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Preparation and reactivity studies of 1,2-bis-triisopropylsilanylsulfanyl-alkenes

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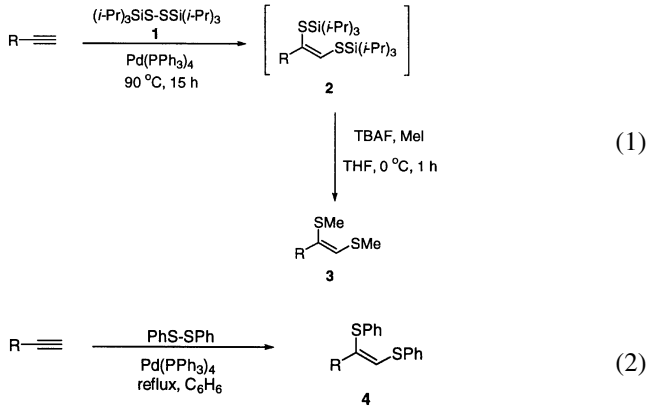
Abstract—The cross-coupling reaction of bis-triisopropylsilyl disulfide **1** on alkynes yielded 1,2-bis-triisopropylsilanylsulfanyl-alkenes **2**, a new chemical class. A series of tri and tetrasubstituted olefins **2** were prepared and their behavior toward electrophiles was studied. The triisopropylsilyl groups could be readily removed by treatment with TBAF at 0°C for 1 h or cesium acetate at 70°C for 2 h. Soft and hard electrophiles were submitted to **2** under these conditions. The electrophiles can either react to yield double-addition products with alkyl and activated halides, epoxides and acyl chlorides or cyclic adducts with chloroformate derivatives. In the latter case, 1,3-dithiol-2-ones or 1,3-dithiol-2-thiones are prepared.

1. Introduction

There has been several reports showing the use of transition metal catalyst in chemical reactions involving thiolates,[1] sulfides[2] and disulfides.[3] In 1997, we published our own results on the palladium-catalyzed reaction of a new disulfide **1** and terminal alkynes that yielded 1,2-bis-methylsulfanyl-alkenes **3** after treatment with methyl iodide–TBAF (Eq. (1)).[4] The initial addition reaction (alkyne→**2**) was an extension of a more specific reaction (alkyne→**4**) described by Ogawa, Sonoda et al. in 1991 (Eq. (2)).[3c] For this transformation, they reported high yields of **4** if aromatic disulfides and diselenides were used. The configuration of **4** was such that the newly formed substituents were always *cis* to each other. In the case of aliphatic disulfides, the results were much less attractive since the yields were very low (0–20%) and therefore greatly limits the possibility of the reaction. In our previous report on the preparation of vinyl 1,2-bis-methylsulfanyl-alkenes **3**, we opened the way for a much more flexible reaction of the palladium cross-coupling reaction between alkynes and disulfide **1**. At that time, we did not pay any special attention to the intermediate **2**. In only one example (R=*t*-butyl), such a compound was isolated by flash chromatography in a modest yield of 55%. We would like to report herein our results on the scope and limitations for the preparation and the reactivity of such intermediates.



(1)

(2)

2. Results and discussion

Disulfide **1** is a bright yellow solid easily prepared[4] by iodide oxidation of the commercially available thiol. A series of mono and disubstituted alkynes were converted to *Z*-1,2-bis-triisopropylsilanylsulfanyl-alkenes. Thus, the desired alkyne was treated with 1.1 equiv. of **1** and 0.05 equiv. of $(Ph_3)_4Pd$ in a 1.0 M solution of toluene at ca. 90°C under nitrogen for approximately 15 h. The reaction conditions varied with the volatility of the substrate and/or the degree of substitution on the triple bond. For volatile starting materials, the reaction was performed in a sealed tube using excess alkyne toward electrophiles.

Less reactive disubstituted alkynes were run at higher concentration and temperature. At the end of each reaction, the solvent was removed and the crude oil was rapidly passed through a short pad of silica gel. This reaction is

Keywords: alkynes; electrophiles; double-addition products.

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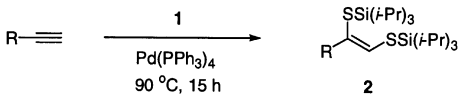
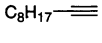
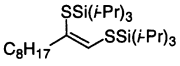
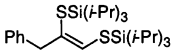
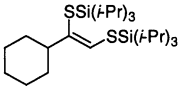
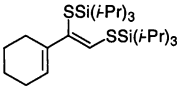
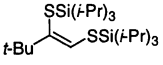
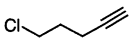
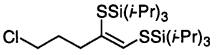
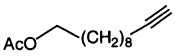
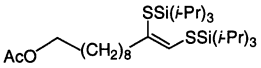
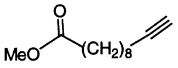
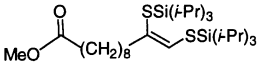
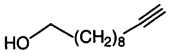
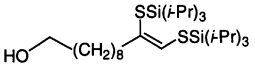
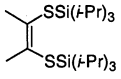
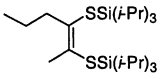
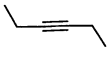
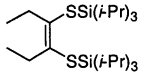
Table 1. Preparation of *Z*-1,2-bis-triisopropylsilanylsulfanyl-alkenes from alkynes

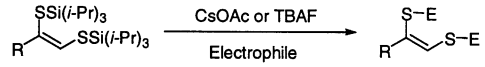


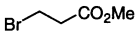
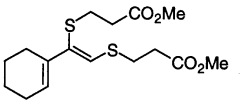
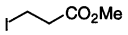
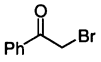
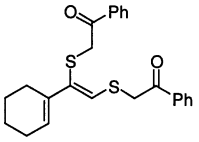
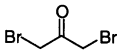
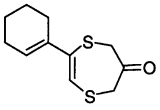
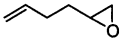
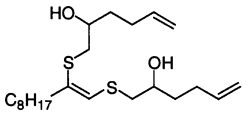
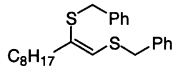
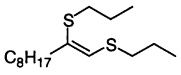
Alkyne	Product	Yield	Compound
		96%	5
		86%	6
		67%	7
		77%	8
		70%	9
		76%	10
		83%	11
		60%	12
		54%	13
		50%	14
		42%	15
		72%	16

quite general and the yields are usually quite satisfactory. Some low yields were not always indicative of the effectiveness of the reaction but reflected mainly the difficulty of the purification. Simple aliphatic alkynes usually worked quite nicely, yet the highly bulky *t*-butyl acetylene gave 3,3-dimethyl-1,2-bis-triisopropylsilanylsulfanyl-but-1-ene **9** in 70% isolated yield. Many functional groups such as alcohol, ester, acetate and halide were tolerated (Table 1) while carboxylic acids were one group that gave poor results (not shown). Disubstituted alkynes also worked but in general lower yields are obtained. These silylated vinyl-sulfides are fairly stable and could be stored for months at room temperature.

With all these 1,2-bis-triisopropylsilanylsulfanyls in hand we examined, in a more general way than previously reported their reactivity toward electrophiles after TBAF deprotection. The two substrates selected for this study were 1-(1,2-bis-triisopropyl silanylsulfanyl-vinyl)-cyclohexene **8** and 1,2-bis-triisopropylsilanylsulfanyl-dec-1-ene **5**. The electrophiles examined varied from activated and non-activated halides to epoxides (Table 2). Therefore, to a 0°C solution of **8** in toluene–DMF was added 2.5 equiv. of the halide followed by 2.5 equiv. of TBAF and the reaction mixture was left stirring for 1 h. The final product obtained corresponded to an addition of the electrophile on both sulfur atoms as expected. The reaction worked satisfactorily

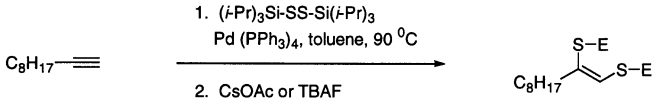
Table 2. Double-addition products of electrophiles to *Z*-1,2-bis-trisopropylsilanylsulfanyl-alkenes

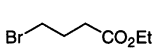
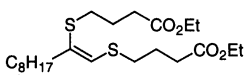
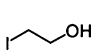
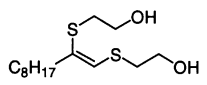
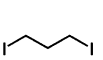
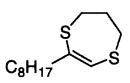


R	Electrophile	Product	Yield	Compound
			54%[a]	17
		" "	60%[a]	17
			70%[a]	18
			34%[a]	19
			71%[b]	20
			75%[b]	21
		" "	66%[b]	21
			73%[b]	22
		" "	76%[b]	22

[a] To the starting material in toluene–DMF (1:1, 0.5 M) at 0°C was added the electrophile followed by TBAF. The mixture was stirred 1 h at 0°C.
[b] To the starting material in toluene–CH_3CN (1:1, 0.5 M) was added the electrophile followed by cesium acetate. The mixture was stirred 2 h at 70°C.

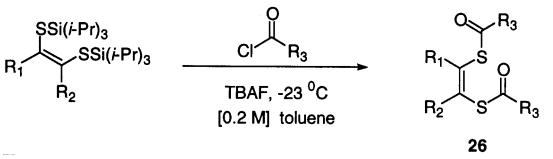
Table 3. Double-addition products from a one-pot 2-step reaction



Electrophile	Product	Yield	Compound
		65%[a]	23
		67%[a]	24
		69%[b]	25

[a] Cesium acetate was used to remove the silyl groups.
[b] TBAF was used to remove the silyl groups.

Table 4. Double-addition products of acyl chlorides to Z-1,2-bis-triisopropylsilanylsulfanyl-alkenes



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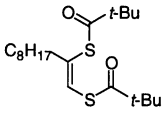
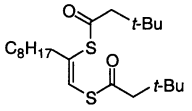
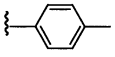
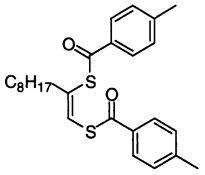
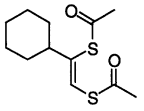
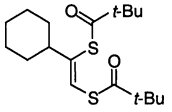
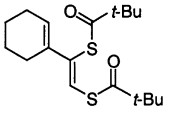
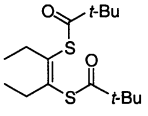
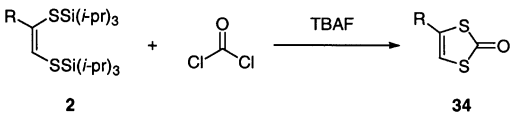
R_1	R_2	R_3	product	yield (%)	Compound
C_8H_{17}	H	t-Bu		70%[a]	27
C_8H_{17}	H	CH_2t-Bu		87%	28
C_8H_{17}	H			86%	29
	H	CH_3		57%[b]	30
	H	t-Bu		77%	31
	H	t-Bu		55%	32
CH_2CH_3	CH_2CH_3	t-Bu		68%	33

[a] The reaction was performed at 0°C.
[b] The reaction was performed at −78°C.

with iodo and bromopropionate in 60 and 54% isolated yield. For activated halides such as 2-bromoacetophenone, the yield was slightly higher and reached 70%. Finally, reagents that had two electrophilic sites led to cyclic adducts. With 1.2 equiv. of 1,3-dibromoacetone, the 7-membered ring ketone **19** was formed in only 34% yield. We then looked at epoxides versus substrate **5**. We did experience a lot of problems using TBAF and 1,2-epoxy-7-octene and decided to search for a different deprotecting agent. We found that cesium acetate was efficient enough to remove the silyl groups but at higher temperature. Therefore a mixture of **5**, 2.5 equiv. of the epoxide and 2.5 equiv. of cesium acetate were heated to 70°C for 2 h. The expected diol **20** was isolated in 71%. We did not encounter the same success with other type of epoxides. For example, cyclopentene oxide did not furnish any trace of compound under these conditions although this could be explained by the reduced reactivity of 1,2-disubstituted epoxides. Having a different method to remove the triisopropylsilyl groups, we decided to examine the cesium acetate conditions with other aliphatic and benzylic halides. As can be seen in Table 2, benzyl bromide seems to be superior over benzyl chloride while there is no difference between the iodo and bromopropane. Overall, the yields were in the range 66–76%.

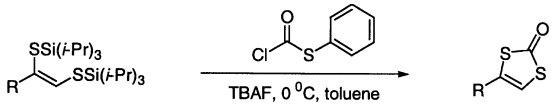


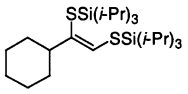
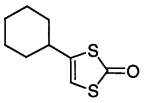
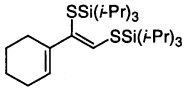
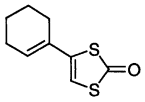
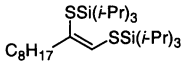
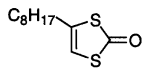
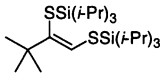
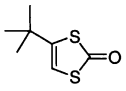
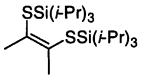
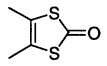
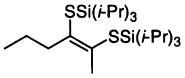
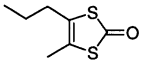
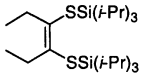
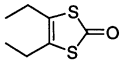
2 34

Scheme 1.

Interestingly, the final products of double addition could

Table 5. Preparation of 1,3-dithiol-2-ones from **Z**-1,2-bis-triisopropylsilanylsulfanyl-alkenes and phenyl chlorothiolformate



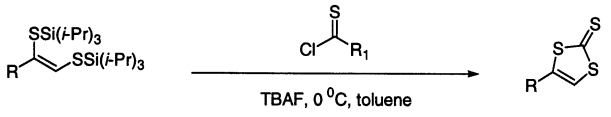
substrate	product	yield (%)	Compound
		75%	35
		61%[a]	36
		63%	37
		88%	38
		71%[a]	39
		67%[a]	40
		40%[a]	41

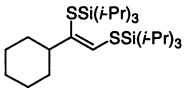
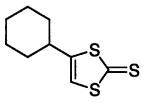
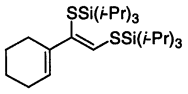
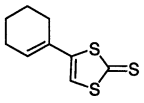
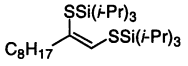
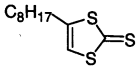
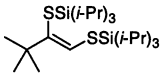
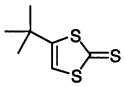
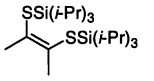
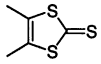
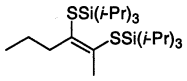
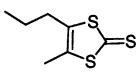
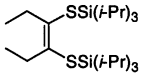
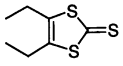
[a] Reaction was performed at −23°C.

also come from a one-pot 2-step reaction if one decided to start from the alkyne in the following way. The catalyzed cross-coupling addition of the alkyne and reagent **1** was run at 90°C for 15 h followed by treatment of the mixture with either TBAF/halide or cesium acetate/halide. Table 3 shows three examples obtained from 1-decyne in such a way. Typically, the overall yields (65–69%) for this 2-step process are in the same limit as the ones achieved from compound **5** with similar electrophiles.

So far we have focused our efforts on soft electrophiles. However some hard electrophiles could also be used. For instance, when substrate **2** was subjected to acyl chlorides and TBAF, the corresponding bis-thiolester was isolated in reasonably good yield. The choice of the temperature at which the reaction was performed proved to be important for two reasons. First, the yield can be increased if the reaction is carried out at lower temperature (−23°C) and second, the final compounds are easier to purify since they are less contaminated by impurities coming from side reactions. In basic media, acyl chlorides having α-hydrogen are know to be converted to ketenes[5] which are prone to fast oligomerization.[6] This problem can be greatly reduced by running the reaction at −23°C or even −78°C as in the case of acetyl chloride. In some instances, these conditions were still not sufficient. Propionyl chloride is an example, which gave too many undesirable side products, and we were not able to isolate the bis-addition product in satisfactory purity. Sterically hindered α-hydrogen acyl chlorides like *t*-butylacetyl chloride gave limited side products and a higher yield of **28** could be achieved. Obviously, these problems can be overcome by using acyl chlorides that possess no α-hydrogen. Pivaloyl chloride and *p*-toluoyl chloride fall in this category and as can be seen in Table 4, these electrophiles usually behaved very well with different substrates. We then turned our attention to phosgene, an even more reactive electrophile. This, we anticipated would lead to 1,3-dithiol-2-one **34** (Scheme 1). In fact, phosgene was not the best choice for this type of reaction with low yield of **34**. Triphosgene, a solid phosgene equivalent was more appropriate but yet, the yields were not satisfactory. Finally, we found that something less reactive would be good enough for our purpose. Phenyl chlorothiolformate was the reagent of choice for this transformation. Table 5 summarized the end result for this conversion with seven bis-triisopropylsilyl-alkenes. The yields are generally good particularly for the *t*-butyl derivative **38** with 88%. Also, some reactions were run at −23°C for optimum yields,

Table 6. Preparation of 1,3-dithiol-2-thiones from *Z*-1,2-bis-triisopropylsilanylsulfanyl-alkenes and thiophosgene or phenyl chlorothionoformate



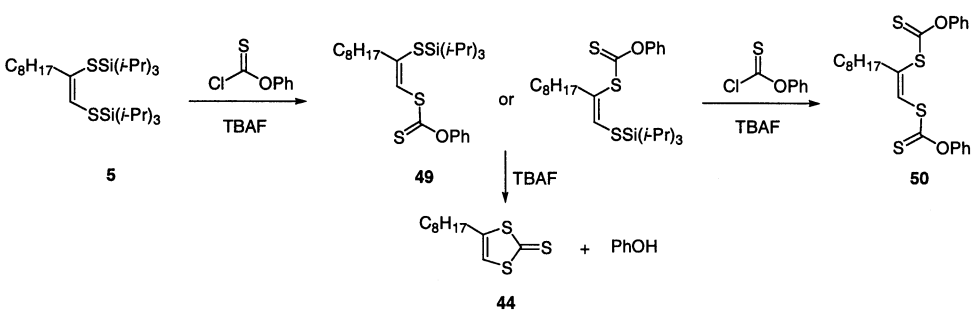
substrate	product	R_1= Cl yield (%)	R_1= OPh yield (%)	compound
		56%	94%	42
		59%	89%	43
		58%	88%	44
		51%	85%	45
		38%	78%[a]	46
		—	63%[a]	47
		—	35%[a]	48

[a] The reaction was performed at −23°C.

mainly in the cases of tetrasubstituted olefins. Other chloroformates (phenyl chloroformate, 4-nitrophenyl chloroformate and 4-methoxyphenyl chloroformate) were tested with less success.

In the same vein, 1,3-dithiol-2-thiones (the sulfur analogues of **34**) could be prepared by two different reagents. Under the standard reaction conditions (2.3 equiv. of TBAF at 0°C for 1 h) thiophosgene was much more efficient than phosgene to give the cyclic adduct. The yields are very consistent and remained in the 55% range (Table 6). The only exception to this came from compound **46** (38%). However this reaction still can be enhanced if one use phenyl chlorothionoformate instead of thiophosgene. This time the yield increased to 55% using the same conditions and reached 78% at −23°C. The superiority of this reagent can be seen in all the other substrates given in Table 6. In particular, the reaction was highly efficient with trisubstituted olefins with isolated yields between 85 and 94% (**42**–**45**).

The probable mechanism for this reaction (and most likely phenyl chloroformate) is described in Scheme 2. Starting



Scheme 2.

with **5**, the first attack of one of the thiolates on the chlorothionoformate gives **49** followed by the expulsion of the chloride ion. Subsequently, an intramolecular attack from the other thiolate on the thione resulted in the cyclic product **44** (88%) together with phenol as a side product. It did make sense to presume that the chloride ion would be expulsed before the phenol group. This was confirmed when the reaction was repeated with an excess of chlorothionoformate. The major compound is still **44** (71%) but a second product (**50**) which corresponds to the addition of two equivalents of chlorothionoformate could be isolated in 12% yield.

3. Conclusion

A collection of 1,2-bis-triisopropylsilanylsulfanyl-alkenes **2** was prepared. They represent a new class of compounds and the reactivity of these species toward electrophiles was investigated. These bis-triisopropylsilanylsulfany-alkenes are readily deprotected with either cesium acetate at 70°C or TBAF at 0°C and trapped with a wide variety of soft electrophiles to produce products of double addition. Hard electrophiles such as acyl chlorides and chloroformates were also captured by **2** to generate 1,3-dithiol-2-ones or 1,3-dithiol-2-thiones.

4. Experimental

4.1. Data for compounds

4.1.1. Bis(triisopropylsilyl)disulfide (1). To 9.75 g of triisopropylsilanethiol in 50 mL of benzene was added portionwise sodium hydride (1.05 equiv.) and the resulting suspension was allowed to stir for 10 min. A solution of iodine in 150 mL of benzene was added until a slight pink color remained. The suspension was filtered through celite and the solvent evaporated to yield an orange oil. The crude oil was crystallized overnight in hexane at −5°C to give 7.63 g (79%) of bright yellow crystals (**4**). Mp: 38°C. ^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.16 (6H, d, J=7.4 Hz) and 1.40 (1H, m, J=7.4 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 12.96 and 18.66; Anal. calcd for $C_{18}H_{42}S_2Si_2$: C, 57.07; H, 11.18; S, 16.93. Found: C, 57.43; H, 11.55; S, 16.50.

4.2. General procedure for the addition of bis-triisopropylsilyl disulfide 1 to alkynes

4.2.1. 1,2-Bis-triisopropylsilanylsulfanyl-dec-1-ene (5). To a solution of 1-decyne (500 mg, 3.61 mmol) in 3.6 mL of toluene was added bis-triisopropylsilyl disulfide **1** (1.44 g, 3.81 mmol) followed by $Pd(PPh_3)_4$ (200 mg, 0.18 mmol). The solution was stirred at 90°C overnight and then cooled to rt. After evaporation to dryness, the product was purified on a short pad of silica gel using hexane to yield 1.80 g (96%) of the desired compound **5** as a yellow oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.25 (s, 1H), 2.28 (t, J=7.2 Hz, 2H), 1.55 (m, 2H), 1.31 (m, 16H), 1.14 (m, 36H), 0.88 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 132.5, 122.9, 42.7, 31.8, 29.4, 29.2, 28.7, 28.5, 22.6, 18.5, 18.3, 14.0, 13.9, 12.7; HRMS calcd for $C_{28}H_{60}S_2Si_2+H^+$: 517.3753. Found: 517.3753.

4.2.2. (2,3-Bis-triisopropylsilanylsulfanyl-allyl)-benzene (6). To a solution of 3-phenyl-1-propyne (200 mg, 1.70 mmol) in 2 mL of benzene was added disulfide **1** (685 mg, 1.81 mmol) followed by $Pd(PPh_3)_4$ (100 mg, 0.09 mmol). Purification on a short pad of silica gel using 30% of toluene in hexane afforded 736 mg (86%) of compound **6** as a light yellow oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.18 (m, 5H), 5.93 (s, 1H), 3.62 (s, 2H), 1.37 (m, 3H), 1.18 (d, J=7.2 Hz, 18H), 1.09 (m, 3H), 0.98 (d, J=6.4 Hz, 18H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.7, 130.7, 129.2, 128.2, 126.2, 48.6, 18.6, 18.2, 13.9, 12.5; HRMS calcd for $C_{27}H_{50}S_2Si_2+H^+$: 495.2971. Found: 495.2969.

4.2.3. (1,2-Bis-triisopropylsilanylsulfanyl-vinyl)-cyclohexane (7). To a solution of cyclohexylethyne 1.00 g, 9.24 mmol) in 10 mL of benzene was added disulfide **1** (3.85 g, 10.2 mmol) followed by $Pd(PPh_3)_4$ (534 mg, 0.46 mmol). Purification on a short pad of silica gel using hexane afforded 3.04 g (67%) of **7**. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.22 (s, 1H), 2.02 (m, 3H), 1.77 (m, 2H), 1.67 (m, 1H), 1.27 (m, 6H), 1.11 (m, 41H); ^{13}C NMR (75 MHz, acetone-d_6) δ 139.0, 122.5, 51.3, 34.5, 28.1, 27.7, 19.7, 19.4, 15.2, 14.0; HRMS calcd for $C_{26}H_{54}S_2Si_2+H^+$: 486.3284. Found: 486.3284.

4.2.4. 1-(1,2-Bis-triisopropylsilanylsulfanyl-vinyl)-cyclohexene (8). To a solution of 1-ethynylcyclohexene (450 mg, 4.24 mmol) in 4.2 mL of benzene was added disulfide **1** (1.69 g, 4.45 mmol) followed by $Pd(PPh_3)_4$ (245 mg, 0.21 mmol). Purification on a short pad of silica gel using hexane afforded 1.62 g (77%) of compound **8**. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.57 (s, 1H), 6.31 (m, 1H), 2.14 (m, 4H), 1.59 (m, 4H), 1.29 (m, 6H), 1.12 (m, 36H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.1, 133.1, 126.7, 123.9, 27.2, 25.6, 23.0, 22.2, 18.5, 18.3, 13.9, 12.7; HRMS calcd for $C_{26}H_{52}S_2Si_2+H^+$: 485.3127. Found: 485.3126.

4.2.5. 3,3-Dimethyl-1,2-bis-triisopropylsilanylsulfanyl-but-1-ene (9). To a solution of 3,3-dimethyl-1-butyne (1.56 g, 19.0 mmol) in 10 mL of benzene was added disulfide **1** (4.0 g, 10.6 mmol) followed by $Pd(PPh_3)_4$ (610 mg, 0.53 mmol). Purification on a short pad of silica gel using hexane afforded 3.39 g (70%) of the title compound **9**. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.53 (s, 1H), 1.50 (m, 3H), 1.28 (m, 3H), 1.14 (m, 45H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 141.8, 122.6, 40.3, 30.2, 18.9, 18.4, 14.2, 12.7; HRMS calcd for $C_{24}H_{52}S_2Si_2+H^+$: 461.3127. Found: 461.3128.

4.2.6. 5-Chloro-1,2-bis-triisopropylsilanylsulfanyl-pent-1-ene (10). To a solution of 5-chloro-1-pentyne (630 μL, 6.03 mmol) in 6 mL of toluene was added disulfide **1** (2.50 g, 6.57 mmol) followed by $Pd(PPh_3)_4$ (346 mg, 0.31 mmol). Purification on a short pad of silica gel using hexane afforded 2.21 g (76%) of the title compound **10**. ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.39 (s, 1H), 3.49 (t, J=6.2 Hz, 2H), 2.47 (t, J=6.8 Hz, 2H), 2.03 (m, 2H), 1.3 (m, 6H), 1.12 (m, 36H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 129.9, 125.6, 43.8, 39.2, 30.7, 18.5, 18.3, 13.9, 12.6; HRMS calcd for $C_{23}H_{49}ClS_2Si_2+H^+$: 480.2503. Found: 480.2502.

4.2.7. Acetic acid 10,11-bis-triisopropylsilanylsulfanyl-undec-10-enyl ester (11). To a solution of 10-undecyn-1-yl

acetate (720 mg, 3.66 mmol) in 3.7 mL of toluene was added disulfide **1** (1.53 g, 4.04 mmol) followed by $Pd(PPh_3)_4$ (200 mg, 0.18 mmol). Purification on a short pad of silica gel using 2% ethyl acetate in hexane afforded 1.75 g (83%) of the desired compound **11** as an orange oil. ^1H NMR (500 MHz, $CDCl_3$) δ 6.25 (s, 1H), 4.05 (t, J=6.8 Hz, 2H), 2.28 (t, J=7.3 Hz, 2H), 2.04 (s, 3H), 1.59 (m, 4H), 1.28 (m, 16H), 1.13 (m, 36H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 171.1, 132.4, 123.1, 64.5, 42.7, 29.4, 29.3, 29.2, 28.7, 28.5, 28.4, 25.8, 20.9, 18.5, 18.3, 13.9, 12.6; HRMS calcd for $C_{31}H_{64}O_2S_2Si_2+H^+$: 588.3886. Found: 588.3888.

4.2.8. 10,11-Bis-triisopropylsilanylsulfanyl-undec-10-enoic acid methyl ester (12). To a solution of methyl-10-undecynoate (954 mg, 4.86 mmol) in 4.8 mL of toluene was added disulfide **1** (1.99 g, 5.25 mmol) followed by $Pd(PPh_3)_4$ (278 mg, 0.24 mmol). Purification on a short pad of silica gel using 2% ethyl acetate in hexane afforded 1.73 g (60%) of the desired compound **12**. ^1H NMR (300 MHz, $CDCl_3$) δ 6.25 (s, 1H), 3.66 (s, 3H), 2.28 (m, 4H), 1.57 (m, 4H), 1.29 (m, 14H), 1.12 (m, 36H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 174.0, 132.4, 122.9, 51.2, 42.6, 33.9, 29.1, 28.9, 28.5, 28.4, 24.8, 18.4, 18.2, 13.8, 12.6; HRMS calcd for $C_{30}H_{62}O_2S_2Si_2+H^+$: 574.3730. Found: 574.3729.

4.2.9. 10,11-Bis-triisopropylsilanylsulfanyl-undec-10-en-1-ol (13). To a solution of 10-undecyn-1-ol (816 mg, 4.85 mmol) in 4.8 mL of toluene was added disulfide **1** (2.00 g, 5.41 mmol) followed by $Pd(PPh_3)_4$ (270 mg, 0.24 mmol). Purification on a short pad of silica gel using 8% ethyl acetate in hexane afforded 1.44 g (54%) of the title compound **13**. ^1H NMR (500 MHz, $CDCl_3$) δ 6.25 (s, 1H), 3.63 (t, J=6.6 Hz, 2H), 2.28 (t, J=7.3 Hz, 2H), 1.56 (m, 4H), 1.29 (m, 16H), 1.13 (m, 36H); ^{13}C NMR (100 MHz, $CDCl_3$, at 320 K) δ 133.1, 123.1, 63.0, 42.9, 32.9, 29.5, 29.4, 28.8, 28.7, 25.8, 18.6, 18.4, 14.1, 12.9; HRMS calcd for $C_{29}H_{62}OS_2Si_2+H^+$: 546.3781. Found: 546.3780.

4.2.10. 2,3-Bis-triisopropylsilanylsulfanyl-but-2-ene (14). To a solution of 2-butyne (1.65 mL, 21.1 mmol) in 6 mL of toluene was added disulfide **1** (4.0 g, 10.6 mmol) followed by $Pd(PPh_3)_4$ (610 mg, 0.53 mmol). The mixture was stirred at 100°C for 15 h. Purification on a short pad of silica gel using hexane afforded 2.31 g (50%) of the desired compound **14** as a yellow oil. ^1H NMR (300 MHz, $CDCl_3$) δ 2.12 (s, 6H), 1.30 (m, 6H), 1.16 (m, 36H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 129.8, 26.4, 18.6, 13.8; HRMS calcd for $C_{22}H_{48}S_2Si_2+H^+$: 433.2814. Found: 433.2814.

4.2.11. 2,3-Bis-triisopropylsilanylsulfanyl-hex-2-ene (15). To a solution of 2-hexyne (2.1 mL, 18.5 mmol) in 5.3 mL of toluene was added disulfide **1** (3.51 g, 9.24 mmol) followed by $Pd(PPh_3)_4$ (534 mg, 0.46 mmol). The mixture was stirred at 130°C for 15 h. Purification on a short pad of silica gel using hexane afforded 1.79 g (42%) of the desired compound **15** as an orange oil. ^1H NMR (500 MHz, $CDCl_3$) δ 2.34 (m, 2H), 2.13 (s, 3H), 1.57 (m, 2H), 1.31 (m, 6H), 1.13 (m, 36H), 0.92 (t, J=7.7 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 134.7, 131.4, 41.9, 26.1, 21.6, 18.7, 18.6, 13.9, 13.8, 13.7; HRMS calcd for $C_{24}H_{52}S_2Si_2+H^+$: 461.3127. Found: 461.3128.

4.2.12. 3,4-Bis-triisopropylsilanylsulfanyl-hex-3-ene (16). To a solution of 3-hexyne (2.4 mL, 21.1 mmol) in 6 mL of toluene was added disulfide **1** (4.0 g, 10.6 mmol) followed by $Pd(PPh_3)_4$ (610 mg, 0.53 mmol). The mixture was stirred at 130°C for 15 h. Purification on a short pad of silica gel using hexane afforded 3.52 g (72%) of compound **16** as a light yellow oil. ^1H NMR (500 MHz, $CDCl_3$) δ 2.36 (q, J=7.4 Hz, 4H), 1.31 (m, 6H), 1.11 (m, 42H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 137.5, 32.4, 18.7, 13.8, 13.2; HRMS calcd for $C_{24}H_{52}S_2Si_2+H^+$: 461.3127. Found: 461.3128.

4.2.13. 3-[2-Cyclohex-1-enyl-2-(2-methoxycarbonyl-ethylsulfanyl)-vinylsulfanyl]-propionic acid methyl ester (17). To a solution of compound **8** (520 mg, 1.10 mmol) in 2.4 mL of toluene:DMF (1:1) at 0°C, was added methyl-3-iodopropionate (575 mg, 2.71 mmol) or methyl 3-bromopropionate (450 mg, 2.71 mmol) followed by solid TBAF (700 mg, 2.71 mmol). The solution was stirred 1 h at 0°C and then quenched with ammonium acetate (25%), washed with water and brine. The organic phase was dried over $MgSO_4$, filtered and evaporated to dryness. Flash chromatography using 20% ethyl acetate in hexane, afforded 220 mg (60%) of the title compound **17** when 3-iodopropionate was used as electrophile. ^1H NMR (300 MHz, $CDCl_3$) δ 6.43 (s, 1H), 6.15 (m, 1H), 3.66 (s, 3H), 3.64 (s, 3H), 2.97 (t, J=7.4 Hz, 2H), 2.81 (t, J=7.6 Hz, 2H), 2.64 (t, J=7.4 Hz, 2H), 2.51 (t, J=7.6 Hz, 2H), 2.14 (m, 4H), 1.64 (m, 2H), 1.53 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 172.4, 171.9, 134.4, 131.8, 131.5, 126.8, 51.8, 51.6, 35.4, 34.5, 28.8, 28.1, 26.7, 25.7, 22.7, 22.1; HRMS calcd for $C_{16}H_{24}O_4S_2+H^+$: 345.1194. Found: 345.1196.

4.2.14. 2-[2-Cyclohex-1-enyl-2-(2-oxo-2-phenyl-ethylsulfanyl)-vinylsulfanyl]-1-phenyl-ethanone (18). Following the procedure used for compound **17**; to a solution of **8** (500 mg, 1.03 mmol) in 2 mL of toluene/DMF (1:1) at 0°C was added 2-bromoacetophenone (513 mg, 2.58 mmol) and solid TBAF (675 mg, 2.58 mmol). After purification by flash chromatography using 2% ethyl acetate in toluene, 295 mg (70%) of the desired compound **18** was obtained. ^1H NMR (300 MHz, $CDCl_3$) δ 7.93 (d, J=7.5 Hz, 2H), 7.79 (d, J=7.5 Hz, 2H), 7.55–7.31 (m, 6H), 6.59 (s, 1H), 6.14 (m, 1H), 3.95 (s, 2H), 3.87 (s, 2H), 2.05 (m, 4H), 1.57 (m, 2H), 1.47 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.6, 193.9, 135.6, 134.7, 133.6, 133.4, 132.9, 131.7, 131.0, 128.6, 128.5, 128.4, 128.2, 127.4, 38.7, 38.3, 26.3, 25.6, 22.5, 21.8; HRMS calcd for $C_{24}H_{24}O_2S_2+H^+$: 409.1296. Found: 409.1296.

4.2.15. 2-Cyclohex-1-enyl-[1,4]dithiepin-6-one (19). Following the procedure used for compound **17**; to a solution of **8** (700 mg, 1.44 mmol) in 2.8 mL of toluene/DMF (1:1) at 0°C was added 1,3-dibromoacetone (373 mg, 1.73 mmol) and solid TBAF (943 mg, 3.61 mmol). Purification by flash chromatography using 40% toluene in hexane afforded 110 mg (34%) of the desired compound **19**. ^1H NMR (300 MHz, $CDCl_3$) δ 6.21 (s, 1H), 6.14 (s, 1H), 4.04 (s, 2H), 3.94 (s, 2H), 2.17 (m, 4H), 1.67 (m, 2H), 1.57 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 200.3, 137.0, 135.7, 127.7, 114.1, 39.9, 37.9, 27.4, 25.7, 22.7, 21.8; HRMS calcd for $C_{11}H_{14}OS_2+H^+$: 227.0564. Found: 227.0565.

4.2.16. 1-[2-(2-Hydroxy-hex-5-enylsulfanyl)-dec-1-enylsulfanyl]-hex-5-en-2-ol (20). To a solution of **5** (90 mg,

0.17 mmol) in 0.34 mL of toluene/acetonitrile (1:1) was added 1,2-epoxy-5-hexene (48 mg, 0.44 mmol) and cesium acetate (84 mg, 0.44 mmol). The mixture was heated at 70°C for 2 h then cooled to rt. The reaction was diluted with ethyl acetate, washed with ammonium acetate (25%), water and brine. The organic phase was then dried over $MgSO_4$, filtered and evaporated. After purification by flash chromatography with 20% ethyl acetate in hexane, 48 mg (71%) of compound **20** was obtained as a 1:1 diastereomeric mixture. ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.18 (s, 1H), 5.82 (m, 2H), 5.02 (m, 4H), 3.69 (m, 1H), 3.55 (m, 1H), 3.31 (d, J=2.3 Hz, 0.5H), 3.05 (m, 1H), 2.92 (m, 2H), 2.66 (m, 1.5H), 2.49 (m, 1H), 2.21 (m, 6H), 1.55 (m, 6H), 1.25 (m, 10H), 0.87 (t, J=6.8 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) characteristic peaks are: δ 138.0, 137.9, 137.8, 133.0, 132.2, 130.0, 129.8, 114.9, 114.8, 114.7, 70.1, 69.6, 68.9, 68.5; HRMS calcd for $C_{22}H_{40}O_2S_2+H^+$: 401.2548. Found: 401.2546.

4.2.17. 1-[2-(2-Methylsulfanyl-benzene)-dec-1-enylsulfanyl]-methyl-benzene (21). Following the procedure used for compound **20**; to a solution of **5** (500 mg, 0.97 mmol) in 2 mL of toluene/DMF (1:1) was added benzyl bromide (345 μL, 2.90 mmol) or benzyl chloride (239 μL, 2.90 mmol) and cesium acetate (464 mg, 2.42 mmol). After flash chromatography using 20% toluene in hexane, 280 mg (75%) of compound **21** was isolated when benzyl bromide was used as electrophile. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.25 (m, 10H), 6.06 (s, 1H), 3.87 (s, 4H), 2.08 (t, J=7.2 Hz, 2H), 1.36 (m, 2H), 1.21 (m, 10H), 0.87 (t, J=6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.0, 137.9, 132.7, 128.7, 128.6, 128.4, 128.2, 127.3, 127.0, 126.8, 37.9, 37.6, 35.9, 31.8, 29.2, 29.1, 28.8, 28.2, 22.6, 14.0; HRMS calcd for $C_{24}H_{32}S_2+H^+$: 385.2024. Found: 387.2023.

4.2.18. 1,2-Bis-propylsulfanyl-dec-1-ene (22). Following the procedure used for compound **20**; to a solution of **5** (800 mg, 1.55 mmol) in 3 mL of toluene/acetonitrile (1:1) was added 1-iodopropane (377 μL, 3.87 mmol) or 1-bromopropane (422 μL, 4.64 mmol) and cesium acetate (742 mg, 3.87 mmol). After flash chromatography using 10% toluene in hexane, 326 mg (73%) of compound **22** was obtained when 1-iodopropane was used as electrophile. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.04 (s, 1H), 2.67 (t, J=7.3 Hz, 4H), 2.24 (t, J=7.5 Hz, 2H), 1.49–1.72 (m, 6H), 1.28 (m, 10H), 1.05 (t, J=7.3 Hz, 6H), 0.88 (t, J=7.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 131.9, 126.8, 36.8, 36.0, 33.2, 31.7, 29.3, 29.1, 28.8, 28.4, 23.5, 23.2, 22.5, 13.9, 13.3, 13.1; HRMS calcd for $C_{16}H_{32}S_2+H^+$: 289.2024. Found: 289.2023.

4.2.19. 4-[2-(3-Ethoxycarbonyl-propylsulfanyl)-dec-1-enylsulfanyl]-butyric acid ethyl ester (23). To a solution of 1-decyne (200 mg, 1.45 mmol) in 1.5 mL of toluene was added disulfide **1** (575 mg, 1.52 mmol) and $Pd(PPh_3)_4$ (84 mg, 0.07 mmol). The solution was stirred at 90°C overnight and cooled to rt. The reaction mixture was diluted with 1.5 mL of DMF followed by the addition of ethyl 4-bromobutyrate (518 μL, 3.62 mmol) and cesium acetate (694 mg, 3.62 mmol). The reaction was stirred at 70°C for 2 h and cooled to rt. After dilution with ethyl acetate, the solution was washed with ammonium acetate (25%), water and brine. The organic phase was dried over $MgSO_4$, filtered and evaporated to dryness. Purification by flash chromatography using 2% ethyl acetate in hexane afforded 405 mg (65%) of the desired compound **23**. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.07 (s, 1H), 4.13 (m, 4H), 2.73 (t, J=7.1 Hz, 4H), 2.46 (dd, J=7.3, 9.0 Hz, 4H), 2.24 (t, J=7.6 Hz, 2H), 2.00–1.83 (m, 4H), 1.49 (m, 2H), 1.25 (m, 16H), 0.88 (t, J=6.5 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 172.9, 172.7, 131.9, 127.3, 60.2, 60.1, 36.6, 33.0, 32.7, 32.5, 31.7, 30.4, 29.2, 29.1, 28.8, 28.4, 25.4, 24.9, 22.5, 14.1, 13.9; HRMS calcd for $C_{22}H_{40}O_4S_2+H^+$: 433.2446. Found: 433.2448.

4.2.20. 2-[2-(2-Hydroxy-ethylsulfanyl)-dec-1-enylsulfanyl]-ethanol (24). Following the procedure used for compound **23**; to a solution of 1-decyne (200 mg, 1.45 mmol) in 1.5 mL of toluene was added disulfide **1** (575 mg, 1.52 mmol) and $Pd(PPh_3)_4$ (84 mg, 0.07 mmol). After 15 h, the reaction mixture was diluted with 1.5 mL of DMF followed by the addition of 2-iodoethanol (282 μL, 3.62 mmol) and cesium acetate (694 mg, 3.62 mmol). Purification by flash chromatography using 60% ethyl acetate in hexane afforded 283 mg (67%) of the desired compound **24**. Mp: 41.3°C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.22 (s, 1H), 3.77 (t, J=5.7 Hz, 2H), 3.65 (t, J=5.5 Hz, 2H), 2.84 (m, 4H), 2.24 (t, J=7.5 Hz, 2H), 1.52 (m, 2H), 1.27 (m, 10H), 0.88 (t, J=6.6 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 132.5, 129.6, 61.3, 60.1, 36.9, 36.6, 34.6, 31.7, 29.2, 29.1, 28.8, 28.4, 22.5, 14.0; HRMS calcd for $C_{14}H_{28}O_2S_2+H^+$: 293.1609. Found: 293.1608.

4.2.21. 2-Octyl-6,7-dihydro-5*H*-[1,4]dithiepine (25). To a solution of 1-decyne (200 mg, 1.45 mmol) in 1.5 mL of toluene was added disulfide **1** (575 mg, 1.52 mmol) and $Pd(PPh_3)_4$ (84 mg, 0.07 mmol). The mixture was heated at 90°C overnight then cooled to rt. The reaction was diluted with 9.4 mL of THF, cooled to 0°C and 1,3-diiodopropane (185 μL, 1.59 mmol) followed by TBAF (3.6 mL, 3.6 mmol, 1.0 M/THF) were added. After 1 h at 0°C, the reaction was diluted with ethyl acetate, washed with ammonium acetate (25%), water and brine. The organic phase was dried over $MgSO_4$, filtered and evaporated to dryness. Purification by flash chromatography using hexane afforded 249 mg (69%) of compound **25**. ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.82 (s, 1H), 3.36 (m, 4H), 2.14 (m, 4H), 1.47 (m, 2H), 1.27 (m, 10H), 0.88 (t, J=6.8 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 137.8, 115.1, 40.5, 31.7, 31.5, 31.4, 29.2, 29.1, 28.7, 28.6, 22.5, 14.0; HRMS calcd for $C_{13}H_{24}S_2+H^+$: 245.1398. Found: 245.1398.

4.2.22. 2,2-Dimethyl-thiopropionic acid *S*-[1-(2,2-dimethyl-propionylsulfanylmethylene)-nonyl] ester (27). To a solution of compound **5** (249 mg, 0.48 mmol) in 1.2 mL of toluene at 0°C was added pivaloyl chloride (130 μL, 1.06 mmol) followed by TBAF (1.2 mL, 1.2 mmol, 1.0 M/THF). The mixture was stirred at 0°C for 1 h, diluted with ethyl acetate, washed with ammonium acetate (25%), water, bicarbonate and brine. The organic phase was then dried over $MgSO_4$, filtered and evaporated. Purification by flash chromatography using 30% toluene in hexane afforded 125 mg (70%) of the desired compound **27** as a yellow oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.18 (s, 1H), 2.41 (t, J=7.3 Hz, 2H), 1.52 (m, 2H), 1.26 (m, 28H), 0.88 (t,

J=6.1 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 202.2, 202.0, 131.2, 128.4, 47.1, 46.6, 39.3, 31.8, 29.3, 29.1, 28.9, 28.0, 27.2, 27.1, 22.6, 14.0; HRMS calcd for $C_{20}H_{36}O_2S_2+H^+$: 373.2235. Found: 373.2237.

4.2.23. 3,3-Dimethyl-thiobutyric acid *S*-[1-(3,3-dimethyl-butyrylsulfanylmethylene)-nonyl] ester (28). Following the procedure used for compound **27**; to a solution of **5** (200 mg, 0.39 mmol) in 1 mL of toluene at −23°C was added *t*-butyl acetyl chloride (130 μL, 0.93 mmol) followed by TBAF (1.0 mL, 1.0 mmol, 1.0 M/THF). After flash chromatography using 20% toluene and 1% ethyl acetate in hexane, 137 mg (87%) of compound **28** was obtained. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.23 (s, 1H), 2.45 (s, 4H), 2.41 (t, J=6.9 Hz, 2H), 1.50 (m, 2H), 1.26 (m, 10H), 1.07 (s, 9H), 1.03 (s, 9H), 0.88 (t, J=7.1 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 193.6, 193.5, 130.9, 128.3, 56.9, 56.5, 39.2, 31.9, 31.8, 31.7, 29.6, 29.3, 29.1, 28.9, 28.0, 22.6, 14.1; HRMS calcd for $C_{22}H_{40}O_2S_2+H^+$: 401.2548. Found: 401.2546.

4.2.24. 4-Methyl-thiobenzoic acid *S*-[1-(4-methylphenyl-sulfanylmethylene)-nonyl] ester (29). Following the procedure used for compound **27**; to a solution of **5** (207 mg, 0.41 mmol) in 1 mL of toluene at −23°C was added *p*-toluoyl chloride (125 μL, 0.93 mmol) followed by TBAF (1.0 mL, 1.0 mmol, 1.0 M/THF). After flash chromatography using 3% ethyl acetate in hexane 152 mg (86%) of compound **29** was obtained. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.92 (d, J=8.2 Hz, 2H), 7.82 (d, J=8.2 Hz, 2H), 7.56 (s, 1H), 7.25 (d, J=8.0 Hz, 2H), 7.23 (d, J=8.1 Hz, 2H), 2.57 (t, J=7.4 Hz, 2H), 2.41 (s, 3H), 2.37 (s, 3H), 1.61 (m, 2H), 1.28 (m, 10H), 0.87 (t, J=7.1 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.2, 186.9, 144.7, 144.6, 134.0, 133.7, 131.0, 129.3, 129.1, 127.7, 127.4, 39.5, 31.8, 29.3, 29.1, 28.9, 28.1, 22.6, 21.6, 21.6, 14.0; HRMS calcd for $C_{26}H_{32}O_2S_2+H^+$: 441.1922. Found: 441.1924.

4.2.25. Thioacetic acid *S*-(2-acetylsulfanyl-2-cyclohexyl-vinyl) ester (30). Following the procedure used for compound **27**; to a solution of **7** (306 mg, 0.63 mmol) in 1.5 mL of toluene at −78°C was added acetyl chloride (105 μL, 1.48 mmol) and TBAF (1.5 mL, 1.5 mmol, 1.0 M/THF). After flash chromatography using 4% ethyl acetate in hexane, 93 mg (57%) of compound **30** was obtained. ^{1}H NMR (300 MHz, DMSO-d_6) δ 7.18 (s, 1H), 2.39 (s, 3H), 2.37 (s, 3H), 2.25 (m, 1H), 1.72 (m, 4H), 1.63 (m, 1H), 1.32–1.11 (m, 5H); ^{13}C NMR (100 MHz, DMSO-d_6, at 325 K) δ 196.4, 195.7, 140.4, 132.7, 51.9, 36.5, 35.5, 35.2, 30.6, 30.4; HRMS calcd for $C_{12}H_{18}O_2S_2+H^+$: 259.0826. Found: 259.0827.

4.2.26. 2,2-Dimethyl-thiopropionic acid *S*-[1-cyclohexyl-2-(2,2-dimethyl-propionylsulfanyl)-vinyl] ester (31). Following the procedure used for compound **27**; to a solution of **7** (260 mg, 0.53 mmol) in 1.3 mL of toluene at −23°C was added pivaloyl chloride (150 μL, 1.23 mmol) followed by TBAF (1.3 mL, 1.3 mmol, 1.0 M/THF). After flash chromatography using 40% toluene in hexane, 141 mg (77%) of compound **31** was obtained as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.26 (s, 1H), 2.21 (m, 1H), 1.87 (m, 2H), 1.76 (m, 2H), 1.65 (m, 1H), 1.29 (s, 9H), 1.27 (m, 5H), 1.23 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 202.4, 202.1, 135.5, 128.1, 47.8, 47.1, 46.6, 31.8, 27.2, 27.1, 26.2, 25.9; HRMS calcd for $C_{18}H_{30}O_2S_2+H^+$: 343.1765. Found: 343.1765.

4.2.27. 2,2-Dimethyl-thiopropionic acid *S*-[1-cyclohex-1-enyl-2-(2,2-dimethyl-propionylsulfanyl)-vinyl] ester (32). Following the procedure used for compound **27**; to a solution of **8** (296 mg, 0.61 mmol) in 1.5 mL of toluene at −23°C was added pivaloyl chloride (180 μL, 1.46 mmol) followed by TBAF (1.5 mL, 1.5 mmol, 1.0 M/THF). After flash chromatography using 50% toluene in hexane, 114 mg (55%) of compound **32** was obtained as a yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45 (s, 1H), 6.17 (m, 1H), 2.35 (m, 2H), 2.15 (m, 2H), 1.72 (m, 2H), 1.57 (m, 2H), 1.31 (s, 9H), 1.25 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 202.0, 201.8, 135.1, 129.7, 127.9, 127.3, 47.2, 46.6, 27.2, 27.1, 26.2, 25.9, 22.6, 21.8; HRMS calcd for $C_{18}H_{28}O_2S_2+H^+$: 341.1609. Found: 341.1609.

4.2.28. 2,2-Dimethyl-thiopropionic acid *S*-[2-(2,2-dimethyl-propionylsulfanyl)-1-ethyl-but-1-enyl] ester (33). Following the procedure used for compound **27**; to a solution of **16** (305 mg, 0.65 mmol) in 1.6 mL of toluene at −23°C was added pivaloyl chloride (190 μL, 1.56 mmol) and TBAF (1.6 mL, 1.6 mmol, 1.0 M/THF). After flash chromatography using 4% toluene in hexane, 140 mg (68%) of compound **33** was obtained as a colorless oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.52 (q, J=7.5 Hz, 4H), 1.24 (s, 18H), 1.11 (t, J=7.5 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 204.2, 141.4, 46.8, 29.0, 27.3, 13.2; HRMS calcd for $C_{16}H_{28}O_2S_2+H^+$: 317.1609. Found: 317.1608.

4.3. General procedure for the preparation of 1,3-dithiol-2-one

4.3.1. 4-Cyclohexyl-[1,3]dithiol-2-one (35). To a solution of **7** (350 mg, 0.63 mmol) in 1.4 mL of toluene at 0°C was added phenyl chlorothiolformate (91 μL, 0.68 mmol) followed by TBAF (1.6 mL, 1.6 mmol, 1.0 M/THF). The mixture was stirred 1 h, diluted with ethyl acetate and washed with ammonium acetate (25%), water and brine. The organic phase was then dried over $MgSO_4$, filtered and evaporated. The compound was isolated by flash chromatography using 25% toluene and 1% ethyl acetate in hexane to yield 95 mg (75%) of **35** as a yellow oil which was identical to an authentic sample by ^{1}H and ^{13}C NMR.[7]

4.3.2. 4-Cyclohex-1-enyl-[1,3]dithiol-2-one (36). Following the procedure used for compound **35**; to a solution of **8** (461 mg, 0.95 mmol) in 2.3 mL of toluene at −23°C, was added phenyl chlorothiolformate (138 μL, 1.02 mmol) followed by TBAF (2.3 mL, 2.3 mmol, 1.0 M/THF). The compound was isolated by flash chromatography using 50% toluene in hexane to yield 121 mg (61%) of compound **36** as a white solid which was identical to an authentic sample by ^{1}H and ^{13}C NMR.[7]

4.3.3. 4-Octyl-[1,3]dithiol-2-one (37). Following the procedure used for compound **35**; to a solution of **5** (404 mg, 0.77 mmol) in 1.9 mL of toluene at 0°C was added phenyl chlorothiolformate (115 μL, 0.85 mmol) followed by TBAF (1.9 mL, 1.9 mmol, 1.0 M/THF). The compound

was isolated by flash chromatography using 30% toluene in hexane to yield 111 mg (63%) of compound **37** as a yellow oil which was identical to an authentic sample by ^{1}H- and ^{13}C NMR.[7]

4.3.4. 4-*t*-Butyl-[1,3]dithiol-2-one (38). Following the procedure used for compound **35**; to a solution of **9** (454 mg, 0.98 mmol) in 2.4 mL of toluene at 0°C, was added phenyl chlorothiolformate (148 μL, 1.1 mmol) followed by TBAF (2.5 mL, 2.5 mmol, 1.0 M/THF). The compound was isolated by flash chromatography using 30% toluene in hexane to yield 150 mg (88%) of compound **38** as a yellow oil which was identical to an authentic sample by ^{1}H and ^{13}C NMR.[7]

4.3.5. 4,5-Dimethyl-[1,3]dithiol-2-one (39).[8] Following the procedure used for compound **35**; to a solution of **14** (505 mg, 1.15 mmol) in 2.9 mL of toluene at −23°C, was added phenyl chlorothiolformate (175 μL, 1.27 mmol) followed by TBAF (2.9 mL, 2.9 mmol, 1.0 M/THF). The compound was purified by flash chromatography using 40% toluene in hexane to yield 121 mg (71%) of compound **39**. Mp: 44.5–45.2°C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.15 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.2, 122.8, 13.8; HRMS calcd for $C_5H_6OS_2+H^+$: 146.9938. Found: 146.9939.

4.3.6. 4-Methyl-5-propyl-[1,3]dithiol-2-one (40). Following the procedure used for compound **35**; to a solution of **15** (400 mg, 0.87 mmol) in 2.2 mL of toluene at −23°C, was added phenyl chlorothiolformate (129 μL, 0.95 mmol) and TBAF (2.2 mL, 2.2 mmol, 1.0 M/THF). The compound was purified by flash chromatography using 40% toluene in hexane to yield 102 mg (67%) of compound **40** as a yellow oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.52 (t, J=7.4 Hz, 2H), 2.15 (s, 3H), 1.58 (m, 2H), 0.97 (t, J=7.3 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.3, 128.8, 122.6, 30.4, 23.3, 13.8, 13.4; HRMS calcd for $C_7H_{10}OS_2+H^+$: 175.0251. Found: 175.0251.

4.3.7. 4,5-Diethyl-[1,3]dithiol-2-one (41). Following the procedure used for compound **35**; to a solution of **16** (398 mg, 0.86 mmol) in 2.2 mL of toluene at −23°C, was added phenyl chlorothiolformate (130 μL, 0.95 mmol) followed by TBAF (2.2 mL, 2.2 mmol, 1.0 M/THF). The compound was purified by flash chromatography using 20% toluene in hexane to yield 61 mg (40%) of compound **41**. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.57 (q, J=7.5 Hz, 4H), 1.19 (t, J=7.5 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.3, 129.6, 22.0, 14.9; HRMS calcd for $C_7H_{10}OS_2+H^+$: 175.0251. Found: 175.0251.

4.4. General procedure for the preparation of 1,3-dithiol-2-thione

4.4.1. 4-Cyclohexyl-[1,3]dithiole-2-thione (42). *Method A*: To a solution of **7** (400 mg, 0.82 mmol) in 2 mL of toluene at 0°C was added thiophosgene (69 μL, 0.91 mmol) followed by TBAF (1.9 mL, 1.9 mmol, 1.0 M/THF). The mixture was stirred 1 h at 0°C then diluted with ethyl acetate. The organic phase was washed with ammonium acetate (25%), water, brine and dried over $MgSO_4$. After evaporation to dryness, the compound was purified by flash chromatography using 2% ethyl acetate in hexane to afford 100 mg (56%) of the desired compound **42**.

Method B: To a solution of **7** (343 mg, 0.62 mmol) in 1.4 mL of toluene at 0°C was added phenyl chlorothionoformate (95 μL, 0.68 mmol) followed by TBAF (1.6 mL, 1.6 mmol, 1.0 M/THF). The mixture was stirred for 1 h at 0°C then diluted with ethyl acetate and washed with ammonium acetate (25%), water and brine. The organic phase was dried over $MgSO_4$, filtered and evaporated to dryness. After flash chromatography using 30% toluene and 1% ethyl acetate in hexane, 126 mg (94%) of compound **42** was obtained as an orange solid. Mp: 64–65°C. ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.64 (s, 1H), 2.59 (m, 1H), 1.98 (m, 2H), 1.84 (m, 2H), 1.74 (m, 1H), 1.35 (m, 4H), 1.22 (m, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 213.3, 154.7, 120.4, 41.0, 33.8, 25.9, 25.4. Elemental analysis calcd for $C_9H_{12}S_3$: C, 49.95; H, 5.59; S, 44.46. Found: C, 49.89; H, 5.51; S, 44.47.

4.4.2. 4-Cyclohex-1-enyl-[1,3]dithiole-2-thione (43). Following method A, with compound **8** (430 mg, 0.88 mmol), thiophosgene (82 μL, 1.06 mmol) and TBAF (2.0 mL, 2.0 mmol, 1.0 M/THF) in 2.2 mL of toluene, 111 mg (59%) of compound **43** was obtained after flash chromatography using 2% ethylacetate in hexane. Following method B, with compound **8** (250 mg, 0.52 mmol), phenyl chlorothionoformate (78 μL, 0.57 mmol) and TBAF (1.3 mL, 1.3 mmol, 1.0 M/THF) in 1.3 mL of toluene, 98 mg (89%) of compound **43** was obtained as a orange solid. Mp: 107–108°C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.71 (s, 1H), 5.95 (t, J=4.0 Hz, 1H), 2.28 (m, 2H), 2.21 (m, 2H), 1.74 (m, 2H), 1.64 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 212.3, 148.5, 131.2, 129.4, 119.5, 26.1, 25.8, 22.1, 21.5; HRMS calcd for $C_9H_{10}S_3+H^+$: 215.0023. Found: 215.0023.

4.4.3. 4-Octyl-[1,3]dithiole-2-thione (44). Following method A, with compound **5** (500 mg, 0.97 mmol), thiophosgene (88 μL, 1.16 mmol) and TBAF (2.2 mL, 2.2 mmol, 1.0 M/THF) in 2.4 mL of toluene, 138 mg (58%) of compound **44** was obtained after flash chromatography using 2% ethyl acetate in hexane. Following method B, with compound **5** (305 mg, 0.59 mmol), phenyl chlorothionoformate (88 μL, 0.64 mmol) and TBAF (1.5 mL, 1.5 mmol, 1.0 M/THF) in 1.4 mL of toluene, 120 mg (88%) of compound **44** was obtained as an orange oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.64 (s, 1H), 2.61 (t, J=7.5 Hz, 2H), 1.61 (m, 2H), 1.27 (m, 10H), 0.89 (t, J= 6.7 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 213.5, 148.5, 122.0, 31.6, 31.2, 29.7, 29.0, 28.9, 28.7, 22.5, 14.0; HRMS calcd for $C_{11}H_{18}S_3+H^+$: 247.0649. Found: 247.0648.

4.4.4. Side-product (50). Following method B, with compound **5** (400 mg, 0.77 mmol), phenyl chlorothionoformate (235 μL, 1.72 mmol) and TBAF (1.9 mL, 1.9 mmol, 1.0 M/THF) in 1.9 mL of toluene, 140 mg (71%) of compound **44** was obtained and 48 mg (12%) of the title compound **50** as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (s, 1H), 7.42 (m, 4H), 7.33 (m, 2H), 7.11 (m, 4H), 2.62 (t, J=7.4 Hz, 2H), 1.65 (m, 2H), 1.26 (m, 10H), 0.87 (t, J=6.6 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 209.1, 208.4, 154.3, 154.2, 134.7, 133.8, 129.6, 129.6, 126.8, 126.8, 122.0, 121.9, 39.0, 31.8, 29.3, 29.2, 28.9,

28.1, 22.6, 14.1; HRMS calcd for $C_{24}H_{28}O_2S_4+H^+$: 477.1050. Found: 477.1049.

4.4.5. 4-*t*-Butyl-[1,3]dithiole-2-thione (45). Following method A, with compound **9** (687 mg, 1.49 mmol), thiophosgene (136 μL, 1.79 mmol) and TBAF (1.5 mL, 1.5 mmol, 1.0 M/THF) in 3.7 mL of toluene, 145 mg (51%) of compound **45** was obtained after flash chromatography using 2% ethyl acetate in hexane. Following method B, with compound **9** (450 mg, 0.99 mmol), phenyl chlorothionoformate (150 μL, 1.11 mmol) and TBAF (2.5 mL, 2.5 mmol, 1.0 M/THF) in 2.5 mL of toluene, 161 mg (85%) of compound **45** was obtained as an orange solid. Mp: 86–87°C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.65 (s, 1H), 1.34 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 213.6, 159.5, 120.0, 36.8, 30.9; HRMS calcd for $C_7H_{10}S_3+H^+$: 191.0023. Found: 191.0023.

4.4.6. 4,5-Dimethyl-[1,3]dithiole-2-thione (46).[9] Following method A, with compound **14** (300 mg, 0.69 mmol), thiophosgene (64 μL, 0.83 mmol) and TBAF (1.6 mL, 1.6 mmol, 1.0 M/THF) in 1.7 mL of toluene, 42 mg (38%) of compound **46** was obtained after flash chromatography using 2% ethyl acetate in hexane. Following method B, with compound **14** (500 mg, 1.15 mmol), phenyl chlorothionoformate (176 μL, 1.27 mmol) and TBAF (2.9 mL, 2.9 mmol, 1.0 M/THF) in 2.9 mL of toluene at −23°C, 145 mg (78%) of compound **46** was obtained as a yellow solid after flash chromatography using 40% toluene in hexane. Mp: 88–90°C. ^{1}H NMR (300 MHz, $CDCl_3$) δ 2.18 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 211.5, 134.7, 13.2; HRMS calcd for $C_5H_6S_3+H^+$: 162.9710. Found: 162.9710.

4.4.7. 4-Methyl-5-propyl-[1,3]dithiole-2-thione (47). Following method B, with compound **15** (404 mg, 0.88 mmol), phenyl chlorothionoformate (132 μL, 0.96 mmol) and TBAF (2.2 mL, 2.2 mmol, 1.0 M/THF) in 2.2 mL of toluene at −23°C, 105 mg (63%) of compound **47** was obtained as a yellow oil after flash chromatography using 40% toluene in hexane. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.52 (t, J=7.5 Hz, 2H), 2.18 (s, 3H), 1.98 (t, J=7.3 Hz, 3H), 1.61 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 211.7, 140.8, 134.5, 30.2, 23.5, 13.4, 13.3; HRMS calcd for $C_7H_{10}S_3+H^+$: 191.0023. Found: 191.0023.

4.4.8. 4,5-Diethyl-[1,3]dithiole-2-thione (48). Following method B, with compound **16** (410 mg, 0.89 mmol), phenyl chlorothionoformate (144 μL, 1.04 mmol) and TBAF (2.2 mL, 2.2 mmol, 1.0 M/THF) in 2.2 mL of toluene at −23°C, 60 mg (35%) of compound **48** was obtained as a yellow oil after flash chromatography using 3% ethyl acetate in hexane. ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.62 (q, J=7.5 Hz, 4H), 1.22 (t, J=7.5 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 211.7, 141.6, 21.8, 15.2; HRMS calcd for $C_7H_{10}S_3+H^+$: 191.0023. Found: 191.0023.

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