DOI: 10.1002/ejoc.200700707

Synthesis of 3-Alkynylselenophene Derivatives by a Copper-Free Sonogashira Cross-Coupling Reaction

Diego Alves,[a] Joel S. dos Reis,[a] Cristiane Luchese,[a] Cristina W. Nogueira,[a] and Gilson Zeni*[a]

Keywords: Palladium / Cross-coupling / Selenium / Selenophene

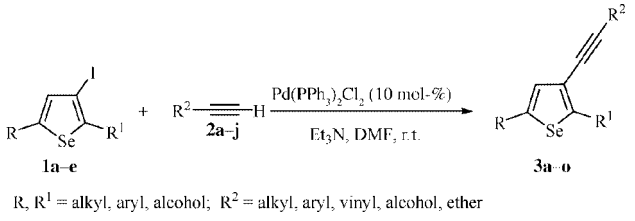
3-Iodoselenophene derivatives undergo direct Sonogashira cross-coupling reactions with several terminal alkynes in the presence of a catalytic amount of $Pd(PPh_3)_2Cl_2$ in DMF with Et_3N as the base under cocatalyst-free conditions. This cross-coupling reaction proceeded cleanly under mild conditions and was performed with propargylic alcohols and propargylic ethers, as well as alkyl, vinyl and aryl alkynes to furnish the corresponding 3-alkynylselenophenes in good-to-excellent yields.

Introduction

Palladium-catalyzed carbon–carbon bond formation, a key stage in the synthesis of many currently interesting heterocycle-containing compounds,[1] has proved to proceed generally and effectively. As a consequence of the current interest in the development of coupling substrates that are more economic and more easily accessible and reactive, even under mild conditions, there has been significant progress in the optimization of palladium-catalyzed coupling systems. The palladium-catalyzed cross-coupling reactions of vinyl or aryl halides with terminal alkynes is a powerful and versatile synthetic tool for the preparation of substituted acetylenes.[2] Numerous modifications to the original protocol and the improvement of many aspects of $sp–sp^2$ carbon bond formation have led to widespread application of this reaction in the synthesis of a variety of compounds, including various heterocyclic compounds.[3] Carbon–carbon bond formation is thus a useful method for the synthesis of building blocks that can be used in the preparation of natural products.[4]

Among heterocycles, chalcogenophene derivatives play an important role in organic synthesis because of their excellent electrical properties and environmental stability. Chalcogenophene oligomers are compounds of current interest because many of them show photoenhanced biological activity,[5] and α-type chalcogenophene oligomers, such as 5,2′:5′,2′′-terthiophene, produce crystalline, electroconductive-doped polythiophenes on electrochemical polymerization.[6]

Halochalcogenophenes are an important class of compounds that can undergo further functionalization.[7] In particular, 2-iodo- and 2-bromoselenophenes are useful substrates for a variety of C–C, C–N and C–S bond-forming reactions. Our continued interest in the syntheses[8] and applications[7] of chalcogenophenes in organic synthesis prompted us to examine and expand the scope of the Sonogashira reaction of 3-iodoselenophene derivatives with different terminal alkynes to obtain 3-alkynylselenophenes **3a–o** (Scheme 1).



R, R^1 = alkyl, aryl, alcohol; R^2 = alkyl, aryl, vinyl, alcohol, ether

Scheme 1. General scheme for the cross-coupling of 3-iodoselenophene derivatives with terminal alkynes.

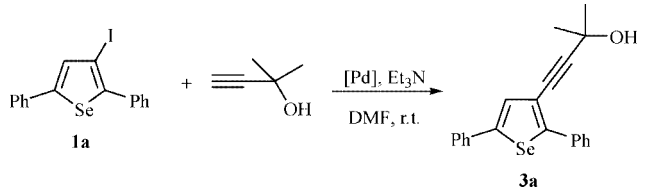
Results and Discussion

Our initial studies focused on the development of optimal reaction conditions. For this purpose, 2,5-diphenyl-3-iodoselenophene (**1a**) and 2-methyl-3-butyn-2-ol (**2a**) were used as standard substrates. Starting 3-iodoselenophene **1a** was prepared by using an electrophilic cyclization protocol.[8] Thus, a mixture of 3-iodoselenophene **1a** (0.5 mmol), alkyne **2a** (1.5 mmol) and Et_3N (1mL) in DMF (2.5 mL) was treated with a variety of palladium catalysts (Table 1).

[a] Laboratório de Síntese, Reatividade, Avaliação Farmacológica e Toxicológica de Organocalcogênios, CCNE, Universidade Federal de Santa Maria,
Santa Maria, Rio Grande do Sul, 97105-900, Brazil
Fax: +55-55-3220-8998
E-mail: gzeni@quimica.ufsm.br

Supporting information for this article is available on the WWW under http://www.eurjoc.org or from the author.

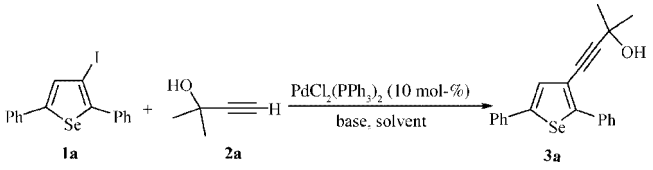
Table 1. Influence of catalyst in the reaction of **1a** and **2a**.[a]



Entry	Palladium salt [mol-%]	Yield of **3a** [%]
1	$PdCl_2(PPh_3)_2$ (10)	91
2	$PdCl_2(PhCN)_2$ (10)	14
3	$PdCl_2$ (10)	26
4	$Pd(OAc)_2$ (10)	25
5	$Pd(acac)_2$ (10)	16
6	$Pd(PPh_3)_4$ (10)	trace
7	$Pd(dba)_2$ (10)	17
8	$Pd(dppe)_2$ (10)	trace
9	$PdCl_2(PPh_3)_2$ (5)	57
10	$PdCl_2(PPh_3)_2$ (1)	21

[a] Reaction time was 12 h.

Table 2. Optimization of reaction conditions.[a]



Entry	Base	Solvent	Yield of **3a** [%][a]
1	Et_3N	DMF	91
2	K_2CO_3	DMF	65
3	KOAc	DMF	62
4	K_3PO_4	DMF	46
5	KOH	DMF	79
6	Et_3N	THF	39
7	Et_3N	CH_2Cl_2	52
8	Et_3N	toluene	28
9	Et_3N	MeOH	28
10	Et_3N	pyrrolidine	trace
11	Et_3N	DME	60
12	Et_3N	1,4-dioxane	trace
13	Et_3N	DMSO	88
14	Et_3N	H_2O	65

[a] Reaction time was 12 h.

We found that the cross-coupling reaction of 3-iodoselenophene **1a** with terminal alkyne **2a** was best catalyzed by $PdCl_2(PPh_3)_2$ (Table 1, Entry 1). By using this catalyst (10 mol-%), corresponding 3-alkynylselenophene **3a** was obtained in high yield (91% isolated product). Other palladium complexes, such as $PdCl_2(PhCN)_2$, $PdCl_2$, $Pd(OAc)_2$, $Pd(acac)_2$, $Pd(PPh_3)_4$, $Pd(dba)_2$ and $Pd(dppe)_2$, were less effective (Table 1, Entries 2–8). It is important to note that when the amount of catalyst was reduced from 10 to 1 mol-%, a decrease in yield was observed (Table 1, Entries 9 and 10).

We also observed that the nature of the base was critical to the success of the coupling. When different bases such as K_2CO_3, KOAc, K_3PO_4 and KOH were used instead of Et_3N, moderate yields of desired product **3a** were obtained (Table 2, Entries 2–5).

With regard to the influence of the solvent in this coupling reaction, optimal results were achieved by using DMF and DMSO (Table 2; Entries 1 and 13). By using CH_2Cl_2, DME or H_2O (Table 2, Entries 7, 11 and 14, respectively) as the solvents moderate yields were obtained, whereas other solvents such as THF, toluene and MeOH (Table 2, Entries 6, 8 and 9, respectively) furnished only small amounts of desired product **3a**. Only trace amounts of product **3a** were obtained with the use of pyrrolidine or 1,4-dioxane as the solvent (Table 2, Entries 10 and 12, respectively).

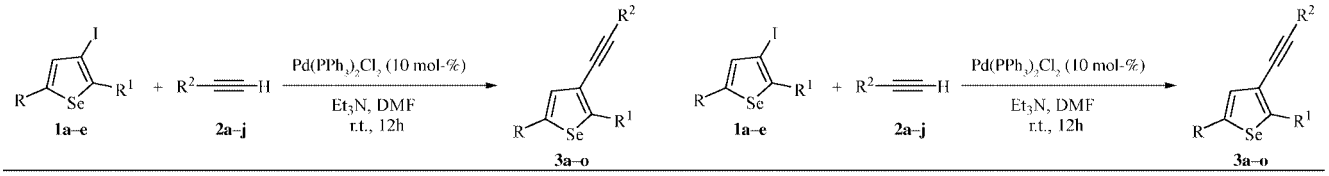
Careful analysis of the results of these reactions revealed the optimum conditions to include the use of $PdCl_2(PPh_3)_2$ (10 mol-%), 3-iodoselenophene **1a** (0.5 mmol), terminal alkyne **2a** (1.5 mmol) and Et_3N (1 mL) in DMF (2.5 mL) at room temperature for 12 h. Under these reaction conditions we were able to prepare 4-(2,5-diphenylselenophen-3-yl)-2-methyl-but-3-yn-2-ol (**3a**) in 91% yield. To demonstrate the efficiency of this protocol and to explore the generality of our method, we extended the reaction to several terminal alkynes and other 3-iodoselenophenes (Table 3).

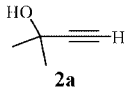
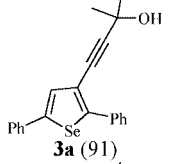
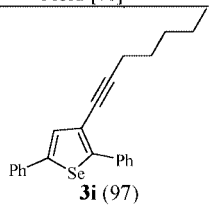
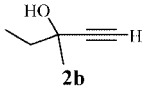
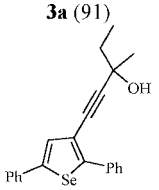
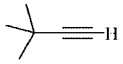
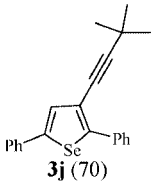
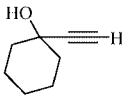
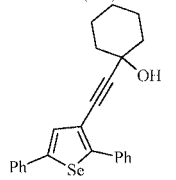
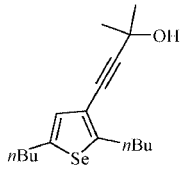
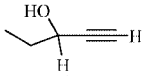
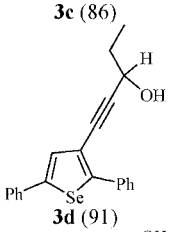
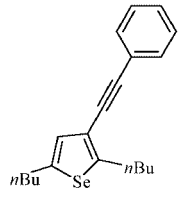
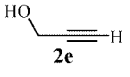
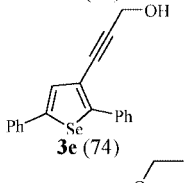
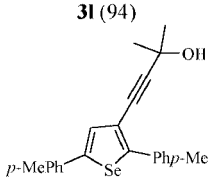
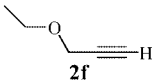
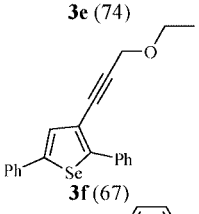
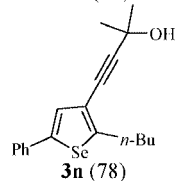
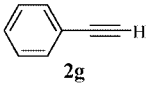
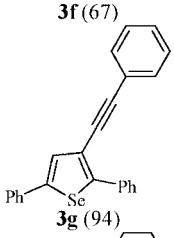
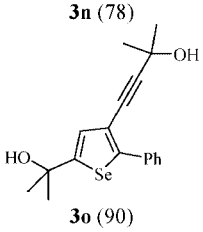
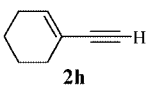
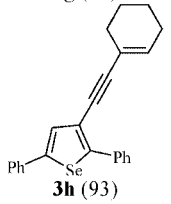
The reaction worked well for a variety of propargylic alcohols (Table 3). Both hindered and nonhindered propargylic alcohols gave the desired products in excellent yields (Table 3, Entries 1–5). Our experiments showed that the reaction with propargylic ether gave the coupled product in moderate yield (Table 3, Entry 6). Alkynes containing an aryl or vinyl group were coupled in excellent yields (Table 3, Entries 7 and 8). We found that steric effects have an influence on the coupling reaction, as alkyne **2j** containing a *tert*-butyl group gave a lower yield of product relative to that obtained with *n*-pentane-substituted alkyne **2i** (Table 3, Entry 9 vs. 10).

In an attempt to broaden the scope of our synthetic procedure, the possibility of performing the reaction with other 3-iodoselenophenes containing a hydroxy, an aryl or an alkyl group within the side chain was also investigated. As illustrated in Table 3, the cross-coupling reaction of **1b–e** with alkynes, under the same reaction conditions, led to corresponding coupling products **3k–o** in high yields (Table 3, Entries 11–15).

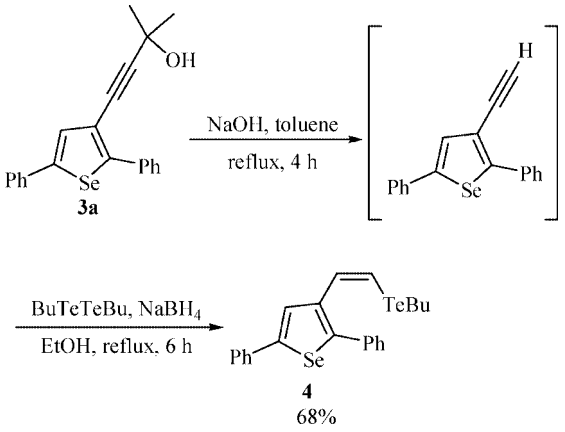
The 3-alkynylselenophenes obtained by this protocol appear highly promising as intermediates in the preparation of more highly substituted selenophenes. To demonstrate this, we carried out the synthesis of vinylic telluride **4** from compound **3a**. Many classes of organotellurium compounds have been prepared and studied to date and vinylic tellurides are certainly the most useful and promising of these in organic synthesis.[9] Thus, 3-alkynylselenophene **3a** was treated with NaOH in toluene and heated under reflux for 4 h. The terminal alkyne generated in situ was treated with BuTeTeBu and $NaBH_4$ in ethanol, and the reaction mixture was stirred under reflux for 6 h to give corresponding vinylic telluride **4** in 68% yield (Scheme 2).

Table 3. Cross-coupling reaction of 3-iodoselenophenes **1a–e** and alkynes **2a–j**.



Entry	Substrate	Alkyne	Product Yield [%][a]	Entry	Substrate	Alkyne	Product Yield [%][a]
1	**1a**	 **2a**	 **3a** (91)	9	**1a**	 **2i**	 **3i** (97)
2	**1a**	 **2b**	 **3b** (97)	10	**1a**	 **2j**	 **3j** (70)
3	**1a**	 **2c**	 **3c** (86)	11	**1b**	**2a**	 **3k** (83)
4	**1a**	 **2d**	 **3d** (91)	12	**1b**	**2g**	 **3l** (94)
5	**1a**	 **2e**	 **3e** (74)	13	**1c**	**2a**	 **3m** (94)
6	**1a**	 **2f**	 **3f** (67)	14	**1d**	**2a**	 **3n** (78)
7	**1a**	 **2g**	 **3g** (94)	15	**1e**	**2a**	 **3o** (90)
8	**1a**	 **2h**	 **3h** (93)				

[a] Yields of **3a–o** are given for isolated products.



Scheme 2. Synthesis of vinylic telluride **4**.

Conclusions

We have explored the Sonogashira reaction of 3-iodoselenophenes with several terminal alkynes in the presence of a catalytic amount of $Pd(PPh_3)_2Cl_2$ with DMF as the solvent and Et_3N as the base under mild cocatalyst-free conditions. We thus established a new route for the preparation of 3-alkynylselenophene derivatives, which were produced in excellent yields. The 3-alkynylselenophenes obtained appear to be highly promising as intermediates in the preparation of more highly substituted selenophenes. Studies of the biological activity of these compounds are under study in our lab.

Experimental Section

General Procedure for Iodoselenophene–Alkyne Cross-Coupling Reactions: To a Schlenk tube, under an atmosphere of argon, containing the appropriate 3-iodoselenophene (0.50 mmol) in DMF (2.5 mL) was added $Pd(PPh_3)_2Cl_2$ (0.035g, 0.05 mmol). The resulting solution was stirred for 5 min at room temperature. After this time, the appropriate terminal alkyne (1.5 mmol) dissolved in Et_3N (1 mL) was added dropwise, and the reaction mixture was allowed to stir at room temperature for 12 h. After this time, the mixture was diluted with CH_2Cl_2 (20 mL) and washed with brine (3×20 mL). The organic phase was separated, dried with $MgSO_4$ and concentrated under vacuum. The residue was purified by flash chromatography on silica gel (ethyl acetate/hexane, 1:8).

Diphenylselenophen-3-yl)-2-methyl-but-3-yn-ol (3a): Yield: 0.166 g (91%). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.83–7.81 (m, 2 H), 7.54–7.50 (m, 3 H), 7.42–7.29 (m, 6 H), 2.11 (s, 1 H), 1.60 (s, 6 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 151.7, 147.4, 135.5, 135.4, 129.5, 128.9, 128.4, 128.1, 128.0, 127.9, 125.9, 119.9, 94.6, 79.4, 65.6, 31.2 ppm. MS: *m*/*z* (%) = 347 (100), 305 (77), 281 (61), 128 (50), 77 (21). HRMS: calcd. for $C_{21}H_{18}OSe$ 366.0523; found 366.0529.

1-(2,5-Diphenylselenophen-3-yl)-3-methylpent-1-yn-3-ol (3b): Yield: 0.183 g (97%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.83–7.78 (m, 2 H), 7.56–7.50 (m, 3 H), 7.44–7.29 (m, 6 H), 2.07 (s, 1 H), 1.76 (q, J = 7.5 Hz, 2 H), 1.54 (s, 3 H), 1.05 (t, J = 7.5 Hz, 3 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 151.7, 147.4, 135.5, 135.4, 129.7, 128.9, 128.4, 128.1, 128.0, 127.9, 126.0, 120.0, 93.7, 80.5, 69.2, 36.4, 29.1, 9.0ppm. MS: *m*/*z* (%) = 361 (100), 332 (53), 317 (22), 281 (71), 206 (44), 129 (56), 77 (35). HRMS: calcd. for $C_{22}H_{20}OSe$ 380.0679; found 380.0683.

1-(2,5-Diphenylselenophen-3-ylethynyl)cyclohexanol (3c): Yield: 0.174 g (86%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.84–7.79 (m, 2 H), 7.56–7.51 (m, 3 H), 7.43–7.29 (m, 6 H), 2.12 (s, 1 H), 1.72–1.52 (m, 8 H), 1.36–1.17 (m, 2 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 151.6, 147.4, 135.5, 135.4, 129.8, 128.9, 128.4, 128.1, 128.0, 127.9, 126.0, 120.2, 93.8, 81.3, 69.3, 39.9, 25.2, 23.3 ppm. MS: *m*/*z* (%) = 387 (100), 305 (32), 281 (65), 206 (47), 129 (63), 77 (41). HRMS: calcd. for $C_{24}H_{22}OSe$ 406.0836; found 406.0831.

1-(2,5-Diphenylselenophen-3-yl)pent-1-yn-3-ol (3d): Yield: 0.166 g (91%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.83–7.78 (m, 2 H), 7.55–7.50 (m, 3 H), 7.44–7.29 (m, 6 H), 4.54–4.49 (m, 1 H), 2.00 (s, 1 H), 1.87–1.73 (m, 2 H), 1.04 (t, J = 7.4 Hz, 3 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 151.9, 147.5, 135.5, 135.4, 129.7, 128.9, 128.5, 128.1, 128.0, 127.9, 126.0, 119.9, 90.9, 82.0, 64.3, 30.8, 9.4 ppm. MS: *m*/*z* (%) = 347 (100), 318 (21), 281 (69), 206 (52), 129 (73), 77 (35). HRMS: calcd. for $C_{21}1H_8OSe$ 366.0523; found 366.0528.

3-(2,5-Diphenylselenophen-3-yl)prop-2-yn-1-ol (3e): Yield: 0.128 g (74%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.82–7.77 (m, 2 H), 7.55–7.29 (m, 9 H), 4.46 (s, 2 H), 1.78 (s, 1 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 152.2, 147.6, 135.4, 135.3, 129.7, 128.9, 128.6, 128.2, 128.0, 127.9, 125.9, 119.8, 88.2, 82.7, 51.6 ppm. MS: *m*/*z* (%) = 319 (100), 281 (55), 206 (47), 129 (63), 77 (40). HRMS: calcd. for $C_{19}1H_4OSe$ 338.0210; found 338.0207.

3-(3-Ethoxyprop-1-ynyl)-2,5-diphenylselenophene (3f): Yield: 0.122 g (67%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.83–7.78 (m, 2 H), 7.55–7.50 (m, 3 H), 7.44–7.29 (m, 6 H), 4.34 (s, 2 H), 2.61 (q, J = 6.9 Hz, 2 H), 1.24 (t, J = 6.9 Hz, 3 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 152.1, 147.5, 135.5, 135.4, 129.8, 128.9, 128.5, 128.1, 128.0, 127.9, 126.0, 120.0, 86.5, 83.1, 65.4, 58.6, 15.0 ppm. MS: *m*/*z* (%) = 365 (100), 320 (73), 281 (41), 206 (61), 129 (55), 77 (47). HRMS: calcd. for $C_{21}1H_8OSe$ 366.0523; found 366.0518.

2,5-Diphenyl-3-phenylethynylselenophene (3g): Yield: 0.180 g (94%). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.92–7.89 (m, 2 H), 7.61 (s, 1 H), 7.58–7.56 (m, 2 H), 7.49–7.29 (m, 11 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 151.8, 147.5, 135.7, 135.5, 131.4, 129.6, 129.0, 128.6, 128.4, 128.16, 128.15, 128.14, 128.0, 126.1, 123.4, 120.6, 90.3, 86.9 ppm. MS: *m*/*z* (%) = 383 (100), 306 (56), 282 (77), 204 (38), 128 (51), 101 (19), 77 (28). HRMS: calcd. for $C_{24}1H_6Se$ 384.0417; found 384.0411.

3-Cyclohex-1-enylethynyl-2,5-diphenylselenophene (3h): Yield: 0.180 g (93%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.88–7.83 (m, 2 H), 7.57–7.25 (m, 9 H), 6.19–6.14 (m, 1 H), 2.22–2.12 (m, 4 H), 1.68–1.59 (m, 4 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 150.5, 147.0, 135.8, 135.6, 135.1, 129.8, 128.9, 128.4, 128.0, 127.9, 127.8, 126.0, 121.0, 120.8, 92.4, 84.2, 28.9, 25.8, 22.3, 21.5 ppm. MS: *m*/*z* (%) = 387 (100), 306 (65), 281 (56), 206 (42), 129 (39), 77 (62). HRMS: calcd. for $C_{24}H_{20}Se$ 388.0730; found 388.0734.

3-Hept-1-ynyl-2,5-diphenylselenophene (3i): Yield: 0.182 g (97%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.87–7.83 (m, 2 H), 7.56–7.49 (m, 3 H), 7.41–7.28 (m, 6 H), 2.39 (t, J = 7.1 Hz, 2 H), 1.67–1.49 (m, 2 H), 1.46–1.28 (m, 4 H), 0.91 (t, J = 7.1 Hz, 3 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 150.3, 146.9, 135.8, 135.6, 130.2, 128.9, 128.4, 127.9, 127.8, 127.8, 126.0, 121.3, 91.7, 77.7, 31.1, 28.2, 22.2, 19.5, 14.0 ppm. MS: *m*/*z* (%) = 377 (100), 362 (73), 348 (33), 334 (30), 320 (26), 281 (56), 206 (58), 129 (61), 77 (53). HRMS: calcd. for $C_{23}H_{22}Se$ 378.0887; found 378.0882.

3-(3,3-Dimethylbut-1-ynyl)-2,5-diphenylselenophene (3j): Yield: 0.127 g (70%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.89–7.85 (m, 2 H), 7.56–7.48 (m, 3 H), 7.44–7.27 (m, 6 H), 1.31 (s, 9 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 150.2, 146.8, 135.8, 135.6, 130.1, 128.9, 128.3, 127.9, 127.8, 127.7, 126.0, 121.2, 99.6, 76.5, 30.8, 28.2 ppm. MS: *m*/*z* (%) = 363 (100), 318 (63), 281 (68), 206 (42), 129 (58), 77 (39). HRMS: calcd. for $C_{22}H_{20}Se$ 364.0730; found 364.0733.

4-(2,5-Dibutylselenophen-3-yl)-2-methylbut-3-yn-2-ol (3k): Yield: 0.134 g (83%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 6.76 (s, 1 H), 2.89 (t, *J* = 7.8 Hz, 2 H), 2.75 (t, *J* = 7.5 Hz, 2 H), 2.07 (s, 1 H), 1.70–1.56 (m, 10 H), 1.49–1.28 (m, 4 H), 0.97–0.88 (m, 6 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 155.0, 148.5, 128.0, 119.6, 94.6, 78.5, 65.7, 34.3, 34.2, 32.1, 31.6, 31.1, 22.1, 22.0, 13.8, 13.7 ppm. MS: *m*/*z* (%) = 307 (100), 278 (34), 242 (77), 211 (63), 183 (52), 155 (39), 129 (32). HRMS: calcd. for $C_{17}H_{26}OSe$ 326.1149; found 326.1153.

2,5-Dibutyl-3-phenyletynylselenophene (3l): Yield: 0.161 g (94%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.55–7.45 (m, 2 H), 7.36–7.28 (m, 3 H), 6.88 (s, 1 H), 3.00 (t, *J* = 7.8 Hz, 2 H), 2.78 (t, *J* = 7.5 Hz, 2 H), 1.76–1.30 (m, 8 H), 0.99–0.89 (m, 6 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 155.2, 148.5, 131.3, 128.2, 128.1, 127.8, 123.8, 120.3, 90.1, 85.9, 34.5, 34.3, 32.2, 31.3, 22.2, 22.1, 13.8, 13.7 ppm. MS: *m*/*z* (%) = 343 (100), 266 (72), 242 (70), 211 (51), 183 (62), 155 (44), 129 (47). HRMS: calcd. for $C_{20}H_{24}Se$ 344.1043; found 344.1048.

4-(2,5-Di-*p*-methylphenylselenophen-3-yl)-2-methylbut-3-yn-2-ol (3m): Yield: 0.184 g (94%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.71 (d, *J* = 8.3 Hz, 2 H), 7.44–7.40 (m, 3 H), 7.22–7.15 (m, 4 H), 2.38–2.36 (m, 6 H), 1.99 (s, 1 H), 1.60 (s, 6 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 151.5, 147.0, 138.1, 137.9, 132.8, 132.7, 129.6, 129.2, 129.0, 127.8, 125.9, 119.4, 94.5, 79.7, 65.7, 31.3, 21.3, 21.2 ppm. MS: *m*/*z* (%) = 375 (100), 345 (47), 309 (78), 128 (58), 91 (57). HRMS calcd. for $C_{23}H_{22}OSe$ 394.0836; found 394.0840.

4-(2-Butyl-5-phenylselenophen-3-yl)-2-methylbut-3-yn-2-ol (3n): Yield: 0.134 g (78%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.77–7.72 (m, 2 H), 7.40–7.25 (m, 3 H), 6.96 (s, 1 H), 2.81 (t, *J* = 7.5 Hz, 2 H), 2.02 (s, 1 H), 1.73–1.56 (m, 8 H), 1.41 (sext., *J* = 7.5 Hz, 2 H), 0.94 (t, *J* = 7.5 Hz, 3 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 150.6, 150.4, 135.9, 130.7, 128.3, 127.9, 127.7, 118.4, 94.2, 79.8, 65.7, 34.2, 32.2, 31.2, 22.1, 13.8 ppm. MS: *m*/*z* (%) = 327 (100), 297 (52), 261 (56), 246 (33), 232 (21), 155 (45), 128 (42), 77 (34). HRMS: calcd. for $C_{19}H_{22}OSe$ 346.0836; found 346.0831.

4-[5-(1-Hydroxy-1-methylethyl)-2-phenylselenophen-3-yl]-2-methylbut-3-yn-2-ol (3o): Yield: 0.156 g (90%). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.76–7.71 (m, 2 H), 7.40–7.25 (m, 3 H), 7.05 (s, 1 H), 2.61 (s, 1 H), 2.46 (s, 1 H), 1.62 (s, 6 H), 1.55 (s, 6 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 159.6, 151.1, 135.7, 128.3, 127.95, 127.94, 127.8, 118.4, 94.1, 79.6, 72.7, 65.6, 31.9, 31.2 ppm. MS: *m*/*z* (%) = 311 (100), 281 (72), 245 (45), 206 (31), 128 (56), 77 (21). HRMS: calcd. for $C_{18}H_{20}O_2Se$ 348.0629; found 348.0624.

3-(2-Butyltellanylvinyl)-2,5-diphenylselenophene (4): Powered NaOH (0.044g; 1.1 mmol) was added to a two-neck round-bottomed flask, equipped with a reflux condenser, containing a solution of alkynylselenophene **3a** (0.365g, 1.0 mmol) in dry toluene (2 mL) under an argon atmosphere. The mixture was slowly heated to reflux. The reaction mixture became dark brown and was heated at reflux for 4 h. The resulting solution was cooled to room temperature and a solution of dibutylditelluride (0.185g; 0.5 mmol) in 95% EtOH (10 mL) was added. $NaBH_4$ (0.092g; 2.5 mmol) was added with vigorous stirring and gas evolution was observed during addition. The reaction mixture was stirred at reflux for 6 h, allowed to reach room temperature, diluted with EtOAc (60 mL) and washed with brine (3 × 30 mL) and water (3 × 30 mL). The organic phase was dried with anhydrous $MgSO_4$, the solvent was removed under reduced pressure and the residue was purified by flash chromatography on silica gel (hexane). Yield: 0.335 g (68%). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.80 (s, 1 H), 7.59–7.57 (m, 2 H), 7.48–7.23 (m, 9 H), 6.91 (d, *J* = 10.8 Hz, 1 H), 2.76 (t, *J* = 7.4 Hz, 2 H), 1.83 (quint., *J* = 7.4 Hz, 2 H), 1.42 (sext., *J* = 7.4 Hz, 2 H), 0.94 (t, *J* = 7.4 Hz, 3 H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 148.1, 138.6, 136.1, 132.9, 129.6, 129.4, 128.9, 128.5, 127.7, 127.6, 126.1, 125.3, 124.2, 105.1, 34.0, 24.9, 13.4, 8.4 ppm. MS: *m*/*z* (%) = 495 (100), 438 (25), 311 (86), 282 (70), 210 (62), 204 (38), 184 (75), 128 (51), 77 (25). HRMS: calcd. for $C_{22}H_{22}SeTe$ 495.9949; found 495.9954.

Supporting Information (see footnote on the first page of this article) Spectroscopic data for **3a**–**o** and **4**.

Acknowledgments

We are grateful to Conselho Nacional de Desenvolvimento Científico e Tecnológico, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (SAUX) and Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul for a fellowship and financial support.

[1] a) K. Masui, H. Ikegami, A. Mori, *J. Am. Chem. Soc.* **2004**, *126*, 5074–5075; b) G. Zeni, C. W. Nogueira, R. B. Panatieri, D. O. Silva, P. H. Menezes, A. L. Braga, C. C. Silveira, H. A. Stefani, J. B. T. Rocha, *Tetrahedron Lett.* **2001**, *42*, 7921–7923; c) G. Zeni, D. S. Lüdtke, C. W. Nogueira, R. B. Panatieri, A. L. Braga, C. C. Silveira, H. A. Stefani, J. B. T. Rocha, *Tetrahedron Lett.* **2001**, *42*, 8927–8930; d) J. P. Parrish, Y. C. Jung, R. J. Floyd, K. W. Jung, *Tetrahedron Lett.* **2002**, *43*, 7899–7902.

[2] a) K. Sonogashira, Y. Tohda, N. Hagihara, *Tetrahedron Lett.* **1975**, *16*, 4467–4470; b) K. Takahashi, Y. Kuroyama, K. Sonogashira, N. Hagihara, *Synthesis* **1980**, 627–630. For a review, see: c) E. Negishi, L. Anastasia, *Chem. Rev.* **2003**, *103*, 1979–2017; d) K. Sonogashira in *Metal Catalyzed Cross-Coupling Reactions* (Eds.: F. Diederich, P. J. Stang), Wiley-VCH, Weinheim, **1998**.

[3] J. J. Li, G. W. Gribble in *Palladium in Heterocyclic Chemistry*, Tetrahedron Organic Chemistry Series, Pergamon, Amsterdam, **2000**, vol. 2, pp. 3–621.

[4] a) G. Zeni, R. B. Panatieri, E. Lissner, P. H. Menezes, A. L. Braga, H. A. Stefani, *Org. Lett.* **2001**, *3*, 819–821; b) D. Alves, C. W. Nogueira, G. Zeni, *Tetrahedron Lett.* **2005**, *46*, 8761–8764.

[5] J. Lam, H. Breteler, T. Arnason, L. Hansen in *Chemistry and Biology of Naturally-Occurring Acetylenes and Related Compounds*, Elsevier, Amsterdam, **1988**.

[6] a) J. Nakayama, T. Konishi, *Heterocycles* **1988**, *27*, 1731–1754; b) M. Kuroda, J. Nakayama, M. Hoshino, N. Furusho, T. Kawata, S. Ohba, *Tetrahedron* **1993**, *49*, 3735–3748.

[7] a) O. S. R. Barros, A. Favero, C. W. Nogueira, P. H. Menezes, G. Zeni, *Tetrahedron Lett.* **2006**, *47*, 2179–2182; b) P. Prediger, A. V. Moro, C. W. Nogueira, L. Savegnago, J. B. T. Rocha, G. Zeni, *J. Org. Chem.* **2006**, *71*, 3786–3792; c) O. S. R. Barros, C. W. Nogueira, E. C. Stangherlin, P. H. Menezes, G. Zeni, *J. Org. Chem.* **2006**, *71*, 1552–1557; d) G. Zeni, *Tetrahedron Lett.* **2005**, *46*, 2647–2651; e) R. P. Panatieri, J. S. Reis, L. P. Borges, C. W. Nogueira, G. Zeni, *Synlett* **2006**, *18*, 3161–3163.

[8] D. Alves, C. Luchese, C. W. Nogueira, G. Zeni, *J. Org. Chem.* **2007**, *72*, 6726 –6734.

[9] a) G. Zeni, D. S. Ludtke, R. B. Panatieri, A. L. Braga, *Chem. Rev.* **2006**, *106*, 1032–1076; b) N. Petragnani, H. A. Stefani, *Tetrahedron* **2005**, *61*, 1613–1679; c) G. Zeni, A. L. Braga, H. A. Stefani, *Acc. Chem. Res.* **2003**, *36*, 731–738; d) J. V. Comasseto, L. W. Ling, N. Petragnani, H. A. Stefani, *Synthesis* **1997**, 373.

Received: July 28, 2007
Published Online: November 2, 2007

