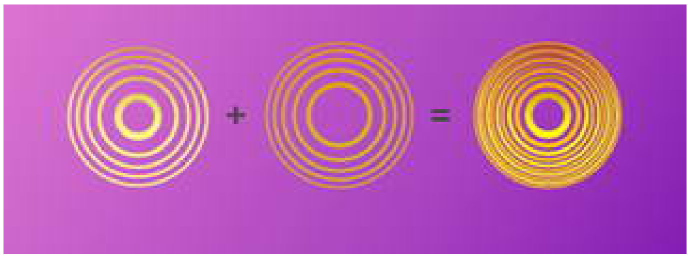
# A Sharper Focus for Soft X-rays

June 30 2005



***Zone Plate Lenses Capable of Better than 15-Nanometer Resolution***

Progress in nanoscience and nanotechnology depends not only on examining the surfaces of things but on seeing deep inside biological organisms and material structures to identify what they're made of — and what electronic, magnetic, optical, and chemical processes may be in play.

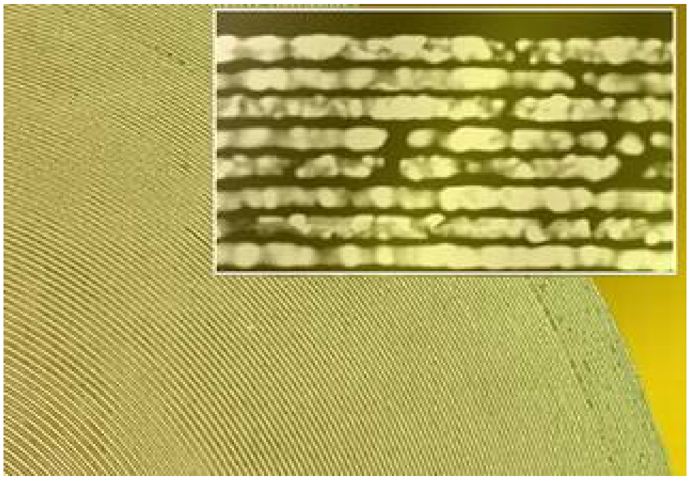
*Image: The Center for X-Ray Optics' new technique for creating high-resolution zone plates involves two separate patterns of alternating zones fabricated sequentially and overlaid on the same wafer.*

For measuring internal variations in shape, organization, magnetism, polarization, or chemical make-up over distances of a few nanometers (billionths of a meter), x-ray microscopy not only complements electron microscopy but also offers important advantages. The XM-1 x-ray microscope at the Advanced Light Source, located at the Department of Energy's Lawrence Berkeley National Laboratory, uses bright beams of "soft" x-rays to produce images that not only reveal structures but can identify their chemical elements and measure their electromagnetic and other properties as well.

Now a new method for creating optical devices with nanoscale accuracy has allowed researchers in Berkeley Lab's Center for X-Ray Optics (CXRO), which built and operates the XM-1, to achieve an extraordinary resolution of better than 15 nanometers, with the promise of even higher resolution in the near future. CXRO's Weilun Chao, Bruce Harteneck, Alexander Liddle, Erik Anderson, and David Attwood describe their achievement in a letter to Nature, June 30, 2005.

"Our new technique permits fabrication of remarkably small three-dimensional structures," says Weilun Chao of Berkeley Lab's Materials Sciences Division, who helped develop the technique as part of his recent doctoral thesis in the Electrical Engineering and Computer Sciences Department at the University of California at Berkeley. "We believe this is a breakthrough in the difficult process of fabricating small structures by means of electron beam lithography."

Since x-rays can't be focused by glass lenses, the XM-1 uses lenses made of zone plates, disks of concentric rings of metal from which soft x-rays are diffracted to a focus. An objective lens called a "micro" zone plate (MZP) projects a full-field image of the sample — whether the interior of frozen bacteria or layers of a magnetic alloy — onto a charge-coupled device. The smaller the gap between the MZP's rings, the tighter the focus, and the higher the resolution of the image.



With the new technique the zones were spaced approximately 15 nanometers apart (30 nanometers between the centers of each gold zone). Future improvements will be directed at narrower zones with no gaps and even closer spacing.

CXRO fabricates its own zone plates with an electron-beam lithography tool called the Nanowriter. An energetic beam of electrons just 7 nanometers wide carves preprogrammed patterns in a silicon wafer coated with a resist. The carved-out circular patterns in the resist are then replaced with opaque gold to form an object that under magnification superficially resembles a long-playing gold record album — but one only 30 micrometers (millionths of a meter) in diameter.

To achieve high resolution depends on the ability to squeeze the zones close together, with a placement accuracy no less than one-third the width of the zones themselves. Accurate placement of 15-nanometer-wide zones allows no more than 5-nanometer leeway. In fact the Nanowriter is capable of placement accuracy to within 2 nanometers, allowing for even greater improvements in resolution in the future.

Unfortunately, no matter how accurately it is aimed, even a tight beam of electrons spreads out when it hits the resist. Electron scattering, combined with inherent limits in the resolution of the resist itself, makes it impossible at this time to maintain high contrast and optical separation between features. Previously the best separation between zones the Nanowriter could achieve to make the XM-1's current objective lens was 25 nanometers.

To overcome this limit, the CXRO researchers decided to overlay and combine two different zone-plate patterns. Opaque zones are typically given even numbers, so in this scheme the first pattern contains zones 2, 6, 10, 14, and so on, and the second contains zones 4, 8, 12, 16, and so on. The first pattern is carved into the resist-coated wafer; then the zones formed by the electron patterning are filled with gold. The wafer is coated with resist again to make the second pattern.

When combined, the critical outer zones of the combined patterns were less than 15 nanometers apart, accurately placed to within less than 2 nanometers. Aligning the separately processed patterns was the key to success. Accuracy was achieved with software that calculated the deflection and distortion of the Nanowriter's beam as it traced out the concentric circular patterns.

The placement of the zones in the first MZP made with this technique was nearly perfect, although there was room for improvement in other areas. The opaque gold zones were broken by tiny gaps, and they were wider (and the transparent zones between them narrower) than they should have been, reducing the zone plate's efficiency. Nevertheless, the experimental MZP was used to obtain images sharper than any previously achieved with an x-ray microscope.

Not only were images of test patterns (lines formed by layers of chromium and silicon in cross-section) sharper than those made with the XM-1's current 25-nanometer-resolution MZP, the new MZP was able to obtain sharp images of lines a mere 15 nanometers apart — where the older zone plate had seen only a featureless field of gray.

"Nanoscience and nanotechnology are everywhere around us — biology and chemistry are nanoscience by nature — but we need better analytical tools to see what we're looking at," says David Attwood of the Materials Sciences Division, founder and former director of the Center for X-Ray Optics and a professor of electrical engineering at UC Berkeley. "Electron microscopy, scanning-tunneling microscopes, atomic-force microscopes — they're all good, but they can't give you identification of chemical elements and compounds. The great advantage of photons is that there are very specific differences in their interactions with atoms: you can tell when you're looking at iron; you know when you're looking at cobalt."

Because they need bright beams of photons, x-ray microscopes are presently found only at synchrotrons like those in the United States that are sponsored by the Department of Energy. In their letter to Nature, however, the CXRO researchers suggest that before too many years new sources of very bright, soft x-rays — for example, from compact, laser-based x-ray sources — will make it possible to build x-ray microscopes that will fit on the bench top. Nanoscience and nanotechnology will be both the beneficiaries and the driving forces behind the widening horizon for nanoscale analysis, which has been opened by the new techniques in soft-x-ray optics.

"Soft x-ray microscopy at a spatial resolution better than 15nm," by Weilun Chao, Bruce D. Harteneck, J. Alexander Liddle, Erik H. Anderson, and David T. Attwood, appears in the 30 June 2005 issue of *Nature*.

**Link**: More on the XM-1 Microscope and the Center for X-Ray Optics

Source: Berkeley Lab