Soft X-Ray Imaging of spin dynamics at high spatial and temporal resolution

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Studies of ultrafast spin dynamics are of both fundamental and technological interest. Combining magnetic soft X-ray microscopy which is capable of providing a spatial resolution in the near-10 nanometer regime with the inherent time structure of current synchrotron sources allowing for a time resolution on a sub-70ps scale provides a unique opportunity to address spin dynamics in nanosize magnetic structures, such as studies of vortex dynamics or spin current induced phenomena in nanowires.

The full field soft x-ray microscope, XM1, at the Advanced Light Source (ALS) shown in Fig 1 has been upgraded to allow for time resolved studies during the "two bunch" operational mode in order to meet these challenges. Due to the limited number of photons per electron bunch which is not sufficient to obtain snapshot single images a stroboscopic pump and probe scheme is used (Fig. 2). The X-ray magnetic circular dichroism (X-MCD) effect, which is used as magnetic contrast mechanism detects the difference of the absorption coefficient near an element specific absorption edge for parallel and antiparallel orientation between photon helicity and local magnetiation projected onto the photon propagation direction. Diffractive Fresnel zone plates are used as X-ray optical elements and provide a spatial resolution down to 15nm, which approaches fundamental magnetic length scales such as magnetic exchange lengths. As a pure photon-in/photon-out based technique X-ray microscopy images can be recorded in external static and dynamic magnetic fields giving access to study magnetization reversal phenomena on the nanoscale.

A pump-probe stroboscopic technique has been implemented into XM-1 with commercially available high-speed electronics. To excite the spin structure of the ferromagnetic specimen either magnetic field or current pulses with rise times of about 100ps and duration of a few nsec are launched into either coplanar waveguides (to create a field pulse) as shown in Figure 2or directly into the sample. Varying the delay time between the pump and the subsequent probe pulses, i.e 70ps short flashes of elliptically polarized X-rays by a programmable digital delay line one can record the time evolution of the spin dynamics up to several 10s of nsec with high spatial resolution. The magnetization of the samples relaxes back into the orginal ground state configuration before the next pump-probe sequence is triggered by the next probe pulse at 3MHz. A high-speed avalanche photodiode allows for an accurate determination of time zero, i.e. where the pump pulse sets in. All signals are monitores by high-speed sampling oscilloscope and full time resolved data sequence can be recorded semi-automatically by specialized software.

Typical samples that were studied so far included are 1-4 micrometer small and 50nm thin permalloy elements of various shapes. Our results on rectangular structures (Fig 3) allowed us to study gyroptropic vortex motion, the domain wall dynamics and the dynamics within closure domains at high spatial resolution. Comparison with micromagnetic simulations shows an excellent agreement thus providing accurate experimental evidence for fundamental parameters such as material specific damping constants.

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References

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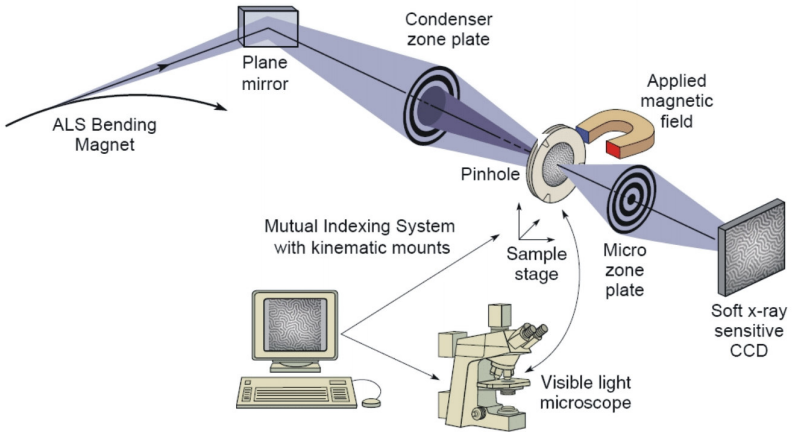

Fig. 1 Schematical optical layout of the full-field soft x-ray microscope XM-1 at the ALS.

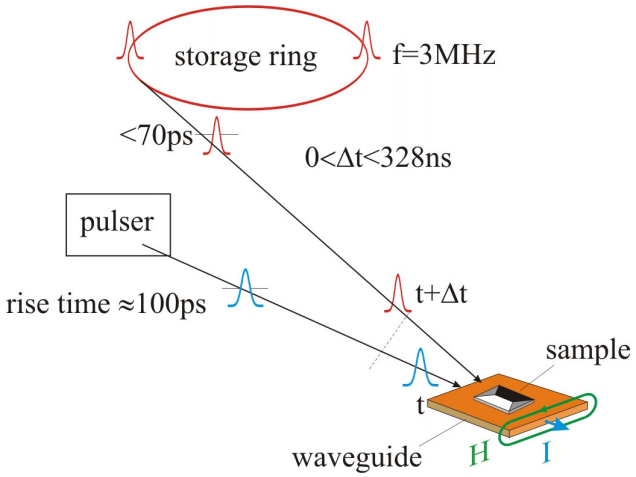

Fig 2. Stroboscopic pump and probe scheme for time resolved soft X-ray microscopy.

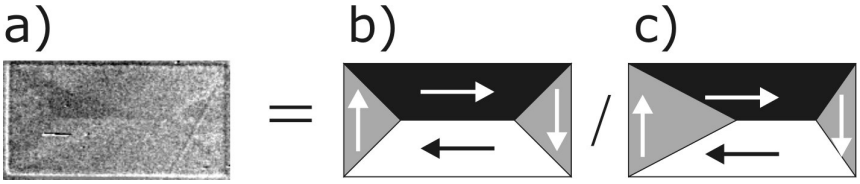

Fig. 3 a) Typical differential example of time resolved X-ray microscopy image showing the spin dynamics in a rectangular PY element obtained by subtracting X-ray images recorded at different delay times. b),c) Schematic configurations of the magnetization direction at various delay times explaining the difference image shown in a)