Spin-wave manipulation

The directional manipulation of spin waves, a long-awaited technique in spintronics, has now been realized by shaping a light pulse. Takuya Satoh from the University of Tokyo talked to *Nature Photonics* about the technique.

■ What is the motivation for your work?

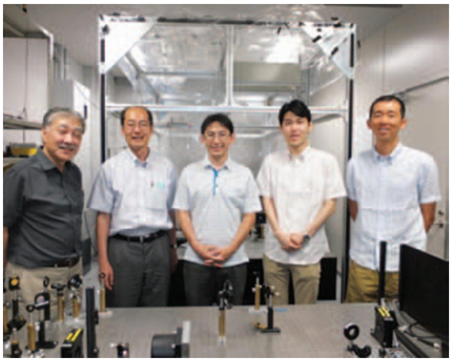
Originally optical spin excitation did not seem very special to me, because it is obvious that the spin state can be excited to its upper state by acquiring photon energy. When I was investigating a novel optical measurement technique, I happened to read a paper in which the authors had achieved non-thermal, ultrafast spin manipulation through the use of light polarization of a pump beam (A. V. Kimel *et al.*, *Nature* **435,** 655; 2005). Their observation of spin excitation was focused only within the illuminated area, but the proposed technique seemed versatile and exciting. Another paper that gave me inspiration for our work is one that reported the experimental demonstration of spin-wave propagation in yttrium iron garnet using an applied electric voltage (Y. Kajiwara *et al.*, *Nature* **464,** 262; 2010). I looked through the paper of Kajiwara *et al.* and felt that maybe we could optically manipulate spin waves.

■ Why do you use a bismuth-doped iron garnet crystal for your work?

Yttrium iron garnet has been well known as a magnetic material for a long time. Among magnetic materials it is unique in that it is transparent to near-infrared light, is electrically insulating and is ferrimagnetic with a very low damping factor at room temperature. There is no other material like this. Considering the paper of Kajiwara *et al.* (*Nature* **464,** 262; 2010), I thought yttrium iron garnet to be the most suitable material for our work. To take advantage of its large magneto-optical effect, I finally decided to use a bismuth-doped iron garnet crystal. Such crystals have been commercially used as optical isolators.

■ What was the most difficult part of the analysis of spin-wave emission?

We easily obtained experimental data that seemed to demonstrate spin-wave propagation. However, it was not clear what kind of spin wave we had excited. Was it a magnetostatic wave or an exchange spin wave? If it was a magnetostatic wave, was it a bulk wave or a surface wave? Also, we did not understand why the wavelength of the emitted spin wave was 200–300 μm. We struggled to find the mechanism behind the emission. We had the idea that the wavenumber of the emitted spin wave might be relevant to the Fourier-transformed spectrum of the spatial intensity distribution of the pump spot. In the simulations we came up against another problem regarding the dispersion, $\omega(\boldsymbol{k})$ (equation (1) of our paper). The function should be valid for all $\boldsymbol{k}$-space. It took a long time to justify the model underlying our simulation. But thanks to a rigorous description of the dispersion function we were able to reproduce the experimental results unbelievably well. No one ever imagined that the spatial intensity distribution of the pump spot determined the wavelength of the spin wave emission, I think.


NORIAKI HORIUCHI

Kazuo Kuroda, Tsutomu Shimura, Takuya Satoh, Yuki Terui and Rai Moriya (left to right). The researchers, from the University of Tokyo in Japan in collaboration with Institute of Magnetism in Ukraine and Tohoku University in Japan, have successfully controlled the direction of spin-wave emission by spatially shaping a light pulse.

■ Can your findings be applied to waves other than spin waves?

Equation (1) of our paper is a general formula describing the relation between the dispersion of an optically excited wave and the spatial intensity distribution of the pump spot. So it can be applicable to, for example, elastic waves induced by laser beam irradiation. In that case we would need to excite low-loss elastic waves with a long decay time for the observation of elastic-wave propagation. The propagation distance would increase and therefore become easy to observe if we excited the elastic waves under conditions where their group velocity becomes large.

■ What are the challenges and future research directions?

I am planning to develop the pump–probe measurement technique to give flexible control of the initial phase of the excited spin precession. This will allow us to synthesize two-dimensional spin waves. Unfortunately, in our technique, the initial phase is fixed to be 0 or π, corresponding to right-handed or left-handed polarized light, respectively.

I am also curious about the spin-wave behaviour for larger wavenumbers. To be honest, the wavenumber was small in our experiment and the spin wave was described by the magnetic dipolar interaction only. However, if the wavenumber is large, the properties of spin waves are dominated by the exchange interaction. So if we can narrow the pump spot size from 50 μm to about the nanoscale, by using, for example, near-field optical techniques, I expect that the spin-wave propagation might be different from what we reported in our paper.

Another challenge is the study of nonlinear interactions between spin waves. At present, nonlinear interactions can be induced by illuminating with intense microwaves. But we are mostly limited to observing a static phenomenon. For this reason, the pump–probe measurement technique employed in our work is promising as a means of investigating transient nonlinear interactions.

INTERVIEW BY NORIAKI HORIUCHI

Takuya Satoh and his co-workers have an Article on the directional control of spin-wave emission on page 662 of this issue.