Magnetic Imaging with High-Resolution Soft X-Ray Holographic Microscopy

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X-ray Fourier transform holography has become a competitive technique to investigate magnetic samples with sub-50 nm spatial resolution by exploiting x-ray magnetic circular dichroism at the L-edges of 3d transition metals [1, 2]. The obtainable resolution depends on the maximum recorded scattering angle and the size of the reference hole of the optics mask [3]. With the possibility to fabricate sub-30 nm reference holes and to employ a large-area CCD camera, a resolution down to 10 nm becomes feasible. Hence, this enables the study, e.g. of magnetic nanoparticles and the structure of domain walls, not accessible to synchrotron radiation imaging before.

With our newly built X-ray holographic microscope (XHM) end station, we record diffraction patterns and holograms with a large-area CCD camera of 4k x 4k pixels (pixel size 15 x 15 μm^2) that accepts a scattering angle of up to ± 10°. The design of separated sample and optic mask allows for free movement across the sample with a piezo-controlled sample stage with nm resolution. A permanent-magnet assembly enables controlled application of in-plane as well as out-of-plane fields up to 140 mT [4].

Optics masks (1.2 µm thick $(Au/Pd)_{10}$ multilayer) are structured via focused ion beam technology (FIB). Gallium-Ions (Ga^+) with an energy of 30 keV are focused to a spot size of 10 nm. A visual assessment of the structuring process is possible with an integrated scanning electron microscope (SEM). This method allows the fabrication of optics masks with sub-30 nm reference hole diameters.

In first experiments at the P04 Beamline (PETRA III/DESY) we carried out a series of experiments to test and demonstrate the capabilities of our holographic end station with regard to element specificity, magnetic sample behavior in applied in-plane and out-of-plane magnetic fields and spatial resolution. Magnetic coupling of CoPd/FePd double alloy layers have been investigated using the XHM by recording holography images at the Co L_3 and Fe L_3 absorption edge (Fig.1 a, b). The reconstructed holograms show the same formation of domains in the CoPd and FePd alloys, but with varying degree of magnetic contrast due to different mass ratio of the materials (Fig.1 a, b). Moreover, we carried out magnetic field dependent measurements of the domain formation in NiFe/CoPd double alloy layers performed at the Co L_3 absorption edge. Fig. 1c shows the change of domain pattern in different out-of-plane (perpendicular to the sample) magnetic fields. Fig. 2 shows the spatial resolution determination of our XHM via 20/80 % criterion by use of the reconstructed hologram of a Co/Pt multilayer. We determined a spatial resolution of 16 nm ± 1 nm.

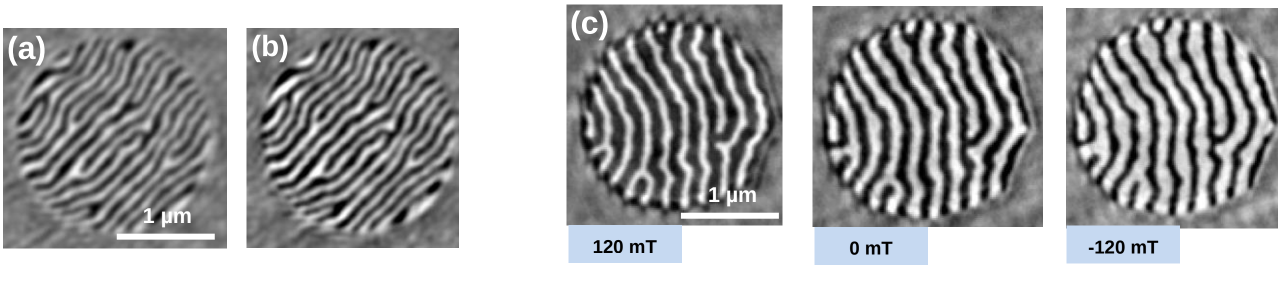

Figure 1: Holography images at the Co L_3 (a) and at the Fe L_3 absorption edge (b) of a $Si_3N_{4,50nm}$/$(Fe_{50}Pd_{50})_{40nm}(Co_{35}Pd_{65})_{40nm}/Pd_{2nm}$ sample. Series of holograms at the Co L_3 edge of a Pd_{2nm}/$(Co_{35}Pd_{65})_{40nm}/Ru_{1nm}/(Ni_{80}Fe_{20})_{10nm}/Al_{2nm}$ sample in different out-of-plane magnetic field (c).

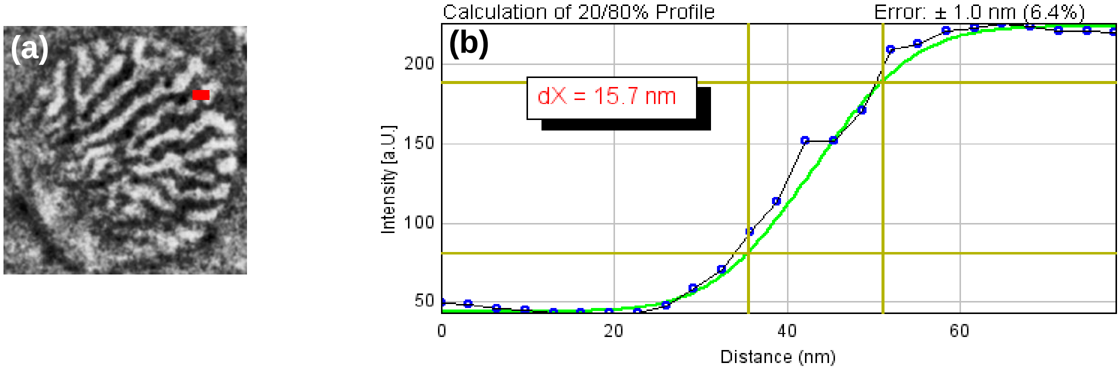

Figure 2: Holography image of a FIB-structured $(Co_{0.7nm}/Pt_{1.5nm})_8$ multilayer (sample see [5]) (a). Line profile across the domain wall to determine the resolution via 20/80 % criterion (b) (red mark in holography image).

Magnetic particles have attracted much attention due to their high potential in different technological fields of application, i.e. in ultrahigh density storage media or down scaling of magnetic logic known as spintronics [6]. In our group, we have successfully fabricated nanostructures that span a large scale of sizes, i.e. from 10 nm up to 200 nm, with perfect or random dot arrangement on a Si_3N_4 membrane. Fabrication of magnetic Co/Pt nanodots utilizing filled diblock copolymers with shadow mask sputtering produces mono- and polydisperse nanodots with diameters between 10 nm and 40 nm [7, 8]. Additionally we have fabricated nanodots with a diameter between 40 nm and 200 nm via e-beam lithography.

In Fig. 3, we employed our XHM to image magnetic nanodots with different sizes to get access to the magnetic behavior of single nanodots or nanodot ensembles with regard to their mutual interaction.

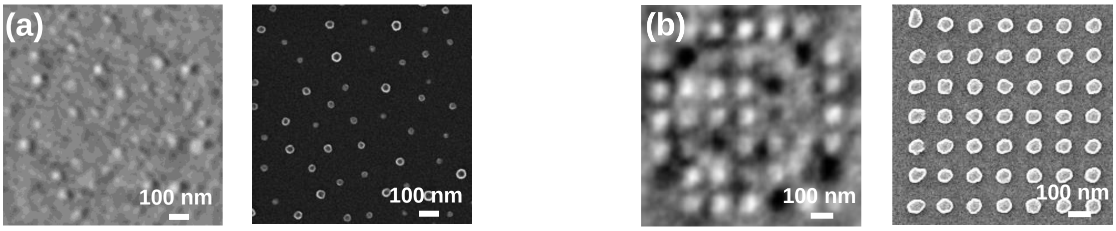

Figure 3: Holography image of $Pt_{3nm}/Co_{1.5nm}/Pt_{2nm}/Co_{1.5nm}/Pt_{3nm}$ nanodots on a Si_3N_4 membrane and a corresponding SEM micrograph (a). The nanodots were fabricated by means of shadow mask sputtering. The diameters vary between 30 - 100 nm. Holography image of $Pt_{5nm}/(Co_{0.8nm}/Pt_{1.4nm})_8/Pt_{0.6nm}$ nanodots on a Si_3N_4 membrane and a corresponding SEM micrograph (b). The array was fabricated by means of e-beam lithography with a dot diameter of 78 nm.

References

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