Manuscript Style Guide

Synthesis of highly substituted allenylsilanes by alkylidenation of silylketenes

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Abstract

Allenylsilanes are useful intermediates in organic synthesis. An attractive, convergent but little used approach for their synthesis is the alkylidenation of stable silylketenes. Reactions thus far have been limited to the use of unsubstituted silylketenes (or equivalents) with stabilised or semi-stabilised ylides only. The current study explores the reactions of substituted ketenes prepared through rhodium(II)-mediated rearrangement of silylated diazoketones. A range of novel 1,3-disubstituted and 1,3,3-trisubstituted allenylsilanes were prepared using stabilised and semi-stabilised ylides. Alkylidenation with non-stabilised phosphorus ylides was not viable, but the use of titanium-based methylenating reagents was successful, allowing access to 1-substituted allenylsilanes. Many novel allenylsilanes may be accessed by alkylidenation of substituted silylketenes. Importantly, for the first time, simple methylenation of silylketenes has been achieved using titanium carbenoid-based reagents.

Keywords

allenylsilanes; rhodium(II) octanoate-mediated rearrangement; silylketenes; titanium carbenoids; ylide
Introduction

Allenylsilanes are versatile intermediates for organic synthesis [1,2]. They have two main modes of reactivity: firstly, as propargyl anion equivalents in thermal [3,4] or Lewis acid-mediated [5,6] addition to carbonyls, acetics and imines, and secondly as three-carbon partners in [3+2] annulation reactions. Thus, reaction with aldehydes [7], imines/iminiums [7,8], enones [9-11] and nitrosyl cations [12] leads to dihydrofurans, dihydropyrroles, cyclopentenes and isoxazoles respectively [13]. In most cases the silicon is retained in the final product and can be used as a handle for further synthetic elaboration.

Amongst the myriad methods to prepare allenylsilanes [1,14], an attractive disconnection is to consider a Wittig-type alkylidenation of a silylketene (Figure 1).

Figure 1: Alkylidenation approach to the synthesis of allenylsilanes.

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This convergent approach potentially allows for tremendous variation in substitution pattern at both termini of the allenysilane, yet has been little exploited thus far. Ruden first demonstrated that the stabilised phosphorane carbethoxymethylenetriphenylphosphorane underwent Wittig condensation with trimethylsilylketene at sub-ambient temperature in high yield, but found that non-stabilised phosphoranes led to complex mixtures of products [15]. Other workers later extended this chemistry to include a wider range of stabilised phosphoranes, but attempts to promote the reaction with semi-stabilised ylides such as benzylidenetriphenylphosphorane were unsuccessful unless bis(trialkylsilyl)ketenes were used as substrates [16,17]. Thus, only 3-substituted and 3,3-disubstituted allenysilanes have thus far been accessed by alkylidenation of silylketenes, whilst no reports of the successful introduction of non-stabilised ylide equivalents have been forthcoming.

A second impediment to the generalisation of the approach has been the paucity of methods for preparing substituted silylketenes [18,19]. Methods based upon the thermolysis of siloxyalkynes [20] and dehydrohalogenation of substituted α-silyl acid halides [21,22] have not found general application. We recently reported a mild and functional group tolerant approach to substituted silylketenes based upon a rhodium-mediated formal Wolff rearrangement of silylated diazoketones [23]. Related photolytic approaches also hold some promise [24-27]. These methods allow access for the first time to a wide range of substituted silylketenes which will allow the chemistry of these fascinating persistent ketenes [18] to be better delineated.

In this paper we outline the synthesis of 1,3-disubstituted and 1,3,3-trisubstituted allenysilanes by the condensation of stabilised and semi-stabilised ylides with substituted silylketenes, and report for the first time the methylenation of silylketenes to give 1-substituted allenysilanes using titanium-based methodology.
Results and Discussion

Our investigations began with the preparation of substituted silylketenes 1 as substrates for the alkylidenation chemistry. This was carried out under our previously reported conditions for rhodium(II) octanoate-mediated rearrangement of silyl diazoketones 2 [23], which in turn were prepared by C-silylation of the parent diazoketones 3 with triethylsilyl triflate [28] (Scheme 1, Table 1). It should be noted that while the alkyl-substituted silylketenes are relatively stable and show little decomposition at room temperature over several days, the (hetero)aromatic-substituted silylketenes are much less robust and should be used quickly or stored in a freezer.

![Scheme 1: Synthesis of substituted silylketenes 1.](image)

The results and discussion section should contain a description of the experimental results that substantiates the conclusions of the work. A comprehensible discussion which links the results to related investigations and to existing knowledge in the relevant field should follow. The sections may also be separated. The presentation of experimental details in this section should be kept to a minimum. Information already obvious in tables, figures or schemes should not be reiterated in the text if not necessary for any important discussion.
With the requisite silylketenes in hand, attention turned to their reaction with the carboethoxy-stabilised phosphoranes 4 and 5. At the outset, it was by no means certain that these would react efficiently with substituted silylketenes 1 since it is well documented that nucleophiles attack silylketenes anti to the silicon [29], i.e. the phosphoranes would be approaching from the same side as the R1-substituent. Since in all previous examples this substituent has been a hydrogen atom, the extension to bulkier substituents could not be taken for granted. In the event, however, we were pleased to find that in nearly all cases the desired allenylsilanes were formed in moderate to excellent yield (Scheme 2, Table 2, see Supporting Information File 1 for full experimental data).

**Scheme 2:** Reaction of substituted silylketenes with ester-stabilised phosphoranes.
Table 2: Reaction of substituted silylketenes with ester-stabilised phosphoranes.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Ketene</th>
<th>Ylide</th>
<th>Temp (°C)</th>
<th>t (h)</th>
<th>Solvent</th>
<th>Yield 6/7 (%)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1a</td>
<td>4</td>
<td>80</td>
<td>24</td>
<td>PhH</td>
<td>54%</td>
</tr>
<tr>
<td>2</td>
<td>1a</td>
<td>5</td>
<td>rt</td>
<td>3</td>
<td>CH₂Cl₂</td>
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</tr>
<tr>
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<td>1b</td>
<td>4</td>
<td>110</td>
<td>24</td>
<td>toluene</td>
<td>45%</td>
</tr>
<tr>
<td>4</td>
<td>1b</td>
<td>5</td>
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<tr>
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<tr>
<td>6</td>
<td>1c</td>
<td>5</td>
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<tr>
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<td>1d</td>
<td>4</td>
<td>110</td>
<td>48</td>
<td>toluene</td>
<td>22%&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>1d</td>
<td>5</td>
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<td>48</td>
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<td>78%</td>
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<tr>
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<td>4</td>
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<td>24</td>
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<tr>
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<td>1f</td>
<td>4</td>
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<td>5</td>
<td>CH₂Cl₂</td>
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<tr>
<td>11</td>
<td>1h</td>
<td>4</td>
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<td>12</td>
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<td>4</td>
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<td>1</td>
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<tr>
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<td>1i</td>
<td>4</td>
<td>rt</td>
<td>10</td>
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<tr>
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<td>1i</td>
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<tr>
<td>15</td>
<td>1j</td>
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<td>80</td>
<td>12</td>
<td>PhH</td>
<td>74% (19%)</td>
</tr>
</tbody>
</table>

<sup>a</sup>60% of starting material recovered

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As expected, reactions with the more substituted ylide 4 were significantly slower than those with the parent ylide 5 (compare reaction temperatures and times, entries 1, 3 and 5 versus entries 2, 4 and 6). […] 

**Supporting Information**

Supporting information features copies of \(^1\)H NMR spectra of silylated diazoketones 2 and silylketenes 1, plus \(^1\)H and \(^{13}\)C NMR spectra of allenylsilanes 6, 7, and 14–19.

Supporting Information File 1:
File Name: S1.pdf
File Format: PDF
Title: Experimental part

Supporting Information File 2:
File Name: S2.pdf
File Format: PDF
Title: NMR spectra of compounds 1,2,6 and 7

Supporting Information File 3:
File Name: S3.pdf
File Format: PDF
Title: NMR spectra of compounds 14–19

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- the file name
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- a concise and descriptive title of 15 words maximum
- optional: a detailed description of the dataset.
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References

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