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Titanium(IV)/Tridentate BINOL Derivative as Catalyst for *meso*-Aziridine Ring-Opening Reactions: High Enantioselectivity, Strong Positive Non-Linear Effect and Structural Characterization

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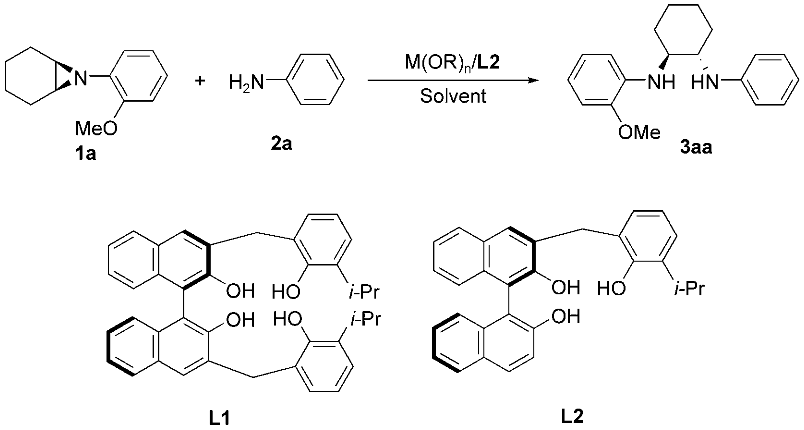
Abstract: A titanium-based chiral Lewis acid was found to be effective for the ring-opening reactions of *meso*-aziridines with aniline nucleophiles. The products were generally isolated in high yields and with high to excellent enantioselectivity. The catalytic system was studied by X-ray single crystal analysis. In experiments on non-linear effects a strong non-linear effect of the catalyst system was observed.

Keywords: *meso*-aziridines; desymmetrization; non-linear effect; titanium; vicinal diamines; X-ray structure

The synthesis and transformation of aziridines has attracted much attention especially in the last decade.[1] Due to the strain of the three-membered ring, aziridines are reactive towards a variety of nucleophiles, allowing many useful molecules to be synthesized. Recently, enantioenriched ring-opened products have been obtained when reactive nucleophiles such as TMSCN, MeMgBr, and $TMSN_3$ were employed,[2] however, use of weaker nucleophiles like anilines has been less successful. In our previous report, we detailed asymmetric reactions of *meso*-azirdines with anilines promoted by the Nb(V)/tetradentate BINOL ligand (**L1**) that provided vicinal diamines in good to high yields, but the best *ee* was 84% [Scheme 1, $M(OR)_n = Nb(OMe)_5$].[3] Because of the importance of the reaction, we searched for more effective and selective catalysts. Herein, we report a Ti(IV)/tridentate BINOL derivative **L2** [Scheme 1, $M(OR)_n = Ti(O\text{-}i\text{-}Pr)_4$] catalyst that leads to excellent enantioselectivity in the reaction.

In combination with various titanium sources, BINOL and its derivatives form highly effective asymmetric catalysts that have been used successfully in a range of enantioselective syntheses.[4] In most systems, however, the substrates are limited to alde-



Scheme 1. Asymmetric aziridine ring opening reaction with $M(OR)_n$/BINOL-derived complex.

hydes, ketones, and epoxides. The fact that Ti(IV)/BINOL catalysts activate nitrogen-containing substrates effectively to perform enantioselective reactions is unusual,[5] probably due to the strong affinity between Ti(IV) and the substrates. Thus, it was very surprising when we found that the combination of $Ti(O\text{-}i\text{-}Pr)_4$ and BINOL-derived tridentate ligand **L2** smoothly catalyzed the reaction of aziridine **1a** and aniline **2a** with promising results (Table 1, entry 1). To the best of our knowledge, this is the first example of a Ti complex promoting a ring-opening reaction of an aziridine.

Table 1. Asymmetric ring-opening reaction of *meso*-aziridine **1a** by chiral Ti(IV)/**L2** complex.[a]

Entry	H_2O:$Ti(O\text{-}i\text{-}Pr)_4$	Solvent	Yield [%]	*ee* [%]
1[b]	–	toluene	70	64
2	–	toluene	73	77
3[c]	–	toluene	35	56
4[b]	1:2	toluene	91	84
5	1:2	toluene	97	89
6[d]	1:2	toluene	97	75
7[b]	1:2	CH_2Cl_2	61	33
8[b]	1:2	Et_2O	51	51
9[e]	1:2	toluene	quant.	82
10[f]	1:2	toluene	quant.	90
11[g]	1:2	toluene	88	90
12[g,h]	1:2	toluene	93	95
13[g,i]	1:2	toluene	79	92

[a] Reaction between **1a** (0.2 M) and **2a** (1.0 equiv.) was conducted in the presence of $Ti(O\text{-}i\text{-}Pr)_4$/**L2** (10 mol%) and $MgSO_4$ in organic solvent at 0 °C for 40 h.

[b] No $MgSO_4$.

[c] Glassware was flame-dried.

[d] Water was added immediately followed by addition of **1a** and $MgSO_4$.

[e] **2a:** 1.5 equiv.

[f] **2a:** 0.5 equiv.

[g] -10 °C.

[h] **2a:** 1.2 equiv, slow addition over 22.5 h.

[i] Catalyst loading was 1.0 mol%, and substrate concentration was 0.1 M.

The Ti(IV)/**L2** complex was prepared from the reaction of $Ti(O\text{-}i\text{-}Pr)_4$ and one equivalent of **L2** at 60 °C for 3 h. Owing to the potential decomposition of titanium phenoxide in water, we reasoned that the removal of trace water from the reaction system should be helpful. After trials of several drying reagents, we were pleased to find that the selectivity of the reaction was improved considerably when anhydrous $MgSO_4$ was added (Table 1, entry 2). However, when the reaction was performed under rigorously anhydrous conditions, it was found that the yield and the selectivity decreased (Table 1, entry 3). In addition, the reproducibility of the reaction was problematic. We scrutinized the reaction conditions and ascertained that the presence of water was indispensable to form an effective catalyst in the system.[6]

We then investigated in detail the optimization of the the reaction conditions. When the ratio of H_2O:$Ti(O\text{-}i\text{-}Pr)_4$ was 2: 1, the reaction gave the best result (Table 1, entry 4). The addition of anhydrous $MgSO_4$ was still required to improve the reaction (entry 5). Comparing solvents revealed that toluene was the best medium for this reaction, and, surprisingly, the addition order was critical. The best results were obtained when water was added to a mixture of the catalyst, aziridine **1a** and $MgSO_4$. Investigation of starting material stoichiometries revealed that an excess aziridine leads to higher selectivity and slow addition of aniline was conducive to high enantioselectivity. Overall, under the optimized conditions the ring-opened product was obtained in high yield and excellent enantioselectivity (93% yield and 95% *ee*). The amount of catalyst could be reduced to 1 mol% without significantly affecting the enantioselectivity.

Having established the optimal catalyst and reaction conditions, we examined the scope of the reaction with a variety of differently substituted anilines. As shown in Table 2, excellent enantioselectivity was obtained in the aziridine ring-opening reaction with several anilines. Both electron-withdrawing and electron-donating substituents were suitable. Generally, *meta*-substituted anilines provided better selectivity, and *ortho*-substituted anilines gave the desired 1,2-diamines in lower yields and selectivity.

Table 2. Substrate scope of asymmetric ring-opening reaction of *meso*-aziridine **1a** by chiral Ti(IV)/**L2** complex.

Entry	Cat. X [mol%]	Amine	Yield [%]	*ee* [%]
1[b]	2	aniline (**2a**)	88	92
2[b]	10	*p*-toluidine (**2b**)	63	90
3	10	*m*-toluidine (**2c**)	81	93
4	5	*o*-toluidine (**2d**)	42	73
5[b]	10	*p*-chloroaniline (**2e**)	90	91
6[b]	5	*m*-chloroanilne (**2f**)	84	93
7[b]	10	*o*-chloroaniline (**2g**)	49	82
8	2.5	*p*-fluoroaniniline (**2h**)	62	85
9	5	*m*-fluoroaniline (**2i**)	82	91
10	5	*p*-bromoaniline (**2j**)	62	89
11	5	*m*-bromoaniline (**2k**)	74	88
12	5	*p*-iodoaniline(**2l**)	69	89
13	5	*m*-iodoaniline (**2m**)	54	78
14[b]	10	*p*-anisidine(**2n**)	51	73
15	5	*m*-anisidine (**2o**)	51	79

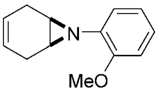
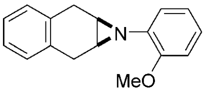
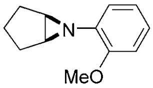
[a] Reaction between **1a** (0.2 M) and **2** (1.0 equiv.) was conducted in the presence of $Ti(O\text{-}i\text{-}Pr)_4$/**L2** (X mol%), H_2O (2X mol%) and $MgSO_4$ in toluene at -10 °C for 40 h.

[b] **2** (1.2 equiv.) was added over 22.5 h.

Other aziridines were also tested in the Ti(IV)/**L2** catalyst system, and the results are shown in Table 3. It was found that the Ti(IV)/**L2** catalyst worked well with some other aziridines. Whilst aziridine **1b** showed lower reactivity and enantioselectivity (entry 2), the reaction at higher temperature improved the yield with still relatively good *ee* (entry 3). When aziridines **1c** and **1d** were employed, good yields and moderate to good enantioselectivities were obtained (entries 4 and 5).

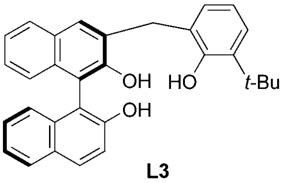
Furthermore, the effect of N-substituents was examined in the Ti(IV)/**L3** catalyst system (Table 4). While high yield and enantioselectivity were also obtained using aziridine **1a**, it was surprising to find that especially the enantioselectivity decreased using similar aziridines **1e** and **1f**. It is noted that aziridine **1g** without the *o*-alkoxy substituent gave the corresponding 1,2-diamine in 94% yield with 72% *ee.*

Table 3. Asymmetric ring-opening reactions of *meso*-aziridines by chiral Ti(IV)/**L2** complex.[a]

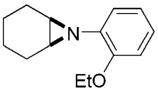
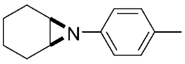
Entry	Aziridine	Yield [%]	*ee* [%]
1	**1a**	93	95
2	**1b** 	30	71
3[b]		89	60
4[c]	**1c** 	85	68
5[c]	**1d** 	74	61

[a] Reaction between aziridine **1** (0.2 M) and **2a** (1.0 equiv) was conducted in the presence of Ti(O-*i*Pr)$_4$/**L2** (10 mol%) and MgSO$_4$ in toluene at −10 °C for 40 h.[b] 50 °C.[c] 0 °C.

Table 4. Asymmetric ring-opening reactions of *meso*-aziridines by chiral Ti(IV)/**L3** complex.[a]



L3

Entry	Aziridine	Yield [%]	*ee* [%]
1	**1a**	94	91
2	**1e** 	68	72
3	**1f** 	quant.	76
4	**1g** 	94	72

[a] Reaction between aziridine **1** (0.2 M) and **2a** (1.0 equiv.) was conducted in the presence of Ti(O-*i*-Pr)$_4$/**L3** (10 mol%) and MgSO$_4$ in toluene at −10 °C for 40 h.

Elucidation of the nature and structure of catalysts or their precursors provides important information for the rational design of new catalysts. Ti/BINOL complexes are infamous in that they exhibit various coordination numbers and geometries, undergo rapid and facile change in coordination environment, and have a distinct tendency to form multipart oligomers or supramolecular assemblies.[7] Such structural complexity often frustrates efforts towards structural rationalization of catalytic behavior. Our efforts to grow crystals suitable for single crystal diffraction studies of enantiopure Ti(IV)/**L2** complex have been unsuccessful to date. After several disappointing trials, we changed our strategy and grew crystals from racemic mixtures. Finally, crystals of a binuclear titanium compound, Ti$_2$(*R*-**L2**)(*S*-**L2**)(O-*i*-Pr)$_2$ (*RS*-**4**),[8] and a pentatitanium compound, Ti$_5$(μ$_3$-O)$_2$(μ-O)(**L2**)$_4$ (O-*i*-Pr)$_2$ (*rac*-**5**),[9] were obtained. Their structures are shown in Figure 1 and Figure 2 (see also Scheme 2).

Yellow crystals of compound *RS*-**4** were isolated from a mixture of an equal amount of enantiopure Ti(IV)/**L2** complexes in ether. As shown in Figure 1, the molecule possesses a crystallographic inversion center. The titanium atoms are five-coordinate with a highly distorted trigonal bipyrimidal geometry. The tridentate ligands adopt a double bidenate chelating form with the central aryloxo as a bridge to link the

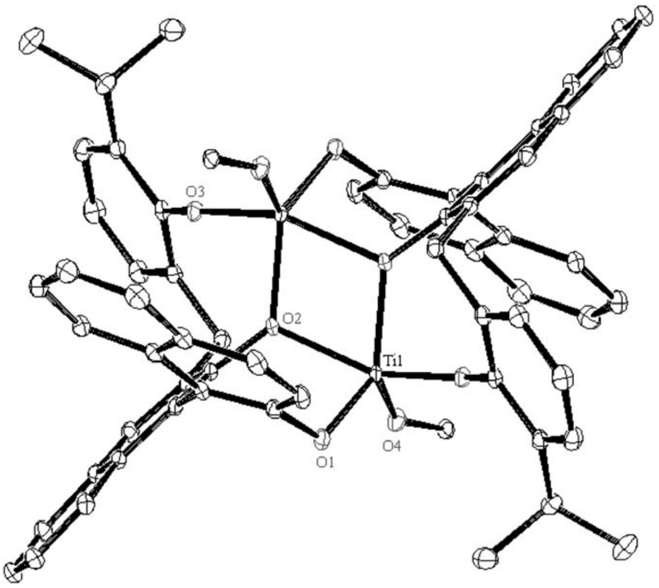


Figure 1. ORTEP drawing of *RS*-**4** (40% ellipsoids). Hydrogen and selected carbon atoms have been omitted for clarity.

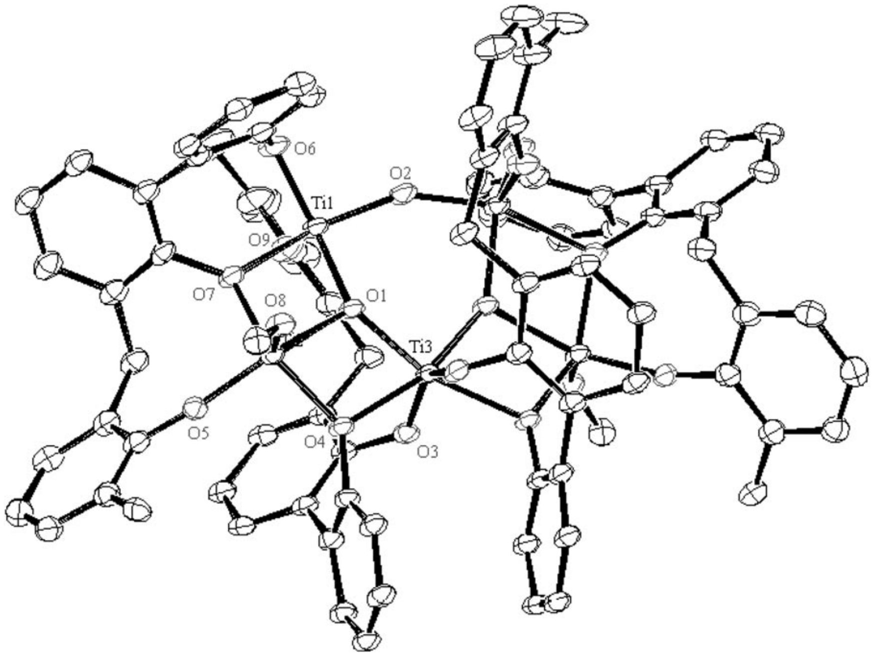


Figure 2. ORTEP drawing of *rac*-**5** (40% ellipsoids). Hydrogen and selected carbon atoms have been omitted for clarity.

$\mathrm{Ti(O\text{-}\mathit{i}\text{-}Pr)_4} + R\text{-}\mathbf{L2} \longrightarrow R\text{-}\mathbf{4}$

$\mathrm{Ti(O\text{-}\mathit{i}\text{-}Pr)_4} + S\text{-}\mathbf{L2} \longrightarrow S\text{-}\mathbf{4}$

$\mathrm{Ti(O\text{-}\mathit{i}\text{-}Pr)_4} + RS\text{-}\mathbf{L2} \longrightarrow RS\text{-}\mathbf{4}$

Scheme 2. Preparation of the chiral Ti(IV) catalysts.

titanium atoms. The dihedral angle of the binaphthyl is 64.01(9)°.

Compound $\mathrm{Ti_5(\mu_3\text{-}O)_2(\mu\text{-}O)(\mathbf{L2})_4(O\text{-}\mathit{i}\text{-}Pr)_2}$ (*rac*-**5**) were obtained from an equimolar mixture of *R*-**4**/H_2O and *S*-**4**/H_2O. This compound contains a new arrangement of five Ti(IV) atoms which are linked by two μ_3-O atoms and a μ_2-O atom. The molecule has a crystallographic C_2 symmetry axis that runs through the μ_2-O atom (O2) and Ti3 metal (Figure 2). The central titanium atom (Ti3) is six-coordinate with adopts a distorted octahedral geometry. The other Ti atoms are five-coordinate with distorted trigonal bipyramidal arrangements. BINOL is capable of an impressive structure flexibility allowing it to accommodate the range of required chelating or bridging coordination geometries without significant strain, this is also true for the tridenate ligand **L2**. In compound **5**, one unique tridentate ligand adopts a double bidenate chelating form as that in compound *RS*-**4**, and its dihedral angle is 59.3(2)°. However, another independent tridenate ligand has a different coordinative mode where it binds to all three independent Ti atoms. The outer BINOL-oxo links two Ti atoms., and the dihedral angle of **B** is 51.5(2)°. It should be reiterated that **5** is racemic, and equal amounts of both enantiomer are observed in the crytal structure (one unit is depicted in Figure 2 for clarity).

To obtain further information of the catalysts, we carried out catalysis with low *ee* ligands/complexes to ascertain if any non-linear effects (NLE) were operating. While the catalytic systems of titanium and BINOL frequently exhibit strong NLE in several reactions,[10] our results shown in Table 5 and Figure 3 are interestingly unique if a little complicated. First, when non-racemic **L2** was used for the preparation of non-racemic titanium catalysts and *RS*-**4**, a significant

Table 5. NLE results in asymmetric ring-opening reaction of aziridines by Ti(IV)/**L**.[a]

Method **A**[b]		Method **B**[b]		Method **C**[b]	
ee [%] of *R*-**L2**	*ee* [%] of product	*ee* [%] of *R*-**4**/H_2O	*ee* [%] of product	*ee* [%] of *R*-**4**	*ee* [%] of product
23	84	25	26	25	42
42	88	50	45	50	69
70	89	75	63	75	84
100	90	100	76	100	88

[a] Reaction between **1a** (0.2 M) and **2a** (1.0 equiv.) was conducted in the presence of non-racemic catalyst (5 mol%), H_2O (10 mol%) and $MgSO_4$ in toluene at −10 °C for 40 h.

[b] In Method **A**, non-racemic **L2** was used for the preparation of the catalyst. In Method **B**, the catalyst was prepared from mixing *R*-**4**/$H_2O$and *S*-**4**/H_2O, which were prepared and treated with H_2O separately in advance. In Method **C**, the catalyst was prepared from mixing *R*-**4** and *S*-**4**, which were prepared separately in advance. H_2O was added after mixing.

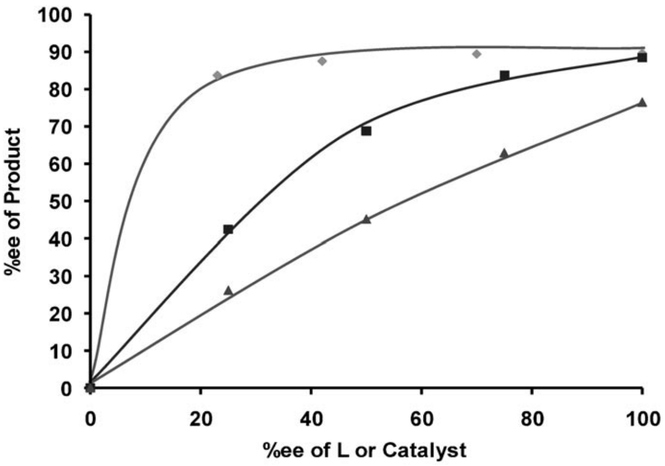


Figure 3. NLE profiles of chiral Ti/L catalyst prepared by Method **A** (diamond), Method **B** (triangle), and Method **C** (square).

positive NLE was observed (Method **A**). This result might be explained by the nature of homochiral complexes. Indeed, *RS*-**4** is not soluble in common solvents, like CH_2Cl_2, CH_3OH, toluene, and diethyl ether. It is very stable, and no changes were observed when water was added to its suspension in toluene. In contrast, it was assumed that the homochiral complexes reacted readily with water in toluene to form catalytically active species. Thus, the preferential formation of *RS*-**4**, the difference of the reactivity to water and solubility in toluene between homochiral compounds and *RS*-**4** were considered to be the reasons for the strong NLE. Next, *R*-**4**/H_2O and *S*-**4**/H_2O were used for the preparation of non-racemic titanium catalysts, and NLE experiments were performed (Method **B**). Interestingly, the *ee*s of the products were almost equal to the *ee*s of the catalysts. It was assumed that *rac*-**5** was formed preferentially, and that the catalyst was stable in solution, no ligand scrambling was observed under the reaction conditions. In addition, it was confirmed that *rac*-**5** was active for the aziridine ring-opening reaction. Finally, NLE experiments were conducted using non-racemic titanium catalysts prepared from *R*-**4** and *R*-**5** (Method **C**). In this case, a slight positive NLE was observed. It is most likely that homogeneous complexes *R*-**4** and *S*-**4** are not stable in solutions and that ligand scrambling might occur. It was confirmed that *RS*-**4** could be obtained quantitatively from their racemic mixture.

In summary, we report the first example of a Ti/BINOL derivative catalyst in the highly enantioselective ring-opening reactions of *meso*-aziridines. The isolation and structural characterization of $Ti_2(R\text{-}\mathbf{L2})(S\text{-}\mathbf{L2})(O\text{-}i\text{-}Pr)_2$ (*RS*-**4**) and $Ti_5(\mu_3\text{-}O)_2(\mu\text{-}O)(\mathbf{L2})_4(O\text{-}i\text{-}Pr)_2$(*rac*-**5**) sheds a light on the possible formation and the structure of the actual catalyst. The results from the studies of NLE indicate the complexity of this catalytic system. Studies on the substrate scope and the application of this new Ti/**L2** catalyst in other reactions are in progress.

Experimental Section

Typical Procedure for Asymmetric Ring Opening Reaction of Aziridines

$Ti(O\text{-}i\text{-}Pr)_4$ (7.1 mg, 0.025 mmol) and **L2** (10.8 mg, 0.025 mmol) in toluene (1.25 mL) was stirred at 60 °C for 3 h. After cooling to room temperature, the resulting yellow solution was added to a 10-mL flask in which aziridine **1a** (0.25 mmol) and $MgSO_4$ (50 mg) were placed. The yellow suspension was stirred at 0 °C for 30 min, and then 3.0 M solution of water in 2-propanol (16.5 μL) was added. The mixture turned to dark red, and was stirred at the temperature for another 30 min. The mixture was cooled to −10 °C, and **2a** (0.30 mmol) in toluene (0.25 mL) was added over a period of 22.5 h using a syringe pump. After the addition of **2a**, the reaction mixture was stirred for further 17.5 h, and then quenched with saturated $NaHCO_3$ (10 mL). The mixture was extracted with CH_2Cl_2 (3 × 10 mL). The organic extracts were combined, and dried with anhydrous Na_2SO_4. After filtration and concentration, the crude product was purified by preparative thin-layer chromatography (benzene:hexane:ethyl acetate = 19:10:1) to afford the desired product. The optical purity was determined by HPLC analysis using a chiral column.

References

[1] For examples of synthesis and transformation of aziridines: a) G. S. Singh, M. D′hooghe, N. D. Kimpe, *Chem. Rev.* **2007**, *107*, 2080; b) I. D. G. Watson, L. Yu, A. K. Yudin, *Acc. Chem. Res.* **2006**, *39*, 194; c) *Aziridine and Epoxide in Organic Synthesis*, (Ed.: A. K. Yudin), Wiley-VCH, Weinheim, **2006**; d) Z. Lu, Y. Zhang, W. D. Wuff, *J. Am. Chem. Soc.* **2007**, *129*, 7185; e) J. Vesely, I. Ibrahem, G.-L. Zhao, R. Rios, A. Córdova, *Angew. Chem.* **2007**, *119*, 792; *Angew. Chem. Int. Ed.* **2007**, *46*, 778; f) J. Y. Choi, R. F. Borch, *Org. Lett.* **2007**, *9*, 215.

[2] a) E. B. Rowland, G. B. Rowland, E. Rivera-Otero, J. C. Antilla, *J. Am. Chem. Soc.* **2007**, *129*, 12084; b) Z.-B. Luo, X.-L. Hou, L.-X. Dai, *Tetrahedron: Asymmetry* **2007**, *18*, 443; c) I. Fujimori, T. Mita, K. Maki, M. Shiro, A. Sato, S. Furusho, M. Kanai, M. Shibasaki, *J. Am. Chem. Soc.* **2006**, *128*, 16438; d) Y. Fukuta, T. Mita, N. Fukuda, M. Kanai, M. Shibasaki, *J. Am. Chem. Soc.* **2006**, *128*, 6312; e) T. Mita, I. Fujimori, R. Wada, J. Wen, M. Kanai, M. Shibasaki, *J. Am. Chem. Soc.* **2005**, *127*, 11252; f) Z. Li, M. Fernandez, E. N. Jacobsen, *Org. Lett.* **1999**, *1*, 1611; g) P. Muller, P. Nury, *Org. Lett.* **1999**, *1*, 439; h) M. Hayashi, K, Ono, H. Hoshimi, N. Oguni, *J. Chem. Soc., Chem. Commun.* **1994**, 2699; i) Z. D. Zhang, R. Scheffold, *Helv. Chim. Acta* **1993**, ***76***, 2602.

[3] K. Arai, S. Lucarini, M. M. Salter, K. Ohta, Y. Yamashita, S. Kobayashi, *J. Am. Chem. Soc.* **2007**, *129*, 8103.

[4] Recent examples of Ti/BINOL asymmetric catalysis: a) Y. Muramatsu, T. Harada, *Angew. Chem.* **2008**, *120*, 1104; *Angew. Chem. Int. Ed.* **2008**, *47*, 1088; b) C.-A. Chen, K.-H. Wu, H.-M. Gau, *Angew. Chem.* **2007**, *119*, 5469; *Angew. Chem. Int. Ed.* **2007**, *46*, 5373; c) K.-H. Wu, H.-M. Gau, *J. Am. Chem. Soc.* **2006**, *128*, 14808; d) T. Kano, T. Hashimoto, K. Maruoka, *J. Am. Chem. Soc.* **2005**, *127*, 11926; e) J. G. Kim, K. M. Waltz, I. F. Garcia, D. Kwiatkowski, P. J. Walsh, *J. Am. Chem. Soc.* **2004**, *126*, 12580; f) S. Takizawa, H. Somei, D. Jayaprakash, H. Sasai, *Angew. Chem.* **2003**, *115*, 5889; *Angew. Chem. Int. Ed.* **2003**, *42*, 5711; g) Y. Yuan, X. Zhang, K. Ding, *Angew. Chem.* **2003**, *115*, 5636; *Angew. Chem. Int. Ed.* **2003**, *42*, 5478; h) C.-M. Yu, J.-Y. Lee, B. So, J. Hong, *Angew. Chem.* **2002**, *114*, 169; *Angew. Chem. Int. Ed.* **2002**, *41*, 161; i) X. Li, G. Lu, W. H. Kwok, A. S. C. Chan, *J. Am. Chem. Soc.* **2002**, *124*, 12636; j) J. Balsells, T. J. Davis, P. Carroll, P. J. Walsh, *J. Am. Chem. Soc.* **2002**, *124*, 10336.

[5] a) A. Tillack, V. Khedkar, H. Jiao, M. Beller, *Eur. J. Org. Chem.* **2005**, 5001; b) G. Sundararajan, N. Prabagaran, B. Varghese, *Org. Lett.* **2001**, *3*, 1973.

[6] a) G. Pescitelli, L. D. Bari, P. Salvadori, *J. Organomet. Chem.* **2006**, *691*, 2311; b) Y. Yamashita, H. Ishitani, H. Shimizu, S. Kobayashi, *J. Am. Chem. Soc.* **2002**, *124*, 3292; c) L. J. P. Martyn, S. Pandiaraju, A. K. Yudin, *J. Organomet. Chem.* **2000**, *603*, 98; d) M. Terada, Y. Matsumoto, Y. Nakamura, K. Mikami, *Chem. Commun.* **1997**, 281; e) G. H. Posner, H. Dai, D. S. Bull, J.-K. Lee, F. Eydoux, Y. Ishihara, W. Welsh, N. Pryor, S. Petr Jr. , *J. Org. Chem.* **1996**, *61*, 671.

[7] a) Q.-S. Guo, H.-B. Song, J.-S. Li, *Z. Anorg. Allg. Chem.* **2006**, *632*, 721; b) B. Liu, F.-Y. Jiang, H.-B. Song, J.-S. Li, *Tetrahedron: Asymmetry* **2006**, *17*, 2149; c) H.-Z. Tang, P. D. Boyle, B. M. Novak, *J. Am. Chem. Soc.* **2005**, *127*, 2136; d) K. M. Waltz, P. J. Carroll, P. J. Walsh, *Organometallics* **2004**, *23*, 127; e) S. Pandiaraju, G. Chen, A. Lough, A. K. Yudin, *J. Am. Chem. Soc.* **2001**, *123*, 3850; f) T. J. Davis, J. Balsells, P. J. Carroll, P. J. Walsh, *Org. Lett.* **2001**, *3*, 699; g) N. W. Eilerts, J. A. Heppert, *Polyhedron* **1995**, *14*, 3255; h) N. W. Eilerts, J. A. Heppert, M. L. Kennedy, F. Takusagawa, *Inorg. Chem.* **1994**, *33*, 4813.

[8] Yellow crystals of $\mathrm{Ti_2}$(*R*-**L2**)(*S*-**L2**)(O-*i*-Pr)$_2$ (*RS*-**4**) were isolated from a mixture of an equal amount of enantiopure *R*-**4** and *S*-**4** in ether. Crystal data for *RS*-**4**: triclinic, space group *P*-1, $a=11.418(1)$ Å, $b=12.178(1)$ Å, $c=12.996(1)$ Å, $\alpha=75.57(3)°$, $\beta=84.14(3)°$, $\gamma=63.74(3)°$, $V=1569.3(2)$ Å^3, $Z=1$, *R* value [*I*> 2ø] *R*1=0.0331. CCDC 685274 contains the supplementary crystallographic data *RS*-**4**. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre *via* www.ccdc.cam.ac.uk/data_request/cif.

[9] Compound $\mathrm{Ti_5}(\mu_3\text{-O})_2(\mu\text{-O})$(**L2**)$_4$(O-*i*-Pr)$_2$ (*rac*-**5**) was obtained from a racemic mixture of enantiopure *RR*-**4**/$\mathrm{H_2O}$ and *SS*-**4**/$\mathrm{H_2O}$ in diethyl ether. Crystal data for *rac*-5: monoclinic, space group *C*2/*c*, $a=31.936(6)$ Å, $b=23.275(5)$ Å, $c=17.572(4)$ Å, $\beta=106.96(3)°$, $V=12494(4)$ Å3, $Z=4$, R value [I> 2ø] *R*1=0.0692. CCDC 685275 contains the supplementary crystallographic data for *rac*-**5**. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre *via* www.ccdc.cam.ac.uk/data_request/cif.

[10] a) H. Bao, J. Zhou, Z. Wang, Y. Guo, T. You, K. Ding, *J. Am. Chem. Soc.* **2008**, *130*, 10116; b) K. Mikami, M. Terada, T. Korenaga, Y. Matsumoto, M. Ueki, R. Angelaud, *Angew. Chem.* **2000**, *112*, 3676; *Angew. Chem. Int. Ed.* **2000**, *39*, 3532; c) C. Girard, H. B. Kagan, *Angew. Chem.* **1998**, *110*, 3088; *Angew. Chem. Int. Ed.* **1998**, *37*, 2922, and references cited therein.