Physicists Observe an Exotic “Multiferroic” State in an Atomically Thin Material

2022-02-27
Discovery shows for the first time that multiferroic properties can exist in a two-dimensional material; could lead to more efficient magnetic memory devices.

MIT physicists have discovered an exotic “multiferroic” state in a material that is as thin as a single layer of atoms. Their observation is the first to confirm that multiferroic properties can exist in a perfectly two-dimensional material. The findings, published in Nature, pave the way for developing smaller, faster, and more efficient data-storage devices built with ultrathin multiferroic bits, as well as other new nanoscale structures.“Two-dimensional materials are like LEGOs — you put one on top of another to make something different from either piece alone,” says study author Nuh Gedik, professor of physics at MIT. “Now we have a new LEGO piece: a monolayer multiferroic, which can be stacked with other materials to induce interesting properties.”

In addition to Gedik, the study’s authors at MIT include lead author Qian Song, Connor Occhialini, Emre Egeçen, Batyr Ilyas, and Riccardo Comin, the Class of 1947 Career Development Associate Professor of Physics, along with collaborators in Italy and Japan and at Arizona State University.

Curiously coupled

In materials science, “ferroic” refers to the collective switching of any property in a material’s electrons, such as the orientation of their charge or magnetic spin, by an external field. Materials can embody one of several ferroic states. For instance, ferromagnets are materials in which electron spins collectively align in the direction of a magnetic field, like flowers pivoting with the sun. Likewise, ferroelectrics are composed of electron charges that automatically align with an electric field.

In most cases, materials are either ferroelectric or ferromagnetic. Rarely do they embody both states at once.

“That combination is very rare,”Comin says. “Even if one took the entire periodic table and put no boundary on the combination of elements, there are not many of these multiferroic materials that can be produced.”

But in recent years, scientists have synthesized materials in the lab that exhibit multiferroic properties, behaving as both ferroelectrics and ferromagnets, in curiously coupled fashion. For instance, the magnetic spins of electrons can be switched by not just a magnetic field but also an electric field.

This coupled, multiferroic state is particularly exciting for its potential to advance magnetic data-storage devices. In conventional magnetic hard drives, data are written onto a rapidly rotating disk patterned with tiny domains of magnetic material. A small tip suspended over the disk generates a magnetic field that can collectively switch a domain’s electron spins in one direction or another to represent either a “0” or a “1” — the basic “bits” that encode data.

The tip’s magnetic field is typically produced by an electrical current, which requires significant energy, some of which can be lost in the form of heat. In addition to overheating a hard drive, electrical currents have a limit to how fast they can generate a magnetic field and switch magnetic bits. Physicists like Comin and Gedik believe that if these magnetic bits could be made from a multiferroic material, they could be switched using faster and more energy-efficient electric fields, rather than current-induced magnetic fields.

“If using electric fields, the process of writing bits would be much faster because fields can be created in a circuit within a fraction of a nanosecond — potentially hundreds of times faster than with electrical current,” Comin says.

One large hurdle for device integration has been size. Thus far, physicists have only observed multiferroic properties in relatively large samples of three-dimensional materials, too large to work into nanoscale memory bits. No one has been able to synthesize a perfectly two-dimensional multiferroic material.

“All known examples of multiferroics are in 3D, and there was a fundamental question: Can these states exist in 2D, in a single atomic sheet?” Comin says.

Ferroic flakes

To answer that, the team looked to nickel iodide (NiI2), a synthetic material that is known to be multiferroic in bulk form.

“In our case, it was a dual challenge, to try to make nickel iodide into a 2D form and to measure it to see if it retained multiferroic properties,” Comin says.

While other two-dimensional materials such as graphene can be made simply by exfoliating the layers from bulk versions such as graphite, nickel iodide is more finicky. The team needed a new way to synthesize the material in 2D form. The team, led by Song, borrowed from a technique known as epitaxial growth, in which thin atomic sheets of material are “grown” on another base material. In their case, Song and his colleagues used hexagonal boron nitride as the bulk foundation, which they placed in a furnace. Over this material, they flowed powders of nickel and iodide, which settled onto boron nitride in perfect, atom-thin flakes of nickel iodide.

To test each flake’s multiferroic properties, Gedik and Comin employed optical techniques developed in their respective labs to probe the material’s magnetic and electrical response.

‘The wavelength of light we use is around half a micron, so we can zoom in on a small region of this flake and study its properties with great precision,” Comin explains.

The researchers progressively chilled the 2D flakes to temperatures as low as 20 kelvins, where the material was previously observed to exhibit multiferroic properties in 3D form. They then carried out separate optical tests to probe first the material’s magnetic, then electrical properties. At around 20 K, the material was found to be both ferromagnetic and ferroelectric.

The team’s experiments confirm that nickel iodide is multiferroic in its two-dimensional form. What’s more, the study is the first to demonstrate that multiferroic order can exist in two dimensions — the ideal dimensions for building nanoscale, multiferroic memory bits.

“We now have a material that’s multiferroic in 2D. Before, we didn’t know what to work with if we wanted to make a nanoscale multiferroic device. Now we do. And we are starting to make these devices in our lab now,” Comin says. “We want to use electric fields to control magnetism, to see how fast we can switch multiferroic bits, and how we can miniaturize these devices. That’s the roadmap, and now we’re much closer.”

This research was supported by the Department of Energy and, in part, by the National Science Foundation and the Gordon and Betty Moore Foundation.

Read the original article on Massachusetts Institute of Technology (MIT).