

Synthesis of Propargylic Fluorides from Allenylsilanes

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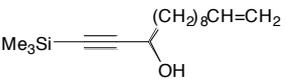
SUPPORTING INFORMATION

General. Infrared spectra were recorded on a Paragon 1000 FT-IR spectrometer and only peaks of interest are reported. ¹H NMRs were reported on Bruker DPX 200, DPX 400 and AV 400 spectrometers, at a frequency of 200 and 400 MHz respectively. ¹³C NMRs were recorded on Bruker DPX 200, AV 400 and AMX500 spectrometers at a frequency of 50, 100 or 125 MHz respectively with CDCl₃ or Acetone-d₆ as the internal reference. Mass spectra (*m/z*) were recorded on Micromass GCT in Chemical Ionisation (NH₃, CI⁺) or Field Ionisation (FI). Analytical thin layer chromatography (TLC) was performed on Merck Silica 60 F₂₅₄ plates. All reactions were carried out under an argon atmosphere in dried glassware with magnetic stirring.

General Procedure for the Synthesis of Alkynols¹

To a stirred solution of trimethylsilylacetylene (331 μL, 2 mmol) in dry THF (4 mL) at -78°C, was added a solution of *n*-BuLi (2.5M) in hexane (0.96 mL, 2.4 mmol). The solution was stirred for 30 minutes prior to addition of the aldehyde (2 mmol). The mixture was stirred for a further 5 minutes and then warmed to 0°C for 2 h. The reaction was then quenched with H₂O (10 mL), the aqueous layer extracted with Et₂O (3x15 mL). The combined organic layers were collected and dried over MgSO₄, and concentrated at reduced pressure. The resulting crude product was purified by column chromatography.

All alkynols used for the synthesis of the corresponding allenylsilanes have been previously described in the literature except 1-(trimethylsilyl)tridec-12-en-1-yn-3-ol.

 **1-(Trimethylsilyl)tridec-12-en-1-yn-3-ol:** $\nu_{\max}(\text{film})/\text{cm}^{-1}$
3333, 2172, 1641 and 1250; δ_{H} (400 MHz; CDCl₃) 0.17 (9H, s),
1.24-1.50 (12H, m), 1.64-1.72 (2H, m), 1.77 (1H, broad s),
2.03 (2H, q, *J* = 7.0 Hz), 4.35 (1H, t, *J* = 6.6 Hz), 4.92 (1H, d, *J* = 10.0 Hz), 4.99 (1H,
dd, *J* = 17.2, 1.0 Hz), 5.81 (1H, ddt, *J* = 17.2, 10.0, 6.8 Hz); δ_{C} (100 MHz; Acetone-d₆)
1.1, 27.0, 30.7, 30.8, 31.0, 31.1, 31.2, 35.5, 39.8, 63.6, 88.6, 110.7, 115.6, 140.8.

General Procedure for the Synthesis of Mesylates²

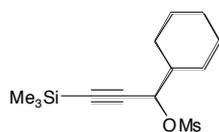
To a stirred solution of the silylated alkynol (2 mmol) in dry DCM (alcohol free, 2 mL) at 0°C, triethylamine (558 μL, 4 mmol) was added. This was followed by the addition of methanesulfonyl chloride (232 μL, 3 mmol). The reaction was allowed to warm up to room temperature and stir for 3.5 h. It was quenched with H₂O (15 mL) and

¹ A. Ajamian and J. L. Gleason, *Org. Lett.*, 2003, **5**, 2409.

² M. C. Pacheco and V. Gouverneur, *Org. Lett.*, 2005, **7**, 1267.

the aqueous layer was extracted with DCM (3x15 mL). The combined organic layers were dried with MgSO₄ and then filtered and concentrated at reduced pressure.

All mesylates used for the synthesis of the corresponding allenylsilanes have been previously described in the literature except 1-cyclohexyl-3-(trimethylsilyl)prop-2-ynylmethanesulfonate.



1-Cyclohexyl-3-(trimethylsilyl)prop-2-ynylmethanesulfonate:
 $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 2178, 1177 and 846; δ_{H} (400 MHz; CDCl₃) 0.20 (9H, s), 1.07-1.40 (5H, m), 1.67-1.90 (6H, m), 3.18 (3H, s), 4.98 (1H, d, J = 6.0 Hz); δ_{C} (100 MHz; CDCl₃) 0.6, 27.2, 29.6, 29.8, 29.9, 40.2, 44.3, 77.6, 95.9, 102.1; m/z (FI) C₁₃H₂₄O₃SSi (M⁺) calc. 288.1215, found 288.1211.

General Procedures for the Synthesis of Allenylsilanes

Protocol A:³ To a stirred solution of CuCN·2LiCl [prepared by dissolving copper(I) cyanide (537 mg, 6 mmol) and lithium chloride (509 mg, 12 mmol) in dry THF (12 mL)], a solution of *n*-BuLi in hexane (6 mmol) was added drop-wise at -78°C under an argon atmosphere. After 15 minutes, a solution of 5-phenyl-1-(trimethylsilyl)-1-pent-1-yn-3-ylmethanesulfonate (2 mmol) in dry THF (5 mL) was added. It was left for 2 h and then allowed to warm up to room temperature overnight. The reaction mixture was quenched with NH₄Cl (25 mL) and the aqueous layer extracted with Et₂O (3x20 mL). The combined organic layers were dried with MgSO₄ and then filtered and concentrated at reduced pressure, affording 487 mg of product (yellow oil, 90% yield).

Protocol B:⁴ The mesylate was prepared by adding *n*-BuLi (1.6M) in hexane (2.7 mL, 4.32 mmol) and lithium bromide (375 mg, 4.32 mmol) to a stirred solution of 1-[(trimethylsilyl)ethynyl]cyclohexanol (843 mg, 4.32 mmol) in dry THF (9 mL) at -78°C. After 30 minutes at this temperature, methane sulfonyl chloride (351 μ L, 4.54 mmol) was added and stirred at this temperature for 1 h. The mesylate in solution was used as such in the next step. For the synthesis of the silylated allene, *n*-BuLi (1.6M) in hexane (8.1 mL, 12.96 mmol) was added drop-wise at -78°C to a stirred solution of CuCN·2LiCl [prepared by dissolving copper(I) cyanide (1161 mg, 12.96 mmol) and lithium chloride (1099 mg, 25.92 mmol) in dry THF (20 mL)]. After 15 minutes, the freshly prepared mesylate was added. It was left for 2 h at -78°C and then allowed to warm up to room temperature overnight. The mixture was quenched by NH₄Cl (15 mL) and extracted with Et₂O (3x15 mL). The organic layers were collected and dried over MgSO₄ and concentrated at reduced pressure. The crude was purified by column chromatography (silica, hexane) affording 259 mg of pure product (yellow oil, 25% over the 2 steps).

Protocol C:⁵ To a stirred solution of triphenyl phosphine (934 mg, 3.56 mmol) was added DIAD (701 μ L, 3.56 mmol) at -15°C in THF (5 mL) under an argon atmosphere. After 10 minutes, a solution of 1-(trimethylsilyl)-8-(*tert*-butyldimethylsilyloxy)oct-1-yn-3-ol (772 mg, 2.37 mmol) in dry THF (2 mL) was added, followed by *o*-nitrobenzene sulfonyl hydrazone (769 mg, 3.56 mmol) 10 minutes

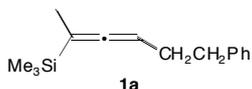
³ T. Nishiyama, T. Esumi, Y. Iwabuchi, H. Irie and S. Hatakeyama, *Tetrahedron Lett.*, 1998, **39**, 43.

⁴ H. Westmijze and P. Vermeer, *Synthesis*, 1979, 390.

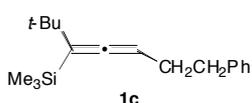
⁵ A. G. Myers and B. Zheng, *J. Am. Chem. Soc.*, 1996, **118**, 4492.

later. This was kept at -15°C for a further hour, before being allowed to warm-up to room temperature overnight. After concentrating the mixture at reduced pressure, the crude was purified by column chromatography (silica, hexane) affording 512 mg of a colourless oil (70%).

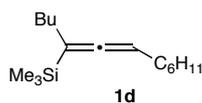
Allenylsilanes **1b**⁶ and **1e**⁷ have been previously reported.



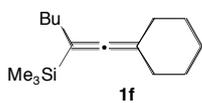
Trimethyl(6-phenylhexa-2,3-dien-2-yl)silane (1a): Protocol A was used. $\nu_{\text{max}}(\text{film})/\text{cm}^{-1}$ 1939, 1496, 1248 and 839; δ_{H} (400 MHz; Acetone- d_6) 0.07 (9H, s), 1.62 (3H, dd, $J = 3.0, 1.0$ Hz), 2.23-2.29 (2H, m), 2.69 (2H, t, $J = 7.6$ Hz), 4.79-4.83 (1H, m), 7.14-7.29 (5H, m); δ_{C} (100 MHz; Acetone- d_6) 1.9, 15.7, 30.2, 36.0, 83.5, 91.6, 125.7, 128.2, 128.5, 142.5, 205.6; m/z (FI) $\text{C}_{15}\text{H}_{22}\text{Si}$ (M^+) calc. 230.1491, found 230.1491.



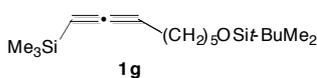
(2,2-Dimethyl-7-phenylhepta-3,4-dien-3-yl)trimethylsilane (1c):⁸ Protocol A was used. $\nu_{\text{max}}(\text{film})/\text{cm}^{-1}$ 1937, 1448 and 839; δ_{H} (400 MHz; Acetone- d_6) 0.16 (9H, s), 1.08 (9H, s), 2.28 (2H, dt, $J = 8.8, 6.8$ Hz), 2.69-2.74 (2H, m), 4.90 (1H, t, $J = 6.4$ Hz), 7.14-7.30 (5H, m); m/z (FI) $\text{C}_{18}\text{H}_{28}\text{Si}$ (M^+) calc. 272.1960, found 272.1960.



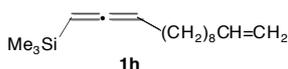
(4-Cyclohexylbuta-2,3-dien-2-yl)trimethylsilane (1d): Protocol A was used. $\nu_{\text{max}}(\text{film})/\text{cm}^{-1}$ 1934 and 838; δ_{H} (400 MHz; Acetone- d_6) 0.09 (9H, s), 0.90 (3H, t, $J = 6.5$ Hz), 1.06-1.50 (10H, m), 1.60-1.80 (6H, m), 1.95-2.01 (1H, m), 4.82-4.86 (1H, m); δ_{C} (100 MHz; Acetone- d_6) -0.3, 15.3, 24.1, 27.9, 27.9, 33.2, 35.4, 35.5, 38.9, 93.6, 98.9, 204.7; m/z (FI) $\text{C}_{13}\text{H}_{24}\text{Si}$ (M^+) calc. 250.2117, found 250.2121



(1-Cyclohexylidenehex-1-en-2-yl)trimethylsilane (1f): Protocol B was used. $\nu_{\text{max}}(\text{film})/\text{cm}^{-1}$ 1941, 1247 and 838; δ_{H} (400 MHz; Acetone- d_6) 0.14 (9H, s), 0.95 (3H, t, $J = 7.0$ Hz), 1.35-1.78 (10H, m), 2.02 (2H, t, $J = 7.0$ Hz), 2.13-2.16 (4H, m); δ_{C} (100 MHz; Acetone- d_6) 0.0, 15.3, 23.8, 24.7, 28.0, 29.4, 32.9, 33.1, 39.4, 44.5, 96.3, 98.6, 202.9; m/z (FI) $\text{C}_{15}\text{H}_{28}\text{Si}$ (M^+) calc. 237.2039, found 237.2035.



tert-Butyldimethyl[8-(trimethylsilyl)octa-6,7-dienyloxy]silane (1g): Protocol C was used. $\nu_{\text{max}}(\text{film})/\text{cm}^{-1}$ 3584, 1938 and 1250; δ_{H} (400 MHz; CDCl_3) 0.05 (6H, s), 0.09 (9H, s), 0.90 (9H, s), 1.41-1.43 (4H, m), 1.48-1.55 (2H, m), 1.94-2.01 (2H, m), 3.64 (2H, t, $J = 6.0$ Hz), 4.80 (1H, q, $J = 6.4$ Hz), 4.92-4.95 (1H, m); δ_{C} (100 MHz; CDCl_3) -4.2, 0.2, 19.8, 27.1, 27.3, 29.5, 31.2, 34.4, 64.5, 83.9, 84.9, 212.0; m/z (FI) $\text{C}_{17}\text{H}_{37}\text{Si}_2\text{O}$ (MH^+) calc. 313.2305, found 312.2296.



Trimethyl(trideca-1,2,12-trienyl)silane (1h): Protocol C was used. $\nu_{\text{max}}(\text{film})/\text{cm}^{-1}$ 1938, 1641 and 1249; δ_{H} (400 MHz; CDCl_3) 0.09 (9H, s), 1.25-1.42 (12H, m), 1.92-1.99 (2H, m),

⁶ T. Katsuhira, T. Harada, K. Maejima, A. Osada and A. Oku, *J. Org. Chem.*, 1993, **58**, 6166.

⁷ J.-H. Pi and X. Huang, *Tetrahedron Lett.*, 2004, **45**, 2215.

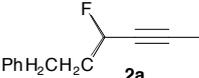
⁸ For ^{13}C NMR see characterization of the deuterated analogue: T. Harada, T. Katsuhira, A. Osada, K. Iwazaki, K. Maejima and A. Oku, *J. Am. Chem. Soc.*, 1996, **118**, 11377.

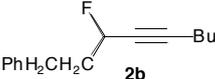
2.04 (2H, dtt, $J = 8.0, 6.8, 1.2$ Hz), 4.76 (1H, q, $J = 6.8$ Hz), 4.88 (1H, dt, $J = 6.8, 3.6$ Hz), 4.93 (1H, m, $J = 10.0$ Hz), 4.99 (1H, ddt, $J = 17.2, 2.0, 1.6$ Hz), 5.81 (1H, ddt, $J = 17.2, 10.0, 6.8$ Hz); δ_C (100 MHz; $CDCl_3$) -0.9, 27.8, 28.9, 29.1, 29.2, 29.4, 29.5, 29.7, 33.8, 82.4, 83.4, 114.1, 139.2, 210.0; m/z (FI) $C_{16}H_{30}Si$ (M^+) calc. 250.2117, found 250.2104.

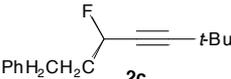
General Procedures for Electrophilic Fluorodesilylation

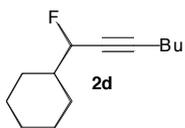
Protocol A: To a solution of trimethyl (1-phenylnona-3,4-dien-5-yl)silane (387 mg, 1.42 mmol) in acetonitrile (11 mL) was added SelectfluorTM (501 mg, 1.42 mmol). The mixture was kept under an argon atmosphere at room temperature for 6 h before quenching with $NaHCO_3$ (sat.) (15 mL). The aqueous layer was extracted with Et_2O (3x15 mL), and the combined organic layers were dried with $MgSO_4$. This was then concentrated at reduced pressure and the crude was purified by column chromatography (silica, hexane) affording the propargylic fluoride.

Protocol B:² To a stirred solution of trimethyl (1-phenylnona-3,4-dien-5-yl)silane (1.3 mmol) in acetone (13 mL) was added $NaHCO_3$ (164 mg, 1.95 mmol) and SelectfluorTM (553 mg, 1.56 mmol) under an argon atmosphere. Stirring was continued at room temperature for 4 d. The solvent was then removed at reduced pressure and Et_2O (15 mL) was added. The suspension was filtered through basic alumina and washed with Et_2O . The solvent was then evaporated at reduced pressure affording 163 mg of product (yellow oil, 58% yield).

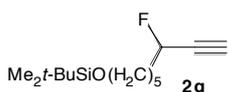
 **(3-Fluorohex-4-ynyl)benzene (2a):** Protocol A was used. ν_{max} (film)/ cm^{-1} 2247, 1496 and 1348; δ_H (400 MHz; Acetone- d_6) 1.88 (3H, ddd, $J = 6.8, 2.0, 1.2$ Hz), 1.97-2.19 (2H, m), 2.70-2.85 (2H, m), 5.12 (1H, m, $J_{H-F} = 48.7$ Hz), 7.17-7.32 (5H, m); δ_C (100 MHz; Acetone- d_6) 4.2 (d, $J = 3.2$ Hz), 32.4 (d, $J = 4.4$ Hz), 39.8 (d, $J = 22.7$ Hz), 77.9 (d, $J = 25.7$ Hz), 84.0 (d, $J = 164$ Hz), 86.7 (d, $J = 10.2$ Hz), 127.9, 130.2, 130.3, 142.8; δ_F (376.56 MHz; Acetone- d_6) -173.0; m/z (FI) $C_{12}H_{13}F$ (M^+) calc. 176.1002, found 176.1001.

 **(3-Fluoronon-4-ynyl)benzene (2b):** Protocol A was used. ν_{max} (film)/ cm^{-1} 2241, 1604, 1497, 1455 and 1348; δ_H (400 MHz; Acetone- d_6) 0.92 (3H, t, $J = 7.2$ Hz), 1.39-1.55 (4H, m), 1.99-2.20 (2H, m), 2.29 (2H, qd, $J = 6.8, 2.0$ Hz), 2.72-2.86 (2H, m), 5.14 (1H, ddt, $J = 48.9, 8.0, 2.0$ Hz), 7.17-7.32 (5H, m); δ_C (100 MHz; Acetone- d_6) 14.8, 19.6 (d, $J = 3.0$ Hz), 23.5, 32.2 (d, $J = 2.5$ Hz), 32.4 (d, $J = 4.6$ Hz), 39.9 (d, $J = 22.8$ Hz), 78.8 (d, $J = 26.1$ Hz), 84.0 (d, $J = 165.0$ Hz), 91.0 (d, $J = 10.3$ Hz), 127.9, 130.2, 130.3, 142.8; δ_F (376.56 MHz; Acetone- d_6) -172.7; m/z (FI) $C_{15}H_{20}F$ (MH^+) calc. 219.1471, found 219.1470.

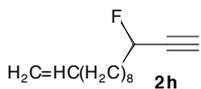
 **(3-Fluoro-6,6-dimethylhept-4-ynyl)benzene (2c):** Protocol B was used. ν_{max} (film)/ cm^{-1} 2246, 1496 and 1349; δ_H (400 MHz; Acetone- d_6) 1.24 (9H, s), 1.96-2.20 (2H, m), 2.72-2.85 (2H, m), 5.14 (1H, dt, $J = 48.8, 6.4$ Hz), 7.17-7.33 (5H, m); δ_C (100 MHz; Acetone- d_6) 27.6 (d, $J = 2.6$ Hz), 30.6 (d, $J = 2.6$ Hz), 31.0 (d, $J = 4.5$ Hz), 38.6 (d, $J = 22.8$ Hz), 76.1 (d, $J = 26.2$ Hz), 82.4 (d, $J = 165.3$ Hz), 97.5 (d, $J = 10.4$ Hz), 126.5, 128.8, 128.9, 141.4; δ_F (376.56 MHz; Acetone- d_6) -172.7; m/z (FI) $C_{15}H_{19}F$ (M^+) calc. 218.1471, found 218.1475.



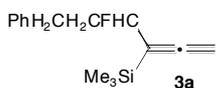
(1-Fluorohept-2-ynyl)cyclohexane (2d): Protocol A was used. $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 2236 and 1338; δ_{H} (400 MHz; Acetone- d_6) 0.91 (3H, t, $J = 7.2$ Hz), 1.06-1.31 (6H, m), 1.40-1.55 (4H, m), 1.64-1.71 (2H, m), 1.73-1.90 (3H, m), 2.25-2.31 (2H, m), 4.90 (1H, m, $J_{\text{H-F}} = 48.8$ Hz); δ_{C} (100 MHz; Acetone- d_6) 14.8, 19.6 (d, $J = 3.0$ Hz), 23.5, 27.3, 27.9, 29.3, 29.4 (d, $J = 4.6$ Hz), 32.3 (d, $J = 2.6$ Hz), 45.0 (d, $J = 20.8$ Hz), 78.0 (d, $J = 26.3$ Hz), 88.5 (d, $J = 166.0$ Hz), 91.2 (d, $J = 10.3$ Hz); δ_{F} (376.56 MHz; Acetone- d_6) -177.5; m/z (FI) $\text{C}_{13}\text{H}_{21}\text{F}$ (M^+) calc. 196.1627, found 196.1628.



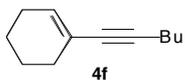
tert-Butyl(6-fluorooct-7-ynyloxy)dimethylsilane (2g): Protocol A was used. $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 3584, 2126, 1345 and 1255; δ_{H} (400 MHz; Acetone- d_6) 0.05 (6H, s), 0.89 (9H, s), 1.28-1.57 (6H, m), 1.74-1.93 (2H, m), 3.31 (1H, dd, $J = 5.6, 2.0$ Hz), 3.65 (2H, t, $J = 6.4$ Hz), 5.20 (1H, dtd, $J = 48.0, 6.2, 2.0$ Hz); δ_{C} (100 MHz; Acetone- d_6) -4.2, 19.8, 25.8 (d, $J = 4.3$ Hz), 27.1, 27.3, 34.3, 37.6 (d, $J = 22.2$ Hz), 64.4, 79.0 (d, $J = 10.3$ Hz), 82.3 (d, $J = 25.9$ Hz), 84.1 (d, $J = 165.6$ Hz); δ_{F} (376.56 MHz; Acetone- d_6) -175.7; m/z (FI) $\text{C}_{14}\text{H}_{28}\text{FOSi}$ (M^+) calc. 258.1815, found 259.1806.



11-Fluorotridec-1-en-12-yne (2h): Protocol A was used. $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 2127, 1641 and 1345; δ_{H} (400 MHz; Acetone- d_6) 1.30-1.55 (14H, m), 1.74-1.89 (2H, m), 3.32 (1H, dd, $J = 5.6, 2.0$ Hz), 4.91 (1H, d, $J = 10.0$ Hz), 4.99 (1H, d, $J = 17.2$ Hz), 5.19 (1H, dtd, $J = 48.0, 6.4, 2.0$ Hz), 5.81 (1H, ddt, $J = 17.2, 10.0, 6.8$ Hz); δ_{C} (100 MHz; Acetone- d_6) 26.1 (d, $J = 4.3$ Hz), 30.66, 30.75, 30.8, 31.0, 31.1, 35.5, 37.6 (d, $J = 21.9$ Hz), 79.0 (d, $J = 10.3$ Hz), 82.4 (d, $J = 26.0$ Hz), 84.1 (d, $J = 165.6$ Hz), 115.6, 140.8; δ_{F} (376.56 MHz; Acetone- d_6) -175.6; m/z (FI) $\text{C}_{13}\text{H}_{21}\text{F}$ (M^+) calc. 196.1627, found 196.1627.



(4-Fluoro-6-phenylhexa-1,2-dien-3-yl)trimethylsilane (3a): $\nu_{\max}(\text{film})/\text{cm}^{-1}$ 1933, 1497, 1328 and 1249; δ_{H} (400 MHz; Acetone- d_6) 0.17 (9H, s), 1.98-2.16 (2H, m), 2.68-2.85 (2H, m), 4.60 (1H, dd, $J = 2.4, 0.8$ Hz), 4.62 (1H, dd, $J = 2.8, 0.8$ Hz), 5.12 (1H, m, $J_{\text{H-F}} = 48.8$ Hz), 7.17-7.32 (5H, m); δ_{C} (100 MHz; CDCl_3) 0.2, 33.0 (d, $J = 4.5$ Hz), 39.3 (d, $J = 22.0$ Hz), 72.4 (d, $J = 1.8$ Hz), 94.0 (d, $J = 169.0$ Hz), 98.7 (d, $J = 30.9$ Hz), 127.8, 130.3, 140.3, 210.3 (d, $J = 14.4$ Hz); δ_{F} (376.56 MHz; Acetone- d_6) -171.5; m/z (FI) $\text{C}_{15}\text{H}_{21}\text{FSi}$ (M^+) calc. 248.1397, found 248.1399.



Enyne **4f** has been previously reported.⁹

⁹ R. K. Dieter, N. Chen, H. Yu, L. E. Nice and V. K. Gore, *J. Org. Chem.*, 2005, **70**, 2109.