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: 01/05/2002 to: 06/05/2002	**Date of report:** August 30, 2002
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Report:

This beam time was dedicated to determine the imaging quality of beryllium parabolic refractive lenses that were fabricated at the Aachen University (RWTH). Both the full field imaging capabilities and the microbeam characteristics were determined for a beryllium lens composed of $N = 91$ single lenses. A special sealed container was designed to avoid lens oxidation and the contact with the beryllium surfaces. A standardized procedure was determined together with the safety group of the ESRF for bringing Be lenses to the ESRF on a routine basis for future experiments.

For full field imaging, an object was illuminated from behind with undulator radiation at $E = 12\mathrm{keV}$. Using the lens ($f = 493\mathrm{mm}$) that was located $L_1 = 545\mathrm{mm}$ behind the object the magnified image was formed on photographic film placed $L_2 = fL_1/(L_1 - f) = 5160\mathrm{mm}$ behind the lens (magnification $9.5\times$). (The film was required because the ESRF could not provide adequate replacement for the FReLoN2000 camera at ID22 that did not work. This slowed down the experiment significantly, as exposure times and focusing had to be determined off-line after developing the film.) To control the coherence of the beam, the B_4C-diffuser developed during earlier experiments was used (see reports MI-470 and earlier MI-506).

To test the field of view and the image distortion, a nickel mesh (2000mesh used in electron microscopy) was imaged. Fig. 1 shows the images nearly free of distortion of the same mesh recorded using an aluminium lens [1] (inset) and beryllium lens (large image) [2]. The field of view in the case of the Be lens is $450\mu\mathrm{m}$ (FWHM). To determine the resolution, a gold test structure ($2\mu\mathrm{m}$ pitch, $1\mu\mathrm{m}$ width, $2\mu\mathrm{m}$ thickness on Si wafer) with small scale defects was imaged. Fig. 2 compares the images obtained by projection imaging using the FReLoN2000 camera optimized for highest resolution (a) and the magnified images using

an Al (b) and Be (c) objective lens. The images acquired with the Be lens are by far superior to the others and have a resolution estimated by the size of the edge contrast fringes of about 100 to 200nm. A detailed quantitative analysis of the resolution is in progress. Various other objects were imaged, as-well.

Figure 1

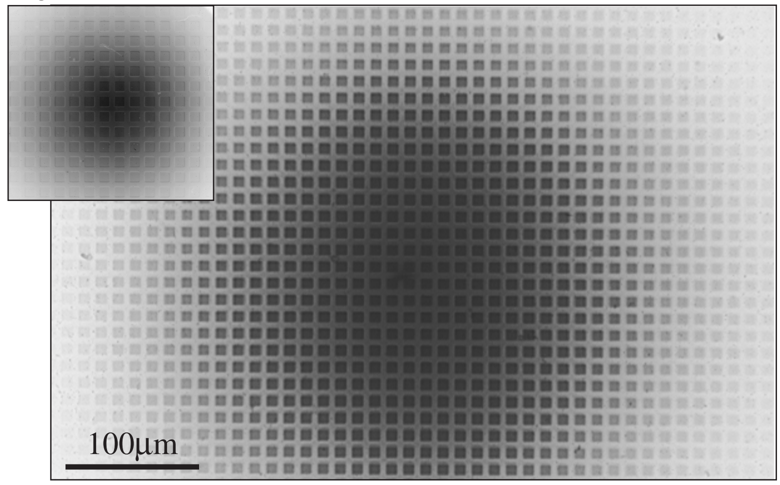
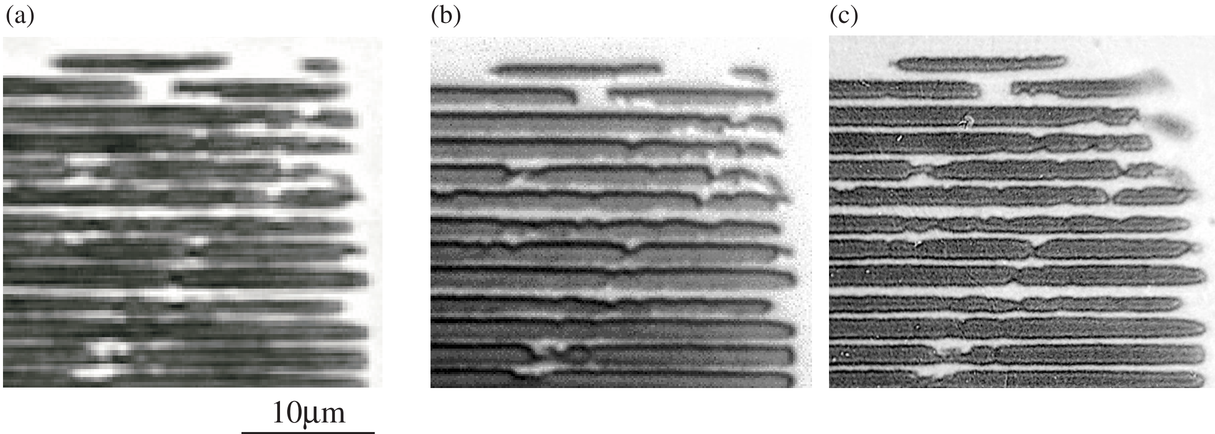


Figure 2

(a) (b) (c)



The lens was used to produce an intensive microbeam, imaging the undulator source onto the sample position in a demagnifying geometry. The microbeam was characterized at $8\mathrm{keV}$, $12\mathrm{keV}$, and $18\mathrm{keV}$ using a fluorescence knife-edge technique. At $12\mathrm{keV}$, its lateral extensions were $11\mu\mathrm{m} \times 1.14\mu\mathrm{m}$ (H×V FWHM). Behind the lens, $1.05 \cdot 10^{11}\mathrm{ph/s}$ were measured. About 70% of this radiation lie inside the microbeam, the rest being scattered by inhomogeneities in the lens material and by Compton scattering. The following lens parameters were extracted from this experiment: $R = 202\mu\mathrm{m} \pm 5\mu\mathrm{m}$, $d = 170\mu\mathrm{m} \pm 20\mu\mathrm{m}$. The geometric aperture $R_0 < 800\mu\mathrm{m}$ was determined optically before the experiment.

The experiment showed that distortion free high resolution imaging in a large field of view is possible using refractive lenses. The imaging properties should be tested in more detail in the future. In addition, the lenses should be used to improve the 3D resolution of magnifying tomography [3]. Microbeams with monochromatic fluxes above $10^{11}\mathrm{ph/s}$ are generated for energies above about $12\mathrm{keV}$ (this will be improved by reducing the thickness d). In the future, the scattering inside the lens will be reduced by using a more homogeneous lens material. The Be lenses perform as expected from theoretical calculations. The results will be published in Review of Scientific Instruments and SPIE 4783.

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

[2] C. G. Schroer, et al., "Beryllium parabolic refractive X-ray lenses", in Design and Microfabrication of Novel X-Ray Optics, ed., *D. C. Mancini*, Proc. SPIE **4783**, (2002). To be published.

[3] C. G. Schroer, et al., "Nanotomography based on hard x-ray microscopy with refractive lenses", *Appl. Phys. Lett.*, **81** (8), 1527-1529 (2002). This article was selected for publication in *Virt. J. Nanoscale Sci. & Tech.*, **6** (8), art. 21 (2002) by the editor of that journal.