Recent achievements with magnetic soft X-ray microscopy at XM-1

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INTRODUCTION

Studies of magnetic domain structures in systems of low dimensionality are a major issue both from a fundamental physics point of view and in a technologically relevant context. The systems of interest are thin single or stacked multicomponent multilayered magnetic films and are often laterally patterned micro- and nanostructures.Though a large number of imaging techniques is established the outstanding challenge they have to meet, is a layer-resolved (e.g. via chemical sensitivity) spatio-temporal recording of the switching behavior of the magnetic domain structure as this determines largely the technological functionality. Supported by intensive micromagnetic simulations a comprehensive fundamental understanding and a subsequent potential design of the magnetic domain structures is essential.

X-ray magnetic circular dichroism (X-MCD) yields at element-specific spin-orbit coupled (e.g. $L_{3,2}$ and $M_{5,4}$ absorption edges large values up to 50%. In combination with soft X-ray transmission microscopy this serves as huge magnetic contrast mechanism to image magnetic domain structures at a resolution down to 25nm provided by Fresnel zone plate optics (magnetic soft X-ray transmission microscopy (M-TXM)) [1,2]. A description of the technique is found elsewhere [3]. Here we report the recent achievements by selected examples taken at the XM-1 beamline at the ALS/Berkeley CA.

RESULTS

In Fig. 1 the domain pattern of an amorphous 59nm thin $Gd_{25}Fe_{75}$ film with a pronounced perpendicular anisotropy is shown. The images have been taken at the Fe L_3 (a) and the Gd M_5 (b) edge thus probing the local magnetization of Fe and Gd, resp., in an element-specific manner. Though at these two edges the spin-orbit coupling is both parallel the observed reversal of magnetic contrast reflects the antiparallel 3d-4f coupling and proofs the magnetic character of the structures.

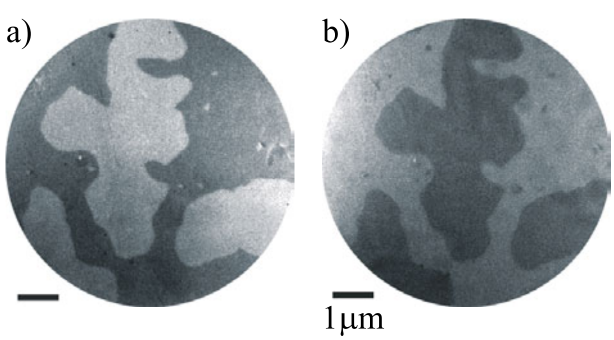

Figure 1 Domain structure of a $Gd_{25}Fe_{75}$ film taken at the Fe L_3 (a) and the Gd M_5 (b) edge.

The magnetization switching can be addressed by recording the domains within complete hysteresis loops. In Fig. 2 a (0.4nmFe/0.4nmGd)x75 multilayered system with lithographically written line elements with a width of 300nm emerging from a continuous film were studied at saturation (a) and at an applied magnetic field perpendicular to the films surface of 4kOe (b). The maze pattern observed in the continuous film starts penetrating from the left side of the image into the GdFe line structures as a straight line domain. A corresponding white line domains emerges from the right. If the sense of rotation from up to down does not fit for both domains, the melting of these two domains is blocked until at a higher magnetic field finally they are forced to form one single line. As can be seen in the third line from the bottom this is not always the case.

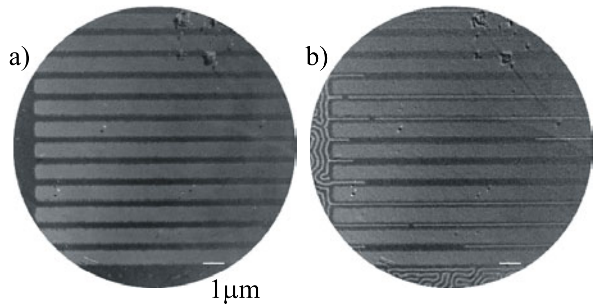

Figure 2 Domain structure in a lithographically edged line pattern (width 300nm) of a multilayered 75x(0.4nm Fe/ 0.4nm Gd) system. a) saturated state, b) domain structure at 0.4kOe.

As the dichroic contrast is given by the projection of the magnetization onto the photon propagation direction both in-plane and out-of-plane systems can be imaged. Amorphous Terfenol-D ($Fe_{66.5}Tb_{9.5}Dy_{24.0}$/2at%Zr) layers exhibit an anisotropy perpendicular to the film plane as they are far from thermodynamically equilibrium.

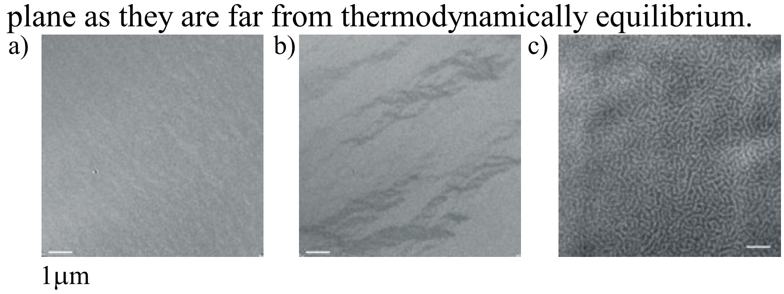

Figure 3 Magnetic domains in Terfenol-D recorded at the Fe L_3 edge in-plane (a,b) and out-of-plane (c).

However, thermal treatment at elevated temperatures (about 500-600K) forces the anisotropy into the film plane. In Fig. 3a) and b) the results obtained with a 70nm thin sample thermally treated at 500K are shown. A typical in-plane domain pattern can be observed if the magnetic field applied along the sample´surface and horizontal in the paper plane is increased from 0 Oe (a) to 200 Oe (b). The corresponding domains for the non-tempered (out-of-plane) system are shown in (c).

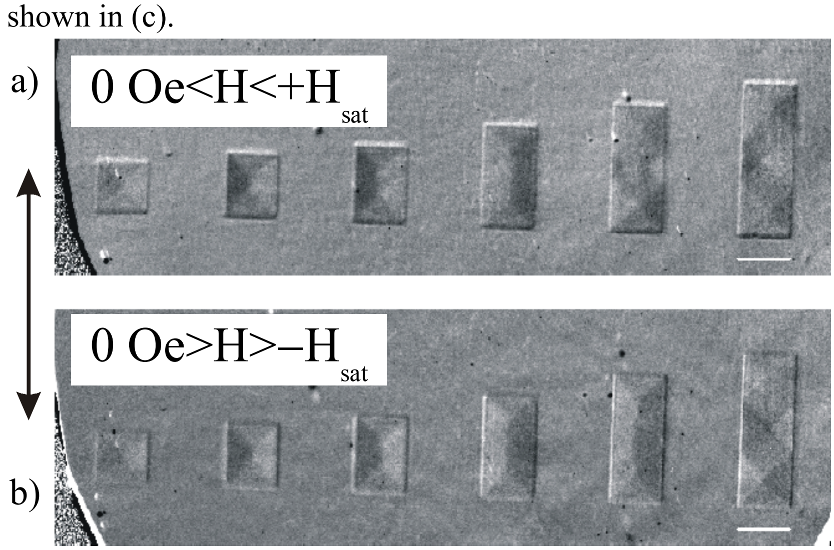

Figure 4 Variation of the domain patterns with size in 50nm thick Permalloy ($Fe_{20}Ni_{80}$) nanostructures. Field direction along the vertical direction (see arrow). The bar is 1μm.The bar is 1μm.

Results of the magnetic domain structure recorded at the Ni L_3 edge within varying external magnetic fields in 50nm thin PY (Permalloy $Fe_{20}Ni_{80}$) patterned elements are shown in Fig. 4. The variation of the domain pattern with varying aspect ratio (width to height) between 1 and 3 is clearly visible. In Fig. 1a) and b) the field direction was along the fixed width of 1μm. Up to an aspect ratio of 1.5 a single closure domain pattern appears, while a more complex configuraton (cross tie wall) emerges for larger aspect ratios.

OUTLOOK

An outlook to the potentials of M-TXM is time dependent imaging where the inherent pulsed time structure of the synchrotron light in the sub-nanosecond regime will be used to study spin dynamics.

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