Ultrafast science using pulsed ultrashort X-ray sources.

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Ultrafast processes involving the electrons and spins are important issues for both fundamental science and for the applications, in order to optimize both, the recording speed and densities, down to the picosecond time and nanometer length scales. Application of ultrashort Infra-Red (IR) laser pulses allows ultimately the manipulation of the local magnetization in magnetic films. The important time scales are below one picosecond down to the femtosecond scale. In order to understand the change of the initial magnetic or structural state, induced by IR laser pulses, it is essential to describe the individual and fundamental processes taking place during the first hundred femtoseconds. Since the first observation of laser induced spin dynamics [1] performed by time resolved magneto-optics, the mechanisms responsible for the femtosecond demagnetization have been widely debated, but no consensus could be found until today.

Recently, time-resolved X-ray Magnetic Circular Dichroism (XMCD) using synchrotron facilities and X-ray free electron sources have provided femtosecond time resolution and thus new information concerning femtosecond demagnetization dynamics. The XMCD spectroscopy is an element-specific tool which can be used to study ultrafast magnetization, electronic or structural dynamics with chemical resolution. Whereas at high X-ray energies (E ~20 keV) the dynamics of the crystalline structure and phase transitions can be described, at soft X-ray energies (E ~1eV) it is now possible to measure the dynamics of the spin and orbital magnetic moments with a high temporal resolution (100 fs) [2-5].

One of the recent results using the new potentialities of the XMCD technic, show that right after the IR laser excitation, interatomic transfer of angular moment takes place at the femtosecond scale, whereas the global demagnetization proceeds, illustrating one of the most efficient way of conservation of angular moment, during the loss of magnetization in the system (Figure 1). In parallel, a continuously increasing number of spectro-microscopy technics emerged where XMCD is used as a fingerprint for the ultrafast mechanisms involved in the ultrafast dynamics of spins. For instance, in addition to the circular polarization, the coherence of the X-ray beam is used to observe the dynamics of magnetic domains or the dynamics of the recovery of the magnetic order, focussing on the reversible or irreversible domain transformations in single pump-probe experiments, setting the limits of multi pump-probe experiments [6].

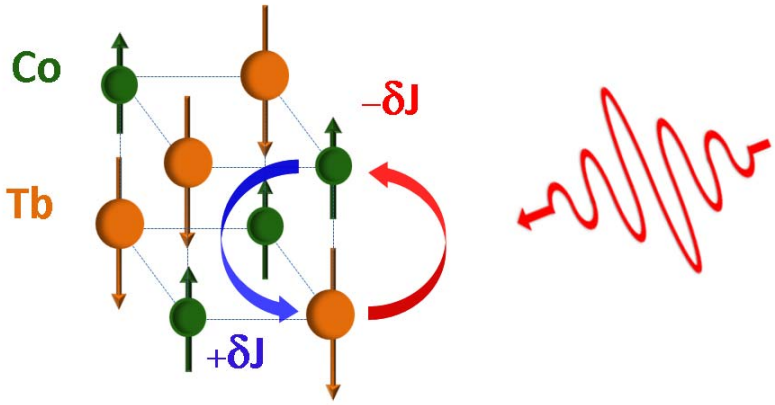

Figure 1: Transfer of angular momenta between two different elements after an external laser pulse excitation.

[1] E. Beaurepaire, J.C. Merle, A. Daunois, and J.-Y. Bigot, Phys. Rev. Lett. **76**, 4250 (1996).
[2] C. Boeglin, E. Beaurepaire, V. Halté, V. Lopez-Flores, C. Stamm, N. Pontius, H. A. Dürr, and J.-Y. Bigot, Nature **465**, 458 (2010).
[3] M. Wietstruk, A. Melnikov, C. Stamm, T. Kachel, N. Pontius, M. Sultan, C. Gahl, M. Weinelt, H. A. Dürr, and U. Bovensiepen, Phys. Rev. Lett. **106**, 127401 (2011).
[4] V. López-Flores, N. Bergeard, V. Halté, C Stamm, N. Pontius, M. Hehn, E. Otero, E. Beaurepaire, C. Boeglin , Phys. Rev. B **87**, 214412 (2013)
[5] N. Bergeard, V. López-Flores, V. Halté, C Stamm, N. Pontius, M. Hehn, E. Beaurepaire and C. Boeglin, Nature Com. **5**, 3466 (2014).
[6] N. Bergeard, Stefan Schaffert, Víctor López-Flores, Nicolas Jaouen, Jan Geilhufe, Christian M. Günther, Michael Schneider, Catherine Graves, Tianhan Wang, Benny Wu, Andreas Scherz, Cédric Baumier, Renaud Delaunay, Franck Fortuna, Marina Tortarolo, Bharati Tudu, Oleg Krupin, Michael P. Minitti, Joe Robinson, William F. Schlotter, Joshua J. Turner, Jan Lüning, Stefan Eisebitt, and Christine Boeglin, Phys. Rev. B **91**, 054416 (2015).