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Introduction

Solid state chemistry on the nanoscale: Achievements, challenges, and opportunities

The rapid expansion of nanoscale science and technology has provided fertile ground for research at the intersection of multiple fields, including chemistry, physics, biology, materials science, and various engineering disciplines. Solid state chemistry plays a central role in these endeavors, providing the foundation of crystal chemistry and the various aspects of solid state synthesis, characterization, property measurements, computational modeling, and structure–property relationships that are necessary for the development, understanding, and application of nanomaterials. Nanoscale solids are diverse, ranging from metals and metal compounds to organic solids and polymers. As a result, research in nanoscience draws from, and builds upon, all facets of solid state chemistry.

This special issue of the *Journal of Solid State Chemistry* is titled "Solid State Chemistry on the Nanoscale: Achievements, Challenges, and Opportunities" to highlight the current state of the field, which is certainly very exciting and diverse! Achievements during the past two decades have given us the ability to routinely synthesize high-quality nanoscale solids in a variety of systems, discover and understand their size- and shape-dependent properties, and develop novel ways of utilizing them in applications. At the same time, many challenges still exist as we try to push toward more complex solids and architectures, more exotic properties, and more advanced applications. There is a continual need to expand the diversity of accessible nanoscale solids and enhance our understanding of them. Finally, all of these past achievements and surmountable current challenges point to significant opportunities for future advances in the nanoscience of solid state chemistry and ultimately in technology, medicine, energy, the environment, and other areas where nanoscale solids play a prominent role.

The concept and research articles included in this special issue span the synthesis, characterization, physical properties, and applications of nanoscale solids. As befits a solid state chemistry journal, there is particular emphasis on the diversity of solids that can be synthesized as nanoscale materials. Throughout the issue, contributions discuss nanoscale metals, alloys, intermetallic compounds, oxides, chalcogenides, nitrides, and phosphides. One defining feature of nanoscale solids is the effect that particle size, shape, and dimensionality have on properties. Accordingly, several articles discuss the synthesis of size- and shape-controlled nanocrystals, including zero-dimensional (0D) spheres, 1D rods and wires, 2D sheets, and more elaborate morphologies such as hollow and core/shell particles. The synthesis of solids at the nanoscale is often carried out at significantly lower temperatures, and under much different reaction conditions, than are typically required for preparing bulk-scale analogues of the same solids. As such, one of the themes running through many of the contributions involves the low-temperature solution synthesis of solids. The ability to make both equilibrium and non-equilibrium solids using "beaker chemistry" is an important link between molecular (solution) chemistry and solid state chemistry, and is especially rich for nanoscale solids. A variety of novel synthetic routes to nanoscale solids are also highlighted, including the use of thin films, surfaces, patterned substrates, self-assembly, oriented aggregation, and biological and physical templates.

Along with synthesis comes characterization, and readily available modern tools are changing the "standard" in regard to what is considered appropriate characterization for nanoscale solids. Throughout all of the articles, a palette of techniques is used for structural characterization, including electron microscopy imaging, X-ray and electron diffraction, light and X-ray scattering, elemental analysis, and various spectroscopic techniques that include UV-visible, Raman, FT-IR, and photoluminescence. Beyond this, we are learning more and more of the details of nanoscale solids that impact their properties, and new methods and tools are being developed for this purpose. For example, this issue contains a concept article describing the use of electron tomography to understand the distribution of dopants in semiconductor nanostructures. Other concept articles highlight state-of-the-art diffraction capabilities for unraveling the structures of nanoscale solids, advanced spectroscopic techniques for studying the structures and properties of nanoscale magnetic semiconductors, and electric force microscopy for probing the electrical characteristics of nanostructures. As new characterization tools and techniques are developed, the types of questions that can be answered increase in complexity, as does our understanding of nanoscale solids and their structure–property relationships.

Parallel to bulk-scale solids, one of the primary motivations for synthesizing and characterizing nanoscale solids is to generate materials with useful physical properties. Because the properties of nanoscale solids are often dependent on size, shape, and dimensionality, as well as on crystal structure, composition, purity, etc., they provide fertile ground for exploration. The articles in this issue represent the diverse spectrum of solid state electrical properties, including metals, semiconductors, and insulators, as well as a variety of interesting and important magnetic properties. Various optical properties (e.g., luminescence and surface plasmon resonance) and catalytic properties (e.g., photocatalytic water splitting, soot combustion, hydrodesulfurization) are also highlighted. Different from bulk-scale solids, surface chemistry can play a key role in the properties and applications of nanoscale solids, and several articles discuss

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the need for appropriate surface functionalization. This is particularly important for biological applications, where solubility and bioconjugation are required. Several articles discuss the use of nanoscale solids for biological applications, including as probes, MRI contrast agents, and antibacterial materials. Finally, one of the exciting aspects of nanoscale solids is the ability to design composites that impart multiple functionalities into a single material. Core/shell, sphere-in-sphere, host/template, and intercalated layered solids serve as highlighted examples of this.

We are in a position to build on past achievements and push toward more complex systems and a deeper understanding of their structures, properties, and structure–property relationships. We are also poised to expand into more advanced applications that build on the foundation provided by solid state chemistry. This includes the design of nanoscale materials with specific functions, even multiple functions, by exploiting new and under-explored degrees of freedom afforded by nanoscale solids. It is clear that solid state chemistry on the nanoscale is a diverse and exciting field with many more advances and discoveries on the horizon!

Guest Editor
Raymond E. Schaak
E-mail address: schaak@chem.psu.edu