Indium compound-catalyzed deoxygenative allylation of aromatic ketones by a hydrosilane–allylsilane system

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Abstract

A combination of chlorodimethylsilane and allyltrimethylsilane effectively promoted the deoxygenative allylation of aromatic ketones in the presence of a catalytic amount of an indium compound to give the terminal alkenes. Indium trihalide or metallic indium showed high catalytic activity. © 2000 Elsevier Science Ltd. All rights reserved.

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Synthetic applications of metallic indium have attracted much attention during the last decade[1] due to its low ionic potential[2] and stability under aqueous conditions.[3] The synthetic potential of indium(III) halides is also increasing.[4] However, they are used in an analogous manner to that of conventional Lewis acids such as aluminum halides and boron halides. There are few synthetic applications peculiar to indium compounds. We have recently reported the $InCl_3$-catalyzed reductive Friedel–Crafts alkylation[5,6] where $InCl_3$ promotes the hydrosilylation of carbonyl compounds with chlorodimethylsilane and the successive deoxygenation led to the carbocationic intermediate which reacts with aromatics. When an excess amount of chlorodimethylsilane was added, the cation was reduced to the corresponding hydrocarbons as previously reported.[7] If the resulting carbocation could be trapped by carbon nucleophiles other than aromatics, a novel protocol of deoxygenative functionalization of ketones could be developed.

In this communication, we report a case of trapping the cation by an allyl group, where indium trichloride characteristically catalyzed the deoxygenative allylation of ketones by using allylsilanes and chlorodimethylsilane.

$$\text{(1)}$$
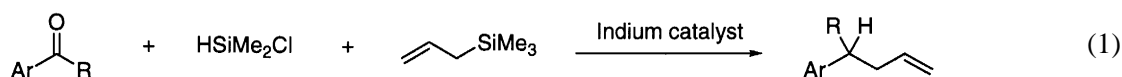
At first, we examined the catalysts in the reaction of acetophenone, chlorodimethylsilane and allyltrimethylsilane (Table 1). Indium trichloride effectively promoted the deoxygenative allylation to furnish

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4-phenyl-1-pentene (**1**) in 86% yield for 2 h (entry 1). It is interesting that even metallic indium gave a moderate yield (41%, entry 4) which could be improved up to 62% under a longer reaction time (entry 5). In contrast, neither AlCl₃, a representative Friedel–Crafts catalyst, nor Sc(OTf)₃, a characteristic promoter for reductive Friedel–Crafts reaction,[6c–e] gave the desired allylated product (entries 6 and 7). Of all the Lewis acids examined, $ZnCl_2$, $BF_3 \cdot OEt_2$, and $CuCl_2$ did not show any catalytic effect at all under similar conditions. These results indicate that indium trichloride is an indispensable catalyst for this type of allylation.
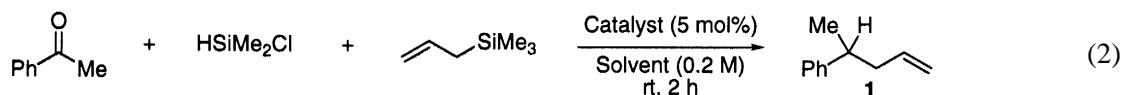
$$\text{Ph} \overset{\text{O}}{\underset{}{\parallel}} \text{Me} \ + \ HSiMe_2Cl \ + \ \diagup\!\!\!\diagdown\!\!\!\diagup SiMe_3 \ \xrightarrow[\substack{\text{Solvent (0.2 M)} \\ \text{rt, 2 h}}]{\text{Catalyst (5 mol\%)}} \ \text{Ph} \overset{\text{Me} \ \text{H}}{\underset{\mathbf{1}}{\diagup\!\!\!\diagdown}} \tag{2}$$

Table 1

Entry	Catalyst	Solvent	Yield/ %[a]	Entry	Catalyst	Solvent	Yield/ %[a]
1	$InCl_3$	CH_2Cl_2	86	8	$InCl_3$	$ClCH_2CH_2Cl$	63
2	$InBr_3$	CH_2Cl_2	60	9	$InCl_3$	cyclohexane	0
3	InI_3	CH_2Cl_2	85	10	$InCl_3$	DMF	0
4	In	CH_2Cl_2	41	11	$InCl_3$	THF	0
5[b]	In	CH_2Cl_2	62	12	$InCl_3$	CH_3CN	35
6	$AlCl_3$	CH_2Cl_2	1	13	$InCl_3$	$CHCl_3$	16
7	$Sc(OTf)_3$	CH_2Cl_2	< 0.2	14	$InCl_3$	CCl_4	0

[a] Yields were determined by GLC. [b] The reaction was carried out for 16 hours.

The choice of solvent was also found to be definitely significant in this deoxygenative allylation as shown in Table 1 (entries 1 and 8–14). The reaction with acetophenone proceeded only when dichloromethane or 1,2-dichloroethane was used as a solvent. In contrast, the use of cyclohexane, DMF or THF completely suppressed the reaction, where the starting ketone was recovered (entries 9–11). Even other haloalkanes such as carbon tetrachloride and chloroform were unsuitable solvents (entries 13 and 14).
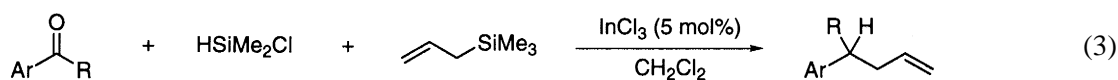
$$\text{Ar} \overset{\text{O}}{\underset{}{\parallel}} \text{R} \ + \ HSiMe_2Cl \ + \ \diagup\!\!\!\diagdown\!\!\!\diagup SiMe_3 \ \xrightarrow[\substack{CH_2Cl_2}]{InCl_3 \ (5 \ mol\%)} \ \text{Ar} \overset{\text{R} \ \text{H}}{\underset{}{\diagup\!\!\!\diagdown}} \tag{3}$$

Table 2

Entry	Ar	R	Conditions	Product	Yield/ %[a]
1	Ph	Et	rt, 2 h	**2**	67
2	Ph	Ph	rt, 2 h	**3**	99
3	Ph	CH_2CH_2Cl	rt, 1 h → 60 °C, 3 h	**4**	70
4	p-Cl-C_6H_4	Me	rt, 2 h	**5**	84
5	p-EtOCO-C_6H_4	Me	rt, 1 h → 60 °C, 3 h	**6**	44
6	p-O₂N-C_6H_4	Ph	rt, 1 h → 60 °C, 2 h	**7**	75
7	$PhCH_2CH_2$	Me	rt, 2 h	complicated mixture	
8	Ph	H	rt, 2 h	complicated mixture	

[a] Yields were determined by GLC.

We then explored the generality of the InCl$_3$-catalyzed deoxgenative allylation of aromatic ketones and the results are summarized in Table 2. The allylation of various types of aromatic ketones proceeded in moderate to excellent yields. Benzophenone, particularly, gave a quantitative yield at ambient temperature. The functionalities such as nitro, ester or chlorine were tolerated under these reducing conditions even at high temperature to give the corresponding olefins selectively (entries 3–6). The reaction with alkylketone gave a complicated mixture including a trace amount of a deoxygenative allylation product (entry 7). A harshly exothermic reaction took place with the use of benzaldehyde to give a complicated mixture (entry 8), in which side reactions such as direct allylation of the aldehyde, hydrosilylation and reductive Friedel–Crafts alkylation would simultaneously occur.[5]

A general procedure is as follows: acetophenone (2.0 mmol) was added to a mixture of indium trichloride (0.1 mmol), chlorodimethylsilane (2.2 mmol) and allyltrimethylsilane (2.2 mmol) in dichloromethane (10 mL) at ambient temperature. The reaction mixture was stirred for 2 h, quenched by water (20 mL), and extracted with ether (20 mL×3). After the organic layer was dried over MgSO$_4$ and concentrated in vacuo, the residue was purified by chromatography (eluted by hexane) on silica gel to give the product **1**.

We propose a plausible reaction path as illustrated in Scheme 1. At first, Lewis acid-promoted hydrosilylation of ketone takes place to form a silyl ether **8**. Then desiloxylation is accelerated by InCl$_3$ (via **8a** or **8b**) to generate the cation **9** (or a cationic species),[8] which is readily trapped by allyltrimethysilane. It is pointed out that the reaction (Table 1, entry 1) was accompanied with only a small amount (8%) of ethylbenzene formed by the trapping of the cation **9** with chlorodimethylsilane instead of allyltrimethylsilane. The stability of the cation intermediate should be an important factor, because *p*-nitrobenzophenone, which is facilely susceptible to hydrosilylation showed more sluggish reaction than benzophenone. This hypothesis is also supported by the fact that aromatic ketones gave higher yields than alkylketones or aldehydes. The diphenylmethyl cation derived from benzophenone, in particular, is very stable to accomplish this reaction course.
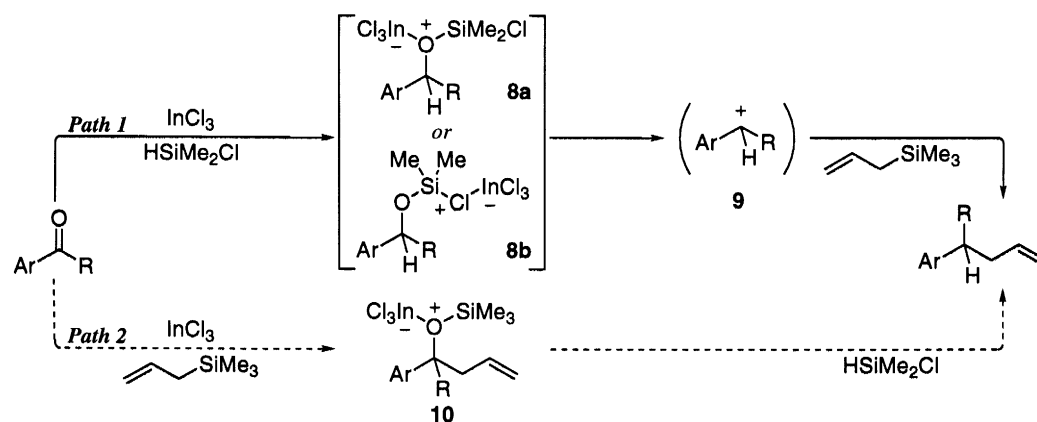
Scheme 1. Plausible reaction paths of the deoxygenative allylation

Another possible path in which the allylation is followed by deoxygenative reduction (*path 2*) can be considered. However, no direct allylation of ketones with allyltrimethylsilane was observed in the presence of an InCl$_3$ catalyst. In addition, no formation of double allylated compounds, which should be facilely formed by the second allylation,[9] was observed. These results rule out *path 2*.

In conclusion, a novel deoxygenative allylation of aromatic ketones, namely, a selective transfunctionalization from carbonyl oxygen into hydrogen and an allyl group, was achieved by using allyltrimethylsilane and chlorodimethylsilane in the presence of a catalytic amount of an indium catalyst. The

disclosure of the detailed role of indium trichloride and further extension of this method are now in progress.

Acknowledgements

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