Small particles, big findings: Maximizing energy gains from tiny nanoparticles

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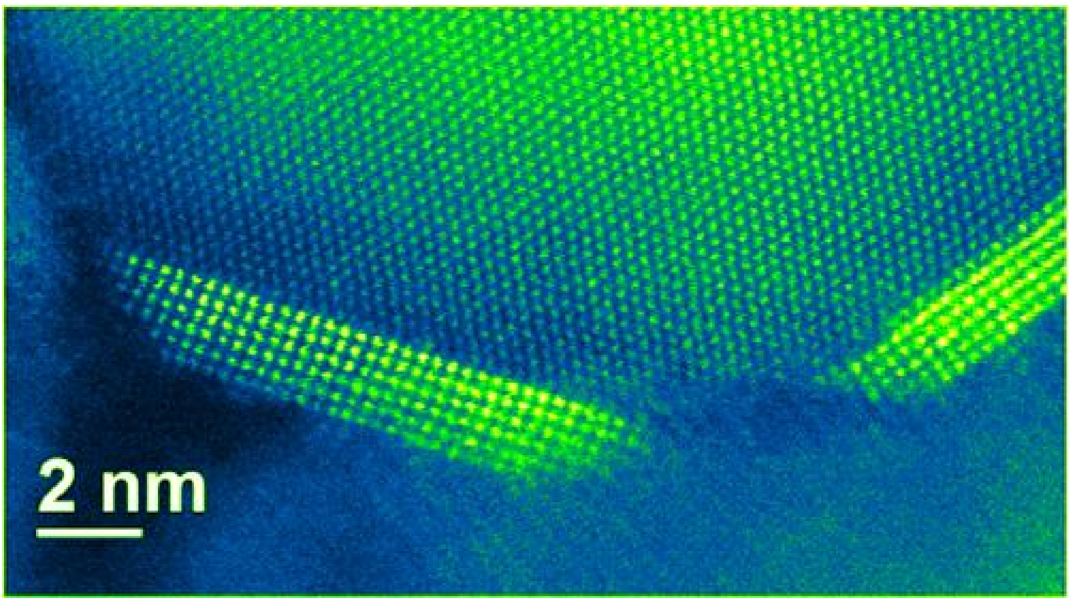

This high-resolution transmission electron micrograph taken at the CFN reveals the arrangement of cerium oxide nanoparticles (bright angular "slashes" at the bottom of the image) supported on a titania substrate (background)‹a combination being explored as a catalyst for splitting water molecules to release hydrogen as fuel and for other energy-transformation reactions.

(Phys.org) —Sometimes big change comes from small beginnings. That's especially true in the research of Anatoly Frenkel, a professor of physics at Yeshiva University, who is working to reinvent the way we use and produce energy by unlocking the potential of some of the world's tiniest structures: nanoparticles.

"The nanoparticle is the smallest unit in most novel materials, and all of its properties are linked in one way or another to its structure," said Frenkel. "If we can understand that connection, we can derive much more information about how it can be used for catalysis, energy, and other purposes."

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Frenkel is collaborating with materials scientist Eric Stach and others at the U.S. Department of Energy's Brookhaven National Laboratory to develop new ways to study how nanoparticles behave in catalysts—the "kick-starters" of chemical reactions that convert fuels to useable forms of energy and transform raw materials to industrial products.

"We are developing a new 'micro-reactor' that enables us to explore many aspects of catalytic function using multiple approaches at Brookhaven's National Synchrotron Light Source (NSLS), the soon-to-be-completed NSLS-II, and the Center for Functional Nanomaterials (CFN)," said Stach, who works at the CFN. "This approach lets us understand multiple aspects of how catalysts work so that we can tweak their design to improve their function. This work could lead to big gains in energy efficiency and cost savings for industrial processes."

High-tech tools for science

Until now, the methods for understanding catalytic properties could only be used one at a time, with the catalyst ending up in a different state for each of the experiments. This made it difficult to compare information obtained using the different instruments. The new micro-reactor will employ multiple techniques—microscopy, spectroscopy, and diffraction—to examine different properties of catalysts simultaneously under operating conditions. By keeping particles in the same structural and dynamic state under the same reaction conditions, the micro-reactor will give scientists a much better sense of how they function.

"These developments have resulted from the combination of unique facilities available at Brookhaven," said Frenkel. "By working closely with Eric, we realized that there was a way to make both x-ray and electron-based methods work in a truly complementary fashion.

Each technique has strengths, Stach explained. "At the NSLS, using powerful beams of x-rays, we can tell how the entire group of nanoparticles behaves, while electron microscopy at the CFN lets us see the atomic structure of each nanoparticle. By having both of these views of the catalysts we can more clearly understand the relationship between catalyst structure and function."

Said Frenkel, "It was very satisfying for us to conduct the first tests with the reactor at each facility and receive positive results. I am particularly grateful to Ryan Tappero, the scientist who runs NSLS beamline X27A, for his expert help with x-ray data acquisition."

Frenkel has had an ongoing collaboration with scientists at Brookhaven. Last year, with post-doctoral research associate Qi Wang, Frenkel and Stach measured properties of nanoparticles using the x-rays produced by the NSLS as well as atomic-scale imaging with electrons at the CFN. As reported in a paper published in the *Journal of the American Chemical Society* earlier this year, they discovered that rather than changing completely from one state to another at a certain temperature and size, as had been previously believed, there is a transition zone between states when particles are changing forms.

"This is of significance fundamentally because until now, the structures were known to merely change from one form to another—they were never envisioned to coexist in different forms," Frenkel said. "With our information we can explain why catalysts often don't work as expected and how to improve them."

Training for young scientists

The collaboration also offers opportunities for students to experience the challenges of research, giving them access to the world-class tools at Brookhaven. Frenkel's undergraduate students at Yeshiva University's Stern College for Women help with measurements, data analysis, and interpretation, and many have already accompanied him to Brookhaven to assist in his work using NSLS and other cutting-edge instruments.

"I'm giving them firsthand experience about what a researcher's life is like early on as they conduct first-rate research," said Frenkel. "This experience opens doors to any field they want to be in."

Alyssa Lerner, a pre-engineering major who has been working with Frenkel at Brookhaven, said the research "has helped me develop skills like computational analysis and critical thinking, which are essential in any scientific field. The hands-on experimental experience has given me a better understanding of how the scientific community operates, helping me make more informed career-related choices as I continue to advance my education."

Pairing up students and mentors to advance education and making use of complementary imaging techniques to enhance energy efficiency—just two of the positive outcomes of this successful collaboration.

"By bringing together multiple complementary techniques to illuminate the same process we're going to understand how nanomaterials work," Frenkel said. "Ultimately, this research will create a better way of using, storing, and converting energy."

More information: Long Li, Lin-Lin Wang, Duane D. Johnson, Zhongfan Zhang, Sergio I. Sanchez, Joo H. Kang, Ralph G. Nuzzo, Qi Wang, Anatoly I. Frenkel, Jie Li, James Ciston, Eric A. Stach, Judith C. Yang, "Noncrystalline-to-Crystalline Transformations in Pt Nanoparticles." *J. Am. Chem. Soc.*, 2013, 135 (35), pp 13062–13072 DOI: 10.1021/ja405497p . Publication Date (Web): July 19, 2013

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