Breaking the picosecond barrier with x-rays: Ultrafast magnetization dynamics

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Ultrafast (picosecond and femtosecond) magnetic writing using laser, current, and field pulses has caught the interest of scientists because of the fascinating physics underlying the exchange of energy and angular momentum in a magnetic material and because of possible application in data storage. However, experiments in ultrafast magnetism pose tough requirements onto the experimental technique, in terms of temporal and also spatial resolution. X-ray microscopy techniques, fast detectors, and the availability of picoseond and in the future femtosecond x-ray pulses have now opened the door to such studies.

Experiments on the dynamics of magnetic domains in response to magnetic field pulses require high spatial resolution (10s of nanometers) but only moderate time resolution (10s of picoseconds). I will first discuss the time-resolved imaging of magnetic vortices with 100 nm spatial resolution using the X-ray Photoemission Electron Microscope PEEM-2 at beamline 7.3.1.1 of the Advanced Light Source [1]. Here, the bunch length of the storage ring sets the time resolution of 80 ps. Magnetic vortices appear in soft-magnetic micron- and sub-micron-size structures and are characterized by a curling magnetization. We observed that the chirality or handedness of the vortex, which is determined by the out-of-plane magnetization of the vortex core, governed the sub-ns dynamics of the structure. The field pulses were generated by an Auston switch, which was triggered by a titanium-sapphire laser. The measured vortex speed and the internal magnetic field at the core agreed well with results of micromagnetic simulations.

Electron and spin relaxation processes in response to an ultrafast optical excitation occur on a much faster time scale, typically 10s of femtoseconds up to several picoseconds. All-optical experiments have demonstrated the possibility of manipulating magnetism using femtosecond laser pulses. X-ray spectroscopy would be an ideal tool to probe such transient magnetic and electronic processes because of the availability of x-ray sum rules that quantify spin moment, orbital moment and magnetic anisotropy, element-by-element. Yet, little progress has been made so far because of the lack of intense, tunable, and polarized sources that produce femtosecond x-ray pulses. X-ray slicing sources and future Linac-based sources promise to penetrate the picosecond barrier but are expensive and not yet commonly available. I will discuss a different approach using a streak camera detector at a conventional EPU beamline, BL 4.0.2 of the Advanced Light Source. First time-resolved magnetic measurements on Fe/Gd multilayers will be presented.

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[1] S.B. Choe et al., Science 304, 420 (2004)