Photons and magnetization

Magnets are often electrically activated, but recent research has demonstrated various schemes that can control magnetization using light and photocarriers. *Nature Photonics* spoke to Petr Němec and Tomas Jungwirth about their recent work on a polarization-independent optical-torque approach.

What was the motivation for this research?

Using photocarriers instead of electrical currents to manipulate magnets is attractive both from a fundamental physics perspective and for potential spintronic applications. It allows magnets to be excited on timescales several orders of magnitude shorter than those achievable using electrical currents. From a practical perspective, magnetic memories, for example, could be written much faster optically than electrically. In addition, the duration of a laser pulse can be much shorter than the typical precession time of magnetization, which allows physical insights to be gained into the general mechanisms by which non-equilibrium charge carriers interact with magnetic moments. Since their discovery about 20 years ago, ferromagnetic semiconductors (particularly GaMnAs) have been considered ideal systems for exploring the possibility of exciting magnets by photocarriers. However, it took many years of material optimization and optical measurements before optical counterparts of current-induced spin torques could be clearly realized.

What work has been done in this area previously?

As mentioned, magnetic semiconductors are suitable materials for exploring the effects of photocarriers on magnetization. The main difficulty with identifying optical analogues of current-induced spin torques was the existence of competing thermal excitation mechanisms. We have devised several complementary schemes to disentangle photocarrier-induced and thermally induced effects, or even to eliminate thermally induced effects completely. These schemes require careful optimization of the micromagnetic parameters of our GaMnAs films, both *ex situ* and *in situ*. There are other types of effects by which light can induce magnetization dynamics: so-called inverse magneto-optical effects. In contrast with optical spin–torque effects, these effects do not rely on photon absorption or photocarrier generation. They have been observed in insulating or metal ferromagnets and typically require higher laser intensities.

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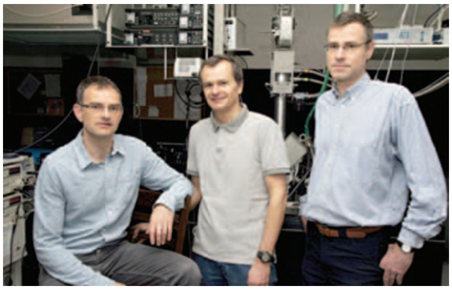

From left to right: Tomas Jungwirth, Petr Němec and Vit Novák.

What did you achieve in your present study?

Following our observation of optical spin-transfer torque induced by circularly polarized light (*Nature Phys.* **8,** 411–415; 2012), we focused on polarization-independent excitations. This is conceptually a more intriguing problem because disentangling the competing thermal excitation mechanism is more challenging, and because the optical spin–orbit torque we were searching for is a relativistic quantum-mechanical phenomenon. The optical spin–orbit torque was directly identified using a technique we developed in an earlier work, which allows the measured dynamic magneto-optical signals in our pump–probe experiments to be translated into the time-dependent magnetization vector trajectory. Critically, this is done without assuming any theoretical model for the magnetization dynamics and without using any fitting parameter. Our experimental method exploits the different dependences of the polar Kerr effect and magnetic linear dichroism on the orientation of the linear polarization of the probe laser pulses to disentangle the contributions to the magneto-optical signal from the out-of-plane and in-plane components of the magnetization motion.

What are the main limitations of this approach?

The main limitation we see at the moment is the general applicability of the optical spin–orbit torque to other material systems. Because it relies on photocarriers, this scheme is most readily applicable to magnetic semiconductors. Simultaneously realizing robust ferromagnetism at room temperature and semiconducting properties in one material is a significant research challenge. However, the optical spin–orbit torque is an inherently relativistic effect, which to the first order can be viewed as a consequence of the carrier-dependent magnetocrystalline anisotropy. As relativistic magnetic anisotropy phenomena are equally present in ferromagnets and antiferromagnets, there is the possibility of overcoming the limit imposed by the low transition temperature of ferromagnetic semiconductors. Antiferromagnetic semiconductors frequently have ordering temperatures well above room temperature, and spin–orbit torque should be readily observable in these materials. This fits within the new general concept of spintronics based on antiferromagnets, which we have been pursuing recently in parallel with these magneto-optical studies.

What was the main challenge in your work?

The biggest challenge was clearly distinguishing between the thermally induced magnetization dynamics and the photocarrier-induced spin–orbit torque in our measured data. Overcoming this challenge would not have been possible without tedious optimization of GaMnAs materials, as well as gaining a detailed understanding of their magneto-optical coefficients both in static and dynamic optical measurements. A detailed assessment of micromagnetic parameters of a series of optimized GaMnAs materials obtained from our optical ferromagnetic resonance measurements has been published recently (*Nat. Commun.* **4,** 1422; 2013).

What are your plans for the future?

Our immediate aim is to move from small-angle precessions induced by optical spin torques to the reorientation of the magnetization. We also intend to expand the range of studied materials; in particular, by including antiferromagnets.

INTERVIEW BY DAVID PILE

Petr Němec, Tomas Jungworth and colleagues have an Article about optical spin–orbit torque on page 492 of this issue.