ESRF	**Experiment title:** Development of CRLs for hard x-ray full field microscopy, magnifying high resolution microtomography, and fluorescence element microtomography	**Experiment number:** MI-506
Beamline: ID22	**Date of experiment:** from: June 27, 2001 to: July 2, 2001	**Date of report:** August 31, 2001
Shifts: 15	**Local contact(s):** C. Rau	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):
Bruno Lengeler (RWTH), Christian G. Schroer* (RWTH), Boris Benner* (RWTH), Marion Kuhlmann* (RWTH), Til Florian Günzler* (RWTH), Timm Weitkamp* (ESRF), Anatoly Snigirev (ESRF), Irina Snigireva (ESRF)

Report:

As part of the development of parabolic compound refractive lenses (PCRLs), the imaging properties of a new generation of aluminium PCRLs where tested, in particular in view of full field microscopy and magnified tomography applications. The imaging properties of the hard x-ray microscope based on the PCRLs were tested in two geometries and for objective lenses that were fabricated under varying conditions.

The microscope was set up at beamline ID22. The sample placed in EH1 was illuminated from behind by monochromatic hard x-rays. The objective lens placed a distance L_1 slightly larger than its focal distance f was used to project a sharp image of the sample onto the FReLoN2000 high resolution CCD-camera located a distance L_2 behind the lens in EH2. Optionally, a diffuser made of B_4C powder (first described in the report for MI-470) was placed a few centimeters before the sample and used to control the coherence of the illuminating radiation.

Two imaging geometries at the energies $E = 20.65\text{keV}$ ($L_1 = 2070\text{mm}$, $L_2 = 22.02\text{m}$) and $E = 24.875\text{keV}$ ($L_1 = 1098\text{mm}$, $L_2 = 23.02\text{m}$) were implemented, yielding a magnification of 10.6 and 20.9, respectively. For these geometries, a nominal resolution is expected of 450nm and 230nm, respectively. At both energies, the imaging properties for a varying degree of coherence were investigated, using a diffuser of 5mm or 2.5mm thickness or no diffuser at all.

Various test grids and patterns were imaged to determine the microscope resolution and aberrations. Fig. 1 shows the x-ray micrograph of a Ni mesh (2000mesh). The image is free of distortions to within the resolution. Apparent in Fig. 1 is also the varying contrast as a function of position in the field of view. This effect is due to diffraction at the sample

and the gaussian attenuation of the resulting in-line hologram by the lens. Here, the coherence was only partially destroyed by the 2.5mm diffuser. Details of the contrast formation of the microscope and phase retrieval schemes will be published in SPIE proceedings and in Rev. Sci. Instrum. In the micrographs obtained, sub-micrometer features can be easily separated. A quantitative analysis is under way.

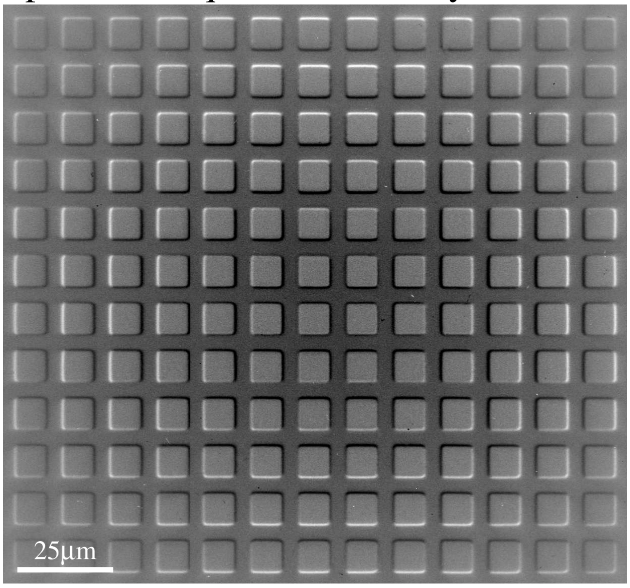

Fig. 1: X-ray micrograph (flat field corrected) of a Ni mesh (2000mesh) recorded at $E = 25\text{keV}$ ($N = 120$, $f = 1048\text{mm}$, $L_1 = 1098\text{mm}$, $L_2 = 23.02\text{m}$).

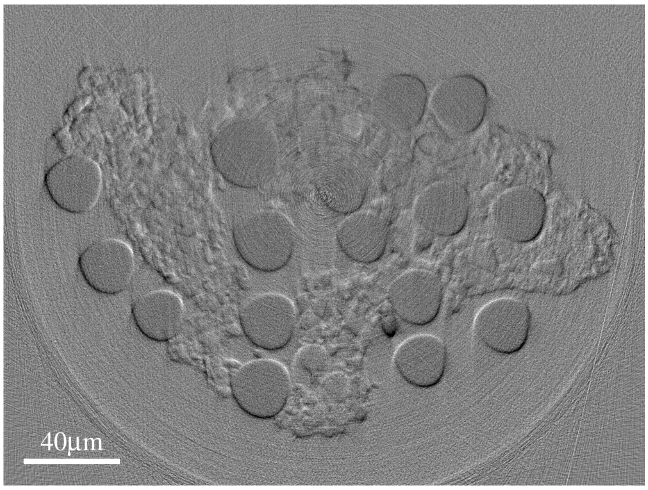

Fig. 2: Magnified tomographic slice through a fiber reenforced concrete sample. The slice was reconstructed using 250 x-ray micrographs (magn. $10.6\times$) recorded at $E = 20.65\text{keV}$.

To obtain the three-dimensional structure of a sample with high resolution, magnified tomograms were recorded. For this purpose, the sample was imaged from a large number (250-500) of perspectives in an angular interval of $180°$. Before the scan and after each several projections, the sample was moved out of the beam to record a flat field image. Dark field images were recorded after the scan. In all, 12 magnified tomograms of various samples under different conditions (coherence of incident radiation, magnification) were recorded.
Fig. 2 shows a reconstructed slice of a fiber reinforced concrete sample. Although it is in principle possible to obtain the same resolution in the reconstruction as in single projections, artifacts due to the mechanical instability of the stages prohibit a high resolution in the reconstruction. Note that the circular fibers are distorted. In addition, the complicated contrast due to coherence effects requires preprocessing (phase retrieval) to obtain quantitative reconstructions from the micrographs. Currently, correction algorithms for these artifacts as well as phase retrieval schemes are being developed.
As a reference, state of the art projection tomograms were recorded to compare them with the magnified tomograms. The evaluation is in progress.
Preliminary results were presented at the SPIE conference in San Diego and at SRI2001 in Madison and will be published in the corresponding proceedings.

C. G. Schroer, B. Benner, T. F. Günzler, M. Kuhlmann, B. Lengeler, C. Rau, T. Weitkamp, A. Snigirev, I. Snigireva, "Magnified Hard X-Ray Microtomography: Toward Tomography with Sub-Micrometer Resolution", in U. Bonse, ed., *Developments in X-Ray Tomography III*, Proc. SPIE 4503, 2001. To be published.

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