ESRF

	Experiment title: Hard X-Ray Projection Lithography using Compound Refractive Lenses	**Experiment number:** MI-470
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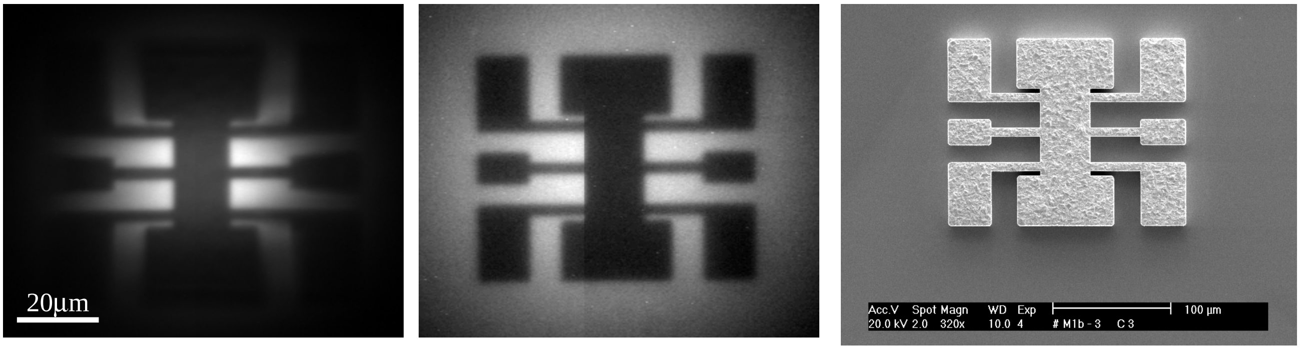
Names and affiliations of applicants (* indicates experimentalists):
Christian G. Schroer* (RWTH), Bruno Lengeler (RWTH), Jörg Appenzeller (RWTH), Thomas Hunger (RWTH), Til Florian Günzler (RWTH), Alexandre Simionovici (ESRF), Anatoly Snigirev (ESRF), Irina Snigireva (ESRF)

Boris Benner* (RWTH), Marion Kuhlmann* (RWTH), Christiane Zimprich* (RWTH)

Report:
The aim of the experiment was to assess the possibilities of x-ray lithography using parabolic compound refractive lenses (CRLs) as reduction optics. The lithography masks with test patterns (grids, lines, dot arrays and other shapes, like a hall bar (see Fig. 1(c)) and the Aachen University of Technology logo (Fig. 2(a))) were fabricated by optical lithography and gold plating. They are between 15μm and 20μm thick deposited on 375μm Si wafers polished from both sides.
The lithography masks were positioned at the beam entrance of EH2. A CRL with $N = 130$ single lenses located $L_1 = 3.62\mathrm{m}$ behind the mask was used to transfer the image of the mask onto the FReLoN2000 (high resolution CCD camera) or a resist covered sample mounted on the stage of the FReLoN. This allowed to observe the image of the mask before exposing the resist. The image distance L_2 was variable between $750\mathrm{mm}$ and $1350\mathrm{mm}$, yielding demagnifications between 2.7 and 4.8 at x-ray energies between 20 and 26keV. Two fixed geometries were used during the experiment: $L_2 = 780\mathrm{mm}$ at 20.5keV (reduction 4.6) and $L_2 = 1284\mathrm{mm}$ at 25keV (reduction 2.8).
In the experimental setup described above, the mask is illuminated with a high degree of spatial coherence and with low divergence. This leads to two unwanted effects. The field of view is reduced, and interference may lead to phase contrast that does not faithfully reproduce the features of the mask. Two avoid both effects, the spatial coherence was destroyed by a diffuser placed into the beam about 30cm before the mask. It was specifically designed for the experiment and consists of a strongly scattering material (B_4C powder pressed between two glass plates) that is rotated. Fig. 1 shows a mask (Hall bar) imaged onto the FReLoN2000 without diffuser (a) and with diffuser (b). Fig. 1(c) shows the electron micrograph of the mask for comparison. The diffuser will be of interest also for

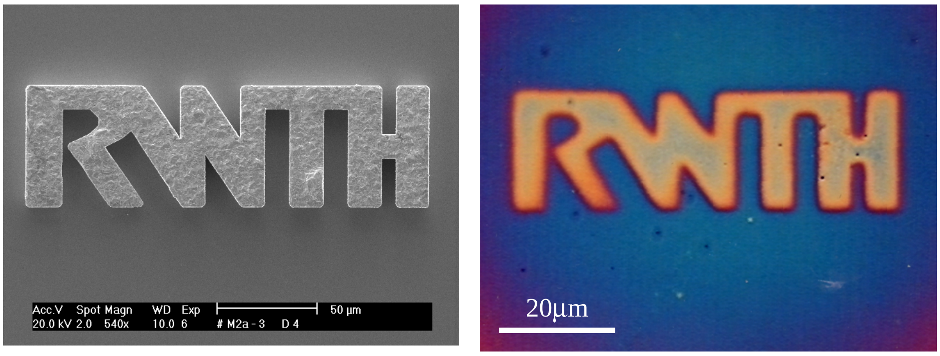
microscopy and magnified tomography, and was indispensable for this experiment.



(a) image of mask without diffusor (b) image of mask with diffusor (c) SEM image of mask

The images of the masks were projected onto resist covered wafers (Si and GaAs). Four resists were tested, two positive (PMMA) and two negative resists (Novolac), one of each mixed with about 5% Pd acetate. Above the Pd K-edge (24.35keV), the addition of Pd increases the absorption in the resist by about one order of magnitude. At 25keV, most of the photo electrons produced in the resist that are responsible for the exposure have low energy (< 4keV) reducing the proximity effect.

Over 20 exposure series were taken during the experiment, with exposure times between a few minutes and about one hour. As an example, the reduced image of the Aachen University of Technology logo (electron micrograph in Fig. 2(a)) imaged into the negative resist (Novolac) is shown in Fig. 2(b). While the imaging properties of the compound refractive lenses are nearly ideal (as measured by a fluorescence knife edge technique), the contrast in the resist was not optimal, due to temperature fluctuations during the baking process needed for development (a new mobile heating surface with accurate temperature control has been purchased for future experiments).



(a) SEM image of lithography mask (b) image on resist (reduction 2.8x)

CRLs are well suited as reduction lenses for x-ray lithography. The method might be useful to transfer small structures into thick resists for MEMS applications. Future experiments should focus on thicker resists and smaller mask features. CRLs made of more transparent lens materials will improve the obtainable feature size and increase the field of view. The results of this experiment will be presented at SRI2001 in Madison, WI.