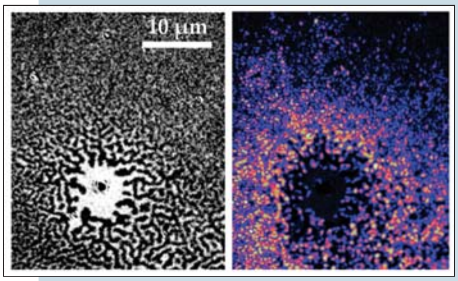
physics update

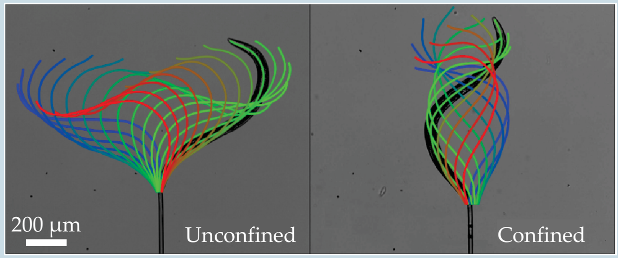
These items, with supplementary material, first appeared at http://www.physicstoday.org.

Spontaneous fluctuations in a ferromagnetic film. A close-up look at the hysteresis loop of a ferromagnet often reveals a series of sudden magnetization jumps. The so-called Barkhausen jumps come from domain-wall fluctuations, whose distributions in size and duration follow a power law and can be analyzed for scaling behavior and critical exponents. But the physics in those critical exponents is a complex mix of disorder, magnetic anisotropy, and dipole–dipole interactions. Andrew Balk and colleagues of NIST's Center for Nanoscale Science and Technology (Balk is also with the University of Maryland) set out to simplify the problem. They nudged the magnetic domain walls in a platinum-cobalt-platinum multilayer into spontaneously fluctuating, even without an external magnetic field. Roughening the interfaces between the different layers with argon ion milling drove the film close to a transition that reorients the cobalt magnetization from perpendicular to parallel orientation relative to the film plane. That trick reduced the magnetic anisotropy and domain wall pinning energies enough to allow spontaneous thermal fluctuations of the domain walls.



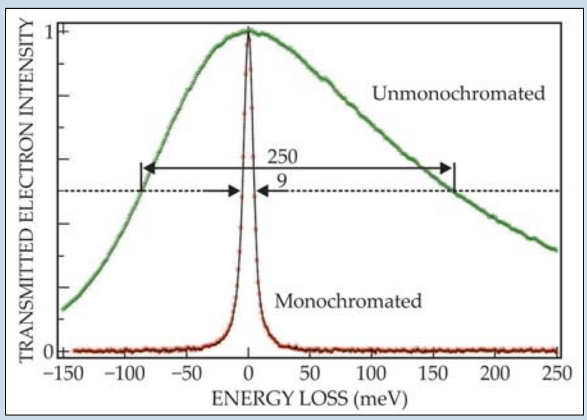
The group used Kerr microscopy, which detects the change in polarization when light reflects off a magnetic sample, to make videos of the changing magnetic domain patterns. The figure's left panel shows one video frame, in which light and dark areas represent oppositely oriented domains; the right panel maps the number of fluctuations summed over a one-minute period—brighter colors indicate more fluctuations. As with field-driven domain-wall motion, the size distribution of the fluctuating areas showed a power-law behavior. (A. L. Balk, M. D. Stiles, J. Unguris, *Phys. Rev. B* **90**, 184404, 2014.) —SC

Watching nematodes swim the channel. For microbes, it's not always open-water swimming. Sperm negotiate narrow reproductive tracts, infectious bacteria navigate thin layers of mucus, and many other microbes live life confined to thin biofilms. Now researchers led by Kari Dalnoki–Veress (McMaster University, Hamilton, Ontario, Canada) have devised a way to probe how confinement affects a microswimmer's stroke. The researchers capture undulating nematodes by the tail, one at a time, with a cantilevered micropipette. The forces the roundworms generate as they wriggle can then be determined with subnanonewton precision by measuring tiny deflections of the pipette. In one setup, the tethered worms swim near a glass plate; in another, they swim in the narrow channel between two plates. In both cases, the undulating motion lies in the plane parallel to the plates—that way, although the boundaries increase the viscous resistance that a worm feels, they don't constrict its range of motion. In the experiments, the nematodes adapt by summoning super strength. They generate nearly three times as much propulsive and lateral force when they're within a couple of



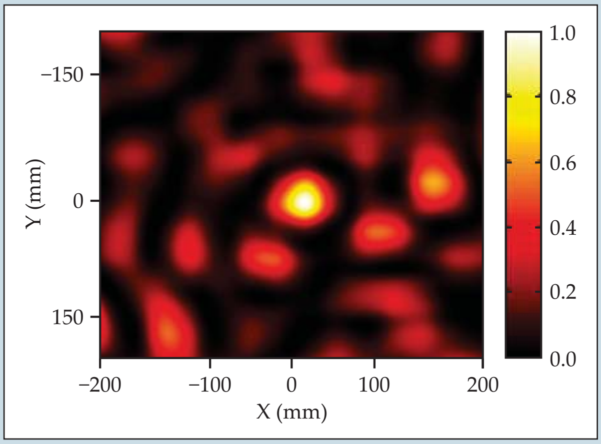
body-widths of a surface as they do in unbounded fluid; in a channel a few body-widths wide, the increase is nearly 10-fold. The time-lapse reconstructions shown here further illustrate the boundaries' influence. Each curve represents the worm's configuration at a different stage of its stroke; the color gives the phase. Under confinement, the nematodes' undulations decrease in amplitude and frequency, which suggests the nearby surfaces may be triggering a modulation from a swimming to a crawling gait. (R. D. Schulman et al., *Phys. Fluids* **26**, 101902, 2014.) —AGS

High-resolution imaging meets vibrational spectroscopy. In a scanning transmission electron microscope (STEM), a high-energy electron beam is focused to near-atomic dimensions and scanned over a thin specimen. In addition to generating images from the scattered electrons, one can simultaneously use an electron spectrometer to map the energy lost by the beam. Among the details energy-loss spectroscopy can reveal are elemental composition and chemical bonding, but the technique has traditionally suffered from poor energy resolution, typically because of fluctuations in the high voltage supplied to the electron source. Now researchers led by Ondrej Krivanek, an adjunct professor of physics at Arizona State University and president of Nion Co, which manufactures commercial STEMs, have ameliorated the problem. By implementing a newly designed monochromator that is immune to voltage variations, they achieve an energy spread of 9 meV, as shown here. That's a nearly 30-fold improvement in energy resolution compared with the unfiltered beam and a 10-fold improvement over earlier monochromator designs. Thanks to



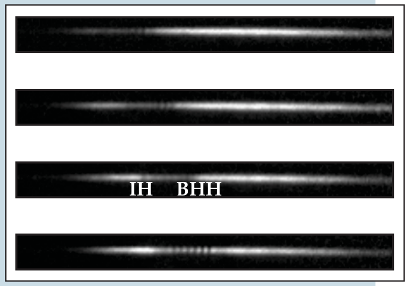
the narrow energy spread, the researchers could resolve the low-energy excitation peaks caused by lattice vibrations in materials such as silicon dioxide, silicon carbide, and titanium hydride. Although the peaks were wider than those measured with more traditional tools such as Raman spectroscopy, energy-loss spectroscopy in a STEM benefits from extremely high spatial resolution: The researchers mapped variations in the phonon spectra at the nanometer length scale as a 2-nm-wide beam scanned the interface between silicon and silicon dioxide. (O. L. Krivanek et al., *Nature* **514**, 209, 2014.) —RMW

A smart wall for cell phones and tablets. Most of our offices and homes reverberate with unseen microwaves that are emitted by a Wi-Fi box or other base station and, hopefully, interact with our wireless devices such as cell phones, laptops, and tablets. Sophisticated antennas in those devices help to capture the multiply scattered waves as they zip by (see the article by Steve Simon and coauthors, PHYSICS TODAY, September 2001, page 38). Still, reception is often spotty at best. To optimize reception, Mathias Fink, Geoffroy Lerosey, and their colleagues at Institut Langevin in Paris are looking at the environment. Using ideas from time-reversal acoustics (see Fink's article in PHYSICS TODAY, March 1997, page 34) and spatial light modulators in optics, they engineered tunable metamaterial panels that focus wireless signals onto a wireless device, say a cell phone. Their prototype spatial microwave modulator (SMM) has 102 unit-cell "pixels," each with two resonators and a feedback loop to the cell phone. When a



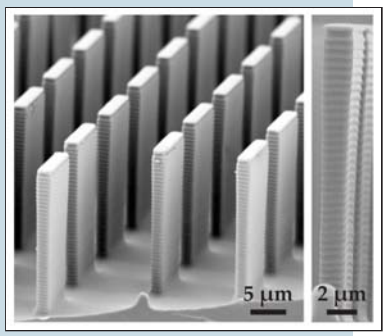
wave at a resonant frequency impinges on a pixel, the secondary resonator adjusts the pixel to reflect with a phase shift of either 0 or π, depending on how the feedback loop is set by the cell phone. The researchers carried out tests with a 0.4-m^2 SMM mounted on one wall in a complex reverberant office room. The SMM enhanced the overall signal centered on the cell phone (at the origin in the figure) by more than an order of magnitude even when the SMM, the source, and the phone were out of each other's line of sight. When the SMM flips the phases, the waves cancel at the phone. According to Fink, not only can such a "smart wall" reduce power needs for wireless communication, but SMMs can enable microwave wavefront shaping for fundamental physics. (N. Kaina et al., *Sci. Rep.* **4**, 6693, 2014.) —SGB

Hawking radiation from fluids. The remarkable black hole radiation predicted 40 years ago by Stephen Hawking has never been observed. But an analogous phenomenon has been seen by Jeff Steinhauer (Technion–Israel Institute of Technology) in a Bose–Einstein condensate (BEC) of rubidium-87 atoms. In the analogue fluid system, sound plays the role that light does for a black hole, and a region in which the fluid flow exceeds the speed of sound substitutes for the light-trapping interior of the black hole (see also PHYSICS TODAY, August 2005, page 19). To generate an analogue black hole horizon separating supersonic and subsonic flow, Steinhauer



accelerated a portion of the BEC by illuminating it with a half-moon-shaped laser spot. Moreover, the potential Steinhauer used to confine his BEC created a second, inner horizon downstream of the black hole horizon, where the flow again became subsonic. The two horizons are indicated on the figure, which shows time-lapse images of the BEC (the top panel is the earliest). Hawking phonons generated at the black hole horizon carry energy away from the supersonic flow region; to conserve energy, the BEC must also accommodate negative-energy modes. Those modes rattle around between the two horizons. The interference between left-moving and right-moving waves creates the fringes seen in the figure. The increasing intensity and contrast with time reflect the exponential growth of negative energy accompanying the continuing emission of Hawking phonons. (J. Steinhauer, *Nat. Phys.* **10**, 864, 2014.) —SKB

Reversed diffraction in bio-inspired photonic materials. Certain butterflies, beetles, and other organisms have evolved intriguing strategies to manipulate their outward appearance through structural coloration, in which perceived color arises from periodic features in the underlying morphology. (See, for instance, the Quick Study by Peter Vukusic, PHYSICS TODAY, October 2006, page 82.) Four years ago, Jean Pol Vigneron and colleagues at the University of Namur in Belgium reported a surprising property of male butterflies of the species *Pierella luna*: A coin-sized iridescent region of their wings will, like a diffraction grating, spectrally decompose incident white light, but the color sequence is the reverse of what one would expect—violet light emerges at a shallow angle, closer to the wing, while red light emerges at a steeper angle, closer to the wing's perpendicular. A close examination of the wing's scales revealed the cause: The scales' ridged tips curl up, away from the wing, forming in essence a vertical transmission grating. Inspired by *P. luna*, Grant England, Joanna Aizenberg, and colleagues at Harvard University have fabricated an ordered array of vertically oriented microdiffraction gratings, shown here.



Each grating mimics a wing scale, and the scallops reproduce the color reversals. But the combination of length scales—the 500-nm periodicity of each micrograting and the orthogonal, micron-scale spacing of the grating array—generates further richness and complexity in the structure's optical signature. For example, the researchers found that tilting the grating pillars could provide a way to dynamically tune the diffraction pattern. They anticipate that hierarchically structured photonic materials will provide a broad platform for further exploring novel behavior and applications. (G. England et al., *Proc. Natl. Acad. Sci. USA* **111**, 15630, 2014.) —RJF ■