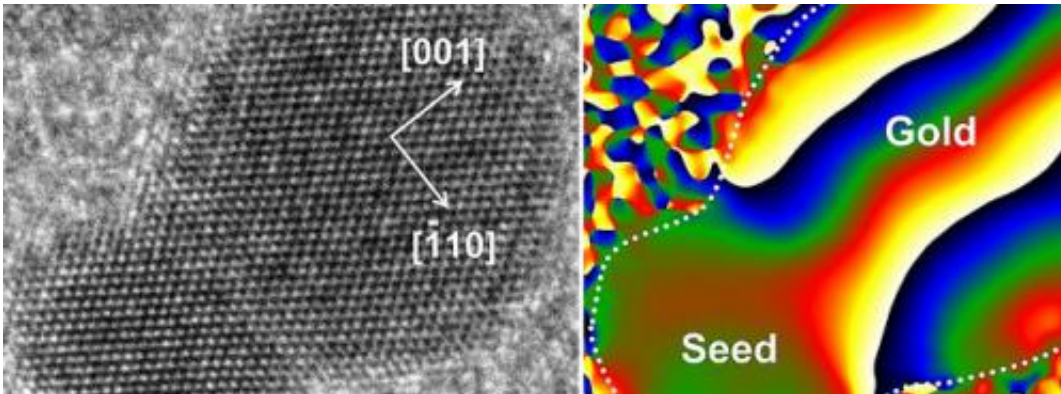


Atomic 'mismatch' creates nano 'dumbbells'

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This picture combines a transmission electron microscope image of a nanodumbbell with a gold domain oriented in direction. The seed and gold domains in the dumbbell in the image on the right are identified by geometric phase analysis. Credit: Soon Gu Kwon

Like snowflakes, nanoparticles come in a wide variety of shapes and sizes. The geometry of a nanoparticle is often as influential as its chemical makeup in determining how it behaves, from its catalytic properties to its potential as a semiconductor component.

Thanks to a new study from the U.S. Department of Energy's (DOE) Argonne National Laboratory, researchers are closer to understanding the process by which nanoparticles made of more than one material – called heterostructured nanoparticles – form. This process, known as heterogeneous nucleation, is the same mechanism by which beads of condensation form on a windowpane.

Heterostructured nanoparticles can be used as catalysts and in advanced energy conversion and storage systems. Typically, these nanoparticles are created from tiny "seeds" of one material, on top of which another material is grown. In this study, the Argonne researchers noticed that the differences in the atomic arrangements of the two materials have a big impact on the shape of the resulting nanoparticle.

"Before we started this experiment, it wasn't entirely clear what's happening at the interface when one material grows on another," said nanoscientist Elena Shevchenko of Argonne Center for Nanoscale Materials, a DOE Office of Science user facility.

In this study, the researchers observed the formation of a nanoparticle consisting of platinum and gold. The researchers started with a platinum seed and grew gold around it. Initially, the gold covered the platinum seed's surface uniformly, creating a type of nanoparticle known as "core-shell." However, as more gold was deposited, it started to grow unevenly, creating a dumbbell-like structure.

Thanks to state-of-the-art X-ray analysis provided by Argonne's Advanced Photon Source (APS), a DOE Office of Science user facility, the researchers identified the cause of the dumbbell formation as "lattice mismatch," in which the spacing between the atoms in the two materials doesn't align.

"Essentially, you can think of lattice mismatch as having a row of smaller boxes on the bottom layer and larger boxes on the top layer. When you try to fit the larger boxes into the space for a smaller box, it creates an immense strain," said Argonne physicist Byeongdu Lee.

While the lattice mismatch is only fractions of a nanometer, the effect accumulates as layer after layer of gold forms on the platinum. The mismatch can be handled by the first two layers of gold atoms – creating

the core-shell effect – but afterwards it proves too much to overcome. "The arrangement of atoms is the same in the two materials, but the distance between atoms is different," said Argonne postdoctoral researcher Soon Gu Kwon. "Eventually, this becomes unstable, and the growth of the gold becomes unevenly distributed."

As the [gold](#) continues to accumulate on one side of the seed nanoparticle, small quantities "slide" down the side of the nanoparticle like grains of sand rolling down the side of a sand hill, creating the dumbbell shape.

The advantage of the Argonne study comes from the researchers' ability to perform in situ observations of the material in realistic conditions using the APS. "This is the first time anyone has been able to study the kinetics of this heterogeneous nucleation process of nanoparticles in real-time under realistic conditions," said Argonne physicist Byeongdu Lee. "The combination of two X-ray techniques gave us the ability to observe the material at both the atomic level and the nanoscale, which gave us a good view of how the [nanoparticles](#) form and transform." All conclusions made based on the X-ray studies were further confirmed using atomic-resolution microscopy in the group of Professor Robert Klie of the University of Illinois at Chicago.

This analysis of nanoparticle formation will help to lay the groundwork for the formation of new materials with different and controllable properties, according to Shevchenko. "In order to design materials, you have to understand how these processes happen at a very basic level," she said.

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An article based on the research, "Heterogeneous nucleation and shape

transformation of multicomponent metallic nanostructures," appeared in the Nov. 2 online issue of *Nature Materials*.

More information: "Heterogeneous nucleation and shape transformation of multicomponent metallic nanostructures." *Nature Materials* (2014) [DOI: 10.1038/nmat4115](https://doi.org/10.1038/nmat4115)

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