Highly efficient and tuneable silicon diffractive lenses for hard X-ray microdiffraction experiments

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Many currently available structural and chemical imaging techniques such as micro X-ray diffraction (microXRD), X-ray absorption spectromicroscopy (microXAS) or scanning X-ray fluorescence microscopy (SXFM) require highly efficient focusing of hard X-rays. Such applications widely rely on performing experiments with micro- and nanometer size beams, with the wish of having an extremely bright beam on the sample under investigation in order to obtain the best signal to noise ratio. This holds true in particular in macromolecular crystallography, since increasing difficulties are observed to grow large crystals for experiments aimed at solving the structure of challenging targets. Developing focusing modules with ultra-high efficiency, yet showing focusing capability for reaching beams with micro- and nanometer size, is thus of paramount importance.

One material of choice for fabricating lenses in this context is silicon, since it has no absorption edge at hard X-ray energies. We developed 1D silicon lenses based on the zone plate equation which present the ideal kinoform profile for efficient X-ray diffraction (see Fig. 1a), allowing a theoretical efficiency reaching unity, only limited by material absorption [1]. We used the metal-assisted chemical etching technique (MAC-Etch) [2,3] to address the challenge of fabricating the high aspect ratio nanostructures required for efficient X-ray diffraction. We here optimized this technique to fabricate lenses with pitch down to 150 nm and a depth of up to 6 µm (see Fig. 1b, c). The design relies on two tilted 1D lenses which decouples focusing in both dimensions and allows tuning of the working energy [4].

Microfocusing experiments were conducted at microXAS - X05LA beamline of the Swiss Light Source, Paul Scherrer Institut and an average efficiency of 60% was obtained at 12.4 keV (see Fig. 1d). Such diffraction efficiency is substantially higher than the ones expected from binary diffractive structures, inherently limited to 40.5% for pure phase structures. The presented results will range from the design and fabrication of our optics followed by characterization measurements in context of micro-focusing experiments performed at the Swiss Light Source, Paul Scherrer Institut.

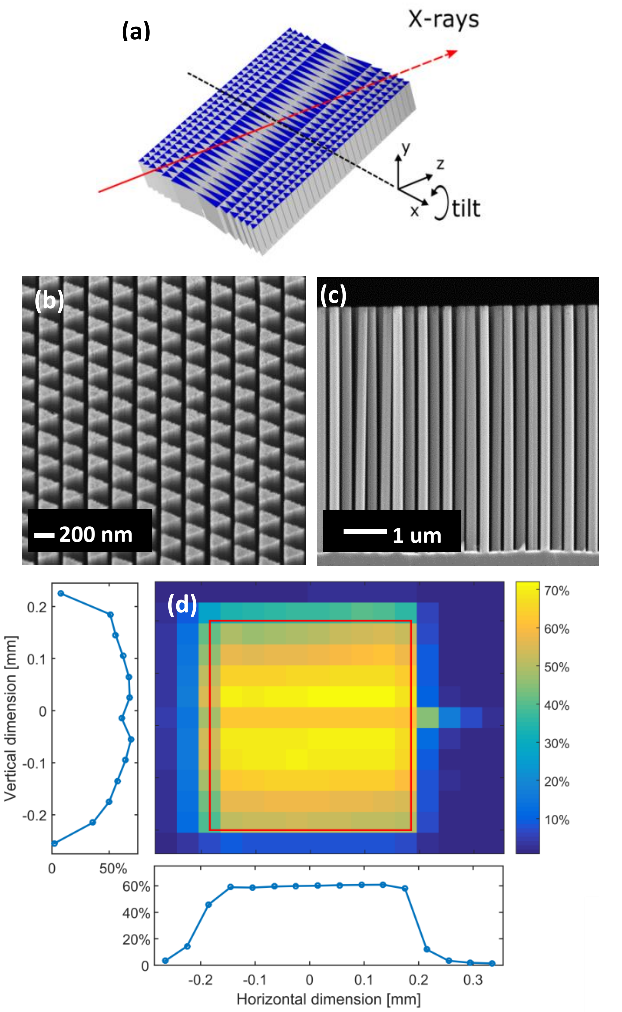

Figure 1. **(a)** Kinoform lens schematic, consisting of a periodic arrangement of small triangular lens elements. SEM pictures of the realized lens: **(b)** 20° tilted view of 200 nm pitch zones. **(c)** Cross section of same nanostructures with aspect ratio of 30:1. **(d)** Space-resolved diffraction efficiency for 1D focusing at 12.4 keV (see colorbar) obtained using a pencil beam. The lens aperture is 400µm x 400µm (red frame). Sub-figures show the averaged efficiency along each dimension.

References

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