Unique Regio- and Stereoselectivity in Pd-Catalyzed Chlorocarbonylation Reaction of 2-Phenylethynyl Selenides and 2-Alkylethynyl Selenides. Highly Stereoselective Synthesis of 2-Seleno-3-chloroacrylates

Xian Huang* and Aiming Sun

Department of Chemistry, Zhejiang University, Xixi Campus, Hangzhou 310028, Peoples Republic of China

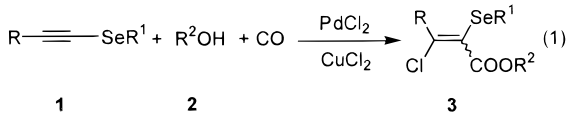
huangx@mail.hz.zj.cn

Received May 8, 2000

Regio- and stereoselectivity in the chloropalladation carbonylation reaction of different acetylenic selenides in the presence of 0.05 equiv of $PdCl_2$ and 3 equiv of cupric chloride under 1 atm of carbon monoxide affording 2-seleno-3-chloroacrylates were investigated. Opposite stereoselectivities were observed with 2-phenylethynyl selenides and 2-alkylethynyl selenides: the reactions of 2-phenylethynyl selenides afforded (*E*)-2-seleno-3-chloro-3-phenylacrylates, while the reactions of 2-alkylethynyl selenides gave (*Z*)-2-seleno-3-chloro-3-alkylacrylates. A chloropalladation carbonylation mechanism for this reaction was proposed. The regio- and stereoselective chloropalladation of the carbon−carbon triple bond in acetylenic selenides affords 1-enylpalladium intermediates, in which the palladium atom connects with the carbon atom bonding with the selenium atom. Carbonylation in the presence of an alcohol affords 2-seleno-3-chloroacrylates.

Introduction

Stereoselectivity is one of the most pursued goals of synthetic organic chemists. The highly stereoselective synthesis of tetrasubstituted alkenes, especially tetrasubstituted 2-enoates, is of high interest because of the capability for further evolution of the functional groups. These compounds are prepared by the Arbusov−Wittig[1] and the Peterson reactions[2] as a mixture of *E* and *Z* isomers. Both methods afford the corresponding products in low yields when enolizable or bulky ketones are used as the substrates. These materials can also be prepared by the reaction of nucleophiles with substituted allylic chlorides[3] and other methods.[4] Among our efforts devoted to the chemistry of alkynes[5] is an interest in the stereoselective synthesis of 3-chloroacrylates, valuable intermediates in organic synthesis[6] and known to exhibit some biological properties.[7] These compounds can usually be prepared by esterification of the corresponding acids[8,9] and the reaction of lithium chloride in acetic acid with 2-alkynoates.[10] Recent reports of the synthesis of substituted 3-chloroacrylates have been published.[11] However, there are no reports of the stereoselective synthesis of functionalized, fully substituted 3-chloroacrylates. In this paper, we report our recent study on the palladium(II)-catalyzed highly regio- and stereoselective carbonylation reaction of acetylenic selenides (eq 1).



1 **2** **3**

R = aryl or alkyl

Results and Discussion

Carbonylation of 2-Phenylethynyl Selenides. The treatment of 2-phenylethynyl ethyl selenide[12] with methanol and 3 equiv of $CuCl_2$ in CO (1 atm) under the catalysis of 5 mol % of $PdCl_2$ afforded a mixture of the expected methyl-2-ethylseleno-3-chloro-3-phenylacrylate (**3b)** and

* To whom correspondence should be addressed. Fax: 86571 8807077.

(1) Wadsworth, W. J. In *Organic Reactions*; John Wiley & Sons: New York, 1977; Vol. 25, pp 660−708.

(2) (a) Peterson, D. J. *J. Org. Chem.* **1968**, *33*, 780. (b) Peterson, D. J.; Hudrlik, P. F. *J. Am. Chem. Soc.* **1975**, *97*, 1464. (c) Ager, D. J. In *Organic Reactions*; John Wiley & Sons: New York, 1990; Vol. 38, pp 1−223.

(3) (a) Mathew, J. *J. Org. Chem.* **1992**, *57*, 2753. (b) Mathew, J.; Alink, B. *J. Org. Chem.* **1990**, *55*, 3880.

(4) (a) Hagiwara, H.; Nakayama, K.; Uda, H. *Bull. Chem. Soc. Jpn.* **1975**, *48*, 3769. (b) Iwai, H.; Kosugi, H.; Uda, H.; Kawai, M. *Bull. Chem. Soc. Jpn.* **1977**, *50*, 242. (c) Nokami, J.; Nishiuchi, K.; Wakabayashi, S.; Okawara, R. *Tetrahedron Lett.* **1980**, 4455. (d) Leyendecker, L.; Comte, M. T. *Ibid.* **1982**, *23*, 5031. (e) Durman, J.; Hunt, P. G.; Warren, S. *Tetrahedron Lett.* **1983**, *24*, 2113.

(5) (a) Zhu, L. S.; Huang, Z. Z.; Huang, X. *Tetrahedron* **1996**, *52*, 9819. (b) Huang, X.; Zhu, L. S., *J. Chem. Soc., Perkin Trans. 1* **1996**, 767. (c) Yang, D. Y.; Huang, X. *Synlett* **1997**, 891.

(6) (a) Smith, A. B.; Kilenyi, S. N. *Tetrahedron Lett.* **1985**, *26*, 4419. (b) Bey, P.; Vevert, J. P. *J. Org. Chem.* **1980**, *45*, 3249. (c) Teutsch, J. G.; Bonnet, A.; Aszodi, J.; Costerousse, G. Eur. Pat. Appl. Ep. **1984**, *153*, 229. (*Chem. Abstr.*, **1986**, *105*, 6351y). (d) Ege, G.; Franz, H. *J. Heterocycl. Chem.* **1982**, *19*, 1267. (e) Larock, R. C.; Narayanan, K.; Hershberger, S. S. *J. Org. Chem.* **1983**, *48*, 4377. (f) Zhang, C.; Lu. X. *Synthesis* **1996**, 586. (h) Miyaura, N.; Sasaki, N.; Itoh, M.; Suzuki, A. *Tetrahedron Lett.* **1977**, 3369.

(7) (a) Herrett, R. A.; Kurtz, A. N. *Science* **1963**, *141*, 1192. (b) Kurtz, A. N.; Herrett, R. A. *Union Carbide Corp., Belg.* **1963**, *631*, 83; *Chem. Abstr.* **1964**, *60*, 15071b.

(8) Kultz, A. N.; Billups, W. E.; Greenlee, R. B.; Hamil, H. F.; Pace, W. T. *J. Org. Chem.* **1965**, *30*, 3141.

(9) Bowden, K. *Can. J. Chem.* **1966**, *44*, 661.

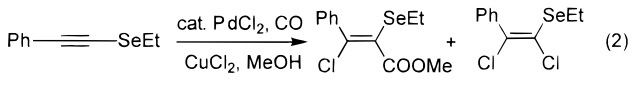
(10) (a) Ma, S.; Lu, X. *Tetrahedron Lett.* **1990**, *31*, 7653. (b) Ma, S.; Lu. X. *J. Chem. Soc., Chem. Commun.* **1990**, 1643. (c) Ma, S.; Lu, X.; Li. Z. *J. Org. Chem.* **1992**, *57*, 709. (d) Lu. X. Zhu, G.; Ma, S. *Chin. J. Chem.* **1993**, *11*, 267.

(11) Li, J.; Jiang, H.; Feng, A.; Jia, L. *J. Org. Chem.* **1999**, *64*, 5984.

(12) Comasseto, J. V.; Ferreira, J. T. B.; Petragnani, N. *J. Organomet. Chem.* **1981**, *216*, 287.

10.1021/jo0006977 CCC: $19.00 © 2000 American Chemical Society
Published on Web 09/01/2000

Table 1. Palladium-Catalyzed Carbonylation of 2-Phenylethynyl Ethyl Selenide (1b) with Methanol (2a) in Different Solvents[a]



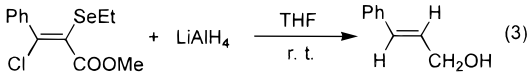
1b **(*E*) - 3b** **(*E*) - 4a**

entry	solvent	reaction time (h)	% yield[b] **3b** (*E*/*Z*)	**4a** (*E*/*Z*)
1	HOAc	36	45 (>98/2)	9 (>98/2)
2	MeOH	24	58 (>98/2)	7 (>98/2)
3	CH_2Cl_2/MeOH (4:1)	16	85 (>98/2)	9 (>98/2)
4	CH_3CN/MeOH (4:1)	24	72 (>98/2)	31 (>98/2)
5	CH_3CN	24	60 (>98/2)	35 (>98/2)
6	THF	24	74 (74/16)	0
7	CH_2Cl_2	4	88 (>98/2)	0
8	C_6H_6	2	93 (>98/2)	0

[a] A mixture of **1b** (209 mg, 1 mmol), $PdCl_2$ (9 mg, 0.05 mmol), $CuCl_2$ (405 mg, 3 mmol), methanol (0.8 mL), and the solvent (10 mL) was stirred under 1atm of carbon monoxide at room temperature. [b] Isolated yield based on **1b**.

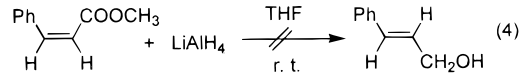
the dichlorination product (**4a**) with moderate to good selectivities of **3b** over **4a** (eq 2, Table 1, entries 1−5). This carbonylation reaction is solvent dependent, similar to previous reports by Lu et al.[13] In all cases in Table 1, the stereoselectivity for **3b** is high. The corresponding reaction in THF afforded **3b** as the sole product albeit in lower stereoselectivity (Table 1, entry 6). Surprisingly, the reaction in CH_2Cl_2 or benzene afforded **3b** in high yield as well as *E*-selectivity (Table 1, entries 7 and 8).

The regio- and the stereoselectivity of this reaction was determined by the treatment of ((*E*)-**3b**) with $LiAlH_4$ at room temperature in THF for 3 h to afford *E*-cinnamyl alcohol ((*E*)-**5**) in 76% isolated yield (eq 3).[14]



(*E*) -3b **(*E*) - 5**

When ***Z***-methyl cinnamate ((*Z*)-**5′**) was treated with $LiAlH_4$ under the same reaction conditions, no *E*-cinnamyl alcohol ((*E*)-**5**) was obtained, and 86% of *Z*-cinnamyl alcohol ((*Z*)-**5**) was isolated, indicating that *E*-cinnamyl alcohol ((*E*)-**5**) was not produced from *Z*-cinnamyl alcohol ((*Z*)-**5**) by isomerization (eq 4).

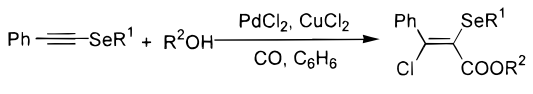


(*Z*) - 5′ **(*E*) - 5**

All the results indicate that the chloropalladation of 2-phenylethynyl ethyl selenide proceeded with strong preference for the addition of the palladium at the carbon bonding with the selenium group, and the chloropalladation of 2-phenylethynyl ethyl selenide is a *syn*-addition process. The procedure can be readily applied to other 2-phenylethynyl selenides with different aliphatic alcohols (Table 2).

The palladium-catalyzed carbonylation reaction of 2-phenylethynyl selenides with different aliphatic alcohols gave good yields of products ((*E*)-**3**) with fairly good regio- and stereoselectivity although the corresponding carbonylation reaction of 2-phenylethynyl phenyl selenide afforded product **3h** with a lower stereoselectivity (Table 2, entry 8).

Table 2. Synthesis of (*E*)-2-Seleno-3-chloro-3-phenylacrylates by Carbonylation of 2-Phenylethynyl Selenides in Benzene[a]

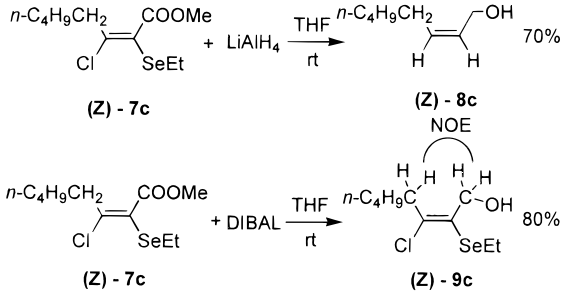


1 **2** **(*E*) - 3**

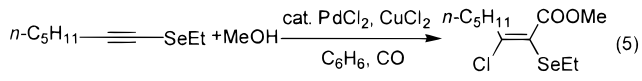
entry	R^1 (**1**)	R^2 (**2**)	reaction time (h)	yield of **3** (%) (***E*/*Z***)[b]
1	Me (**1a**)	Me (**2a**)	1.5	95 (**3a**, >98/2)
2	Et (**1b**)	Me (**2a**)	2	93 (**3b**, >98/2)
3	*i*-Pr (**1c**)	Me (**2a**)	2	90 (**3c**, >97/3)
4	Et (**1b**)	Et (**2b**)	8	75 (**3d**, >97/3)
5	Et (**1b**)	*i*-Pr (**2c**)	4	82 (**3e**, >97/3)
6	Et (**1b**)	*n*-Bu (**2d**)	2.5	88 (**3f**, >99/1)
7	Et (**1b**)	*p*-NO_2PhCH_2 (**2e**)	24	60 (**3g**, >95/5)
8	Ph (**1d**)	Me (**2a**)	24	75 (**3h**, 82/18)

[a] A mixture of **1** (1 mmol), $PdCl_2$ (9 mg, 0.05 mmol), $CuCl_2$ (405 mg, 3 mmol), and alcohol (0.8 mL) in 10 mL of benzene was stirred under atmospheric pressure of carbon monoxide at room temperature. [b] Isolated yield based on **1** used, and the ratio of ***E*/*Z*** was determined by 300 MHz ^1H NMR spectra.

Scheme 1



Carbonylation of 2-Alkylethynyl Selenides. Following the study of 2-phenylethynyl selenides, attention was turned to the difference between 2-phenyethynyl selenides and 2-alkylethynyl selenides. The chlorocarbonylation of 2-pentylethynyl ethyl selenide (**6c**) under similar reaction conditions afforded the (*Z*)-isomer in 82% yield with excellent regio- and stereoselectivity, indicating a completely opposite stereochemistry (eq 5).



6c **2a** **(*Z*) - 7c**

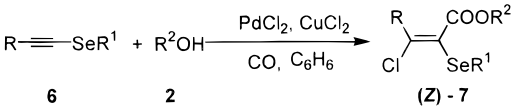
The regio- and stereoselectivity were confirmed by treatment of (*Z*)-**7c** with $LiAlH_4$ to give a 70% yield of the known compound (*Z*)-2-octen-1-ol (*Z*-**8c**).[15] The stereospecificity of this reaction was further confirmed by treatment of (*Z*)-**7c** with DIBAL to give (*Z*)-2-ethylseleno-3-chloro-2-octen-1-ol **(*Z*-9c)**, the configuration of which was determined by NOE (Scheme 1).

The procedure can also be applied to other 2-alkylethynyl selenides with different aliphatic alcohol as shown in Table 3.

The results in Table 3 indicate that when R = *n*-C_4H_9, *n*-C_5H_{11}, *n*-C_6H_{13} and R^1 = CH_3 or C_2H_5, the acetylenic

(13) Ji, J.; Lu, X. *Tetrahedron* **1994**, *50*, 9067.
(14) Goetz, E. B.; Dubois, J. E. *J. Org. Chem.* **1975**, *40*, 221.

Table 3. Palladium-Catalyzed Carbonylation of 2-Alkylethynyl Selenides[a]

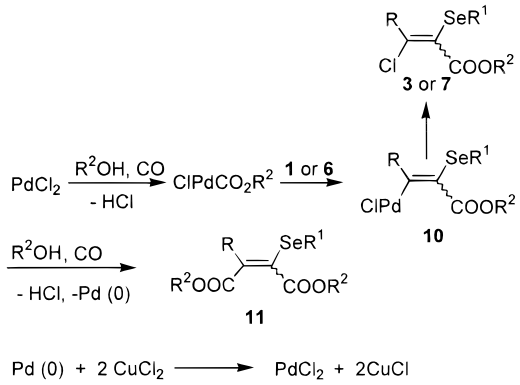


6 **2** **(*Z*) - 7**

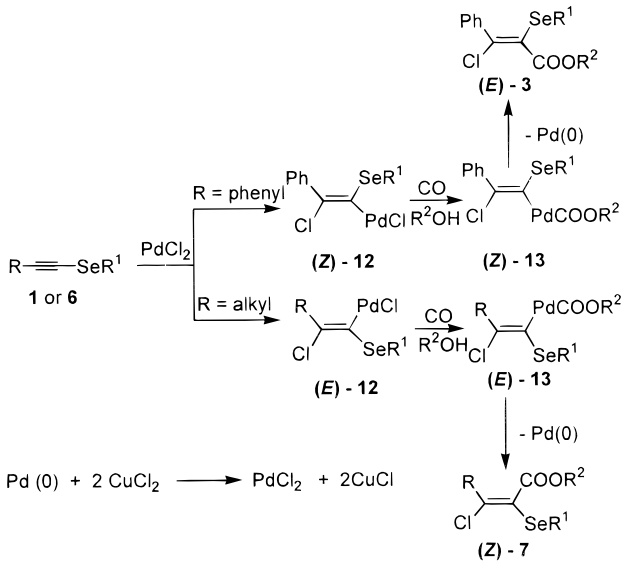
entry	**6** R (**6**)	**6** R^1 (**6**)		R^2 (**2**)	time (h)	yield of **7**(%) (***Z*/*E***)[b]
1	*n*-C_4H_9	CH_3	**6a**	CH_3 (**2a**)	2	86 (**7a**, 100/0)
2	*n*-C_4H_9	C_2H_5	**6b**	CH_3 (**2a**)	3.5	79 (**7b**, >99/1)
3	*n*-C_5H_{11}	C_2H_5	**6c**	CH_3 (**2a**)	2	82 (**7c**, 100/0)
4	*n*-C_5H_{11}	CH_3	**6d**	*n*-C_4H_9 (**2c**)	2	80 (**7d**, >99/1)
5	*n*-C_6H_{13}	CH_3	**6e**	CH_3 (**2a**)	2	79 (**7e**, 100/0)
6	*n*-C_6H_{13}	C_2H_5	**6f**	CH_3 (**2a**)	2.5	75 (**7f**, 100/0)
7	*n*-C_6H_{13}	CH_3	**6e**	*i*-C_3H_7 (**2b**)	10	78 (**7g**, >98/2)
8	*n*-C_4H_9	C_6H_5	**6g**	CH_3 (**2a**)	4	70 (**7h**, 91/9)
9	*n*-C_4H_9	*p*-MeO-C_6H_4	**6h**	CH_3 (**2a**)	4	67 (**7i**, 80/20)
10	pyridine	C_6H_5	**6i**	CH_3 (**2a**)	48	0 **7j**
11	$THPOCH_2$	C_2H_5	**6j**	CH_3 (**2a**)	48	0 **7k**
12	$THPOCH_2$	C_2H_5	**6k**	CH_3 (**2a**)	48	0 **7l**

[a] A mixture of **6** (1 mmol), $PdCl_2$ (9 mg, 0.05 mmol), $CuCl_2$ (405 mg, 3 mmol), and alcohol (0.8 mL) in 10 mL of benzene was stirred under 1 atm of carbon monoxide at room temperature. [b] Isolated yield based on **6** used, and the ratio of ***Z*/*E*** was determined by 300 MHz ^1H NMR spectra.

Scheme 2



Scheme 3



selenides reacted highly regio- and stereoselectively with $CuCl_2$ in CO to afford *Z*-**6a**, *Z*-**6b**, *Z*-**6c**, *Z*-**6d**, *Z*-**6e**, *Z*-**6f**, and *Z*-**6g** in high yields (Table 3, entries 1, 2, 3, 4, 5, 6, and 7). When R^1 = aryl, the reactions were slower with lower stereoselectivities (Table 3, entries 8 and 9). In the case of the acetylenic selenides substituted by a pyridine group (Table 3, entry 10) and $THPOCH_2$ group (Table 3, entries 11 and 12), no chlorocarbonylation products were formed possibly due to the coordination of the hetereoatom with palladium.

Two mechanisms for the reaction are proposed. One is the alkoxycarbonyl palladation chlorination mechanism and the other is the chloropalladation carbonylation mechanism. Heck reported that 3-chloro-2-enoates were formed as byproducts in the dicarboxylation reaction of 1-phenyl-1-propyne and 3,3-dimethyl-1-butyne.[16] If the former mechanism would be operative, the reaction of acetylenic selenides with alcohols in the presence of $PdCl_2$ and $CuCl_2$ under carbon monoxide should give the dicarbonylation product **11** as the byproduct. The formation of the dicarbonylation products has not been observed. Therefore, the alkoxycarbonyl palladation chlorination mechanism was eliminated (Scheme 2).

A chloropalladation carbonylation mechanism for this reaction is proposed as shown in Scheme 3. Palladium attacks the acetylenic carbon with the higher electron density,[17] which determines the regioselectivity of halopalladation. In this case, palladium attacks the carbon bonding with selenium. Vinylpalladium intermediates **12** is formed by chloropalladation of the carbon−carbon triple bond in the presence of $CuCl_2$.[18] Then Pd-coordinated carbon monoxide reacted with R^2OH to afford 1-alkylalkoxylcarbonylpalladium, intermediates (*Z*)-**13** and (*E*)-**13**, which afford the final products (*E*)-**3** or (*Z*)-**7** and Pd(0). $CuCl_2$ oxidizes the palladium(0) to regenerate the active divalent palladium species to finish the catalytic cycle.

In conclusion, the methodology discussed in this paper provides an efficient and general high yield route to 2-seleno-3-chloroacrylates with high regio- and stereoselectivity under mild conditions. Although a possible mechanism has been provided, it remains unclear why

(15) Gavina, F.; Luis, S. V.; Ferrer, P. Costero, A. M.; Marco, J. A. *J. Chem. Soc., Chem. Commun.* **1985**, 297.
(16) Heck, R. F. *J. Am. Chem. Soc.* **1972**, *94*, 2712.
(17) Kaneda, K.; Uchiyama, T.; Fujiwara, Y.; Imanaka, T.; Teranishi, S. *J. Org. Chem.* **1979**, *44*, 55.
(18) (a) Ma, S.; Lu, X. *J. Org. Chem.* **1993**, *58*, 1245. (b) Lu, X.; Zhu, G. *Synlett* **1993**, 68.

the reactions of 2-phenylethynyl selenides afforded (*E*)-2-seleno-3-chloro-3-phenylacrylates while the reactions of 2-alkylethynyl selenides gave (*Z*)-2-seleno-3-chloro-3-alkylacrylates. Due to the ease of converting the carbon−chlorine bond, the carbon−selenium bond, and the carbon−carbon double bond to other functional groups,[19] this methodology will be useful in the synthesis of stereodefinite compounds, such as sterically hindered substituted enoates, substituted allylic alcohols, etc.

Experimental Section

General. All ^{1}H and ^{13}C NMR spectra were recorded at 300 MHz with $CDCl_3$ as solvent. $CuCl_2$ was dried at 130 °C over P_2O_5. All other reagents were used directly as obtained commercially.

General Procedure for the Chloropalladation−Carbonylation of the Acetylenic Selenides. To a mixture of $PdCl_2$ (0.05 mmol, 9 mg) and $CuCl_2$ (3 mmol, 405 mg) in benzene (10 mL) were added an alcohol (0.8 mL) and the acetylenic selenide (**1** or **6**, 1 mmol) under 1 atm of carbon monoxide at room temperature. After the reaction was complete, as monitored by TLC (eluent: hexane/ethyl acetate = 10:1), the mixture was washed with brine and extracted with ether. The combined ether layer was dried over $MgSO_4$. Filtration, evaporation, and chromatography on silica gel (eluent: hexane/ethyl acetate = 10:1) afforded the expected products **3** or **7**.

Methyl (*E*)-2-Methylseleno-3-chloro-3-phenylacrylate (*E*-3a). Starting from 2-phenylethynyl methyl selenide **1a** (195 mg, 1 mmol) and methanol (0.8 mL) to afford 276 mg (95%) of *E*-**3a**. Liquid; ^{1}H NMR 2.31 (s, 3H), 3.52 (s, 3H), 7.25−7.48 (m, 5H); ^{13}C NMR δ 6.766, 52.481, 124.957, 127.776, 128.358, 128.653, 129.254, 133.785, 137.823, 165.852; MS (*m*/*z*) 290 (M^+(^{35}Cl), 96.56), 129 (100); IR (neat) 700, 1432, 1716 cm^{-1}. Anal. Calcd for $C_{11}H_{11}ClO_2Se$: C, 45.62; H, 3.83. Found, C, 45.96; H, 4.06.

Methyl (*E*)-2-Ethylseleno-3-chloro-3-phenylacrylate (*E*-3b). Starting from 2-phenylethynyl ethyl selenide **1b** (209 mg, 1 mmol) and methanol (0.8 mL) to afford 283 mg (93%) of *E*-**3b**. Solid, mp 37−38 °C (from ethyl acetate−hexanes); ^{1}H NMR δ 1.46 (t, J = 7.51 Hz, 3H), 2.85 (q, J = 7.50 Hz, 2H), 3.51 (s, 3H), 7.25−7.42 (m, 5H); ^{13}C NMR δ 15.0, 21.9, 52.8, 124.5, 127.8, 128.1, 129.7, 135.2, 137.9, 166.2; MS (*m*/*z*) 304 (M^+(^{35}Cl), 96.56), 129 (100); IR (neat) 766, 1486, 1718 cm^{-1}. Anal. Calcd for $C_{12}H_{13}ClO_2Se$: C, 47.37; H, 4.28. Found, C, 47.61; H, 4.40.

Methyl (*E*)-2-Isopropylseleno-3-chloro-3-phenylacrylate (*E*-3c). Starting from 2-phenylethynyl isopropyl selenide **1c** (223 mg, 1 mmol) and methanol (0.8 mL) to afford 286 mg (90%) of *E*-**3c**. Solid, mp34−36 °C (from ethyl acetate−hexanes); ^{1}H NMR δ 1.55 (d, J = 6.85 Hz, 6H), 3.55−3.70 (m, 4H), 7.35−7.50 (m, 5H); ^{13}C NMR δ 24.344, 34.442, 52.521, 124.219, 127.862, 128.317, 129.347, 137.995, 138.124, 167.034; MS (*m*/*z*) 318 (M^+(^{35}Cl), 30.99), 216 (100); IR (neat) 698, 1253, 1723 cm^{-1}. Anal. Calcd for $C_{13}H_{15}ClO_2Se$: C, 49.13; H, 4.72. Found, C, 49.38; H, 4.85.

Ethyl (*E*)-2-Ethylseleno-3-chloro-3-phenylacrylate (*E*-3d). Starting from 2-phenylethynyl ethyl selenide **1b** (209 mg, 1 mmol) and ethanol (0.8 mL) to afford 239 mg (75%) of *E*-**3d**. Liquid. ^{1}H NMR δ 0.95 (t, J = 7.14 Hz, 3H), 1.45 (t, J = 7.49 Hz, 3H), 2.85 (q, J = 7.51 Hz, 2H), 4.01 (q, J = 7.14 Hz, 2H), 7.41−7.30 (m, 5H); ^{13}C NMR δ 13.689, 15.535, 20.903, 61.740, 124.801, 127.969, 128.257, 129.198, 135.093, 138.109, 165.683; MS (*m*/*z*) 318 (M^+(^{35}Cl), 100); IR (neat) 766, 1444, 1714 cm^{-1}. Anal. Calcd for $C_{13}H_{15}ClO_2Se$: C, 49.15; H, 4.76. Found, C, 48.83; H, 4.73.

Isopropyl (*E*)-2-Ethylseleno-3-chloro-3-phenylacrylate (*E*-3e). Starting from 2-phenylethynyl ethyl selenide **1b** (209 mg, 1 mmol) and isopropyl alcohol (0.8 mL) to afford 272 mg (82%) of *E*-**3e**. Liquid. ^{1}H NMR δ 0.95 (d, J = 6.28 Hz, 6H), 1.48 (t, J = 7.49 Hz, 3H), 2.85 (q, J = 7.50 Hz, 2H), 4.75−4.91 (m, 1H), 7.25−7.52 (m, 5H); ^{13}C NMR δ 15.613, 20.704, 21.258, 69.734, 125.100, 128.125, 128.231, 129.117, 134.755, 138.217, 165.171; MS (*m*/*z*) 332 (M^+(^{35}Cl), 100); IR (neat) 762, 1486, 1716 cm^{-1}. Anal. Calcd for $C_{14}H_{17}ClO_2Se$: C, 50.69; H, 5.17. Found, C, 50.88; H, 5.25.

***n*-Butyl (*E*)-2-Ethylseleno-3-chloro-3-phenylacrylate (*E*-3f).** Starting from 2-phenylethynyl ethyl selenide **1b** (209 mg, 1 mmol) and *n*-butyl alcohol (0.8 mL) to afford 304 mg (88%) of *E*-**3f**. Liquid. ^{1}H NMR δ 0.85 (t, J = 7.23 Hz, 3H), 0.97−1.09 (m, 2H), 1.26−1.45 (m, 2H), 1.48 (t, J = 7.51 Hz, 3H), 2.87 (q, J = 7.52 Hz, 2H), 3.90 (t, J = 6.52 Hz, 2H), 7.24−7.45 (m, 5H); MS (*m*/*z*) 346 (M^+(^{35}Cl), 100); IR (neat) 766, 1446, 1712 cm^{-1}. Anal. Calcd for $C_{15}H_{19}ClO_2Se$: C, 52.11; H, 5.54. Found, C, 52.28; H, 5.45.

***p*-Nitrobenzyl (*E*)-2-Ethylseleno-3-chloro-3-phenylacrylate (*E*-3g).** Starting from 2-phenylethynyl ethyl selenide **1b** (209 mg, 1 mmol) and *p*-nitrobenzyl alcohol (0.8 mL) to afford 255 mg (60%) of *E*-**3g**. Solid; mp 64−66 °C (from ethyl acetate−hexanes). ^{1}H NMR δ 1.48 (t, J = 7.51 Hz, 3H), 2.85 (q, J = 7.52 Hz, 2H), 5.10 (s, 2H), 6.98 (d, J = 8.73 Hz, 2H), 7.28−7.45 (m, 5H), 8.05 (d, J = 8.77 Hz, 2H); MS (*m*/*z*) 425 (M^+(^{35}Cl), 83.16); IR (neat) 747, 1523, 1718 cm^{-1}. Anal. Calcd for $C_{18}H_{16}NClO_4Se$: C, 50.92; H, 3.80; N, 3.30. Found, C, 51.03; H, 3.91; N, 3.21.

Methyl 2-Phenylseleno-3-chloro-3-phenylacrylate (3h). Starting from 2-phenylethynyl phenyl selenide **1d** (257 mg, 1 mmol) and methanol (0.8 mL) to afford 264 mg (75%) of **3h**. The following data are discernible for *Z*-**3h** and *E*-**3h**, which cannot be separated by chromatography. Liquid; *Z*-**3h**:^{1}H NMR 3.15 (s, 3H), 7.24−7.78 (m, 10H); *E*-**3h**:^{1}H NMR 3.50 (s, 3H), 7.24−7.78 (m, 10H); MS (*m*/*z*) 352 (M^+(^{35}Cl), 100); IR (neat) 766, 1486, 1718 cm^{-1}. Anal. Calcd for $C_{16}H_{13}ClO_2Se$: C, 54.65; H, 3.73. Found, C, 54.96; H, 4.06.

Methyl (*Z*)-2-Methylseleno-3-chloro-2-heptenoate (*Z*-7a). Starting from 2-butylethynyl methyl selenide **6a** (175 mg, 1 mmol) and methanol (0.8 mL) to afford 232 mg (86%) of *Z*-**7a**. Liquid; ^{1}H NMR 0.85 (t, J = 7.32 Hz, 3H), 1.32−1.43 (m, 2H), 1.52−1.63 (m, 2H), 2.16 (s, 3H), 2.49 (t, J = 7.35 Hz, 2H), 3.80 (s, 3H); ^{13}C NMR δ 6.4, 12.4, 21.8, 28.5, 37.6, 52.5, 121.9, 140.2, 164.5. MS (*m*/*z*) 270 (M^+(^{35}Cl), 100); IR (neat) 1378, 1432, 1602, 1718 cm^{-1}. Anal. Calcd for $C_9H_{15}ClO_2Se$: C, 40.09; H, 5.61. Found, C, 39.73; H, 5.65.

Methyl (*Z*)-2-Ethylseleno-3-chloro-2-heptenoate (*Z*-7b). Starting from 2-butylethynyl ethyl selenide **6b** (189 mg, 1 mmol) and methanol (0.8 mL) to afford 224 mg (79%) of *Z*-**7b**. Liquid; ^{1}H NMR 0.85 (t, J = 7.32 Hz, 3H), 1.31−1.45 (m, 5H), 1.53−1.67 (m, 2H), 2.49 (t, J = 7.32 Hz, 2H), 2.79 (q, J = 7.51 Hz, 2H), 3.83 (s, 3H); MS (*m*/*z*) 284 (M^+(^{35}Cl), 45.33), 223 (100); IR (neat) 1436, 1598, 1718 cm^{-1}. Anal. Calcd for $C_{10}H_{17}ClO_2Se$: C, 42.35; H, 6.04. Found, C, 42.60; H, 5.94.

Methyl (Z)-2-Ethylseleno-3-chloro-2-octenoate (*Z*-7c). Starting from 2-pentyl-ethynyl ethyl selenide **6c** (203 mg, 1 mmol) and methanol (0.8 mL) to afford 244 mg (82%) of *Z*-**7c**. Liquid; ^{1}H NMR 0.87 (t, J = 6.82 Hz, 3H), 1.40−1.32 (m, 4H), 1.45 (t, J = 7.52 Hz, 3H), 1.54−1.68 (m, 2H), 2.50 (t, J = 6.65 Hz, 2H), 2.84 (q, J = 7.53 Hz, 2H), 3.79 (s, 3H); ^{13}C NMR δ 16.1, 18.4, 22.3, 23.5, 30.0, 32.9, 40.5, 53.5, 122.1, 143.5, 168.5. MS (*m*/*z*) 298 (M^+(^{35}Cl), 60.62), 93 (100); IR (neat) 1378, 1596, 1721 cm^{-1}. Anal. Calcd for $C_{11}H_{19}ClO_2Se$: C, 44.38; H, 6.43. Found, C, 44.47; H, 6.43.

***n*-Butyl (*Z*)-2-Methylseleno-3-chloro-2-octenoate (*Z*-7d).** Starting from 2-pentyl-ethynyl methyl selenide **6d** (189 mg, 1 mmol) and *n*-butyl alcohol (0.8 mL) to afford 261 mg (80%) of *Z*-**7d**. Liquid; ^{1}H NMR 0.81−0.99 (m, 6H), 1.21−1.50 (m, 6H), 1.55−1.75 (m, 4H), 2.15 (s, 3H), 2.45 (t, J = 7.13 Hz, 2H), 4.19 (t, J = 6.69 Hz, 2H); MS (*m*/*z*) 326 (M^+(^{35}Cl), 58.02), 253 (100); IR (neat) 1242, 1604, 1716 cm^{-1}. Anal. Calcd for $C_{13}H_{23}ClO_2Se$: C, 47.94; H, 7.12. Found, C, 48.17; H, 7.11.

Methyl (*Z*)-2-Methylseleno-3-chloro-2-nonenoate (*Z*-7e). Starting from 2-hexylethynyl methyl selenide **6e** (203 mg, 1 mmol) and methanol (0.8 mL) to afford 235 mg (79%) of *Z*-**7e**. Liquid; ^{1}H NMR 0.85 (t, J = 6.40 Hz, 3H), 1.31−1.42 (m, 6H), 1.52−1.60 (m, 2H), 2.15 (s, 3H), 2.49 (t, J = 7.42 Hz, 2H), 3.85

(19) Hercsi, L.; Heimaus, B.; Allard, C. *Tetrahedron Lett*. **1994**, *35*, 6729.

(s, 3H); ^{13}C NMR δ 6.698, 14.030, 22.472, 27.643, 28.202, 31.427, 38.072, 52.453, 121.408, 141.160, 165.973; MS (*m*/*z*) 298 (M^+(^{35}Cl), 87.25), 209 (100); IR (neat) 1439, 1590, 1721 cm^{-1}. Anal. Calcd for $C_{11}H_{19}ClO_2Se$: C, 44.38; H, 6.43. Found, C, 44.65; H, 6.50.

Methyl (*Z*)-2-Ethylseleno-3-chloro-2-nonenoate (*Z*-7f). Starting from 2-hexyl-ethynyl ethyl selenide **6f** (217 mg, 1 mmol) and methanol (0.8 mL) to afford 234 mg (75%) of *Z*-**7f**. Liquid; ^{1}H NMR 0.90 (t, J = 6.80 Hz, 3H), 1.19−1.35 (m, 6H), 1.40 (t, J = 7.50 Hz, 3H), 1.59−1.66 (m, 2H), 2.51 (t, J = 7.42 Hz, 2H), 2.85 (q, J = 7.50 Hz, 2H), 3.85 (s, 3H); ^{13}C NMR δ 6.489, 14.027, 21.899, 22.494, 27.700, 28.405, 31.532, 38.044, 69.727, 121.903, 139.596, 164.938; MS (*m*/*z*) 312 (M^+(^{35}Cl), 93.74), 223 (100); IR (neat) 1431, 1597, 1722 cm^{-1}. Anal. Calcd for $C_{12}H_{21}ClO_2Se$: C, 46.24; H, 6.79. Found, C, 46.18; H, 6.88.

Isopropyl (*Z*)-2-Methylseleno-3-chloro-2-nonenoate (*Z*-7g). Starting from 2-hexylethynyl methyl selenide **6e** (203 mg, 1 mmol) and isopropyl alcohol (0.8 mL) to afford 254 mg (78%) of *Z*-**7g**. Liquid; ^{1}H NMR 0.84 (t, J = 6.82 Hz, 3H), 1.29−1.37 (m, 12H), 1.62−1.68 (m, 2H), 2.28 (s, 3H), 2.47 (t, J = 7.47 Hz, 2H), 5.15−5.20 (m, 1H); MS (*m*/*z*) 326 (M^+(^{35}Cl), 100); IR (neat) 1435, 1596, 1720 cm^{-1}. Anal. Calcd for $C_{13}H_{23}ClO_2Se$: C, 47.94; H, 7.12. Found, C, 48.18; H, 7.08.

Methyl 2-Phenylseleno-3-chloro-2-heptenoate (7h). Starting from 2-butylethynyl phenyl selenide **6g** (237 mg, 1 mmol) and methanol (0.8 mL) to afford 232 mg (70%) of **7h**. The following data are discernible for *Z*-**7h** and *E*-**7h**, which cannot be separated by chromatography. Liquid; *Z*-**7h**: ^{1}H NMR 0.89 (t, J = 7.26 Hz, 3H), 1.29−1.40 (m, 2H), 1.55−1.70 (m, 2H), 2.51 (t, J = 7.31 Hz, 2H), 3.30 (s, 3H), 7.25−7.61 (m, 5H); (*E*)-**7h**: ^{1}H NMR 0.89 (t, J = 7.26 Hz, 3H), 1.29−1.40 (m, 2H), 1.55−1.70 (m, 2H), 2.71 (t, J = 7.51 Hz, 2H), 3.55 (s, 3H), 7.25−7.61 (m, 5H); MS (*m*/*z*) 332 (M^+(^{35}Cl), 100); IR (neat) 747, 1474, 1715 cm^{-1}. Anal. Calcd for $C_{14}H_{17}ClO_2Se$: C, 50.70; H, 5.17. Found, C, 51.02; H, 5.05.

Methyl 2-(*p*-methoxyphenyl)seleno-3-chloro-2-heptenoate (7i) Starting from 2-butylethynyl (*p*-methoxy)phenyl selenide **6i** (267 mg, 1 mmol) and methanol (0.8 mL) to afford 243 mg (67%) of **7i**. The following data are discernible for *Z*-**7i** and *E*-**7i**, which cannot be separated by chromatography. Liquid; *Z*-**7i**: ^{1}H NMR 0.80 (t, J = 7.26 Hz, 3H), 1.25−1.42 (m, 2H), 1.55−1.67 (m, 2H), 2.51 (t, J = 7.30 Hz, 2H), 3.35 (s, 3H), 3.80 (s, 3H), 6.82 (d, J = 10.04 Hz, 2H), 7.53 (d, J = 10.02 Hz, 2H); *E*-**7i:**^{1}H NMR 0.80 (t, J = 7.26 Hz, 3H), 1.25−1.42 (m, 2H), 1.55−1.67 (m, 2H), 2.71 (t, J = 7.50 Hz, 2H), 3.55 (s, 3H), 3.80 (s, 3H), 6.82 (d, J = 10.04 Hz, 2H), 7.53 (d, J = 10.02 Hz, 2H); ^{13}C NMR δ 13.748, 21.669, 29.814, 37.709, 52.123, 55.280, 114.659, 117.434, 124.555, 137.838, 138.647, 160.385, 165.331; MS (*m*/*z*) 362 (M^+(^{35}Cl), 100); IR (neat) 674, 1717 cm^{-1}. Anal. Calcd for $C_{15}H_{19}ClO_3Se$: C, 49.81; H, 5.29. Found, C, 49.77; H, 5.27.

Preparation of (*Z*)-2-Ethylseleno-3-chloro-2-octen-1-ol (*Z*-9c). Typical Procedure. A mixture of methyl (*Z*)-2-ethylseleno-3-chloro-2-octenoate (*Z*-**7c**) (1 mmol, 298 mg) and DIBAL-H (1.0 mmol) in THF (5 mL) was stirred at room temperature for about 3 h. Then methanol (1.5 mmol) was added to the mixture. The resulting mixture was stirred for 20 min and filtered. The filtrate was washed with saturated aq NH_4Cl to destroy the excess DIBAL-H, separated, and dried over $MgSO_4$. Evaporation of the solvent and chromatography on silica gel (hexane/ethyl acetate = 5:1) afforded 216 mg (80%) of *Z*-**9c**: liquid; ^{1}H NMR 0.85 (t, J = 6.82 Hz, 3H), 1.30−1.42 (m, 4H), 1.45 (t, J = 7.5 Hz, 3H), 1.59−1.72 (m, 2H), 2.12 (s, 1H), 2.52 (t, J = 7.50 Hz, 2H), 2.84 (q, J = 7.42 Hz, 2H), 4.35 (s, 2H); MS (*m*/*z*) 270 (M^+(^{35}Cl), 100); IR (neat) 2924, 3376 cm^{-1}. Anal. Calcd for $C_{10}H_{19}ClOSe$: C, 44.54; H, 7.1. Found, C, 44.87; H, 7.49.

(*Z*)-2-Ethylseleno-3-chloro-2-nonalen-1-ol (*Z*-9f) was prepared similarly: starting from *Z*-**7f** (312 mg, 1 mmol) to afford 224 mg (79%) of *Z*-**9f**. Liquid; ^{1}H NMR 0.85 (t, J = 6.60 Hz, 3H), 1.35−1.25 (m, 6H), 1.45 (t, J = 7.45 Hz, 3H), 1.55−1.70 (m, 2H), 2.03 (s, 1H), 2.55 (t, J = 7.46 Hz, 2H), 2.90 (q, J = 7.40 Hz, 2H), 4.35 (s, 2H); MS (*m*/*z*) 284 (M^+(^{35}Cl), 100); IR (neat) 2920, 3373 cm^{-1}. Anal. Calcd for $C_{11}H_{21}ClOSe$: C, 46.57; H, 7.46. Found, C, 46.75; H, 7.40.

2-(*p*-Methoxyphenyl)seleno-3-chloro-2-hepten-1-ol (9i) was prepared similarly: starting from **7i** (362 mg, 1 mmol) to afford 200 mg (60%) of *Z*-**9i** and 63 mg (19%) of *E*-**9i**.

***Z*-9i:** Liquid; ^{1}H NMR 0.85 (t, J = 7.28 Hz, 3H), 1.23−1.30 (m, 2H), 1.45(s, 1H), 1.51−1.70 (m, 2H), 2.53 (t, J = 7.46 Hz, 2H), 3.75 (s, 3H), 4.10 (s, 2H), 6.77 (d, J = 8.82 Hz, 2H), 7.55 (d, J = 8.84 Hz, 2H); ^{13}C NMR δ 13.873, 21.924, 30.344, 36.160, 55.328, 60.679, 115.200, 117.576, 130.573, 135.039, 136.354, 137.893, 160.430; MS (*m*/*z*) 334 (M^+(^{35}Cl), 100); IR (neat) 2958, 3373 cm^{-1}. Anal. Calcd for $C_{14}H_{19}ClO_2Se$: C, 50.39; H, 5.74. Found, C, 50.67; H, 5.57.

***E*-9i:** ^{1}H NMR 0.85 (t, J = 7.28 Hz, 3H), 1.24−1.38 (m, 2H), 1.55−1.79 (m, 3H), 2.79 (t, J = 7.50 Hz, 2H), 3.85 (s, 3H), 4.30 (s, 2H), 6.82 (d, J = 8.78 Hz, 2H), 7.49 (d, J = 8.83 Hz, 2H); MS (*m*/*z*) 334 (M^+(^{35}Cl), 100); IR (neat) 2950, 3376 cm^{-1}. Anal. Calcd for $C_{14}H_{19}ClO_2Se$: C, 50.39; H, 5.74. Found, C, 50.77; H, 5.58.

Acknowledgment. We thank the National Natural Science Foundation of China for financial support. We also thank Dr. Shengming Ma for helpful discussion.

Supporting Information Available: The ^{1}H NMR spectra of the compounds *E*-**3a**, *E*-**3b**, *E*-**3c**, *E*-**3d**, *E*-**3e**, *E*-**3f**, *E*-**3g**, **3h**, *Z*-**7a**, *Z*-**7b**, *Z*-**7c**, *Z*-**7d**, *Z*-**7e**, *Z*-**7f**, *Z*-**7g**, **7h**, **7i**, *Z*-**9c**, *Z*-**9f**, *Z*-**9i**, and *E*-**9i**; ^{13}C NMR spectra of the compounds *E*-**3a**, *E*-**3b**, *E*-**3c**, *E*-**3d**, *E*-**3e**, *Z*-**7a**, *Z*-**7c**, *Z*-**7e**, *Z*-**7f**, **7i**, and *Z*-**9i**; ^{1}H−^{1}H NOSEY spectra of compounds *Z*-**9c**, *Z*-**9i**, and *E*-**9i**. This material is available free of charge via the Internet at http://pubs.acs.org.

JO0006977