

Samarium Diodide-Promoted Reductive Cleavage of Carbon-Sulfur Bonds: A Novel Stereoselective Generation of Functionalized Vinylsamarium Species and Synthesis of β -Thiobutenolides

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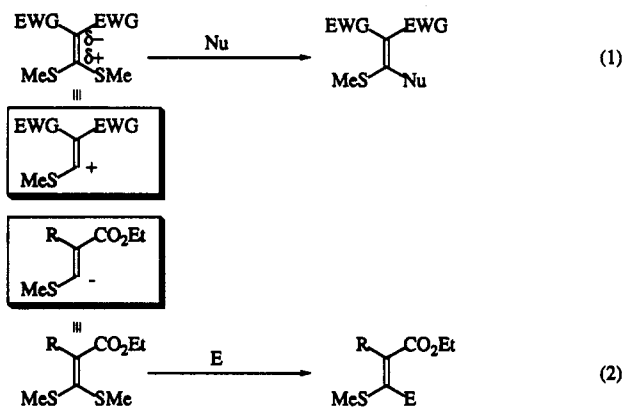
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Summary: (Alkoxy carbonyl)ketene dithioacetals are cleanly reduced by SmI_2 to provide a new and efficient method for the stereoselective generation of the corresponding novel highly functionalized vinylsamarium species which react with a proton, allyl bromide, and aldehydes to give the corresponding reduction products, allylation products, and β -thiobutenolides, respectively.

Ketene dithioacetals exhibit diverse reactivities (normal and umpolung type) owing to the stabilizing influence of a sulfur atom toward neighboring cations or anions and, therefore, are widely used as synthetic intermediates.¹ The reactivities of functionalized ketene dithioacetals having electron-withdrawing groups at the α and α' positions, such as the 1,4-addition of nucleophiles to enone systems followed by the elimination of a methylthio group (a formal substitution reaction of a methylthio group by a nucleophile), have been well-studied.² These compounds serve as vinyl cation equivalents (eq 1 in Scheme I). Although

Scheme I. Reactivity of Functionalized Ketene Dithioacetals



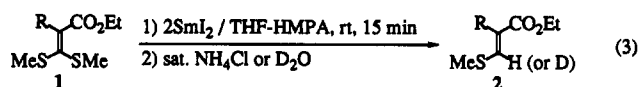
this characteristic is useful for the synthesis of heterocycles,³ it is enforced only by electron-withdrawing functionalities. We report herein a new method for the stereoselective generation of functionalized vinyl anions⁴ in which a ketene dithioacetal moiety shows reverse reactivity to the hitherto known reactivity of ketene dithioacetals (eq 2). Its application to the efficient synthesis of a variety of β -thiobutenolides by the reaction with carbonyl compounds is demonstrated.

Table I. SmI_2 -Promoted Reductive C-S Bond Cleavage Reaction^a

entry	ketene dithioacetal 1	vinyl sulfide 2	% yield ^b
1			90
2			97
3			93 ^c
4			95
5			95

^a Reaction conditions: a substrate (1 mmol) was added to a solution of SmI_2 in THF (50 mL) and HMPA (2.5 mL) at ambient temperature. After the mixture was stirred for 15 min saturated aqueous ammonium chloride was added. ^b Isolated yield by column chromatography. Only (*E*) isomer can be detected by the NMR analysis, otherwise noted. ^c The *E*:*Z* ratio was 94:6 by the NMR analysis.

After several attempts, we found that (ethoxycarbonyl)-ketene dithioacetals 1 are effectively and stereoselectively reduced to vinyl sulfides 2 having an alkoxy carbonyl group by a SmI_2 /THF-HMPA system⁵ followed by hydrolysis with saturated aqueous ammonium chloride (eq 3). As



can be seen in Table I, ketene dithioacetals bearing aliphatic, allylic, and aromatic substituents are cleanly transformed to the corresponding vinyl sulfides in excellent yields. It is worth noting that the vinyl sulfides obtained are only the (*E*)-isomers.⁶ Even in the sterically crowded isopropyl-substituted case, the (*E*)-isomer is predominant (*E*/*Z* = 94/6, entry 3). This may be a new type of selectivity in reactions mediated by samarium(II) and may arise from chelation between the ester group and the samarium atom. As such, the reductive C-S bond cleavage reaction proceeds in a highly selective manner, although the reaction mechanism is as yet unclear.

Our interest turned next to whether these vinyl sulfides are formed by the protonolysis of the corresponding vinylsamarium species or not. In the case of reductions

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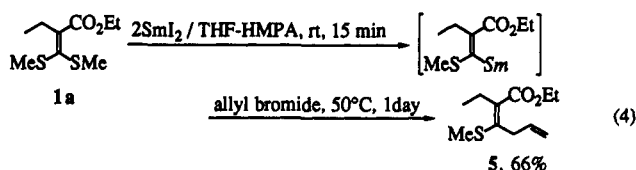
(3) For recent papers from our group, see the following and earlier references cited therein. (a) Hosomi, A.; Miyashiro, R.; Yoshida, R.; Tominaga, Y.; Yanagi, T.; Hojo, M. *J. Org. Chem.* 1990, 55, 5308. (b) Tominaga, Y.; Honkawa, Y.; Hara, M.; Hosomi, A. *J. Heterocycl. Chem.* 1990, 27, 775. (c) For a review, see: Tominaga, Y.; Hojo, M.; Hosomi, A. *J. Synth. Org. Chem., Jpn.* 1992, 50, 48.

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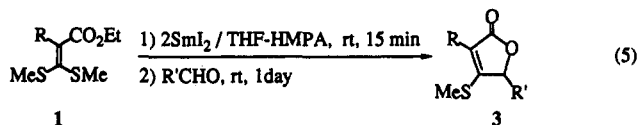
(6) A ¹H nuclear Overhauser enhancement (NOE) experiment on the allylic alcohol 4 derived from 2a by reduction with LiAlH_4 showed (*E*)-stereochemistry around the double bond (¹H NOE for CH_2OH , but none for CH_2CH_3 on the irradiation of the vinyl proton; ¹H NOE for the vinyl proton, but none for CH_2CH_3 on irradiation of CH_2OH).

at sp^2 -carbon atoms induced by SmI_2 , aryl halides are known to be reduced only to their radicals, which then abstract a hydrogen atom from the solvent.^{5,7} Therefore, any other electrophiles cannot be so introduced. The generation of a vinyl anion species by reduction reactions using SmI_2 has remained unexplored,⁸ while acyl⁹ and imino¹⁰ anion species have been recently described. Experiments aimed at the introduction of an allyl group are carried out by the addition of allyl bromide as a carbon electrophile after the reaction of **1a** with SmI_2 under similar conditions to the above. At reflux temperature for 1 day, the corresponding allylated product **5** was obtained in 66% yield (eq 4). Along with the formation of a deuterated **2a**



(98%) after quenching of the intermediate with deuterium oxide, this result strongly suggests that vinylsamarium species are effectively generated in this system.

An application of this highly selective and efficient reduction reaction can be made using aldehydes as the electrophile (eq 5). With a selection of ketene dithioacetals



and aldehydes, the one-pot synthesis of butenolides with a variety of substituents (**3**) can be achieved (Table II).¹¹

To summarize, (alkoxycarbonyl)ketene dithioacetals are cleanly reduced by SmI_2 via a new and efficient method for the stereoselective generation of the corresponding highly functionalized vinylsamarium species, otherwise inaccessible, which can react with a proton, allyl bromide, and aldehydes. Furthermore, an efficient synthesis of β -thiobutenolides by the reaction of these vinylsamarium

Table II. One-Pot Synthesis of Butenolides by SmI_2 -Promoted Reductive C-S Bond Cleavage Reaction^a

entry	ketene dithioacetal 1	aldehyde	butenolide 3	% yield ^b
1				71
2	1a			65
3	1a			82
4	1a			76
5	1a			85
6	1a			80
7				74
8				57
9				50

^a Reaction conditions: a substrate (1 mmol) was added to a solution of SmI_2 in THF (50 mL) and HMPA (2.5 mL) at ambient temperature. After the mixture was stirred for 15 min, an aldehyde (0.5 mmol) was added, and the resulting mixture was stirred for 1 day at the same temperature. ^b Isolated yield based on the aldehyde.

species with carbonyl compounds is described. Using this reductive cleavage of a carbon (sp^2)-sulfur bond by SmI_2 , a formal substitution reaction of a methylthio group by an electrophile occurs, and this represents the reverse of the reactivity expected of a functionalized ketene dithioacetal.

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Supplementary Material Available: Detailed experimental procedures and characterization data for the compounds prepared (7 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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