



Creating Nanostructures via Genetic Engineering

Researchers at NASA's Ames Research Center (Moffet Field, CA), led by Jonathan Trent, Andrew McMillan and Chad Paavola, in collaboration with Nestor Zaluzec of Argonne National Laboratory's (Argonne, IL) Telepresence Microscopy Laboratory, have used modified proteins from extremophile microbes as templates to create mesh-like structures with potential uses in electronics devices.

The team extracted a gene from *Sulfolobus shibatae*, a single-celled bacterium that lives in geothermal hot springs and can tolerate near-boiling temperatures and high acidities. The gene was modified by the addition of instructions that describe how to make a protein that sticks to gold or semiconductors, explains McMillan. It was then cloned into a harmless form of *E. coli* bacteria that rapidly multiplies, producing large quantities of the new protein, Paavola adds. The resulting brew was heated to destroy the unwanted natur-

al *E. coli* proteins, allowing large amounts of the heat-tolerant *Sulfolobus* protein to be isolated.

The protein was assembled into ring structures that are 20 nm across, which were crystallized into flat hexagonal templates up to 100 μm wide. The crystals were then applied to a substrate such as a silicon wafer, and a gold or semiconductor slurry was added. The tiny particles of gold or semiconductor (cadmium selenide/zinc sulfide) stick to the lattices, producing precise, regular arrays of nanoparticles that closely resemble similar patterns used in the microelectronics industry, only much smaller. "After further development, a nanoparticle array could serve as computer memory, a sensor, or a logic device that could perform calculations," McMillan predicts.

"We have demonstrated the feasibility of using genetically engineered proteins to manipulate and arrange materials on a nanometer scale," Trent says. "Our ultimate goal is to prove that we can use

proteins to build devices that will be of value to NASA in the search for life beyond Earth."

Nanoshell Sensors Improve Molecular Analysis

Researchers at Rice Univ. (Houston, TX) have demonstrated the ability to control the electromagnetic field around nanoparticles, which could lead to the development of chemical screening techniques to routinely analyze samples as small as a single molecule, says Naomi Halas, professor of electrical and computer engineering. "This is the first time that anyone has designed and engineered a nanosensor specifically for obtaining chemical information," she asserts. "It has widespread applications in environmental science, chemistry, and biosensing, and it may have very important applications in the early detection of cancer."

Raman spectroscopy is commonly used in chemical analysis and to determine molecular structure. Scientists have known that they could boost the Raman light scattering of a sample, and thus the sensitivity of the analytical technique, by placing the sample next to small metal colloid particles. However, they have not been able to precisely control the electromagnetic state of the metal colloids, so results and interpretations of such studies vary widely, Halas points out.

Her research capitalizes on the tunable optical properties of metal nanoshells, which are layered colloids that consist of a core of non-conducting material covered by a thin metallic shell. She found that varying the core and shell dimensions of the nanoshell provided a way to focus the local electromagnetic field at the surface of the nanoparticles in a controlled way.

The electromagnetic field at a metal surface is believed to be responsible for the greatly increased sensitivity in the spectroscopic signal of molecules



Researcher Jonathan Trent operates a fermenter. Courtesy NASA Ames Research Center.

adsorbed onto that surface, which is known as surface enhanced Raman spectroscopy (SERS). The strength of the field as a function of core and shell dimension is measured by monitoring the SERS response of molecules adsorbed to the nanoparticles' surface. Halas reports that the SERS enhancement appears to be directly and exclusively due to nanoparticle geometry. Effective SERS enhancements of a million times were observed in aqueous solution, which corresponds to absolute enhancements of a trillion times when reabsorption of Raman emission by nearby nanoparticles is taken into account, she adds. The enhancement refers to the increase in the measurable signal strength, which results in greatly increased analytical sensitivity, she explains.

More information about this work can be found in *Applied Physics Letters*, **82** (2), pp. 257–259 (Jan. 13, 2003).

Technique Determines Molecular Structure of Heterogeneous Surfaces

Scientists have improved upon a method that uses the very intense light emitted by the National Synchrotron

Light Source (NSLS) at the U.S. Dept. of Energy's Brookhaven National Laboratory (Upton, NY) to determine the structure of chemically heterogeneous surfaces with submillimeter resolution. The new technique is non-invasive, does not require transparent samples, and provides simultaneous information about the chemical nature and orientation of the molecules on the surface, notes Jan Genzer, a professor of chemical engineering at North Carolina State Univ. (Raleigh) and the leader of the project.

In the basic technique, called near-edge x-ray absorption fine structure (NEXAFS) spectroscopy, intense ultraviolet light produced by the NSLS interacts with a target material. Electrons emitted by the material are collected with a detector to provide information about the concentration and orientation of the molecules. For a chemically heterogeneous surface, the technique needs to be applied sequentially at regular small intervals to scan from one end of the material to the other.

Kirill Efimenko, a senior research associate at North Carolina State, explains that the team combined NEXAFS with a device called a

goniometer (a movable sample holder). "This allows us to automatically move the sample in a vacuum chamber and to probe points separated by a half-millimeter along the surface of the sample where the molecular densities vary."

The technique, called combinatorial NEXAFS, was applied to a rectangular silica surface covered with a layer of organosilane molecules, the concentration of which was highest at the edges of the surface and lower toward the middle. After probing about 100 points along one length of the sample, the scientists successfully reconstructed the expected molecular density profile. They are now studying the geometry of this region to learn more about the nature of the self-assembly of organosilane molecules on a surface.

Combinatorial NEXAFS was also used to investigate how gold nanoparticles form a pattern of decreasing density by following a similar pattern underneath them. Genzer and his colleagues expect that in the future, the technique will be used to study a wide range of heterogeneous materials, including polymers and catalysts.

AIChE **JOURNAL** Perspective

Chemical Engineering and Molecular Biophysics

Over the past decade, bioengineering has focused on understanding the behavior of living systems and manipulating it via genetic engineering, with much less attention being paid to molecular biophysics, remarks Abraham M. Lenhoff, professor of chemical engineering at the Univ. of Delaware (Newark). Molecular biophysics deals with molecular structures (*e.g.*, proteins and nucleic acids), assemblies of these structures (*e.g.*, lipid bilayers), and the relationships of these structures to biological and physical function. The latter, in particular, has provided a natural synergy between molecular biophysics and chemical engineering, since chemical engineers need biophysical property data for bioprocess analysis and design, he says.

There are substantial research challenges in integrating biophysics principles and structural information into methods for solving bioprocessing problems using standard chemical engineering approaches, Lenhoff notes. One important area of research is the estimation of physical properties from molecular structure and the use of the results for engineering design. While this approach is commonly used to design, for in-

stance, distillation columns, empiricism remains common in the design of bioprocess systems, he points out, largely because of a lack of suitable methods for estimating physical properties from molecular structure information.

The physical properties of proteins are determined by the properties of individual amino acids and those of the overall folded structure. Some properties, such as size, shape and charge, can be estimated easily by straightforward calculations. However, the nature of intra- and intermolecular interactions in proteins makes estimating other properties, such as solubilities and adsorption characteristics, much more difficult. "The estimation of structure and properties is essential for bringing analysis and design of bioprocesses onto the same footing as that of more conventional chemical processes," he believes.

Lenhoff points out that chemical engineers have contributed much to existing knowledge of metabolic function, and they are well-suited to continue pushing the frontiers of knowledge in this field. Chemical engineers can make similar contributions to understanding biophysical aspects of living systems, as well as manipulating biophysical systems for applications such as materials synthesis.

He discusses the interaction of chemical engineering and molecular biophysics further in the April issue of the *AIChE Journal*.