Magneto-thermal imaging brings synchrotron capabilities to the lab

By David Nutt

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Coming soon to a lab tabletop near you: a method of magneto-thermal imaging that offers nanoscale and picosecond resolution previously available only in synchrotron facilities.

This innovation in spatial and temporal resolution will give researchers extraordinary views into the magnetic properties of a range of materials, from metals to insulators, all from the comfort of their labs, potentially boosting the development of magnetic storage devices.

"Magnetic X-ray microscopy is a relatively rare bird," said Greg Fuchs, associate professor of applied and engineering physics, who led the project. "The magnetic microscopies that can do this sort of spatial and temporal resolution are very few and far between. Normally, you have to pick either spatial or temporal. You can't get them both. There's only about four or five places in the world that have that capability. So having the ability to do it on a tabletop is really enabling spin dynamics at nanoscale for research."

His team's paper, "Nanoscale Magnetization and Current Imaging Using Time-Resolved Scanning-Probe Magnetothermal Microscopy," published June 8 in the American Chemical Society's journal Nano Letters. The lead author is postdoctoral researcher Chi Zhang.

The paper is the culmination of a nearly 10-year effort by the Fuchs group to explore magnetic imaging with magneto-thermal microscopy. Instead of blasting a material with light, electrons or X-rays, the researchers use a laser focused onto the scanning probe to apply heat to a microscopic swath of a sample and measure the resulting electrical voltage for local magnetic information.

Fuchs and his team pioneered this approach and over the years have developed an understanding of how temperature gradients evolve in time and space.

"You think about heat as being a very slow, diffusive process," Fuchs said. "But in fact, diffusion on nanometer length scales has picosecond times. And that's a key insight. That is what gives us the time resolution. Light is a wave and diffracts. It doesn't want to live down at these very small length scales. But the heat can."

The group has previously used the technique to image and manipulate antiferromagnetic materials – which are difficult to study because they don't produce a magnetic field – as well as magnetic metals and insulators.

While it is easy enough to focus a laser, the major hurdle has been confining that light and generating enough heat on a nanometer scale to get the process to work. And because some phenomena at that scale occur so quickly, the imaging needs to be equally speedy.

"There's a lot of situations in magnetism where stuff is wiggling, and it's small. And this is basically what you need," Fuchs said.

Now that they have refined the process and successfully achieved a spatial resolution of 100 nanometers and a temporal resolution below 100 picoseconds, the team can explore the real minutiae of magnetism, such as skyrmions, quasi-particles in which the magnetic order is twisted. Understanding these kinds of "spin textures" could lead to new high-speed, high-density magnetic storage and logic technologies.

In addition to magnetism, the technique's dependence on electrical voltage means it can be used to measure current density when the voltage interacts with a material. This is a novel approach, since other imaging techniques measure current by gauging the magnetic field the current produces, not the current itself.

Magneto-thermal microscopy does have limitations. Because samples need to be configured with electrical contacts, the material has to be patterned into a device. As a result, the technique can't be applied to bulk samples. Also, the device and the scanning probe must be scaled together. So if you want to measure a phenomenon at the nanoscale, the sample has to be small.

But those limitations are minor compared with the benefits of a relatively low-cost form of magneto-thermal microscopy in your own lab.

"Right now, people have to go to a public facility, like a synchrotron facility, for doing these types of measurements," Zhang said. "You write a proposal, you get a beam time, and you have maybe a few weeks to work, at best. If you didn't get the result you want, then it's maybe another couple of months. So this will be progress for the field."

Co-authors include Jason Bartell, Ph.D. '18; Jonathan C. Karsch '17 and Isaiah Gray, Ph.D. '20

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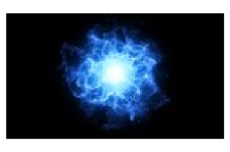

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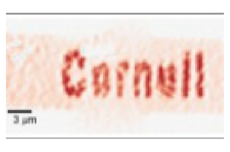

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