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Report:

The goal of this LTP has been to develop instrumentation and research towards magnetic holography, i.e. the retrieval of the magnetic configuration of 2D and 3D nanometric objects using soft x-ray resonant magnetic scattering (SXRMS) in reflection geometry using coherent radiation.

For our experiments, we used the new ID08 vacuum diffractometer, which was commissioned at the time of the first run of our LTP. This diffractometer provides a sample stage with three motorised translations and two motorised rotations, which allow to choose the region of interest on the sample within very good accuracy (~5 microns). This is of prime importance in our case, since we need to know precisely where the x-ray beam illuminates the surface.

A new CCD camera was provided by the Daresbury Magnetic Spectroscopy Group. The CCD chip is back-illuminated and its efficiency is optimised for soft x-rays. The image plate has 2048 x 2048 pixels of 13 micron. It was mounted on a flange at 150° from the incident beam and at ~450 mm from the sample. Since the energy of the x-rays is ~700-800 eV, we are able to study magnetic structures with a typical length scale between 25 nm and 60 µm.

An important part of the experimental development forms the set-up for the pinhole, which is a circular aperture of either 10 or 20 micron positioned in front of the sample, and which provides a very coherent beam and defines a small area on the sample. During the first run, we used an old system with three manual micrometric translations, the pinhole being held at the end of a rod coming from the top flange of the diffractometer. Two of the three translations were motorised for the second and third run of the LTP. For the fourth run, we mounted the pinholes directly onto the sample stage, very close to the sample, wich was mounted on our motors above the sample stage of the diffractometer (Fig. 1). This set-up allowed us to position the sample with an accuracy better than half a micron and very close (~6-7 mm) to the pinhole.

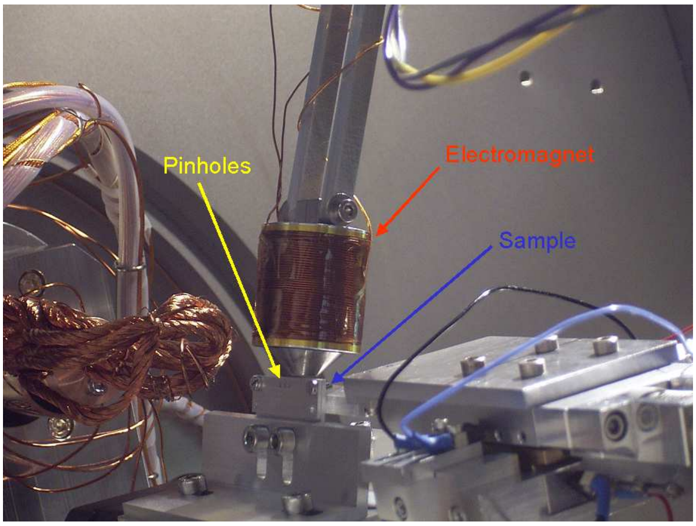

Fig. 1: The experimental set-up in the 4th run of the LTP.

Figure 2 shows the specular reflection for the 10 micron pinhole. The large number of diffraction rings around the specular beam is an indication of the high coherence.

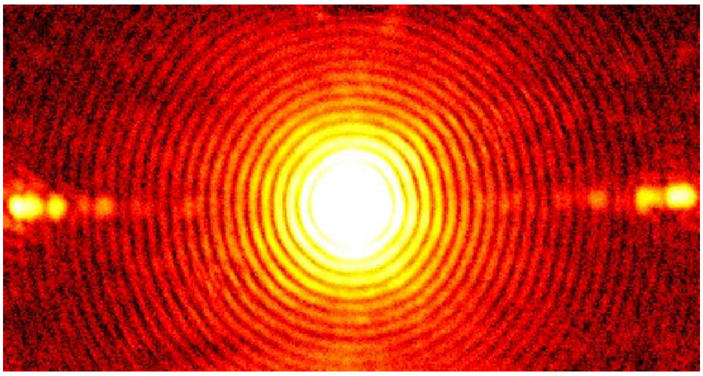

Fig. 2: Specular reflection of the beam. The pinhole results in Airy rings, which show a high coherence of the incident x-ray beam.

Another important feature of the experimental set-up is a small electromagnet, carried by a vertical rod from the top flange and providing a perpendicular field up to 2 kOe at the sample. Due to the drastic temperature increase of the magnet by the high current, we could only apply the field by pulsing it for a second or less. This electromagnet was implemented for the second run of the LTP. For the first run, we used the planar field provided by the standard set-up of the new diffractometer.

Different types of samples were studied. Among them, the etched lines in silicon coverd with a Co/Pt multilayer were of great interest. As their magnetisation of each line is practically single-domain and perpendicular to the surface, they provide a perfect model system for a reconstruction of the magnetic configuration from the magnetic diffraction pattern. Several samples were measured, both in longitudinal and transverse geometries (lines parallel and perpendicular to the scattering plane, respectively) and we recorded high-quality magnetic speckle patterns with high coherence (Fig. 2). We observed the speckle pattern evolving under applied perpendicular magnetic field on the sample and followed the magnetic state of the lines along a magnetisation loop. From the collected data we expect to be able to retrieve the magnetic configuration of the lines step by step along the magnetisation curve.

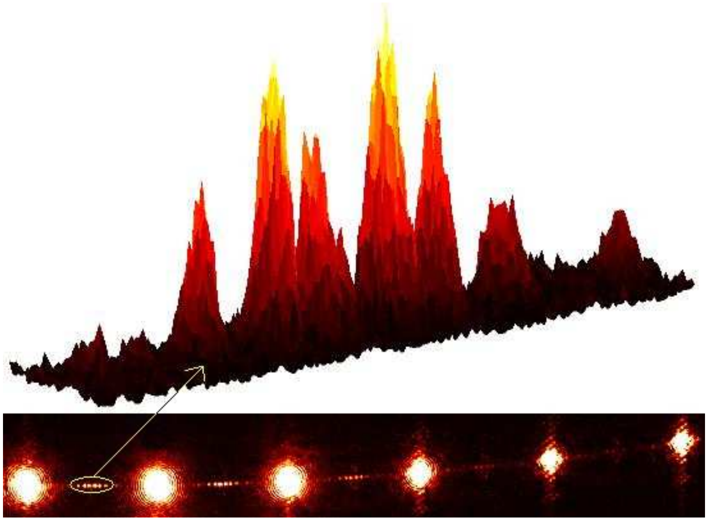

Fig. 3: An SXRMS image from the etched lines covered with a Co/Pt multilayer. The speckles are very well defined, containing up to 150 x-rays.

Other samples were micrometric shapes, lithographied in FePd thin films. These samples are of great interest for the phase retrieval problem, since the support of the unknown function (the magnetisation) is perfectly known from AFM measurements. Moreover, their initial magnetic state was recorded with magnetic force microscopy (MFM) prior to the SXRMS measurements at the ESRF. The SXRMS images will be compared with the Fourier transforms of the MFM images. Figure 3 shows the MFM image of a diamond shaped object together with its SXRMS image of the initial magnetic state.

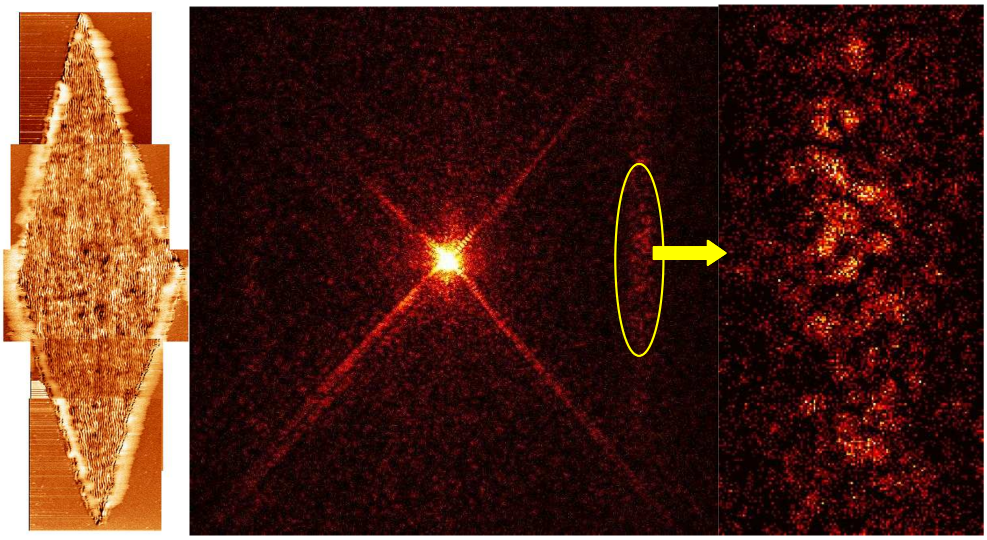

Fig. 4: The 10x40 µm diamond shape lithographied in FePd thin film and the corresponding SXRMS spectrum using coherent, circular polarisation. The magnetic satellite (in yellow circle and enlargement) shows the typical speckle pattern.

This study allowed us to improve our skills in coherent scattering of soft x-rays and to record SXRMS images of high coherence from selected model systems. This experimental work should help us to enable further theoretical work, related to the phase recovery problem.

Further experimental development should be the implementation of micro-focusing on the beamline. This would drastically improve the x-ray flux through the pinhole and allow the study of systems giving low magnetic signals, such as thin films with disordered domains of perpendicular magnetization. Another step towards the understanding of magnetization reversal would be dynamical studies using single-bunch mode.