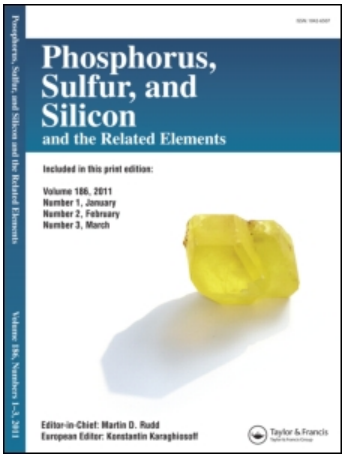

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New Chemistry with Silyl Thioketones

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NEW CHEMISTRY WITH SILYL THIOKETONES

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Abstract. A variety of aryl, alkyl and cycloalkyl silyl thioketones have been synthesized, including silyl thioketones chiral at silicon or at carbon. The multifold of reactions of silyl thioketones allows the synthesis of compounds containing the Si-C-S unit, as well as thioaldehyde S-oxides and derivatives.

INTRODUCTION

Our interest in the chemistry of silyl thioketones[1a,b] is associated with the high reactivity of the carbon- sulphur double bond in either nucleophilic or electrophilic addition as well as in cycloaddition reactions. The various reaction modes allow the synthesis of a variety of compounds containing the Si-C-S unit[2]. A characteristic feature of thiocarbonyl compounds is that they, at least in principle, can be oxidized to the corresponding S-oxides. In addition, silyl thioketones can serve as synthetic equivalents of thioaldehydes, as the silicon can easily be replaced by a proton at the stage of the reaction products.[3a,b,4]

The multifold of reactions of silyl thioketones is illustrated in Chart 1.

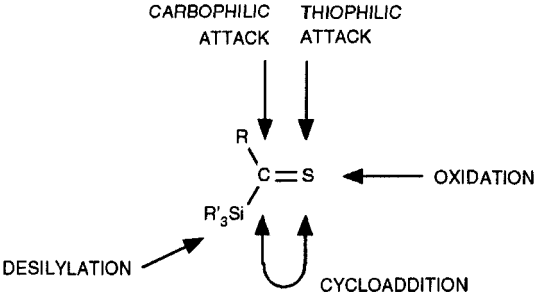
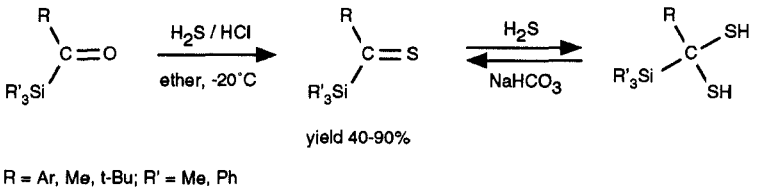


Chart 1

In the past years we synthesized a variety of silyl thioketones with R being an aryl, methyl, tert-butyl group and including silyl thioketones which are chiral at silicon. The present review summarizes the advances obtained in our group.

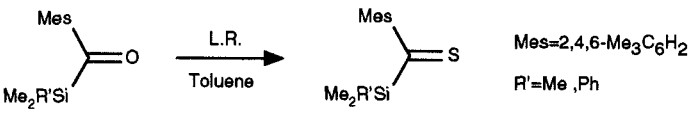
AROMATIC AND ALKYL SILYL THIOKETONES

Of the several methods that can be used to prepare thioketones, the acid-catalysed reaction of acylsilanes with hydrogen sulphide is the method of choice.[5a,b] This thionation method when performed at low temperature allows the synthesis of thermally labile silyl thioketones (Chart 2). The experimental conditions, however, are rather critical. Too long reaction times lead to disappearance of the blue colour of the thione due to the addition of a molecule of hydrogen sulphide to the thione, to give colourless gem-dithiols. In the case of aliphatic derivatives (R=Me, t-Bu in Chart 2), these compounds can be isolated and fully characterized.[1b] Subsequent washing of the ethereal colourless solution with saturated aqueous sodium hydrogen carbonate gives back the thione. The thermal stability of aryl silyl thiones is limited and they are slowly transformed into trimers on standing.[6] The more thermally stable mesityl thiones can be prepared from the acylsilanes with Lawesson reagent in boiling toluene. The t-butyl derivative can be stored at -20°C for many months without noticeable decomposition.



yield 40-90%

R = Ar, Me, t-Bu; R' = Me, Ph



yield 66-72%

Chart 2

Special mention should be made of the decomposition of the methyl silyl thioketone. The products **1** and **2** (Chart 3) could be isolated from the decomposition mixture. Their formation can be rationalized by assuming enethiolization and subsequent thiophilic addition of enethiol to the thioketone to produce **1** and a carbophilic reaction of enethiol to give **2**.[1b] These dimerizations have not been observed before. Remarkably, methyl thioketones show no tendency to exist in the enethiol form, such as methyl tert-butyl thioketone.[7]

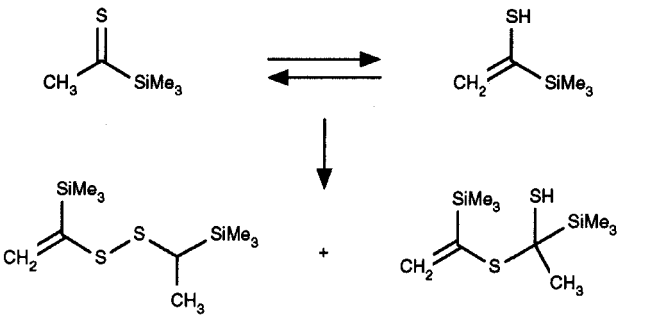


Chart 3

Thiophilic addition reactions

It is well documented that thioketones undergo thiophilic addition reaction upon treatment with organolithium reagents. This behaviour is also exhibited by silyl thioketones and allows the preparation of α-silyl sulphides in good yields (Chart 4).[1b,5] These thiophilic reactions are probably facilitated by the silyl group due to the stabilizing effect of the silyl group on the intermediate α-silyl carbanion. The silyl sulphides can be used for further synthetic pourposes, especially by making use of fluorodesilylation in the presence of carbon electrophiles, such as aldehydes and enones. The best results were obtained with aromatic aldehydes and cyclohexenone when proper anhydrous conditions were used to minimize protodesilylation.[8]

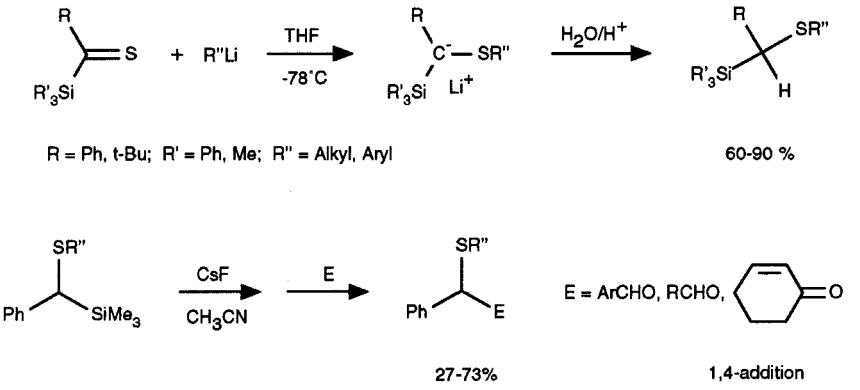
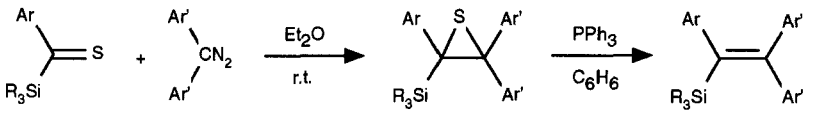


Chart 4

Cycloaddition with 1,3-dipoles,dienes and heterodienes

As stated in the introduction thiocarbonyl compounds are prone to undergo cycloaddition reaction. Treatment of silyl thioketones with diaryldiazomethanes leads to silylated thiiranes in excellent yields[5] (Chart 5).These products are probably formed via an initial cycloaddition to a thiadiazoline which readily looses a nitrogen molecule to yield the three membered sulphur heterocycle. Desulphurization of these products with triphenylphosphine leads to vinyl silanes as shown in Chart 5. Oxidation with one equivalent of mCPBA results in the corresponding thiirane S-oxides in good yields.[9]



50-100% 80-100%

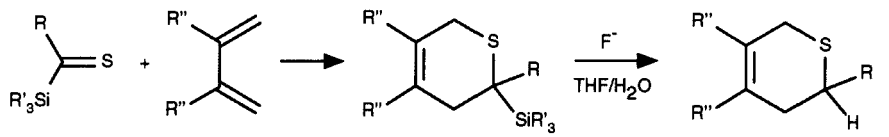
R=Me ,Ph ; Ar=Ph , C_6H_4Me -p ; Ar'=Ph ,C_6H_4 OMe -p , C_6H_4 Me -p

Chart 5

Silyl thioketones react also with various 1,3-dipoles e.g. nitriloxides, nitrilimines and nitrilylides to give silyl substituted 5-membered heterocycles.[10] Heterodienes such as nitrosostyrene[11] and propenoylsilane,[12] similarly produced 6-membered cycloadducts.

[4+2] Cycloaddition of silyl thioketones with 1,3-dienes represents an easy and high yielding approach to silyl dihydrothiopyrans (Chart 6).[4] A variety of dienes has been utilized for this purpose. Protodesilylation of these adducts with TBAF leads to products formally derived from thioaldehydes. In the case of aryl substituted cycloadducts the desilylation took place smoothly at room temperature, however, alkyl substituted derivatives are much more reluctant in this respect;drastic conditions, i.e. a reaction temperature of 110°C, were required for the tert-butyl compound, while the methyl substituted adduct failed to undergo desilylation at higher temperature.[1b]

Oxidation of the aryl silyl thioketone cycloadducts using mCPBA at -50°C did not produce the corresponding S-oxides but thiacyclohexadienes. This can be explained by the initial formation of the expected sulphoxide followed by a thermal Sila-Pummerer rearrangement to give an O-silyl monothioacetal which on subsequent elimination of silanol leads to the diene[4] (Chart 7). Oxidation of the tert-butyl substituted cycloadduct produced however the stable E-sulphoxide and, in addition, 23% yield of 6-t-butyl-2H-thiopyran derived from a Si-Pummerer rearrangement of the Z-sulphoxide.The different behaviour of the two α-silyl sulphoxides with respect to the



yields > 80%

R = Ph, t-Bu, Me; R' = Me, Ph; R" = H, Me

R = Ar	90-100%
R = t-Bu	30%
R = Me	0%

Chart 6

Si-Pummerer rearrangement is probably related to the conformational properties of the thiacyclohexene ring where the presence of the tert-butyl group prevents the interaction between silicon and oxygen in the E-sulphoxide.

Fluorodesilylation of the E-sulphoxide with TBAF in boiling THF leads to a mixture of Z(retention of configuration) and E(inversion of configuration) isomers in a ratio of 2.5:1, implying that this reaction is not stereospecific. The products obtained (Chart 7) are the formal adducts of t-butyl thioaldehyde S-oxide with 2,3-dimethyl butadiene.[1b] The configurational and conformational assignments of these heterocycles as well as of the corresponding sulphones and sulphonium salts were secured by ^{13}C and ^{17}O NMR spectral analysis.[13]

Silyl sulfines

A variety of thiocarbonyl compounds has been oxidized to the corresponding S-oxides (sulfines).[14] In a similar manner silyl thioketones could be converted into silyl sulphines (Chart 8) in excellent yields. When the R group is sterically unhindered (R=Ph,$C_6H_4CH_3$-p,C_6H_4Cl-m) only the E-isomers are obtained. In contrast, substrates with R= mesityl or t-butyl groups give a mixture of E and Z isomers in a ratio 66:34 and 60:40, respectively.[3b] This behaviour is probably attributable to a comparable steric size of the tert-butyl or mesityl groups and the trimethylsilyl group implying that there is no clear kinetic preference for one S-oxide isomer during the oxidation reaction. It is of interest to note that attempted purification of aryl silyl sulfines on silica gel causes a partial protodesilylation to the corresponding thioaldehyde S-oxides.

Mono-substituted sulfines (thioaldehyde S-oxides)

In the sulphur literature only a few examples of thioaldehyde S-oxides (mono-substituted sulfines) have been reported.[15a,b,c] The oxidative route is not feasible because of the instability of thioaldehydes. Desilylation of the silyl sulfines mentioned

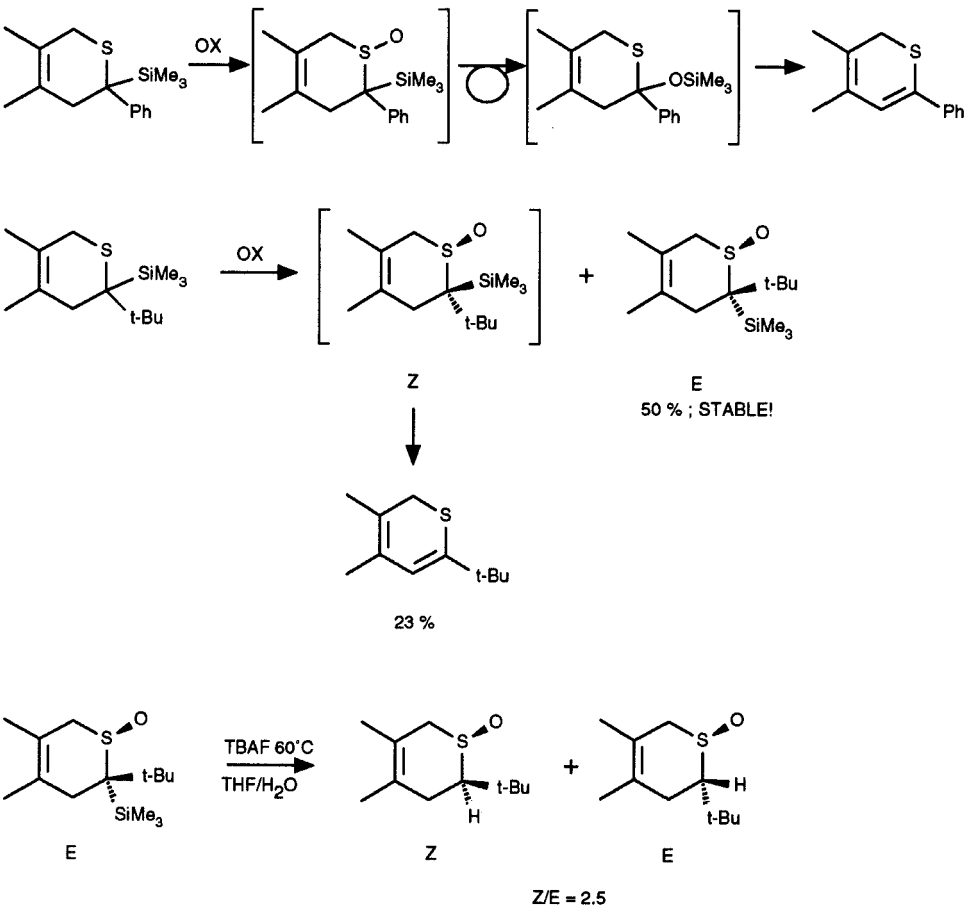


Chart 7

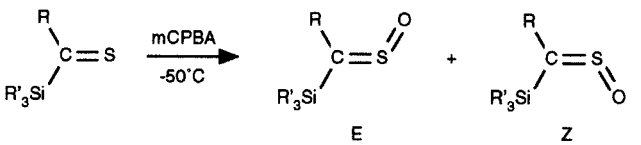
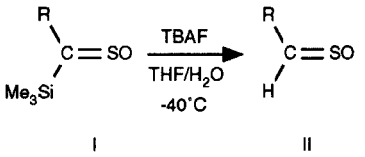


Chart 8

above offers an unique possibility of preparing mono-substituted sulfines in an indirect way.Indeed, treatment of silyl sulfines with an equimolar amount of TBAF in THF/H_2O at -40°C, is a mild procedure for the synthesis of mono-substituted aromatic and aliphatic thioaldehyde S-oxides.[3a,b] The stereochemistry of the desilylation process

was given detailed attention. It was found that in general the displacement of silicon is a stereospecific process, occurring with retention of configuration in the entries 1-3 (Chart 9). In contrast however, with mesityl substituted sulfine loss of stereochemical integrity was observed during the desilylation process. Starting from either pure E or Z mesityl silyl sulfine (entries 5 and 6) the same mixture of Z and E thioaldehyde S-oxides in a ratio 95:5 was obtained. Similar results were obtained with tert-butyl silyl sulfine (entries 7 and 8 in Chart 9).

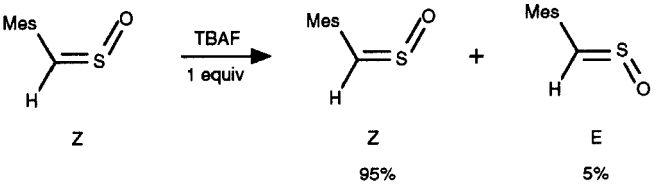


I II

	R	Isomers ratio I	Isomers ratio II	yield%
1	Ph	E	Z:E=99:1	75
2	C_6H_4-CH_3-p	E	Z:E=99.5:0.5	85
3	C_6H_4-Cl-m	E	Z:E=99:1	63
4	Mes	E:Z=66:34	Z:E=95:5	90
5	Mes	E	Z:E=95:5	90
6	Mes	Z	Z:E=95:5	90
7	t-Bu	E	Z:E=77:23	69
8	t-Bu	E:Z=60:40	Z:E=70:30	44

Chart 9

It has been demonstrated that loss of configurational integrity is attributable to an equilibration of thioaldehyde S-oxides in the presence of TBAF, via an addition-elimination reaction of fluoride ion. Pure Z-mesityl sulfine in the presence of one equivalent of TBAF gives a 95:5 mixture of Z and E sulfines (this ratio was also obtained during the desilylation), while in the absence of fluoride no isomerization is observed (Chart 10).



Z Z E

95% 5%

Chart 10

The monosubstituted 2-aryl sulfines prepared above were subjected to cycloaddition with 1,3-dienes at ambient temperature. Mixture of Z and E cycloadducts were obtained in good yields (Chart 11).The relative amount of the two sulphoxides depends on the initial diene/sulfine ratio, the higher this ratio the more Z adduct was produced.[16] This finding contrasts with the normal behaviour of unsimmetrical sulfines in [4+2] cycloaddition reaction which occurs with retention of stereochemistry.[17]

The deviant result with monosubstituted sulfines can be rationalized by invoking a Z to E interconversion of sulfines under the condition of the cycloaddition reaction and a much faster cycloaddition of the E sulfine compared to the Z sulfine. In fact the cycloaddition is a typical example of the Curtin-Hammet principle.[18]

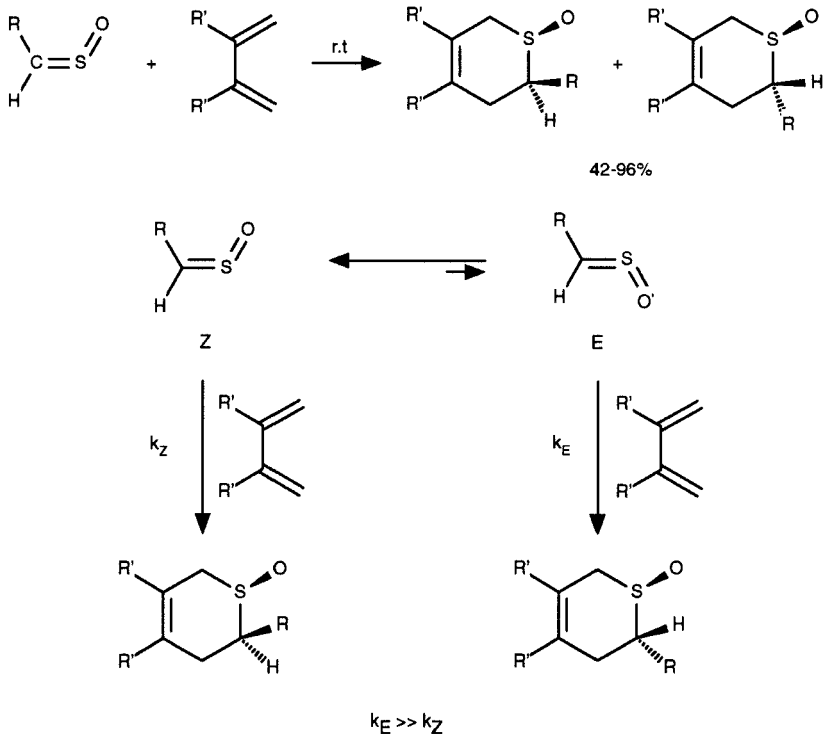


Chart 11

SILYL THIOKETONES CHIRAL AT SILICON

R-(-)-methyl-α-naphthyl-phenylsilyl phenyl thioketone was readily prepared from the corresponding carbonyl compound.[19] Reaction with dienes and organometallics were carried out in order to establish the ability of transferring chirality from silicon to carbon. Appreciable diastereoselectivity (50%d.e.) was found in the cycloaddition of this chiral thione with buta-1,3-diene at -78°C. Protodesilylation of the diastereomeric mixture with TBAF gave dihydrothiopyran with 51% e.e.[20] A similar diastereoselectivity was found[21] in reaction of the chiral thione with organolithium and Grignard reagents, which gave α-silyl sulphides with d.e. values ranging between 35 and 76%. The mixture of diastereomeric α-deuterio-α-silyl benzyl methyl sulphides

(bottom line in Chart 12) gave on protodesilylation α-deuterio benzyl methyl sulphide with 45% e.e. These results lead to the conclusion that in both cases protodesilylation occurs stereospecifically without loss of induced chirality (Chart 12).

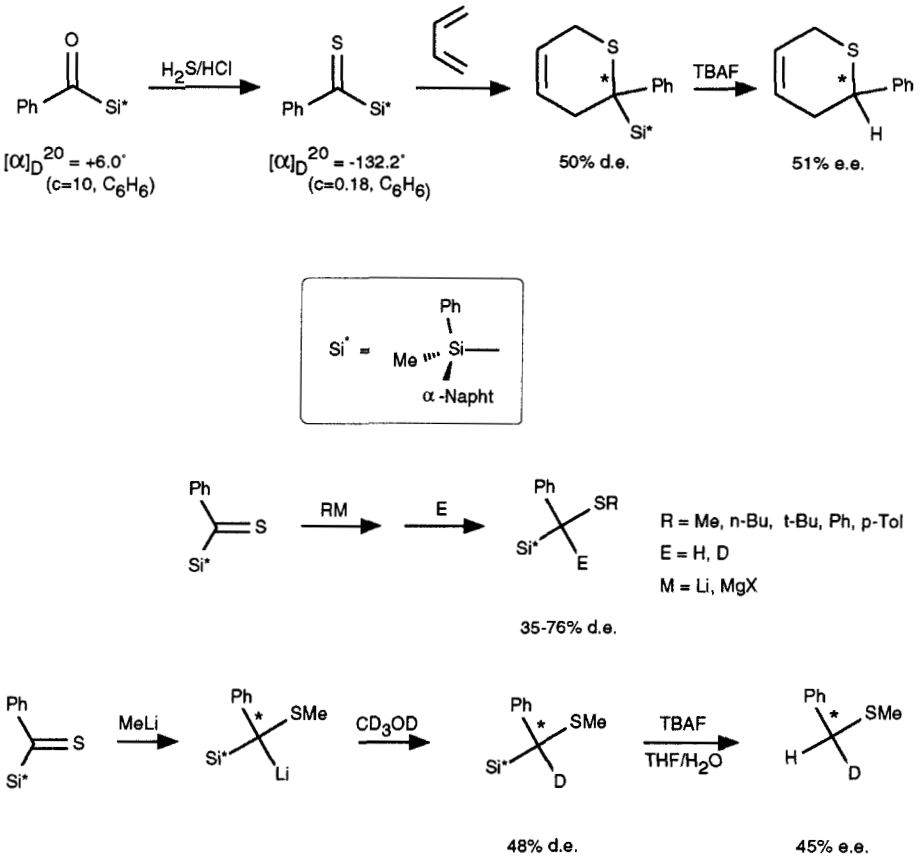
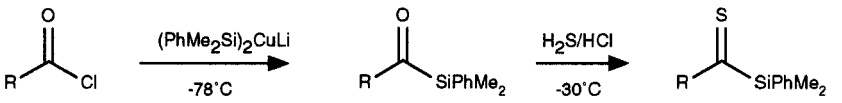


Chart 12

CYLOALKYL SILYL THIOKETONES

The silyl thioketones discussed so far carry an aryl or alkyl substituent. It is of interest to include cycloalkyl silyl thioketones bearing a hydrogen atom at Cα in order to study the involvement of enethiolization in the reaction of silyl thioketones. An additional attractive feature of a cycloalkyl substituent is that a chiral centre can be introduced at Cα or in a more remote position of the cycloalkyl unit. In this manner silyl thioketones chiral at carbon can be made available. The selected cycloalkyl substituents are shown in Chart 13. The compounds in entry 5 are of particular interest as they are accessible

from natural occurring myrtanol. For the synthesis of cycloalkyl silyl ketones, the corresponding cycloalkane carboxylic acid chlorides are suitable starting materials. Best results were obtained with bis(dimethylphenylsilyl)copper lithium[22] as the silylating agent, in fact this reagent has not been used before for such a pourpose. Thionation was performed as described earlier by using H_2S and HCl at low temperature. Good yields were obtained with all the substrates , except for the dihydrochrysantemyl case (Chart 13 entry 4).



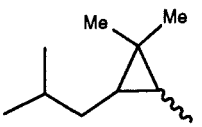
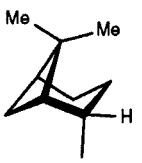
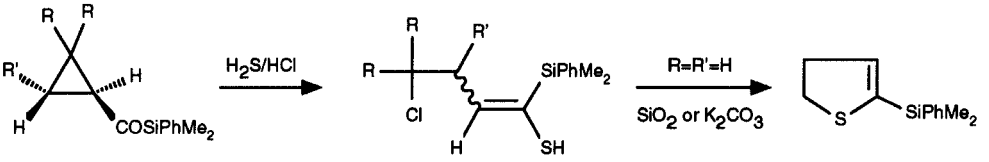
entry	R	yield %	yield %
1		69	85
2		40	95
3		71	82
4		59	-
5		65 $[\alpha]_D$=+51.2 (c=1.6, C_6H_{12})	70 $[\alpha]_D$=-371 (c=0.098, C_6H_{12})

Chart 13

During thionation of the cyclopropyl derivative (Chart 14) it was noticed that the reaction conditions for this process are rather critical: when an excess of HCl is present ring opening is observed with the formation of a chloro enethiol, which, by chromatography on silica gel or with base treatment, cyclizes to a dihydrothiophene derivative. In the case of dihydrochrysanthemyl silyl ketone all attempts to accomplish thionation failed. Only the formation of an enethiol could be achieved (Chart 14).

The cycloalkyl silyl thioketones undergo [4+2] cycloaddition with 1,3-butadiene to yield α-silyl dihydrothiopyrans. It is quite remarkable that these adducts cannot be



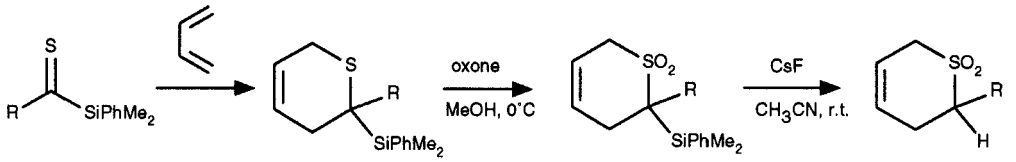
R = R' = H — 70% — 33%

R = Me ; R' = iso-Butyl — 60%

Chart 14

desilylated using fluoride reagents. To solve this problem these adducts were oxidized to the corresponding sulphones and then subjected to desilylation conditions. As expected, these silyl sulphones (Chart 15) can be readily protodesilylated at room temperature for which CsF in CH_3CN/H_2O is the reagent of choice. The resulting desilylated sulphones are formally derived from thioaldehyde S,S-dioxides (sulfenes). It should be noted that sulfenes when generated by dehydrochlorination from alkanesulfonyl chlorides with base do not undergo [4+2] cycloaddition reaction with dienes.[23] This indirect method is an attractive alternative. The chiral myrtanyl substituted silyl thioketone (entry 4) undergoes the Diels-Alder reaction with butadiene in an acceptable chemical yield and with an acceptable asymmetric induction (d.e. 80%). The stereoselectivity was determined by detailed analysis of a 400 MHz ^{1}H-NMR spectrum. Desilylation of the optically active silyl sulfone in entry 4 (Chart 15), using CsF in $MeCN/H_2O$ at ambient temperature, proceeds with a considerable loss of optical purity. Apparently, the intermediate formed on desilylation is not configurationally stable (probably a α-sulfonyl carbanion).

Oxidation of cycloalkyl silyl thiones with mCPBA results in the formation of the corresponding E-sulfine, which apparently is the kinetically preferred product (Chart 16). In spite of the fact that these substrates contain an enethiolizable α-hydrogen, no problems were encountered in the sulfine synthesis. Desilylation of the silyl sulfines, using an equimolar amount of CsF in $MeCN/H_2O$ mixture with sonication, gave thioaldehyde S-oxides (monosubstituted sulfines) in a similar fashion as described above (Chart 8) for aryl and tert-butyl cases. The geometry of the sulfines is almost completely retained in this silyl displacement reaction, in agreement with the observation reported above (Chart 9). The myrtanyl sulfine constitutes a special case: it is in fact the first enantiomerically pure thioaldehyde S-oxide ever prepared $[\alpha]_D$-40°(c=2 in C_6H_{12}) (entry 4 Chart 16). The assignment of sulfine geometry was



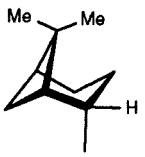
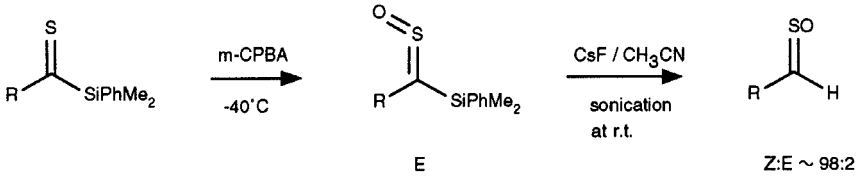
entry	R	yield %	yield%	yield %
1		60	90	81
2		63	82	86
3		96	50	82
4		70 (d.e.=80%)	70 (d.e.=81%)	84 (d.e.=38%)

Chart 15

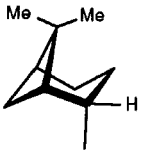
done on the basis of ^{1}H-NMR analysis: the predominant thioaldehyde S-oxide, which has a typical low field proton in the range of 7.65-8.35 ppm is assigned the Z-geometry on the basis of a comparison with NMR data for aromatic[3b] and aliphatic[15a] thioaldehyde S-oxides.

Finally, the reaction of cycloalkyl silyl thiones with organolithium reagents will be described. The reaction of cyclopropyl silyl thioketone is taking a deviant course due to the involvement of enethiolization (Chart 17). In the presence of methyl iodide the initially formed enethiolate could be trapped, otherwise complete decomposition is taking place. The reaction of the corresponding silyl sulfine shows a contrasting behaviour on treatment with MeLi. The isolated product is a mixed acetal as shown in Chart 17. The formation of this product can readily be explained by assuming an initial thiophilic reaction at the sulfine moiety to give an α-substituted silyl sulfoxide and a subsequent Brook rearrangement to the ultimate product. Apparently this sulfine having an enethiolizable α-hydrogen, shows a normal thiophilic behaviour towards MeLi and no involvement of the tautomeric vinyl sulfenate. The different behaviour between the thioketone and its S-oxide is quite remarkable.



E

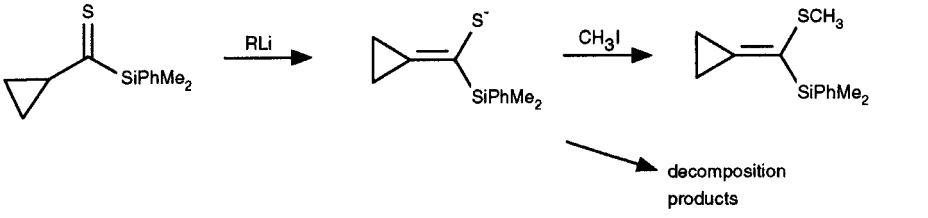
Z:E ~ 98:2

entry	R	yield %[a]	yield %[b]
1		77	27
2		64	42
3		80	60
4		48	100 $[\alpha]_D$=-40 (c=2.0 in C_6H_{12})

a) based on the starting ketone

b) after chromatography

Chart 16



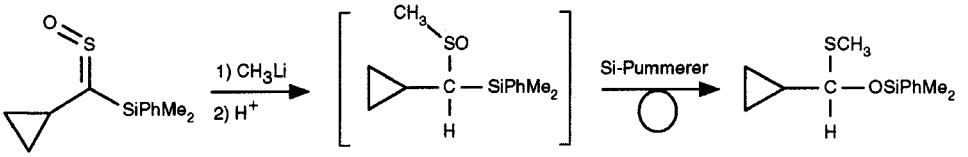


Chart 17

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REFERENCES

1. (a) B.F.Bonini, G.Mazzanti, G.Maccagnani. S.Sarti and P.Zanirato, Chem.Commun., 822 (1981). (b) B.F.Bonini, G.Maccagnani, G.Mazzanti and P.Zani, J.Chem.Soc.,Perkin Trans.1, 2083 (1989)
2. E.Block and M.Aslam, Tetrahedron, 44, 281 (1988).
3. (a) B.F.Bonini., G.Mazzanti, P.Zani, G.Maccagnani, G.Barbaro, A.Battaglia and P.Giorgianni, Chem.Commun., 964 (1986).(b) G.Barbaro, A.Battaglia, P.Giorgianni, B.F.Bonini, G.Maccagnani and P.Zani, J.Org.Chem, 55, 3744 (1990).
4. B.F.Bonini, A.Lenzi, G.Maccagnani, G.Barbaro, P.Giorgianni and D.Macciantelli, J.Chem.Soc.,Perkin Trans.1, 2643 (1987).
5. (a) G.Barbaro, A.Battaglia, P.Giorgianni, G.Maccagnani, D.Macciantelli, B.F.Bonini, G.Mazzanti and P.Zani, J.Chem.Soc.,Perkin Trans.1, 381 (1986). (b) Other procedure for the synthesis of thioacylsilanes: A.Ricci, A.Degl'Innocenti, A.Capperucci and G.Reginato, J.Org.Chem., 54, 19 (1989).
6. B.F.Bonini, G.Mazzanti, G.Maccagnani, P.Zani and E.Foresti, J.Chem.Soc.,Perkin Trans.1, 1499 (1988).
7. D.Paquer and J.Vialle, Bull.Soc.Chim.Fr., 3595 (1969).
8. B.F.Bonini, S.Masiero, G.Mazzanti and P.Zani, Tetrahedron Lett., 32, 815 (1991).
9. B.F.Bonini, E.Foresti, R.Leardini, G.Maccagnani and G.Mazzanti, Tetrahedron Lett., 25, 445 (1984).
10. B.F.Bonini, G.Maccagnani, G.Mazzanti, G.A.L.A.Atwa and P.Zani, Heterocycles, 31, 47 (1990).
11. P.Carisi, G.Mazzanti, P.Zani, G.Barbaro, A.Battaglia and P.Giorgianni, J.Chem.Soc.,Perkin Trans.1, 2647 (1987).
12. B.F.Bonini, S.Masiero, G.Mazzanti and P.Zani, Tetrahedron Lett., 32, 2971 (1991)
13. G.Barbarella, A.Bongini, B.F.Bonini, M.Zambianchi and P.Zani, Tetrahedron, 47, 7677 (1991).
14. B.Zwanenburg, Rec.Trav.Chim.Pays-Bas, 101, 1 (1982).
15. (a) E.Block, L.K.Revelle and A.A.Bazzi, Tetrahedron Lett., 21, 1277 (1980). (b) J.Strating, L.Thijs and B.Zwanenburg, Rec.Trav.Chim.Pays-Bas, 83, 631 (1964). (c) A.M.Hamid and S.Trippett, J.Chem.Soc.C. 1617 (1968).
16. G.Barbaro, A.Battaglia, P.Giorgianni, B.F.Bonini, G.Maccagnani and P.Zani, J.Org.Chem., 56, 2512 (1991).
17. B.Zwanenburg, L.Thijs, J.B.Broens and J.Strating, Rec.Trav.Chim.Pays-Bas, 91, 443 (1972).
18. F.A.Carey and R.J.Sundberg,in Advanced Organic Chemistry, Part A II ed., (Plenum Press New York,1984), Chap.4, pp.219-220.
19. A.G.Brook, J.M.Duff, F.F.Jones and N.R.Davis, J.Am.Chem.Soc., 89, 431 (1967).
20. B.F.Bonini, G.Maccagnani, G.Mazzanti and P.Zani, J.Chem.Soc.Chem.Commun.,

365 (1988).
21. B.F.Bonini, G.Maccagnani, S.Masiero, G.Mazzanti and P.Zani, Tetrahedron Lett., 30, 2677 (1989).
22. J.Fleming, T.W.Newton and F.J.Roessler, J.Chem.Soc. Perkin Trans.1 2577 (1981).
23. J.F.King and R.Rathore in The Chemistry of sulphonic acid, esters and their derivatives, edited by S.Patai and Z.Rappoport, (John Wiley and Sons, New York, 1991), Chap.17 p.697.