Controlling skyrmions with lasers

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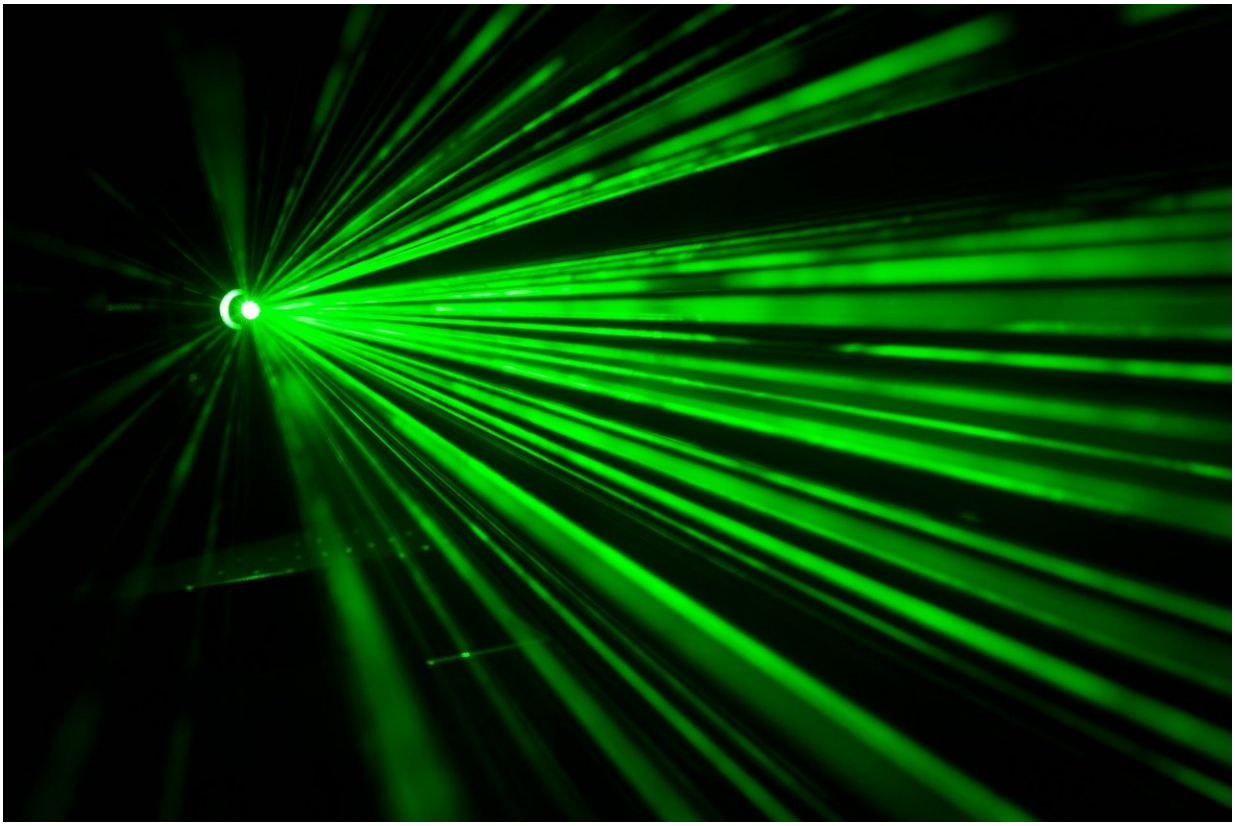

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EPFL scientists have produced controllable stable skyrmions using laser pulses, taking a step towards significantly more energy-efficient memory devices. The work is published in *Physical Review Letters*.

A skyrmion is a collection of electron spins that look like a vortex in

certain magnetic materials. Skyrmions can exist individually or in patterns referred to as lattices. Named after British physicist Tony Skyrme who first theorized the existence of their elementary-particle counterparts in 1962, skyrmions have attracted attention for their potential in being used in so-called "spintronic" devices, which would use the spin rather than the charge of electrons, thus becoming significantly more miniaturized and energy-efficient.

Most interest has been focused on memory-storage technologies. Skyrmions can be rather stable and require very little energy for writing or erasing them: some studies have shown that creating and annihilating skyrmions could be almost 10,000 times more energy-efficient than conventional data-storage devices. However, this would require a fast and reliable way of controlling and manipulating individual skyrmions.

Now, the labs of Fabrizio Carbone and Henrik M. Rønnow at EPFL have been able to write and erase stable skyrmions using laser pulses. The scientists used an iron-germanium alloy, which can host skyrmions at around 0oC, not too far from room temperature. This is important in of itself, as many of these fundamental experiments usually take place at temperatures too low to ever be commercially meaningful.

The researchers took advantage of the super-cooling effect that follows an ultrafast temperature jump, which is itself induced in the alloy by an ultrashort laser pulse. During the super-cooling, skyrmions can be frozen-in in places where they would not occur in conventional equilibrium conditions.

The forming skyrmions were imaged by using time-resolved cryogenic Lorentz electron microscopy, which can "see" magnetic domain structures and magnetization reversal mechanisms in real space and real time. This technique is an evolution of static cryo-electron microscopy, for which Jacques Dubochet won the Nobel Prize in Chemistry in 2017.

"What we did was apply a laser pulse to the alloy while it was kept at a temperature and external magnetic field that normally forbids the appearance of skyrmions," says Fabrizio Carbone. "Individual skyrmions were seen to appear near the edges of the sample at every light flash. Furthermore, once the skyrmions were established, by adjusting the parameters in proximity to the transition between having the skyrmions and not having them anymore, laser pulses can be used to erase them via local heating-induced demagnetization."

The researchers were able to write and erase skyrmions on the alloy within a few hundred nanoseconds to a few microseconds. However, the results also suggest routes to engineer the super-cooling rates for faster control of the skyrmions, down to picoseconds.

"The energy barriers for manipulating skyrmions can be very small," says Carbone. "This means that, if this was a memory-storage device, the energy consumption estimated by our experiments, in which the light properties were not yet tailored to optimize this parameter, is in the region of femto-Joules (quadrillionths of a Joule) per bit, already comparable to the most energy-efficient prototypes available."

Despite being a proof-of-principle study, the researchers couldn't resist thinking in terms of applications. "We actually calculated the energy it requires, without any optimization in our experiment," says Carbone. "And we found that it was already is at the level of the least energy-consuming data-storage device to-date. If implemented into devices, this would mean something like your laptop's battery lasting for about a month before needing to charge."

More information: Laser-induced Skyrmion writing and erasing in an ultrafast cryo-Lorentz transmission electron microscope. *Physical Review Letters*. journals.aps.org/prl/accepted/ … 260e829479aa1cf1bbaa

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