Buta-2,3-dienylstannanes, effective reagents for regioselective buta-1,3-dienylation of aldehydes and acetals

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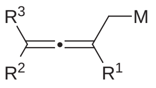
Two buta-2,3-dienylstannanes, 1-tri-*n*-butylstannylbuta-2,3-diene and 1-triphenylstannylbuta-2,3-diene, have been prepared and shown to react with aldehydes and acetals under Lewis acid catalyzed conditions producing (buta-1,3-dien-2-yl)methanol derivatives in high yields.

Recently, buta-2,3-dienylsilanes **1** (M = SiR_3)[1,2] and buta-2,3-dienylboronates **1** [M = $B(OR)_2$],[3] have appeared as useful reagents for the synthesis of (buta-1,3-dien-2-yl)methanol derivatives **2** from aldehydes and acetals. In addition, we have demonstrated that these dienols **2** are valuable precursors for the syntheses of a variety of natural products.[1,4] As part of our interest in developing a catalytic asymmetric reaction of a buta-2,3-dienylmetal **1** with an aldehyde using a chiral Lewis acid,† we directed our attention to buta-2,3-dienylstannanes **1** (M = SnR_3) which are unprecedented as synthetic reagents. Here, we report the first practical syntheses of 1-tri-*n*-butylstannylbuta-2,3-diene **3** and 1-triphenylstannylbuta-2,3-diene **4** and their Lewis acid catalyzed reactions with aldehydes and acetals.



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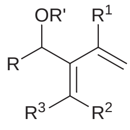

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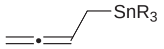
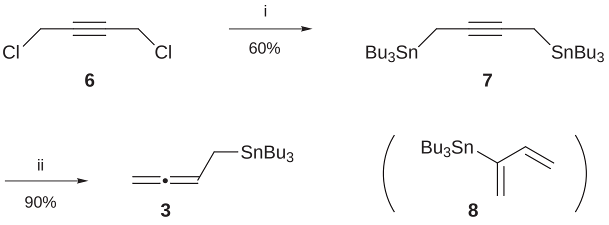


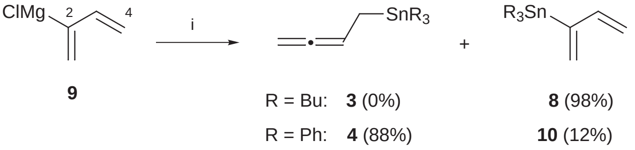
3 R = Bu
4 R = Ph
5 R = Me

Reich and co-workers reported[5] that treatment of 1,4-bis-(trimethylstannyl)but-2-yne with HCl in $CDCl_3$ caused protomonodestannylation to give 1-trimethylstannylbuta-2,3-diene **5**. However, to the best of our knowledge, the results of this NMR experiment have not been further examined in detail. This situation allowed us to examine in detail protomonodestannylations of 1,4-bis(trialkylstannyl)but-2-ynes as one possible route to buta-2,3-dienylstannanes (Scheme 1). After many discouraging results, we eventually found good reaction conditions wherein large quantities of 1-tri-*n*-butylstannylbuta-2,3-diene **3** are obtained with > 95% purity from 1,4-bis(tri-*n*-butylstannyl)but-2-yne **7**. Thus, treatment of **7**, prepared by the reaction of 1,4-dichlorobut-2-yne **6** with tri-*n*-butylstannyllithium,‡ with concentrated HCl in a 16:1 mixture of Et_2O and THF at 0 °C gave **3** cleanly in 90% yield.§ This HCl-promoted protomonodestannylation also turned out to proceed in a reasonable yield (77%) in Et_2O although the reaction was rather sluggish even at room temperature. When THF was used as solvent for this reaction, the yield of **3** decreased to 42%, possibly because of its further protodestannylation giving buta-1,3-diene. It is important to note that purification of **3** by silica gel column chromatography caused isomerization to 2-tri-*n*-butylstannylbuta-1,3-diene **8**. The ratio of **3** and **8** was at best 1 : 1 under these unsatisfactory conditions and varied depending upon the amount of silica gel used. This isomerization, however, could be completely suppressed by use of silica gel pretreated with Et_3N. Compound **3** thus purified was thermally stable and no isomerization occurred during distillation.



Scheme 1 *Reagents and conditions*: i, Bu_3SnLi, THF, −78 °C; ii, conc. HCl, Et_2O–THF, 0 °C.

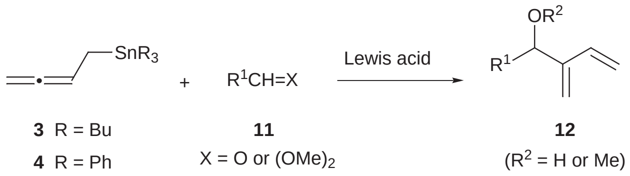
We also investigated the reaction of Ph_3SnCl or Bu_3SnCl with the Grignard reagent **9**[6] prepared from chloroprene (2-chlorobuta-1,3-diene) (Scheme 2). We found that, in the case of Ph_3SnCl, the reaction occurred preferentially at the C4 position to give a 88 : 12 mixture of 1-triphenylstannylbuta-2,3-diene **4** and 2-triphenylstannylbuta-1,3-diene **10** in quantitative yield. Recrystallization of this mixture from *n*-hexane afforded pure **4** in 73% yield.¶ Interestingly, as previously reported,[7] Bu_3SnCl reacted with the Grignard reagent **9** with complete C2 selectivity to give 2-tri-*n*-butylstannylbuta-1,3-diene **8** quantitatively.



Scheme 2 *Reagents and conditions*: i, Bu_3SnCl or Ph_3SnCl, THF, −78 °C.

Having developed practical methods for the preparation of buta-2,3-dienylstannanes **3** and **4**, we then investigated their Lewis acid catalyzed reactions with various aldehydes and acetals (Scheme 3). Table 1 summarizes Lewis acid catalyzed additions of **3** and **4** to aldehydes. It is evident that this reaction has broad applicability for the preparation of **12** (R^2 = H) and $BF_3{\cdot}Et_2O$ is the catalyst of choice, except for the two examples listed in entries 8 and 10. It is also apparent that **3** is much more reactive than **4** in this reaction. Compound **3** was found to gradually isomerize to **8** under these conditions, whereas compound **4** did not undergo such Lewis acid catalyzed isomerization.

As can be seen from Table 2, both **3** and **4** again reacted with acetals in good yields. The mixed titanium reagent [$3TiCl_4{\cdot}Ti(OPr^i)_4$] was found to give better results than $BF_3{\cdot}Et_2O$, especially in the cases of aliphatic acetals (entries 1, 2, 10 and 11). Conversely, the reaction of cinnamaldehyde dimethyl acetal with **3** took place almost quantitatively under $BF_3{\cdot}Et_2O$



Scheme 3

Table 1 Lewis acid catalyzed addition of **3** and **4** to aldehyde **11** (X = O) giving **12** (R^2 = H)[a]

Entry	**3** or **4**	R^1	Lewis acid	Solvent	t/h	Yield (%)[b]
1	**3**	$Ph(CH_2)_2$	$BF_3 \cdot Et_2O$	CH_2Cl_2	2	57
2	**3**	$Ph(CH_2)_2$	$BF_3 \cdot Et_2O$	toluene	9	92
3	**3**	$Ph(CH_2)_2$	$TiCl_4$	CH_2Cl_2	10	17[c]
4	**3**	$Ph(CH_2)_2$	$3TiCl_4 \cdot Ti(OPr^i)_4$	toluene	8	44[c]
5	**3**	$Ph(CH_2)_2$	MgI_2	CH_2Cl_2	4	51[d]
6	**3**	$PhCH_2$	$BF_3 \cdot Et_2O$	toluene	12	83
7	**3**	$PhCH_2$	$TiCl_4$	CH_2Cl_2	0.3	64
8	**3**	(E)-PhCH=CH	$BF_3 \cdot Et_2O$	toluene	10	0[e]
9	**3**	Ph	$BF_3 \cdot Et_2O$	toluene	9	96
10	**4**	Ph	$BF_3 \cdot Et_2O$	CH_2Cl_2	10	0[e]
11	**4**	Ph	$3TiCl_4 \cdot Ti(OPr^i)_4$	CH_2Cl_2	10	40 (65)[f]
12	**3**	n-C_7H_{15}	$BF_3 \cdot Et_2O$	toluene	12	87
13	**4**	n-C_7H_{15}	$BF_3 \cdot Et_2O$	CH_2Cl_2	23	85
14	**3**	c-C_6H_{11}	$BF_3 \cdot Et_2O$	toluene	12	90
15	**4**	c-C_6H_{11}	$BF_3 \cdot Et_2O$	CH_2Cl_2	16	86

[a] All reactions were carried out at −78 °C in the indicated solvent (0.13 mol dm^{-3}) using buta-2,3-dienylstannane (2 equiv.), aldehyde (1 equiv.), and Lewis acid (1 equiv.) unless stated otherwise. [b] Isolated yield. [c] The aldehyde was partly cyclyzed to indan-1-ol which underwent further reaction to produce several by-products. [d] The reaction was carried out at room temperature. [e] Most of the aldehyde was recovered. [f] Yield in parenthesis based on the consumed aldehyde.

Table 2 Lewis acid catalyzed addition of **3** and **4** to acetal **11** (X = $(OMe)_2$) giving **12** (R^2 = Me)[a]

Entry	**3** or **4**	R^1	Lewis acid	Solvent	t/h	Yield (%)[b]
1	**3**	$Ph(CH_2)_2$	$BF_3 \cdot Et_2O$	toluene	12	0[c]
2	**3**	$Ph(CH_2)_2$	$3TiCl_4 \cdot Ti(OPr^i)_4$	toluene	5	95
3	**3**	$PhCH_2$	$3TiCl_4 \cdot Ti(OPr^i)_4$	toluene	5	81
4	**3**	(E)-PhCH=CH	$BF_3 \cdot Et_2O$	toluene	10	99
5	**3**	(E)-PhCH=CH	$3TiCl_4 \cdot Ti(OPr^i)_4$	toluene	10	48
6	**3**	Ph	$BF_3 \cdot Et_2O$	toluene	10	89
7	**3**	Ph	$3TiCl_4 \cdot Ti(OPr^i)_4$	toluene	4	89
8	**4**	Ph	$BF_3 \cdot Et_2O$	toluene	10	86
9	**4**	Ph	$3TiCl_4 \cdot Ti(OPr^i)_4$	CH_2Cl_2	6	70
10	**3**	n-C_7H_{15}	$BF_3 \cdot Et_2O$	toluene	9	0[c]
11	**3**	n-C_7H_{15}	$3TiCl_4 \cdot Ti(OPr^i)_4$	CH_2Cl_2	4	86
12	**4**	n-C_7H_{15}	$3TiCl_4 \cdot Ti(OPr^i)_4$	CH_2Cl_2	7	91
13	**3**	c-C_6H_{11}	$3TiCl_4 \cdot Ti(OPr^i)_4$	CH_2Cl_2	4	96
14	**4**	c-C_6H_{11}	$3TiCl_4 \cdot Ti(OPr^i)_4$	CH_2Cl_2	8	89

[a] Reactions were carried out at −78 °C in the indicated solvent (0.13 mol dm^{-3}) using buta-2,3-dienylstannane (**3**: 2 equiv. **4**: 1.2 equiv.), acetal (1 equiv.) and Lewis acid (1 equiv.). [b] Isolated yield. [c] Most of the aldehyde was recovered.

catalyzed conditions and $3TiCl_4 \cdot Ti(OPr^i)_4$ produced poor result in this particular case (entries 4 and 5).

In conclusion, we have successfully synthesized two buta-2,3-dientylstannanes, 1-tri-n-butylstannylbuta-2,3-diene **3** and 1-triphenylstannylbuta-2,3-diene **4**, in >95% isomeric purity for the first time. These buta-2,3-dienylstannanes react with various aldehydes and acetals regioselectively in a 1,3-rearrangement fashion to give (buta-1,3-dien-2-yl)methanol derivatives in excellent yields. In comparison with the related silicon[1] and boron reagents,[3] buta-2,3-dienylstannanes have the advantage of broad applicability in buta-1,3-dienylations of both aldehydes and acetals. The development of a catalytic asymmetric reaction of buta-2,3-dienylstannanes with aldehydes is the focus of current investigations.

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Notes and references

† A catalytic asymmetric version of this process using either buta-2,3-dienylsilanes or buta-2,3-dienylboronates has not been successfully achieved yet.

‡ Prepared according to Reich's method for 1,4-bis(trimethylstannyl)but-2-yne (ref. 5).

§ Experimental procedure for **3**: To a stirred solution of **7** (7.93 g, 12.5 mmol) in Et_2O (80 ml) with cooling in an ice bath was added a mixture of concentrated HCl (1.3 ml) and THF (5 ml). After stirring at 0 °C for 8 h, the reaction mixture was basified with 5% NaOH (10 ml) and extracted with Et_2O. The extract was washed with water, dried over $MgSO_4$, and concentrated *in vacuo*. Purification by column chromatography [SiO_2 (30 g) pretreated with Et_3N (30 g); n-hexane] afforded **3** (3.86 g, 90%), bp 150 °C (0.2 mmHg) (Kugelröhr).

¶ Experimental procedure for **4**: A flame-dried flask was charged with THF (30 ml) and Grignard reagent **9** (1.6 mol dm^{-3} in THF, 12.5 ml, 20 mmol) under argon and then a solution of Ph_3SnCl (7.71 g, 20 mmol) in THF (15 ml) was added dropwise at −78 °C. After being stirred at −78 °C for 30 min, the reaction mixture was quenched with 5% NaOH (10 ml) and extracted with Et_2O. The extract was dried over $MgSO_4$, concentrated *in vacuo*, and chromatographed [SiO_2 (30 g) pretreated with Et_3N (30 g); n-hexane] to give an 88 : 12 mixture of **4** and **10** as a colorless viscous oil (8.05 g) which solidified during overnight storage in a refrigerator. Recrystallization of this crystalline solid from n-hexane afforded **4** (5.86 g, 73%) as colorless crystals (mp 54–55 °C).

1 For a review on buta-2,3-dienylsilanes, see: S. Hatakeyama, *J. Synth. Org. Chem. Jpn.*, 1997, **55**, 793.
2 T. Nishiyama, T. Esumi, Y. Iwabuchi, H. Irie and S. Hatakeyama, *Tetrahedron Lett.*, 1998, **39**, 43.
3 B. Zheng and M. Srebnik, *J. Org. Chem.*, 1995, **60**, 486; R. Soundararajan, G. Li and H. C. Brown, *J. Org. Chem.*, 1996, **61**, 100; B. Zheng and M. Srebnik, *Synth. Commun.*, 1996, **26**, 393.
4 S. Hatakeyama, M. Yoshida, T. Esumi, Y. Iwabuchi, H. Irie, T. Kawamoto, H. Yamada and M. Nishizawa, *Tetrahedron Lett.*, 1997, **38**, 7887.
5 H. J. Reich, I. L. Reich, K. E. Yelm, J. E. Holladay and D. Gschneidner, *J. Am. Chem. Soc.*, 1993, **115**, 6625.
6 S. Nunomoto and Y. Yamashita, *J. Org. Chem.*, 1979, **44**, 4788.
7 E. Wada, S. Kanemasa, I. Fujiwara and O. Tsuge, *Bull. Chem. Soc. Jpn.*, 1985, **58**, 1942; G. S. Bates, M. D. Fryzuk and C. Stone, *Can. J. Chem.*, 1987, **65**, 2612.

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