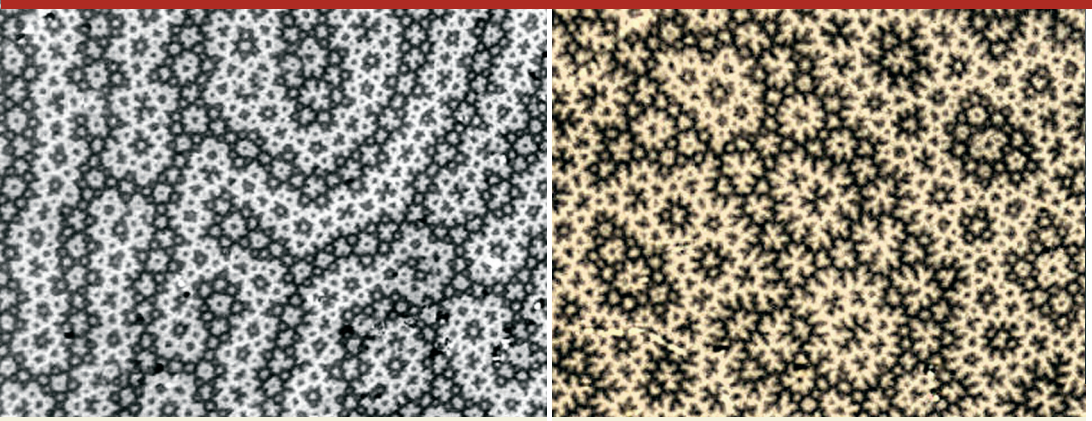
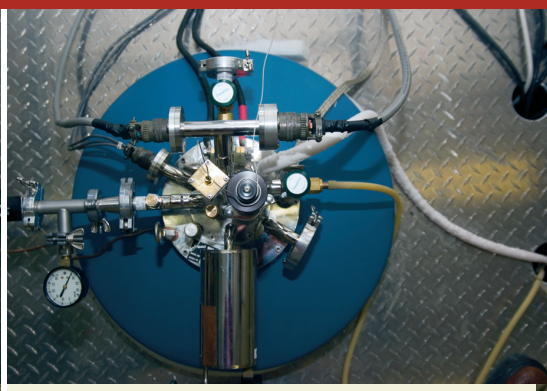
Cunning Patterns of Excelling Nature

Shakespeare's *Othello*



Different magnifications of a neodymium-iron-boron single crystal (grown in senior physicist Paul Canfield's lab) show the distribution of magnetic domains. The elaborate patterns provide Ruslan Prozorov with clues to the material's physical properties.



The tunnel diode resonator allows experimental sensitivity far exceeding commercial setups for studying the properties of superconducting materials.

From temperatures hovering near absolute zero comes clever, spectacular physics

BY SAREN JOHNSTON

Ruslan Prozorov

RUSLAN PROZOROV adjusts the image on his computer monitor, and a magnificent geometry appears. He's literally seeing the magnetic fields associated with the magnetic moments in the crystalline surface of the material under investigation. Somewhat reminiscent of fractals – objects that display self-similar structure over an extended scale range – the geometries Prozorov sees are complex and detailed. The intricate patterns fascinate him, not only for their beauty, but more importantly for their potential to reveal more about a material's physical properties.

"One of my deep interests in physics is to relate the geometry of the magnetic field patterns to the physical properties of a material," says Prozorov an Ames Laboratory associate scientist and an Iowa State University assistant professor of physics. "There are a wide variety of patterns, and I want to understand their connection to actual, measured physical properties."

Prozorov says textbooks often ignore the intricacy of the magnetic field patterns. "Nature behaves in a much more complex way than textbooks tend to describe," he emphasizes. And for Prozorov, that complexity is best studied at the extremely low temperatures associated with liquid helium – around 4.2 Kelvin, or minus 452.11 degrees Fahrenheit – just a few degrees above absolute zero. At these extremely cold temperatures, materials are almost completely free of excitations and vibrations, making it possible to create magnetically ordered or superconducting states – the subjects of Prozorov's investigations.

Magneto-optics "magic"

To shed light on the physical properties of a material, Prozorov employs magneto-optics, a tool that allows him to study the effects arising from the interaction of light with magnetized media. By applying his own unique experimental techniques, he makes the most of what

Ruslan Prozorov prepares a sample for low-temperature magneto-optics study. He applies his own unique measurement techniques to analyze the relationship between the patterns created in the presence of a magnetic field and the macroscopic magnetic properties of the material.

magneto-optics has to offer.

"One of the key ingredients is that I'm able to reach a wide range of temperatures. I can pass liquid helium through the system and observe a material at a few degrees above absolute zero," he says. Taking advantage of the magneto-optical Faraday and Kerr effects, which account for the rotation of the plane of polarization in a magnetic field, Prozorov can observe how the magnetic field patterns form and explore the connection between those patterns and the material's physical properties. "I can literally see the magnetic field with my own eyes," he says.

Prozorov explains that magnetism comes from electrons and their interactions, and each electron has a magnetic moment associated with it called spin. "Spin is actually a mechanical concept, but it's used to refer to the magnetic moment of an electron," he says. In magnetic materials, the magnetic moments can be aligned either up (spin up) or down (spin down). "That's exactly what we're seeing with the magneto-optics," he continues. "Spin up corresponds to bright intensities in the patterns, and spin down corresponds to darker intensities." He notes that these regions of "ups" and "downs" might seem fairly basic, but the reality is much more complex, involving structures of different length scales that are quite fractal in a sense.

Describing his research on magnetism at low temperatures, Prozorov says it is both fundamental and applied. He notes that the fundamental aspect revolves around the use of new tools, such as his magneto-optical setup, to study and measure the physical properties of materials. It's also applied research because unless you know how a material behaves on a small scale, you don't know if it will behave the way you expect it to in a real application. "Part of the reason for a material's unexpected behavior may be these complex patterns, which, if you understand them, may allow you to apply them to different things," he explains.

Low-temp lab

The magneto-optics system combined with the unique experimental techniques Prozorov brings to it is a mainstay of the new low-temperature lab that he has established in one short year since coming to Ames Laboratory from the University of South Carolina. But it is not the only one. A state-of-the-art dilution refrigerator capable of reaching temperatures as low as seven thousandths of a Kelvin above absolute zero provides an unimaginably cold environment in which Prozorov can apply his innovative methods to study various materials and discover more about their physical properties.

Perhaps one of Prozorov's most outstanding contributions to the burgeoning low-temperature lab is the tunnel diode resonator. The device, which is not available commercially, is a self-resonating circuit that is extremely stable and provides experimental sensitivity exceeding commercial setups by orders of magnitude. Prozorov uses it to study properties of superconducting materials.

"There are only a few similar systems in the United States and Europe, and that's it," says Prozorov.

"Cool" work brings recognition

Prozorov's exceptional work on magnetism and superconductivity at low temperatures has not gone unnoticed. He was selected as one of only 23 scientists in the United States to receive a 2006 Sloan Research Fellowship in physics. The prestigious awards are intended to enhance the careers of bright young faculty members in specified fields of science. In addition to the prominence it affords the recipients, the Sloan Research Fellowship provides a cash reward. Prozorov will receive $45,000 over a two-year period, which he may use to support any activity directly related to his research.

As he considers how he wants to apply the funds he'll receive from the Sloan Research Fellowship, Prozorov says he feels fortunate to be a member of the Ames Laboratory research community. "Ames Lab is a unique place in terms of magnetic and superconducting materials, and that's a key ingredient for me," he says. "I don't generally make materials, but I know how to measure them," he adds with aplomb.

For more information:
Ruslan Prozorov, (515) 294-9901
prozorov@ameslab.gov

Research funded by:
DOE Office of Basic Energy Sciences, Materials Science and Engineering Division
National Science Foundation
Alfred P. Sloan Foundation