Like superman's X-Ray vision, new microscope reveals nanoscale details

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Physicists at UC San Diego have developed a new kind of X-ray microscope that can penetrate deep within materials like Superman's fabled X-ray vision and see minute details at the scale of a single nanometer, or one billionth of a meter.

But that's not all. What's unusual about this new, nanoscale, X-ray microscope is that the images are not produced by a lens, but by means of a powerful computer program.

The scientists report in a paper published in this week's early online edition of the Proceedings of the National Academy of Sciences that this computer program, or algorithm, is able to convert the diffraction patterns produced by the X-rays bouncing off the nanoscale structures into resolvable images.

"The mathematics behind this is somewhat complicated," said Oleg Shpyrko, an assistant professor of physics at UC San Diego who headed the research team. "But what we did is to show that for the first time that we can image magnetic domains with nanometer precision. In other words, we can see magnetic structure at the nanoscale level without using any lenses."

One immediate application of this lens-less X-ray microscope is the development of smaller, data storage devices for computers that can hold more memory.

"This will aid research in hard disk drives where the magnetic bits of data on the surface of the disk are currently only 15 nanometers in size," said Eric Fullerton, a co-author of the paper and director of UC San Diego's Center for Magnetic Recording Research. "This new ability to directly image the bits will be invaluable as we push to store even more data in the future."

The development should be also immediately applicable to other areas of nanoscience and nanotechnology.

"To advance nanoscience and nanotechnology, we have to be able to understand how materials behave at the nanoscale," said Shpyrko. "We want to be able to make materials in a controlled fashion to build magnetic devices for data storage or, in biology or chemistry, to be able to manipulate matter at nanoscale. And in order to do that we have to be able to see at nanoscale. This technique allows you to do that. It allows you to look into materials with X-rays and see details at the nanoscale."

"Because there is no lens in the way, putting a bulky magnet around the sample or adding equipment to change the sample environment in some other way during the measurement is much easier with this method than if we had to use a lens," Shpyrko added.

Ashish Tripathi, a graduate student in Shpyrko's lab, developed the algorithm that served as the X-ray microscope's lens. It worked, in principle, somewhat like the computer program that sharpened the Hubble Space Telescope's initially blurred images, which was caused by a spherical aberration in the telescope's mirror before the telescope was repaired in space. A similar concept is employed by astronomers working in ground-based telescopes who use adaptive optics, movable mirrors controlled by computers, to take out the distortions in their images from the twinkling star light moving through the atmosphere.

But the technique Tripathi developed was entirely new. "There was a lot of simulation involved in the development; it was a lot of work," said Shpyrko.

To test their microscope's ability to penetrate and resolve details at the nanoscale, the physicists made a layered film composed of the elements gadolinium and iron. Such films are now being studied in the information technology industry to develop higher capacity, smaller, and faster computer memory and disk drives.

"Both are magnetic materials and if you combine them in a structure it turns out they spontaneously form nanoscale magnetic domains," Shpyrko. "They actually self assemble into magnetic stripes."

Under the X-ray microscope, the layered gadolinium and iron film looks something like baklava dessert that crinkles up magnetically to form a series of magnetic domains, which appear like the repeating swirls of the ridges in fingerprints. Being able to resolve those domains at the nanoscale for the first time is critically important for computer engineers seeking to cram more data into smaller and smaller hard drives.

As materials are made with smaller and smaller magnetic domains, or thinner and thinner fingerprint patterns, more data can be stored in a smaller space within a material. "The way we're able to do that is to shrink the size of the magnetic bits," Shpyrko said.

The technique should find many other uses outside computer engineering as well.

"By tuning the X-ray energy, we can also use the technique to look at different elements within materials, which is very important in chemistry," he added. "In biology, it can be used to image viruses, cells and different kinds of tissues with a spatial resolution that is better than resolution available using visible light."

The scientists used the Advanced Photon Source, the most brilliant source of coherent X-rays in the Western Hemisphere, at the University of Chicago's Argonne National Laboratory near Chicago to conduct their research project, which was funded by the U.S. Department of Energy. In addition to Tripathi, Shpyrko and Fullerton, a professor of electrical and computer engineering at UC San Diego, other co-authors of the paper include UC San Diego physics graduate students Jyoti Mohanty, Sebastian Dietze and Erik Shipton as well as physicists Ian McNulty and SangSoo Kim at Argonne National Laboratory.

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