## Palladium-catalyzed silylation of alcohols with hexamethyldisilane†

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The combination of hexamethyldisilane and a catalytic amount of  $[PdCl(\eta^3-C_3H_5)]_2$ -PPh<sub>3</sub> was found to be effective for the trimethylsilylation of alcohols, where both of the two trimethylsilyl groups of hexamethyldisilane were transferred to alcohols without coproduction of any stoichiometric amount of byproduct but H<sub>2</sub>.

Silvlation of alcohols is an important process not only as a protecting method of alcohols, but also for synthesis of functional organosilicon compounds.1 The treatment of alcohols with a trialkyl(chloro)silane in the presence of a stoichiometric amount of an amine is certainly the most widely used method, where coproduction of HCl·amine is inevitable. One of the most effective alternatives free from such salts is the use of trialkyl(hydro)silanes as silvl sources, often in combination with a transition metal catalyst, giving H<sub>2</sub> as the sole byproduct.<sup>2,3</sup> However, the method becomes impractical when the corresponding hydrosilane is difficult to handle, as in the case with trimethylsilylation, which requires the use of volatile trimethylsilane. Here we report palladium-catalyzed trimethylsilylation of alcohols using readily available hexamethyldisilane.<sup>4</sup> To the best of our knowledge, there has been only one precedent for use of hexamethyldisilane as a silvlation reagent, where tetrabutylammonium fluoride is used as a catalyst.5,6

We have previously reported that the combination of hexamethyldisilane (1a) with D<sub>2</sub>O reduces alkynes into 1,2-dideuterioalkenes with the aid of a palladium catalyst, where D<sub>2</sub>O is silvlated on the O-D bonds to be transformed to hexamethyldisiloxane *via* trimethylsilanol.<sup>7</sup> We expected that the replacement of  $D_2O$ with alcohols should lead to formation of trimethylsilyl ethers. Thus, treatment of 1-hexadecanol (2a: 1.0 equiv.) with 1a (0.60 equiv.) in the presence of  $[PdCl(\eta^3-C_3H_5)]_2$  (3a: 5 mol%) of Pd) and PPh3 (10 mol%) in DMA at 80 °C for 3 h gave 1-(trimethylsiloxy)hexadecane (4a) in 95% yield (eqn (1) and entry 1 of Table 1). Worthy of note is that only 0.60 equiv. of 1a is required, implying that both of the two trimethylsilyl groups of disilane 1a are used as the silvl source. The silvlation is applicable also to secondary and tertiary alcohols (entries 2-4). Both transand cis-1,2-cyclohexanediol reacted equally with 1a to give bissilvlation products (entries 5 and 6). The reaction is compatible with functional groups such as carbonyl, haloalkane and alkene (entries 7–9), and a sugar having a free hydroxy group underwent the silulation (entry 10).

$$\begin{array}{c} [PdCl(\eta^{3}\text{-}C_{3}H_{5})]_{2} \text{ (3a: 5 mol% of Pd)} \\ PPh_{3} (10 \text{ mol%}) \\ \hline 1 : 0.6 \\ 2 \\ 1a \\ \end{array} \xrightarrow{\text{PPh}_{3} (10 \text{ mol%})} RO-SiMe_{3} (1) \\ \hline \end{array}$$

To get an insight into how the silyl groups are transferred from hexamethyldisilane (1a) to alcohols, we performed several stoichiometric reactions using  $[PdCl(\eta^3-PhCHCHPh)]_2$  (3b)

**Table 1** Palladium-catalyzed silvlation of alcohols with hexamethyl-<br/>disilane $^a$ 



<sup>*a*</sup> The reaction was carried out in DMA (1.0 mL) at 80 °C for 3 h using an alcohol (0.80 mmol) and Me<sub>3</sub>SiSiMe<sub>3</sub> (0.48 mmol) in the presence of [PdCl( $\eta^3$ -C<sub>3</sub>H<sub>5</sub>)]<sub>2</sub> (0.040 mmol of Pd) and PPh<sub>3</sub> (0.080 mmol). <sup>*b*</sup> Isolated yield based on the alcohol. <sup>*c*</sup> Me<sub>3</sub>SiSiMe<sub>3</sub> (0.96 mmol), [PdCl( $\eta^3$ -C<sub>3</sub>H<sub>5</sub>)]<sub>2</sub> (0.080 mmol of Pd) and PPh<sub>3</sub> (0.16 mmol) were used. <sup>*d*</sup> Yield of the bis-silylation product.

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and 1,1,2,2-tetramethyl-1,2-diphenyldisilane (1b) instead of  $[PdCl(\eta^3-C_3H_5)]_2$  (3a) and 1a, where phenyl substituents facilitate the tracking of the allyl and the silvl moieties. On treatment of 3b (0.400 mmol of Pd) and PPh<sub>3</sub> (0.800 mmol) with **1b** (0.190 mmol) in the presence of 1-phenylethanol (2b: 3.99 mmol) in DMA at 80 °C for 1 h, we observed the formation of  $PdH(Cl)(PPh_3)_2$  (5), which was confirmed by <sup>31</sup>P NMR (bs, 28.1 ppm).<sup>8</sup> The reaction mixture was analyzed by GC, and was found to contain 1,3,4,6tetraphenyl-1,5-hexadiene (6b as a mixture of diastereomers: 0.187 mmol, 94% yield based on 3b) and 1-[dimethyl(phenyl)siloxy]-1phenylethane (4'b: 0.352 mmol, 93% yield based on 1b) (eqn (2)).<sup>9</sup> PdH(Cl)(PPh<sub>3</sub>)<sub>2</sub> (5) thus generated was found to catalyze the trimethylsilylation of 2b faster than 3a-PPh<sub>3</sub> (1 : 2): the reaction completed within 1 h under the same conditions as entry 2 of Table 1 to give **4b** in 94% yield.<sup>10</sup> It is interesting that the two silvl groups of 1b were used for the silvlation of alcohol during the conversion of  $\pi$ -allylpalladium **3b** into active H–Pd–Cl complex **5**.



Next, we examined how the silvl groups of disilanes are transferred to alcohols under the influence of PdH(Cl)(PPh<sub>3</sub>)<sub>2</sub> (5) (eqn (3)). The reaction of PhMe<sub>2</sub>SiSiMe<sub>2</sub>Ph (1b) with 5 (1.0 equiv.) in the presence of alcohol 2b (10 equiv.) at 0 °C for 1.5 h proceeded with 87% conversion to give 4'b (100% yield) and PhMe<sub>2</sub>SiH (7b: 72% yield), which also was efficiently transformed further to 4'b upon heating at 80 °C for 1 h.<sup>3,11</sup> Silyl ether 4'b observed before heating is possibly generated by the reaction of initially formed PhMe<sub>2</sub>SiCl (8b) with alcohol 2b. Although we failed to detect 8b in the reaction mixture of eqn (3) in the absence of 2b due to its instability in DMA,<sup>12</sup> chlorosilane 8b (60%) and hydrosilane 7b (34%) were observed by GC analysis on treatment of 1b with 5 (1.0 equiv.) in THF at 25 °C for 10 min, with 48% conversion. As chlorosilanes are known to be obtained from hydrosilanes and HCl in the presence of a palladium catalyst,<sup>13</sup> silyl ether 4'b derived from hydrosilane 7b upon heating (eqn (3)) is likely to be produced through chlorosilane 8b in the presence of H-Pd-Cl complex 5.

Considering the generation of a chlorosilane and a hydrosilane as the intermediates for silyl ether 4, catalytic cycles starting with



H–Pd–Cl **5** with the use of Me<sub>3</sub>SiSiMe<sub>3</sub> (**1a**) and [PdCl( $\eta^3$ -C<sub>3</sub>H<sub>5</sub>)]<sub>2</sub> (**3a**) are likely to be depicted as shown in Scheme 1. In Cycle A, H–Pd–Cl **5** first reacts with **1a** to give H–Pd–SiMe<sub>3</sub> and Me<sub>3</sub>SiCl (**8a**), which silylates ROH **2**. Reductive elimination from H–Pd–SiMe<sub>3</sub> gives Me<sub>3</sub>SiH (**7a**) and Pd<sup>0</sup>, which accepts oxidative addition of HCl coproduced on the silylation to regenerate H–Pd–Cl **5**. Hydrosilane **7a** thus generated participates in a similar cycle (Cycle B), transmetalating with H–Pd–Cl **5** to give Me<sub>3</sub>SiCl (**8a**) and H–Pd–H. The cycle goes along a similar scheme to Cycle A but gives H<sub>2</sub> instead of the hydrosilane.

In conclusion, we have disclosed a new method of trimethylsilylation of alcohols with the aid of a palladium catalyst, The most striking feature is high atom-economy, where  $H_2$  is a sole byproduct in use of just a slightly excess amount of a silyl source.<sup>‡</sup>

## Notes and references

‡ General procedure for the trimethylsilylation of alchohols: To a solution of  $[PdCl(\eta^3-C_3H_5)]_2$  (**3a**: 7.4 mg, 0.040 mmol of Pd) and PPh<sub>3</sub> (21 mg, 0.080 mmol) in DMA (1.0 mL) were added successively an alcohol (**2**: 0.80 mmol) and hexamethyldisilane (**1a**: 70 mg, 0.48 mmol). After stirring at 80 °C for 3 h, the resulting mixture was diluted with diethyl ether (20 mL), washed with water (10 mL × 5) and brine (10 mL), and dried over anhydrous sodium sulfate. After filtration, followed by evaporation of the solvent at atmospheric pressure, the resulting mixture was filtered through an alumina plug (10 mL) using hexane (30 mL) as an eluent. Evaporation of the solvent at atmospheric pressure followed by evacuation at 35 °C under *ca.* 20 mmHg gave trimethylsilyl ether **4**.

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- 2 For a review, see: E. Lukevics and M. Dzintara, J. Organomet. Chem., 1985, 295, 265–315.
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- 4 Yamamoto and Kumada reported that the PdCl<sub>2</sub>(PEt<sub>3</sub>)<sub>2</sub>-catalyzed reaction of PhMe<sub>2</sub>SiSiMe<sub>3</sub> with ethanol at 90 °C for 26 h proceeded with 65% conversion to give PhMe<sub>2</sub>SiOEt with evolution of molecular hydrogen. However, hexaalkyldisilanes are considered to be inert under these conditions. K. Yamamoto, M. Kumada, I. Nakajima, K. Maeda and N. Imaki, J. Organomet. Chem., 1968, **13**, 329–341; K. Yamamoto and M. Kumada, J. Organomet. Chem., 1972, **35**, 297–302.
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- 9  $\pi$ -Allyl complex **3b** and disilane **1b** were found to be as equally effective as **3a** and **1a**, respectively, as a palladium precursor and a silylating reagent: the reaction of **2b** with **1b** (0.60 equiv.) in the presence of **3b**– PPh<sub>3</sub> (1:2, 5 mol% of Pd) at 80 °C for 3 h gave **4'b** in 92% yield.
- 10 The higher catalytic activity of PdH(Cl)(PPh<sub>3</sub>)<sub>2</sub> (**5**) was demonstrated by comparison of the reactions stopped at 10 min: 37% **4b** (**5**) νs. <1% **4b** (**3a**–PPh<sub>3</sub>).
- 11 Treatment of **7b** with **5** (1.0 equiv.) and **2b** (10 equiv.) at 80 °C for 1 h gave **4'b** in 89% yield.
- 12 The peak corresponding to 8b was observed on GC analysis of a THF solution, whereas it was not observed in a DMA solution.
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