JOC The Journal of Organic Chemistry

Note

pubs.acs.org/joc

An Iodocyclization Approach to Substituted 3-Iodothiophenes

Bartolo Gabriele,*[,†] Raffaella Mancuso,*[,‡] Giuseppe Salerno,[‡] and Richard C. Larock[§]

[†]Dipartimento di Scienze Farmaceutiche, Università della Calabria, 87036 Arcavacata di Rende (CS), Italy

[‡]Dipartimento di Chimica, Università della Calabria, 87036 Arcavacata di Rende (CS), Italy

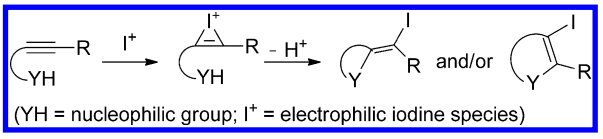
[§]Department of Chemistry, Iowa State University, Ames, Iowa 50011, United States

Supporting Information

ABSTRACT: A novel approach to 3-iodothiophenes by direct iodocyclization of alkynylthiol derivatives is presented. A variety of 1-mercapto-3-yn-2-ols **5** (readily available from alkynylation of the corresponding alpha-mercapto ketones or alpha-mercapto esters) were smoothly converted into the corresponding 3-iodothiophene derivatives **6** in good yields by reaction with molecular iodine in the presence of $NaHCO_3$ at room temperature in MeCN as the solvent.

The iodocyclization of acetylenic substrates bearing a suitably placed nucleophilic group is a powerful synthetic tool for the direct and regioselective synthesis of iodo-substituted carbo- and heterocyclic derivatives (Scheme 1).[1,2] The

Scheme 1. Iodocyclization of Acetylenic Substrates Bearing a Suitably Placed Nucleophilic Group Leading to Iodo-containing Carbo- and Heterocycles

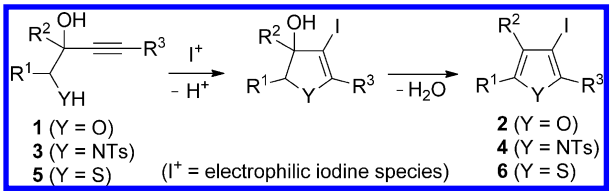


construction of such compounds from simple building blocks under mild conditions, coupled with the presence of the iodo substituent for further functionalization and diversification of the product by a wide variety of cross-coupling reactions, makes such processes particularly attractive in modern organic synthesis.

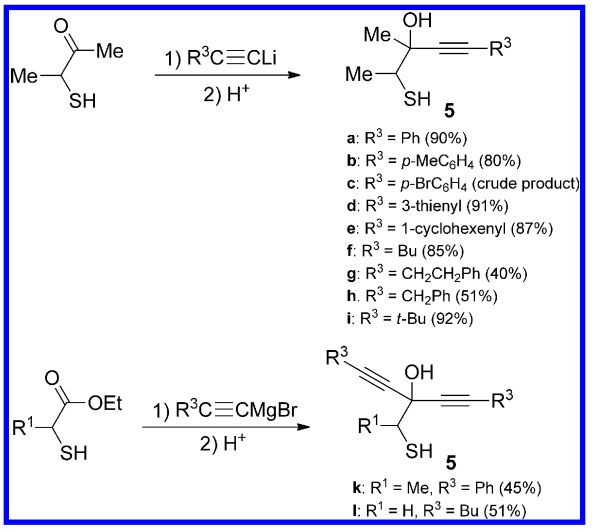
Although many important examples of the formation of oxygen and nitrogen heterocycles by iodocyclization are known (Scheme 1, Y = O or NR), the direct synthesis of iodothiophenes starting from acyclic alkynylthiols has not yet been reported. In particular, the formation of 3-iodofurans **2** and 3-iodopyrroles **4** by the iodocyclization of 3-alkyne-1,2-diols **1**[3] and *N*-tosyl-1-amino-3-alkyn-2-ols **3**,[4] respectively, has recently been published (Scheme 2, Y = O or NTs). However, no analogous iodocyclodehydration of 1-mercapto-3-alkyn-2-ols **5** has been reported so far. We now wish to report such a process (Scheme 2, Y = S), which allows a general and facile synthesis of 3-iodothiophenes **6**[5] under mild conditions starting from readily available substrates.

Starting materials **5a**−**i**, **5k**, and **5l** were prepared by addition of the appropriate alkynyllithium or alkynylmagnesium bromide to commercially available 3-mercaptobutan-2-one, ethyl 2-mercaptopropanoate and ethyl 2-mercaptoacetate, according to Scheme 3. In this way, differently substituted 1-mercapto-3-alkyn-2-ols **5a**−**i** and 1-mercapto-2,2-dialkynyl-2-ols **5k** and **5l** could be easily obtained in fair to excellent yields (40−92%, see

Scheme 2. Formation of 3-Iodofurans (2), 3-Iodopyrroles (4), and 3-Iodothiophenes (6) by the Iodocyclodehydration of 3-Alkyne-1,2-diols (1), *N*-Tosyl-1-amino-3-alkyn-2-ols (3), and 1-Mercapto-3-alkyn-2-ols (5), Respectively



Scheme 3. Synthesis of Starting Materials 5a−i and 5k−l by Alkynylation of 3-Mercaptobutan-2-one, Ethyl 2-mercaptopropanoate and Ethyl 2-mercaptoacetate

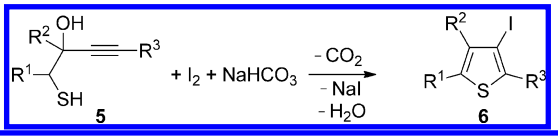


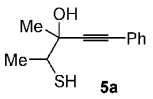
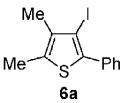
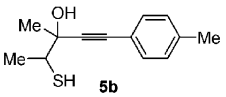
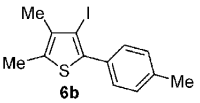
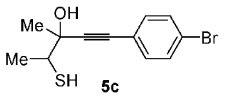
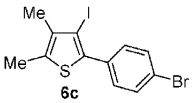
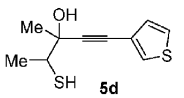
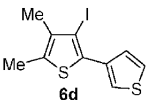
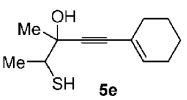
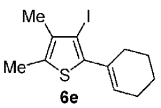
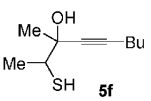
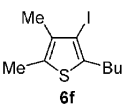
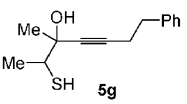
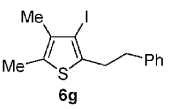
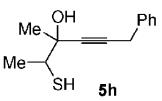
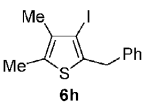
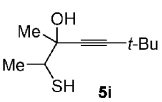
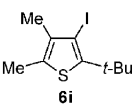
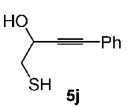
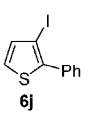
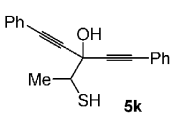
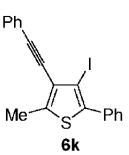
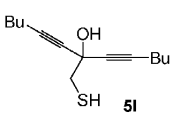
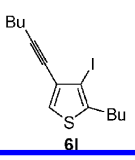
the Experimental Section for details). 1-Mercapto-4-phenylbut-3-yn-2-ol **5j** was prepared as reported in the literature.[6]

Received: May 15, 2012

   dx.doi.org/10.1021/jo301001j | *J. Org. Chem.* XXXX, XXX, XXX−XXX

Table 1. Synthesis of 3-Iodothiophenes 6 by Iodocyclodehydration of 1-Mercapto-3-alkyn-2-ols 5[a]



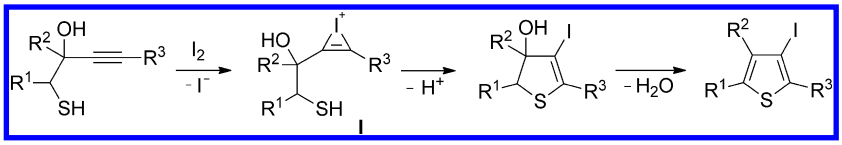
entry	5	6	yield of 6[b] (%)
1	 5a	 6a	71
2	 5b	 6b	83
3	 5c	 6c	65
4	 5d	 6d	65
5	 5e	 6e	71
6	 5f	 6f	67
7	 5g	 6g	70
8	 5h	 6h	68
9	 5i	 6i	65
10	 5j	 6j	82
11[c]	 5k	 6k	88
12[d]	 5l	 6l	85

[a]Unless otherwise noted, all iodocyclization reactions were carried out at 25 °C in MeCN as the solvent (0.05 mmol of starting thiol **5** per mL of MeCN) with a **5**:I_2:$NaHCO_3$ molar ratio of 1:2:2 for 5 h. Conversion of thiol **5** was quantitative in all cases. [b]Isolated yield based on starting thiol **5**. [c]The reaction was carried out with a **5k**:I_2:$NaHCO_3$ molar ratio of 1:3:3. [d]The reaction was carried out with a **5l**:I_2:$NaHCO_3$ molar ratio of 1:2:1.

4-Mercapto-3-methyl-1-phenylpent-1-yn-3-ol (**5a**) was subjected to iodocylization under conditions similar to those already employed for similar substrates,[3,4] involving the use of molecular iodine as the iodinating agent in the presence of $NaHCO_3$ as the

dx.doi.org/10.1021/jo301001j | J. Org. Chem. XXXX, XXX, XXX–XXX

Scheme 4. Proposed Mechanism for the Iodocyclization of 1-Mercapto-3-yn-2-ols 5 to 3-Iodothiophenes 6



base (molar ratio of **5a**:I_2:$NaHCO_3$ = 1:1:1) in MeCN as the solvent (substrate concentration = 0.05 mmol of **5a** per mL of MeCN) at 25 °C. After 5 h reaction time, substrate conversion was complete, and analysis of the reaction mixture revealed the formation of the desired 3-iodo-4,5-dimethyl-2-phenylthiophene (**6a**), which could be isolated in 55% yield (Table S1, entry 1, Supporting Information). After a brief optimization study (see Table S1, Supporting Information), the yield of **6a** could be improved to 71% under conditions similar to those initially employed, but using a **5a**:I_2:$NaHCO_3$ molar ratio of 1:2:2 (Table 1, entry 1).

We next tested the reactivity of other 1,2-dialkyl-substituted 1-mercapto-3-alkyn-2-ols **5b–i**, bearing different substituents on the triple bond (aryl, alkenyl, or alkyl, Table 1, entries 2–9). As can be seen, good yields of the corresponding 3-iodothiophenes **6b–i** have been obtained with all the substrates employed. The reaction also worked nicely when $R^1 = R^2 = H$, as in the case of 1-mercapto-4-phenylbut-3-yn-2-ol **5j**, which was smoothly converted into 3-iodo-2-phenythiophene in 82% yield (Table 1, entry 10). This result shows that the Ingold-Thorpe and reactive rotamer effects[7] are not at work in our reaction. We also tested the reactivity of 1-mercapto-2,2-dialkynyl-2-ols **5k** and **5l** (bearing an additional alkynyl substituent at C-2). With these substrates, better results in terms of product yield were observed by using a molar ratio **5**:I_2:$NaHCO_3$ of 1:3:3 (Table 1, entry 11) or 1:2:1 (Table 1, entry 12) rather than 1:2:2 (Table 1, entries 1–10). Interestingly, the triple bond at C-3 in the corresponding products **6k** and **6l** was not affected (Table 1, entries 11 and 12). Thus, this process allows an easy entry into multifunctionalized thiophenes in one step starting from very simple substrates.

A plausible mechanism for the iodocyclization of 1-mercapto-3-yn-2-ols **5** to 3-iodothiophenes **6** is shown in Scheme 4. According to the previous literature,[1−4] it involves the formation of an iodonium cation **I** as the key intermediate, followed by 5-*endo-dig* cyclization and dehydrative aromatization.

In conclusion, we have reported a novel, general and facile method for the direct synthesis of 3-iodothiophenes by the iodocyclodehydration of 1-mercapto-3-alkyn-2-ols. The reactions are carried out under mild conditions (25 °C) in MeCN as the solvent in the presence of an excess of I_2 as the iodine source and $NaHCO_3$ as the base. The method can be successfully applied to variously substituted substrates, including 1-mercapto-2,2-dialkynyl-2-ols (bearing an additional alkynyl substituent at C-2), which are converted into the corresponding thiophene derivatives without affecting the alkynyl group at C-3.

EXPERIMENTAL SECTION

General Experimental Methods. Melting points are uncorrected. ^{1}H NMR and ^{13}C NMR spectra were recorded at 25 °C in $CDCl_3$ solutions at 300 and 75 MHz, respectively, with Me_4Si as an internal standard. Chemical shifts (δ) and coupling constants (J) are given in ppm and Hz, respectively. IR spectra were taken with an FT-IR spectrometer. Mass spectra were obtained using a GC-MS apparatus at 70 eV ionization voltage. All reactions were analyzed by TLC on silica gel 60 F_{254} or on neutral alumina and by GLC using a gas chromatograph and capillary columns with polymethylsilicone +5% phenylsilicone as the stationary phase. Column chromatography was performed on silica gel 60 (70–230 mesh). Evaporation refers to the removal of solvent under reduced pressure.

Preparation of 1-Mercapto-3-alkyn-2-ols 5a–i. To a cooled (−78 °C), stirred solution of BuLi (1.6 M in hexane) (28 mL, 44.8 mmol) in anhydrous THF (16 mL), maintained under nitrogen, was added dropwise a solution of the 1-alkyne (44.5 mmol) (phenylacetylene, 4.55 g; *p*-methylphenylacetylene, 5.17 g; *p*-bromophenylacetylene, 8.05 g; 3-ethynylthiophene, 4.81 g; 1-ethynylcyclohex-1-ene, 4.72 g; 1-hexyne, 3.66 g; 4-phenyl-1-butyne, 5.79 g; 3-phenyl-1-propyne, 5.17 g; *tert*-butylacetylene, 3.66 g) in anhydrous THF (6 mL). To the resulting mixture was added, at the same temperature under nitrogen, a solution of LiBr (1.56 g, 18 mmol) in anhydrous THF (6 mL). After additional stirring for 0.5 h, was added, at the same temperature under nitrogen, a solution of 3-mercapto-2-butanone (1.77 g, 17.0 mmol) in anhydrous THF (5 mL). The resulting mixture was stirred for an additional 2 h at −78 °C and then allowed to warm up to room temperature. Saturated NH_4Cl (20 mL) and 1 N HCl (10 mL) were added, and the mixture was extracted with Et_2O (3 × 50 mL). The collected organic phases were washed with brine (40 mL) and dried over Na_2SO_4. After filtration and evaporation of the solvent, the crude products were purified by column chromatography using 95:5 hexane–AcOEt as eluent.

Note: 1-(4-Bromophenyl)-4-mercapto-3-methylpent-1-yn-3-ol (**5c**) could not be obtained in a pure state even after repeated purification by column chromatography, so it was used crude for the next iodocyclization step.

*4-Mercapto-3-methyl-1-phenylpent-1-yn-3-ol (**5a**).* Mixture of diastereoisomers A+B, A:B ratio = 2.0, determined by ^{1}H NMR. Yield: 3.16 g, starting from 1.77 g of 3-mercapto-2-butanone (90%). Yellow oil. IR (film): ν = 3448 (s, br), 2567 (vw), 2230 (vw), 756 (s), 692 (s) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.47–7.40 [A (m, 2 H) + B (m, 2 H)], 7.37–7.28 [A (m, 3 H) + B (m, 3 H)], 3.37 [B (s, br, 1 H)], 3.29 [A (quintuplet, J = 6.7, 1 H)], 3.01–2.92 [B (m, 1 H)], 2.82 [A (s, br, 1 H)], 1.96 [A (d, J = 6.7, 1 H)], 1.77 [B (d, J = 10.9, 1 H)], 1.65 [B (s, 3 H)], 1.63 [A (s, 3 H)], 1.56 [B (d, J = 6.9, 3 H)], 1.43 [A (dd, J = 6.7, 0.8, 3 H)]; ^{13}C NMR (75 MHz, $CDCl_3$): δ = 131.74, 131.69, 128.5, 128.3, 122.32, 122.28, 91.4, 89.4, 85.0, 84.4, 72.0, 71.3, 48.5, 46.3, 26.8, 25.5, 22.0, 18.5; GC-MS: diastereomer A: m/z = 206 (0.5) [M$^+$], 145 (100), 43 (72); diastereoisomer B: m/z = 206 (0.6) [M$^+$], 145 (100), 43 (81); anal. calcd for $C_{12}H_{14}OS$ (206.30): C, 69.86; H, 6.84; S, 15.64; found C, 69.71; H, 6.85; S, 15.67

*4-Mercapto-3-methyl-1-p-tolylpent-1-yn-3-ol (**5b**).* Mixture of diastereoisomers A+B, A:B ratio = 1.5, determined by ^{1}H NMR. Yield: 2.99 g, starting from 1.77 g of 3-mercapto-2-butanone (80%). Yellow oil. IR (film): ν = 3434 (m, br), 2566 (vw), 2229 (w), 816 (s) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.36–7.27 [A (m, 2 H), + B (m, 2 H)], 7.13–7.06 [A (m, 2 H) + B (m, 2 H)], 3.43 [B, (s, br, 1 H)], 3.27 [A (quintuplet, J = 6.6, 1 H)], 3.00–2.87 [A (m, 1 H) + B (m, 1 H)], 2.33 [A (s, 3 H) + B (s, 3 H)], 1.96 [A (d, J = 6.6, 1 H)], 1.78 [B (d, J = 10.3, 1 H)], 1.64 [B (s, 3 H)], 1.62 [A (s, 3 H)], 1.53 [B (d, J = 6.6, 3 H)], 1.42 [A (d, J = 6.6, 3 H)]; ^{13}C NMR (75 MHz, $CDCl_3$): δ = 138.6, 131.7, 131.6, 129.0, 119.2, 90.6, 88.7, 85.1, 84.5, 72.0, 71.3, 48.5, 46.3, 26.8, 25.6, 21.9, 21.5, 18.6; GC-MS: diastereomer A: m/z = 220 (M$^+$, <0.5%), 159 (100); diastereomer B: m/z = 220 (M$^+$, <0.5%), 159 (100); anal. calcd for $C_{13}H_{16}OS$ (220.33): C, 70.87; H, 7.32; S, 14.55; found C, 70.95; H, 7.31; S, 14.64.

*4-Mercapto-3-methyl-1-thiophen-3-yl-pent-1-yn-3-ol (**5d**).* Mixture of diastereomers A+B, A:B ratio = 1.6, determined by ^{1}H NMR. Yield: 3.28 g, starting from 1.77 g of 3-mercapto-2-butanone (91%). Yellow oil. IR (film): ν = 3419 (m, br), 2561 (vw), 2231 (w), 783 (s) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.46–7.41 [A (m, 1 H) + B (m, 1 H)], 7.28–7.22 [A (m, 1 H) + B (m, 1 H)], 7.12–7.07 [A (m, 1 H) + B

dx.doi.org/10.1021/jo301001j | J. Org. Chem. XXXX, XXX, XXX–XXX

(m, 1 H)], 3.48−3.38 [B (m, 1 H)], 3.26 [A (quintuplet, J = 6.7, 1 H)], 3.03−2.89 [A (m, 1 H), + B (m, 3 H)], 1.94 [A, (d, J = 6.7, 1 H)], 1.76 [B (d, J = 10.3, 1 H)], 1.63 [B (s, 3 H)], 1.61 [A (s, 3 H)], 1.52 [B (d, J = 6.7, 3 H)], 1.41 [A (d, J = 6.7, 3 H)]; ^{13}CNMR (75 MHz, $CDCl_3$): δ = 129.8, 129.0, 125.4, 121.3, 91.0, 89.1, 80.1, 79.6, 72.0, 71.3, 48.2, 46.1, 26.8, 25.5 21.8, 18.6 ; GC-MS: diastereomer A: m/z = 212 (0.5) [M^+], 151 (62), 43 (100); diastereomer B: m/z = 212 (1) [M^+], 151 (70), 43 (100); anal. calcd for $C_{10}H_{12}OS_2$ (212.33): C, 56.57; H, 5.70; S, 30.20; found C, 56.65; H, 5.68; S, 30.18.

1-Cyclohex-1-enyl-4-mercapto-3-methyl-pent-1-yn-3-ol (**5e**). Mixture of diastereomers A+B, A:B ratio = 2.0, determined by ^{1}H NMR. Yield: 3.11 g, starting from 1.77 g of 3-mercapto-2-butanone (87%). Yellow oil. IR (film): ν = 3434 (m, br), 2570 (vw), 2216 (m), 919 (s) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.16−6.06 [A (m, 1 H) + B (m, 1 H)], 3.30 [B (s, br, 1 H)], 3.19 [A (quintuplet, J = 6.6, 1 H)], 2.95−2.83 [B (m, 1 H)], 2.82 [A (s, br, 1 H)], 2.15−2.03 [A (m, 4 H) + B (m, 4 H)], 1.92 [A (d, J = 6.6, 1 H)], 1.73 [B (d, J = 10.3, 1 H)], 1.68−1.53 [A (m, 4 H) + B (m, 4 H)], 1.61 [B (s, 3 H)], 1.59 [A (s, 3 H)], 1.48 [B (d, J = 7.3, 1 H)], 1.37 [A (d, J = 6.6, 1 H)]; ^{13}C NMR (75 MHz, $CDCl_3$): δ = 135.5, 119.9, 88.6, 86.8, 86.6, 86.2, 71.9, 71.2, 48.5, 46.3, 29.2, 29.1, 26.8 25.63, 25.58, 22.2, 21.9, 21.4, 18.5; GC-MS: diastereomer A: m/z = 210 (<0.5) [M^+], 192 (23), 149 (100), 91 (21); diastereomer B: m/z = 210 (<0.5) [M^+], 149 (100); anal. calcd for $C_{12}H_{18}OS$ (210.34): C, 68.52; H, 8.63; S, 15.25; found C, 68.63; H, 8.61; S, 15.23

2-Mercapto-3-methylnon-4-yn-3-ol (**5f**). Mixture of diastereomers A+B, A:B ratio = 1.4, determined by ^{1}H NMR. Yield: 2.69 g, starting from 1.77 g of 3-mercapto-2-butanone (85%). Yellow oil. IR (film): ν = 3447 (m, br), 2567 (vw), 2240 (vw), 917 (m) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.22 [B (s, br, 1 H)], 3.14 [A (quintuplet, J = 6.9, 1 H)], 2.86 [B (dq, J = 10.5, 6.9, 1 H)], 2.75 [A (s, br, 1 H)], 2.26−2.16 [A (m, 2 H), + B (m, 2 H)], 1.89 [A (d, J = 10.5, 1 H), 1.71 [B (d, J = 6.9, 1 H)], 1.53−1.38 [A (m, 4 H) + B (m, 4 H)], 1.52 [B (s, 3 H)], 1.51 [A (s, 3H)], 1.46 [B (d, J = 6.9, 1 H)], 1.36 [A (d, J = 10.5, 1 H)], 0.92 [B (t, J = 7.3, 3 H)], 0.91 [A (t, J = 7.3, 3 H)]; ^{13}C NMR (75 MHz, $CDCl_3$): δ = 85.6, 85.1, 82.6, 80.6, 71.6, 70.9, 48.4, 46.4, 30.8, 30.7, 27.0, 25.9, 22.0, 21.8, 18.6, 18.3, 13.6; GC-MS: diastereomer A: m/z = 186 (<0.5) [M^+], 125 (95), 43 (100); diastereomer B: m/z = 186 (<0.5) [M^+], 125 (98), 43 (100); anal. calcd for $C_{10}H_{18}OS$ (186.32): C, 64.46; H, 9.74; S, 17.21; found C, 64.53; H, 9.72; S, 17.20.

2-Mercapto-3-methyl-7-phenylhept-4-yn-3-ol (**5g**). Mixture of diastereomers A+B, A:B ratio = 1.5, determined by ^{1}H NMR. Yield: 1.59 g, starting from 1.77 g of 3-mercapto-2-butanone (40%). Yellow oil. IR (film): ν = 3439 (m, br), 2559 (vw), 2237 (w), 698 (m) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.32−7.03 [A (m, 5 H) + B (m, 5 H)], 3.09−2.92 [A (m, 1 H) + B (m, 1 H)], 2.83−2.70 [A (m, 2 H) + B (m, 2 H)], 2.54−2.42 [A (m, 2 H) + B (m, 2 H)], 1.75 [A (d, J = 6.7, 1 H)], 1.52 [B (d, J = 10.3, 1 H)], 1.45 [A (s, 3 H) + B (s, 3 H)], 1.31 [B (d, J = 6.7, 3 H)], 1.26 [A (d, J = 6.7, 3 H)] (*Note: the OH signals were too broad to be detected*); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.3, 128.4, 128.3, 126.3, 84.5, 84.1, 83.4, 81.7, 71.5, 70.9, 48.0, 46.0, 34.8, 26.8, 25.9, 21.4, 20.6, 20.5, 18.7; GC-MS: diastereomer A: m/z = 234 (1) [M^+], 173 (74), 91 (100); diastereomer B: m/z = 234 (1) [M^+], 173 (65), 125 (47), 91 (100); anal. calcd for $C_{14}H_{18}OS$ (234.36): C, 71.75; H, 7.74; S, 13.68; found C, 71.82; H, 7.72; S, 13.67.

2-Mercapto-3-methyl-6-phenyl-hex-4-yn-3-ol (**5h**). Mixture of diastereomers A+B, A:B ratio = 2.0, determined by ^{1}H NMR. Yield: 1.91 g, starting from 1.77 g of 3-mercapto-2-butanone (51%). Yellow oil. IR (film): ν = 3432 (s, br), 2567 (vw), 2243 (w), 697 (m) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.34−7.18 [A (m, 5 H) + B (m, 5 H)], 3.63 [B (s, 2 H)], 3.62 [B (s, 2 H)], 3.16 [A (quintuplet, J = 6.7, 1 H)], 2.94−2.79 [B (m, 1 H)], 1.86 [A (d, J = 6.7, 1 H)], 1.70 [B (d, J = 10.3, 1 H)], 1.56 [B (s, 3 H)], 1.54 [A (s, 3 H)], 1.46 [B (d, J = 6.7, 3 H)], 1.37 [A (d, J = 6.7, 3 H)] (*Note: the OH signals were too broad to be detected*); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 136.5, 136.4, 128.51, 127.84, 127.77, 126.6, 84.8, 83.1, 83.0, 82.5, 71.7, 71.0, 48.2, 46.2, 27.0, 25.8, 24.9, 21.7, 18.7; GC-MS: diastereomer A: m/z = 220 (1) [M^+], 159 (100), 115 (57); diastereomer B: m/z = 220 (2) [M^+], 202 (26), 187 (34), 159 (100), 116 (29), 115 (69); anal. calcd for $C_{13}H_{16}OS$ (220.33): C, 70.87; H, 7.32; S, 14.55; found C, 70.93; H, 7.31; S, 14.54.

2-Mercapto-3,6,6-trimethyl-hept-4-yn-3-ol (**5i**). Mixture of diastereomers A+B, A:B ratio = 1.1, determined by ^{1}H NMR. Yield: 2.91 g, starting from 1.77 g of 3-mercapto-2-butanone (92%). Yellow oil. IR (film): ν = 3436 (m, br), 2570 (vw), 2220 (w), 915 (m), cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.23 [B (s, br, 1 H)], 3.20−3.07 [A (m, 1 H)], 2.91−2.79 [B (m, 1 H)], 2.72 [A (s, br, 1 H)], 1.89 [A (d, J = 6.6, 1 H)], 1.68 [B (d, J = 10.6, 1 H)], 1.51 [B (s, 3 H), 1.50 [A (s, 3 H)], 1.46 [B (d, J = 6.6, 3 H)], 1.36 [A (d, J = 6.6, 3 H)], 1.24 [B (s, 9 H)], 1.22 [A (s, 9 H)]; ^{13}C NMR (75 MHz, $CDCl_3$): δ = 93.8, 93.2, 80.9, 78.9, 73.6, 70.7, 48.6, 46.5, 30.9, 26.9, 25.7, 23.2, 22.0, 20.5, 18.5; GC-MS: diastereomer A: m/z = 186 (absent) [M^+], 125 (40), 43 (100); diastereomer B: m/z = 186 (absent) [M^+], 125 (38), 43 (100); anal. calcd for $C_{10}H_{18}OS$ (186.32): C, 64.46; H, 9.74; S, 17.21; found C, 64.52; H, 9.72; S, 17.19.

Preparation of 1-Mercapto-2,2-dialkynyl-2-ols 5k and 5l. To a suspension of Mg turnings (0.6 g, 24.7 mmol) in anhydrous THF (5 mL), maintained under nitrogen at reflux, was added pure ethyl bromide (0.8 mL) to start formation of the Grignard reagent. The remaining bromide was added dropwise in THF solution (2.0 mL of EtBr in 5 mL of THF; total amount of EtBr added: 4.09 g, 37.5 mmol). The mixture was then allowed to reflux for an additional 20 min. After cooling, the resulting solution of EtMgBr was transferred under nitrogen to a dropping funnel and added dropwise under nitrogen to a solution of the 1-alkyne (39.8 mmol) (phenylacetylene, 4.06 g; 1-hexyne, 3.27 g) in anhydrous THF (10 mL) at 0 °C with stirring. After additional stirring at 0 °C for 15 min, the mixture was allowed to warm up to room temperature, and then was heated at 45 °C and stirred for 2 h. To the hot solution of the 1-alkynylmagnesium bromide thus obtained, was added, dropwise and under nitrogen, a solution of ethyl 2-mercaptopropanoate (1.33 g, 9.94 mmol) or ethyl 2-mercaptoacetate (1.20 g, 9.94 mmol) in anhydrous THF (5 mL). The resulting mixture was allowed to stir at 45 °C for 2 h. After cooling to room temperature, saturated aqueous NH_4Cl (50 mL) and Et_2O (50 mL) were sequentially added, the phases were separated, and the aqueous phase was extracted with Et_2O (3 × 50 mL). The collected organic layers were washed with brine and dried over Na_2SO_4. After filtration and evaporation of the solvent, products **5k** and **5l** were purified by column chromatography on silica gel using 95:5 hexane−AcOEt as the eluent.

3-(1-Mercapto-ethyl)-1,5-diphenyl-penta-1,4-diyn-3-ol (**5k**). Yield: 1.31 g, starting from 1.33 g of ethyl 2-mercaptopropanoate (45%). Yellow oil. IR (film): ν = 3436 (s, br), 2574 (vw), 2227 (m), 755 (s) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.67−7.01 (m, 10 H), 3.46−3.34 (m, 1 H), 1.97 (d, J = 9.1, 1 H), 1.68 (d, J = 4.9, 3 H) (*Note: the OH signal was too broad to be detected*); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 132.0, 131.9, 128.93, 128.90, 128.30, 128.26, 125.5, 121.8, 87.3, 86.3, 85.3, 84.8, 65.8, 47.7, 20.5; GC-MS: m/z = 292 (absent) [M^+], 274 (100), 273 (28); anal. calcd for $C_{19}H_{16}OS$ (292.40): C, 78.05; H, 5.52; S, 10.97; found C, 78.12; H, 5.50; S, 10.95.

7-Mercaptomethyl-trideca-5,8-diyn-7-ol (**5l**). Yield: 1.21 g, starting from 1.20 g of ethyl 2-mercaptoacetate (51%). Yellow oil. IR (film): ν = 3426 (m, br), 2567 (vw), 2231 (m), 729 (m) cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ = 3.08 (s, br, 1 H), 2.96 (d, J = 8.8, 2 H), 2.25 (t, J = 7.0, 4 H), 1.78 (t, J = 8.8, 1 H), 1.58−1.33 (m, 8 H), 0.91 (t, J = 7.3, 6 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 85.2, 79.4, 63.7, 39.5, 30.4, 22.0, 18.4, 13.6.; GC-MS: m/z = 238 (absent) [M^+], 220 (24), 191 (100), 177 (54), 91 (34), 79 (30); anal. calcd for $C_{14}H_{22}OS$ (238.39): C, 70.54; H, 9.30; S, 13.45; found C, 70.63; H, 9.28; S, 13.43.

General Procedure for the Iodocyclization of 1-Mercapto-3-alkyn-2-ols 5a−j and 1-Mercapto-2,2-dialkynyl-2-ols 5k and 5l to Iodothiophenes 6a−l. To a solution of **5** (0.3 mmol) (**5a**, 62 mg; **5b**, 66 mg; **5c**, 86 mg; **5d**, 64 mg; **5e**, 63 mg; **5f**, 56 mg; **5g**, 70 mg; **5h**, 66 mg, **5i**, 56 mg; **5j**, 53 mg; **5k**, 88 mg; **5l**, 72 mg) in MeCN (6 mL) were added $NaHCO_3$ (25 mg or 50 or 75 mg, 0.3 or 0.6 or 0.9 mmol, see Table 1) and I_2 (152 or 228 mg, 0.6 or 0.9 mmol, see Table 1) in this order under nitrogen. The mixture was allowed to stir at 25 °C for 5 h. Saturated aqueous $Na_2S_2O_3$ was then added, and the mixture was allowed to stir for 10 min. The phases were separated, and the aqueous phase was extracted with Et_2O (3 × 10 mL). The collected organic layers were dried over Na_2SO_4. After filtration and evaporation of the solvent, products **6a−l** were purified by column chromatography on silica gel using 99:1 hexane−AcOEt as the eluent.

dx.doi.org/10.1021/jo301001j | *J. Org. Chem.* XXXX, XXX, XXX−XXX

*3-Iodo-4,5-dimethyl-2-phenylthiophene (**6a**).* Yield: 67 mg, starting from 62 mg of **5a** (71%) (Table 1, entry 1). Yellow oil. IR (film): ν = 1598 (m), 1501 (m), 1441 (m), 1167 (m), 1012 (m), 749 (s), 695 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.56−7.47 (m, 2 H), 7.43−7.28 (m, 3 H), 2.42 (s, 3 H), 2.21 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 137.6, 136.1, 132.4, 131.4, 129.5, 128.2, 127.9, 86.0, 17.3, 14.2; GC-MS: m/z = 314 (100) [M^+], 187 (36); anal. calcd for $C_{12}H_{11}IS$ (314.19): C, 45.87; H, 3.53; S, 10.21; found C, 45.95; H, 3.51; S, 10.23.

*3-Iodo-4,5-dimethyl-2-p-tolylthiophene (**6b**).* Yield: 82 mg, starting from 66 mg of **5b** (83%) (Table 1, entry 2). Yellow solid, mp = 54−55 °C. IR (KBr): ν = 1519 (m), 1436 (m), 1164 (m), 1025 (m), 947 (m), 814 (s), 796 (s), 767 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.47−7.39 (m, 2 H), 7.24−7.16 (m, 2 H), 2.43 (s, 3 H), 2.37 (s, 3 H), 2.21 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 137.8, 137.7, 135.9, 132.3, 131.3, 129.4, 129.0, 85.8, 21.3, 17.3, 14.2; GC-MS: m/z = 328 (100) [M^+], 201 (26), 115 (24); anal. calcd for $C_{13}H_{13}IS$ (328.21): C, 47.57; H, 3.99; S, 9.77; found C, 47.65; H, 4.01; S, 9.75

*2-(4-Bromophenyl)-3-iodo-4,5-dimethylthiophene (**6c**).* Yield: 77 mg, starting from 86 mg of crude **5c** (65%) (Table 1, entry 3). White solid, mp = 104−105 °C. IR (KBr): ν = 1500 (m), 1384 (m), 1072 (s), 1009 (s), 826 (s), 782 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.56−7.47 (m, 2 H), 7.45−7.36 (m, 2 H), 2.44 (s, 3 H), 2.21 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 136.4, 136.2, 134.1, 132.8, 131.5, 131.1, 122.2, 86.4, 17.3, 14.2; GC-MS: m/z = 394 (100) [$(M+2)^+$], 392 (98) [M^+], 185 (23); anal. calcd for $C_{12}H_{10}BrIS$ (393.08): C, 36.67; H, 2.56; Br, 20.33; S, 8.16; found C, 36.75; H, 2.54; Br, 20.31; S, 8.14.

*3-(3-Iodo-4,5-dimethylthiopheny-2-yl)thiophene (**6d**).* Yield: 62 mg, starting from 64 mg of **5d** (65%) (Table 1, entry 4). Yellow oil. IR (film): ν = 1529 (m), 1438 (s), 1398 (m), 1158 (m), 848 (m), 775 (m), 746 (m) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.63−7.56 (m, 1 H), 7.39−7.31 (m, 2 H), 2.42 (s, 3 H), 2.20 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 136.2, 135.1, 132.7, 131.6, 128.2, 125.3, 123.2, 85.6, 17.2, 14.1; GC-MS: m/z = 320 (100) [M^+], 160 (12); anal. calcd for $C_{10}H_9IS_2$ (320.21): C, 37.51; H, 2.83; S, 20.03; found C, 37.60; H, 2.81; S, 20.01.

*2-Cyclohex-1-enyl-3-iodo-4,5-dimethylthiophene (**6e**).* Yield: 68 mg, starting from 63 mg of **5e** (71%) (Table 1, entry 5). Yellow solid, mp = 25−26 °C. IR (KBr): ν = 1435 (s), 758 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 6.02−5.95 (m, 1 H), 2.38−2.31 (m, 2 H), 2.36 (s, 3 H), 2.21−2.12 (m, 2 H), 2.14 (s, 3 H), 1.80−1.59 (m, 4 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.4, 135.1, 132.3, 130.2, 130.1, 84.2, 30.0, 25.5, 22.9, 21.8, 17.0, 14.1; GC-MS: m/z = 318 (100) [M^+], 163 (64), 148 (25), 79 (47); anal. calcd for $C_{12}H_{15}IS$ (318.22): C, 45.29; H, 4.75; S, 10.08; found C, 45.33; H, 4.76; S, 10.12.

*2-Butyl-3-iodo-4,5-dimethylthiophene (**6f**).* Yield: 59 mg, starting from 56 mg of **5f** (67%) (Table 1, entry 6). Yellow solid, mp = 115−117 °C. IR (KBr): ν = 1456 (s), 1375 (m) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 2.73 (t, J = 7.7, 2 H), 2.37 (s, 3 H), 2.12 (s, 3 H), 1.68−1.52 (m, 2 H), 1.50−1.33 (m, 2 H), 0.94 (t, J = 7.3, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 139.0, 134.4, 129.5, 86.8, 32.9, 32.3, 22.2, 16.8, 14.1, 13.9; GC-MS: m/z = 294 (32) [M^+], 251 (100), 125 (33); anal. calcd for $C_{10}H_{15}IS$ (294.20): C, 40.83; H, 5.14; S, 10.90; found C, 40.81; H, 5.15; S, 10.89.

*3-Iodo-4,5-dimethyl-2-phenethylthiophene (**6g**).* Yield: 72 mg, starting from 70 mg of **5g** (70%) (Table 1, entry 7). Yellow oil. IR (film): ν = 1603 (m), 1495 (m), 1453 (s), 1164 (m), 749 (s), 698 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.35−6.95 (m, 5 H, Ph), 3.07−2.82 (m, 4 H, CH_2CH_2Ph), 2.36 (s, 3 H, Me), 2.13 (s, 3 H, Me); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.9, 137.6, 131.0, 130.0, 128.5, 128.4, 126.2, 87.2, 36.9, 34.6, 16.7, 14.1; GC-MS: m/z = 342 (19) [M^+], 251 (100); anal. calcd for $C_{14}H_{15}IS$ (342.24): C, 49.13; H, 4.42; S, 9.37; found C, 49.20; H, 4.41; S, 9.35.

*2-Benzyl-3-iodo-4,5-dimethylthiophene (**6h**).* Yield: 67 mg, starting from 66 mg of **5h** (68%). (Table 1, entry 8). Yellow oil. IR (film): ν = 1494 (m), 1452 (s), 1432 (m), 1073 (m), 1029 (m), 763 (m), 697 (s), cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.35−7.05 (m, 5 H), 4.00 (s, 2 H), 2.26 (s, 3 H), 2.06 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 139.2, 137.5, 134.5, 130.7, 128.5, 128.3, 126.4, 87.6, 38.4, 16.6, 13.9; GC-MS: m/z = 328 (100) [M^+], 201 (58), 186 (26); anal. calcd for $C_{13}H_{13}IS$ (328.21): C, 47.57; H, 3.99; S, 9.77; found C, 47.62; H, 3.98; S, 9.80.

*2-tert-Butyl-3-iodo-4,5-dimethylthiophene (**6i**).* Yield: 57 mg, starting from 56 mg of **5i** (65%) (Table 1, entry 9). Yellow solid, mp = 114−115 °C. IR (KBr): ν = 1463 (m), 1363 (m), 1214 (m), 1168 (m), 760 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 2.36 (s, 3 H), 2.14 (s, 3 H), 1.50 (s, 9 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 146.0, 136.5, 127.6, 81.4, 35.1, 30.1, 17.5, 14.0; GC-MS: m/z = 294 (36) [M^+], 279 (100), 152 (22); anal. calcd for $C_{10}H_{15}IS$ (294.20): C, 40.83; H, 5.14; S, 10.90; found C, 40.86; H, 5.15; S, 10.88.

*3-Iodo-4,5-dimethyl-2-phenylthiophene (**6j**).* Yield: 70 mg, starting from 53 mg of **5j** (82%) (Table 1, entry 10). Yellow oil. IR (film): ν = 1597 (w), 1482 (m), 1443 (m), 1137 (w) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.63−7.56 (m, 2 H), 7.46−7.36 (m, 3 H), 7.27 (distorted d, J = 5.3, 1 H), 7.13 (distorted d, J = 5.3, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.4, 136.6, 134.3, 129.5, 128.42, 128.37, 126.7, 78.1; GC-MS: m/z = 286 (76) [M^+], 159 (17), 115 (100); anal. calcd for $C_{10}H_7IS$ (286.13): C, 41.98; H, 2.47; S, 11.21; found C, 42.04; H, 2.46; S, 11.23.

*3-Iodo-5-methyl-2-phenyl-4-phenylethynylthiophene (**6k**).* Yield: 106 mg, starting from 88 mg of **5k** (88%) (Table 1, entry 11). Yellow solid, mp = 80−81 °C. IR (KBr): ν = 2213 (vw), 1442 (m), 1215 (m), 1169 (m), 1070 (m), 755 (s), 690 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.66−7.50 (m, 4 H), 7.45−7.25 (m, 6 H), 2.65 (s, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.0, 138.8, 136.4, 134.3, 131.5, 129.5, 129.4, 128.42, 128.39, 128.34, 127.0, 123.2, 94.4, 85.2, 84.2, 15.4; GC-MS: m/z = 400 (100) [M^+], 271 (20), 239 (17), 213 (17); anal. calcd for $C_{19}H_{13}IS$ (400.28): C, 57.01; H, 3.27; S, 8.01; found C, 57.12; H, 3.26; S, 8.09.

*2-Butyl-4-hex-1-ynyl-3-iodo-thiophene (**6l**).* Yield: 88 mg, starting from 72 mg of **5l** (85%) (Table 1, entry 12). White solid, mp = 32−34 °C. IR (KBr): ν = 2228 (vw), 1465 (s), 1332 (m), 741 (s) cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ = 7.26 (s, 1 H), 2.77 (t, J = 7.9, 2 H), 2.44 (t, J = 6.7, 2 H), 1.71−1.33 (m, 8 H), 0.95 (t, J = 7.3, 3 H), 0.94 (t, J = 7.3, 3 H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.8, 128.5, 124.8, 92.6, 86.6, 76.7, 32.6, 30.7, 22.1, 22.0, 19.1, 13.8, 13.6; GC-MS: m/z = 346 (44) [M^+], 303 (100), 177 (40), 147 (20), 134 (20); anal. calcd for $C_{14}H_{19}IS$ (346.27): C, 48.56; H, 5.53; S, 9.26; found C, 48.61; H, 5.52; S, 9.25.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Table S1 and copies of ^1H and ^{13}C NMR spectra for all products. This material is available free of charge via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Author

*b.gabriele@unical.it; raffaella.mancuso@unical.it

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

Financial support from the Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR, Rome, Italy) is gratefully acknowledged (Progetto di Ricerca d'Interesse Nazionale PRIN 2008A7P7YJ). Thanks are due to the European Commission, FSE (Fondo Sociale Europeo) and Calabria Region for a fellowship grant to R.M.

■ REFERENCES

(1) (a) Larock, R. C. In *Acetylene Chemistry. Chemistry, Biology, and Material Science*; Diederich, F., Stang, P. J., Tykwinski, R. R., Eds.; Wiley-VCH: New York, 2005; Chapter 2, pp 51−99. (b) Banerjee, A. K.; Laya, M. S.; Cabrera, E. V. *Curr. Org. Chem.* **2011**, *15*, 1058−1080. (c) Godoi, B.; Schumacher, R. F.; Zeni, G. *Chem. Rev.* **2011**, *111*, 2937−2980.

(2) For a very recent review, see: (a) Parvatkar, P. T.; Parameswaran, P. S. *Chem.—Eur. J.* **2012**, 5460−5489. For selected recent examples, see: (b) Cho, C.-H.; Jung, D.-I.; Neuenswander, B.; Larock, R. C. *ACS Comb. Sci.* **2011**, *13*, 501−510. (c) Yang, F.; Jin, T.; Bao, M.; Yamamoto, Y. *Tetrahedron* **2011**, *67*, 10147−10155. (d) Majumdar, K. C.; Ghosh, T.;

Shyam Pranab, K. *Synlett* **2011**, 2657−2662. (e) Zhang, X.; Zhou, Y.; Wang, H.; Guo, D.; Ye, D.; Xu, Y.; Jiang, H.; Liu, H. *Adv. Synth. Catal.* **2011**, *353*, 1429−1437. (f) Okitsu, T.; Sato, K.; Potewar, T. M.; Wada, A. J. *Org. Chem.* **2011**, *76*, 3438−3449. (g) Chen, Z.; Huang, G.; Jiang, H.; Huang, H.; Pan, X. J. *Org. Chem.* **2011**, *76*, 1134−1139. (h) Yang, F.; Jin, T.; Bao, M.; Yamamoto, Y. *Chem. Commun.* **2011**, *47*, 4541−4543. (i) Raffa, G.; Belot, S.; Balme, G.; Monteiro, N. *Org. Biomol. Chem.* **2011**, *9*, 1474−1478. (j) Schumacher, R. F.; Rosario, A. R.; Souza, A. C. G.; Menezes, P. H.; Zeni, G. *Org. Lett.* **2010**, *12*, 1952−1955. (k) Stein, A. L.; da Rocha, J.; Menezes, P. H.; Zeni, G. *Eur. J. Org. Chem.* **2010**, 705−710. (l) Mancuso, R.; Mehta, S.; Gabriele, B.; Salerno, G.; Jenks, W. S.; Larock, R. C. *J. Org. Chem.* **2010**, *75*, 897−901.

(3) (a) Bew, S. P.; El-Taeb, G. M. M.; Jones, S.; Knight, D. W.; Tan, W.-F. *Eur. J. Org. Chem.* **2007**, *34*, 5759−5770. (b) Wen, S.-g.; Liu, W.-m.; Liang, Y.-m. *Synthesis* **2007**, 3295−3300. (c) El-Taeb, G. M. M.; Evans, A. B.; Jones, S.; Knight, D. W. *Tetrahedron Lett.* **2001**, *42*, 5945−5948. (d) Bew, S. P.; Knight, D. W. *Chem. Commun.* **1996**, 1007−1008.

(4) Knight, D. W.; Rost, H. C.; Sharland, C. M.; Singkhonrat, J. *Tetrahedron Lett.* **2007**, *48*, 7906−7910.

(5) 3-Iodothiophenes are usually prepared by iodination of the thiophene ring or starting from the corresponding 3-bromothiophenes or 3-aminothiophenes. For selected recent examples, see: (a) Adak, L.; Yoshikai, N. *J. Org. Chem.* **2011**, *76*, 7563−7568. (b) Malamas, M. S.; Erdei, J.; Gunawan, I.; Robichaud, A.; Zhou, P.; Yan, Y.; Solvibile, W.; Turner, J.; Fan, K. Y.; Chopra, R.; Bard, J.; Pangalos, M. N.; Barnes, K.; Hui, Y.; Johnson, M. *Bioorg. Med. Chem. Lett.* **2011**, *18*, 5164−5170. (c) Raster, P.; Weiss, S.; Koenig, B.; Hilt, G. *Synthesis* **2011**, 905−908. (d) Cuesta, L.; Maluenda, I.; Navarro, R.; Urriolabeitia, E. P.; Soler, T. *Inorg. Chem.* **2011**, *50*, 37−45. (e) Huang, Q.; Richardson, P. F.; Sach, N. W.; Zhu, J.; Liu, K. K.-C.; Smith, G. L.; Bowles, D. M. *Org. Process Res. Dev.* **2011**, *15*, 556−564.

(6) Aponick, A.; Li, C.-Y.; Malinge, J.; Marques, E. F. *Org. Lett.* **2009**, *11*, 4624−4627.

(7) (a) Sammes, P. G.; Weller, D. J. *Synthesis* **1995**, 1205−1222. (b) Jung, M. J.; Piizzi, G. *Chem. Rev.* **2005**, *105*, 1735−1766.