HE-3757 - Investigation of stray field coupling effects in Py/Co/Pt patterned structures using grazing incidence HERALDO

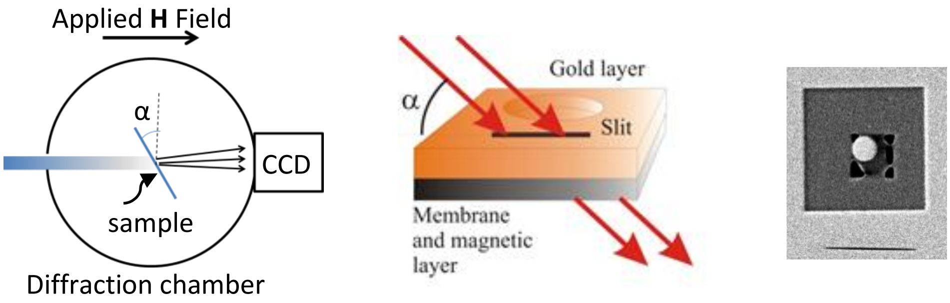
Scientific motivations

We proposed to use x-ray holography with extended reference by autocorrelation linear differential operation (HERALDO), implemented in an off-normal geometry, to investigate magnetic coupling effects in patterned multilayer structures. The aim of the first round of experiments, performed on ID08, was to carry out imaging of 'simple' in-plane magnetic domains in 50 nm thick Permalloy ($Py=Ni_{80}Fe_{20}$) squares and discs, with lateral dimensions less than ~1 micron. We used an applied magnetic field and successfully observed the domain structure variation and the domain wall movement as a function of the field. In future experiments we aim to further our investigation by imaging continuous and patterned NiFe/*Ta*/Co/Pt multilayers, which have similar structures to spin-torque oscillators (STO).

Experimental Set-up

The technique makes use of soft x-ray resonant magnetic scattering (SXMRS) and the tunable nature of the incident photon energy, to provide element specific imaging of magnetic structure. The holographic set-up [shown in Figure 1 (a)] requires a coherent light source, which was produced by placing a 50 µm pinhole into the x-ray beams path, ~700 mm before reaching our sample. The sample consisted of a 50 nm thick, Py magnetic film which was sputtered onto an x-ray transparent Si_3N_4 membrane, so that transmission measurements could be performed. On the reverse side of the membrane, an x-ray opaque Au mask was deposited, and FIB patterned with a 2 µm field of view (FOV) aperture, and near-by extended holographic reference slit (3 µm in length and 30 nm wide). The size and separation of the FOV aperture and extended reference slit were chosen such that when illuminated by the x-rays, they were within the beams coherent area. The continues magnetic Py film was then patterned with FIB milling to form an isolated disc element (~700 nm in diameter) within the FOV aperture [Figure 1 (c) shows an SEM image of the device]. The diffraction chamber on ID08 was fitted with a CCD camera positioned behind the sample, which we used to record far-field diffraction patterns from light scattered by the Py disc within the FOV aperture, and holographic reference slit. The interference between the disc and the reference slit produces a hologram which can be easily reconstructed to form a real space image with magnetic contrast. The strength of the magnetic scattering signal is proportional to $\mathbf{M}\cdot\mathbf{k_i}$, i.e. the projection of the incident wave vector of light, $\mathbf{k_i}$, onto the magnetization $\mathbf{M}$ of the sample. In order to produce a non-zero scattering signal from the in-plane magnetized domains in the Py disc, we rotated the sample by 30 degrees within the x-ray beam. The orientation of the reference slit was chosen so that the direction along the length of the slit was perpendicular to the samples rotation axis. This enabled the x-rays to be transmitted through the slit, and not blocked by the Au mask, when the sample was placed in its rotated position [as demonstrated in Figure 1 (b)]. A magnet was positioned outside the ID08 diffraction chamber which could be used to apply an external magnetic field to our sample whilst images were being taken. This allowed for us to investigate the domain structure within the Py disc as a function of the field.

To position the sample into the x-ray beam we placed a photodiode behind the sample. We then used x and z stage motors to separately move our sample through the beam in each direction whilst recording the transmitted intensity on the photodiode. From these scans we identified a strong peak in intensity when the FOV aperture and reference slit were positioned in the center of the x-ray beam. We then removed the diode out of the beam path so that the scattered x-rays transmitted through the sample could be recorded on the CCD.



SEM of the FOV aperture containing an isolated disc. Close by is the extended reference slit.

(a) (b) (c)

Figure 1 – a) Experimental set-up for imaging in-plane magnetization. b) Schematic of the sample device demonstrating the passage of x-rays through the reference slit. c) Scanning electron micrograph of the device.

Results of the Experiment

We first positioned the sample so that the plane of the magnetic film was perpendicular to the beam propagation. We then applied an external magnetic field which saturated the Py disc so that its magnetization vector was out-of the sample plane. We recorded two holograms with this field applied, one using left circular polarized x-rays, and a second with the reverse helicity. When these two holograms were subtracted, any charge scattering was canceled out, and what remained was a hologram that would reconstruct to give purely magnetic contrast [reconstruction shown in Figure 2. (b)].

After switching off the external magnetic field, we allowed the disc to relax into its magnetic ground state. We then rotated the sample to 30 degrees and imaged the disc at remanence. A difference hologram recorded at 30 degrees is shown in figure 2 (a). In this instance we observed that the disc had an expected vortex ground state with a small out-of-plane vortex core toward the center of the disc [(reconstruction shown in figure 2 (c)]. We proceeded to take images of the disc within a small range of applied magnetic fields and demonstrated domain wall movement as the vortex core was displaced from the centre of the disc as a function of the applied field [figures 2 (d-f)]. We compared the results to micromagnetic simulations performed using OOMMF prior to the experiments [figures 2(h-j)]. We compared these simulations directly with the experimental data and found that the vortex core displacement was much smaller in the simulations at comparable applied magnetic fields. This discrepancy may result from the idealistic nature of the model that cannot precisely account for thermal effects, imperfection of the material, or its geometrical and structural imperfections.

It was found that the reconstructed images, as shown in figure 2, contain some artificial noise (vertical streaks) that obscures the domain pattern. For some images (fig.2e and fig.2f) there was also a periodic pattern or line structure on ‘top’ of the image. Some of these effects (such as the patterns) arise if the center of the image, which is necessary for the correct phase retrieval, is not correctly identified. In this case, we were not able to eliminate these effects. However later experiments at DLS on the same sample showed no defects, suggesting that a different alignment or geometrical configuration can help to eliminate these. At this particular experiment at ESRF the reconstructions were produced after the measurements, we did not have the chance to modify the geometry. In general, the reconstruction can be produced straight after the imaging took place, so the necessary modifications can be nearly instant.

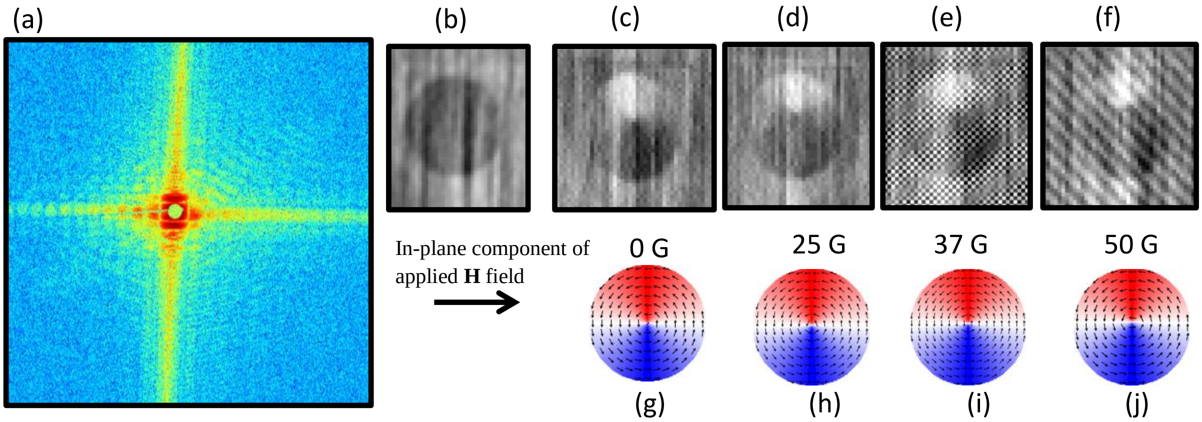


Figure 2 – a) Difference hologram of the 700 nm Py disc recorded with the sample rotated by 30 degrees. (b) Disc imaged in saturating magnetic field with sample plane perpendicular to the beam direction. The dark contrast disc region shows out-of-plane magnetization. (c-f) Reconstructions of disc imaged with the sample rotated to 30 degrees. The contrast shows in-plane magnetization with vortex domain structures. (c) Applied field = 0 G. (d) Applied field = 25 G. (e) Applied field = 37 G. (f) Applied field = 50 G. (g-j) OOMMF simulations of disc within an equivalent applied magnetic field as in (c-f) respectively. Both experimental data and simulations show the vortex core displacement increasing with the applied magnetic field.