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A facile tetrahydrothiophene-catalyzed ylide route to vinyloxiranes†

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Access to vinyloxiranes using aldehydes and allylic bromides in the presence of 1–5 mol% tetrahydrothiophene is reported. Both aliphatic and aromatic aldehydes work well in this reaction and the catalyst loading could be reduced as low as 0.5 mol%.

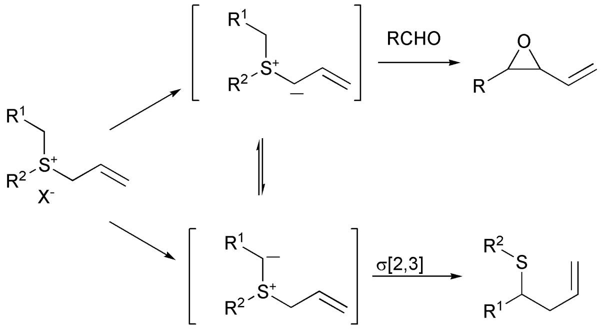
Sulfur ylides, particularly sulfur benzylides, have been developed as good reagents for the preparation of oxirane,[1] cyclopropane[2] and aziridine[3] derivatives since Johnson *et al.*[4] found the reaction of sulfur ylide with aldehydes in 1961. Although vinyloxiranes are versatile building blocks[5] and precursors of functionalized four-carbon sequences,[6] the reactions of allylic sulfur ylide with aldehydes, imines and electron-deficient alkenes were less explored than other ylide reactions, and it is still a challenging problem due to its easy [2,3][7] sigmatropic rearrangement. In order to obviate this rearrangement, typically, diphenyl sulfur ylide was used. Arsenic[8] or tellurium ylides[9] have been also employed to avoid the [2,3] sigmatropic rearrangement. In this way, the desired catalytic version[10] was realized by using 20 mol% diisobutyl telluride. Recently, Dai and Hou reported a one-pot strategy[11] for the synthesis of vinylaziridines and vinyl epoxides *via* sulfur ylides. In some cases, they found that the stereoselectivities of ylide expoxidation[11a] and/or aziridination[3a,11b,c,12] could be tuned by changing both the reaction conditions and the ligands of sulfur ylides. In our study of ylide chemistry,[13] we documented an enantioselective preparation of vinylcyclopropanes using stoichiometric chiral ylides.[14] Very recently, Metzner *et al.* described the first enantioselective synthesis of vinyl oxiranes from allylic chiral sulfur ylides.[15] To the best of our knowledge, no catalytic ylide epoxidation *via* allylic sulfur ylide has been reported, except that Aggarwal *et al.* reported that benzaldehyde reacted with (3,3-diphenyl)alkenyl sulfonyl hydrazone to afford diphenyl vinyl epoxide in the presence of 20 mol% tetrahydrothiophene.[1b] Here we report an efficient catalytic route to vinyloxiranes *via* allylic sulfur ylide.‡

By careful analysis of the reaction of allylic sulfur ylide in the presences of aldehyde (Scheme 1), we think that it is possible to realize catalytic ylide epoxidation when high concentrations of both aldehyde and allylic bromide are used in a one-pot reaction because the high concentration of allylic bromide is beneficial to the formation of sulfur salt and the high concentration of aldehyde could probably lead to the reaction of aldehydes with the sulfur ylide before the ylide rearranged. As alcoholic solvents were found to activate the aldehyde probably due to the formation of hydrogen bonds between solvent and aldehyde,[16] we chose *t*-BuOH as the solvent and used 5 mol% tetrahydrothiophene as the catalyst to start our study. As expected, this catalytic reaction proceeded very well. As shown in Table 1, the reaction of 4-chlorobenzaldehyde with allylbromide **2a** at reflux in the presence of 5 mol% tetrahydrothiophene gave the desired product in quantitative yield when either Cs_2CO_3 or K_2CO_3 was used as the base. This reaction could also be carried out without solvent, but the yield was lower than that when *t*-BuOH was used as the solvent (entry 4 in Table 1). Gratifyingly, the yield was still 83% even when the loading of tetrahydrothiophene was reduced to 0.5 mol% (entry 6).

Further studies showed that both aromatic and aliphatic aldehydes worked very well even on the gram-scale. As described in Table 2, both electron-rich and electron-deficient aromatic aldeydes gave the desired epoxides in excellent yields (entries 1–4). Compared with aromatic aldehydes, aliphatic aldehydes such as cyclohexanecarboxaldehyde and decyl aldehyde always are less active in catalytic ylide reactions. But under our conditions, they worked well (entries 5, 10 and 11). Although the stereoselectivity was not good, the isomers could be separated easily as a single *cis*- and/or *trans*-isomer by flash chromatography. Noticeably, β-trimethylsilylallyl bromide also participated in this reaction to give the corresponding epoxides in excellent yields using only 1 or 5 mol% of catalyst (entries 6–11).

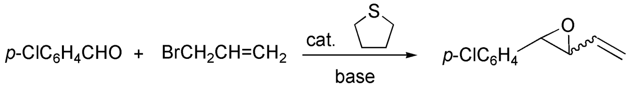
We also tried catalytic asymmetric ylide epoxidation by the use of chiral sulfides **4**, **5** and **6** as the catalyst. Only moderate yields were achieved in the presence of sulfide **4** or **6**. The enantioselectivities were low to moderate (entries 1 and 3 in Table 3). Sulfide **5** could not catalyze this reaction probably because the formation of salt is very difficult.

In conclusion, we have developed an efficient catalytic ylide route to vinyloxiranes *via* allylic sulfur ylides. The cheap and



Scheme 1

Table 1 Effects of reaction conditions on catalytic ylide epoxidation



1a **2a** **3a**

Entry	Solvent	Loading (mol%)[a]	Base	Yield[b]
1	*t*-BuOH	5	Cs_2CO_3	100
2	*t*-BuOH	5	K_2CO_3	100
3	*t*-BuOH	1	K_2CO_3	100
4	—	1	K_2CO_3	58
5	*t*-BuOH[c]	1	K_2CO_3	51
6	*t*-BuOH	0.5	K_2CO_3	83

[a] Tetrahydrothiophene loading. [b] Determined by GC. [c] Trace amount of water was added.

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† Electronic supplementary information (ESI) available: preparation of vinyloxiranes and chiral catalysts. See http://www.rsc.org/suppdata/cc/b3/b304443b/

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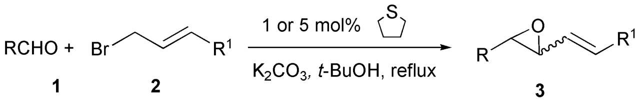
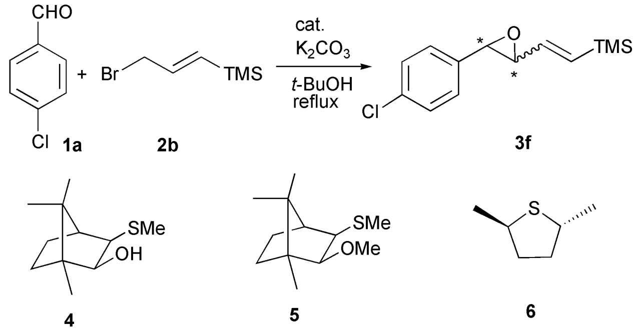
Table 2 Reactions of aldehydes with allylic bromides catalyzed by tetrahydrothiophene[a]



Entry	Loading[b]	R	R^1	*cis*/*trans*[c]	Yield (%)[d]
1	1	4-$\mathrm{ClC_6H_4}$	H	36/64	94
2	1	$\mathrm{C_6H_5}$	H	33/67	85
3	1	4-$\mathrm{NO_2C_6H_4}$	H	38/62	96
4	5	4-$\mathrm{CH_3OC_6H_4}$	H	30/70	85
5	5	*n*-$\mathrm{C_9H_{19}}$	H	55/45	75
6	1	4-$\mathrm{ClC_6H_4}$	TMS	25/75	83
7	1	$\mathrm{C_6H_5}$	TMS	24/76	89
8	1	4-$\mathrm{NO_2C_6H_4}$	TMS	30/70	85
9	1	2-$\mathrm{ClC_6H_4}$	TMS	27/73	85
10	5	*n*-$\mathrm{C_9H_{19}}$	TMS	42/58	88
11	5	*cyclo*-$\mathrm{C_6H_{11}}$	TMS	50/50	78

[a] All reactions were carried out in one-pot at reflux using tetrahydrothiophene (0.06 mmol), β-trimethylsilylallyl bromide (9.75 mmol) [or allylbromide (19.4 mmol)], aldehyde (6.5 mmol), K_2CO_3 (7.8 mmol), *t*-BuOH (2 mL) under dry N_2 atmosphere. [b] mol%. [c] Determined by GC. [d] Isolated yield.

Table 3 Asymmetric ylide epoxidations of **1a**[a]



Entry	Cat.	Loading (mol%)	*cis*/*trans*[b]	ee (%)[c] for *trans*-**3f**	Yield (%)
1	**4**	20	40 : 60	37	40
2	**5**	20	—	—	0
3	**6**	5	34 : 66	25	51

[a] All reactions were carried out in one-pot at reflux using catalyst, β-trimethylsilylallyl bromide (0.6 mmol), aldehyde (0.5 mmol), K_2CO_3 (0.6 mmol), *t*-BuOH (0.5 mL) under dry N_2 atmosphere. [b] Determined by GC. [c] Determined by HPLC.

readily available catalyst, the simple procedure, the mild conditions and the high catalytic efficiency together with the easy separation of *cis*/*trans*-isomers, make this method potentially useful in organic synthesis.

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Notes and references

‡ General procedure: To a Schlenk tube were added tetrahydrothiophene (5.7 mg, 0.06 mmol), allylbromide (1.68 mL, 19.4 mmol), 4-chlorobenzaldehyde (907 mg, 6.5 mmol), dry K_2CO_3 (powdered, 1.07 g, 7.8 mmol) and *t*-BuOH (2 mL, distilled over sodium) under N_2 atmosphere. The resulting mixture was refluxed for 12 h, and then filtered rapidly through a short silica gel column (ethyl acetate eluent). The filtrate was concentrated and the residue was purified by chromatography (hexane/ethyl acetate, 200/1, v/v) on silica gel to afford the desired product, 1.09 g (94%).

1 (*a*) V. K. Aggarwal, H. Abdel-Rahman, L. Fan, R. H. Jones and M. H. Standen, *Chem. Eur. J.*, 1996, **2**, 1024; (*b*) V. K. Aggarwal, E. Alonso, G. Hynd, K. M. Lydon, M. J. Palmer, M. Porcelloni and J. R. Studley, *Angew. Chem., Int. Ed.*, 2001, **40**, 1430; (*c*) J. Zanardi, C. Leriverend, D. Aubert, K. Julienne and P. Metzner, *J. Org. Chem.*, 2001, **66**, 5620; (*d*) K. Julienne, P. Metzner, V. Henryon and A. Greiner, *J. Org. Chem.*, 1998, **63**, 4532; (*e*) V. K. Aggarwal, J. N. Harvey and J. Richardson, *J. Am. Chem. Soc.*, 2002, **124**, 5747; (*f*) V. K. Aggarwal, G. Hynd, W. Picoul and J.-L. Vasse, *J. Am. Chem. Soc.*, 2002, **124**, 9964.

2 (*a*) V. K. Aggarwal, J. D. Vicente and R. V. Bonnert, *Org. Lett.*, 2001, **3**, 2785; (*b*) V. K. Aggarwal, E. Alonso, G. Fang, M. Ferrara, G. Hynd and M. Porcelloni, *Angew. Chem., Int. Ed.*, 2001, **40**, 1433.

3 (*a*) A.-H. Li, Y.-G. Zhou, L.-X. Dai, X.-L. Hou, L.-J. Xia and L. Lin, *J. Org. Chem.*, 1998, **63**, 4338; (*b*) V. K. Aggarwal, M. Ferrara, C. J. O'Brien, A. Thompson, R. H. Jones and R. Fieldhouse, *J. Chem. Soc., Perkin Trans. 1*, 2001, 1635; (*c*) V. K. Aggarwal, J. H. Charmant, C. Ciampi, J. M. Hornby, C. J. O'Brien, G. Hynd and R. Parsons, *J. Chem. Soc., Perkin Trans. 1*, 2001, 3159.

4 A. W. Johnson and R. B. LaCount, *J. Am. Chem. Soc.*, 1961, **83**, 417.

5 (*a*) T. Hudlicky and J. W. Reed, *Comprehensive Organic Synthesis*, ed. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, **vol. 5**, p. 899; (*b*) M. Lautens, S. G. Ouellet and S. Raeppel, *Angew. Chem., Int. Ed.*, 2000, **39**, 4079; (*c*) E. Schaumann and F. Tries, *Synthesis*, 2002, 191; (*d*) C. Hertweck and W. Boland, *J. Org. Chem.*, 2000, **65**, 2458; (*e*) C. Hertweck and W. Boland, *J. Org. Chem.*, 1999, **64**, 4426.

6 (*a*) J. A. Marshall, *Chem. Rev.*, 1989, **89**, 1503; (*b*) M. Lautens, M. L. Maddess, E. O. Sauer and S. G. Ouellet, *Org. Lett.*, 2002, **4**, 83; (*c*) B. M. Trost and C. Jiang, *J. Am. Chem. Soc.*, 2001, **123**, 12907; (*d*) S. Araki, K. Kameda, J. Tanaka, T. Hirashita, H. Yamamura and M. Kawai, *J. Org. Chem.*, 2001, **66**, 7919; (*e*) M. Lautens, S. G. Ouellet and S. Raeppel, *Angew. Chem., Int. Ed.*, 2000, **39**, 4079.

7 J. A. Marshall, The Wittig Rearrangement, in *Comprehensive Organic Synthesis*, ed. B. M. Trost and I. Fleming, Pergamon, Oxford, 1991, **vol. 3**, p. 975.

8 J. B. Ousset, C. Mioskowski and G. Solladie, *Tetrahedron Lett.*, 1983, **24**, 4419.

9 (*a*) A. Osuka and H. Suzuki, *Tetrahedron Lett.*, 1983, **24**, 5109; (*b*) Z.-L. Zhou, Y.-Z. Huang, L.-L. Shi and J. Hu, *J. Org. Chem.*, 1992, **57**, 6598.

10 Z.-L. Zhou, L.-L. Shi and Y.-Z. Huang, *Tetrahedron Lett.*, 1990, **31**, 7657.

11 (*a*) Y.-G. Zhou, A.-H. Li, X.-L. Hou and L.-X. Dai, *Chem. Commun.*, 1996, 1353; (*b*) A.-H. Li, L.-X. Dai and X.-L. Hou, *Chem. Commun.*, 1996, 491; (*c*) A.-H. Li, L.-X. Dai, X.-L. Hou and M.-B. Chen, *J. Org. Chem.*, 1996, **61**, 4641.

12 (*a*) X.-L. Hou, X.-F. Yang, L.-X. Dai and X.-F. Chen, *Chem. Commun.*, 1998, 747; (*b*) X.-F. Yang, M.-J. Zhang, X.-L. Hou and L.-X. Dai, *J. Org. Chem.*, 2002, **67**, 8097.

13 (*a*) S. Ye, L. Yuan, Z.-Z. Huang, Y. Tang and L.-X. Dai, *J. Org. Chem.*, 2000, **65**, 6257; (*b*) S. Ye, Y. Tang and L.-X. Dai, *J. Org. Chem.*, 2001, **66**, 5717; (*c*) Z.-Z. Huang, S. Ye, W. Xia and Y. Tang, *Chem. Commun.*, 2001, 1384; (*d*) Z.-Z. Huang and Y. Tang, *J. Org. Chem.*, 2002, **67**, 5320; (*e*) Z.-Z. Huang, S. Ye, W. Xia, Y.-H. Yu and Y. Tang, *J. Org. Chem.*, 2002, **67**, 3096.

14 S. Ye, Z.-Z. Huang, C.-A. Xia, Y. Tang and L.-X. Dai, *J. Am. Chem. Soc.*, 2002, **124**, 2432.

15 J. Zanardi, D. Lamazure, S. Miniére, V. Reboul and P. Metzner, *J. Org. Chem.*, 2002, **67**, 9083.

16 (*a*) Y. Huang and V. H. Rawal, *J. Am. Chem. Soc.*, 2002, **124**, 9662; (*b*) Y. Yuan, X. Li and K. Ding, *Org. Lett.*, 2002, **4**, 3309.