Magnetic Soft X-Ray Microscopy

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Modern magnetic materials with applications to magnetic storage and sensor technologies are currently focusing on thin films and multilayered systems often accompanied with a lateral micropatterning. Imaging magnetic microscopic processes on a sub-micrometer length and sub-ns time scale provides key information that will contribute significantly to a thorough understanding of the underlying physics and will support current technological developments.

Magnetic transmission soft X-ray microscopy offers a superior combination of the following features which match ideally the needs both for fundamental studies in magnetism and to characterize technologically relevant magnetic systems

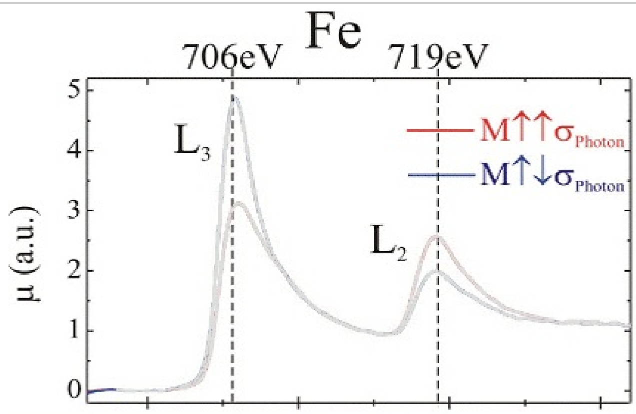
- high lateral resolution (Fresnel zone plate optical elements)
- sub-ns time resolution (pulsed time structure of Synchrotron radiation)
- elemental specificity (XMCD contrast)
- high sensitivity to thin layers (large magnetic absorption cross section)
- magnetisation reversal studies (recording images in applied magnetic fields)
- large field of view (typical tens of microns)
- short exposure times (typical secs per image)

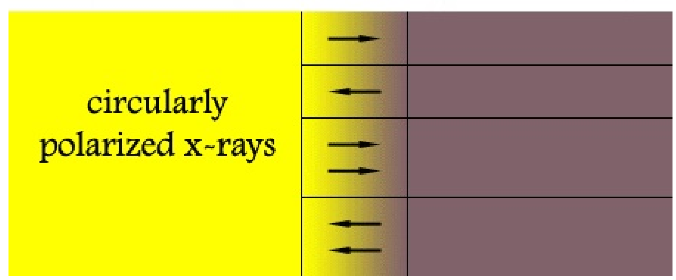
Magnetic transmission X-ray microscopy (MTXM) uses X-ray magnetic circular dichroism as magnetic contrast mechanism. In the vicinity of element-specific binding energies of inner core levels, such as $2p_{3/2}$ and $2p_{1/2}$ levels which correspond to $L_3$and L_2 absorption edges, the X-ray absorption coefficient depends strongly on the relative orientation between the helicity of the photons and the projection of the local magnetization onto the photon propagation direction.

With phase sensitive X-ray optics, also magnetic phase contrast imaging has been demonstrated recently.

Principle of MTXM

Illuminate a ferromagnetic specimen with circularly polarized X-rays at a specific wavelength and record the transmitted photons with a high resolution soft X-ray microscope.



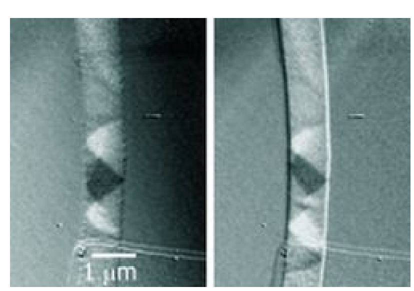


Examples of Recent Results

Direct Imaging of Stochastic Current Induced Domain-Wall Motion

Pulses of nanosecond duration and of high current density up to 1.0×10^{12} A/m^2 are used to move and to deform the domain wall. The current pulse drives the wall either undisturbed, i.e., as composite particle through the wire, or causes structural changes of the magnetization. Repetitive pulse measurements reveal the stochastic nature of current-induced domain-wall motion.

G. Meier, et al., Phys. Rev. Lett. **98**, 187202 (2007), also selected for Physical Review Focus



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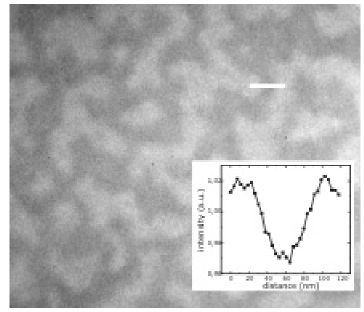
Imaging at fundamental magnetic length scales



With a spatial resolution of 15nm magnetic soft X-ray microscopy can probe local hysteresis behaviour on a granular length scale in a 50 nm thick $(Co_{83}Cr_{17})_{87}Pt_{13}$nanogranular alloy film recorded at the Co L_3absorption edge (777eV). Inset: Intensity profile across a magnetic domain (white line) proofing 15nm spatial resolution.

D.-H. Kim, et al. J. Appl. Phys. 99, 08H303 (2006) also selected in Virtual Journal of Nanoscale Science & Technology, 13(17) May 1, 2006

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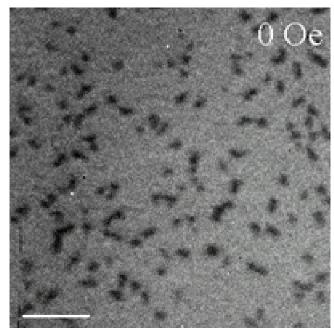
Domain nucleation in nanogranular CoCrPt alloys

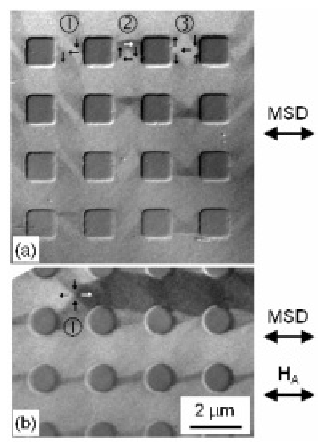


The image shows the magnetic domain pattern in a 50 nm thick $(Co_{83}Cr_{17})_{87}Pt_{13}$ nanogranular alloy film recorded at the Co L_3 absorption edge (777eV) in an external magnetic field of 0 Oe.

M.-Y. Im, et al. Appl. Phys. Lett. 83(22) (2003) 4589-4591 also selected in Virtual Journal of Nanoscale Science & Technology, 8(23) December 8, 2003

In collaboration with

Cobalt antidot arrays



Co antidot arrays with 2 mm period were fabricated on X-ray transparent membranes and imaged with MTXM:

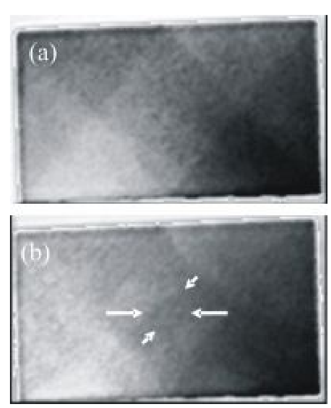
(a) as-grown flux closure states in array with square holes: S-state at position 1, Landau state at position 2, flower state at position 3

(b) a domain chain forms on application of a magnetic field with the end of
the chain comprising four 90º walls.

L. Heyderman et al., J. Magn. Magn. Mat 316 99 (2007)

In collaboration with at

Fast Magnetization Dynamics in Patterned Elements



(a) Seven domain Landau configuration in a 50nm thin 2x4 mm^2 rectangular PY element before a magnetic excitation.

(b) Domain configuration 2ns after the excitation pulse.

P. Fischer, et al J. Magnetism and Magnetic Materials (2007) **310(2)** pt 3 (2007) 2689-2692

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