An improved method for the conversion of oxiranes to thiiranes and the discrimination of their base peaks in EI-MS

Hsing-Ming Chen,[a] Po-Yuan Chen,[b] Chih-Feng Wang,[c] Jui-Chi Tsai,[b] and Eng-Chi Wang[b,*]

[a]Department of Nutrition and Health Science, Fooyin University, Kaohsiung 831, Taiwan
[b]Department of Medicinal and Applied Chemistry, Kaohsiung Medical University, Kaohsiung 807, Taiwan
[c]Department of Materials Science & Engineering, I-Shou University, Kaohsiung 82445, Taiwan
E-mail: enchwa@kmu.edu.tw

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Abstract
An efficient method for the conversion of oxiranes to thiiranes by treatment with excess ammonium thiocyanate in aqueous media under reflux or by microwave irradiation is reported.

Keywords: Epoxides, ammonium thiocyanate, thiiranes, base peak, EI-MS

Introduction

Thiiranes are valuable synthetic building blocks with industrial potential for the preparation of polymers,[1] liquid crystals,[2] adhesives,[3] as many others.[4] In addition, thiirane is an essential heterocyclic core of various compounds with biological activity including selective gelatinase inhibitors,[5] selective A_1 adenosine receptor agonists,[6] potential topoisomerase I inhibitors,[7] estrogen synthetase inhibitor[8]. As a result chemists have made efforts to create an efficient and environmentally benign method for the synthesis of thiiranes. Strategies for the preparation of thiiranes include (1) reaction of alkenes with various reagents including dichlorodisulfides,[9] and iodothiocyanate,[10] (2) reaction of ketones with a sulfuryl lithium,[11] (3) reduction of 1-(benzthiazol-2-yl-sulfanyl)-2-alkanones with sodium hydride,[12] (4) reaction of epoxides with ammonium thiocyanate,[13] or potassium thiocyanate;[14] (5) conversion of epoxides with thiourea,[15] as well as other methods.[16] Among the methods described above, preparation of thiiranes from epoxides, by reaction ammonium thiocyanate with various catalysts and solvents, has been intensively studied and summarized in Table 1.

Although numerous reaction conditions have been investigated, disadvantages such reaction time, use of environmentally unfriendly solvents and toxic heavy metal catalysts remain to be addressed. Herein we disclose a method to convert epoxides to thiiranes in aqueous media either

by heating under reflux or by microwave irradiation with varying wave lengths. The method requires no metallic catalyst or organic solvent and the base peaks of resulting thiiranes in EI-MS are also discussed.

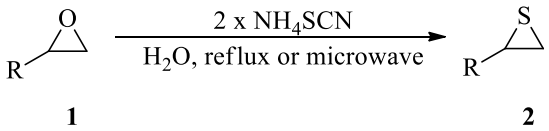
Table 1. Reported methods for the conversion of epoxides to thiiranes by ammonium thiocyanate with various conditions

Reagent	Solvent (Co-solvent)	Catalyst	Reaction Temp.	Reaction Time (min.)	Yields (%)	Ref.
NH_4SCN	H_2O, NaOH	PVA & PAA	25 or 45°C	30-100 min.	86-96	13a
NH_4SCN	CH_3CN	$RuCl_3$	25 or 80°C	15-120 min.	93-100	13b
NH_4SCN	*tert*-BuOH	CAN	rt	15-480 min	90-100	13c
NH_4SCN	CH_3CN	Oxalic acid	Reflux	30 min.	95	13d
NH_4SCN	*tert*-BuOH	$LiBF_4$	Reflux	20 min.	95	13e
NH_4SCN	CH_3CN	$Bi(OTf)_3$	20°C	15 min.	98	13f
NH_4SCN	CH_3CN	$(NH_4)_8[CeWO_{36}]$ $20H_2O$	Reflux	0.5-3.5 hr	88-98	13g
NH_4SCN	CH_3CN	Iron (III) trifluoroacetate	rt	30-60 min	91-98	13h
NH_4SCN	CH_3CN	$SbCl_3$	Reflux	25-40 min.	95-98	13i
NH_4SCN	CH_3CN	P4VP-$Ce(OTf)_4$	rt	15-40 min.	85-92	13j
NH_4SCN	CH_3CN	$BiCl_3$	Reflux	10-35 min.	96-99	13k
NH_4SCN	CH_3CN	$TiO(TFA)_3$	Reflux	15-40 min.	90-97	13l

Results and Discussion

In our studies, (Table 2) we found that thiiranes can be efficiently obtained from the reaction of epoxide and excess ammonium thiocyanate (2 equv.) in aqueous media by microwave irradiation. Heating under reflux results in a longer reaction time and lower yields than for microwave irradiation. For example, in entry 3, under reflux conditions, it took 3 hours to completely consume the starting styrene oxide (**1c**), and only trace of styrene thiirane (**2c**) was formed. In contrast, styrene thiirane (**2c**) was obtained in 92 % yield by microwave irradiation using a 160 W source. Furthermore, in entry 4, it took 4 hours to give 2-(naphthalene-1-oxymethyl)thiirane (**1d**) in 53% yield under reflux conditions, but only 45 min to produce 2-(naphthalene-1-oxymethyl)thiirane (**2d**) in 90% yield by microwave irradiation using a 300 W source.

Table 2. The comparison of conversion of epoxides to thiiranes with ammonium thiocyanate in aqueous media either by reflux or by microwave irradiation



a. R=$C_6H_5CH_2OCH_2$
b. R=$C_6H_5OCH_2$
c. R=C_6H_5
d. R=1-naphthalenoxymethyl
e. R=4-methoxyphenoxymethyl
f. R=3,4-dimethoxyphenoxymethyl
g. R=3-isopropoxy-4-methoxyphenoxymethyl
h. R=3,4-methylenedioxyphenylmethyl

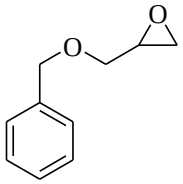
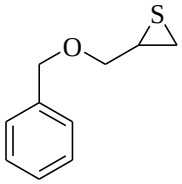
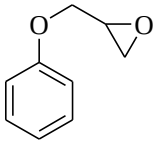
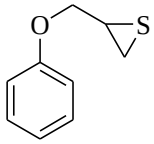
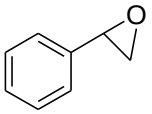
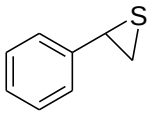
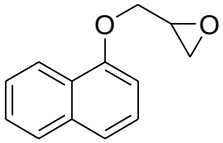
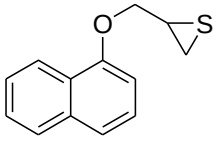
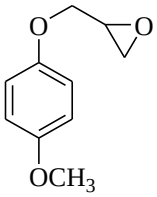
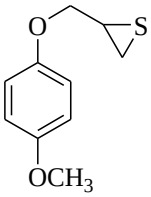
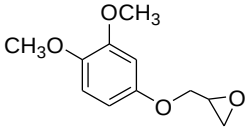
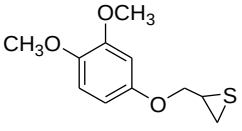
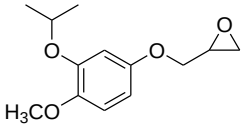
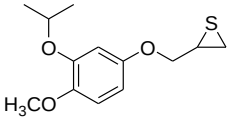
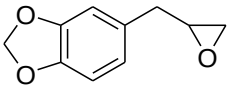
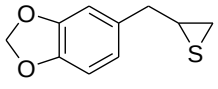
Entry	Epoxide **1**	Product[a] **2**	Reflux		Microwave irradiation		
			Time (min)	Yield (%)	Energy (W)	Time (min)	Yield[b] (%) GC[b] (Isolated)[c]
1	 **1a**	 **2a**	210	81	130 160	5 6	81 93 (89)
2	 **1b**	 **2b**	180	75	130 130	3 5	82 95 (90)
3	 **1c**	 **2c**	180	2	160	5	92 (88)
4	 **1d**	 **2d**	240	53	200 200 300	12 60 45	25 78 95 (90)
5	 **1e**	 **2e**	210	59	130 170 170	5 5 10	72 86 92 (90)

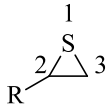
Table 2 (continued)

6	 **1f**	 **2f**	210	35	130 180 180	5 7 10	60 67 92 (89)
7	 **1g**	 **2g**	-	-	160 160	5 10	50 85 (80)
8	 **1h**	 **2h**	240	57	180 200	15 40	43 92 (90)

[a]All thiiranes prepared have satisfactory spectral data; thiiranes **2a**, **2b**, **2c**, **2d**, and **2e** are known compounds, but **2f**, **2g**, and **2h** are new. [b]Determined by gas chromatography. [c]Isolated from silica gel column chromatography. [–]The reflux reaction condition was skipped for no enough starting material.

The structures of thiiranes (**2a-h**) were confirmed by ^{1}H-NMR and ^{13}C-NMR (**Table 3)**. The EI-MS, HRMS of **2a-h** and elemental analysis of **2d-h** are reported in **Table 4**.

Table 3. The Selected Signals of ^{1}H-NMR and ^{13}C-NMR spectra of thiiranes (**2a-h**)



2

a. R=$C_6H_5CH_2OCH_2$
b. R=$C_6H_5OCH_2$
c. R=C_6H_5
d. R=1-naphthalenoxymethyl
e. R=4-methoxyphenoxymethyl
f. R=3,4-dimethoxyphenoxymethyl
g. R=3-isopropoxy-4-methoxyphenoxymethyl
h. R=3,4-methylenedioxyphenylmethyl

Thiiranes	Selected signals of ^{1}H-NMR ($CDCl_3$, 200 MHz)	^{13}C-NMR ($CDCl_3$, 50 MHz)
2a (R = $C_6H_5CH_2OCH_2$)	2.18 (dd, *J* 5.2, 1.2 Hz, 1H, H_a-3), 2.48 (dd, *J* 6.0, 1.2 Hz, 1H, Hb-3), 3.08 (m, 1H, H-2), 3.47 (dd, *J* 10.8, 6.0 Hz, 1H, H_a-4), 3.66 (dd, *J* 10.8, 5.2 Hz, 1H, H_b-4).	23.7, 32.1, 73.0, 74.5, 76.4, 127.6, 1 127.7, 128.3, 137.8.

Table 3 (continued)

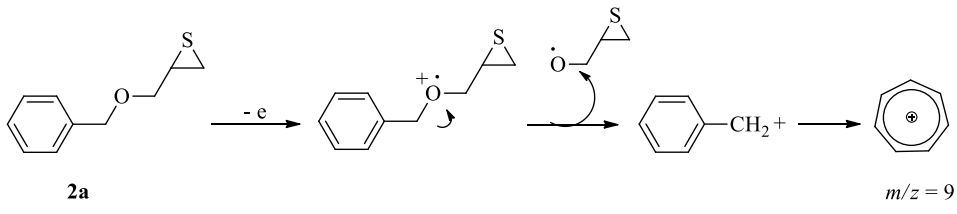
2b ($R = C_6H_5OCH_2$)	2.31 (dd, *J* 5.2, 1.2 Hz, 1H, H_a-3), 2.59 (dd, *J* 6.0, 1.2 Hz, 1H, H_b-3), 3.26 (m, 1H, H-2), 3.88 (dd, *J* 10.2, 6.8 Hz, 1H, H_a-4), 4.19 (dd, *J* 10.2, 5.2 Hz, 1H, H_b-4).	23.8, 31.3, 72.3, 114.4, 121.0, 129.4, 158.2.
2c ($R = C_6H_5$)	2.65 (dd, *J* 5.8, 1.4 Hz, 1H, H_a-3), 2.87 (dd, *J* 6.6, 1.4 Hz, 1H, H_b-3), 3.89 (dd, *J* 5.8, 6.6 Hz, 1H, H-2)	27.3, 36.3, 126.7, 127.6, 128.3, 128.6.
2d (R = 1-naphthalenoxy-methyl)	2.29 (dd, *J* 5.2, 1.2 Hz, 1H, H_a-3), 2.54 (dd, *J* 6.2, 1.2 Hz, 1H, H_b -3), 3.30 (m, 1H, H-2), 3.99 (dd, *J* 10.2, 6.8 Hz, 1H, H_a-4), 4.22 (dd, *J* 10.2, 6.4 Hz, 1H, H_b-4).	23.7, 31.4, 72.5, 104.9, 120.6, 121.9, 125.2, 125.4, 125.6, 126.4, 127.3, 134.4, 154.0.
2e (R = 4-methoxyphen-oxymethyl)	2.30 (dd, *J* 5.2, 1.2Hz, 1H, H_a-3), 2.59 (dd, *J* 6.4, 1.2 Hz, 1H, H_b -3), 3.24 (m, 1H, H-2), 3.85 (dd, *J* 10.4, 7.2Hz, 1H, H_a-4), 4.16 (dd, *J* 10.4, 5.2 Hz, 1H, H_b-4).	23.9, 31.5, 55.7, 73.5, 114.7, 115.9, 152.5, 154.2.
2f (R = 3,4-dimethoxy-phenoxymethyl)	2.32 (dd, *J* 5.2, 1.4 Hz, 1H, H_a-3), 2.60 (dd, *J* 6.2, 1.4 Hz, 1H, H_b-3), 3.25 (m, 1H, H-2), 3.88 (dd, *J* 10.2, 7.0 Hz, 1H, H_a-4), 4.15 (dd, *J* 10.2, 5.6 Hz, 1H, H_b-4).	23.8, 31.4, 55.8, 56.3, 73.1, 76.4, 77.0, 77.6, 101.0, 104.0, 111.5, 143.8 149.8 152.9.
2g (R = 3-isopropoxy-4-methoxyphenoxy-methyl)	2.31 (dd, *J* 5.6, 1.2 Hz, 1H, H_a-3), 2.60 (dd, *J* 6.2 Hz, 1.2 Hz, 1H, H_b -3), 3.25 (m, 1H, H-2) 3.85(dd, *J* 10.2, 7.0 Hz, 1H, H_a-4), 4.14(dd, *J* 10.2, 5.6 Hz, 1H, H_b-4).	22.0, 23.9, 28.8, 31.4, 56.6, 71.7, 73.2, 104.8, 105.1, 112.8, 148.2 152.8, 175.6.
2h (R = 3,4-methylene-dioxyphenylmethyl)	2.26 (dd, *J* 5.2, 1.2 Hz, 1H, H_a-3), 2.54 (dd, $J_{cis\text{-}gem}$ 6.2, 1.2 Hz, 1H, H_b-3), 2.80 (dd, *J* 14.1, 7.0 Hz, 1H, H_a-4), 2.91 (dd, *J* 14.1, 5.7 Hz, 1H, H_b-4), 3.04 (m, 1H, H-2)	25.6, 36.0, 42.2, 100.9, 108.2, 109.0, 121.5 133.0, 146.3, 147.6.

Table 4. The EI-MS, HRMS and EA data of thiiranes (**2a-h**)

Thiiranes	EI-MS	HRMS	Elemental Analysis* % Calcd (Found)		
2a (R = $C_6H_5CH_2OCH_2$)	181(M^{+1} 68), 163(30), 107(39), 92(42), 91(100), 79(17).	Calcd 180.0603 Found 180.0603	C, --	H, --	S --
2b (R = $C_6H_5OCH_2$)	166(M^+, 37), 165(30), 133(17), 74(19), 73(100).	Calcd 166.0447 Found 166.0449	C, --	H, --	S --
2c (R = C_6H_5)	136(M^+, 81), 135(100), 104(14), 91(44)	Calcd 136.0341 Found 136.0342	C, --	H, --	S --
2d (R = 1-naphthalenoxy-methyl)	216(M^+ 34), 116(22), 115(58), 73(100).	Calcd 216.0603 Found 216.0605	C, 72.19 (72.20)	H, 5.59 (5.62)	S 14.82 (14.80)
2e (R = 4-methoxyphen-oxymethyl)	196(M^+, 26), 123(33), 95(28), 73(100).	Calcd 196.0553 Found 196.0555	C, 61.20 (61.30)	H, 6.16 (6.22)	S 16.34 (16.56)
2f (R = 3,4-dimethoxy-phenoxymethyl)	226(M^+, 83), 154(53), 153(41), 125(55), 74(38), 73(100).	Calcd 226.0658 Found 226.0659	C, 58.38 (58.39)	H, 6.24 (6.26)	S 14.17 (14.16)
2g (R = 3-isopropoxy-4-methoxyphenoxy methyl)	254(M^+, 36), 222(15), 212(27), 182(22), 165 (39), 140(47), 139(63), 111(43), 73(100).	Calcd 254.0971 Found 254.0973	C, 61.39 (61.51)	H, 7.13 (7.29)	S 12.61 (12.69)
2h (R = 3,4-methylene-dioxyphenylmethyl)	194(M^+, 100), 161(36), 135(29), 131(24), 103 (19), 77(12)..	Calcd 194.0396 Found 194.0399	C, 61.83 (61.80)	H, 5.19 (5.20)	S 16.51 (16.55)

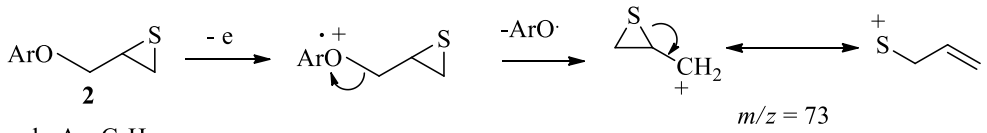
*The elemental analysis of thiiranes **2d**, **2f**, **2g**, and **2h** are measured.

The thiiranes have a characteristic base peak in EI-MS. For example, the fragment of *m/z* 73 in compound **2b**, **2d**, **2e**, **2f**, and **2g**; but *m/z* 91 in compound **2a**, *m/z* 135 in compound **2c**, and *m/z* 194 (M^+) in compound **2h** was found as base peak. The resulting thiiranes (**2a-h**) could be classified into four categories based on their base peaks in EI/MS: i) benzyloxymethylthiirane (**2a**), ii) aryloxymethylthiirane (**2b**, **2d**, **2e**, **2f** and **2g**), iii) phenylthiirane (**2c**), and iv) *O*-functional arymethylthiirane (**2h**). The base peak in EI-MS can be used as for structural identification. The mechanism for formation of the base peak in each category of thiiranes (**2a-h**) is proposed. The formation of base peak *m/z* 91 of benzyloxymethylthiirane (**2a**) involves the loss of a radical from the oxymethylenethiiryl group when initially impacted by an electron, and subsequent cleavage of the C-O bond to generate the benzylic cation which spontaneously converts to a stable tropyllium ion *m/z* 91, equation 1.



(**1**)

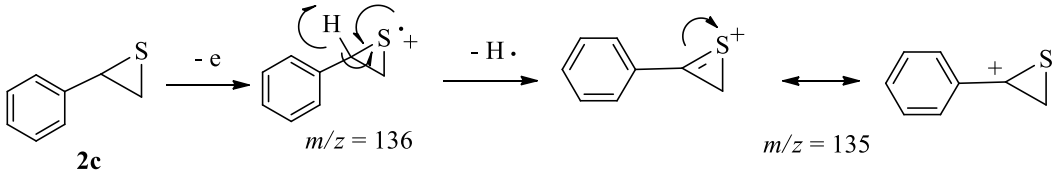
The formation of the base peak *m/z* 73 is common to aryloxymethylthiiranes **2b**, **2d**, **2e**, and **2f**, equation 2.



b. Ar=C_6H_5;
d. Ar=$C_{10}H_7$;
e. Ar=4-$OCH_3C_6H_4$;
f. Ar=3,4-$OCH_3C_6H_3$
g. Ar=3-isopropoxy-4-methoxy

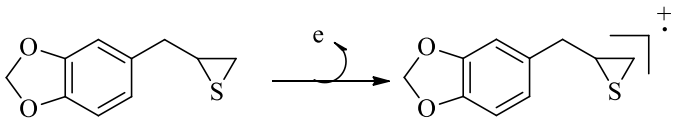
(**2**)

The formation of base peak *m/z* 135 of phenylthiiranes (**2c**) is proposed to result as shown in equation 3, from molecular ion, *m/z* 136 by the loss of one hydrogen radical to generate the resonance stablisied phenyl thiirene cation, *m/z* 135.



(**3**)

The formation of base peak of *O*-functional arymethylthiirane (**2h**) is proposed to result as shown in equation 4.



2h $m/z = 194$ (**4**)

Conclusions

In general in aqueous ammonium thiocyanate solution, epoxides can be converted into thiiranes, by heating under reflux or in higher yield by microwave irradiation .The formation of base peak in EI-MS of resulting the thiiranes was rational.

Experimental Section

General. Melting points (Yanaco micro melting-point apparatus) were uncorrected. ^{1}H-NMR and ^{13}C-NMR spectra were obtained on a Varian Gemini-200 or Varian Unity plus 400. Chemical shifts were measured in parts per million with respect to TMS. MS spectra were recorded on a Chem/hp/middle instrument. HRMS spectra were performed on a JEOL JMS SX/SX 102A instrument. Elemental analyses were recorded on a Heraeus CHN-O Rapid analyzer. Silica gel (230-400 mesh) for column chromatography and the precoated silica gel plate (60 F-254) for TLC were purchased from E. Merck Co. UV light (254 nm) was used to detect spots on TLC plates after development. Microwave irritating was carried on CEM, Discover or PROLABO, SYNTHEWAVE 402 microwave apparatus.

Benzyl glycidyl ether (**1a**) was prepared according to the known procedure,[17] epoxides (**1b**, **1d-1f**) were prepared from the epoxidation of corresponding allyl compounds with *m*CPBA in dichloromethane at 0^{o}C, and epoxides **1c** and **1g** were purchased from Aldrich.

General procedure for the conversion of oxiranes (**1a-g**) **to thiiranes** (**2a-h**)
The mixture of epoxide (20 mmol), NH_4SCN (3.04 g, 40 mmol), and H_2O (200 mL) was stirred and heated to reflux or the mixture of epoxide (2 mmol), NH_4SCN (0.3 g, 4.0 mmol), and H_2O (30 mL) was heated and irradiated on the microwave reactor with various reaction time, and energy (130 W to 300 W, see Table 2). When the starting material, epoxide, was completely consumed, the resulting mixture was extracted with EtOAc (20 mL × 5). The separated organic layer was combined and washed by brine (20 mL × 1), dried by anhydrous magnesium sulfate, and filtered. The filtrate was concentrated *in vacuo*, and the resulting residue was purified by silica gel column chromatography (EtOAc: *n*-hexane = 1: 10) to get pure thiiranes (**2a-h**).

2-Benzyloxymethylthiirane (**2a**).[17](0.29 g, 89%, by irritating with 160 W, 6 min) was obtained as colorless liquid, R_f = 0.69 (EtOAc: *n*-hexane = 1: 2), ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 2.18 (dd, *J* = 5.2, 1.2 Hz, 1H, H_a-3), 2.48 (dd, *J* = 6.0, 1.2 Hz, 1H, H_b-3), 3.08 (m, 1H, H-2), 3.47 (dd, *J* = 10.8, 6.4 Hz, 1H, Ha-4), 3.66 (dd, *J* = 10.8, 6.0 Hz, 1H, Hb-4), 4.56 (s, 2H, $OC\underline{H}_2C_6H_5$), 7.33 (m, 5H, ArH); ^{13}C-NMR ($CDCl_3$, 50 MHz) δ 23.7, 32.1, 73.0, 74.5, 127.6, 127.7, 128.3, 137.8; EI-MS (70eV) *m/z* 181 (M^{+1}, 68), 163 (30), 108 (40), 93 (42), 91 (100), 79 (17); HRMS (EI, *m/z*): Calcd for $C_{10}H_{12}OS$: 180.0603. Found: 180.0603.

2-Phenoxymethylthiirane (**2b**).[14e] (0.30 g, 90%, by irritating with 130 W, 5 min) was obtained as colorless liquid, R_f = 0.54 (EtOAc: *n*-hexane = 1: 6), ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 2.31 (dd, *J* = 5.2 Hz, 1.2 Hz, 1H, H_a-3), 2.59 (dd, *J* = 6.0, 1.2 Hz, 1H, H_b-3), 3.26 (m, 1H, H-2), 3.88 (dd, *J* = 10.2, 6.8 Hz, 1H, H_a-4), 4.19 (dd, *J* = 10.2 Hz , 5.2 Hz, 1H, H_b-4), 6.93 (m, 3H, ArH), 7.28 (m, 2H, ArH) ; ^{13}C-NMR ($CDCl_3$, 50 MHz) δ 23.8 , 31.3, 72.3, 114.4, 121.0, 129.4, 158.2; EI-MS (70eV) *m/z* 166 (M^+, 37), 133 (17), 120 (10), 105 (7), 91 (100), 91 (4), 77 (6), 75 (20), 73 (100); HRMS (EI, *m/z*): Calcd for $C_9H_{10}OS$: 166.0447, Found: 166.0449.

2-Phenylthiirane (**2c**).[14e] (0.30 g, 88%, by irritating with 160 W, 5 min) was obtained as colorless liquid, R_f = 0.83 (EtOAc: *n*-hexane = 1: 6), ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 2.65 (dd, *J* = 5.8, 1.4 Hz, 1H, 1H, H_a-3), 2.87 (dd, *J* = 6.6 Hz, 1.4 Hz, 1H, H_b-3), 3.89 (dd, *J* = 5.8, 6.6 Hz, 1H, H-2), 7.28 (m, 5H, ArH); ^{13}C-NMR ($CDCl_3$, 50 MHz) δ 27.3, 36.1, 126.7, 127.6, 128.3, 128.6; EI-MS (70eV) *m/z* 136 (M^+, 81), 135 (100), 104 (14), 92 (44), 79 (15); HRMS (EI, *m/z*): Calcd for C_8H_8S: 136.0341, Found: 136.0342.

2-(Naphthalen-1-yloxymethyl)thiirane (**2d**).[14e](0.29 g, 90%, by irritating with 300 W, 45 min) was obtained as colorless liquid, R_f = 0.55 (EtOAc: *n*-hexane = 1: 5), ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 2.29 (dd, *J* = 5.2, 1.2 Hz, 1H, H_a-3), 2.54 (dd, *J* = 6.2, 1.2 Hz, 1H, H_b-3), 3.30 (m, 1H, H-2), 3.99 (dd, *J* = 10.2, 6.8 Hz, 1H, H_a-4), 4.22 (dd, *J* = 10.2, 5.6 Hz, 1H, H_b-4), 6.66 (d, *J* = 7.6 Hz, 1H, ArH), 7.28 (t, *J* = 8.0 Hz, 1H, ArH), 7.43 (m, 3H, ArH), 7.75 (dd, *J* = 6.2, 3.2 Hz, 1H, ArH), 8.29 (dd, *J* = 6.2, 3.6 Hz, 1H, ArH); ^{13}C-NMR ($CDCl_3$, 50 MHz) δ 23.7, 31.4, 72.5, 104.9, 120.6, 121.9, 125.2, 125.4, 125.6, 126.4, 127.3, 134.4, 154.0; EI-MS (70eV) *m/z* 216 (M^+,30), 215 (17), 184 (11), 144 (9), 117 (32), 115 (49), 89 (13), 74 (100); HRMS (EI, *m/z*): Calcd for $C_{13}H_{12}OS$: 216.0603, Found: 216.0605.

2-(4-Methoxyphenoxymethyl)thiirane (**2e**).[14e] (0.29 g, 90%, by irritating with 170 W, 10 min) was obtained as colorless crystals, mp 63°C (EtOAC + *n*-hexane), R_f = 0.63 (EtOAc: *n*-hexane = 1: 2), ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 2.30 (dd, *J* = 5.2, 1.2 Hz, 1H, H_a-3), 2.59 (dd, *J* = 6.2, 1.2 Hz, 1H, H_b-3), 3.24 (m, 1H, H-2), 3.76 (s, 3H, $ArOCH_3$), 3.85 (dd, *J* = 10.4, 7.2 Hz, 1H, H_a-4), 4.16 (dd, *J* = 10.4, 5.2 Hz, 1H, H_b-4), 6.84 (m, 4H, ArH), ^{13}C-NMR ($CDCl_3$, 50 MHz) δ 23.9, 31.5, 55.7, 73.5, 114.7, 115.9, 152.5, 154.2; EI-MS (70eV) *m/z* 196 (M^+, 26), 124 (11), 123 (33), 109 (9), 96 (28), 73 (100); HRMS (EI, *m/z*): Calcd for $C_{10}H_{12}O_2S$: 196.0553, Found: 196.0555; Anal Calcd for $C_{10}H_{12}O_2S$: C, 61.20; H, 6.16; S, 16.34; Found: C, 61.18; H, 6.23; S, 16.50.

2-(3,4-Dimethoxyphenoxymethyl)thiirane (**2f**). (0.29 g, 89%, by irritating with 180 W, 10 min) was obtained as colorless crystals, mp 46°C (EtOAC + *n*-hexane), R_f = 0.47 (EtOAc: *n*-hexane = 1: 6), ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 2.32 (dd, *J* = 5.2, 1.4 Hz, 1H, H_a-3), 2.60 (dd, *J* = 6.2, 1.4

Hz, 1H, H_b-3), 3.25 (m, 1H, H-2), 3.83 (s, 3H, $ArOCH_3$), 3.85 (s, 3H, $ArOCH_3$), 3.87 (dd, *J* = 10.2, 5.6 Hz, 1H, H_a-4), 4.15 (dd, *J* = 10.2, 5.6 Hz, 1H, H_b-4), 6.39 (dd, *J* = 8.8, 2.8 Hz, 1H, ArH), 6.55 (d, *J* = 2.8 Hz, 1H, ArH), 6.76 (d, *J* = 8.8 Hz, 1H, ArH); ^{13}C-NMR ($CDCl_3$, 50 MHz) δ 23.8, 31.4, 55.8, 56.3, 73.1, 101.0, 104.0, 111.5, 143.8, 149.8, 152.9; EI-MS (70 eV), 226 (M^+, 83), 194 (17), 155 (53), 153 (41), 125 (55), 110 (16), 75 (38), 74 (100); HRMS (EI, *m/z*): calcd for $C_{11}H_{14}O_3S$: 226.0658. Found: 226.0659. Anal calcd for $C_{11}H_{14}O_3S$: C, 58.38; H, 6.24; S, 14.17. Found: C, 58.39; H, 6.26; S, 14.16.

2-(3-Isopropoxy-4-methoxyphenoxymethyl)thiirane (**2g**). (0.26 g, 80%), by irritating with 160 W, 10 min) was obtained as colorless crystals, mp 37°C (EtOAC + *n*-hexane), R_f = 0.58 (EtOAc: *n*-hexane = 1: 3), ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 1.37 (d, *J* = 6.0 Hz, 6H, $ArOCH\underline{Me}_2$), 2.31 (dd, *J* = 5.6, 1.2 Hz, 1H, Ha-3), 2.59 (dd, *J* = 6.2, 1.2 Hz, 1H, Hb-3), 3.25 (m, 1H, H-2) , 3.80 (s, 3H, $ArOCH_3$), 3.85 (dd, *J* = 10.2, 7.0 Hz, 1H, H_a-4), 4.14 (dd, *J* = 10.2, 5.6 Hz, 1H, H_b-4), 4.51 (hept, *J* = 6.0 Hz, 1H, $ArOC\underline{H}Me_2$), 6.40 (dd, *J* = 8.8, 3.0 Hz, 1H, ArH), 6.56 (d, *J* = 3.0 Hz, 1H, ArH), 6.78 (d, *J* = 8.8 Hz, 1H, ArH); ^{13}C-NMR ($CDCl_3$, 50 MHz) δ 22.0, 23.9, 28.8, 31.4, 56.6, 71.3, 73.2, 104.8, 105.1, 112.8, 148.2, 152.8, 175.7; EI-MS (70eV) *m/z* 254 (M^+, 36), 222 (15), 212 (27), 182 (22), 165 (39), 140 (47), 139 (63),111 (43), 73 (100); HRMS (EI, *m/z*): Calcd for $C_{13}H_{18}O_3S$: 254.0971, Found: 254.0973; Anal Calcd for $C_{13}H_{18}O_3S$: C, 61.39; H, 7.13; S, 12.61; Found: C, 61.51; H, 7.29; S, 12.69.

4-(3,4-Dimethoxyphenylmethyl)thiirane (**2h**). (0.29 g, 90%, by irritating with 200 W, 40 min) was obtained as colorless liquid, R_f = 0.52 (EtOAc: *n*-hexane = 1: 6), ^{1}H-NMR ($CDCl_3$, 200 MHz) δ 2.26 (dd, *J* = 5.4, 1.2 Hz, 1H, H_a-3), 2.54 (dd, *J* = 6.2, 1.2 Hz, 1H, H_b-3), 2.80 (dd, *J* = 14.1, 7.0 Hz, 1H, Ha-4), 2.91 (dd, *J* = 14.1, 5.7 Hz., 1H, Hb-4), 3.04 (m, 1H, H-2), 5.94 (s, 2H, -$OC\underline{H}_2O$-), 6.73 (m, 3H, ArH); ^{13}C-NMR ($CDCl_3$, 50 MHz) δ 25.6, 36.0, 42.2, 100.9, 108.2, 109.0, 121.5, 133.0, 146.3, 147.6; EI-MS (70eV) *m/z* 194 (M^+, 100), 161 (36), 135 (29), 131 (24), 103 (19); HRMS (EI, *m/z*): Calcd for $C_{10}H_{12}OS$: 194.0396. Found: 194.0399.

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References

1. (a) Kudo, H.; Makino, S.; Kameyama, A.; Nishikubo, T. *Macromolecules* **2005**, *38*, 5964. (b)Kameyama, A.; Murakami, Y.; Nishikubo, T. *Macromolecules* **1999**, *35*, 1407. (c) Imai, T.; Hayakawa, K.; Satoh, T.; Kaga, H.; Kakuchi, T. *Polym. Sci. Pol. Chem.* **2002**, *40*, 3443.
2. (a) Gottarelli, G.; Mariani, P.; Spada, G. P.; Samori, B.; Forni, A.; Solladie, G.; Hibert, M.

Tetrahedron, **1983**, *39*, 1337. (b) Scherowsky, G.; Gay, J. *Liq. Cryst.* **1989**, *5*, 1253.
3. (a) Chino, K.; Suga, K.; Ikawa, M.; Satoh, H. *J. Appl. Polym. Sci*. **2001**, *82*, 29537. (b). Kadoma Y. *Dent. Mater. J*. **2002**, *21*, 156.
4. (a) Goethals, E. J. *Polym. Sci. Pol. Rev.* **1968**, *2*, 73. (b) Fokin, A. V.; Allakhvediev, M. A.; Kolomiets, A. F.; *Russ. Chem. Rev.* (Engl. Transl.) **1990**, *59*, 705.
5. Testero, S. A.; Lee, M.; Staran, R. T.; Espahbodi, M.; Llarrull, L. I.; Toth, M.; Mobashery, S.; Chang, M. *Med. Chem. Lett*. **2011**, *2*, 177.
6. Sally, A. H.; Stephen, P. B.; Joel, L.; Peter J. S. *Bioorg. Med. Chem.* **2004**, *12*, 4877.
7. Cho, H. J.; Jung, M. J.; Kwon, Y.; Na, Y. *Bioorg. Med*. *Chem. Lett*. **2009**, *19*, 6766.
8. Kellis, J. T. Jr.; Childers, W. E.; Robinson, C. H.; Vickery, L. E. *J. Biol. Chem*. **1987**, *262*, 4421.
9. Lautenschlaeger, F. K.; Schwartz, N. V. *J. Org. Chem*. **1969**, *34*, 3991.
10. Woodgate, P. D.; Lee, H. H.; Rutledge, P. S.; Cambie, R. C. *Tetrahedron Lett*. **1976**, *18*, 1531.
11. Meyers, A. I.; Ford, M. E.; *Tetrahedron Lett.* **1975**, *16*, 2861.
12. Di Nunno, L.; Franchini, C.; Nacci, A.; Scilimati, A.; Sinicropi, M. S. *Tetrahedron-Asymmetr.* **1999**, *10*, 1913.
13. (a) Tamami, B.; Kolahdoozan, M. *Tetrahedron Lett*., **2004**, *45*, 1535; (b) Iranpoor, N.; Kazemi, F. *Tetrahedron Lett*., **1997**, *53*, 11377; (c) Iranpoor, N.; Kazemi, F. *Synthesis* **1996**, 821; (d) Kazemi, F.; Kiasat, A. R. *Phosphorus Sulfur* **2003**, *178*, 1333; (e) Kazemi, F.; Kiasat, A. R.; Ebrahimi, S. *J. Chem. Res. Synop*. **2002**, *4*, 176; (f) Mohammadpoor-Baltork, Iraj; Khosropour, Ahmad R. *Molecules*, **2001**, *6*, 996; (g) Mirkhani, V.; Tangestaninejad, S.; Alipanah, L. *Synth. Commun.* **2002**, *32*, 621; (h) Iranpoor, N.; Adibi, H. *Bull. Chem. Soc. Jpn.* **2000**, *73*, 675; (i) Mohammadpoor-Baltork, I.; Khosropoor, A. R. *Indian J. Chem. Sect. B.* **1999**, *38*, 605; (j) Iranpoor, N.; Tamami, B.; Shekarriz, M. *Synth. Commun*. 1999, 29, 3313; (k) Mohammadpoor-Baltork, I.; Aliyan, H. *Synth. Commun*. **1998**, *28*, 3943; (l) Iranpoor, N.; Zeynizadeh, B. *Synth. Commun.* **1988**, *28*, 3913.
14. (a) Yadav, J. S.; Reddy, B. V. S.; Reddy, Ch. Srinivas; Rajasekhar, K. *J. Org. Chem.* **2003**, *68*, 2525; (b) Yadav, J. S.; Reddy, B. V. S.; Baishya, G. *Syn. Lett*. **2003**, *3*, 396; (c) Brimeyer, M. O.; Mehrota, A.; Quici, S.; Nigam, A.; Regen, S. L. *J. Org. Chem.* **1980**, *45*, 4254; (d) Blatt, A. H. *Org. Synth. Coll.; Vol. IV*; 1963; 232. (e) Reddy, C. S.; Nagavani, S. *Heteroatom Chem*. **2008**, *19*, 97.
15. (a) Kazemi, F.; Kiasat, A. R.; Ebrahimi, S. *Synth. Commun*. **2003**, *33*, 595. (b) Mohammadpoor-Baltork, I.; Aliyan, H.; *J. Chem. Res. Synop.* **2000**, *3*, 122; (c) Tangestaninejad, S.; Mirkhani, V. *Synth. Commun*. **1999**, *29*, 2079. (d) Kazami, F.; Kiasat, A. R.; Ebrahim, S. *Phosphorus Sulfur* **2001**, *176*, 135. (e) Zeynizadeh, B.; Baradarani, M. M.; Eisavi, R. *Phosphorus Sulfur* **2011**, *186*, 2208. (f) Eisavi, R.; Zeynizadeh, B.; Baradarani, M. M. *Phosphorus Sulfur* **2011**, *186*, 1902.
16. (a) Kaboudin, B.; Norouzi, H. *Tetrahedron Lett*. **2004**, *45*, 1283; (b) Iranpoor, N.; Firouzabadi, H.; Shekarize, M. *Org. Biomol. Chem.* **2003**, *1*, 724; (c) Takido, T.; Kobayashi,

Y.; Itabashi, K. *Synthesis*, **1986**, *9*, 779; (d) Tangestaninejad, S.; Mirkhani, V. *J. Chem. Res. Synop.* **1999**, *6*, 370. (e) Wu, L.; Yang, L.; Fang, L.; Yang, C.; Yan, F. *Phosphorus Sulfur* **2010**, *185*, 2159. (f) Wu, Liqiang; Wang, Yongxue; Yan, Fulin; Yang, C. *Bull. Korean Chem. Soc.* **2010**, *31*, 1419.

17. Brugat, N.; Duran, J.; Polo, A.; Real, J.; lvarez-Larena, A.; Piniella, J. F. *Tetrahedron-Asymmetr.* **2002**, *13*, 569.

