ORNL mirrors powerful tools for studying micro-, nano-materials

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Precision mirrors to focus X-rays and neutron beams could speed the path to new materials and perhaps help explain why computers, cell phones and satellites go on the blink.

In the last few years, a team led by Gene Ice of the Department of Energy's Oak Ridge National Laboratory has improved by a factor of nearly 10 the performance of mirrors that enable researchers to examine variations in structure and chemistry and even individual nanoparticles. Information at this fine level is essential to understanding composition and structure of materials, and researchers continue to push the boundaries.

"There's a worldwide race to develop high-performance mirrors that will dramatically expand the capabilities of major science facilities like the Advanced Photon Source and the Spallation Neutron Source," said Ice, a member of ORNL's Metals & Ceramics Division. "We are now able to see in far greater detail the three-dimensional heterogeneous - or dissimilar -- structure of materials and study internal interactions of one nanoparticle next to another."

The stage was set a few years ago when Ice and colleagues developed differentially deposited X-ray micro-focusing mirrors. When installed on a beam line at the Advanced Photon Source at Argonne National Laboratory, these mirrors allowed researchers to obtain a resolution of 500 nanometers. One nanometer is equivalent to about three atoms in width. With recent advances in the optics and manufacturing processes, the ORNL team and collaborators at Argonne have now obtained a resolution of 70 nanometers. The ultimate goal is 1 nanometer.

The advantage of using mirrors instead of other techniques is that their focal properties are nearly independent of X-ray or neutron wavelengths. This allows them to be used to perform experiments that could not be done with other methods.

Neutron beams and X-rays both provide non-destructive testing of small samples of materials and allow scientists to examine grain boundary stresses, crystalline structure and orientation of the grains that make up material. Neutron beams probe deeper into a material and are especially useful for studying magnetic materials and structures with low atomic numbers -- hydrogen, helium and carbon -- while X-rays can examine individual nanoparticles.

The X-ray mirrors, which are similar to ones that received an R&D 100 award in 2000, are about 20 millimeters long, or about the size of a quarter. One mirror of the two-mirror system was fabricated using a differential polishing method while the other was made by profile coating an ultra-flat substrate. Both techniques produce monolithic optics more stable and more compact than is possible with dynamically bent mirror optics.

Neutron mirrors are much bigger -- about 800 millimeters (31.5 inches) long -- and increase the effectiveness of small neutron beams by a factor of about 100. Fabrication methods for neutron mirrors are further along than those for X-ray mirrors, which Ice describes as a work in progress. In both cases, precision is critical. The surface profile of an X-ray mirror must be within 1/10th of a micro-radian, which, to put into perspective, is equivalent to a deviation of just 6/1,000ths of an inch over a mile, Ice said.

This research addresses a number of goals of DOE's Office of Basic Energy Sciences, which seeks a better understanding of three-dimension grain growth, deformation of polycrystals and cracks at the so-called mesoscale - materials between 1/10th of a micron to hundreds of microns. With this knowledge, researchers hope to answer questions about electrical migration in interconnects within integrated circuits. Failures at this level lead to problems with electronic equipment in everything from automobiles to satellites.

This research has attracted considerable attention from NASA and several potential industry partners, including Ford Motor Corp. and General Electric, according to Ice, who describes the response as "overwhelming."

Other ORNL researchers involved in the project are Ben Larson, John Budai and John Tischler of the Condensed Matter Sciences Division and Eliot Specht and Judy Pang of the Metals & Ceramics Division.

Source: Oak Ridge National Laboratory