Z-contrast microscope first to resolve, identify individual light atoms

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(PhysOrg.com) -- Using the latest in aberration-corrected electron microscopy, researchers at the Department of Energy's Oak Ridge National Laboratory and their colleagues have obtained the first images that distinguish individual light atoms such as boron, carbon, nitrogen and oxygen.

The ORNL images were obtained with a Z-contrast scanning transmission electron microscope (STEM). Individual atoms of carbon, boron, nitrogen and oxygen--all of which have low atomic numbers--were resolved on a single-layer boron nitride sample.

"This research marks the first instance in which every atom in a significant part of a non-periodic material has been imaged and chemically identified," said Materials Science and Technology Division researcher Stephen Pennycook. "It represents another accomplishment of the combined technologies of Z-contract STEM and aberration correction."

Pennycook and ORNL colleague Matthew Chisholm were joined by a team that includes Sokrates Pantelides, Mark Oxley and Timothy Pennycook of Vanderbilt University and ORNL; Valeria Nicolosi at United Kingdom's Oxford University; and Ondrej Krivanek, George Corbin, Niklas Dellby, Matt Murfitt, Chris Own and Zotlan Szilagyi of Nion Company, which designed and built the microscope. The team's Z-contrast STEM analysis is described in an article published today in the journal *Nature*.

The new high-resolution imaging technique enables materials researchers to analyze, atom by atom, the molecular structure of experimental materials and discern structural defects in those materials. Defects introduced into a material--for example, the placement of an impurity atom or molecule in the material's structure--are often responsible for the material's properties.

The group analyzed a monolayer hexagonal boron nitride sample prepared at Oxford University and was able to find and identify three types of atomic substitutions--carbon atoms substituting for boron, carbon substituting for nitrogen and oxygen substituting for nitrogen. Boron, carbon, nitrogen and oxygen have atomic numbers--or Z values--of five, six, seven and eight, respectively.

The annular dark field analysis experiments were performed on a 100-kilovolt Nion UltraSTEM microscope optimized for low-voltage operation at 60 kilovolts.

Aberration correction, in which distortions and artifacts caused by lens imperfections and environmental effects are computationally filtered and corrected, was conceived decades ago but only relatively recently made possible by advances in computing. Aided by the technology, ORNL's Electron Microscopy group set a resolution record in 2004 with the laboratory's 300-kilovolt STEM.

The recent advance comes at a much lower voltage, for a reason.

"Operating at 60 kilovolts allows us to avoid atom-displacement damage to the sample, which is encountered with low Z-value atoms above about 80 kilovolts," Pennycook said. "You could not perform this experiment with a 300-kilovolt STEM."

Armed with the high-resolution images, materials, chemical and nanoscience researchers and theorists can design more accurate computational simulations to predict the behavior of advanced materials, which are key to meeting research challenges that include energy storage and energy efficient technologies.

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