MAGNETIC SOFT X-RAY MICROSCOPY - IMAGING FAST SPIN DYNAMICS IN MAGNETIC NANOSTRUCTURES

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Abstract

Magnetic soft X-ray microscopy combines 15nm spatial resolution with 70ps time resolution and elemental sensitvity. Fresnel zone plates are used as X-ray optics and X-ray magnetic circular dichroism serves as magnetic contrast mechanism. Thus scientifically interesting and technologically relevant low dimensional nanomagnetic systems can be imaged at fundamental length and ultrafast time scales in a unique way. Studies include magnetization reversal in magnetic multilayers, nanopatterned systems, vortex dynamics in nanoelements and spin current induced phenomena.

Keywords – Soft X-ray microscopy, Fresnel zone plates, Spin dynamics, Nanomagnetism , Spin currents

Introduction

Magnetism on the nanometer scale and its spin dynamics on a nsec to fsec time scale is currently a scientfically highly attractive topic, since it addresses both fundamental magnetic lengh scales e.g. magnetic exchange lengths in the sub-10nm range and fast time scales in the sub-ns to psec regime where precessional and relaxation phenomena, domain wall motion and vortex dynamics occur. Ultimately the fundamental time scale in magnetism is given by the time required to transfer energy and momentum from the electronic into the spin system, which will occur on a fsec time scale.

There is also a strong technological interest in fundamental magnetization processes on the nanometer length and nsec time scale driven by current developments of future ultrahigh density magnetic data storage media and miniaturized magnetic sensor technology. It is still an open question how to control e.g. the switching field distribution in future magnetic storage devices where the bit size approaches the granular length scale. New technological concepts such as spintronics, where in addition to the charge the spin of the electron is considered, require to control the electron spin on a nanoscale with ps timing. Logical elements for spintronics, non-volatile magnetic random access memories (MRAM) or 3dim magnetic data storage devices are just a few of the potential applications. New ideas are being investigated, trying to speed up magnetization reversal, e.g. by precessional switching or to reverse the magnetization by pure spin currents, that are injected into nanoscale magnetic elements. The search for novel materials such as multiferroic systems is fueled by the demand to create new functionalities, e.g. to manipulate the magnetisation by pure electrical fields.

New analytical tools are required and a direct visualization of the magnetization is very appealing. The grand challenge to modern magnetic microscopies is to provide both a spatial resolution in the nanometer regime, a time resolution on a ps to fs scale and elemental specificity which allows to study such advanced magnetic materials.
Magnetic transmission soft X-ray microscopy (MTXM) is a powerful novel technique that combines X-ray magnetic circular dichroism (X-MCD) as huge and element specific magnetic contrast mechanism with high spatial and temporal resolution down to 15nm and 70ps, resp. As a pure photon-in/photon-out based technique the images can be recorded in external magnetic fields giving access to study magnetization reversal phenomena on the nanoscale [1].

Experiments

Fresnel zone plates (FZPs) used as X-ray optical elements provide high spatial resolution down to currently 15nm. FZPs are circular diffration gratings with a radially increasing line density. They can be fabricated using state-of-the-art nanolithography and the outermost zone width Δr determines largely the spatial resolution that can be obtained.
The effect of X-ray magnetic circular dichroism (X-MCD) provides a large magnetic contrast mechanism. X-MCD measures the dependence of the X-ray absorption in a ferromagnetic media on the relative orientation between the magnetization of the sample and the helicity of the circularly polarized X-rays. The latter can be easily obtained at synchrotron radiation sources, e.g. by viewing the radiation emitted from a bending magnet above and below the orbital plane of the electrons. Inherent elemental specificity is provided since X-MCD occurs only in the vicinity of element specific absorption edges, such as the L_3 and L_2 edges, corresponding to the binding energies of inner core atomic levels, where the photon energy can be easily tuned to.
The experiments presented here were obtained at XM-1, the high resolution soft X-ray microscope located at beamline 6.1.2 at the Advanced Light Source in Berkeley CA (USA), which is currently the only system worldwide which is dedicated to studies of nanomagnetism. There are two FZPs. A condensor zone plate together with a pinhole close to the sample forms a linear monochromator due to the wavelength dependence of the focal length of FZPs and second, the radiation passing through the sample is projected through the micro zone plate (MZP), which is the lens determining the lateral resolution, onto a CCD camera, where the images are recorded.
Circularly polarized X-rays are selected by an aperture located upstream the condenser. Typical exposure times for magnetic imaging range from 0.5-3 sec and each image covers about 10-15μm field-of-view.
Studies of spin dynamics are performed within a stroboscopic pump-probe scheme utilizing the inherent time structure of the emitted X-ray pulses. At the ALS runnning in two-bunch mode there are two electron bunches circulating in the ring each with a width of 70ps and therefore emitting at 3MHz X-ray flashes that can be used for time resolved spin dynamics experiments at XM-1. The pump is an electronic pulse with a rise time of 100ps which, when launched into microcoils or planar waveguide structures creates a magnetic field pulse, which excites the magnetization of the sample into a precessional motion. This fast motion can then be probed by flashing the X-ray pulses onto the sample with varying delay time between pump and probe pulse. Instead of magnetic field excitations, the study of spin current induced excitations have become recently focus of our research.

Results

The features of magnetic soft X-ray micrscopy are demonstrated by the following examples:

Elemental specificity can be turned into layer resolved imaging by recording the magnetic domain structure in a ferromganetically coupled system containing a PtCo multilayer and an amorphous TbFe layer. Both of them have a pronounced perpendicular magnetic anisotropy. Tuning the photon energy to either the Co or the Fe L absorption edges, one can identify an antiparallel coupling between the two layers. Recording the images within varying external magnetic fields provides valuable information on magnetic domain structure in each layer which reflects the different coercive field strengths in each layer.

The high spatial resolution of 15nm that can now be obtained with magnetic soft X-ray microscopy was used to study the magnetization reversal in a nanogranular CoCrPt thin layer [2], which are candidates for perpendicular magnetic recording media. TEM analysis revealed an average grain size of about 20nm and by imaging the magnetic domain structure in varying external magnetic fields we could identify the reversal on the length scale of the individual grains.

Time resolved magnetic soft X-ray microscopy [3] was used to study vortex dynamics in single patterned rectangular PY elements upon excitation with short magnetic field pulses. Spin waves and domain wall motion could be observed which will be interpreted based on micromagnetic simulations.

Instead of conventional Oersted field excitations, the injection of spin currents in magnetic nanoelements creates a torque on the noncollinear magnetic structure so as to start a vortex motion which is different from the Oersted excitation. These experiments can be used to understand quantitatively the role of adiabatic and non-adiabatic contributions to the spin torque.

Magnetic phase contrast can be observed by utilizing novel Fourier optical elements which are sensitive to phase contrast [4]. This might open interesting applications in imaging fsec spin dynamics at upcoming high brightness fsec X-ray sources.

Summary

Magnetic soft X-ray microscopy combines high spatial and temporal resolution with inherent elemental sensitivity which is required to image spin dynamics in nanoscale magnetic elements approaching fundamental length and time scales.

References

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