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Report:

We report on experiments using Fourier transform holography to image the in-plane magnetization of a magnetic microstructure. Magnetic sensitivity is achieved via the x-ray magnetic circular dichroism effect by recording holograms in transmission at off-normal incidence. The reference beam is defined by a narrow hole milled at an inclined angle into the opaque mask (see Fig. 1a). We present magnetic domain images (see Fig. 2 difference) of an in-plane magnetized Co element with a size of 2µm x 2µm x 20 nm (Fig. 1b). The domain pattern shows a multi-vortex state that deviates from the simple Landau ground state. (Abstract of [1])

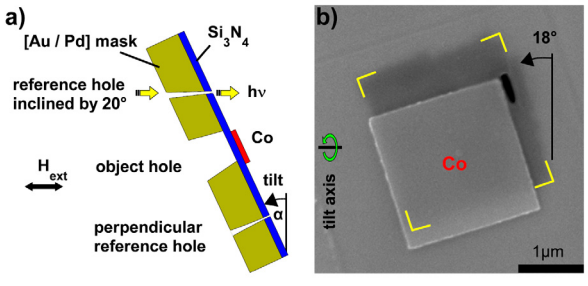

Fig 1: (a) Optic mask and sample assembly, (b) SEM micrograph of the FIB-milled magnetic microstructure

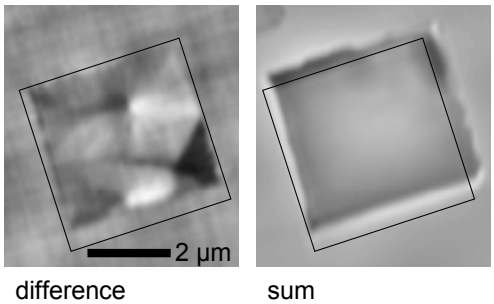

Fig 2: Magnetic microstructure visible in the image reconstruction of the difference hologram and the coresponding sum image.

The sample has been fabricated using focused ion beam milling. A square shaped microstructure has been placed behind the square sized object hole on the opposite side of the membrane, so that the Co microstructure is placed almost exactly in the object beam if the sample is tilted at 30°.

We recorded holograms with right (RCP) and left (LCP) circularly polarized light at 778 eV (Co L_3 absorption edge). The sample has been imaged at different tilt angles up to 30°. The intensity of the magnetic signal in the difference hologram (RCP-LCP) and in the reconstruction is increasing with the tilt angle. It is possible to achieve magnetic object-hole images (object reference correlation in the reconstruction) even if the reference channel direction is 10° misaligned to the incoming beam (e.g. using a 20° aligned reference pinhole at 30° sample tilt angle). At misalignments larger than 15° the magnetic image vanishes rapidly.

In the second part, we studied the magnetic microstructure of Co/Pt multilayer films with uniaxial perpendicular anisotropy that were coupled to an iron layer of increasing thickness (wedge) by soft X-ray holographic microscopy (first developed at ESRF [2]). The coupling strength between the Co/Pt multilayer and the Fe layer has been controlled by Pt spacer layer of increasing thickness in the orthogonal direction (crossed wedges). The domain size evolution as a function of Fe thickness has been analyzed (see Fig. 3). The local Fe thickness could be determined using X-ray absorption spectroscopy. An interesting result is that the domain size shrinks and that domains with perpendicular Co magnetization can still be observed up to 9 nm Fe thickness.
An analytical model for the domain size in the phase of canted magnetization is worked out in [3] and is demonstrated with results from holography experiments at the ESRF.
In hysteresis measurements using magneto optical Kerr-effect it was found, that at a certain Fe thickness, the magnetization decomposes into domains. Analyzing the anisotropy constants up to second order from the hard axis hysteresis loops, the domain decay is correlated with a change of the system from perpendicular magnetization into the phase of canted magnetization. The shift of domain decay and the transition into the canted phase was determined as a function of Fe-layer and Pt-spacer-layer thicknesses, comparing line scans with RCP and LCP light at the Co L_3 absorption edge (see Fig 4).

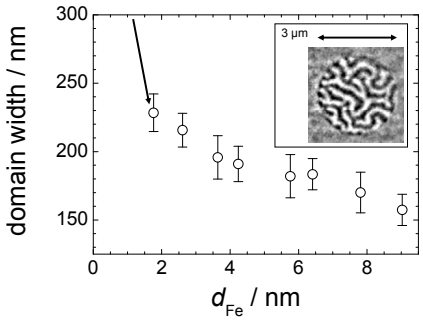

Fig. 3: Domain width for increasing Fe thickness at 1 nm Pt spacer layer (inset: XHM domain image at Co edge).

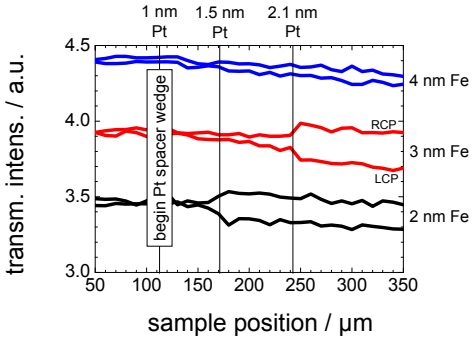

Fig. 4: Transmission line scans with RCP and LCP polarized light (3 µm beam size) across the Pt spacer wedge at different Fe thicknesses.

If the magnetization is remanent after saturation the absorption will be different for RCP and LCP light, so the transmitted intensity splits into two levels. In the area where the multilayer decomposes into magnetic domains, the absorption is the same for RCP and LCP. The domain decay shifts towards higher Fe thickness if the Pt spacer becomes thicker. The signal-to-noise ratio at the Fe L_3 absorption edge was not sufficient to directly reconstruct the iron domain structure. Nevertheless, the comparison of the magnetic speckle patterns in the difference holograms at both absorption edges suggests identical domain patterns for Fe and Co.

[1] C. Tieg, R. Frömter, D. Stickler, S. Hankemeier, A. Kobs, S. Streit-Nierobisch, C. Gutt, G. Grübel, and H. P. Oepen, “Imaging the in-plane magnetization in a Co microstructure by Fourier transform holography”, Appl. Phys. Lett., submitted to Appl. Phys. Lett.
[2] D. Stickler, R. Frömter, H. Stillrich, C.n Menk, C. Tieg, S. Streit-Nierobisch, M. Sprung, C. Gutt, L.-M. Stadler, O. Leupold, G. Grübel, and H. P. Oepen, „Soft X-ray holographic microscopy“, Appl. Phys. Lett. **96**, 042501 (2010)
[3] D. Stickler, R. Frömter, H. Stillrich, C. Menk, C. Tieg, C. Gutt, S. Streit-Nierobisch, L.-M. Stadler, G. Grübel, and H.P. Oepen, “Domain size in systems with canted magnetization”, prepared for Phys. Rev. B