Breakthrough in nanotechnology imaging under extremely high pressures

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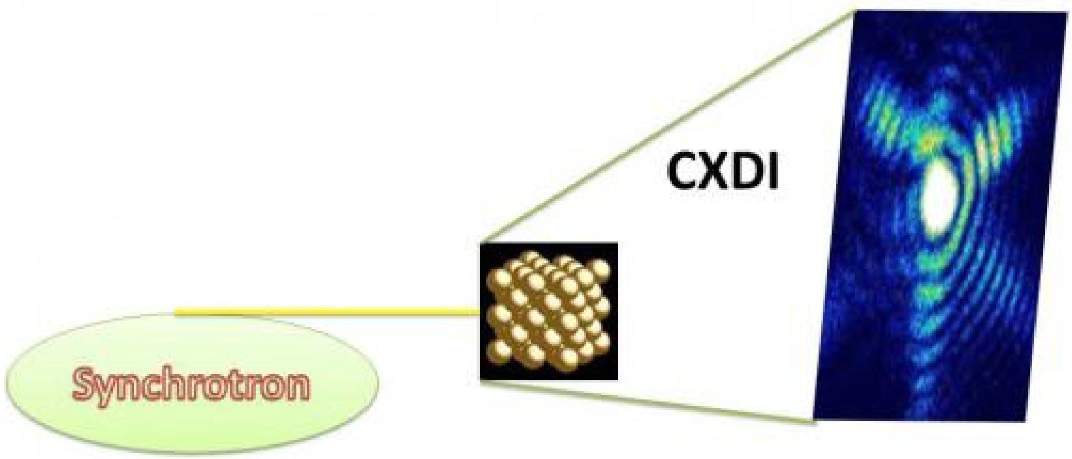

Highly coherent X-rays from synchrotron sources can be used for imaging nanomaterials in 3-D at tens of nanometer of spatial resolution. This image shows a monochromatic hard X-rays patterns from a single crystal gold particle, which produces a speckle-like fringe image. Inverting such "diffraction images" under certain conditions can result in a high-resolution distribution of the electron density (amplitude) and strain of the lattice structure (phase shift). Credit: Wenge Yang

A team of researchers has made a major breakthrough in measuring the structure of nanomaterials under extremely high pressures. For the first time, they developed a way to get around the severe distortions of high-energy X-ray beams that are used to image the structure of a gold nanocrystal. The technique, described in April 9, 2013, issue of *Nature Communications*, could lead to advancements of new nanomaterials created under high pressures and a greater understanding of what is happening in planetary interiors.

Lead author of the study, Wenge Yang of the Carnegie Institution's High Pressure Synergetic Consortium explained: "The only way to see what happens to such samples when under pressure is to use high-energy X-rays produced by synchrotron sources. Synchrotrons can provide highly coherent X-rays for advanced 3-D imaging with tens of nanometers of resolution. This is different from incoherent X-ray imaging used for medical examination that has micron spatial resolution. The high pressures fundamentally change many properties of the material."

The team found that by averaging the patterns of the bent waves—the diffraction patterns—of the same crystal using different sample alignments in the instrumentation, and by using an algorithm developed by researchers at the London Centre for Nanotechnology, they can compensate for the distortion and improve spatial resolution by two orders of magnitude.

"The wave distortion problem is analogous to prescribing eyeglasses for the diamond anvil cell to correct the vision of the coherent X-ray imaging system," remarked Ian Robinson, leader of the London team.

The researchers subjected a 400-nanometer (.000015 inch) single crystal of gold to pressures from about 8,000 times the pressure at sea level to 64,000 times that pressure, which is about the pressure in Earth's upper mantle, the layer between the outer core and crust.

The team conducted the imaging experiment at the Advanced Photon Source, Argonne National Laboratory. They compressed the gold nanocrystal and found at first, as expected, that the edges of the crystal become sharp and strained. But to their complete surprise, the strains disappeared upon further compression. The crystal developed a more rounded shape at the highest pressure, implying an unusual plastic-like flow.

"Nanogold particles are very useful materials," remarked Yang. "They are about 60% stiffer compared with other micron–sized particles and could prove pivotal for constructing improved molecular electrodes, nanoscale coatings, and other advanced engineering materials. The new technique will be critical for advances in these areas."

"Now that the distortion problem has been solved, the whole field of nanocrystal structures under pressure can be accessed," said Robinson. "The scientific mystery of why nanocrystals under pressure are somehow up to 60% stronger than bulk material may soon be unraveled."

Provided by Carnegie Institution for Science

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