Axially Chiral Spirosilanes via Catalytic Asymmetric Intramolecular Hydrosilation

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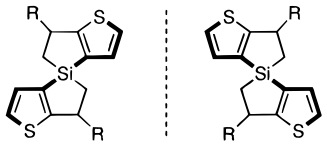
Chiral spiranes having axial chirality are of special interest due to their rigid chiral environments of C_2 symmetry by the perpendicular arrangement of two planes.[1] The spiranes would thus be promising chiral building units for material science, especially for chiral macromolecules such as molecular squares[2−4] and polymers with main chain chirality.[5] However, there is only a limited number of optically pure spiranes available, because optical resolution has been the only method of attaining them.[1] To the best of our knowledge, asymmetric syntheses of the axially chiral spiranes have rarely been reported.[6] We now report the first catalytic asymmetric synthesis of an axially chiral spirane, spirosilane, of C_2 symmetry.

We have designed a 5-silaspiro[4.4]nonane derivative (**1**) having a silicon atom on the spiro center and two thiophene rings fused with the skeleton as handles for further derivatization. We anticipated that the incorporation of the silicon atom



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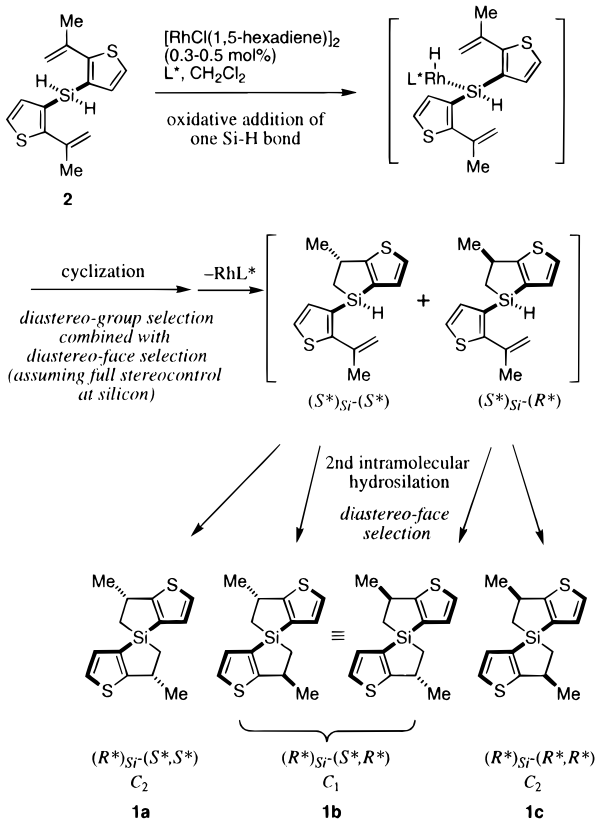
would enable us to construct the chiral spiro skeleton by intramolecular hydrosilation.[7] Thus, the Rh(I)-complex-catalyzed asymmetric intramolecular hydrosilation of bis(alkenyl)dihydrosilane (**2**) has been examined, as shown in Scheme 1.

Scheme 1



The present reaction proceeds sequentially in two steps. Since the two hydrogen atoms on the silicon in **2** are homotopic, the reaction can start with either Si−H bond to give the same result. For simplicity in Scheme 1, the plausible reaction pathways are described as if the reaction starts with the left-hand Si−H bond, which undergoes oxidative addition to a Rh(I) complex containing a chiral ligand to give a chiral intermediate. The first intramolecular hydrosilation involves a diastereotopic group selection between the two alkenyl groups combined with a diastereotopic face selection of the alkenyl group to generate chiral centers on the silicon atom and on the carbon atom simultaneously. On the basis of the assumption of complete group selection, two diastereomers, the $(S^*)_{Si}$−(S^*) and $(S^*)_{Si}$−(R^*) isomers,[8] can be formed. The second step is a simple diastereotopic face selection of the remaining alkenyl group to generate the third chiral center on the carbon atom, resulting in the formation of four diastereomers, two sets of C_2 and C_1 symmetrical isomers each from the first two diastereomers. However, the two C_1 symmetrical diastereomers, each derived from the first two diastereomers, are identical. Thus, three diasteromers, the $(R^*)_{Si}$−(S^*,S^*) (**1a**), $(R^*)_{Si}$−(S^*,R^*) (**1b**), and $(R^*)_{Si}$−(R^*,R^*) (**1c**) isomers,[8,9] can be formed. If the reaction is nondiastereoselective, the diastereomers should be formed in the statistical ratio of **1a**/**1b**/**1c** = 1:2:1. Since each has a

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(2) Quite recently, the successful synthesis of chiral tetranuclear molecular squares has been reported: Anderson, S.; Neidlein, U.; Gramlich, V.; Diederich, F. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 1596. Neidlein, U.; Diederich, F. *Chem. Commun.* **1996**, 1493. Stang, P. J.; Olenyuk, B. *Angew. Chem., Int. Ed. Engl.* **1996**, *35*, 732.

(3) A spiro building unit (racemic) has recently been applied to the synthesis of molecular squares: Small, J. H.; McCord, D. J.; Greaves, J.; Shea, K. J. *J. Am. Chem. Soc.* **1995**, *117*, 11588.

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(6) Recently, the catalytic asymmetric synthesis of spiro compounds of C_1 symmetry has been attained by way of the palladium-catalyzed intramolecular Heck-type arylations: (a) Carpenter, N. E.; Kucera, D. J.; Overman, L. E. *J. Org. Chem.* **1989**, *54*, 5846. (b) Ashimori, A.; Overman, L. E. *J. Org. Chem.* **1992**, *57*, 4571.

(7) For intramolecular hydrosilation, see: (a) Tamao, K.; Nakagawa, Y.; Ito, Y. *Org. Synth.* **1995**, *73*, 94. For asymmetric intramolecular hydrosilation of olefins, see: (b) Tamao, K.; Tohma, T.; Inui, N.; Nakayama, O.; Ito, Y. *Tetrahedron Lett.* **1990**, *31*, 7333. (c) Bergens, S. H.; Noheda, P.; Whelan, J.; Bosnich, B. *J. Am. Chem. Soc.* **1992**, *114*, 2121. (d) Bergens, S. H.; Noheda, P.; Whelan, J.; Bosnich, B. *J. Am. Chem. Soc.* **1992**, *114*, 2128. (e) Wang, X.; Bosnich, B. *Organometallics* **1994**, *13*, 4131. (f) Barnhart, R. W.; Wang, X.; Noheda, P.; Bergens, S. H.; Whelan, J.; Bosnich, B. *Tetrahedron* **1994**, *50*, 4335.

(8) Throughout the paper, the absolute configuration of the silicon central chirality is shown first with a subscript *Si*. The difference in the absolute configurations of silicon between **1** and the precursors is merely due to the priority sequence.

(9) The absolute configurations at the silicon atom in **1** are named according to the central chirality notation.[1]

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Scheme 2

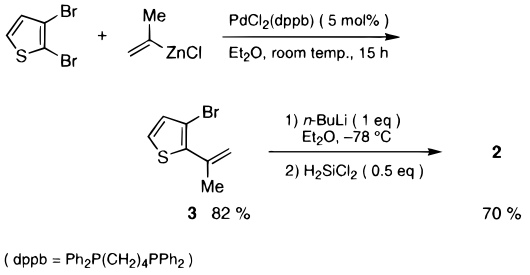


Table 1. Asymmetric Intramolecular Hydrosilation of Bis(alkenyl)silane **2**[a]

entry	ligand	temp/time ((°C)/(h))	total yield of **1** (%)[b]	isomer ratio[c] (**1a**:**1b**:**1c**)	**1a**[c] (% ee)
1	(*R*)-BINAP	20/168	37	29:58:13	58[d]
2	(*S*)-(*R*)-BPPFA	10/9	51	12:60:28	36[d]
3	(*R*,*R*)-DIOP	0/10	78	82:17:1	83[d]
4	(*R*,*R*)-TM-SILOP	0/3	78	95:4:1	99[d]
5	(*R*,*R*)-TBDM-SILOP	0/3	83	96:4:trace	99[d]
6	(*R*,*R*)-TBDM-SILOP[e]	−20/3	83	98:2:trace	99[d]
7	(*R*,*R*)-TIP-SILOP	0/9	62	96:4:trace	98[d]
8	(*R*,*R*)-TP-SILOP[e]	10/3	61	87:12:1	98[d]

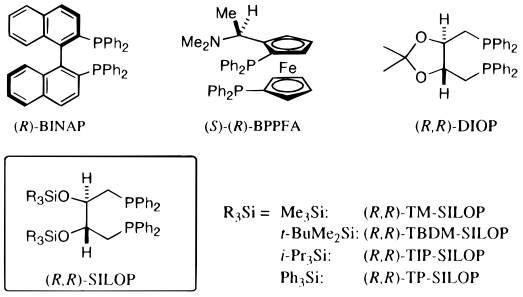
[a] [Rh(1,5-hexadiene)Cl]$_2$ (0.3−0.5 mol %) and ligand (L/Rh = 1.1−1.3) were used as a catalyst system unless otherwise stated. [b] Isolated yield. [c] Isomer ratio and enantiomeric excess of **1a** were determined using a capillary GC equipped with a chiral column (Chrompack, Cyclodex-β 236M). [d] Absolute configuration of the major isomer is $(R)_{Si}$-(*S*,*S*); see the text. [e] Carried out in the presence of 1.9−2.0 mol % of [Rh(1,5-hexadiene)Cl]$_2$ and 4.2−4.3 mol % of SILOP.

mirror image arising from the opposite group selection, there is a total of six optical isomers. One of the six would be selectively formed by the appropriate choice of the chiral ligand.

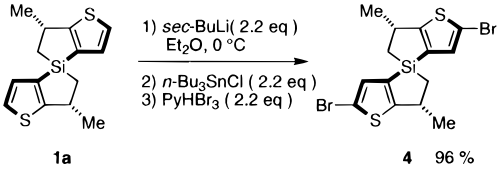
Bis(alkenyl)dihydrosilane **2** was prepared in two steps starting from 2,3-dibromothiophene, as shown in Scheme 2. Thus, the cross-coupling reaction of 2,3-dibromothiophene with 2-propenylzinc chloride catalyzed by PdCl$_2$(dppb) selectively gave monocoupling product **3** in 82% yield,[10] which was subsequently treated with *n*-BuLi and dichlorosilane to afford **2** in 70% yield.

The asymmetric intramolecular hydrosilation of **2** was carried out in dichloromethane using a catalytic amount of [Rh(1,5-hexadiene)Cl]$_2$ and chiral phosphine ligands. The results are summarized in Table 1. As expected, the reaction smoothly proceeded to form spirosilanes **1**, which were isolated by column chromatography as a mixture of diastereomers. With (*R*)-BINAP[11] or (*S*)-(*R*)-BPPFA[12] as a ligand (see structures, Chart 1), the stereoselectivities are quite low, as seen from the rough statistical isomer ratios and thus low % ee of **1a** (entries 1 and 2). However, the use of (*R*,*R*)-DIOP[13] (see structures, Chart 1) as a chiral ligand leads to relatively high diastereoselectivity to afford **1a** as a major product, whose enantiomeric excess reaches 83% (entry 3). Quite high selectivities have been attained by use of the new chiral diphosphine ligands SILOPs[14] (2,3-bis(siloxy)-1,4-bis(diphenylphosphino)butanes), which have a skeleton similar to DIOP and various siloxy groups (entries 4−8) (see structures, Chart 1). One of the significant features of the SILOPs is the fine-tuning ability of the chiral environment in their metal complexes by merely changing the bulkiness of the siloxy groups. For the present hydrosilation, (*R*,*R*)-TBDM-SILOP, having *tert*-butyldimethylsiloxy groups, gives the highest diastereoselectivities and enantioselectivities for **1a** up to 98% and up to 99% ee, respectively (entries 5 and 6). TBDM-SILOP also gives the highest chemical yield by a fast reaction even at −20 °C in the presence of 2 mol % of catalyst.[15] As the siloxy groups become bulkier, the selectivities tend to become lower. While the induction mechanism of the high diastereo- and enantioselectivities is still unclear at this stage, it is noteworthy that almost only one enantiomer among the six possible isomers (three sets of enantiomers) has been selectively formed through three stereoselection steps using the SILOPs.

Chart 1



Scheme 3



Further purification of **1** by HPLC (Wakosil 5sil, Wako) and repeated recrystallizations from benzene gave optically pure **1a** ($[\alpha]_D^{24} = -37.2$ (*c* 0.69, $CHCl_3$)). The absolute configuration of **1a** has been determined to be $(R)_{Si}$−(*S*,*S*) by X-ray crystallography: the Flack parameter was −0.14(7).

The optically pure spirosilanes are obtainable via only three steps starting from 2,3-dibromothiophene. This ready availability promises a wide applicability of the spirosilanes as a new chiral building unit. Noteworthy is the advantage that the α-positions of the fused thiophene rings can be readily functionalized via metalation. For example, **1a** was transformed into dibromospirosilane **4** in one-pot via lithiation, stannylation, and bromodestannylation, as shown in Scheme 3. Molecular designs and the synthesis of chiral oligomers and polymers and chiral molecular assemblies using the spirosilanes are now in progress in our laboratory.

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Supporting Information Available: Experimental procedures, spectroscopic and analytical data for compounds **1**−**4**, and crystallographic information of **1a** (15 pages). See any current masthead page for ordering and Internet access instructions.

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(14) For the synthesis and X-ray structures of SILOPs and their Rh(I) complexes, see: Tamao, K.; Nakamura, K.; Yamaguchi, S.; Shiro, M.; Saito, S. *Chem. Lett.* **1996**, 1007.

(15) For comparison, for (*R*,*R*)-DIOP ([Rh(hexadiene)$_2$Cl]$_2$, 2 mol %; Rh/DIOP = 1:1), the reaction did not go to completion at −20 °C even after 7 days.