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Nanoscale magnetic imaging using picosecond thermal gradients[1]

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Research and development in spintronics is challenged by the lack of table-top magnetic imaging technologies that posses the simultaneous temporal resolution and spatial resolution to characterize magnetization dynamics in emerging spintronic devices. In addition, many of the most exciting magnetic material systems for spintronics are difficult to image with any method. To address this challenge, we developed a spatiotemporal magnetic microscope based on picosecond heat pulses that stroboscopically transduces an in-plane magnetization into a voltage signal. When the magnetic device contains a magnetic metal like FeCoB or NiFe, we use the time-resolved anomalous Nernst effect. When it contains a magnetic insulator/normal metal bilayer like yttrium iron garnet/platinum, we use the combination of the time-resolved longitudinal spin Seebeck effect and the inverse spin Hall effect. We demonstrate that these imaging modalities have time resolutions in the range of 10-100 ps and sensitivities in the range of $0.1 - 0.3^{\circ}/\sqrt{Hz}$, which enables not only static magnetic imaging, but also phase-sensitive ferromagnetic resonance imaging. One application of this technology is for magnetic torque vector imaging, which we apply to a spin Hall device. We find an unexpected variation in the spin torque vector that suggests conventional, all-electrical FMR measurements of spin torque vectors can produce a systematic error as large as 30% when quantifying the spin Hall efficiency. Finally, I will describe how time-resolved magnetic imaging can greatly exceed the spatial resolution of optical diffraction. We demonstrate scanning a sharp gold tip to create near-field thermal transfer from a picosecond laser pulse to a magnetic sample as the basis of a nanoscale spatiotemporal microscope.

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