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ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office using the **Electronic Report Submission Application:**

http://193.49.43.2:8080/smis/servlet/UserUtils?start

Reports supporting requests for additional beam time

Reports can now be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** Soft X-ray holographic microscopy	**Experiment number**: HE-2674
Beamline: ID8	**Date of experiment**: from: 23.4.2008 to: 29.4.2008	**Date of report**: 30.08.2009
Shifts: 18	**Local contact(s)**: Carsten Tieg	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

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Report:

The ultimate X-ray microscope provides a resolution that is limited by the short wavelength of the radiation, it has a large field of view, and it allows positioning of arbitrarily connected objects in the beam. The image formation process should be simple, unambiguous, and free of artifacts. Scanning transmission x-ray microscopy (STXM) provides a scanning mode with a straightforward data analysis. The resolution of STXM, however, is limited by the spot size on the sample. Coherent diffractive imaging (CDI), on the contrary, promises to reach diffraction-limited resolution by measuring oversampled diffraction pattern. The demanding image reconstruction and the need for isolated objects, however, prevent a widespread and easy-to-use application of the method.

Much simpler is the image formation process using Fourier Transform Holography (FTH), where the scattered radiation from the sample interferes with a reference wave and forms a hologram on the detector. Simple reverse Fourier transform of the measured diffraction pattern yields an unambiguous image of the object. The spatial resolution in FTH-based methods is limited by the size of the reference aperture - today FTH is especially attractive in the soft X-ray regime where the photon energy can be tuned to element-specific core level energies allowing for element-specific contrast in the images. This can be used for example to image magnetic domain structures using X-ray magnetic circular dichroism (XMCD).

In practice, the need for a reference wave close to the object imposes severe restrictions on the design and hindered widespread applications of FTH methods: So far, the FTH optics (semitransparent object hole and holes for the reference waves) have been physically linked to the sample, i.e. the optical FTH mask has been prepared directly into an opaque metal film on one side of a transparent Si3N4 membrane that carried the sample on the other side. This setup locks the field of view to a 2 micron sized sample area, without the possibility to investigate other areas on the sample.

The key to overcome the restriction of a position-fixed and size-limited FOV in soft x-ray holography is to separate the imaging elements from the actual sample by using two silicon nitride membranes. The principal setup realized in HE-2674 is illustrated in Fig. 1. We have used commercial $0.5 \times 0.5mm^2$ silicon nitride membranes with a thickness of 200 nm supported by a $5 \times 5mm^2$ silicon frame. The upstream membrane acts as support for the opaque 800 nm thick Au film. We used focussed ion beam milling (FIB) to mill a 2 μm (diameter) aperture for the object beam and three holes with diameters of 100, 320 and 350 nm for the reference beams into the Au film. The downstream membrane, which is mounted face-to-face to the optics membrane, supports the sample. It is fixed to a piezomotor-driven in-vacuum x/y–stage. The stage allows with nanometer precision that both membranes can glide smoothly with respect to each other.

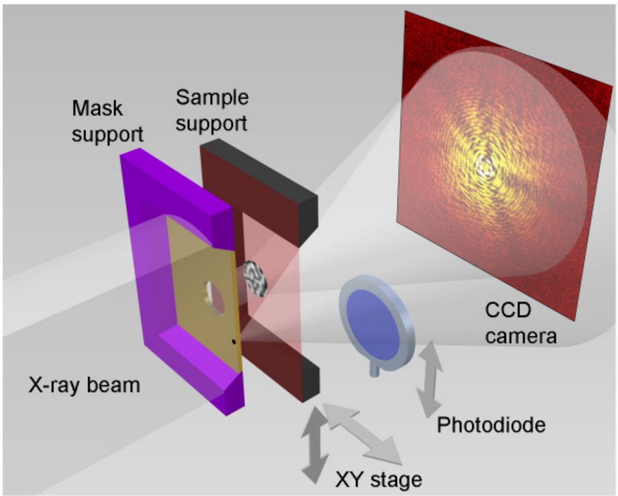

Fig 1: Schematic of the X-ray holographic microscopy setup.

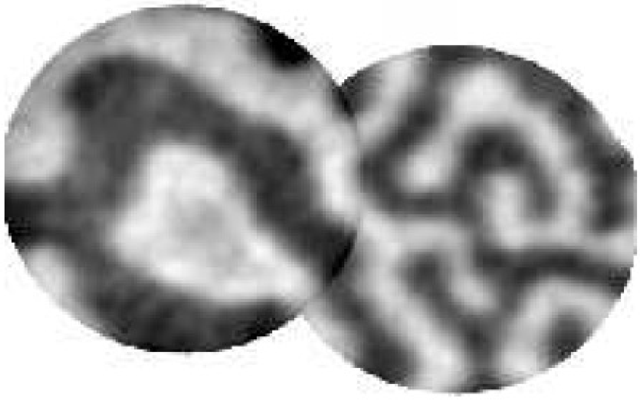

Fig 2: Magnetic domain structure of a Co/Pt film obtained by measuring at two different - slightly overlapping - positions on the sample.

The potential of our concept for magnetic imaging is demonstrated in Fig 2). The image shows the magnetic domain structure of the demagnetized state in a [Co0.7 nm/Pt2 nm]8 multilayer covered by an Fe film. The Fe film was deposited in form of a wedge. Its thickness increases from 0.5 nm at the left to 1.5 nm at the right of the image. The domain image shows the reconstruction of two holograms recorded at the Co L3 edge exploiting the XMCD contrast. The exposure time for a single hologram was 140 s. As before, the diameter of the FOV-defining object hole is 2 μm. The white and black regions correspond to magnetic domains with an opposite out-of-plane magnetisation. One can clearly identify a dependence of the domain size on the Fe thickness. In fact, the imaged region shows the beginning of a spin reorientation from out-of-plane for thin Fe coverages to in-plane for thick Fe coverages.

In summary, we have demonstrated in a proof-of principle experiment that the optical elements in soft x- ray holography can be physically separated from the sample by the use of two Silicon Nitride membranes [1]. Using two membranes allows to arbitrarily shift the field-of-view on the sample. Its size is constrained to a few μm as a result of intensity and coherence restrictions. Large sample areas were imaged by sequentially recording holograms at different FOV-positions and matching together the individual reconstructed images. This opens the door to study physical properties that depend on parameters which vary along sample dimensions exceeding the size of a single FOV. The preparation effort for imaging is strongly reduced since the mask can be re-used and the technically demanding mask fabrication by FIB milling has to be done only once. We believe that our concept will lead to a much broader use of soft x-ray holography due to the increased flexibility and microscopy-like capabilities.

[1] 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, “Soft X-ray holographic microscopy“, Appl. Phys. Lett., submitted