ESRF

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Report:

We report on experiments using Fourier transform holography (FTH) to image the domain structure in Co/Pt multilayers. The sensitivity to the out-of-plane component of the magnetization is achieved via the X-ray magnetic circular dichroism in transmission at normal incidence. To enhance the magnetic contrast, we re-corded holograms with right (RCP) and left (LCP) circularly polarized light at 778 eV (Co L_3 absorption edge).

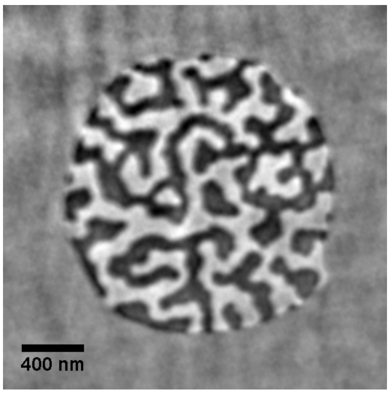

Fig 1: Object hole reconstruction with a spatial resolution of 22 nm.

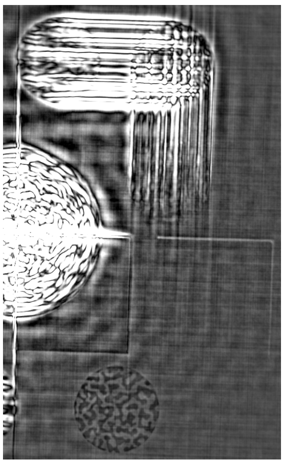

Fig. 2: Fast Fourier Transform of a HERALDO sample hologram.

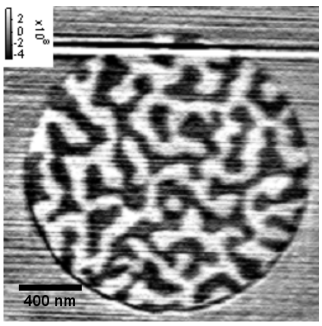

Fig. 3: Reconstruction of the HERALDO object hole image.

At first, the potential of magnetic FTH for imaging with high special resolution has been evaluated. For that purpose the CCD-camera was mounted closer to the sample. The sample to CCD separation of 18 cm should theoretically give a resolution in real space at best of 11 nm. With a 40 nm reference hole, the reconstructed object images show a 80/20 resolution of 22 nm (Fig. 1).

We have successfully imaged the first magnetic sample using a HERALDO scheme [1]. A differential operator has been used to reconstruct the object of an extended reference source (Fig. 3). The fast Fourier transform of the hologram contains an object hole image of a point-like reference source (lower center of Fig. 2), while the extended L-shaped source results in an image that is smeared out (upper center). The reconstruction via the HERALDO algorithm shows a much higher magnetic contrast than holograms obtained with a single reference hole for the given exposure time. The analysis of the image obtained by HERALDO has a 20% higher resolution (18 nm) compared to the image taken with a point reference (see above).

The second task was concerned with correlation between domain structure and magneto-transport properties. Magnetic nanowires with widths of 100 nm–400 nm and a length of 1µm were imaged via soft X-ray holographic microscopy, a technique first developed at ESRF [2]. The wires were fabricated on a SiN membrane using a multi-step processes, including UV photolithography and FIB milling (Fig. 4). The delicate step was to structure the ferromagnetic multilayer without destroying the magnetic properties of the Co/Pt multilayer. The fabrication process was successful, as can be seen from the magnetic image that displays out-of-plane magnetized domains. Due to the electrical contacts, the optical mask and the sample could not be brought in ultimately close contact and thus the images were blurred. By means of a propagation operator [3] the latter could be compensated in the image reconstruction (Fig. 5).
The domain structure surprisingly does not show the expected alignment of the domain walls perpendicular to the stripe but a mixture of domain walls aligned along and perpendicular to the wire axis (Fig. 5). Images have been taken while applying a magnetic field perpendicular to the sample surface. On changing the magnetic field, those images show a complicated remagnetization process that is probably due to domain wall pinning.

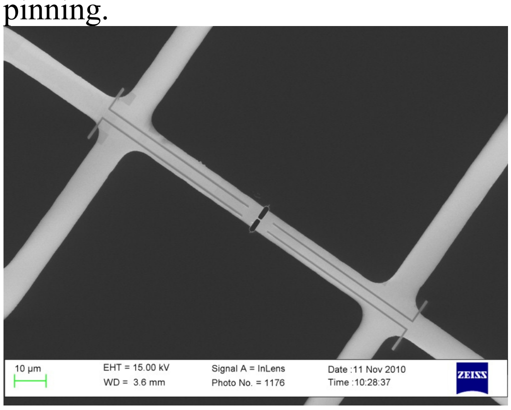

Fig. 4: FIB milled 300 nm wide nanowire in the center part of a UV lithography structured Co/Pt double-cross.

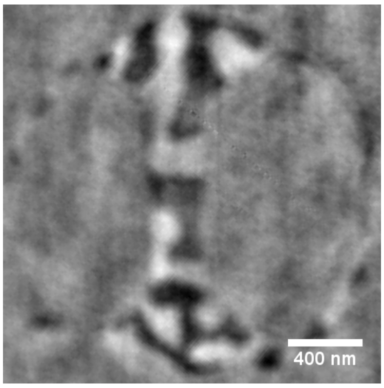

Fig. 5: Reconstruction of the magnetic nanowire behind the object hole.

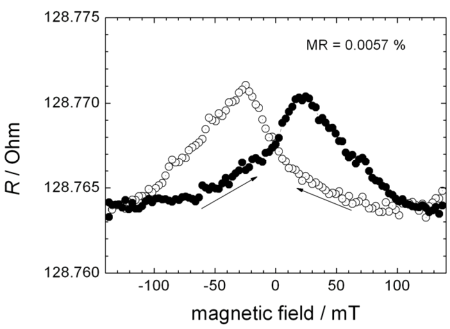

Fig. 6: In-situ magnetoresistance measurements of the 300 nm Co/Pt nanowire.

We measured the magnetoresistance (MR) of the nanowires in-situ, using the Keithley pulse/delta 6221/2182A combination with an accuracy of 10^{-5}. Fig. 6 displays a MR measurement of the nanowire with a width of 300 nm, acquired while scanning the magnetic field amplitude perpendicular to the surface. The plot in Fig. 6 is averaged over 10 individual runs. Extremely small MR signals in the range of $6*10^{-5}$ R_0 have been resolved.
The resistance increase in low fields is caused by the very existence of domains and as a result of domain walls. Bloch walls oriented along the wire can cause an increase of the resistance due to anisotropic MR. The existence of domain walls of such orientation has been identified in the reconstructed domain pattern.

An analytical model for the domain size of homogeneous multilayer films in the phase of canted magnetization has been elaborated in [4] and was demonstrated with results from holography experiments at ID08.

[1] D. Zhu, et al., Phys. Rev. Lett. **105**, 043901 (2010).
[2] D. Stickler, R. Frömter, H. Stillrich, C. Menk, C. Tieg, S. Streit-Nierobisch, M. Sprung, C. Gutt, L.-M. Stadler, O. Leupold, G. Grübel, and H. P. Oepen, Appl. Phys. Lett. **96**, 042501 (2010).
[3] E. Guehrs et al., Opt. Express **18**, 18922 (2010).
[4] D. Stickler, R. Frömter, H. Stillrich, C. Menk, C. Tieg, H.P. Oepen C. Gutt, S. Streit-Nierobisch, L.-M. Stadler, G. Grübel, F. Yakhou-Harris , "Domain size in systems with canted magnetization", Phys. Rev. B **84**, 104412 (2011).