Light control of magnetism: various time- and length scales

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While the basic possibilities for direct laser manipulation of magnetization have been indicated a long time ago, only recently was it possible to apply such control in magnetically ordered materials [1,2].

The question was immediately triggered whether one could use the same mechanism for practical switching of the magnetization in e.g. recording media. A seemingly straightforward answer came very soon afterwards, with a direct demonstration of all-optical light helicity-dependent magnetic recording in thin films of metallic GdFeCo alloys [3]. In spite of the fact that the switching was clearly reproducible and robust, the exact process and mechanism of it remained elusive for a long time. The most obvious explanation via the inverse Faraday effect could only very qualitatively account for the observed features. Taking into account several factors, all-optical switching of the magnetization in rare-earth - transition metal alloys was assigned to a completely different effect: a combination of ultrafast laser-induced demagnetization with the angular-momentum conservation in the exchanged-coupled sublattices of a ferrimagnet, on a sub-picosecond time scale [4].

In spite of the recent extensive work on all-optical switching of magnetization in a variety of samples [5,6], confusion persists as to its mechanism. Here we demonstrate, using various time-resolved imaging techniques, that this confusion may be largely due to the fact that this phenomenon involves behavior on multiple scales, both in space and time. At 100's fs, independent demagnetization of sublattices is observed accompanied by spin diffusive processes at <10 nm distances, as shown by time-resolved X-ray scattering [7]. This is followed by the exchange spring driven behavior [4] with reversal and formation of skyrmion-like domains [8] at a few ps times.

In order to tune the exchange interaction between the sublattices, the alloyed samples were replaced with multilayers. Intriguingly, very large scale coherent precession could be observed that accompany the growth of large domains [9]. The presence of the compensation point added an extra spatial feature to the reversal dynamics in the multilayer samples.

To be technologically meaningful, the all-optical switching must be able to compete with the bit densities of conventional storage devices, restricting optically-switched magnetic areas to sizes well below the diffraction limit. We have recently demonstrated reproducible all-optical switching of magnetic domains of few tens of nm size [10], in a ferrimagnetic TbFeCo alloy using gold plasmonic antenna structures. It has also been found that the focusing of light to a nm-sized area is helped by the light interference effects occurring within the magnetic structures themselves [11].

To summarize, such ultrafast exchange-driven ultrafast magnetization dynamics is not only potentially useful, but also provides us with invaluable information about the behavior of magnets away from their thermodynamic equilibrium. For recent review the reader is referred to ref. 4. Considering the progress in the development of compact ultrafast lasers, optical control of magnetic order may also potentially revolutionize data storage and information processing technologies.

References:

1. A.V. Kimel et al., Nature, **435**, 655 (2005)
2. F. Hansteen et al., Phys. Rev. Lett. **95**, 047402 (2005).
3. C.D. Stanciu et al, Phys. Rev. Lett. **99**, 047601 (2007).
4. A. Kirilyuk, A.V. Kimel, and Th. Rasing, Rep. Prog. Phys. **76** , 026501 (2013).
5. C.-H. Lambert et al, Science **345**, 1337 (2014).
6. S. Mangin et al., Nature Materials **13**, 287 (2014).
7. C.E. Graves et al, Nature Materials **12**, 293 (2013).
8. M. Finazzi et al, Phys. Rev. Lett. **110**, 177205 (2013).
9. M. Savoini et al, submitted.
10. T.M. Liu et al, submitted.
11. L. Le Guyader et al, Nature Comm. **6**, 5839 (2015).