selective control over the diffraction properties of beams having different polarizations. When the crystal is cooled as a whole, the random orientations of the polar regions result in polarization-insensitive beam propagation. However, if a temperature gradient is applied across the crystal, then the beam's diffraction properties become dependent on its polarization. Experimental results demonstrate that it is possible to suppress diffraction for one polarization while allowing diffraction for beams of another polarization. This is a useful feature that could be used for applications such as polarization-sensitive imaging.

The work of DelRe *et al.* used a beam size of 15 µm, which is much larger than the optical wavelength of 632.8 nm for a He–Ne laser. The researchers make the interesting theoretical prediction that their scheme may be capable of cancelling diffraction even in beams of subwavelength width. However, diffraction would be completely suppressed only for beams with a special type of square-shaped profile. It remains to be seen how such beams can be excited in practice, and whether partial diffraction cancellation could be accessible for more commonly occurring beam shapes such as the Gaussian profile. If the manipulation of subwavelength beams is successfully realized, this may offer new possibilities for imaging.

The diffraction cancellation method of DelRe *et al.* has particular features that must be carefully considered, especially for any potential applications in imaging. Although diffraction can be suppressed for Gaussian beams, other beam shapes may exhibit strong reshaping, which would prevent their use in imaging. In particular, DelRe *et al.* show that a stripe beam (strongly elongated along one transverse direction) exhibits instability and breaks into several non-diffracting beams with approximately Gaussian profiles. Another limitation is that if the optical wavelength is varied, diffraction cancellation becomes non-exact for Gaussian beams. The response time for beam self-trapping in KTN:Li is relatively slow — of the order of 100 s. DelRe *et al.* suggest that the concept of scale-free optics could be realized in other crystals or glass-ceramics featuring ferroelectric and photorefractive properties, and it would be important to reduce response times as much as possible in such structures.

The concept of scale-independent diffraction cancellation is a fascinating and fundamentally important advance in the field of nonlinear optics. Nevertheless, further detailed investigations are needed to determine the operating conditions under which this approach will be beneficial. ❐

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References

1. DelRe, E., Spinozzi, E., Agranat, A. J. & Conti, C. *Nature Photon.* **5,** 39–42 (2011).
2. Christodoulides, D. N., Lederer, F. & Silberberg, Y. *Nature* **424,** 817–823 (2003).
3. Joannopoulos, J. D., Meade, R. D. & Winn, J. N. *Photonic Crystals: Molding the Flow of Light* (Princeton University, 2008).
4. Rakich, P. T. *et al. Nature Mater.* **5,** 93–96 (2006).
5. Szameit, A. *et al. Nature Phys.* **5,** 271–275 (2009).
6. Stegeman, G. I. & Segev, M. *Science* **286,** 1518–1523 (1999).
7. Kivshar, Yu. S. & Agrawal, G. P. *Optical Solitons: From Fibers to Photonic Crystals* (Academic, 2003).

SPINTRONICS

Coherent terahertz control

Spin and charge terahertz excitations in solids are promising for implementing future technologies such as spintronics and quantum computation, but coherently controlling them has been a significant challenge. Researchers have now manipulated coherent spin waves in an antiferromagnet using the intense magnetic field of ultrashort terahertz pulses.

Junichiro Kono

Controlling quantum coherent states in solids is a key technical requirement for implementing future information technologies such as spintronics (using the spin of elementary particles to store data and perform processing tasks) and quantum computation. The realization of such technologies requires an appropriate excitation or transition in a solid with a long coherence time that can be driven and manipulated by external means.

Electromagnetic pulses in the terahertz (THz, or 10^{12} Hz) frequency range can excite a wide variety of spin and charge excitations in solids, including plasmons, phonons, magnons, intersubband transitions, cyclotron and spin resonances, and superconducting gap excitations. However, coherently exciting and controlling such excitations has proved a challenge, primarily because there are few sources that produce ultrashort and intense pulses of electromagnetic fields in the THz range. This frequency range is also known as the 'technology gap' between electronics and photonics, and is considered to be the last frontier of the electromagnetic spectrum remaining to be exploited by solid-state technology.

Now, writing in *Nature Photonics*[1], Tobias Kampfrath and co-workers demonstrate that the magnetic component of intense, ultrashort THz pulses can be used to coherently control collective spin excitations, known as magnons, in solids. The researchers used single-cycle THz pulses to turn on and off coherent magnons in antiferromagnetically ordered nickel oxide at room temperature with a resonance frequency of ~1 THz. An ultrashort (~8 fs) optical probe pulse was used to monitor the THz-induced magnetic dynamics directly in the time domain through time-resolved Faraday rotation (a magnetic-field-induced change in the polarization of the probe light). Through pump-power-dependent measurements and detailed simulations, Kampfrath *et al.* concluded that the magnetic field component of the THz field was addressing the spins selectively through a magnetic dipole interaction (Fig. 1).

This work should be considered in context with the ongoing efforts of many groups in the area of spintronics to manipulate electronic spins optically[2]. In particular, over the past decade, ultrafast magneto-optical studies of magnetically ordered systems have produced an assortment of exciting and sometimes conflicting results, whose microscopic understanding has been elusive[3–6]. It has been experimentally established that an optical pulse can induce changes in magnetism on ultrashort timescales, but exactly how light can modify magnetism in such a quasi-instantaneous manner is a matter of controversy. An important point to note is that in these previous studies of ultrafast magneto-optics, the light field itself never directly coupled with the magnetic order — its primary role has been to excite a transient, non-equilibrium distribution of carriers, which subsequently relaxed in energy and momentum while interacting with the lattice and ordered spins. As a result, magnetism was only indirectly affected and modified by light. This is distinctly different from the work of Kampfrath and co-workers[1], in which the magnetic field component of the intense THz field directly interacts with and modifies the magnetic state of the system via the Zeeman torque $\propto \mathbf{S} \times \mathbf{B}$, where **S** is the electron spin angular momentum and **B** is the transient magnetic field, thereby inducing and manipulating coherent magnons (Fig. 1).

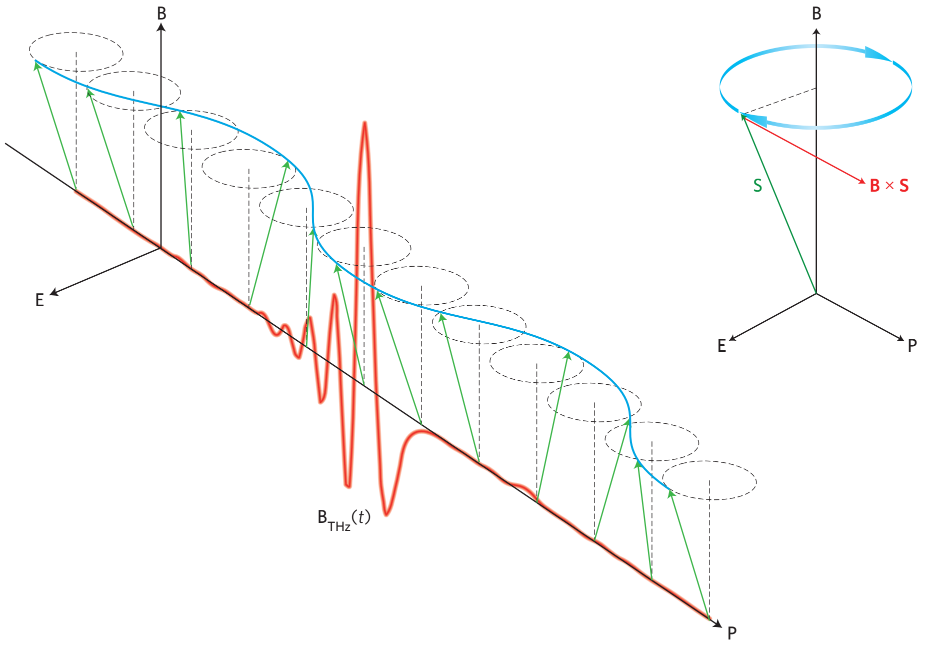

Figure 1 | The magnetic field component (**B**) of an ultrashort terahertz pulse — perpendicular to both the electric field component (**E**) and the propagation direction (the Poynting vector **P**) — excites coherent magnons through the magnetic dipole interaction. The torque exerted by the magnetic field on the spin (**S**; shown inset) induces spin precession. The magnon, shown by the line connecting the spin tips, has a period of ~1 ps.

The use of pulsed a.c. magnetic fields with megahertz and gigahertz frequencies for coherent manipulation of spins has a long history in the field of nuclear magnetic resonance (NMR), dating back to the pivotal spin-echo experiments of Erwin Hahn in 1950[7]. More recently, pulsed NMR methods have been used to perform quantum computation using molecules[8]. However, decoherence times in solids are so short that ultrafast (femtosecond or picosecond) pulses of high-intensity magnetic fields are necessary for performing coherent control experiments on magnetic excitations in solids. Large pulsed magnetic fields (in excess of 100 T) can be produced using various destructive methods[9], but the microsecond-scale pulse widths remain too large for studying coherent magnetic phenomena in solids. The existence of a transient high magnetic field within ultrashort optical pulses has long been recognized by laser scientists as a potentially useful tool, but an effective demonstration of their utility did not exist until now[1].

Kampfrath *et al.* used a transient magnetic field with a peak field-strength of 0.13 T in their experiments, which gave a correspondingly high-intensity electric field component of $\sim$0.4 MV cm^{-1}. The effect of the huge electric field was surprisingly small, however, with no sign of heat deposited by the field. This was primarily because nickel oxide is an insulator, in which the free-carrier absorption of THz electric fields is negligibly small. The Zeeman torque exerted on the spins by the transient magnetic fields initiated magnon oscillations, which were then either enhanced or reduced, depending on the arrival time of the second magnetic field pulse. Simulations based on a Landau–Lifshitz–Gilbert equation for magnetic coupling successfully reproduced these experimental observations.

The findings of Kampfrath *et al.* open up an entirely new field of research into the interactions of intense and ultrashort pulses of magnetic fields with matter. A range of exciting new experiments using such coherent magnetic field pulses in the THz range are now on the horizon, including the coherent manipulation of spins in solids — possibly even single electron spins — for the purposes of quantum information processing. Transient megagauss (>100 T) fields might one day become available through further improvements in generation techniques, and such intense and transient magnetic fields may allow the development of magnetic-dipole-excited nonlinear optics in non-perturbative regimes. There are, however, several technical challenges that must be overcome before further progress can be made. The main problem is related to the heating and damage problems associated with the intense electric field component of the THz field, which is orders of magnitude larger than the magnetic field component. Such problems were avoided in the work of Kampfrath *et al.* by using an insulating antiferromagnetic specimen, but coherent excitations and manipulations in magnetic and/or superconducting systems containing itinerant electrons are expected to be even more exotic and interesting to study with intense magnetic fields. New ideas are now needed to enable such innovative experiments. ❐

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References

1. Kampfrath, T. *et al. Nature Photon.* **5,** 31–34 (2011).
2. Awschalom, D. D. & Samarth, N. in *Semiconductor Spintronics and Quantum Computation* (eds Awschalom, D. D. *et al.*) 147–194 (Springer, 2002).
3. Zhang, G., Hübner, W., Beaurepaire, E. & Bigot, J.-Y. in *Spin Dynamics in Confined Magnetic Structures I* (eds Hillebrands, B. & Ounadjela, K.) 245–288 (Springer, 2002).
4. Wang, J. *et al. J. Phys. Cond. Matt.* **18,** R501–R530 (2006).
5. Koopmans, B. *et al. Nature Mater.* **9,** 259–265 (2010).
6. Kirilyuk, A., Kimel, A. V. & Rasing, Th. *Rev. Mod. Phys.* **82,** 2731–2784 (2010).
7. Hahn, E. L. *Phys. Rev.* **80,** 580–594 (1950).
8. Gershenfeld, N. A. & Chuang, I. L. *Science* **275,** 350–356 (1997).
9. Herlach, F. & Miura, N. *High Magnetic Fields: Science and Technology* Vol. 1 (World Scientific, 2003).