Petahertz Magnetization Dynamics

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In contrast to conventional electronics, where only the charge of electrons is considered, spintronics is based on the utilization of both charge and spin. Due to this additional degree of freedom, spintronic devices can potentially provide higher processing speed or better energy efficiency [1,2]. However, while sub-femtosecond control of the electronic properties of solids has previously been demonstrated [3], the lack of direct coupling between light and spin has limited the manipulation speed of magnetic properties to the few-tens-of-femtoseconds timescale. Here we introduce a technique able to follow the magnetic properties of a solid with attosecond resolution and demonstrate the direct sub-femtosecond all-optical manipulation of its spin degrees of freedom.

We probe the time-evolution of the magnetic and electronic properties of solids and their coupling using a novel atto-XMCD scheme. In our experiment, a circularly polarized attosecond pulse (probe) (~310 as FWHM duration, centered at 66 eV corresponding to the M-edges of Nickel) is transmitted through a thin magnetized Nickel (Ni) film or Nickel-Platinum (Ni/Pt) multilayer sample. Reversing the magnetization direction allows to record the polarization dependent X-Ray absorption of Ni (X-Ray Magnetic Circular Dichroism, XMCD), which directly measures the magnetic moment of the Ni atoms. Dynamics are initiated by a carrier-envelope-phase stable sub-4 fs near-infrared electric laser field (pump). Coincidentally, attosecond transient absorption spectroscopy reveals changes of the electronic properties and gives a clear reference for the arrival of the laser pulse [3].

Our results show an instantaneous response of both, charge and spin, to the laser pulse electric field in the Ni/Pt multilayer sample (Fig.1 a). The exceptionally fast demagnetization in the first 10 fs after laser excitation is the first experimental evidence for theoretically predicted optically induced spin transfer (OISTR) [4]: simultaneously with the charge transfer due to electronic excitation, the spin of excited electrons is transferred from the ferromagnetic (Ni) to the paramagnetic (Pt) material in the multilayer sample. This reduces the majority spin in Ni, inducing an instantaneous demagnetization of the ferromagnet. Fig. 1 b shows a reference measurement performed with a Ni film. As OISTR is not possible in pure Ni, no demagnetization happens during the pump laser pulse.

To conclude, with our novel experimental scheme we demonstrate sub-femtosecond optical spin manipulation in matter. Access and control of the magnetic properties of solids on the attosecond time-scale paves the way towards spintronic devices operating at Petahertz clock rates.

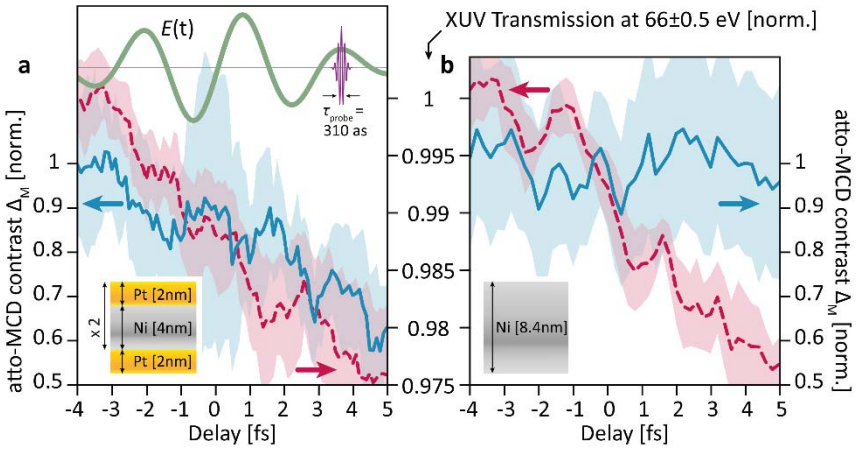

Fig. 1 a) Magnetization (blue) and electronic response (red, dashed) in the Ni/Pt multilayer system as a function of the delay between the near-infrared pump and XUV probe pulse. b) Corresponding data for a pure Nickel film.

References:

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