Mapping Spin Waves with a Strobe Light

A method for imaging spin waves in magnetic materials uses flash-like intensity variations in a laser beam to capture the wave motion at specific moments in time.

By **Michael Schirber**

The magnetic moments, or spins, in certain materials can twirl in a coordinated wave pattern that might one day be used to transmit information in so-called spintronic devices. Researchers have developed a new way to image these spin waves using an infrared laser that essentially flashes on and off at a frequency that matches that of the spin waves [**1**]. Unlike other spin-wave probes, this strobe method can directly capture phase information that is relevant to certain applications, such as hybrid devices that combine spin waves with other types of waves.

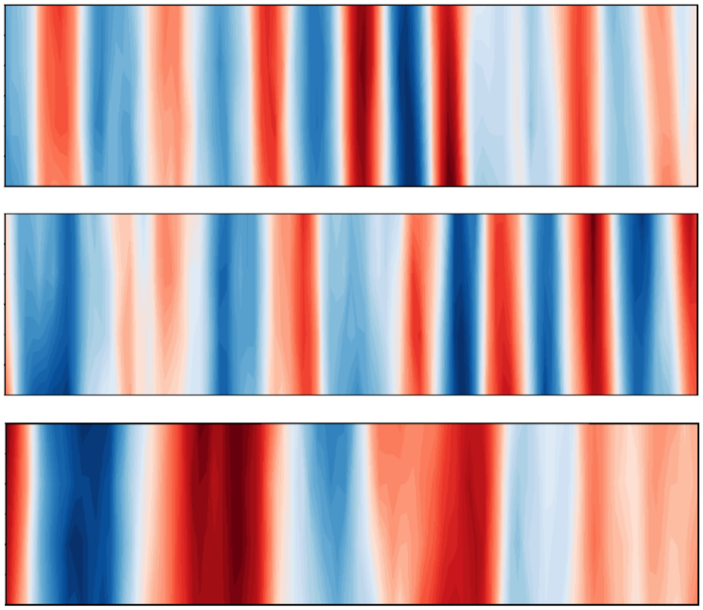
A spin wave can be triggered in a magnetic material when some perturbation causes a spin to oscillate, which can then generate a wave of oscillations that ripple through neighboring spins. Spin waves have several properties that make them good candidates for information carriers. For one, they have relatively small wavelengths—a few hundred nanometers at a frequency of 1 GHz, whereas a 1-GHz photon has a wavelength of about 30 cm. This compactness could conceivably allow researchers to build spintronic components, such as waveguides and logic gates, at the nanoscale. Another advantage of these waves is that the spins remain in place, and only their orientation changes. So the heat losses that affect the moving charges in traditional electronics don't exist.

Freeze frame. Researchers have developed a new "strobe light" method for capturing spin waves in magnetic materials.
Credit: Pixel-Shot/Stock.adobe.com

And yet researchers are still trying to understand and manipulate spin-wave behavior. To study spin waves, one of the most common techniques involves pump–probe spectroscopy with visible or UV light. In this method, a strong laser pulse excites a spin wave in a target material, followed by a second, weaker pulse whose polarization is affected by the spins. By measuring this polarization shift, researchers can map out the amplitude of the spin wave. But obtaining the phase requires more complicated optical setups. This phase information is important for studying the interaction of spin waves with other types of waves, such as light and sound waves.

Wei Zhang of the University of North Carolina at Chapel Hill and his colleagues have developed a strobe method that can directly record both the amplitude and phase of spin waves. They previously used this technique to measure phase shifts at fixed points in a material [**2**, **3**], but now they have adapted it to allow images of spin waves to be captured.

The strobe method works by illuminating the spins with light



Wave maps. As a demonstration of their strobe technique, researchers generated spin waves in a sample and imaged them over a rectangular region: 2 mm × 0.5 mm. The colors indicate the recorded phase information: red bands correspond to spins pointing out of the page, while blue bands correspond to spins pointing into the page. The maps show how the wavelength increases as the drive frequency increases: 4.275 GHz (top), 4.375 GHz (middle), 4.675 GHz (bottom). This behavior was expected, as the velocity of spin waves is not constant—they move faster at higher frequencies.
Credit: Y. Xiong *et al.* [1]

flashes at a rate that is similar to their rotation rate. The typical spin-wave frequency is in the gigahertz range, so the strobe light needs to be turned on and off, or "modulated," at gigahertz frequencies. "You cannot do gigahertz modulation for visible and UV light," Zhang says. For that reason, he and his colleagues use a continuous-wave infrared (IR) laser whose intensity is varied at gigahertz frequencies by an electro-optical modulator.

The researchers shine this modulated laser beam on a sample and record a similar polarization shift as in pump–probe spectroscopy. To set the timing of the flashes, the team drives their electro-optical modulator with an electronic signal that is also used to excite a spin wave in the sample. Thanks to this synchronization, the flashes arrive at well-defined moments in the wave's progression, allowing both the amplitude and the phase of the wave to be measured. "It's like taking a series of snapshots of the oscillation," Zhang says.

To produce maps, Zhang and his colleagues scan the surface of a target with their IR beam. As a demonstration, they studied composite samples made of a magnetic insulator called YIG and a magnetic alloy called permalloy. They measured the propagation speed of spin waves of various wavelengths and also recorded the spin-wave behavior at the boundaries between different materials.

Zhang says researchers could use the technique to investigate spin-wave propagation through waveguides and logic gates. Another application would be investigating hybrid devices, which attempt to combine the advantages of spin waves with those of other wave-based information carriers, such as photons and phonons.

"The spin-wave microscopy technique utilizes an IR strobe light, offering both conceptual and technological advantages over commonly used optical spin-wave measurement methods," says magnetism expert Benjamin Jungfleisch from the University of Delaware. He notes limitations to the new technique in its time resolution, but its IR technology benefits from being compact, affordable, and widely available. Spintronics researcher Luqiao Liu from MIT says that the strobe method has "huge potential" in studying the interactions in hybrid platforms.

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