DIAMOND REFRACTIVE MICRO-LENSES PRODUCED WITH ION BEAM LITHOGRAPHY

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ABSTRACT

The capability of ion-beam lithography for fabrication of rotationally parabolic refractive diamond X-ray micro-lenses that are of interest to the field of high-resolution X-ray focusing and microscopy has been shown. Three single half-lenses with curvature radii of 4.8 µm were produced and stacked to form a compound refractive lens, which provided diffraction-limited focusing of X-ray radiation at the P14 beamline of PETRA-III (DESY). As shown with SEM, the lenses are free of expressed low- and high-frequency shape modulations with a figure error of < 200 nm and surface roughness of 30 nm. Precise micro-manipulation and stacking of individual lenses are demonstrated, which opens up new opportunities for compact X-ray microscopy with nanometer resolution.

DIAMOND X-RAY REFRACTIVE OPTICS

Advantages:

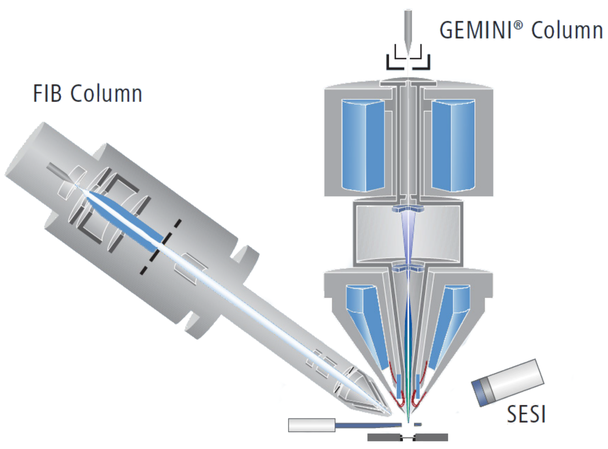
- Single crystal material (does not produce speckles)
- High thermal conductivity and temperature stability
- Diamond lenses 2.7 times more compact than polymer lenses

Disadvantage:

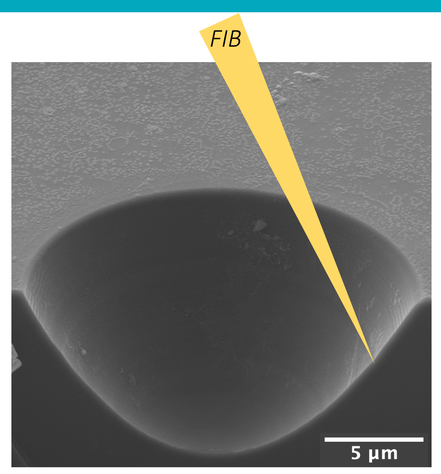
- Hardest material to process

Material	Diamond	Be	Al	Si	Ni
E/R/F	12 keV/5 µm/0.1 m				
N	5	11	7	7	2
A_{eff}, µm	113	186	34	32	12

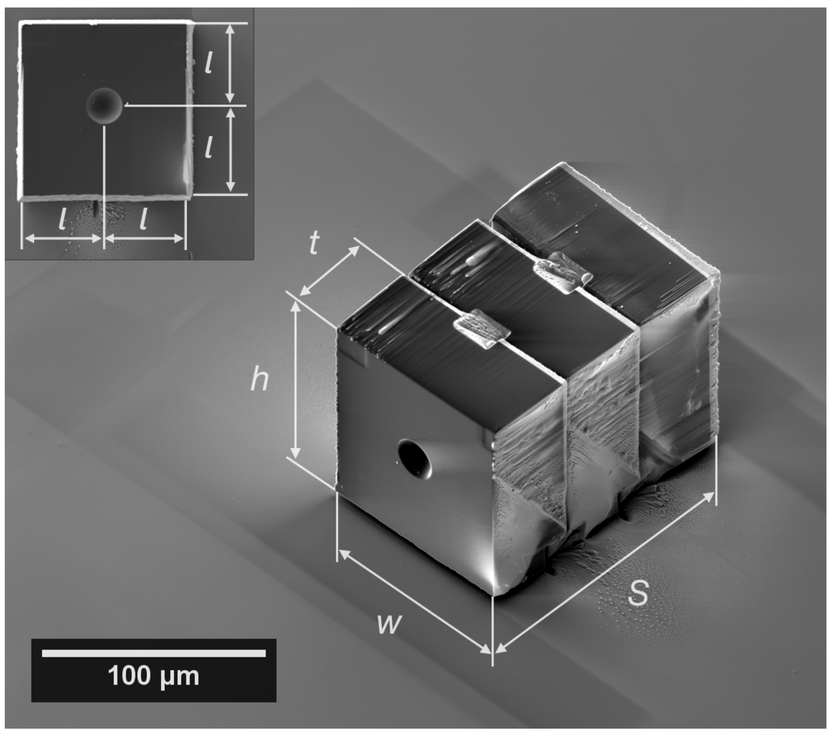
LENS MANUFACTURING



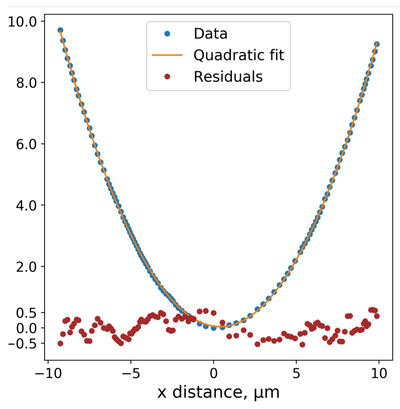
Scheme of dual-beam (FIB-SEM) systems



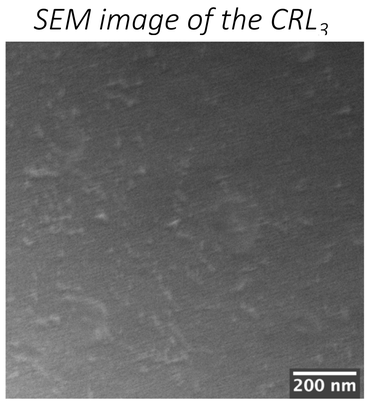
Tilted (54°) SEM images of the micro-lens



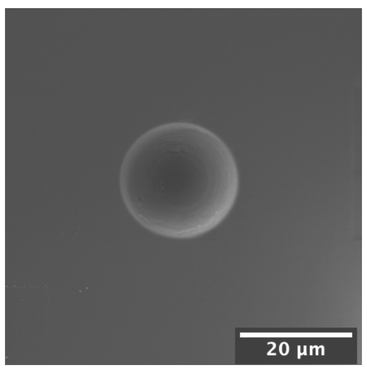
SEM image of the CRL_3



Parabolic fit of the single lens

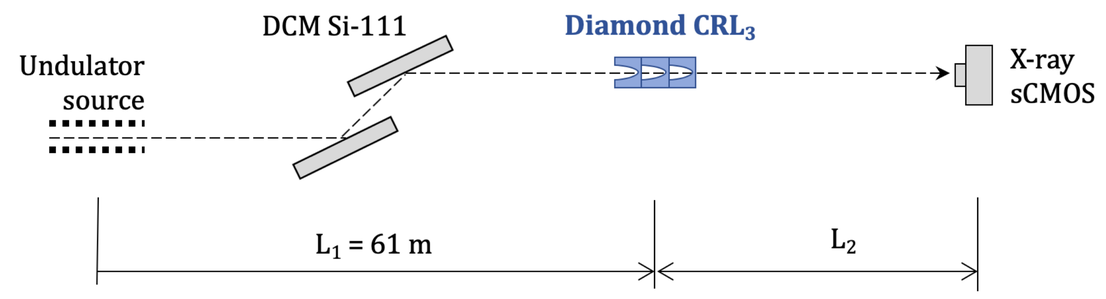


Surface surface quality assessment



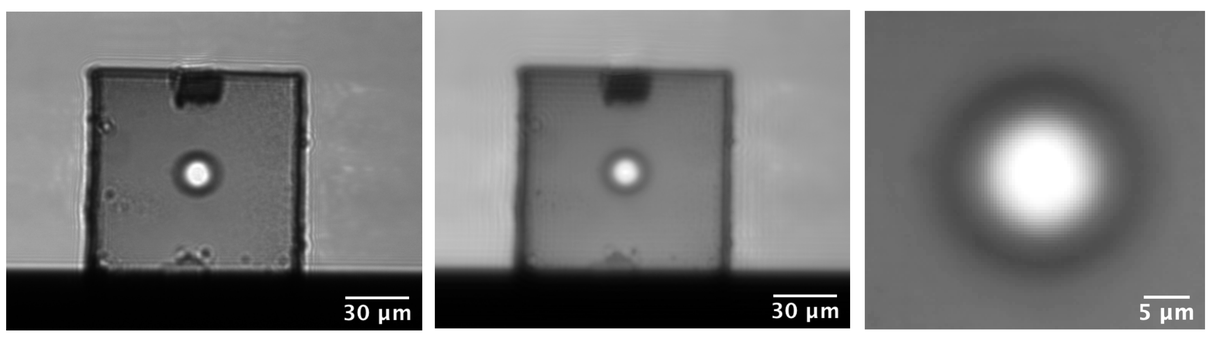
SEM image of circularity of lens aperture

X-RAY TESTS



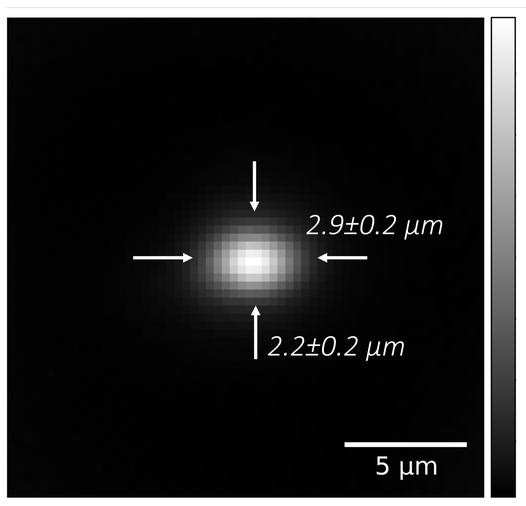
The scheme of the experimental setup at the P14 beamline of PETRA-III (DESY. L_2 can be varied to switch between near-field radiography and focusing modes

X-ray Radiography

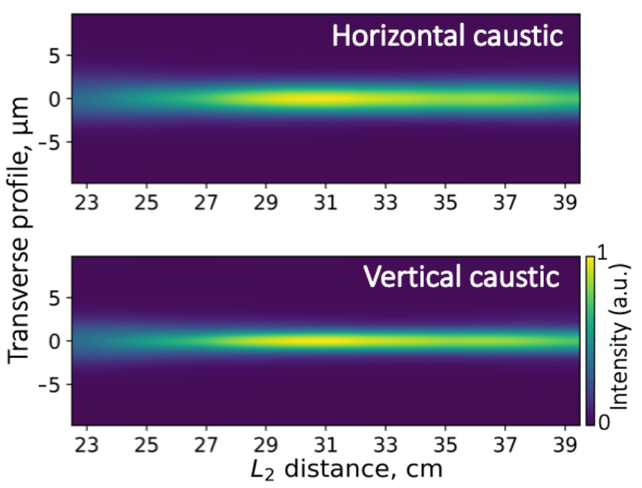


Raw image and single-distance CTF-based phase retrieval

Focusing of the diamond CRL_3



X-ray image reveals the focus of the CRL_3 at L_2 = 30.5 cm.



The caustics in both horizontal and vertical directions

Conclusions

- With the help of IBL, we managed to mill the hardest of current materials - diamond - and produce micro-scale diamond half-lenses. Lenses had a rotationally parabolic profile with radii of parabola apexes of <5 µm;
- As has been confirmed with SEM, the profiles of produced lenses were free of expressed low- and high-frequency modulations: figure errors of fabricated lenses were <200 nm, while the surface roughness was estimated to be 30 nm;
- The optical performance of the CRL_3 was successfully tested at a third-generation synchrotron, where the lenses provided diffraction-limited focusing of X-ray radiation and demonstrated intensity profiles with Gaussian distributions at every measured longitudinal position (along the optical axis) downstream of the CRL_3

P. Medvedskaya, I. Lyatun, S. Shevyrtalov, M. Polikarpov, I. Snigireva, V. Yunkin, and A. Snigirev, "Diamond refractive micro-lenses for full-field X-ray imaging and microscopy produced with ion beam lithography", Opt. Express, 2020; **https://doi.org/10.1364/OE.384647**

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