a consulting professor in materials science and engineering at Stanford and an adjunct professor of applied science at the University of California—Davis. Wadsworth is the co-author of over 230 scientific papers, one book, and four patents. He is the recipient of several awards and has served on numerous academic, industrial, professional, and government councils and committees.

## X-Ray Images of Lanthanum Iron Oxide Reveal Alignment of Nanocrystalline Magnetic Domains

Researchers at the Advanced Light Source (ALS), an x-ray spectromicroscopy facility located at Lawrence Berkeley National Laboratory, have produced images that reveal that the alignment of tiny magnetic domains in lanthanum iron oxide, each only a few hundred nanometers in size, corresponds to a particular orientation of the material's crystals.

Andreas Scholl, a member of the Experimental Systems Group at ALS, led by Howard Padmore, said, "A modern read head uses layers of very thin films with different magnetic properties. As the head passes over the hard disk, these layers sense the orientation of the domains on the disk and cause the head's electrical resistance to change in response."

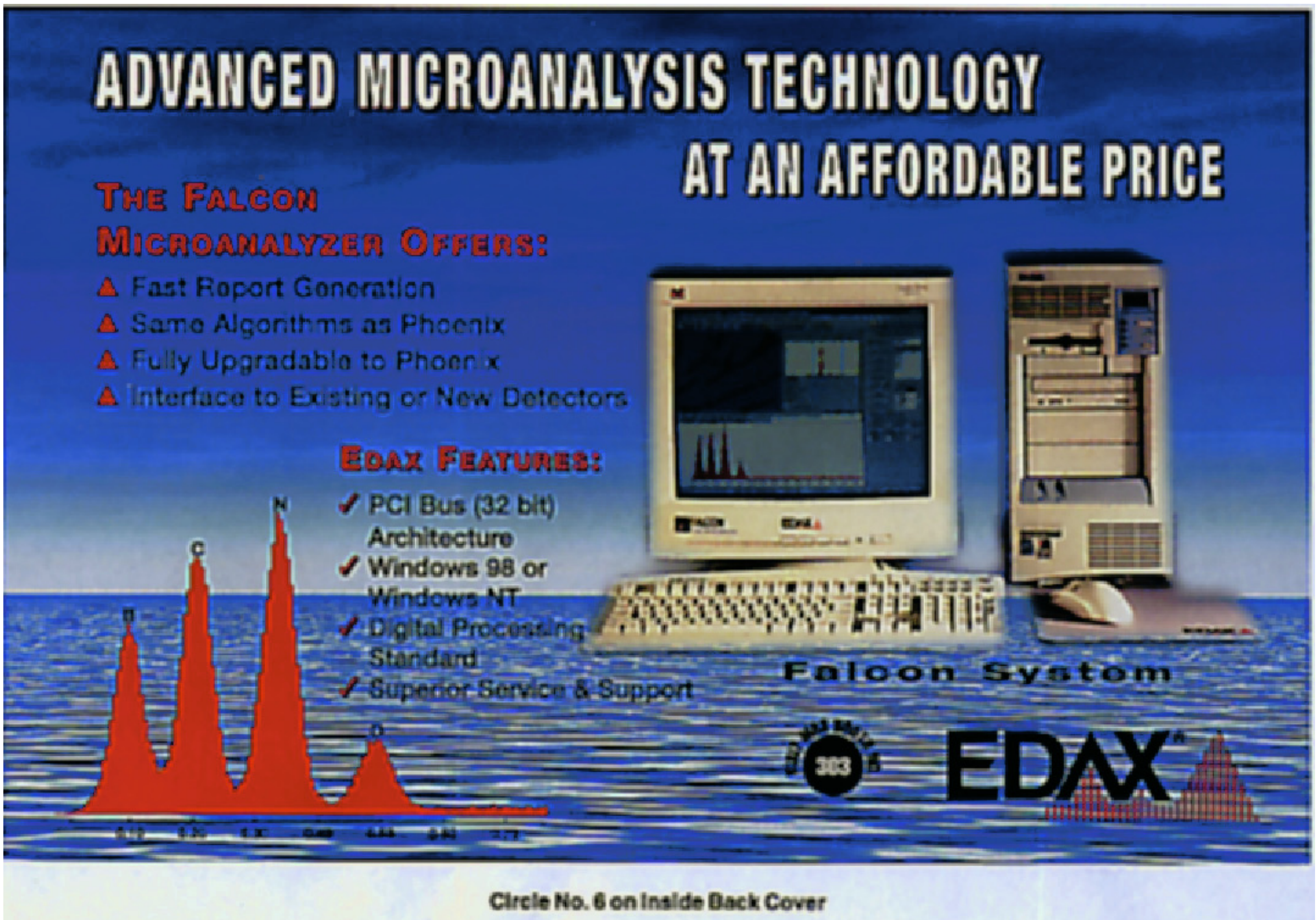
Scholl said that when the head's ferromagnetic layers share the same magnetic orientation, there is less electrical resistance than when they are magnetically opposed. In order for one layer to switch independently of another, however, one must be "pinned" by an underlying antiferromagnetic layer, which is insensitive to applied magnetic fields.

There are many different materials with ferromagnetic and antiferromagnetic properties, but read heads are constructed from these on a trial-and-error basis," said Joachim Stöhr of IBM Almaden Research Center in San Jose. "Nobody really knows the mechanism that couples the ferromagnet to the antiferromagnet."

As reported in the February 11 issue of *Science*, the researchers used molecular-beam epitaxy to deposit single layers of lanthanum oxide and iron oxide one after the other to build up the compound. They gradually heated the samples in the PEEM2 microscope to ensure that the images were due to magnetism and another feature of the thin film. The Néel temperature (like the Curie temperature of other magnetic materials) is the temperature at which antiferromagnetic materials lose magnetism. When the thin-film sample was heated, image contrast vanished and returned again as the sample cooled. However, whereas in bulk the Néel temperature of lanthanum iron oxide is 740 K, in the sample it was 670 K.

Jin Won Seo of the University of Neuchâtel said, "We think that what lowers the Néel temperature of our lanthanum iron oxide sample is structural deformation. It's a film only 40 nm thick, laid on a substrate of strontium titanium oxide. When an epitaxial thin film of one material is laid onto a substrate of a different material, it's almost impossible to get the two crystal lattices to match perfectly, and atoms get pushed out of place, which modifies magnetic properties."

Seo compared the images of magnetic domains with her transmission electron micrographs of the same sample. The



crystal structure of lanthanum iron oxide (perovskite structure) has a long axis that lay in the plane of the thin-film sample along two directions at right angles. Both the size and orientation of the sample's crystal domains coincided with its magnetic domains, showing that they are closely correlated.

Lanthanum iron oxide is an antiferromagnetic material whose domain structure is large enough to be resolved by the PEEM2, but it is not the material used in technological devices. Eric Fullerton of IBM Almaden Research Center said that "in current read-head devices, more common antiferromagnets like nickel oxide and iron manganese are used." He said that the study of those materials will require higher resolution.

## Graphite Fugitive Layer Assists Formation of Nonporous Zirconia Layer on Fuel-Cell Tubes

Solid-oxide fuel cells convert gaseous, hydrogen-rich fuels like natural gas, biogas, alcohols, and coal-derived gas directly into electrical energy. They do this in a reaction that eventually breaks the fuel down into water and carbon dioxide. The tubular solid-oxide fuel cells, consisting of bundles of tubes with oxygen flowing inside and gaseous hydrocarbon flowing over the tubes, operates at about 1800°F. Working with Merrilea J. Mayo and Clive A. Randall, both associate professors of materials science and engineering at The Pennsylvania State University, postdoctoral associate Rajendra N. Basu developed a method to apply a gas-tight layer of zirconia on the tubes. Along with separating the fuel from the air in order to avoid an explosion, zirconia serves as a conductor of oxygen ions.

Mayo said, "Electricity is produced by the oxygen gas-to-oxygen ion interconversion, which occurs at the surfaces of the zirconia film: On the air-exposed surface, oxygen gas separates into oxygen ions. The ions travel through the film, then give up their electrons on the other side when they react with hydrogen to form water. The electrons thus generated are captured in an external circuit, to provide an electricity source."

Basu, who is a scientist at Central Glass and Ceramic Research Institute, a national laboratory in Calcutta, India, said that other researchers have tried using electrophoretic deposition to make zirconia coating, "but with limited success." While electrochemical vapor deposition is used to make these coatings, the existing method is very expensive, driving up the costs of manufacturing solid oxide fuel cells.

In electrophoretic deposition, a suspension of yttrium-doped zirconium oxide powder is made in very high concentration acetic acid. The application of an electrical potential allows the charged powder to move toward and deposit on the electrode with the opposite charge. The object with its powder coating is then fired at a very high temperature so that the coating forms into a continuous film on the underlying material.

However, depositing zirconium oxide on the bare, porous-ceramic cathode-tube surfaces of the tubular solid-oxide fuel cells leads to an inhomogeneous coating that is not gas-tight. The researchers deduced that the pores of the cathode tube were the source of the problem and tried a fugitive layer of carbon between the tube and the coating. This graphite layer serves as a uniform cathode, and the zirconium oxide deposits evenly on the surface. During firing, the graphite sublimes and the coating deposits evenly on the tube's surface.

"We achieved a very even, homogeneous layer without any porosity," said