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GUEST EDITORIAL

Nanoparticles for Catalysis

Metal nanoparticles dispersed on the surfaces of oxide and carbon materials form the basis for many catalysts and electrocatalysts of great importance to future energy and fuel technologies. The past decade has witnessed an explosion in new methods for synthesizing metal nanoparticles with controlled compositions, sizes, shapes, and structures and for elegantly controlling the ways in which these nanoparticles can be connected to and even surrounded by support materials like oxides. Already, these systems have been used to prepare novel catalysts with great promise for industrial applications. At the same time, there has been a rapid progress in fundamental understanding of the effects of particle size and shape (i.e., facet), the support material, and the particle/support interface on the activity, selectivity, and long-term stability of such nanoparticle-based catalysts. The purpose of this special issue on "Nanoparticles for Catalysis" is to collect a series of Accounts by the leading experts to give an overview of recent major developments in these respects. From this special issue, the readers can quickly learn about the most powerful synthetic methods and state-of-the-art characterization techniques that have been utilized to control and analyze these nanoparticle-based catalysts and start to see the relationship between their structural details and catalyst performance, while at the same time develop a fundamental understanding of the basic principles that dictate these relationships. The articles were organized into five groups, with each group being focused on one specific theme.

The first group of eight articles addresses the fundamental aspects of catalysis by nanoparticles. These studies employ structurally well-defined model catalysts (often based on flat single crystals covered by nanoparticles) to clarify the relationships between catalytic performance (i.e., activity per surface atom, selectivity to the desired product, and resistance to deactivation by sintering) and the atomic-level structural details of the catalytic nanomaterial. The aim is to understand these relationships well enough so one can tailor the catalyst to achieve the desired performance.

The second group of five articles center on recent developments in the chemical syntheses of metal nanoparticles with controlled shapes. The surfaces of these nanoparticles are enclosed by a mix of low-index facets, such as {100} and {111} in different proportions. Nanoparticles covered by high-index facets have also been demonstrated in recent years. As a major advantage over the traditional heterogeneous catalysts comprised of nanoparticles with poorly defined shapes, the use of nanoparticles with an exact shape will enable people to control what types of atomic structures are presented on the surface and at what proportions. As a result, it is much easier to investigate and elucidate the reaction mechanism. It is also feasible to enhance the activity of a catalyst by engineering the shape of nanoparticles to ensure that their surfaces will contain the most active facets and at the highest possible ratio.

The third group of four papers discusses how to enhance the catalytic performance of nanoparticles by engineering their surface coatings or surroundings. The strategies include the development of core−shell nanostructured catalysts by forming oxide shells on the metal nanoparticles. The oxide shells can potentially prevent the metal nanoparticles in a catalyst from sintering, but the oxide coatings have to be sufficiently porous to allow molecules to diffuse to/from the catalyst. Atomic layer deposition (ALD) has also been utilized for the preparation of supported catalysts. As a unique feature of ALD, it is self-limiting, offering a superb control over the size and composition of nanoparticles and even locations where atoms are deposited.

The fourth group of four papers showcases recent achievements in the development of hydrogen fuel cell electrocatalysts. Over the past decade, major progress has been made in developing highly active electrocatalysts to mitigate the sluggish reaction kinetics associated with the oxygen reduction reaction (ORR) on the cathode. Benefiting from the long-term studies of ORR kinetics and the recent density functional theory (DFT) calculations, it is now feasible to design Pt-based bimetallic nanoparticles with

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high levels of control over size, shape, and composition to satisfy, at least in part, the stringent structural requirements for greatly improved activity. High-throughput methods have also been developed for optimizing both the electrocatalysts and support materials used for ORR. Besides Pt-based nanoparticles, nonprecious metal catalysts (NPMCs) have recently attracted great attention for ORR in basic solutions. It is encouraging to note that this research has progressed to a level where electrocatalysts made of earth-abundant elements such as Fe, Co, N, and C can have activity comparable to carbon-supported Pt in some measures.

The last group of two papers is focused on the design and synthesis of nanoparticles for photocatalysis and photoelectrocatalysis using cocatalysts for semiconductor-based systems. One of the articles discusses new strategies for structuring cocatalysts on semiconductors to generate interfaces for oxidation and reduction, to suppress charge recombination and reverse reactions, and to maximize light harvesting. In a new way to utilize light for chemical transformation, the localized surface plasmon resonance associated with metal nanoparticles made of Au, Ag, and Cu can also be used to catalyze chemical reactions. Under irradiation of light, the chemical reactions are thought to be catalyzed through a direct, electron driven photocatalytic process.

It is hoped that this special issue will bring to our readers some exciting, representative, and timely snapshots of research on nanoparticle-based catalysts. Because of the highly dynamic nature of this fast-evolving field, it is impossible to cover every aspect of research in this field. There is no doubt that this field will continue to develop strongly, with contributions from researchers in chemistry, physics, chemical engineering, and materials science. It is also hoped that our readers will enjoy the mix of topics presented here and perhaps find the inspiration to push this field a step further toward greater success in both knowledge development and commercialization.

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Guest Editors