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: Nov. 21, 2001 to: Nov. 27, 2001	**Date of report:** April 26, 2002
Shifts: 15	**Local contact(s):** C. Rau	*Received at ESRF:*

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Report:
During this second part of the long term proposal, the beam time was subdivided into two parts: In part one, we have investigated basic properties of a first beryllium lens. In part two, demagnifying imaging was tested using Al lenses in view of future x-ray lithography applications.
Shortly before the experiment, we were able to fabricate the first beryllium lenses. 16 individual lenses were available that were aligned in a newly designed, vacuum tight lens holder that allows one to keep the lenses under nitrogen atmosphere to avoid corrosion of the beryllium. This small number of lenses did not allow us to characterize them in view of high resolution imaging and microbeams with small lateral extension, since the focal distance was not small enough (at $E = 14.5\text{keV}$, $f = 3.9\text{m}$).
The lenses were characterized in three imaging geometries: Firstly, the source was imaged onto the FReLoN2000 in a demagnifying geometry. Temporal fluctuations of the beam did not allow us to obtain an image of the source that can be evaluated quantitatively in view of image size. Secondly, the Be lenses were used as “field lens” in the lithography experiment (see below). Thirdly, the secondary slits of ID22 were imaged onto the FReLoN2000 in a demagnifying geometry. The image of the slit is shown in Fig. 1 taken with the Be lens at $E = 14.5\text{keV}$ ($N = 16$, $f = 3.87\text{mm}$, $L_1 = 22.3\text{mm}$, $L_2 = 4.66\text{m}$), demonstrating that the lens images straight lines free of distortion and has, therefore, the desired parabolic shape. The intensity variations visible in Fig. 1 are due to interference fringes produced at inhomogeneities of the total reflexion mirror and the monochromator that are located before the slit. After several days of irradiation, the Be lenses did not show any signs of deterioration. Up to now, over 80 Be lenses of good quality were fabricated at our institute. They will be characterized in detail during the third beam time of MI-506 in May.

Fig. 1:

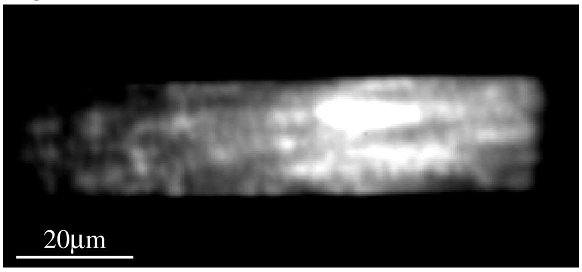


Fig. 2:

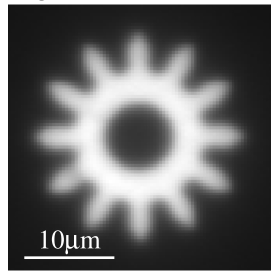
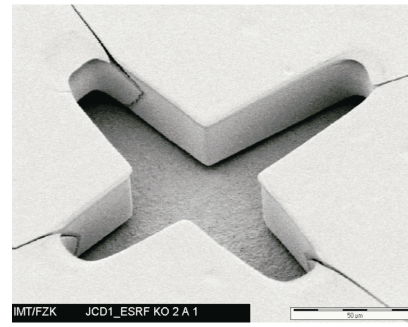


Fig. 3:



In collaboration with the IMT in Karlsruhe (Dr. S. Achenbach, Prof. V. Saile) we have investigated the possibilities of demagnifying imaging using refractive lenses for hard x-ray lithography. Demagnifying x-ray lithography allows one to generate smaller feature sizes with coarser masks and avoids wear due to the contact between mask and resist. The large depth of field allows one to produce steep flanks in thick resist. This is of particular interest for MEMS fabrication. The experimental setup (in EH2 of ID22) consisted of an aluminium refractive lens ($N = 165$ for $E = 24.5\mathrm{keV}$, $N = 108$ for $E = 20\mathrm{keV}$) that was used to image an x-ray mask placed $L_1 = 3.66\mathrm{m}$ before the lens onto x-ray sensitive resist or the FReLoN2000 at a distance $L_2 = 905\mathrm{mm}$ behind the lens. This yields a demagnification of nearly 4. To avoid interference effects due to the high degree of spatial coherence at $59\mathrm{m}$ from the undulator source, a B_4C diffuser [3] was brought into the beam path before the sample. The beryllium lens placed before the sample was used to capture the full undulator beam and focus it through the aluminium objective lens. This way, an area of over $700\mu\mathrm{m}$ was illuminated on the mask.

Fig. 2 shows the image of an x-ray lithography mask (gold on titanium membrane) projected onto the FReLoN2000 at $20\mathrm{keV}$. The image of the cog wheel has a diameter of $22.5\mu\mathrm{m}$, while its original size on the mask is $90\mu\mathrm{m}$. As the teeth have features in the range of $1 - 2\mu\mathrm{m}$, the blurring due to the limited resolution of the FReLoN becomes significant.

Fig. 3 shows the image of a cross pattern transferred into $60\mu\mathrm{m}$ thick resist. The developed pattern shows deviations from the illuminated pattern. The reasons for this are currently investigated, the most probable being the proximity effect and an insufficient contrast of the mask at high energies (mask thickness: $30\mu\mathrm{m}$). Both these effects could be avoided in the future by using Beryllium lenses at low energies.

The results of this experiment were shown at the user meeting on poster 64. In the meantime, the data from the first part of MI-506 has been evaluated: A magnified tomogram of a fragment of an AMD K6 microprocessor was reconstructed with an unprecedented resolution of 310nm in three dimensions. These results have been submitted for publication in Appl. Phys. Lett.

[1] C. G. Schroer, et al., "Magnified Hard X-Ray Microtomography: Toward Tomography with Sub-Micrometer Resolution", in U. Bonse, ed., *Developments in X-Ray Tomography III*, Proc. SPIE **4503**, 23 (2001).

[2] B. Lengeler, et al., "Parabolic refractive X-ray lenses", *J. Synchrotron Rad.*, **9**, 119-124 (2002).

[3] C. G. Schroer, et al., "High Resolution Imaging and Lithography with Hard X-Rays Using Parabolic Compound Refractive Lenses", *Rev. Sci. Instrum.*, **73** 1640 (2002)