Zernike Colloquium

December 5th, 2024
16:00h
5111.0080

Shaken, not stirred:
ultrafast magnetic switching via phononic resonances

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Excitations of the crystal lattice have a significant impact on the orbital dynamics of the electrons, and through it, also on spins. Recently, ultrafast optical techniques have provided new insights into the spin-lattice coupling including angular momentum transfer from magnetization to phonons [1,2]. It should therefore be possible to realize the opposite process, by driving the lattice and thus controlling the magnetization, on the same (femtosecond) time scale.
To provide resonant excitation of the optical phonon modes, we use pulses from FELIX (Free Electron Lasers for Infrared eXperiments, Nijmegen, The Netherlands). Single pulses of IR/THz light with photon energy ranging between 25 meV and 124 meV (wavelength 10-50 micron) are typically used.
We have thus demonstrated that the resonant excitation of circularly-polarized optical phonons in paramagnetic substrates can permanently reverse the magnetic state of the overlayer [3]. This was shown to be the result of a phono-magnetic effect, which is a low-frequency analogue of the inverse Faraday effect. With the handedness of the phonons steering the direction of switching, such effect offers a selective and potentially universal method for ultrafast non-local control over magnetic order.
Moreover, a different and ultimately universal behaviour, characterized by displacive modification of crystal potentials, is driven by linearly-polarized excitation. The magnetic switching was shown to create very peculiar quadrupolar spatial patterns [4], confirming the mechanism. The mechanism appears to be very universal, and is shown to work in samples with very different crystallographic symmetry and magnetic properties, including weak ferromagnets and antiferromagnets, but also completely different systems such as ferroelectrics [5]. The dynamics of the domain formation was shown to proceed via a strongly inhomogeneous magnetic state resulting in a self-organization of magnon-polarons [6] and development of magneto-elastic solitons.

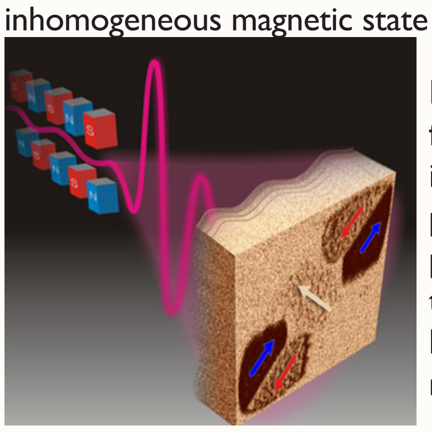

Figure: A single picosecond pulse from the free electron laser FELIX in the frequency range of optical phonons creates a peculiar guadru-pole pattern of reversed magnetiza-tion, which serves as a fingerprint of lattice-strain driven reversal mecha-nism [4].

[1] C. Dornes et al, Nature 565, 209 (2019).
[2] S.R. Tauchert et al, Nature 602, 73 (2022).
[3] C.S. Davies, F.G.N. Fennema, A. Tsukamoto, I. Razdolski, A.V. Kimel & A. Kirilyuk, Nature 628, 540 (2024).
[4] A. Stupakiewicz, C.S. Davies, K. Szerenos, D. Afanasiev, K. S. Rabinovich, A.V. Boris, A. Caviglia, A.V. Kimel, & A. Kirilyuk, Nat. Phys. 17, 489 (2021).
[5] M. Kwaaitaal, D.G. Lourens, C.S. Davies & A. Kirilyuk, Nat. Photon. 18, 569 (2024).
[6] M. Gidding, T. Janssen, C.S. Davies & A. Kirilyuk, Nat. Commun. 14, 2208 (2023).

Coffee from 15:30h
Drinks & Snacks after

university of groningen
faculty of science and engineering