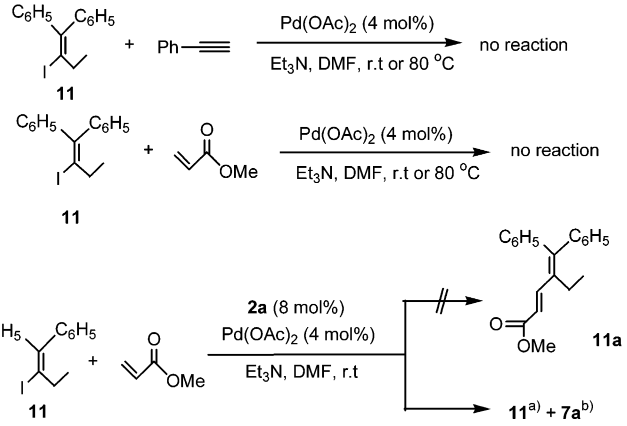
SCHEME 4. A Plausible Heck Reaction Mechanism



shown in Scheme 2. The corresponding coupling products **9a** and **10a** were obtained in good yields. In the Suzuki reaction, the palladium catalyst of Pd(PPh$_3$)$_4$ (5 mol %) is more effective than Pd(OAc)$_2$ under identical conditions[17] and higher temperature (65 °C) is required in THF with Cs$_2$CO$_3$ as the base to afford the corresponding product **9a** in 82% yield (Scheme 2). On the other hand, the Negishi reaction can be carried out at room temperature to produce the product **10a** in 79% yield (Scheme 3).

The mechanism for these palladium-catalyzed cross-coupling reactions of 2-iodo-4-phenylchalcogenyl-1-butenes **2** or **3** was considered to proceed via an identical intermediate **E**, having an intramolecular chelation of selenium or sulfur atom to Pd metal center.[8] Using the Heck reaction as an example, the catalytic cycle is described in Scheme 4. The in situ formed Pd(0) catalyst inserts into the C−I bond of compounds **2** or **3** via an oxidative addition to give the intermediate **E**, which is chelated by the phenylchalcogenyl group on the basis of ^{77}Se NMR spectroscopic investigation (see the Supporting Information). The reaction of Pd complex **E** with a vinylic molecule produces the intermediate **F** stereoselectively. Afterward, the intermediate **F** turns into the intermediate **G**[18] via a reductive elimination, which subsequently produces the products **7** or **8** and regenerates the Pd(0) catalyst in the presence of a base. The intramolecular chelation is responsible for most of these coupling reactions such as the Heck reaction to be fairly effective at room temperature.

SCHEME 5. The Control Experiments



^{a} 95% of **11** was recovered. ^{b}92% isolated yield based on compound **2a**.

To further verify this mechanistic assumption of the intramolecular chelation promoted effect on the coupling reaction, three control experiments were performed under identical conditions. We synthesized 1,1-diphenyl-2-iodo-1-butene **11** and applied it to the Sonogashira reaction with phenylacetylene[8] and the Heck reaction with methyl acrylate under the same conditions, respectively (Scheme 5). We found that no reactions occurred even at higher temperature (80 °C) in both cases. Another control experiment was conducted and the result was also outlined in Scheme 5. We added compound **2a** (2.0 equiv to Pd(OAc)$_2$) in the Heck reaction of compound **11** with methyl acrylate. We found that compound **2a** was similarly transformed to compound **7a** in good yield at room temperature, but compound **11** was recovered mostly and the corresponding compound **11a**, derived from the Heck reaction of **11** with methyl acrylate, was not formed at room temperature. These results suggest that the phenylchalcogenyl group is indeed necessary for these coupling reactions such as the Heck reaction proceeding smoothly at room or higher temperature (60−80 °C).

Moreover, we attempted to introduce a phenylselenyl group into the substituted iodobenzene to examine whether it has a promotion effect on the cross-coupling reaction of aromatic iodide under similar reaction conditions. We managed to synthesize the iodobenzene compound **12** having a phenylselenyl group at the adjacent position via the known synthetic method[8] because a similar intramolecular chelation of the phenylchalcogenyl group to Pd center in compound **12** has been reported before in some reactions (Scheme 6).[19] This compound was subjected to the Sonogashira and Heck reactions under the same conditions (Scheme 6). The corresponding normal Sonogashira reaction product **13** was obtained in good yield (78%) at room temperature rather than the

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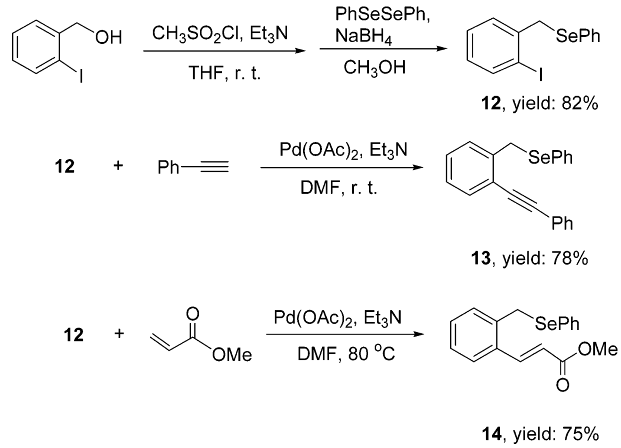
[17] The optimization of the reaction conditions is summarized in the Supporting Information.

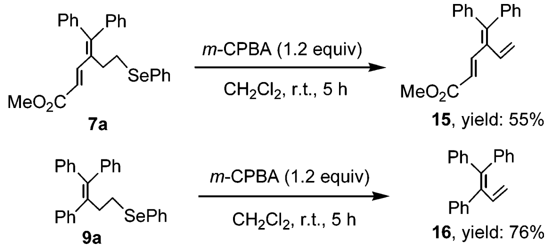
[18] The intramolecular chelation in the intermediate **G** obliges the hydride to be cis at the iodine and this is important for the reductive elimination, see: Hills, I. D.; Fu, G. C. *J. Am. Chem. Soc.* **2004**, *126*, 13178.

[19] (a) Dupont, J.; Beydoun, N.; Pfeffer, M. *J. Chem. Soc., Dalton Trans.* **1989**, 1715. (b) Spencer, J.; Pfeffer, M. *J. Org. Chem.* **1995**, *60*, 1005.

SCHEME 6. Synthesis and Sonogashira-/Heck-Type Reaction of Compound 12



SCHEME 7. Oxidation of Seleno Compounds 7a and 9a (0.3 mmol) with *m*-CPBA



corresponding dienyne product.[8] On the other hand, higher reaction temperature (80 °C) was required to afford the corresponding product **14** in 75% yield in the Heck reaction. These results suggest that the sterically demanding position of the phenylchalcogenyl group in 2-iodo-4-(phenylchalcogenyl)-1-butenes is crucial in these coupling reactions either to give different products from compound **12** such as the Sonogashira reaction or under milder conditions than compound **12** such as the Heck reaction. The more flexible phenylchalcogenyl group in 2-iodo-4-(phenylchalcogenyl)-1-butenes might be able to coordinate to the active Pd center in a more easy way. Another reason for the distinction between the reactions might be that the five-membered ring of palladacycle from compound **12** is more stable than intermediate **E** (Scheme 4), which might be less reactive under identical conditions and therefore a higher temperature is necessary for the insertion step.

Furthermore, as indicated in our previous work,[8] oxidation of compounds **7a** and **9a** with *m*-CPBA in dichloromethane furnishes the corresponding products **15** and **16** in moderate to good yields by a selenoxide elimination process under mild conditions (Scheme 7).

Conclusion

We have found that several typical palladium-catalyzed cross-coupling reactions of 2-iodo-4-phenylchalcogenyl-1-butenes **2** or **3** proceeded smoothly under mild conditions (room temperature) to give the corresponding coupling products in moderate or good to high yields in most cases because of the existence of a sterically demanding intramolecular chelation of the phenylchalcogenyl group in **2** or **3** to a certain palladium center. A plausible mechanism has been proposed based on the control experiments and ^{77}Se NMR spectroscopic investigation (see the Supporting Information). This is another interesting case for the selenium- or sulfur-ligated Pd(II) complexes in the effective coupling reaction. Efforts are underway to elucidate the mechanistic details and the scope and limitations of these coupling reactions.

Experimental Section

General Methods. Melting points are uncorrected. ^{1}H and ^{13}C NMR spectra were recorded at 300 and 75 MHz, respectively. Mass spectra were recorded by EI, MALDI, and ESI methods, and HRMS was measured by the EI method. Organic solvents used were dried by standard methods when necessary. Commercially obtained reagents were used without further purification. All reactions were monitored by TLC plates. Flash column chromatography was carried out with silica gel or Al_2O_3 at increased pressure.

Typical Reaction Procedure for the Heck Reaction of 2-Iodo-4-phenylchalcogenyl-1-butenes 2 or 3 with Methyl Acrylate. To a solution of 1,1-diphenyl-2-iodo-4-phenylselenyl-1-butene **2a** (147 mg, 0.3 mmol) in DMF (2.0 mL) was added methyl acrylate (35 mg, 0.4 mmol), Et_3N (40 mg, 0.4 mmol), and $Pd(OAc)_2$ (3 mg, 4 mol %). The mixture was stirred for 10 h at room temperature (monitored by TLC) and then quenched with the addition of water (5.0 mL). The mixture was extracted with diethyl ether (5.0 mL). The organic layer was washed with brine and dried over anhydrous Na_2SO_4, then the solvent was removed under reduced pressure and the residue was subjected to flash column chromatography to give the product **7a** (126 mg, 94%) as a white solid. Mp 83−84 °C; IR (KBr) ν 3055, 2947, 1716, 1614, 1436, 1293, 1167, 861, 737, 701 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz, TMS) δ 2.77 (2H, t, J = 7.5 Hz, CH_2), 3.00 (2H, t, J = 7.5 Hz, CH_2), 3.72 (3H, s, OCH_3), 5.95 (1H, d, J = 15.9 Hz, =CH), 7.10−7.23 (7H, m, Ar), 7.30−7.34 (8H, m, Ar), 7.54 (1H, d, J = 15.9 Hz, =CH); ^{13}C NMR ($CDCl_3$, 75 MHz, TMS) δ 25.7, 31.5, 51.4, 117.9, 126.7, 127.5, 127.9, 128.0, 128.3, 128.8, 129.0, 129.5, 130.3, 132.3, 133.3, 140.6, 141.6, 144.0, 151.0, 167.6; MS (EI) *m/e* 448 (M$^+$, 0.4), 291 (2), 231 (67), 215 (19), 202 (14), 188 (15), 174 (100), 144 (32), 91 (26). Anal. Calcd for $C_{26}H_{24}O_2Se$ requires C 69.79, H 5.41; found C 69.83, H 5.24.

Typical Reaction Procedure for the Kumada Reaction of 2-Iodo-4-phenylselenyl-1-butenes 2 with Phenylmagnesium Bromide. To a solution of 1,1-diphenyl-2-iodo-4-phenylselenyl-1-butene **2a** (147 mg, 0.3 mmol) in diethyl ether (2.0 mL) was added a solution of phenylmagnesium bromide in diethyl ether (0.4 mL, 1.0 mol/L) and $Pd(OAc)_2$ (1 mg, 1.5 mol %). The mixture was stirred for 3 h at room temperature (monitored by TLC) and then quenched with water (5.0 mL). The mixture was extracted with diethyl ether (5.0 mL). The organic layer was washed with brine and dried over anhydrous Na_2SO_4, then the solvent was removed under reduced pressure and the residue was subjected to flash column chromatography to give the product **9a** (111 mg, 84%) as a white solid. Mp 98−100 °C; IR (KBr) ν 3054, 3019, 1598, 1477, 1074, 762, 735, 699 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz, TMS) δ 2.85 (4H, t, J = 4.5 Hz, CH_3), 6.87−6.90 (2H, m, Ar), 7.00−7.02 (3H, m, Ar), 7.08−7.30 (15H, m, Ar); ^{13}C NMR ($CDCl_3$, 75 MHz, TMS) δ 25.5, 36.7, 126.0, 126.4, 126.5, 126.8, 127.4, 128.0, 128.3, 128.9, 129.2, 129.6, 130.1, 130.5, 132.0, 138.9, 140.7, 141.2, 142.4, 142.7; MS (EI) *m/e* 440 (M$^+$, 8), 269 (12), 205 (46), 191 (48), 167 (17), 91 (100). Anal. Calcd for $C_{28}H_{24}Se$ requires C 76.53, H 5.50; found C 76.58, H 5.61.

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Supporting Information Available: The spectroscopic data (^{1}H, ^{13}C, ^{77}Se NMR and NOSEY spectroscopic data) and analytic data of the compounds shown in Tables 1 and 2 and Schemes 1−6 and a detailed description of experimental procedures. This material is available free of charge via the Internet at http://pubs.acs.org.

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