of an individual NV center (indicated optically by fluorescence) in response to a magnetic field across a sample. The atomic size and quantum behavior of NV centers have allowed scientists like Maletinsky to measure magnetic fields with nanoscale resolution. And because this sensitivity is preserved under ambient conditions, NV centers can be used to detect tiny magnetic fields in materials ranging from high-temperature superconductors to living cells—materials closed off to cold-temperature technologies such as superconducting quantum interference devices (or SQUIDs) and magnetic resonance force microscopes.

At cryogenic temperatures, however, the tables are turned. NV-based sensors have never been shown to operate under such cold conditions.

Maletinsky's team addressed this problem by immersing their room-temperature NV sensor in a liquid-helium cryostat, allowing them to plunge to an operating temperature of about 4 K. The low tendency of helium to boil, Maletinsky says, allows their system to be very "quiet," a key priority when the sensor is a single quantum spin nestled in a diamond nanopillar welded to the tip of an atomic force microscope.

With this system, the research team could quantitatively image the stray field emanating from magnetic vortices across a sample of $YBa_2Cu_3O_{7-\delta}$, a high-temperature superconductor known to form these quantum defects when cooled below its transition temperature (about 89 K) under an applied magnetic field. More importantly, the research team was able to extract a notoriously elusive measure known as the London penetration depth, which describes how far a magnetic field penetrates into a superconductor.

The key to making such highly sensitive, high-resolution measurements, Maletinsky says, is how close the delicate NV sensor can be brought to a sample surface. "Tip-to-sample distance is the crucial figure of merit in these experiments."

Ania Jayich would agree.

An assistant professor in the Physics Department, Jayich leads a group who published their own work on cryogenic NV-based sensing concurrently with Maletinsky's team in *Nature Nanotechnology* (doi:10.1038/NNANO.2016.68).

"High spatial resolution is possible because our sensor is so small," Jayich says. "But the sensor is ultimately limited by the distance to the sample, not its size."

And herein lies a significant challenge for researchers like Jayich and Maletinsky. A shorter tip-to-sample distance should mean higher sensitivity. But because one quantum phenomenon is being used to detect another, at short distances, sample surface effects can compromise the "quantumness" of a NV center, as Jayich puts it. "It's a problem that plagues almost all quantum technologies," she says. "Quantum behavior is very delicate and very sensitive to its environment."

Within these limits, however, Jayich's group resolved magnetic domains smaller than 100 nm in a hard disk using their NV-sensing system, which is unlike that developed by Maletinsky's team.

Instead of a single diamond pillar, Jayich's group glues an entire array of pillars to their scanning tip, producing a micro-hairbrush structure. This arrangement makes it difficult to precisely control how close a NV center on a single bristle reaches a sample surface. However, it allows the researchers to produce several NV centers at once and choose the brightest and most stable one for imaging. The structure also holds promise for conducting wide-field experiments in which multiple NV centers can be optically addressed to quickly scan across large areas. But this and other improvements to NV-based imaging, some argue, may not come until much later.

Eli Zeldov, a professor at the Weizmann Institute of Science in Rehovot, Israel, acknowledges that NV-based sensors have made significant progress within the last few years, with a performance ceiling on par with that of the nanoSQUID imaging technology he has helped pioneer. Nevertheless, he argues that NV-based sensing currently remains a relatively slow and complicated technique, both in fabrication and in operation.

"It requires microwaves, it requires optics, it requires very delicate equipment," Zeldov says. "It's tricky. This can improve with time, but there's still quite a lot of room for improvement."

But for NV researchers like Jayich and Maletinsky , there may be no time like the present.

"We have established this system that already has really good sensitivity, excellent spatial resolution, and is quantitative," Maletinsky says. "I think now we're in a position where we can demonstrate very meaningful applications with the performance we already have."

Omar Fabian

Kirigami honeycomb material exhibits a "Poisson's switch"

The ancient Japanese art of origami that uses strategic folding has found many interesting technological applications such as the Miura-Ori method for folding/unfolding antennas in satellites. Perhaps less known is kirigami where, in addition to folding, cutting is also allowed. Kirigami has also been a subject of intense scientific investigation, not least because several natural systems such as bird wings have periodic polyhedral designs that could easily be reproduced using kirigami techniques.

Robin Neville, Fabrizio Scarpa, and Alberto Pirrera, from the University of Bristol, UK, report how a class of kirigami cellular materials show large shape and volume deformations that could find potential applications in many shape-morphing materials. The researchers start with a flat sheet of poly ether ether ketone—a thermoplastic polymer. A pattern of slits is cut into the sheet, which is then corrugated and folded repeatedly to give a honeycomb architecture. The ease of this method allows the process to be applied to many starting materials and to be automated. By varying a small number of initial parameters such as the

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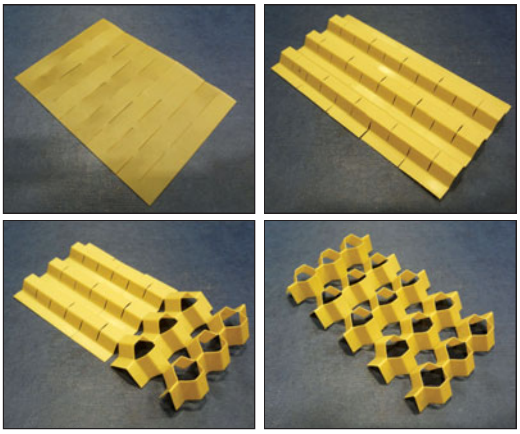
folding angle and width of the slit, for example, different kinds of honeycombs can be designed.

Using complex numerical analysis and finite element methods, the group was able to extract mechanical information such as the Poisson's ratio of the cellular material. It was found that if the stiffness of the connection between two cells—modeled as a hinge connector and hence called "hinge stiffness"—is much greater than that of the sheet, the cell walls bend in response to stress. If the material of the sheet is stiffer than the connection, the honeycomb material bends at the folds.

Interestingly, the researchers found that the kirigami honeycomb material shows a "Poisson's switch." This refers to the observation that on either side of a critical folding angle, the Poisson's ratio of the material switches and shows the opposite sign. The researchers reported in a recent issue of *Scientific Reports* (doi:10.1038/srep31067) that by using smart materials, the fold angle could be manipulated to expand or contract the honeycomb. "Experimental verification of the predicted switch between negative and positive Poisson's ratio over relatively small changes in fold angle argues well for practical use of this approach in ingenious aerospace applications," says Anselm Griffin, a professor at Georgia Institute of Technology. Others in the field have commented positively on this work. Daniel Inman from the University of Michigan says, "Morphing has game-changing possibilities from automotive to aircraft and even civil structures. The work is significant as it brings new possibilities to the mechanism side of shape-changing structures allowing many new designs to be considered. As advanced manufacturing moves from polymers to metals, the impact of this work is even greater."



A kirigami honeycomb material in different stages of evolution. Credit: Robin M. Neville, Fabrizio Scarpa, and Alberto Pirrera.

Vineet Venugopal

Energy Focus

Electric fields help oxygen slip through the cracks for ultralow power electronics

The recent increase in connectivity of the modern world has left us dependent on the battery life of our personal electronics, forcing us to keep a watchful eye on the icon in the corner of our screen as it ticks toward 0%. Enormous amounts of time and effort have been dedicated to discovering new battery materials and improving existing ones that pack larger energy-storage capacities into smaller spaces. However, making our electronics more energy efficient may be complementary extending the lifetime of our electronics.

As reported in *Nature Communications* (doi:10.1038/ncomms12264), a research team led by Dustin Gilbert and Alexander Grutter from the National Institute of Standards and Technology (NIST), have implemented a recently demonstrated "magneto-ionic" approach in a push toward ultralow power electronics. Their approach utilizes electric fields to alter the chemical and magnetic makeup of materials, and opens pathways to nonvolatile memory and logic devices that potentially require much less power to operate.

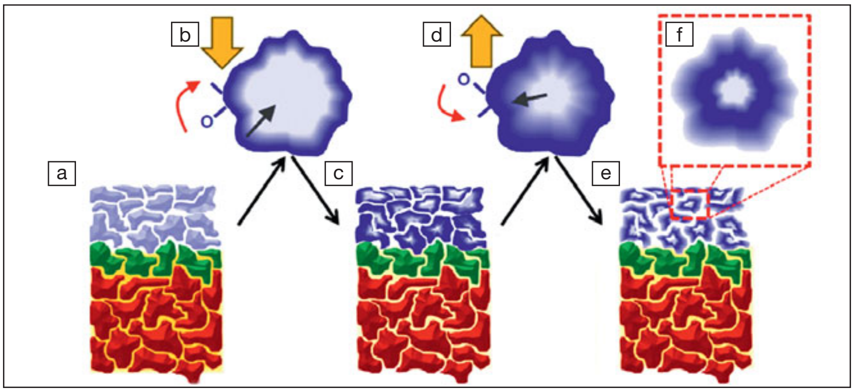


Illustration of oxygen migration mechanism: (a) as-grown film, (b,c) positive electrical bias, and (d,e) negative electrical bias. AlOx (red), GdOx (green), metallic ferromagnetic Co (light blue), insulating non-FM Co (dark blue), and interstitial oxygen (orange). Credit: *Nature Communications*.

Gilbert says, "In classical electronics you're relying on the charge of an electron; as the electron moves through your material, scattering produces heat. In this [new approach] there's essentially no movement of the electrons; you're applying a voltage only and no real current. The voltage drags oxygen from the oxide into the neighboring metallic material, changing its magnetic properties."

The researchers grew thin-film heterostructures with special consideration given to ensuring clean, well-defined interfaces between the AlO_x, GdO_x, and Co layers. Utilizing a powerful technique called polarized neutron reflectometry (PNR), the researchers were able to probe the chemical and magnetic profile of the sampl e as a function of depth. PNR measurements revealed diffusional migration of oxygen from the AlO_x and GdO_x oxide layers into the Co layer when the films were heated

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