Technical University of Denmark

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Stöhr, Frederik; Simons, Hugh; Jakobsen, Anders Clemen; Jensen, Flemming; Hansen, Ole; Poulsen, Henning Friis

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<u>F. Stöhr</u>, H. Simons, Anders C. Jakobsen, F. Jensen, O. Hansen & H.F. Poulsen

Technical University of Denmark, Lyngby, 2800, Denmark

Introduction and Objectives

Refractive lenses are versatile optical components and act e.g. as condensers or objectives in hard (E > 10 keV) X-ray microscopes [1]. One-dimensional focusing lenses may be realized by microfabrication techniques, whereas the main challenge is the transfer of the lithographically defined two-dimensional pattern into the substrate. Deficiencies in the fabrication result in non-uniform lenses. Likewise, X-ray absorption in the lenses limits flux gains and resolution. By optimizing the manufacture and introducing new lens materials we seek to realize more uniform and more efficient X-ray optics.

Results and Discussion

• With respect to Si lens design, we included sacrificial structures surrounding the lens target structures. This effectively improved the sidewall verticality upon deep reactive ion etching. Process control was facilitated by a characterization procedure based on replica molding and atomic force microscopy [2].

• An absorption-minimizing (kinoform) lens comprising 60 'adiabatically arranged' single lens elements was realized and tested at ESRF ID06 (Figure 1). We measured a 180 µm long line beam with a waist of 300 nm (FWHM), corresponding to an aspect ratio of 600. A flux gain of 75 at 17 keV was achieved.

• We explored a new route for X-ray lens manufacture: injection molding. A preliminary test of a thermoplastic lens showed a 60 µm long line beam with a waist of 700 nm and a gain of 50 at 17 keV.

• We addressed the challenge of making objectives in silicon by the interdigitation of lenslets alternately focusing in the vertical and horizontal directions. With a silicon objective in a bright-field hard X-ray microscope we demonstrated a resolution of 500 nm, close to theoretical expectations [3].

Conclusions

Including sacrificial structures in the lens manufacture facilitates obtaining uniform silicon X-ray lenses with etch depths beyond 100 µm without sacrificing optical quality. Polymer lenses produced by injection molding are promising in respect to high efficiency optics at low cost. The silicon objective presents a viable alternative for imaging with hard X-rays.

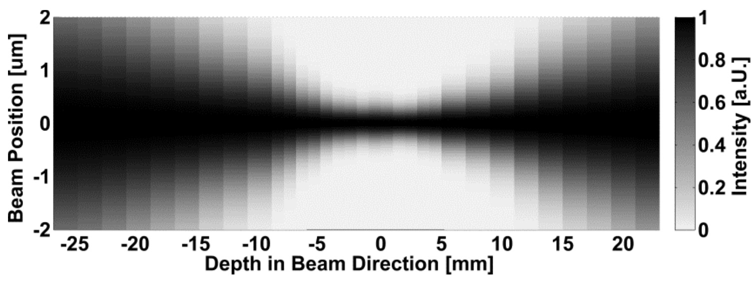

Figure 1. Reconstructed vertical profile of a 180 um long line beam based on absorptive knife-edge measurements around the focus of a silicon lens with focal length of 230 mm at 17 keV.

References

[1] H. Simons et al. Nat. Commun. **6**, 6098 (2015).

[2] F. Stöhr et al. Microelectron. Eng. **141**, 6-11 (2015).

[3] H. Simons et al. (submitted).