Researchers kick-start magnetic spin waves at nanoscale in pursuit of low energy computing

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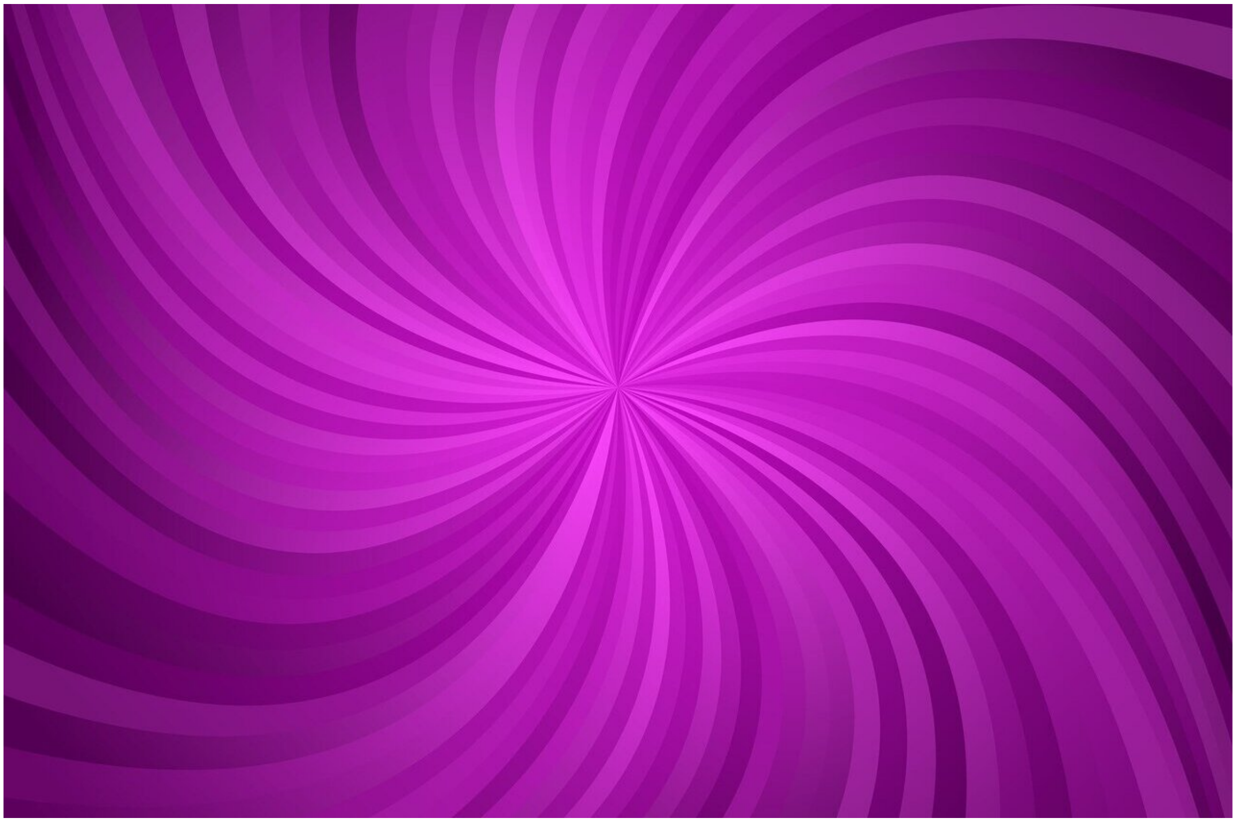

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An international team from Delft, Lancaster, Nijmegen, Kiev and Salerno has demonstrated a new technique to generate magnetic waves that propagate through the material at a speed much faster than the speed of sound.

These so-called spin waves produce a lot less heat than conventional electric currents, making them promising candidates for future computation devices with significantly reduced power consumption.

Physicists and engineers from all around the world are constantly thinking of ways to improve the performance of data processing devices. Many of their ideas revolve around substituting the electrical currents, which carry the signals in conventional electronics, with waves. Waves are coherent excitations, which means that information can be encoded into both the amplitude and the phase of the wave. Interference and diffraction, natural phenomena for a wave of any nature, enable the creation of so-called wave-based logic circuits, the tiny building blocks for future data processing applications. Since waves travel through materials with significantly lower resistance than electric currents, they have the potential to drastically reduce power consumption in future computing.

Spin waves in antiferromagnets

Magnetic waves, also called spin waves, are one of the most promising candidates for wave-based logic devices. Experiments using spin waves in regular (ferro)magnets have shown that it is possible to build small logic devices without using electrical currents. Ferromagnets are characterized by a net magnetization. Due to the latter, we can write and read magnetic information on ferromagnets with the help of an external magnetic field.

In recent years, there has been a focus shift towards the use of antiferromagnets. In antiferromagnetic materials, the microscopic magnetic moments of neighboring atoms—the spins—are tightly coupled and alternate between two opposite orientations, such that there is no net magnetisation. The existence of this alternating order leads to significantly higher spin-wave propagation velocities and the possibility of terahertz (trillion of hertz) operational clock-rates. However, absence of the magnetisation also makes antiferromagnets magnetically 'invisible': it is very hard to detect and influence the antiferromagnetic order. Practice has shown that generating and detecting spin waves that can move through antiferromagnetic media is even harder. As a result, computing concepts based on antiferromagnetic spin waves have so far existed as a theoretically appealing but experimentally uncharted field of exciting opportunities. Finding new ways to control the 'magnetic moments' in antiferromagnets is therefore of crucial importance.

The international team of researchers has now succeeded in creating nanometer-size coherent magnetic waves in an antiferromagnet that travel at supersonic velocities through the material. Their trick was to use ultrashort pulses of light to both create and detect these spin waves. "While we knew that ultrashort pulses of light are capable of influencing magnetic properties of antiferromagnetic materials, the possibility to launch short-wavelength propagating spin waves with light was still quite unexpected", says researcher Jorrit Hortensius of Delft University of Technology. "This is because light pulses lack the momentum necessary to create short-wavelength—or large momentum—spin waves."

A local ultrafast kick

It has been known for a few years that ultrashort pulses of light might hold the key to creating high-frequency propagating spin waves. Within a picosecond (a millionth of a millionth of a second), such pulses can shake up the ordered magnetic system and start magnetic motion in antiferromagnets. However, typically the excited area remains localized and does not support propagation. Making the excitation to travel across the material required another hidden ingredient. "Most antiferromagnetic materials are dielectrics, which means that they are transparent for visible light. We instead used ultraviolet light that is absorbed strongly, so that we only shake the spins very close to the material's surface, within the so-called skin-depth", says researcher Dmytro Afanasiev. "The combination of the ultrafast kick with the strong confinement at the material's surface turned out to be the combination to induce the propagation of antiferromagnetic spin waves."

The spin waves have wavelengths of around 100 nm, which is a lot smaller than the wavelength of the light. This makes the researchers believe that they might have created even smaller spin waves, even though they cannot observe them with their current instruments. Jorrit Hortensius: "As spin waves with very small wavelengths are the most interesting for creating highly compact computational elements, we are very curious to know what the limit is."

This work brings future spin-wave devices in antiferromagnets closer to reality. Rostislav Mikhaylovskiy from Lancaster University says: "Traditionally the antiferromagnetic materials have been considered practically useless since they do not possess magnetisation. However, very recently the unique functionalities of antiferromagnets triggered a real boom in their studies. We believe that our findings will stimulate further research into antiferromagnetic spin waves and eventually bring an antiferromagnet-based logic device into practical reach—potentially opening the door to a radical reduction in the power needed for computing."

More information: J. R. Hortensius et al, Coherent spin-wave transport in an antiferromagnet, *Nature Physics* (2021). DOI: 10.1038/s41567-021-01290-4

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