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NANOSCIENCE TURNS GREEN

Molecular-level materials assembly with chemical building blocks offers promise, opportunity

We face serious economic and environmental challenges during the next few decades as a consequence of emerging new economies and continuing population growth. Projected demands on natural resources significantly exceed Earth's resource base and thus threaten our environment and our way of life. Given the central role of chemical products in modern societies, the development of sustainable chemical practices is essential to avoid depleting our natural resources and damaging our ecosystems. Chemists must invent and develop sustainable chemical practices if our environment and economies are to thrive in this century.

Environmentally benign or "green" chemistry strives to address environmental protection and sustainability through hazard reduction and improved efficiency. Industrial and academic chemists have used green chemistry to develop new processes and products that reduce hazards to the environment and human health.

However, to date, the scope of green chemistry remains limited primarily to the transformations of molecular species by using new catalysts or alternative reaction media. The development of green chemical methods to prepare functional high-performance materials, particularly nanoscale materials, has been virtually unexplored and offers a significant opportunity for the future.

Controlling properties at the molecular level is a key to success in both nanoscience and green chemistry. As the important length scales in functional materials approach nanometer dimensions, chemists are already playing key roles in developing and manufacturing new materials and devices. In the future, chemists will develop alternative device structures, invent methods for organizing matter on short length scales, and provide solutions for interfacial reactivity issues that arise as surface-to-volume ratios increase. Because many of these approaches involve chemical building blocks whose properties can be tailored at the molecular level, principles of green chemistry can be readily incorporated into materials design and production. Throughout the design and development process, chemists will have an opportunity and a responsibility to practice green chemical strategies.

The use of chemical building blocks to assemble materials offers many advantages. Building blocks can be synthesized using green preparation methods and assembled under mild, reversible reaction conditions that provide low-energy routes to correct errors in the assembly. In principle, assemblies can even be disassembled and the building blocks reused. With respect to performance, molecular assemblies allow properties to be easily tuned and provide opportunities for facile construction of three-dimensional materials.

PHOTO BY JACK LIU

BUILDING SKILLS **Hutchison (standing) and graduate student Kathryn Parent observe while graduate student Marvin Warner acquires data.**

Combining green chemistry with nanoscience will have a significant impact on electronic materials. Because many hazardous materials are used in traditional semiconductor manufacturing processes, alternative technologies designed in accordance with green chemical principles are needed. At the same time, as the sizes of electronic devices approach the nanoscale, continued miniaturization faces fundamental physical limitations and exponentially rising manufacturing costs. Alternatives to silicon-based devices based on nanoscale assemblies fabricated using green assembly methods are particularly attractive solutions to this long-term problem.

We are currently investigating the electrical properties of nanoscale assemblies that transport charge through sequential tunneling events and may form the basis for future electronic devices. The assemblies are prepared by biomolecular nanolithography, a biomimetic method of organizing metal nanoparticles into assemblies designed to incorporate the aims of green chemistry. A biopolymer template stretched out on a surface acts as a scaffold for chemical assembly of the nanoparticles into well-defined architectures, such as lines and grids. This approach has already led to nanoscale assemblies that demonstrate stable electrical behavior at room temperature. The assemblies appear to be tolerant of defects and useful in building nanoscale circuits.

This is just one example of how molecular-level control can produce functional nanoscale assemblies through green synthesis methods. A generalized road map for the future design and development of green nanoscale materials involves the use of green chemistry to prepare the building blocks, chemical assembly of building blocks for circuit fabrication, templates to pattern features on surfaces, and molecular-level tuning to design defect-tolerant systems and systems that take advantage of the third dimension. The challenge for the future is to use these principles to design high-performance and green materials by taking advantage of our abilities to control properties at the molecular level.

To meet the challenges I describe, we will need to change our educational programs to prepare students to excel in green chemistry and nanoscience, both of which are highly interdisciplinary areas. Future curricula must continue to provide students with fundamental training in chemical principles and prepare them to work with a wide range of scientists, engineers, and policy makers.

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