Multilayer Laue lenses enable studies of nanostructures with ultra-high resolution

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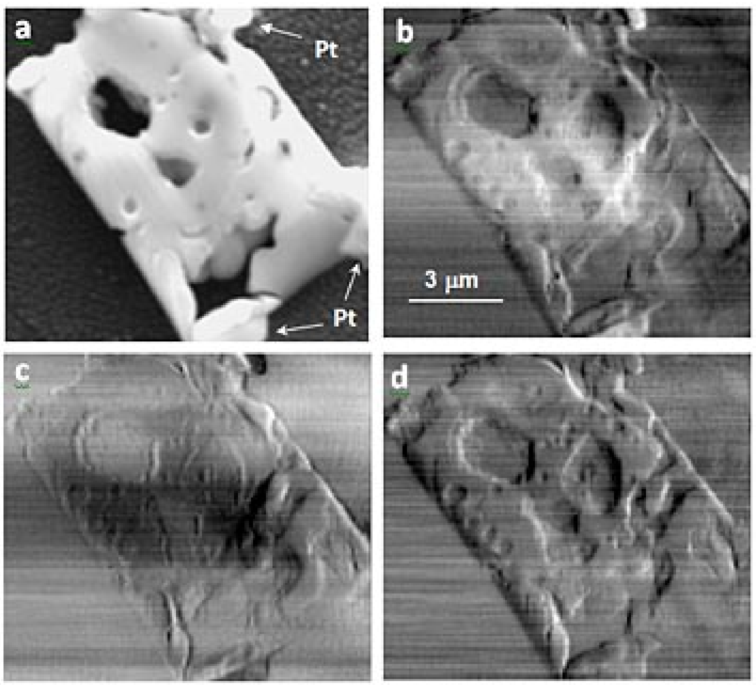

(a) Scanning electron microscope (SEM) image of the solid oxide fuel cell (SOFC) specimen adhered on a Si3Ni4 window with Pt welding. (b-d) are horizontal phase-gradient scanning x-ray microscope images obtained by differential intensity, moment analysis and Fourier-shift fitting algorithms, respectively. Artifacts and blurring effects can be seen in (b) and (c), as compared to (d).

(Phys.org) —Microscopes have been a centerpiece of experimental science since at least the 16th century, providing a window into the material world at extraordinarily small scales. As the structures examined decrease in size – some measuring just billionths of a meter – capturing an x-ray image at high spatial resolution while retaining sufficient imaging contrast becomes more difficult.

One method of addressing this challenge is scanning x-ray microscopy, which uses a highly focused x-ray beam to produce spatial images of a specimen. In keeping with the scientific mission of Brookhaven National Laboratory's National Synchrotron Light Source II (NSLS-II), an advanced nanofocusing optic dubbed multilayer Laue lens (MLL) is being developed by the optics fabrication group for nanoscale imaging. The development has progressed to a prototype MLL microscope (see 2011 publication in *Optics Express* 19, 15069-15076).

For nanostructures that absorb x-rays very slightly, however, viewing them via absorption contrast becomes infeasible. Although the phase contrast provides a good way to study such a transparent object, historically researchers have found it difficult, if not impossible, to obtain accurate phase information of an object using x-rays because a detector only measures intensity. In scanning x-ray microscopy, previous attempts have been made to obtain quantitative phase information of a specimen, but none has worked well with MLLs, sacrificing the high-resolution power they provide for phase imaging.

As a result of years of groundbreaking research, a team of researchers in the Hard X-ray Nanoprobe (HXN) group at NSLS-II has solved this problem, together with their collaborators from Argonne National Laboratory, University of Connecticut and Chosun University in Korea. This research is detailed in a paper published in Nature's *Scientific Reports*, February 19, 2013.

Brookhaven physicist Hanfei Yan, the paper's lead author, and his collaborators describe a new mathematical algorithm that clarifies, or "fits", the optical patterns that emerge from the scanning x-ray microscope, producing a quantitative phase image with far fewer artifacts and less blurring than existing methods. This novel technique pairs scanning x-ray microscopy with MLLs, fully exploiting its ultra-high resolution imaging capability for studies on nanostructures. When applied in a state-of-the-art light source like NSLS-II, a facility that will produce the brightest x-ray beams in the world, the nanofocusing power of MLLs will enable the study of nanostructures as small as 10 nm with an unprecedented level of precision.

The technique is so-called differential phase contrast imaging. Just as a beam of light "bends" when refracted by a prism, an x-ray beam can "bend" when refracted by a specimen. The characteristics of the specimen are then encoded in the emerging far field pattern, and by analyzing this pattern researchers are able to construct a quantitative phase image.

"Quantitative phase imaging at the nanoscale will enable us to examine the structural, compositional and possibly chemical state change of a specimen for which conventional contrast mechanism such as absorption and fluorescence imaging may not work," said Yan.

To verify the validity of this method, a solid oxide fuel cell (SOFC) anode sample composed of nickel and Yttria-stabilized zirconia cermet, a composite material made of ceramic and metallic elements, was investigated. When compared to images produced by conventional phase-imaging techniques, the superior image contrast of the method using an MLL microscope with a "fitting" algorithm is evident (see figure).

"The high sensitivity of the phase to structural and compositional variations makes this technique extremely powerful in correlating the electrode performance in SOFC," said Wilson Chu, a professor at University of Connecticut.

Currently, a next-generation MLL microscope with below 1-nm stability is under development, led by Evgeny Nazaretski, a co-author of the paper, and will be used as the workhorse at HXN beamline. "At NSLS-II, we will explore the full power of the MLL microscope and provide users not only a tool with high resolution, but also with new imaging capabilities," said Yong Chu, another co-author of the paper and also group leader of the HXN beamline.

Yan and his collaborators conducted the experiment at 26-ID of Advanced Photon Source at Argonne Lab, using a monochromatic x-ray beam with photon energy of 12 keV focused by a pair of multilayer Laue lenses placed orthogonally with respect to each other.

More information: Summary Slide (pdf)

Provided by Brookhaven National Laboratory