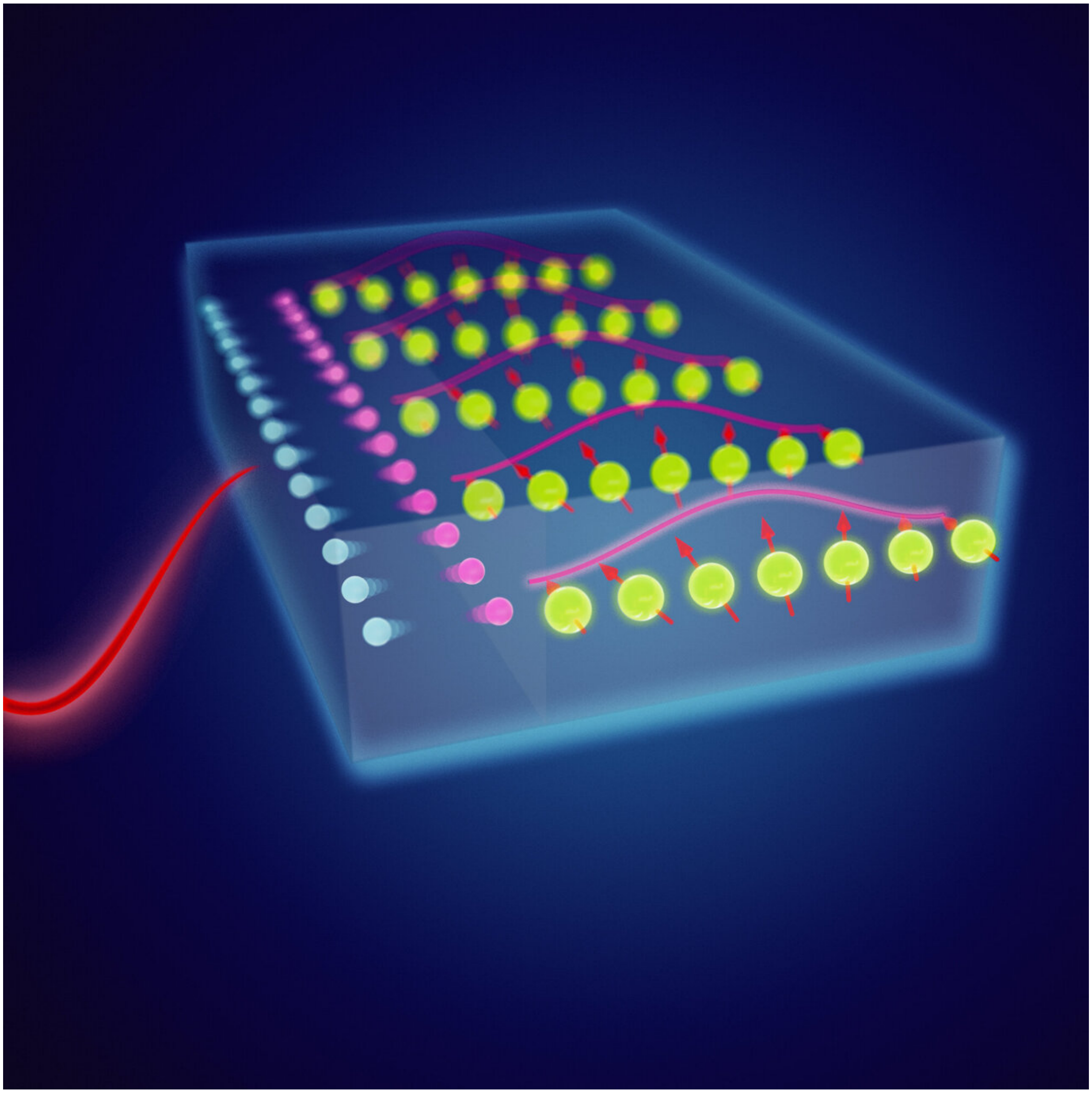
Scientists couple terahertz radiation with spin waves

January 31 2023



A terahertz light wave (from left) is converted into a spin wave (right) in a sample of thin metallic layers. In a heavy metal layer (left), electrical currents are first excited by the terahertz field. Within an ultrashort time, the spin Hall effect leads to the accumulation of spins with a certain orientation at the interface with a ferromagnetic layer (right). This directed spin current then triggers a coherent, nanomater-wavelength spin wave in the ferromagnetic material. Credit: HZDR/Juniks

An international research team led by the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) has developed a new method for the efficient coupling of terahertz waves with much shorter wavelengths, so-called spin waves. As the experts report in the journal *Nature Physics*, their experiments, in combination with theoretical models, clarify the fundamental mechanisms of this process previously thought impossible. The results are an important step for the development of novel, energy-saving spin-based technologies for data processing.

"We were able to efficiently excite high-energy spin waves using terahertz light in a sandwich-like material system consisting of two metal films a few nanometers thick, with a ferromagnetic layer sandwiched in between," says Dr. Sergey Kovalev of the Institute of Radiation Physics at HZDR, where the experiments were conducted. Electrons have an effective spin which behaves like a spinning top.

And like a gyroscope, an external perturbation can tilt the spin's axis of rotation: A gyroscopic motion, called precession, follows suit. In ferromagnetic materials, there is a very strong interaction between the electron spins, and as a result, a precession started locally continues in the form of a spin wave throughout the ferromagnetic material layer.

This is interesting because a spin wave—like any wave—can be used as an information carrier. While each electron spin is in motion, in the ferromagnets considered it remains in its position in the atomic lattice, therefore no current flow is involved. So, unlike in today's computer chips, there are no heat losses due to currents in spin-based devices.

Conveniently, the characteristic frequencies of the high-energy spin waves are in the terahertz range. This is exactly the target range for novel ultrafast technologies for data transmission and processing. Coupling optical terahertz technology with spin-based devices could therefore enable completely new and efficient concepts for IT technologies.

Problem: Communication between different types of waves

Similar to light, which can also be described in terms of individual particles called photons, the energies of spin waves are quantized, and the quanta of spin waves are called magnons. Magnons and terahertz photons have the same energies and should therefore be easily convertible into each other. But there is a problem along the way: the completely different speed of the two wave phenomena.

Terahertz waves travel as electromagnetic radiation at the speed of light, while spin waves are tied to the existence of interacting spins. Their propagation speed is hundreds of times slower than that of light. And while terahertz waves have a wavelength of slightly less than a millimeter, the wavelength of spin waves, on the other hand, is in the range of only a few nanometers. As a result, the terahertz wave has no chance of transferring its energy specifically and directly to a much slower spin wave.

To solve this problem, the researchers have devised a combination of extremely thin metallic layers of tantalum and platinum, in the middle of which they have inserted a thin layer of a ferromagnetic nickel-iron alloy. This combination of materials is precisely tuned to "translate" signals from the world of light into the world of spins.

From light to spin in many steps

They developed and produced their functional layer material at the HZDR Institute of Ion Beam Physics and Materials Research. To do so, they gradually vapor deposited metal films onto a thin glass substrate. "In the experiment, we then bombarded the samples with intense terahertz pulses and measured their rapidly time-varying magnetization with optical laser pulses. We found characteristic oscillations of the magnetization, even for times when the exciting terahertz pulse was no longer interacting with the sample at all," Kovalev explains.

"We varied many factors, such as external magnetic fields and different material compositions of the layers, until we could confidently show that these were indeed the spin waves we were looking for," says teammate Dr. Ruslan Salikhov, who is working on new functional magnetic materials.

For this transformation of an electromagnetic wave into a spin wave, the team took advantage of a whole range of different quantum effects. Figuratively speaking, these effects ensure that the terahertz wave and spin wave understand each other. First, terahertz radiation accelerates free electrons in the heavy metal, allowing microscopic currents to form.

These currents are converted into spin currents by the so-called spin Hall effect, i.e., currents of electrons that have only a very specific spin orientation and thus can transport the resulting angular momentum in local space. At the interfaces between the heavy metal and the ferromagnet, this angular momentum then exerts a torque on the spins in the ferromagnet. This torque delivers precisely the perturbation that leads to the formation of spin waves.

By comparing different samples, the scientists have now been able to show that the terahertz field itself is not capable of directly generating spin waves. Only the detour leads to success. They were thus able to confirm theoretical predictions about the efficiency of spin-orbit torques on picosecond time scales.

The new sample system therefore functions as a terahertz-driven source of spin waves that could, in principle, be easily integrated into circuits. This work is an important step towards the use of terahertz technology in novel electronic components. At the same time, the demonstrated method opens up new possibilities for non-contact characterization of spin-based devices.

More information: Ruslan Salikhov et al, Coupling of terahertz light with nanometre-wavelength magnon modes via spin–orbit torque, *Nature Physics* (2023). DOI: 10.1038/s41567-022-01908-1

Provided by Helmholtz Association of German Research Centres

Citation: Scientists couple terahertz radiation with spin waves (2023, January 31) retrieved 27 April 2024 from https://phys.org/news/2023-01-scientists-couple-terahertz.html