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Elimination of β-Thioalkoxy Alcohols under Mitsunobu Conditions. A New Synthesis of Conjugated Enynes from Propargylic Dithioacetals

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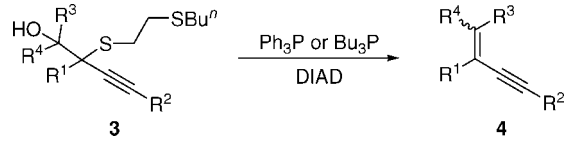

Treatment of propargylic dithiolanes **1** with ^{n}BuLi followed by a carbonyl electrophile yields the corresponding homopropargylic alcohol **3**. Upon treatment with 2 equiv of PPh_3 and DIAD, elimination of SR and OH moieties from **3** affords the corresponding olefins **4** in moderate to good yield. The reaction can be considered an alternative of McMurry coupling of two different carbonyl equivalents.

Introduction

Carbon−carbon double bond formation by means of elimination of β-heteroatom substituted alcohols is well-documented.[1−6] The starting material can be easily accessible from a heteroatom-stabilized carbanion and a carbonyl electrophile. We recently reported that aryl- or alkynyl-substituted β-hydroxythioethers **3**, obtained from the reaction of dithioacetals **1** with BuLi and then with an aldehyde **2**, can readily undergo low-valent iron-promoted elimination reaction leading to the stereoselective synthesis of olefins **4** (eq 1).[7,8] The net reaction can be considered as an alternative of McMurry coupling of two different carbonyl equivalents. It is known that oxiranes,[9] aziridines,[10] as well as thiiranes[11] are obtained selectively from the corresponding β-heteroatom-substituted alcohols. In addition, the sulfur moiety of an episulfonium ion can be extruded in the presence of a nucleophile (e.g., Bu_3P or Et_3N) to give alkenes (eq 2).[12] It is envisaged that the hydroxyl group in **3** may be converted into a suitable leaving group so that intramolecular displacement may occur to generate in situ an episulfonium ion **5**. A similar extrusion process may lead to the corresponding alkenes. In this paper, we report an unprecedented protocol for the elimination of β-hydroxythioethers under Mitsunobu condi-

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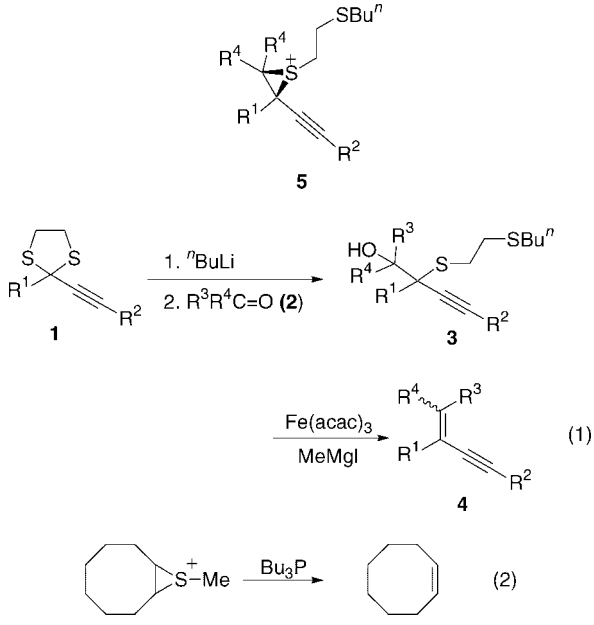
TABLE 1. Elimination of β-Thioalkoxy Alcohols under Mitsunobu Conditions

entry	substrate **1**	R^1	R^2	R^3	R^4	PR_3	yield of **3** (dr)[a]	yield of **4** (*E*/*Z*)
1	**1a**	^{i}Pr	Bu	Ph	H	PPh_3	**a** 74 (2.3/1)	**a** 81 (2.9/1)[b]
2				Bu	H	PPh_3	**b** 54[c]	**b** 43 (10/1)
3						PBu_3		**b** 61 (24/1)
4				Mes	H	PPh_3	**c** 72 (1.1/1)	**c** 65 (1/20)
5				1-Naphthyl	H	PPh_3	**d** 87 (6.0/1)	**d** 72 (1/3.9)
6				*p*-C_6H_4OMe	H	PPh_3	**e** 56 (6.4/1)	**e** 91 (5.0/1)
7				*p*-C_6H_4Br	H	PPh_3	**f** 51 (5.4/1)	**f** 68 (1.7/1)
8	**1b**	^{i}Pr	TMS	Ph	H	PPh_3	**g** 72 (4.6/1)	**g** 78 (3.2/1)
9	**1c**	Bu	TMS	Ph	H	PPh_3	**h** 78 (5.3/1)	**h** 72 (14/1)[d]
10						PBu_3		**h** 72 (6.5/1)
11				Bu	H	PPh_3	**i** 35 (1.3/1)	**i** 48 (1/1.2)
12						PBu_3		**i** 69 (1/1.5)
13				*p*-$C_6H_4CF_3$	H	PPh_3	**j** 80 (3.6/1)	**j** 48 (3.3/1)
14						PBu_3		**j** 81 (3.3/1)
15				*p*-C_6H_4CN	H	PPh_3	**k** 83 (1.6/1)	**k** 39 (1.4/1)
16						PBu_3		**k** 89 (2.0/1)
17				*o*-tol	H	PPh_3	**l** 67 (1.7/1)	**l** 76 (2.1/1)
18	**1d**	Bu	Bu	*p*-$C_6H_4CO_2Bu^t$	H	PPh_3	**m** 37 (1.7/1)	**m** 62 (1.6/1)
19				Me	Me	PBu_3	**n** 53	**n** 17
20				Ph	Ph	PBu_3	**o** 78	**o** 28
21								**o** 44[e]
22								**o** 45[f]

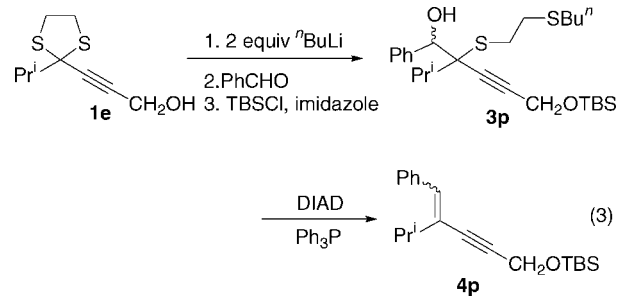
[a] Diastereomeric ratio (major isomer/minor isomer) was determined by ^{1}H NMR integrals. [b] When 1 equiv of Mitsunobu reagent was used, the yield was 63%. [c] dr cannot be resolved by ^{1}H NMR. [d] Identical results were obtained when the reaction was carried out from −78 to −30 °C. [e] Reaction time = 48 h. [f] 4 equiv each of DIAD and Bu_3P were used.

tions for the olefination of propargylic dithioacetals with a carbonyl compound.



Results and Discussion

The starting **3** were obtained from the reaction of **1** with ^{n}BuLi followed by treatment with **2** according to literature procedures.[7] In the beginning of this study, several Lewis acids ($BF_3 \cdot OEt_2$, BBr_3, and $TiCl_4$) were employed to react with **3c**, only starting material being recovered in 63−85% yields. Interestingly, when **3** was allowed to react with 2 equiv each of DIAD and Ph_3P in THF at rt for 18 h under Mitsunobu conditions,[13,14] alkene **4** was obtained in moderated to good yield. Representative examples are summarized in Table 1. The stereochemical assignments for **4** were based on NOE experiments. Mitsunobu reaction of **3p** obtained from **1e** [(1). BuLi, (2) PhCHO, (3) TBSCl, imidizole] under the same conditions gave the corresponding enyne **4p** (*E*/*Z* = 1.6/1) in 38% yield (eq 3).



Interestingly, the yield of **4** was significantly improved when Ph_3P was replaced by Bu_3P (entries 3, 12, 14, and 16). Tertiary alcohols are normally quite unreactive under typical Mitsunobu conditions.[15] Indeed, when **3n** was allowed to react with DIAD and Ph_3P at rt, no reaction was observed. However, alkenes **4n** and **4o** were isolated in low yield from the corresponding **3n** and **3o** when Bu_3P was employed (entries 19−22), starting materials being recovered in 40−80% yield. It is noteworthy that longer reaction time (entry 21) or excess of Mitsunobu reagent (entry 22) gave better yield of the reaction.

The reaction can also be carried out in one pot from **1**. Thus, reaction of **1a** with BuLi and then with benzaldehyde gave the corresponding alkoxide, which was directly treated with 2 equiv each of DIAD and Ph_3P to give **4a** (*E*/*Z* = 4.5/1) in 34% yield.

(14) α-Hydroxyalkyldithiolanes have been known to be converted into 2-azido-1,4-dithianes under Mitsunobu conditions in the presence of sodium azide. 1,2-Sulfur migration has been suggested. The corresponding 2,3-dihydro-1,4- dithiins are isolated as side products. See: Afonso, C. A. M.; Barros, M. T.; Maycock, C. D. *Tetrahedron* **1999**, *55*, 801.

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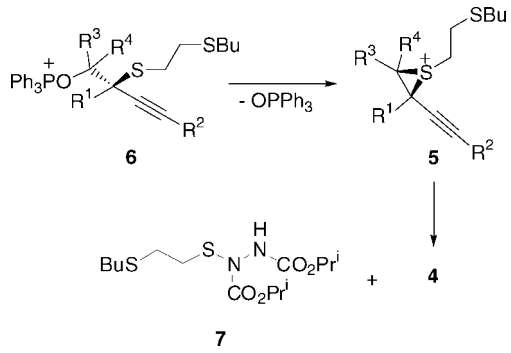
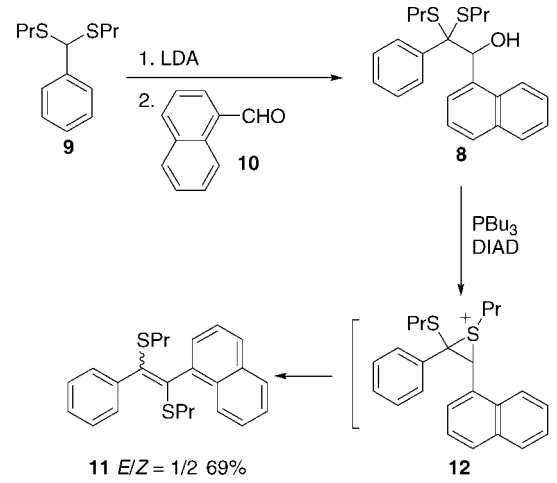
SCHEME 1. Possible Mechanism for the Formation of 4

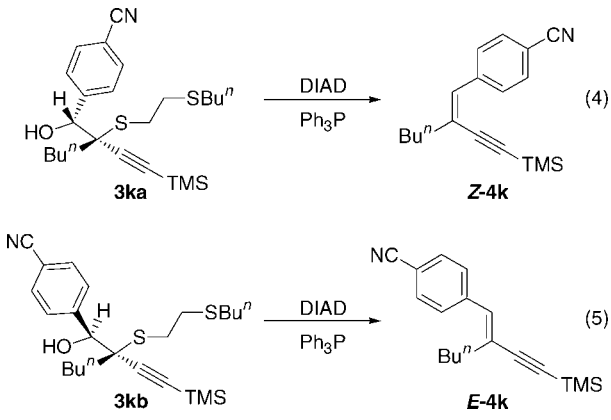


SCHEME 2. Evidence for Thio Migration



It is worthy to mention that the stereoselectivities of the elimination reaction under Mitsunobu conditions were very different from those of the low-valent iron-promoted reactions.[7] Apparently, the two processes may proceed via very different mechanisms. In addition, the stereoselectivity appeared to be temperature independent (entry 9). It seems plausible that the hydroxyl group in **3** would be activated by R_3P to generate intermediate **6**. The phosphine oxide may serve as a leaving group with the concomitant participation of the neighboring sulfur moiety leading to the formation of episulfonium ion **5** (Scheme 1). Stereoselective extrusion of the sulfur moiety[16] may lead to the corresponding olefin stereospecifically. The fate of the sulfur moiety was assigned to be **7** as detected by the high-resolution mass spectrometry.[16] Presumably, the episulfonium ion may be attached by the amidic anion leading to **4** and **7**. These results support the earlier mechanism proposed by Smit et al.[12a]

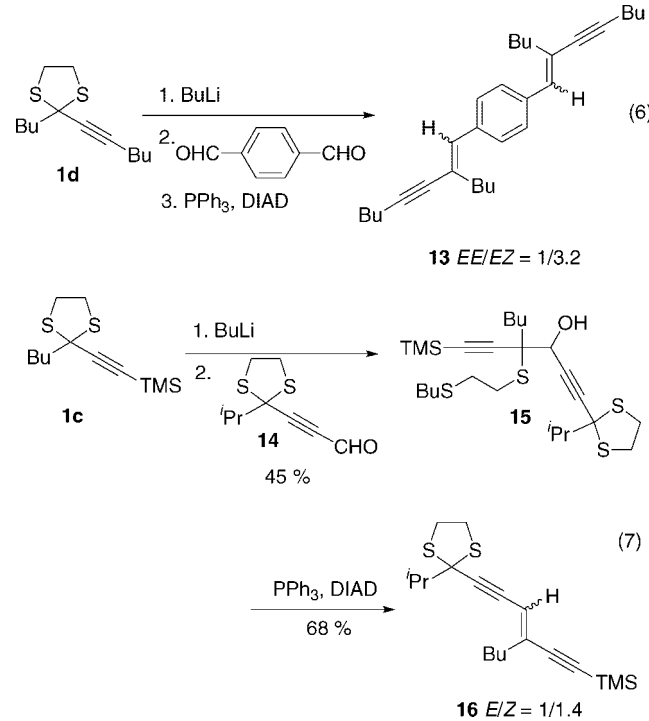
The stereospecificity has been tested by studying the elimination reaction of diasteromerically pure β-thioalkoxyalcohol. Thus, treatment of **3ka** with 2 equiv each of Bu_3P and DIAD afforded stereospecifically *Z*-**4k** in 71% yield (eq 2). On the other hand, the reaction of the other diastereomer **3kb** (94% de) under the same conditions afforded **4k** (*E*/*Z* = 34/1) in 71% yield (eq 5). If the conversion of **6** to **5** would occur via an S_N2-type mechanism, the stereochemistry for **3ka** and **3kb** would thus be assigned.



It is interesting to note that a bulky aryl substituent in **3** would lead the elimination process to form *Z* isomer predominantly (entries 4 and 5). Isomerization may take place to give thermodynamically more stable products.

To establish the sulfur migration shown in Scheme 1, **8**, prepared from the carbanion derived from the corresponding dithioacetal **9** and aldehyde **10**, was treated with 2 equiv each of DIAD and Bu_3P under the usual conditions to give **11** (*E*/*Z* = 1/2) in 69% yield. Apparently, the sulfur migration may take place leading to **11** via the episulfonium ion intermediate **12** (Scheme 2).[17] It is noteworthy that 1,2-thio migration in cyclic dithioacetals is well documented.[18]

When terephthaldehyde was employed, bis-enyne **13** was obtained from in 27% overall yield from **1a** (eq 6). Treatment of **1c** with BuLi followed by aldehyde **14** having a dithiolane functionality afforded alcohol **15** in 45% yield. Reaction of **15** under Mitsunobu conditions for 18 h gave the corresponding endiyne **16** in 68% yield (eq 7). It is worthy to note that the silyl substituent in **16** can be further modified by functional group transformation. This strategy could be used for the convergent synthesis of higher homologues of conjugated enynes. A similar approach has been employed toward the synthesis of monodispersed polymers without repetitive units.[19]



(16) Calcd for $C_{14}H_{29}O_4N_2S_2$ (M + 1) 353.1569, found 353.1572.

Conclusions

In summary, we have demonstrated a new enyne preparation by coupling of a carbonyl compound with a propargylic dithioacetal. A range of substituted enynes can be readily obtained by this protocol. The present reaction can compliment our earlier work[7] on low-valent iron-promoted elimiation of β-thioalkoxy alcohols. An episulfonium ion intermediate has been suggested. Both reactions can be considered as an alternative of McMurry-type coupling of two different carbonyl equivalents to give the corresponding olefins.

Experimental Section

3-(2-Isopropyl-1,3-dithiolan-2-yl)prop-2-yn-1-ol (1e). Under N_2, to a THF solution (50 mL) of 2-ethynyl-2-isopropyl-1,3-dithiolane[7] (3.35 g, 20 mmol, 1.0 equiv) cooled at −78 °C was added dropwise BuLi (10 mL, 1.25 equiv, 2.5 M hexane solution). After stirring 0.5 h, formaldehyde gas was introduced to the mixture until white participate appeared. The mixture was gradually warmed to rt and stirred for 8 h, quenched with sat. NH_4Cl, washed with brine, and extracted with EtOAc. The organic layer was dried ($MgSO_4$) and filtered and the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/EtOAc = 3/1) to give **1e** as a pale yellow liquid (3.60 g, 89%). ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.22 (d, J = 6.8 Hz, 6 H), 1.78 (t, J = 6.2 Hz, 1 H), 2.27 (sept, J = 6.7 Hz, 1 H), 3.37−3.60 (m, 4 H), 4.35 (d, J = 6.4 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.1, 39.7, 40.4, 50.9, 66.2, 83.3, 86.4; IR (KBr) •3371 cm^{-1}; HRMS (FAB) (M) calcd for $C_9H_{15}OS_2$ 203.0564, found 203.0566.

General Procedure for Prepartion of Homopropargylic Alcohol 3. Under N_2 atmosphere, to a THF solution (50 mL) of **1** (5.0 mmol, 1.0 equi.) cooled at −78 °C was added dropwise BuLi (2.2 mL, 1.10 equiv, 2.5 M hexane solution). After the solution was stirred for 1 h, carbonyl compound (1.0 equiv) in THF (10 mL) was then added dropwise and the mixture was gradually warmed to rt and stirred for 2−8 h, quenched with sat. NH_4Cl, washed with brine, and extracted with ether. The organic layer was dried ($MgSO_4$) and filtered and the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/EtOAc = 10−30/1) to give **3**.

7-(α-Hydroxybenzyl)-7-isopropyl-8,11-dithiapentadec-5-yne (3a): 74% (dr ratio = 2.3/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.92 (t, J = 6.7 Hz, 3 H), 0.94 (t, J = 6.7 Hz, 3 H), 1.12 (d, J = 6.4 Hz, 3 H), 1.34 (d, J = 6.4 Hz, 3 H), 1.34−1.48 (m, 4 H), 1.48−1.60 (m, 4 H), 1.88 (sept, J = 6.4 Hz, 1 H), 2.29 (t, J = 7.0 Hz, 2 H), 2.41−2.68 (m, 6 H), 3.08 (d, J = 6.8 Hz, 1 H), 4.80 (d, J = 6.8 Hz, 1 H), 7.27−7.33 (m, 3 H), 7.49−7.58 (m, 2 H); characteristic ^{1}H NMR signals for the minor isomer: δ 2.16 (sept, J = 6.7 Hz), 2.88 (d, J = 4.8 Hz, 1 H); IR (KBr) ν 3446 cm^{-1}; HRMS (FAB) (M + H)$^+$ calcd for $C_{19}H_{29}OS_2$ 337.1660, found 337.1666.

7-(1-Hydroxypentyl)-7-isopropyl-8,11-dithiapentadec-5-yne (3b): 72%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.92 (t, J = 7.4 Hz, 9 H), 1.02−1.12 (m, 6 H), 1.28−1.64 (m, 14 H), 1.68−1.80 (m, 1 H), 1.95−2.14 (m, 1 H), 2.28 (t, J = 6.8 Hz, 2 H), 2.50 (t, J = 7.8 Hz, 2 H), 2.62−2.98 (m, 4 H), 3.56−3.64 (m, 1 H); IR (KBr) ν 3482 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{21}H_{41}OS_2$ 373.2599, found 373.2599.

7-(α-Hydroxy-2,4,6-trimethylbenzyl)-7-isopropyl-8,11-dithiapentadec-5-yne (3c): 51% (dr ratio = 1.1/1); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.82−0.98 (m, 6 H), 1.02−1.18 (m, 6 H), 1.23−1.48 (m, 6 H), 1.52−1.66 (m, 2 H), 1.70−1.98 (m, 1 H), 2.07−2.17 (m 1 H), 2.23−2.47 (m, 11 H), 2.50−2.62 (m, 2 H), 2.6−2.84 (m, 4 H), 5.63−5.68 (m, 1 H), 6.81 (s, 2 H); characteristic ^{1}H NMR signals for the major isomer δ 2.09 (d, J = 3.6 Hz, 1 H), 5.66 (d, J = 3.6 Hz, 1 H); minor isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.15 (d, J = 3.6 Hz, 1 H), 5.64 (d, J = 3.6 Hz, 1 H); IR (KBr) ν 3455 cm^{-1}; HRMS (FAB) (M) calcd for $C_{26}H_{42}OS_2$ 434.2677, found 434.2686.

7-[α-Hydroxy-(1-naphthylmethyl)]-7-isopropyl-8,11-dithiapentadec-5-yne (3d): 87% (dr ratio = 6.0/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.72−1.12 (m, 6 H), 1.17−1.58 (m, 11 H), 1.76−1.90 (m, 2 H), 2.08−2.62 (m, 6 H), 3.22 (d, J = 8.6 Hz, 1 H), 5.86 (d, J = 8.6 Hz, 1 H), 7.40−7.52 (m, 3 H), 7.77−7.86 (m, 2 H), 7.93−7.98 (d, J = 7.6 Hz, 1 H), 8.18−8.24 (m, 1 H); characteristic ^{1}H NMR signals for the minor isomer δ 2.77 (d, J = 6.0 Hz, 1 H), 8.37 (d, J = 8.0 Hz, 1 H); IR (KBr) ν 3426 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{27}H_{39}OS_2$ 443.2441, found 443.2442.

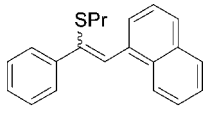
7-(α-Hydroxy-4-methoxybenzyl)-7-isopropyl-8,11-dithiapentadec-5-yne (3e): 80% (dr ratio = 6.4/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.92 (t, J = 7.0 Hz, 3 H), 0.94 (t, J = 7.0 Hz, 3 H), 1.11 (d, J = 6.4, Hz, 6 H), 1.34−1.47 (m, 4 H), 1.48−1.58 (m, 4 H), 1.84 (sept, J = 6.6 Hz, 1 H), 2.29 (t, J = 7.0 Hz, 2 H), 2.47 (t, J = 7.4 Hz, 2 H), 2.51−2.72 (m, 4 H), 3.04 (d, J = 6.0 Hz, 1 H), 3.82 (s, 3 H), 4.74 (d, J = 6.0 Hz, 1 H), 6.82−6.88 (m, 2 H), 7.42−7.47 (m, 2 H); characteristic ^{1}H NMR signals for the minor isomer δ 3.90 (s, 3 H), 4.78 (d, J = 4.8 Hz, 1 H); IR (KBr) ν 3467 cm^{-1}; HRMS (EI$^+$) (M) calcd for $C_{24}H_{38}O_2S_2$ 422.2313, found 422.2309.

7-(α-Hydroxy-4-bromobenzyl)-7-isopropyl-8,11-dithiapentadec-5-yne (3f): 56% (dr ratio = 5.4/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.92 (t, J = 7.4 Hz, 3 H), 0.94 (t, J = 7.2 Hz, 3 H), 1.11 (d, J = 6.6, Hz, 3 H), 1.13 (d, J = 6.6 Hz, 3 H), 1.35−1.46 (m, 4 H), 1.47−1.57 (m, 4 H), 1.84 (sept, J = 6.6 Hz, 1 H), 2.27 (t, J = 7.0 Hz, 2 H), 2.46 (t, J = 7.2 Hz, 2 H), 2.49−2.68 (m, 4 H), 3.11 (d, J = 6.8 Hz, 1 H), 4.76 (d, J = 6.8 Hz, 1 H), 7.38−7.45 (m, 4 H); characteristic ^{1}H NMR signals for the minor isomer δ 2.32 (t, J = 7.0 Hz, 2 H), 3.04 (d, J = 4.8 Hz, 1 H), 4.78 (d, J = 4.8 Hz, 1 H); IR (KBr) ν 3405 cm^{-1}; HRMS (FAB) (M + H)$^+$ calcd for $C_{23}H_{36}OBrS_2$ 471.1391, found 471.1389.

3-(α-Hydroxybenzyl)-3-isopropyl-1-trimethylsilyl-4,7-dithiaundec-1-yne (3g): 83% (dr ratio = 4.6/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.19 (s, 9 H), 0.90 (t, J = 6.4 Hz, 3 H), 1.08−1.20 (m, 6 H), 1.36−1.42 (m, 2 H), 1.44−1.58 (m, 2 H), 1.87 (sept, J = 6.6 Hz, 1 H), 2.40−2.64 (m, 6 H), 2.41−2.68 (m, 6 H), 3.08 (d, J = 6.8 Hz, 1 H), 4.82 (d, J = 6.8 Hz, 1 H), 7.26−7.34 (m, 3 H), 7.50−7.60 (m, 2 H); characteristic ^{1}H NMR signals for the minor isomer δ 0.23 (s, 9 H), 2.96 (d, J = 4.8 Hz, 1 H).[7]

3-Butyl-3-(α-hydroxybenzyl)-1-trimethylsilyl-4,7-dithiaundec-1-yne (3h): 78% (dr ratio = 5.3/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.20 (s, 9 H), 0.84−0.97 (m, 6 H), 1.22−1.70 (m, 8 H), 2.51 (t, J = 7.2 Hz, 2 H), 2.60−2.93 (m, 4 H), 3.18 (d, J = 4.8 Hz, 1 H), 4.60 (d, J = 4.8 Hz, 1 H), 7.28−7.34 (m, 3 H), 7.46−7.52 (m, 2 H); characteristic ^{1}H NMR signals for the minor isomer δ

(17) No extrusion of sulfur moiety to give vinyl sulfide **11′** was observed. The presence of an extra thiolato substituent on olefin in **12** might result in different behavior.



11′

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0.21 (s, 9 H), 2.56 (t, J = 7.4 Hz, 2 H), 3.20 (d, J = 2.2 Hz, 1 H), 4.71 (d, J = 2.2 Hz, 1 H); IR (KBr) ν 3458 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{23}H_{39}OSiS_2$ 423.2212, found 423.2209.

3-Butyl-3-(1-hydroxypentyl)-1-trimethylsilyl-4,7-dithiaundec-1-yne (3i): 35% (dr ratio = 1.3/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.19 (s, 9 H), 0.90−0.96 (m, 9 H), 1.25−1.87 (m, 14 H), 2.23 (d, J = 6.2 Hz, 1 H), 2.57 (t, J = 7.4 Hz, 2 H), 2.68−3.00 (m, 4 H), 3.48−3.56 (m, 2 H); characteristic ^{1}H NMR signals for the minor isomer δ 0.20 (s, 9 H); IR (KBr) ν 3484 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{21}H_{43}OS_2Si$ 403.2525, found 403.2517.

3-Butyl-3-(α-hydroxy-4-trifluoromethylbenzyl)-1-trimethylsilyl-4,7-dithiaundec-1-yne (3j): 80% (dr ratio = 3.6/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.20 (s, 9 H), 0.83−0.96 (m, 6 H), 1.19−1.78 (m, 8 H), 2.51 (t, J = 7.4 Hz, 2 H), 2.63−3.00 (m, 4 H), 3.33 (d, J = 4.6 Hz, 1 H), 4.63 (d, J = 4.6 Hz, 1 H), 7.57 (d, J = 8.4 Hz, 2 H), 7.62 (d, J = 8.4 Hz, 2 H); characteristic ^{1}H NMR signals for the minor isomer δ 0.21 (s, 9 H), 3.45−3.52 (m, 1 H), 4.76 (br s, 1 H); IR (KBr) ν 3449 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{24}H_{38}OF_3SiS_2$:491.2085, found 491.2079.

3-Butyl-3-(α-hydroxy-4-cyanobenzyl)-1-trimethylsilyl-4,7-dithiaundec-1-yne (3k): 83% (dr ratio = 1.6/1). The two isomers were separated by preparative HPLC (LiChrospher Si 60, eluent:$CHCl_3$/EtOAc = 100/1): major isomer (**3kb**) ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.18 (s, 9 H), 0.90 (t, J = 8.0 Hz, 3 H), 0.91 (t, J = 7.4 Hz, 3 H), 1.16−1.66 (m, 8 H), 2.52 (t, J = 7.6 Hz, 2 H), 2.62−3.01 (m, 4 H), 3.37 (d, J = 4.4 Hz, 1 H), 4.61 (d, J = 4.4 Hz, 1 H), 7.59−7.64 (m, 4 H); minor isomer (**3ka**) ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.20 (s, 9 H), 0.84 (t, J = 7.2 Hz, 3 H), 0.93 (t, J = 7.4 Hz, 3 H), 1.18−1.66 (m, 8 H), 2.57 (t, J = 7.2 Hz, 2 H), 2.62−3.01 (m, 4 H), 3.52 (d, J = 1.6 Hz, 1 H), 4.73 (d, J = 1.6 Hz, 1 H), 7.59−7.64 (m, 4 H); IR (KBr) ν 3471 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{24}H_{38}ONSiS_2$ 448.2164, found 448.2175.

3-Butyl-3-(α-hydroxy-*o*-methylbenzyl)-1-trimethylsilyl-4,7-dithiaundec-1-yne (3l): 67% (dr ratio = 1.7/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.18 (s, 9 H), 0.85−0.95 (m, 6 H), 1.24−1.66 (m, 8 H), 2.40 (s, 3 H), 2.46−2.88 (m, 8 H), 3.23 (d, J = 5.2 Hz, 1 H), 4.89 (d, J = 5.2 Hz, 1 H), 7.09−7.16 (m, 1 H), 7.17−7.22 (m, 2 H), 7.77−7.82 (m, 1 H); characteristic ^{1}H NMR signals for the minor isomer δ 0.18 (s, 9 H), 2.94 (d, J = 4.0 Hz, 1 H), 5.04 (d, J = 4.0 Hz, 1 H), 7.60−7.65 (m, 2 H); IR (KBr) P 3455 cm^{-1}; HRMS (FAB) (M + H)$^+$ calcd for $C_{24}H_{41}OSiS_2$ 437.2368, found 437.2370.

7-Butyl-7-(α-hydroxy-4-(*tert*-butoxycarbonyl)benzyl)-8,11-dithiapentadec-5-yne (3m). Under N_2 atmosphere, to a DCM solution (45 mL) of 4-carboxybenzaldehyde (4.5 g, 30 mmol), imidazole (4.08 g, 60 mmol), 4-dimethylaminopyridine (0.37 g, 3 mmol), and *tert*-butanol (8.6 mL, 90 mmol) cooled at 0 °C was added a DCM solution (15 mL) of DCC (6.81 g, 33 mmol, 1.1 equiv) dropwise. The mixture was stirred for 3 h at rt and filtered. The filtrate was washed with 0.5 N $HCl_{(aq)}$ and $NaHCO_{3(sat.)}$. The organic layer was dried ($MgSO_4$) and filtered and the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/$CHCl_3$ = 1/1) to give *tert*-butyl 4-formylbenzoate as a white solid (2.91 g, 49%). Mp 45−46 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.60 (s, 9 H), 7.90 (d, J = 8.0 Hz, 2 H), 8.11 (d, J = 8.0 Hz, 2 H), 10.06 (s, 1 H).[20]

3m: 37% (dr ratio = 1.7/1); major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.82−1.00 (m, 9 H), 1.18−1.68 (m, 17 H), 2.27 (t, J = 7.0 Hz, 2 H), 2.50 (t, J = 7.4 Hz, 2 H), 2.63−2.88 (m, 4 H), 3.32 (d, J = 4.4 Hz, 1 H), 4.60, (d, J = 4.4 Hz, 1 H), 7.51−7.55 (m, 4 H), 7.7.91−7.95 (m, 2 H); characteristic ^{1}H NMR signals for the minor isomer δ 3.46 (d, J = 1.8 Hz, 1 H), 4.73 (d, J = 1.8 Hz, 1 H); IR (KBr) ν 3471 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{29}H_{47}O_3S_2$ 507.2967, found 507.2959.

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7-Butyl-7-(2-hydroxy-2-propyl)-8,11-dithiapentadec-5-yne (3n): 53%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.82−0.96 (m, 9 H), 1.2−1.68 (m, 19 H), 1.79 (dt, J = 4.1, 12 Hz, 1 H), 2.26 (t, J = 7.0 Hz, 2 H), 2.41 (s, 1 H), 2.52 (t, J = 7.4 Hz, 2 H), 2.63−2.78 (m, 2 H), 2.83−2.96 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.6, 13.7, 14.2, 18.6, 22.0, 22.1, 22.9, 25.5, 28.8, 31.0, 31.8, 31.9, 32.9, 33.2, 36.7, 60.6, 76.1, 78.1, 89.4; IR (KBr) ν 3487 cm^{-1}; HRMS (EI$^+$) (M) calcd for $C_{20}H_{38}OS_2$ 358.2364, found 358.2353.

7-Butyl-7-(1-hydroxy-1,1-diphenylmethyl)-8,11-dithiapentadec-5-yne (3o): 78%; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.85 (t, J = 7.2 Hz, 3 H), 0.91 (t, J = 7.2 Hz, 3 H), 0.93 (t, J = 7.2 Hz, 3 H), 1.23−1.62 (m, 12 H), 1.95−2.19 (m, 4 H), 2.47−2.58 (m, 4 H), 2.63−2.79 (m, 2 H), 2.98 (s, 1 H), 7.21−7.44 (m, 10 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.8, 14.0, 14.1, 22.1, 22.4, 22.7, 29.9, 30.6, 30.7, 31.7, 31.8, 31.9, 32.0, 33.8, 81.3, 108.1, 118.0, 127.0, 127.2, 127.7, 145.0, 145.1; IR (KBr) P3488 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{30}H_{42}OS_2$ 483.2755, found 483.2756.

4-Isopropyl-4-(α-hydroxybenzyl)-5,8-dithia-2-dodecyn-1-yl *tert*-Butyldimethylsilyl Ether (3p). Under N_2 atmosphere, to a THF solution (50 mL) of **1e** (1.01 g, 5.0 mmol, 1.0 equiv) cooled at−78 °C was added dropwise BuLi (4.4 mL, 2.2 equiv, 2.5 M hexane solution). After the solution was stirred for 1 h, benzaldehyde (0.51 mL, 5.0 mmol, 1.0 equiv) in THF (10 mL) was added dropwise at − 78 °C. The mixture was gradually warmed to rt and stirred for 8 h, quenched with sat. NH_4Cl, washed with brine, and extracted with ether. The organic layer was dried ($MgSO_4$) and filtered and the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/EtOAc = 9/1) to give the crude diol (1.47 g, 77%).

Under N_2 atmosphere, to a DCM solution (40 mL) of the crude diol (1.47 g, 3.85 mmol) and imidazole (0.26 g, 3.85 mmol, 1.0 equiv) cooled at −78 °C was added TBSCl (0.58 g, 3.85 mmol, 1.0 equiv) in DCM (10 mL) dropwise. The mixture was gradually warmed to rt and stirred for 8 h and then washed with brine. The organic layer was dried ($MgSO_4$) and filtered and the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/EtOAc = 30/1) to give **3p** as a pale yellow liquid (1.51 g, 63% in two steps, dr ratio = 3.5/1). Major isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.12 (s, 6 H), 0.88−0.98 (m, 12 H embodied a singlet at 0.93 for ^{t}Bu group), 1.14 (d, J = 6.7 Hz, 6 H), 1.33−1.42 (m, 2 H), 1.47−1.56 (m, 2 H), 1.89 (sept, J = 6.7 Hz, 1 H), 2.41−2.70 (m, 6 H), 3.10 (s, 1 H), 4.40 (s, 2 H), 4.84 (s, 1 H), 7.26−7.36 (m, 3 H), 7.50−7.60 (m, 2 H); characteristic ^{1}H NMR signals for the minor isomer δ 0.14 (s, 6 H), 2.19 (sept, J = 6.8 Hz, 1 H), 4.43 (s, 2 H); IR (KBr) P 3459 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{26}H_{45}O_2SiS_2$ 481.2630, found 481.2632.

General Procedure for the Preparation of Enyne 4. Under N_2 atmosphere, to a THF solution (5 mL) of **3** (0.5 mmol, 1.0 equiv) and Ph_3P (0.26 g, 1.0 mmol, 2.0 equiv) was added DIAD (0.20 mL 1.0 mmol, 2.0 equiv) at rt. After being stirred for 18 h, the mixture was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/$CHCl_3$ = 1/0 to 10/1) to give **4**.

2-Isopropyl-1-phenyloct-1*E*-en-3-yne (4a): 81% (*E*/*Z* = 3.0/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.97 (t, J = 7.4 Hz, 3 H), 1.13 (d, J = 6.4 Hz, 6 H), 1.44−1.66 (m, 4 H), 2.40 (t, J = 6.8 Hz, 2 H), 3.04 (sept, J = 6.6 Hz, 1 H), 6.70 (s, 1 H), 7.20−7.36 (m, 5 H); characteristic ^{1}H NMR signals for *Z* isomer δ 2.48 (t, J = 7.0 Hz, 2 H), 2.55 (sept, J = 6.8 Hz, 1 H), 6.49 (s, 1 H), 7.82 (d, J = 7.6 Hz, 2 H); HRMS (FAB) (M) calcd for $C_{17}H_{22}$ 226.1722, found 226.1721.

6-Isopropyldodec-5*E*-en-7-yne (4b): 43% (*E*/*Z* = 10/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.89 (t, J = 7.2 Hz, 3 H), 0.93 (t, J = 7.2 Hz, 3 H), 1.04 (d, J = 7.0 Hz, 6 H), 1.28−1.38 (m, 4 H), 1.39−1.57 (m, 4 H), 2.09 (td, J = 7.4, 6.8 Hz), 2.32 (t, J = 7.0 Hz, 2 H), 2.73 (sept, J = 7.0 Hz, 1 H), 5.66 (t, J = 7.4 Hz, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 14.4, 19.4, 21.9, 22.4, 22.8, 27.9, 28.4, 31.5, 32.0, 79.9, 88.3, 129.6, 134.2; characteristic ^{1}H

NMR signals for *Z* isomer δ 5.58 (t, *J* = 7.0 Hz, 1 H); HRMS (FAB) (M) calcd for $C_{15}H_{26}$ 206.2035, found 206.2040.

2-Isopropyl-1-mesityloct-1*Z*-en-3-yne (4c): 65% (*E*/*Z* = 1/20); characteristic ^{1}H NMR signals for *E* isomer δ 0.85 (t, *J* = 7.4 Hz, 3 H), 6.61 (s, 1 H); *Z* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.01 (t, *J* = 7.4 Hz, 3 H), 1.07 (d, *J* = 6.8 Hz, 6 H), 1.41−1.53 (m, 2 H), 1.61−1.70 (m, 2 H), 2.28 (s, 6 H), 2.31 (s, 3 H), 2.33 (t, *J* = 7.4 Hz, 2 H), 2.55 (sept, *J* = 6.8 Hz, 1 H), 6.46 (s, 1 H), 6.87 (s, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.4, 20.7, 21.4, 21.5, 22.5, 23.3, 31.1, 37.8, 79.0, 99.6, 126.5, 127.3, 132.2, 133.6, 135.3, 135.7; HRMS (FAB) (M) calcd for $C_{10}H_{28}$ 268.2191, found 268.2188.

2-Isopropyl-1(1-naphthyl)-oct-1-*Z*-en-3-yne (4d): 72% (*E*/*Z* = 1/3.9); characteristic ^{1}H NMR signals for *E* isomer δ 0.89 (t, *J* = 7.2 Hz, 3 H), 1.28 (d, *J* = 6.8 Hz, 6 H), 2.32 (t, *J* = 6.8 Hz, 2 H), 2.70 (sept, *J* = 6.8 Hz, 1 H), 7.14 (s, 1 H); *Z* isomer δ 1.00 (t, *J* = 7.2 Hz, 3 H), 1.09 (d, *J* = 6.6 Hz, 6 H), 1.50−1.69 (m, 4 H), 2.46 (t, *J* = 7.0 Hz, 2 H), 2.79 (sept, *J* = 6.6 Hz, 1 H), 7.09 (s, 1 H), 7.30 (d, *J* = 7.2 Hz, 1 H), 7.42−7.54 (m, 3 H), 7.78 (d, *J* = 8.0 Hz, 1 H), 7.81−7.89 (m, 1 H), 7.97−8.07 (m, 1 H); HRMS (FAB) (M) calcd for $C_{17}H_{22}$ 276.1878, found 276.1875.

2-Isopropyl-1-(4-methoxyphenyl)oct-1*E*-en-3-yne (4e): 91% (*E*/*Z* = 5.0/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.96 (t, *J* = 7.2 Hz, 3 H), 1.13 (d, *J* = 6.7 Hz, 6 H), 1.40−1.66 (m, 4 H), 2.39 (t, *J* = 6.8 Hz, 2 H), 3.04 (sept, *J* = 6.7 Hz, 1 H), 3.82 (s, 3 H), 6.64 (s, 1 H), 6.82−6.89 (m, 2 H), 7.14−7.19 (m, 2 H); characteristic ^{1}H NMR signals for *Z* isomer δ 3.80 (s, 3 H), 6.43 (s, 1 H), 7.78−7.81 (m, 2 H); HRMS (FAB) (M) calcd for $C_{18}H_{24}O$ 256.1827, found 256.1831.

1-(4-Bromophenyl)-2-isopropyl-oct-1E-en-3-yne (4f): 68% (*E*/*Z* = 1.7/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.94 (t, *J* = 7.4 Hz, 3 H), 1.10 (d, *J* = 6.5 Hz, 6 H), 1.44−1.61 (m, 4 H), 2.38 (t, *J* = 7.0 Hz, 2 H), 2.95 (sept, *J* = 6.5 Hz, 1 H), 6.58 (s, 1 H), 7.04−7.08 (m, 2 H), 7.40−7.44 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.8, 19.3, 21.8, 22.1, 28.8, 31.1, 79.9, 92.0, 120.6, 130.1, 131.2, 131.3, 133.5, 135.8; characteristic ^{1}H NMR signals for *Z* isomer δ 2.47 (t, *J* = 7.0 Hz, 2 H), 2.53 (sept, *J* = 6.8 Hz, 1 H), 6.42 (s, 1 H), 7.67−7.71 (m, 2 H); HRMS (FAB) (M) calcd for $C_{17}H_{21}{}^{79}Br$ 304.0827, found 304.0824.

2-Isopropyl-1-phenyl-4-trimethylsilylbut-1*E*-en-3-yne (4g): 78% (*E*/*Z* = 3.2/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.25 (s, 9 H), 1.15 (d, *J* = 6.8 Hz, 6 H), 3.04 (sept, *J* = 6.8 Hz, 1 H), 6.83 (s, 1 H), 7.20−7.37 (m, 5 H); characteristic ^{1}H NMR signals for *Z* isomer δ 0.26 (s, 9 H), 1.19 (d, *J* = 6.4 Hz, 6 H), 2.56 (sept, *J* = 6.1 Hz, 1 H), 6.57 (s, 1 H), 7.86 (d, *J* = 7.6 Hz, 2 H).[7]

(3-Butyl-4-phenylbut-3*E*-en-1-yn-1-yl)trimethylsilane (4h): 72% (*E*/*Z* = 13.5/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.26 (s, 9 H), 0.93 (t, *J* = 7.4 Hz, 3 H), 1.33−1.44 (m, 2 H), 1.58−1.79 (m, 2 H), 2.39 (t, *J* = 7.6 Hz, 2 H), 6.92 (s, 1 H), 7.22−7.30 (m, 3 H), 7.31−7.38 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 0.24, 14.1, 22.5, 30.7, 31.0, 93.7, 107.7, 125.4, 127.0, 128.1, 128.7, 136.5; characteristic ^{1}H NMR signals for *Z* isomer δ 0.29 (s, 9 H), 2.32 (t, *J* = 7.6 Hz, 2 H), 6.56 (s, 1 H), 7.87 (d, *J* = 7.6 Hz, 2 H); HRMS (FAB) (M) calcd for $C_{17}H_{24}Si$ 256.1674, found 256.1654.

(3-Butyloct-3*E*-en-1-yn-1-yl)trimethylsilane (4i): 69% (*E*/*Z* = 1/1.5); characteristic ^{1}H NMR signals for *E* isomer δ 0.19 (s, 9 H), 5.92 (t, *J* = 7.6 Hz, 1 H); *Z* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.20 (s, 9 H), 0.87−0.95 (m, 6 H), 1.26−1.42 (m, 6 H), 1.44−1.53 (m, 2 H), 2.05−2.14 (m, 2 H), 2.26 (q, *J* = 7.2 Hz, 2 H), 5.69 (t, *J* = 7.2 Hz, 1 H); HRMS (FAB) (M) calcd for $C_{15}H_{28}Si$ 236.1960, found 236.1961.

[3-Butyl-4-(4-trifluomethylphenyl)but-3*E*-en-1-yn-1-yl]trimethylsilane (4j): 48% (*E*/*Z* = 3.3/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.26 (s, 9 H), 0.93 (t, *J* = 7.2 Hz, 3 H), 1.32−1.46 (m, 2 H), 1.59−1.70 (m, 2 H), 2.37 (t, *J* = 7.8 Hz, 2 H), 6.90 (s, 1 H), 7.34 (d, *J* = 8.2 Hz, 2 H), 7.59 (d, *J* = 8.2 Hz, 2 H); characteristic ^{1}H NMR signals for *Z* isomer δ 0.28 (s, 9 H), 0.97 (t, *J* = 7.4 Hz, 3 H), 6.56 (s, 1 H), 7.95 (d, *J* = 8.4 Hz, 2 H); HRMS (FAB) (M) calcd for $C_{18}H_{23}F_3Si$ 324.1521, found 324.1525.

[3-Butyl-4-(4-cyanophenyl)but-3*E*-en-1-yn-1-yl]trimethylsilane (4k): 39% (*E*/*Z* = 1.4/1). When 0.25 mL of Bu_3P was used in place of Ph_3P, 89% yield of **4k** was isolated (*E*/*Z* = 2.0/1). Under these conditions, **3ka** was converted into *Z*-**4k** in 71% yield and **3kb** (94% de) into *E*-**4k** (containing 3% *Z*-**4k**) in 71% yield. *E*-**4k**: ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.25 (s, 9 H), 0.91 (t, *J* = 7.4 Hz, 3 H), 1.30−1.42 (m, 2 H), 1.58−1.66 (m, 2 H), 2.34 (t, *J* = 7.6 Hz, 2 H), 6.84 (s, 1 H), 7.31 (d, *J* = 8.4 Hz, 2 H), 7.61 (d, *J* = 8.4 Hz, 2 H). *Z*-**4k**: ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.26 (s, 9 H), 0.95 (t, *J* = 7.2 Hz, 3 H), 1.37−1.42 (m, 2 H), 1.58−1.66 (m, 2 H), 2.33 (t, *J* = 7.6 Hz, 2 H), 6.53 (s, 1 H), 7.58 (d, *J* = 8.4 Hz, 2 H), 7.92 (d, *J* = 8.4 Hz, 2 H); HRMS (FAB) (M) calcd for $C_{18}H_{24}NSi$ 282.1678, found 282.1678.

[3-Butyl-4-(4-tolyl)but-3*E*-en-1-yn-1-yl]trimethylsilane (4l): 67% (*E*/*Z* = 2.1/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.25 (s, 9 H), 0.86 (t, *J* = 7.4 Hz, 3 H), 1.25−1.35 (m, 2 H), 1.52−1.67 (m, 2 H), 2.22 (t, *J* = 7.6 Hz, 2 H), 2.27 (s, 3 H), 6.90 (s, 1 H), 7.09−7.24 (m, 4 H); characteristic ^{1}H NMR signals for *Z* isomer δ ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.19 (s, 9 H), 0.96 (t, *J* = 7.2 Hz, 3 H), 1.19 (d, *J* = 6.4 Hz, 6 H), 1.35−1.46 (m, 2 H), 2.30−2.36 (m, 5 H), 6.70 (s, 1 H), 8.09−8.14 (m, 1 H); HRMS (FAB) (M^+) calcd for $C_{18}H_{26}Si$ 270.1804, found 270. 1801.

2-Butyl-1-(4-*tert*-butoxycarbonylphenyl)oct-1*E*-en-3-yne (4m): 62% (*E*/*Z* = 1.6/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.88−0.99 (m, 6 H), 1.29−1.66 (m, 17 H, embodied a singlet at 1.60 for *tert*-butyl group), 2.28−2.40 (m, 2 H), 2.45 (t, *J* = 7.2 Hz, 2 H), 6.76 (s, 1 H), 7.26 (d, *J* = 8.0 Hz, 2 H), 7.93 (d, *J* = 8.0 Hz, 2 H); characteristic ^{1}H NMR signals for *Z* isomer δ ^{1}H NMR ($CDCl_3$, 400 MHz) δ 6.48 (s, 1 H), 7.83 (d, *J* = 8.4 Hz, 2 H), 7.91 (d, *J* = 8.4 Hz, 2 H); HRMS (FAB) (M) calcd for $C_{23}H_{32}O_2$ 340.2402, found 340.2398.

3-Butyl-2-methylnon-2-en-4-yne (4n): 17% (Bu_3P was used); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.92 (t, *J* = 7.2 Hz, 3 H), 0.94 (t, *J* = 7.2 Hz, 3 H), 1.26−1.38 (m, 4 H), 1.41−1.57 (m, 4 H), 1.73 (s, 3 H), 1.93 (s, 3 H), 2.12 (t, *J* = 7.6 Hz, 2 H), 2.36 (t, *J* = 6.8 Hz, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.8, 14.2, 19.3, 19.7, 22.1, 22.5, 23.7, 31.0, 31.4, 32.2, 81.3, 91.8, 117.6, 137.3; HRMS (EI^+) (M) calcd for $C_{14}H_{24}$ 192.1878, found 192.1873.

2-Butyl-1,1-diphenyloct-1-en-3-yne (4o): 28% (Bu_3P was used); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.85 (t, *J* = 7.6 Hz, 3 H), 0.88 (t, *J* = 7.4 Hz, 3 H), 1.22−1.38 (m, 4 H), 1.39−1.48 (m, 2 H), 1.55−1.65 (m, 2 H), 2.21 (t, *J* = 7.4 Hz, 2 H), 2.28 (t, *J* = 6.8 Hz, 2 H), 7.11−7.42 (m, 10 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 14.4, 19.7, 22.2, 22.6, 30.9, 31.5, 34.7, 81.5, 94.0, 122.0, 126.4, 126.5, 127.0, 127.6, 129.2, 129.4, 141.3, 141.9, 145.0; HRMS (FAB) (M) calcd for $C_{24}H_{28}$ 316.2191, found 316.2193.

(5-Phenyl-4-isopropyl-pent-4*E*-en-2-yn-1-yl *tert*-butyldimethylsilyl ether (4p): 38% (*E*/*Z* = 1.6/1); *E* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.19 (s, 9 H), 0.96 (s, 6 H), 2.14 (d, *J* = 6.8 Hz, 6 H), 3.06 (sept, *J* = 6.8 Hz, 1 H), 4.53 (s, 2 H), 6.77 (s, 1 H), 7.21−7.39 (m, 5 H); characteristic ^{1}H NMR signals for *Z* isomer δ 0.17 (s, 9 H), 0.96 (s, 6 H), 2.19 (d, *J* = 6.8 Hz, 6 H), 2.58 (sept, *J* = 6.7 Hz, 1 H), 4.58 (s, 2 H), 6.56 (s, 1 H), 7.78−7.84 (m, 2 H); HRMS (EI^+) (M) calcd for $C_{20}H_{30}OSi$ 314.2066, found 314.2062.

1-(Naphthyl)-2-phenyl-2,2-bis(propylthio)ethanol (8). Under N_2 atmosphere, to a THF solution (50 mL) of benzaldehyde bispropyldithioacetal (1.20 g, 5 mmol) cooled at −78 °C was added dropwise LDA (2.5 mL, 1.0 equiv, 2.0 M THF/*n*-heptane/ethylbenzene solution). After the solution was stirred for 2 h, 1-naphthaldehyde (0.68 mL, 5.0 mmol) in THF (10 mL) was added. The mixture was gradually warmed to rt and stirred for 8 h, quenched with sat. NH_4Cl, washed with brine, and extracted with ether. The organic layer was dried ($MgSO_4$) and filtered and the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/EtOAc = 10/1) to give **8** as a light yellow solid (0.89 g, 45%): mp 78−79 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.90 (t, *J* = 7.2 Hz, 3 H), 1.16 (t, *J* = 7.4 Hz, 3 H), 1.45−1.55 (m, 2 H), 1.73−1.87 (m, 2 H), 2.23−2.31 (m, 1 H), 2.47−2.55 (m, 1 H), 2.89−3.07 (m, 2 H), 3.88 (s, 1 H), 5.84 (s, 1

H), 6.68 (d, $J = 7.2$ Hz, 1 H), 7.14−7.29 (m, 4 H), 7.40−7.46 (m, 2 H), 7.47−7.53 (m, 2 H), 7.73 (d, $J = 8.0$ Hz, 1 H), 7.78−7.84 (m, 1 H), 8.08−8.14 (m, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 14.1, 14.3, 22.0, 22.4, 32.0, 33.1, 72.5, 123.7, 124.2, 124.8, 125.1, 127.3, 127.6, 128.3, 128.4, 130.1, 132.1, 132.9, 133.1, 136.7; IR (KBr) ν 3449 cm^{-1}; HRMS (ESI) (M + Na)$^+$ calcd for $C_{24}H_{28}OS_2Na$ 419.1479, found 419.1489.

1-(2-Phenyl-1,2-bis(propylthio)vinyl)naphthalene (11). In a manner similar to that described in the general procedure for the preparation **4**, **8** (99 mg, 0.25 mmol) and PBu_3 (0.25 mL, 1 mmol) were converted to **11** as a colorless liquid (65 mg, 69%, *E*/*Z* = 1/2): characteristic ^{1}H NMR signals for *E* isomer δ 0.64 (t, J = 7.4 Hz, 3 H), 0.68 (t, $J = 7.4$ Hz, 3 H), 1.22−1.37 (m, 4 H); *Z* isomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.79 (t, $J = 7.4$ Hz, 3 H), 0.99 (t, $J = 7.4$ Hz, 3 H), 1.37−1.46 (m, 2 H), 1.59−1.66 (m, 2 H), 2.05−2.14 (m, 2 H), 2.45 (t, $J = 7.2$ Hz, 2 H), 6.93−6.97 (m, 2 H), 7.07−7.09 (m, 2 H), 7.17 (d, $J = 8.0$ Hz, 1 H), 7.24−7.30 (m, 1 H), 7.41−7.60 (m, 1 H), 7.60−7.67 (m, 2 H), 7.78 (d, J = 8.0 Hz, 1 H), 7.89−7.95 (m, 1 H), 8.21−8.25 (m, 1 H); HRMS-FAB (M$^+$) calcd for $C_{24}H_{26}S_2$ 378.1476, found 378.1480.

1,4-Bis(2-butyloct-1*E*-en-3-yn-1-yl)benzene (13). Under N_2 atmosphere, to a THF solution (50 mL) of **1d**[7] (1.21 g, 5.0 mmol, 1.00 equiv) cooled at −78 °C was added dropwise BuLi (2.2 mL, 1.10 equiv, 2.5 M hexane solution). After the solution was stirred for 1 h, terephthaldehyde (0.34 g, 2.5 mmol, 0.50 equiv) in THF (20 mL) was added dropwise. The mixture was gradually warmed to rt and stirred for 8 h, quenched with sat. NH_4Cl, washed with brine, and extracted with ether. The organic layer was dried ($MgSO_4$) and filtered and the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/EtOAc = 10/1) to give corresponding diol (1.26 g, 69%).

A THF solution (5 mL) of the diol (368 mg) and PPh_3 (524 mg, 2 mmol, 4.00 equiv) was allowed to react with DIAD (0.40 mL, 2 mmol, 4.00 equiv) and the mixture was stirred at rt for 18 h, then evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane) to give **13** (78 mg, 39%, 27% in two steps, *EE*/*EZ* = 1/3.2): characteristic ^{1}H NMR signals for *EE* isomer δ 6.74 (s, 2 H), 7.20 (s, 4 H); *EZ* isomer δ 0.90−0.99 (m, 12 H), 1.32−1.67 (m, 16 H), 2.29 (t, $J = 7.2$ Hz, 2 H), 2.39 (t, J = 6.8 Hz, 4 H), 2.44−2.50 (m, 2 H), 6.43 (s, 1 H), 6.73 (s, 1 H), 7.19 (d, $J = 8.4$ Hz, 2 H), 7.78 (d, $J = 8.4$ Hz, 2 H); HRMS (FAB) (M) calcd for $C_{30}H_{42}$ 402.3287, found 402.3292.

2-Isopropyl-2-(2-formylethynyl)-1,3-dithiolane (14). To a DCM solution (100 mL) of **1e** (2.02 g, 10 mmol) was added PCC (2.16 g, 10 mmol) and celite (2.16 g) at rt. After being stirred for 12 h, the mixture was filtered and the filtrate was evaporated in vacuo to give the residue, which was chromatographed on silica gel (hexane/$CHCl_3$ = 3/1) to give **14** as an orange yellow liquid (1.74 g, 87%). ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.24 (d, $J = 6.7$ Hz, 6 H), 2.34 (sept, $J = 6.7$ Hz, 1 H), 3.40−3.58 (m, 4 H), 9.28 (s, 1 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.2, 39.9, 40.0, 65.3, 84.2, 97.2, 176.4; IR (KBr) ν 1662 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_9H_{13}OS_2$ 201.0408, found 201.0410.

Alcohol 15. According to general procedure for the preparation of **3**, **1c**[7] (1.29 g, 5.0 mmol) and **14** (1.00 g, 5.0 mmol) were converted to **15** as a pale yellow liquid (1.16 g, 45%, dr ratio = 1.3/1). Major diastereomer ^{1}H NMR ($CDCl_3$, 400 MHz) δ 0.20 (s, 9 H), 0.88−0.96 (m, 6 H), 1.24 (d, $J = 6.8$ Hz, 6 H), 1.30−1.47 (m, 4 H), 1.49−1.73 (m, 4 H), 2.23−2.32 (m, 1 H), 2.56 (t, J = 6.6 Hz, 2 H), 2.68−3.16 (m, 5 H), 3.35−3.42 (m, 2 H), 3.48−3.57 (m, 2 H), 4.44 (d, $J = 6.4$ Hz, 1 H); characteristic ^{1}H NMR signals for the minor diastereomer δ 0.21 (s, 9 H), 2.57 (t, $J = 6.6$ Hz, 2 H), 4.41 (d, $J = 9.6$ Hz, 1 H); IR (KBr) ν 3421 cm^{-1}; HRMS (FAB) (M + H) calcd for $C_{25}H_{45}OSiS_4$ 517.2123, found 517.2128.

Endiyne 16. According to teh general procedure for the preparation of **4**, **15** (258 mg, 0.5 mmol) and PPh_3 were converted to **16** as a colorless liquid (119 mg, 68%, *E*/*Z* = 1/1.4): characteristic ^{1}H NMR signals for *E* isomer δ 0.20 (s, 9 H), 0.93 (t, $J = 7.4$ Hz, 3 H), 1.22 (d, $J = 6.8$ Hz, 6 H), 2.31 (sept, $J = 6.8$ Hz, 1 H), 2.36 (t, $J = 7.4$ Hz, 2 H), 5.86 (s, 1 H); *Z* isomer δ 0.21 (s, 9 H), 0.91 (t, $J = 7.2$ Hz, 3 H), 1.28 (d, $J = 6.6$ Hz, 6 H), 1.29−1.41 (m, 2H), 1.46−1.58 (m, 2H), 2.15−2.21 (m, 2H), 2.32 (sept, $J = 6.6$ Hz, 1 H), 3.36−3.46 (m, 2H), 3.46−3.60 (m, 2H), 5.71 (t, $J = 1.2$ Hz, 1 H); HRMS (FAB) (M + H) calcd for $C_{19}H_{31}SiS_2$ 351.1636, found 351.1631.

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Supporting Information Available: ^{1}H NMR spectra of **1e**, **3a**−**f**, **3h**−**p**, **3ka**, **3kb**, **4a**−**p**, *Z*-**4k**, *E*-**4k**, **8**, **11**, and **13**−**16**. This material is available free of charge via the Internet at http://pubs.acs.org.

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