

Stereoselective synthesis of 1,4-dienylsilanes via hydromagnesiation of alkynylsilanes

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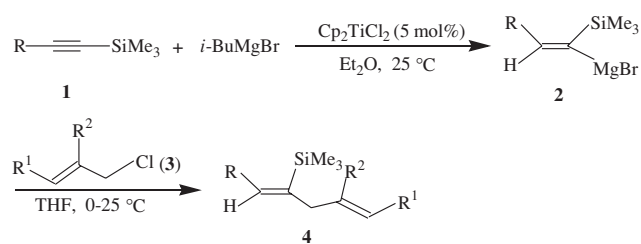
Hydromagnesiation of alkynylsilanes **1** gave (*Z*)- α -silylvinyl Grignard reagents **2**, which underwent coupling reaction with allylic chlorides **3** to give stereoselectively 1,4-dienylsilanes **4** in good yields: the products **4** can undergo the desilylation reaction in the presence of a catalytic amount of hydriodic acid to afford stereoselectively 1,4-dienes **5** in high yields.

Keywords: hydromagnesiation, alkynylsilane, 1,4-dienylsilane, 1,4-diene

The 1,4-diene unit is a key structural feature of many fatty acid derived natural products including arachidonic acid, several of the leukotrienes, and a variety of insect pheromones.¹ Many methods can be used for the synthesis of 1,4-dienes. The stereospecific reduction of 1,4-diyne by catalytic hydrogenation over Lindlar catalyst or reduction with sodium in liquid ammonia gives the *Z,Z*- or *E,E*-1,4-dienes, respectively.² The tandem alkylation-reduction of $\alpha, \beta, \gamma, \delta$ -unsaturated ketones forms 1,4-dienes regioselectively.³ The methylcopper-induced cross-coupling of alkenylboranes with allylic halides affords 1,4-dienes stereoselectively.⁴ The palladium-catalysed stereo- and regioselective coupling of allylic derivatives with alkenylmetals also gives 1,4-dienes highly selectively.⁵ The heteroatom-containing 1,4-dienes are also useful as building blocks because many useful functional group transformations can be achieved by introduction and removal of heteroatom functions. However, the synthesis of 1,4-dienes containing heteroatoms has received less attention. Only the regioselective synthesis of 1-silyl substituted 1,4-dienes⁶ and the stereoselective synthesis of 1,4-dienyl selenides⁷ have been described in the literature. Hydromagnesiation has emerged as a unique hydrometalation with some attractive features, such as the high regioselectivity and stereoselectivity observed with alkynylsilanes.⁸ We now report that 1,4-dienylsilanes could be synthesized by hydromagnesiation of alkynylsilanes, followed by the treatment with allylic chlorides.

Alkynylsilanes **1** were prepared according to the literature.⁹ Hydromagnesiation of alkynylsilanes **1** at 25°C in diethyl ether for 6 hours gave (*Z*)- α -silylvinyl Grignard reagents **2**, which reacted with allylic chlorides **3** in THF to afford 1,4-dienylsilanes **4**. The yields were 60–78% (Scheme 1).

Investigations of the crude products **4** by ¹H NMR spectroscopy (300 MHz) showed their isomeric purities to be more than 97%. One olefinic proton signal of **4** splits characteristically into one triplet at δ 5.8–6.1 with a coupling constant $J = 7.5$ Hz, which indicated that hydromagnesiation to the alkynylsilanes had taken place with strong preference for the addition of the magnesium atom at the carbon adjacent to the silyl group. The stereochemistry of the reaction product was assigned on the basis of the results of differential NOE experiments. Thus irradiation of the ethylenic proton resulted in a positive NOE on the hydrogen atoms of the alkyl groups linked to the other ethylenic carbon atom. The typical results of the reaction are summarised in Table 1.



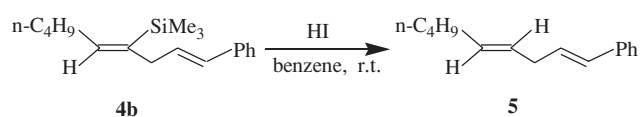
Scheme 1

Table 1 Synthesis of 1,4-dienylsilanes

R	R ¹	R ²	Product	Yield/% ^a
<i>n</i> -C ₄ H ₉	H	H	4a	69
<i>n</i> -C ₄ H ₉	Ph	H	4b	73
<i>n</i> -C ₄ H ₉	H	CH ₃	4c	65
<i>i</i> -C ₅ H ₁₁	H	H	4d	72
<i>i</i> -C ₅ H ₁₁	Ph	H	4e	78
<i>i</i> -C ₅ H ₁₁	H	CH ₃	4f	74
<i>n</i> -C ₆ H ₁₃	H	H	4g	60
<i>n</i> -C ₆ H ₁₃	Ph	H	4h	70
PhCH ₂	H	H	4i	62

^aIsolated yield based on the alkynylsilane **1** used.

Vinylsilanes are important synthetic intermediates owing to the versatile reactivity of the silyl group and the carbon–carbon double bond.¹⁰ 1,4-Dienylsilanes can undergo desilylation with retention of configuration easily to provide an effective method of stereoselective synthesis of 1,4-dienes. Thus, desilylation of **4b** at room temperature in benzene for 2 h in the presence of a catalytic amount of hydriodic acid afforded stereoselectively (*E,E*)-1-phenyl-1,4-nonadiene **5** in 86% yield (Scheme 2). The stereochemistry of compound **5** was easily established, since the ¹H NMR spectrum of **5** gives rise to a doublet at δ 5.62 with a coupling constant of 15.1 Hz and a doublet at δ 6.39 with a coupling constant of 16.0 Hz, which is consistent with an (*E,E*)-configuration. Our results show that the hydromagnesiation-allylation-desilylation sequence of alkynylsilanes provides a practical route to the stereoselective synthesis of 1,4-dienes.



Scheme 2

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† This is a Short Paper, there is therefore no corresponding material in *J. Chem. Research (M)*.

In summary, compared to other methods that have been reported,²⁻⁵ the present method for the synthesis of 1,4-dienes has the advantages of easily available starting materials, mild reaction conditions, convenient manipulation, good yields and high stereoselectivity.

Experimental

The ¹H NMR spectra were recorded in CDCl₃ on a Bruker PC-300 (300 MHz) instrument. IR spectra were obtained on a Perkin-Elmer 683 spectrometer as neat films. Microanalyses were carried out using a Yanaco MT-3 CHN microelemental analyzer. All solvents were dried, deoxygenated and freshly distilled before use.

General procedure for synthesis of 1,4-dienylsilanes: To a solution of isobutylmagnesium bromide (4.5 mmol) in Et₂O (7 ml) was added Cp₂TiCl₂ (50 mg, 0.2 mmol) at 0°C under Ar, and the mixture was stirred for 30 min at that temperature. To this solution was added alkynylsilane **1** (4.0 mmol), and the mixture was stirred for 6 h at 25°C. After removal of the Et₂O under reduced pressure (2 h, r.t./2 torr), the residue was dissolved in THF (6 ml), cooled to 0°C, and a solution of allylic chloride **3** (4.5 mmol) in THF (3 ml) was added dropwise over 30 min with stirring. The reaction mixture was brought to 25°C gradually and stirred for 6 h, quenched with sat. aq NH₄Cl (25 ml) and extracted with Et₂O (2×30 ml). The organic layer was washed with sat. aq NH₄Cl (20 ml) and H₂O (3×30 ml) and dried (MgSO₄). Removal of solvent under reduced pressure gave an oil, which was purified by column chromatography on silica gel using light petroleum (b.p. 30–60°C) as eluent.

Compound 4a: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3078, 2957, 2874, 1636, 1612, 1466, 1248, 911, 836, 758; $\delta_{\text{H}}(\text{CDCl}_3)$ 5.96 (t, $J = 7.5$ Hz, 1H), 5.89–5.76 (m, 1H), 4.95 (m, 2H), 2.80 (d, $J = 6.0$ Hz, 2H), 2.12 (m, 2H), 1.56–1.32 (m, 4H), 0.90 (t, $J = 6.4$ Hz, 3H), 0.12 (s, 9H); Anal. Calcd for C₁₂H₂₄Si: C, 73.47; H, 12.24. Found: C, 73.19; H, 12.08.

Compound 4b: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3082, 3025, 2955, 2873, 1648, 1612, 1598, 1495, 1448, 1248, 967, 837; $\delta_{\text{H}}(\text{CDCl}_3)$ 7.40–7.23 (m, 5H), 6.37 (d, $J = 15.9$ Hz, 1H), 6.26 (m, 1H), 6.07 (t, $J = 7.5$ Hz, 1H), 2.99 (d, $J = 6.1$ Hz, 2H), 2.20 (m, 2H), 1.44–1.37 (m, 4H), 0.95 (t, $J = 6.4$ Hz, 3H), 0.20 (s, 9H); Anal. Calcd for C₁₈H₂₈Si: C, 79.41; H, 10.29. Found: C, 79.17; H, 10.11.

Compound 4c: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3075, 2926, 2856, 1647, 1610, 1457, 1248, 837, 758; $\delta_{\text{H}}(\text{CDCl}_3)$ 5.88 (t, $J = 7.5$ Hz, 1H), 4.72 (s, 1H), 4.63 (s, 1H), 2.83 (s, 2H), 2.07 (m, 2H), 1.71 (s, 3H), 1.45–1.36 (m, 4H), 0.90 (t, $J = 6.4$ Hz, 3H), 0.13 (s, 9H); Anal. Calcd for C₁₃H₂₆Si: C, 74.29; H, 12.38. Found: C, 74.40; H, 12.29.

Compound 4d: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3078, 2956, 2871, 1636, 1609, 1468, 1384, 1367, 1248, 910, 837, 760, 689; $\delta_{\text{H}}(\text{CDCl}_3)$ 5.93 (t, $J = 7.4$ Hz, 1H), 5.79 (m, 1H), 5.03–4.92 (m, 2H), 2.80 (d, $J = 6.1$ Hz, 2H), 2.13 (m, 2H), 1.57 (m, 1H), 1.25 (m, 2H), 0.89 (d, $J = 6.6$ Hz, 6H), 0.14 (s, 9H); Anal. Calcd for C₁₃H₂₆Si: C, 74.29; H, 12.38. Found: C, 74.02; H, 12.19.

Compound 4e: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3081, 3025, 2954, 2875, 1648, 1612, 1495, 1467, 1384, 1366, 1248, 967, 836, 743, 692; $\delta_{\text{H}}(\text{CDCl}_3)$ 7.38–7.18 (m, 5H), 6.34 (d, $J = 15.8$ Hz, 1H), 6.21 (m, 1H), 6.03 (t, $J = 7.5$ Hz, 1H), 2.97 (d, $J = 6.1$ Hz, 2H), 2.14 (m, 2H), 1.58 (m, 1H), 1.28 (m, 2H), 0.92 (d, $J = 6.6$ Hz, 6H), 0.17 (s, 9H); Anal. Calcd for C₁₉H₃₀Si: C, 79.72; H, 10.49. Found: C, 79.50; H, 10.26.

Compound 4f: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3075, 2955, 2871, 1648, 1614, 1467, 1384, 1367, 1248, 890, 837, 756; $\delta_{\text{H}}(\text{CDCl}_3)$ 5.94 (t, $J = 7.5$ Hz, 1H), 4.76 (s, 1H), 4.64 (s, 1H), 2.73 (s, 2H), 2.15 (m, 2H), 1.68 (s, 3H), 1.56 (m, 1H), 1.27 (m, 2H), 0.89 (d, $J = 6.6$ Hz, 6H), 0.13 (s, 9H); Anal. Calcd for C₁₄H₂₈Si: C, 75.00; H, 12.50. Found: C, 74.72; H, 12.38.

Compound 4g: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3079, 2925, 2856, 1637, 1613, 1457, 1248, 910, 837, 758, 689; $\delta_{\text{H}}(\text{CDCl}_3)$ 5.94 (t, $J = 7.5$ Hz, 1H), 5.76 (m, 1H), 4.96 (m, 2H), 2.80 (d, $J = 6.4$ Hz, 2H), 2.09 (m, 2H), 1.46–1.20 (m, 8H), 0.89 (t, $J = 6.4$ Hz, 3H), 0.13 (s, 9H); Anal. Calcd for C₁₄H₂₈Si: C, 75.00; H, 12.50. Found: C, 74.81; H, 12.27.

Compound 4h: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3082, 3026, 2926, 2856, 1649, 1612, 1495, 1448, 1248, 966, 837, 757, 692; $\delta_{\text{H}}(\text{CDCl}_3)$ 7.41–7.20 (m, 5H), 6.38 (d, $J = 16.0$ Hz, 1H), 6.26 (m, 1H), 6.08 (t, $J = 7.5$ Hz, 1H), 3.01 (d, $J = 5.9$ Hz, 2H), 2.21 (m, 2H), 1.52–1.27 (m, 8H), 0.94 (t, $J = 6.4$ Hz, 3H), 0.21 (s, 9H); Anal. Calcd for C₂₀H₃₂Si: C, 80.00; H, 10.67. Found: C, 79.76; H, 10.49.

Compound 4i: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3079, 3058, 2957, 1635, 1614, 1596, 1495, 1249, 837, 690; $\delta_{\text{H}}(\text{CDCl}_3)$ 7.51–7.12 (m, 5H), 6.13 (t, $J = 7.5$ Hz, 1H), 5.84 (m, 1H), 4.96 (m, 2H), 3.52 (d, $J = 7.2$ Hz, 2H), 2.81 (d, $J = 6.1$ Hz, 2H), 0.11 (s, 9H); Anal. Calcd for C₁₅H₂₂Si: C, 78.26; H, 9.57. Found: C, 77.98; H, 9.36.

Desilylation reaction of the 1,4-dienylsilane 4b: To a solution of 1,4-dienylsilane **4b** (0.5 mmol) in benzene (1 ml) was added aq 57% HI (0.04 ml). The mixture was stirred at r.t. for 2 h, quenched with sat. aq NaHCO₃ (10 ml) and extracted with Et₂O (2×15 ml). The ethereal solution was washed with H₂O (3×20 ml), dried (MgSO₄) and concentrated under reduced pressure. The oily residue was purified by flash column chromatography on silica gel using light petroleum (b.p. 30–60°C) as eluent to give **5** as oil. Yield 86%.

Compound 5: $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3081, 3026, 2957, 2871, 1650, 1599, 1495, 1449, 965, 742, 692; $\delta_{\text{H}}(\text{CDCl}_3)$ 7.45–7.18 (m, 5H), 6.39 (d, $J = 16.0$ Hz, 1H), 6.24 (m, 1H), 5.62 (dt, $J = 15.1, 7.2$ Hz, 1H), 5.43 (m, 1H), 2.93 (m, 2H), 2.08 (m, 2H), 1.49–1.19 (m, 4H), 0.91 (t, $J = 6.4$ Hz, 3H); Anal. Calcd for C₁₅H₂₀: C, 90.00; H, 10.00. Found: C, 89.78; H, 9.85.

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