Nano Focus

Novel artificial spin structure produces rewriteable magnetic ice

Magnetic-storage devices, such as those used in computer hard disks, function on the binary principle—each of the two magnetic polarities represents 1 or 0. In order to increase storage capacity and functionalities, researchers have been studying artificial spin ices—structures wherein the constituents obey analogs of Pauling's ice rule that dictates the positioning and ordering of protons in water ice. Artificial spin ices are magnetic systems with single-domain ferromagnetic nanostructures that have potential applications in data storage, memory, and logic devices.

Traditional artificial square spin ices have single-domain magnetic islands with only two ordered states, the magnetic moments either point inward or outward at the vertex of a square lattice. The large energy barrier required to rearrange the islands at room temperature limits the configuration of multiple ordered states for magnetic-storage applications. However, the assumption here is that connections between the pairs of positive and negative magnetic charges in spins cannot be altered.

In a recent issue of *Science* (doi: 10.1126/science.aad8037), a research team led by Yong-Lei Wang and Zhi-Li Xiao in the Materials Science Division at Argonne National Laboratory, proposed and validated a theoretical, artificial, magnetic charge ice structural design. The new structure suggests a different pattern of connections between magnetic charge pairs, leading to eight possible ordered states that could be controlled by external magnetic fields. These additional ordered states could provide a platform for designing future magnetic-storage devices.

"The novelty of this research is the new way of thinking: instead of focusing on spins, we tackled the associated magnetic charges that allow us to design and create artificial magnetic structures with more controllability," says Wang, the corresponding author of this work. "This research not only introduces several new spin structures, but also provides a method for designing new artificial spin structures by decoupling spins and magnetic charges, which would greatly enrich the materials [selection] for [the] artificial spin ice community."

A magnetic force microscope (MFM) was demonstrated to manipulate the charge ordering. A two-dimensional solenoid magnet can apply in-plane magnetic fields in any orientation for long-range tunability of the entire magnetic spin ice sample. For local patterning of several magnetic charges, a magnetic tip of the MFM generates stray fields that interact with individual magnetic charges. This provides

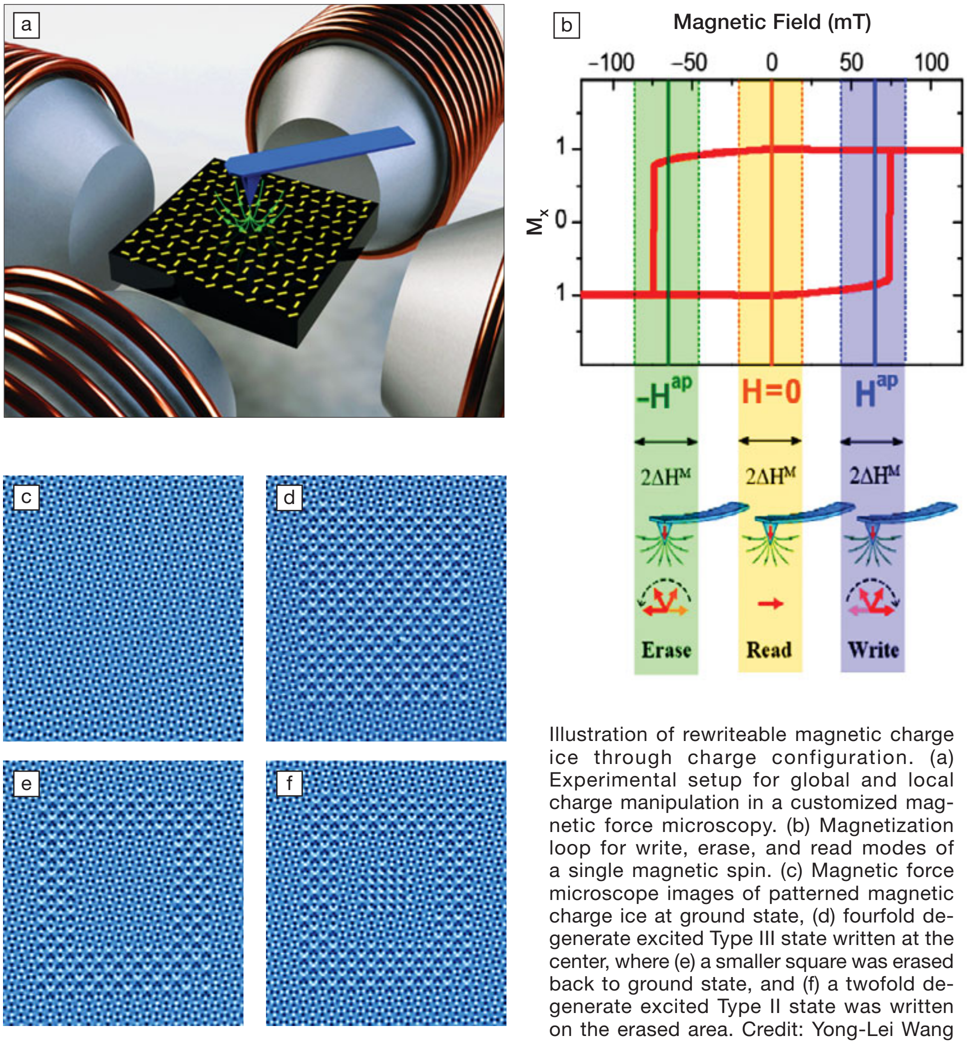


Illustration of rewriteable magnetic charge ice through charge configuration. (a) Experimental setup for global and local charge manipulation in a customized magnetic force microscopy. (b) Magnetization loop for write, erase, and read modes of a single magnetic spin. (c) Magnetic force microscope images of patterned magnetic charge ice at ground state, (d) fourfold degenerate excited Type III state written at the center, where (e) a smaller square was erased back to ground state, and (f) a twofold degenerate excited Type II state was written on the erased area. Credit: Yong-Lei Wang and Zhi-Li Xiao.

write, erase, or read function by adjusting the applied fields with varying distance to the sample surface.

A baseline in-plane magnetic field reduces the activation threshold for switching the spin state first, then the magnetic tip applies a small additional field to trigger the switch, causing a "write" action. Reversing the applied field "erases" the switch, and turning off the applied field resembles the "read" mode.

"In principle, our artificial magnetic charge ice could benefit the investigations and applications in any two-dimensional materials systems that change properties in a magnetic field," Wang says.

"The paper demonstrates a method of directly writing patterns into specific moments of an artificial ice array of nanomagnets," says Peter E. Schiffer, professor of physics and Vice Chancellor for Research at the University of Illinois at Urbana-Champaign. "Through the clever use of array geometry and external magnetic field, this microscopic control opens the door to new flexibility in the study of artificial spin ice."

YuHao Liu

Energy Focus

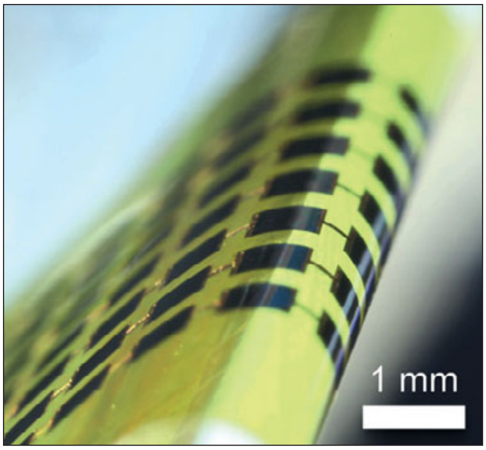
New process enables ultrathin, ultraflexible GaAs photovoltaics

By modifying a commonly used technique for printing solar cells on flexible materials, a team of South Korean scientists have created photovoltaics so flexible that they can bend around a pencil. As reported in a recent issue of *Applied Physics Letters* (doi:10.1063/1.4954039), the photovoltaics are based on ultrathin solar cells that are as efficient as similarly formed thicker cells, but can withstand extreme bending. These properties are ideal for powering wearable electronics like fitness trackers, as well as other devices that require mechanically flexible power sources.

The researchers created their ultrathin solar microcells out of gallium arsenide (GaAs). They stamped the cells directly onto a flexible substrate covered in gold using a modified version of a process called transfer-printing. Transfer-printing usually involves stamping solar cells onto an adhesive layer that lies on top of a substrate electrode. In this case, however, the team bypassed the adhesive layer altogether.

The researchers used heat and pressure to adhere the solar microcells directly to the gold-covered substrate. This process also melted a preexisting layer of photoresist over the microcells. The photoresist acted as a temporary adhesive and protected the microcells from damage when the stamp was peeled away. The photoresist was then removed, leaving behind a photovoltaic just 1 μm thick and extremely flexible.

The key to their success is the adhesive process, according to Jongho Lee, a professor at Gwangju Institute of Science and Technology and the leader of this research group. "Others usually use an interlayer adhesive between the solar cells and substrate. The interlayer adhesive, even with a conductive adhesive, increases the electrical and thermal resistance, reducing electrical performance." The interlayer adhesive, even with a conductive adhesive, increases the electrical and thermal resistance, reducing electrical performance." By eliminating the interlayer, the researchers eliminated this loss and reduced the thickness of the photovoltaic.



An optical image of the solar microcells wrapped around the edge of a glass slide 1 mm thick. Credit: Photo by Juho Kim. Reproduced with permission from *Appl. Phys. Lett.* **208**, 253101 (2016); doi: 10.1063/1.4954039. © 2016 AIP Publishing.

Most photovoltaics created by transfer-printing solar cells onto a flexible substrate are 2–4 times thicker than those created by this research team. Traditional designs use laterally conducting solar cells that require a thick bottom contact layer. This layer absorbs light, but does not generate electricity. By using vertically conducting solar cells, the researchers were able to reduce the thickness of the bottom contact layer without reducing performance.

In addition, most designs feature a thick base layer in order to absorb more photons and generate more electricity. In the new design this isn't necessary. The layer of gold in direct contact with the thin bottom contact layer acts as a reflector, rerouting photons back into the solar cell and giving them another chance to be absorbed.

John A. Rogers, an expert on flexible electronics from Northwestern University who was not affiliated with the research, considers the work to demonstrate powerful approaches for releasing GaAs cells from a source wafer and printing them onto substrates. "The authors introduce some interesting means to control the interface mechanics in a way that allows transfer-printing without separate adhesive layers," he says.

Looking to the future, Rogers continues, "An opportunity for the materials community is in the development of advanced release layers and associated epitaxial growth methods to enable this scheme to be used with multijunction solar cells that offer even higher performance."

The team is now working to optimize and extend the technology and process they developed in order to produce more efficient large-area solar-cell arrays.

Kendra Redmond