

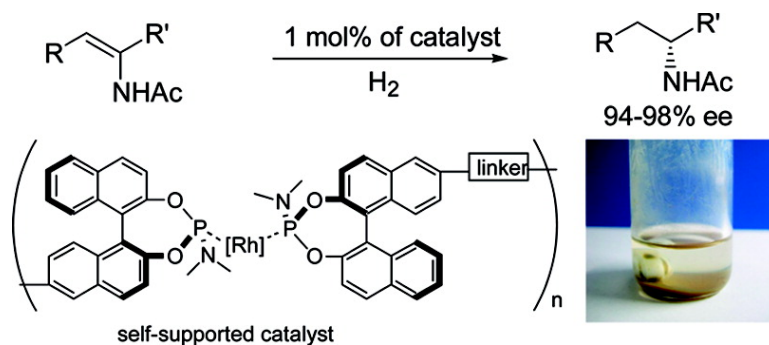
Communication

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Self-Supported Heterogeneous Catalysts for Enantioselective Hydrogenation

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The immobilization of homogeneous chiral catalysts using various solid insoluble supports, including inorganic materials, organic polymers, and membranes as supports, could solve some problems of homogeneous catalysts such as difficult recovery of expensive chiral catalyst and metal contaminants leached from the catalysts in the products, to some extent.^{1,2} However, in the classical approaches, the chiral ligands or the catalytically active units are randomly anchored onto irregular polymers and other supports, and the resulted immobilized catalysts often displayed reduced enantioselectivity and less efficiency in the catalysis in comparison with their homogeneous counterparts. The functional metal-organic assemblies might provide an alternative approach to heterogeneous catalysis to overcome the problems mentioned above since these self-assembled materials have shown permanent porosity and absorption capacity for organic guest molecules.³ Aoyama and co-workers have demonstrated the catalytic properties of nonchiral metal-organic solids for Diels–Alder reaction.⁴ Accordingly, the design and synthesis of chiral metal-organic frameworks or polymers might provide a facile strategy for asymmetric heterogeneous catalysis, because the bridged chiral ligand can spontaneously form a chiral environment on the surface of the solids or inside the cavities of the materials for enantioselective control of the reaction, and the metal ion acts as the catalytically active center without using any supports.⁵ Therefore, the use of chiral metal-organic assemblies can be considered as a “self-supported strategy”⁵ for heterogenization of homogeneous catalyst in enantioselective reactions.^{6,7} In the present work, we report our results on the heterogenization of Feringa’s MonoPhos/Rh⁸ catalyst using self-supported strategy for enantioselective hydrogenations of α -dehydroamino acid and enamide derivatives,⁹ affording a variety of enantioenriched biologically important compounds with high yields and enantioselectivities.

The linker-bridged bis-MonoPhos ligands (**1a–c**) were prepared by the reaction of hexamethylphosphorus triamide (HMPT) with corresponding bis-BINOL derivatives^{6c} in good yields. The ligands **1a–c** and the catalyst precursor $[\text{Rh}(\text{cod})_2]\text{BF}_4$ were dissolved in toluene and dichloromethane, respectively. The solution of $[\text{Rh}(\text{cod})_2]\text{BF}_4$ in dichloromethane was added to the solution of ligands **1a–c**, and the orange solids precipitated immediately. After removal of the solvents, the resulting powders (**2a–c**) were washed with toluene to remove the trace amount of soluble low-molecular weight materials. Elemental analysis showed that the composition of the resulting solids were consistent with the structures of **2a–c** expected. As shown in Figure 1a, these yellow polymeric solids were completely insoluble in toluene and, accordingly, fulfill one of the basic prerequisites of heterogeneous catalysis, and toluene was selected as the reaction mediate for the heterogeneous hydrogenation of olefin derivatives. SEM images showed that these solids were composed of micrometer particles (Figure 1b), while powder X-ray diffraction (PXRD) indicated that they were non-crystalline solids. The self-supported catalysts **2a–c** were then submitted to the catalysis of the hydrogenation of some representa-

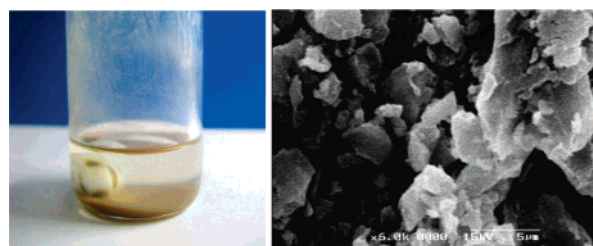
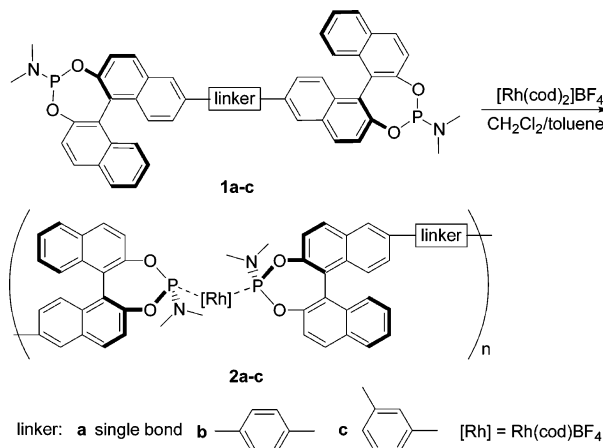


Figure 1. (a) Self-supported chiral Rh catalyst **2a** (yellow solids at the bottom of the reactor) in toluene. (b) SEM image of the self-supported Rh catalyst **2a**. The scale bar indicates 5 μm .

Scheme 1. Heterogenization of Feringa’s Catalyst by Self-Supported Strategy



tive substrates, including β -aryl- or alkyl-substituted dehydro- α -amino acid and enamide derivatives **3a–d** (Table 1). The reactions were carried out at room temperature under 40 atm pressure of H_2 with a substrate concentration of 0.2 M. As shown in Table 1, for all three catalysts examined, the complete conversion of the substrates could be achieved within 10 h and the enantioselectivities of hydrogenation were excellent (94.3–97.3% ee), which are comparable to the cases of homogeneous catalysis at the same level of catalyst loading.⁸ Particularly, the self-supported catalysts demonstrated improved enantioselectivity (entries 4, 8, and 12) in the hydrogenation of **3d** in comparison with the cases using MonoPhos/Rh homogeneous catalyst (87.8–88.8% ee) under otherwise identical conditions.¹⁰

In an effort to probe the heterogeneous or homogeneous nature of the above catalyst systems, the supernatants of **2c** in toluene were employed for the catalysis of hydrogenation of **3a** under the same experimental conditions; no product was observed at all. This experiment unambiguously demonstrated the heterogeneous nature of the present catalytic systems. The inductively coupled plasma (ICP) spectroscopy analyses of the reaction mixtures containing substrate **3a** or product **4a** after filtration of the insoluble **2c**

Table 1. Enantioselective Hydrogenation of Olefin Derivatives **3a–d** under the catalysis of **2a–c**^a

entry	catalyst	substrate	ee (%) ^b
1	2a	3a	95.8
2	2a	3b	95.7
3	2a	3c	96.6
4	2a	3d	97.3
5	2b	3a	94.3
6	2b	3b	94.9
7	2b	3c	94.7
8	2b	3d	96.8
9	2c	3a	95.0
10	2c	3b	95.9
11	2c	3c	96.2
12	2c	3d	95.9

^a All of the reactions were carried out at 25 °C under 40 atm pressure of H₂ at a substrate concentration of 0.2 M for 10 h (substrate/catalyst = 100:1). The conversion of the substrates determined by ¹H NMR was >99%.
^b Determined by HPLC on a Chiralcel AD column and GC on a Supelco BETA-DEX120 or GAMMA-DEX 225 column.

Table 2. Recycling and Reuse of the Self-Supported Catalysts **2c** in Enantioselective Hydrogenation of **3a**^a

run	conversion (%)	ee (%)
1	>99	95.0
2	>99	93.5
3	>99	90.2
4	>99	90.9
5	>99	90.5
6	>99	90.0
7	>99	89.5

^a All of the reactions were carried out under the experimental conditions of entry 9 in Table 1.

indicated that no detectable rhodium leached into the organic solution and the concentrations of phosphorus in organic phase were less than 3 ppm for each round of hydrogenation, which further confirmed the heterogeneous nature of the present systems.

Recycling of the present self-supported catalyst was quite simple. After the completion of the hydrogenation, simple filtration under an Ar atmosphere afforded the separation of the solid-state catalyst and products in solution. The separated solids were charged with solvent and substrates again for the next run. The reusability of the present self-supported catalyst system was examined in the hydrogenation of **3a** with catalyst **2c**. As shown in Table 2, in the second and third runs, the enantioselectivities of the reaction dropped slightly (from 95 to 93.5 and 90.2%, respectively). On the other hand, the ee of the product from the third run to the seventh run remains almost constant (90.9–89.5%). We did not observe significant deterioration of activity in the recovered catalyst even after seven times of use. Therefore, such chiral metal-organic polymeric assemblies have the advantages not only of heterogeneous catalysts such as easy recovery and convenient recycle but also of facile preparation, robust chiral frameworks,

and high density of the catalytically active units, as well as comparable performance to that of the free catalysts in terms of both activity and enantioselectivity.

In conclusion, we have demonstrated a self-supported strategy in the generation of heterogeneous enantioselective catalyst through assembly of bridged monophosphoramidate chiral ligand with Rh-(I) ion for asymmetric hydrogenation of olefin derivatives, affording a variety of enantioenriched amino acid and amine derivatives with high yields and enantioselectivities. This strategy might provide a new direction in asymmetric catalysis, particularly for the development of practical heterogeneous asymmetric synthesis of optically active compounds.

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Supporting Information Available: Experimental procedures and figures of SEM and PXD images of catalysts and chiral HPLC or CG analysis of the products (PDF). This material is available free of charge via the Internet at <http://pubs.acs.org>.

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