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Using DNA to Build Nanomaterials

Scientists use complementary strands of synthetic DNA to build functional materials from the bottom up. Future applications include biosensors, optical nano-devices, and new kinds of solar cells.

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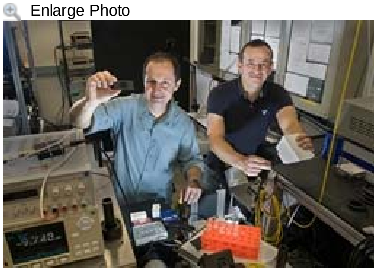

Photo courtesy of Brookhaven National Laboratory

Oleg Gang, left, and Mircea Cotlet at Brookhaven's Center for Functional Nanomaterials.

One central idea in the field of nanoscience is that if you can build things from the bottom up, atom-by-atom or molecule-by-molecule, you can rationally design materials to achieve desired functions. Taking a cue from how nature does this—using genetic code to instruct the construction of proteins and whole organisms from plants to people—scientists have devised a new way to use DNA's specificity in the construction of inanimate nanoscale structures.

The method relies on the attractive forces between the bases A, T, G, and C on complementary strands of DNA. By attaching hair-like extensions of synthetic DNA with specific "recognition sequences" to various nanoparticles, the researchers can get the nanoparticles to link up in solution.

At Brookhaven National Laboratory's Center for Functional Nanomaterials—one of DOE's five Nanoscale Science Research Centers supported by the DOE Office of Science—this work has moved quickly from intriguing concept to functional 3D systems, such as optically tunable materials from metallic and fluorescent nano-components. These and other functional nanomaterials made using DNA-directed self-assembly have enormous potential for the design of materials in a wide range of fields from solar energy conversion to computing and medicine.

"In biology, DNA is mainly an informational material, while in nanoscience, DNA is an excellent structural material due to its natural ability to self-assemble according to well-specified programmable rules," said Oleg Gang, the Brookhaven physicist who leads the research team. "Using biological materials such as DNA, we are developing approaches to control the assembly of inorganic nano-objects. However, in order to really turn this attractive approach into nanotechnology, we have to understand the complexity of interaction in such hybrid systems."

The research started with simple studies: capping synthetic strands of DNA onto individual gold nanoparticles, customized to recognize and bind to complementary DNA located on other particles. This process forms clusters, or aggregates, of gold particles. Later the scientists achieved greater control by also using non-complementary strands, anchoring the assembly on a surface, and incorporating different kinds of particles, for example, silver and light-emitting quantum dots.

"Quantum dots—tiny crystals of semiconductor materials that fluoresce, or emit light, in response to photoexcitation—have enormous potential for use in a wide range of fields from solar energy conversion to computing and medicine," said Mircea Cotlet, a physical chemist at Brookhaven's CFN and lead author on that particular study.

Such types of clusters built from different kinds of nanoparticles allow for building materials with tailored properties by combining two or three different kinds of particles in one cluster. Anchoring the assembly on a surface yields even greater precision, and therefore a more predictable, reproducible high-throughput construction technique for building clusters from nanoparticles.

"When a particle is attached to a support surface, it cannot react with other molecules or particles in the same way as a free-floating particle," Gang explained. This is because the support surface blocks about half of the particle's reactive surface. Attaching a DNA linker or other particle that specifically interacts with the bound particle then allows for the rational assembly of desired particle clusters.

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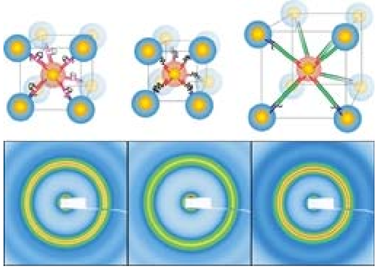

"By controlling the number of DNA linkers and their length, we can regulate interparticle distances and a cluster's architecture," said Gang. "Together with the high specificity of DNA interactions, this surface-anchored technique permits precise assembly of nano-objects into more complex structures."

Fine tuning the technique and borrowing methods used in growing more traditional macroscale crystals, the Brookhaven team was the first to produce stable three-dimensional, ordered, crystalline nanostructures. The ability to engineer such 3-D structures is essential to producing functional materials that take advantage of the unique properties that may exist at the nanoscale—for example, enhanced magnetism, improved catalytic activity, or new optical properties.

The research team's latest advance has been linking individual semiconductor quantum dots with gold nanoparticles to enhance the intensity of light emitted by individual quantum dots by up to 20 times. This research will greatly advance scientists' ability to study and modify the optical properties of quantum dots, and could eventually lead to improved solar energy conversion devices, light-controlled electronics, and biosensors.

Image courtesy of Brookhaven National Laboratory

These illustrations show how a 3-D crystal made from nanoparticles changes between two distinct states via an intermediate structure (top row, middle) when looped (left) versus unlooped (right) double-stranded DNA chains are used to link the particles. The scientists were able to measure the distance between the particles in each structure by recording x-ray scattering patterns (bottom row). Switching from looped to unlooped DNA increased the interparticle distance by about 6 nanometers.

Approaches based on self-assembly offer tremendous cost- advantages and an ease of manufacturing compared to lithographic methods. Self-assembly using biomolecules addresses tasks that are intrinsically challenging for conventional lithography processes, such as creating three-dimensional architectures or structures containing nano-objects of various kinds. Entirely new types of materials can be fabricated using these approaches for revealing emergent functional properties and applications in energy conversion, information processing, and medicine.

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