# Nickel-Catalyzed Carbostannylation of Alkynes with Allyl-, Acyl-, and Alkynylstannanes: Stereoselective Synthesis of Trisubstituted Vinylstannanes

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Carbostannylation of internal alkynes should be one of the most useful tools for stereoselective synthesis of olefins, since the resulting trisubstituted vinylstannanes are readily converted into various tetrasubstituted ethenes via various synthetic transformations.[1] There have been, however, only a limited number of reports on this synthesis subject.[1b,2] Although Yamamoto and co-workers have reported that allylstannanes add to terminal alkynes with *anti*-selectivity when a Lewis acid catalyst is used, available alkynes are limited to terminal ones.[3] *Anti*-selective allylstannylation of alkynes is found also by Hosomi and co-workers and is mediated by such a radical initiator as AIBN to give a mixture of stereo- and regioisomers, the internal alkynes being restricted to relatively electron-deficient ones.[4] On the other hand, the palladium-catalyzed alkynylstannylation of alkynes proceeds with exclusive *syn*-selectivity and acceptable regioselectivity.[5,6] However, the scope of the reaction is limited to alkynylstannanes and relatively electron-deficient alkynes. Herein we report that the nickel-catalyzed carbostannylation of alkynes has following superb features: (1) a nickel(0) complex mediates the reaction of even relatively electron-rich internal alkynes, (2) the reaction is applicable not only to alkynylstannanes but also to acyl- and allylstannanes, (3) *syn*-selectivity results also in allylstannylation of alkynes, and (4) regioselectivities are much higher than the palladium-catalyzed alkynylstannylation.

The catalytic activity of various nickel complexes was first examined for the reaction of allyl(tributyl)tin (**1a**, $R^1 = R^2 = H$) with 1-octyne (**2a**, $R^3 = $ hexyl, $R^4 = H$) (Scheme 1). The conversion of **1a** and the ratio of carbostannylation products **3a** and **4a** were readily monitored by ^{119}Sn NMR; the results obtained from the reaction carried out at 80 °C for 1 h are summarized in Table 1. As can be readily seen, reaction with 5 mol % of bis-(1,5-cyclooctadiene)nickel(0), Ni(cod)$_2$, in toluene gave a 68:32 mixture of **3a** and **4a** in 85% conversion (entry 1).[7] Polar solvents accelerated the reaction at the slight expense of regioselectivity (entries 2−4). Octane or pyridine as a solvent retarded the reaction (entries 5 and 6). Use of triphenylphosphine (10 mol %) or
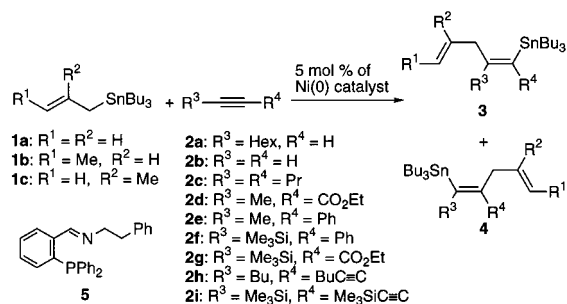
**Scheme 1**

**Table 1.** Nickel-Catalyzed Carbostannylation of 1-Octyne (**2a**) with Allyl(tributyl)tin (**1a**)[a]

| entry | solvent | conv (%)[b] | **3a:4a**[b] | entry | solvent | conv (%)[b] | **3a:4a**[b] |
|---|---|---|---|---|---|---|---|
| 1 | toluene | 85 | 68:32 | 4 | 1,4-dioxane | 85 | 65:35 |
| 2 | DMF | 92 | 58:42 | 5 | octane | 70 | 58:42 |
| 3 | DME | 91 | 60:40 | 6 | pyridine | 20 | 60:40 |

[a] The reaction was carried out in a solvent (0.3 mL) at 80 °C using allyl(tributyl)tin (0.46 mmol) and 1-octyne (1.38 mmol) for 1 h in the presence of Ni(cod)$_2$ (23 $\mu$mol). [b] Determined by ^{119}Sn NMR.
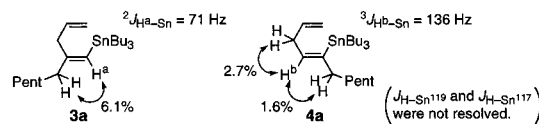
**Table 2.** Nickel-Catalyzed Allylstannylation of Alkynes[a]

| entry | allylstannane | alkyne | temp (°C) | time (h) | yield (%)[b] | product(s) | **3:4**[c] |
|---|---|---|---|---|---|---|---|
| 1 | **1a** | **2a** | 80 | 5 | 93 | **3a, 4a** | 64:36 |
| 2[d] | | **2b** | 80 | 14 | 80 | **3b** | − |
| 3 | | **2c** | 80 | 0.5 | 77 | **3c** | − |
| 4 | | **2d** | 100 | 12 | 78 | **3d, 4d** | 65:35 |
| 5 | | **2e** | 100 | 12 | 77 | **3e** | >99:1 |
| 6 | | **2f** | 100 | 14 | 76 | **3f** | >99:1 |
| 7 | | **2g** | 100 | 40 | 78 | **3g** | >99:1 |
| 8 | | **2h** | 100 | 14 | 64 | **3h** | >99:1 |
| 9 | | **2i** | 100 | 8 | 70 | **3i** | >99:1 |
| 10 | **1b** | **2e** | 100 | 14 | 64 | **3j** | >99:1 |
| 11 | **1c** | **2c** | 80 | 3 | 87 | **3k** | − |

[a] The reaction was carried out in toluene (0.3 mL) using an organostannane (0.46 mmol), an alkyne (1.38 mmol), and Ni(cod)$_2$ (23 $\mu$mol). [b] Isolated yield based on the organostannane. [c] Determined by ^{119}Sn NMR. [d] The reaction was carried out under an acetylene atmosphere (1 atm).

*N*-(2-diphenylphosphinobenzylidene)-2-phenylethylamine (**5**) (5 mol %), an efficient ligand for the palladium-catalyzed alkynylstannylation of alkynes,[5] inhibited the reaction.

The allylstannylation of various alkynes with Ni(cod)$_2$ catalyst was next studied in toluene (Scheme 1 and Table 2). Whereas acetylene (**2b**) also reacted with **1a** in good yield (entry 2), phenylacetylene and ethyl propiolate did not give significant amounts of carbostannylation products due to competitive self-polymerization of the alkynes. In contrast, internal alkynes gave good yields of the corresponding carbostannylation products, irrespective of electron-withdrawing or -donating character of substituent $R^3$ and/or $R^4$ (entries 3−9). Furthermore, a single

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(2) Multistep synthesis of trisubstituted vinylstannanes has been reported. Wang, K. K.; Chu, K.-H.; Lin, Y.; Chen, J.-H. *Tetrahedron* **1989**, *45*, 1105−1118.
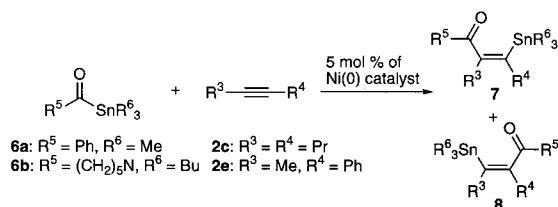(3) Asao, N.; Matsukawa, Y.; Yamamoto, Y. *Chem. Commun.* **1996**, 1513−1514.
(4) Miura, K.; Itoh, D.; Hondo, T.; Saito, H.; Ito, H.; Hosomi, A. *Tetrahedron Lett.* **1996**, *37*, 8539−8542.
(5) Shirakawa, E.; Yoshida, H.; Kurahashi, T.; Nakao, Y.; Hiyama, T. *J. Am. Chem. Soc.* **1998**, *120*, 2975−2976.
(6) Depending on the ligand, the palladium-catalyzed carbostannylation is accompanied by dimerization of alkynes. Shirakawa, E.; Yoshida, H.; Nakao, Y.; Hiyama, T. *J. Am. Chem. Soc.* **1999**, *121*, 4290−4291.
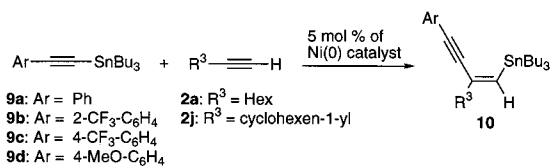
(7) Configuration of the carbostannylation products was determined by NMR studies (coupling constants and NOE) of the alkenylstannanes and/or the alkenes obtained by protonolysis. For example, the stereochemistry of **3a** and **4a** was determined on the basis of NOE (irradiation at the methine peak) and the H−Sn coupling constant, as shown below. For the coupling constants between tin and olefinic protons in alkenylstannanes, see: Leusink, A. J.; Budding, H. A.; Marsman, J. W. *J. Organomet. Chem.* **1967**, *9*, 285−294.

**Scheme 2**



6a: R^5 = Ph, R^6 = Me    2c: R^3 = R^4 = Pr
6b: R^5 = (CH₂)₅N, R^6 = Bu    2e: R^3 = Me, R^4 = Ph

**Table 3.** Nickel-Catalyzed Acylstannylation of Alkynes[a]

| entry | acylstannane | alkyne | time (h) | yield (%)[b] | product(s) | 7:8[c] |
|-------|-------------|--------|----------|--------------|-----------|--------|
| 1 | 6a | 2c | 2 | 65 | 7a | — |
| 2 |  | 2e | 1.5 | 61 | 7b, 8b | 83:17 |
| 3 | 6b | 2c | 1.5 | 66 | 7c | — |
| 4 |  | 2e | 2 | 81 | 7d, 8d | 64:36 |

[a] The reaction was carried out in toluene (0.3 mL) at 100 °C using an organostannane (0.46 mmol) and an alkyne (0.69 mmol) in the presence of Ni(cod)₂ (23 μmol). [b] Isolated yield based on the organostannane. [c] Determined by ¹¹⁹Sn NMR.

**Scheme 3**



9a: Ar = Ph          2a: R^3 = Hex
9b: Ar = 2-CF₃-C₆H₄    2j: R^3 = cyclohexen-1-yl
9c: Ar = 4-CF₃-C₆H₄
9d: Ar = 4-MeO-C₆H₄

regioisomer formed in the reaction of unsymmetrical internal alkynes except for ethyl 2-butynoate. The regioselectivity is proved to be extremely sensitive to the type of R^3 and/or R^4: a Bu₃Sn group invariably adds to the carbon having a more electron-withdrawing group. Crotyltin added to 1-phenyl-1-propyne without any allylic rearrangement (entry 10). Methallyltin also gave the corresponding carbostannylation product (entry 11).

The nickel catalyst was demonstrated to be effective also for the acylstannylation of alkynes. For example, benzoyl(trimethyl)-tin and piperidinocarbonyl(tributyl)tin reacted with 4-octyne or 1-phenyl-1-propyne stereoselectively with Ni(cod)₂ catalyst, giving (Z)-β-stannyl-α,β-unsaturated carbonyl compounds (Scheme 2 and Table 3). To the best of our knowledge, this is the first example of acylstannylation of alkynes.

The carbostannylation reaction with alkynylstannanes is also effected with a nickel(0) catalyst. Particularly, the one prepared from Ni(acac)₂ and diisobutylaluminum hydride (1:2 ratio) (Scheme 3 and Table 4) was more effective than Ni(cod)₂ for this reaction. For example, phenylethynyl(tributyl)tin reacted with 1-octyne in the presence of 5 mol % of the in situ-generated Ni-(0) catalyst (toluene, 80 °C, 24 h) to give (Z)-2-hexyl-4-phenyl-1-tributylstannyl-1-buten-3-yne in 72% yield (entry 1). (Phenyl-ethynyl)stannanes with a variety of substituents gave the corresponding carbostannylation products (entries 2−4). The alkynyl moiety of 1-ethynylcyclohexene solely reacted (entry 5). It is noteworthy that the regioselectivity is perfect, in sharp contrast to the palladium-catalyzed alkynylstannylation that always gave mixtures of regioisomers.[5] Internal alkynes failed to give products, as was the case with palladium catalyst. Although electron-deficient terminal alkynes were not suitable for the nickel catalyst as in the allystannylation, the palladium catalyst can complement the reaction of such substrates.[5]

**Table 4.** Nickel-Catalyzed Alkynylstannylation of Alkynes[a]

| entry | alkynylstannane | alkyne | time (h) | yield (%)[b] | product |
|-------|-----------------|--------|----------|--------------|---------|
| 1 | 9a | 2a | 24 | 72 | 10a |
| 2 | 9b | 2a | 4 | 82 | 10b |
| 3 | 9c | 2a | 10 | 70 | 10c |
| 4 | 9d | 2a | 36 | 56 | 10d |
| 5 | 9b | 2j | 5 | 79 | 10e |

[a] The reaction was carried out in toluene (0.5 mL) at 80 °C using an alkynylstannane (0.76 mmol) and an alkyne (2.3 mmol) in the presence of a Ni(0) catalyst prepared in situ from Ni(acac)₂ (38 μmol) and a 1.5 M toluene solution of diisobutylaluminum hydride (76 μmol). [b] Isolated yield based on the organostannane.

**Scheme 4**



52% yield based on 1a
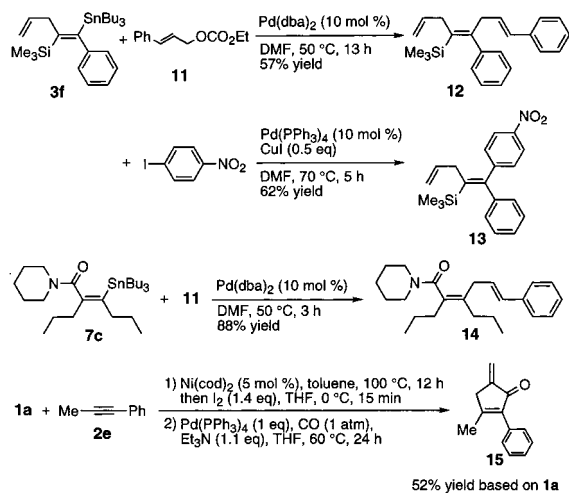
The utility of the carbostannylation products derived from internal alkynes is demonstrated by transformation of the carbostannylation products to tetrasubstituted ethenes (Scheme 4). Dienylstannane 3f coupled with cinnamyl carbonate 11 or 4-iodonitrobenzene to give 1,4-diphenyl-1,4,7-octatriene 12 or 1,1-diaryl-1,4-pentadiene 13; β-acylethenylstannane 7c afforded α,β-unsaturated carboxamide 14 in good yields. Exclusive syn- and high regioselectivities of the nickel-catalyzed carbostannylation reaction readily allows one to synthesize tetrasubstituted ethenes without troublesome separation of isomers. For example, the reaction of 1-phenylpropyne with 1a followed by the Negishi cyclization[8] gave cyclopentenone 15 in 52% total yield.

In conclusion, we have disclosed that, in the presence of a nickel catalyst, the carbostannylation of both electron-rich and -deficient alkynes takes place with allyl- acyl- or alkynylstannanes to give various alkenylstannanes stereo- and regioselectively. This, coupled with the palladium-catalyzed reaction, has made multiply substituted ethenes readily accessible with high stereospecificity. Further studies on synthetic applications to various organostannanes and unsaturated target compounds as well as on the reaction mechanism are in progress in our laboratories.

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