Multilayer Laue Lenses with Long Working Distances

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Introduction

Multilayer Laue Lenses (MLLs) are innovative diffractive X-ray optics with a high numerical aperture (NA) that enable X-ray focusing to sub-10 nm spatial resolution even for hard x-rays [1]. The principle of MLLs relies on diffraction. The individual layers (zones) are made in such a way, that constructive interference occurs at the focus.

Synthesis of Multilayer Laue Lenses

Alternating thin layers must be deposited with a thickness gradient so that they follow zone plate law. Free-standing coatings are structured by short-pulse laser followed by FIB thinning for the target photon energy [2]. Fig. 1 shows the schematic of an MLL.

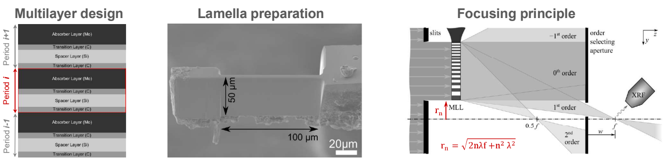

Fig. 1: Design, fabrication and focusing of Multilayer Laue Lenses.

Results

Application of MLL in synchrotron beamlines

Novel synchrotron X-ray sources provide a very intense beam with extraordinary high brilliance and coherence. The performance of MLLs in focusing a synchrotron beam to a small spot size has been well documented [3,4]. Currently, one major challenge is a limited working distance (WD) impeding the investigation of real specimens. Therefore, the development of MLLs with large WD and acceptable resolution is crucial. Table 1 lists three types of our MLLs with long, very long and extra-long WD (LWD, VLWD, ELWD) developed at Fraunhofer IWS in cooperation with AXO DRESDEN.

Table 2: MLL parameters and properties.

	Tested		*Under test*
MLL design	**LWD**	**VLWD**	**ELWD**
Materials	Mo/C/Si/C	Mo/C/Si/C	Mo/C/Si/C
Focal length (mm) @ 12 keV	9	45	67.5
Working distance (mm) @ 12 keV	3.1	25	39
Geometry	Flat tilted	Flat tilted	Flat tilted
Stack height (µm)	50	100	150
Individual layers	12000	17000	24000
Focus size FWHM (nm)	22×22	80×80	85×85

An integrated MLL mount was developed: This mount integrates the vertically and the horizontally focusing MLL to a 2D operating lens device and provides all required degrees of freedom for the internal alignment. This significantly reduces the complexity of the final integration to the beamline. Fig. 2 shows all MLL designs installed on the ESRF ID13 beamline and corresponding sample at the focal position. An order sorting aperture blocks the higher-order diffractions and the direct beam.

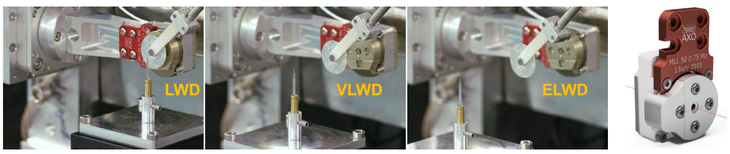

Fig. 2: Comparison of MLL designs at 12 keV.

The focusing characteristics is typically evaluated with ptychography [5,6]. Our MLLs were tested at PETRA III, P03, operating at 12.7 keV. These lenses exhibited the focus size of 30×40 nm² and as shown in Fig. 4, the minimal features of reconstructed test patterns could be resolved. Fig. 5 also shows preliminary results from experiments at ID13, ESRF.

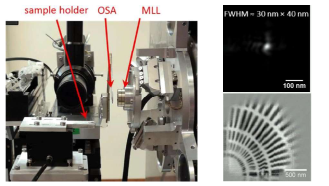

Fig. 4: Experimental setup and ptychographic reconstruction at PETRA III, P03.

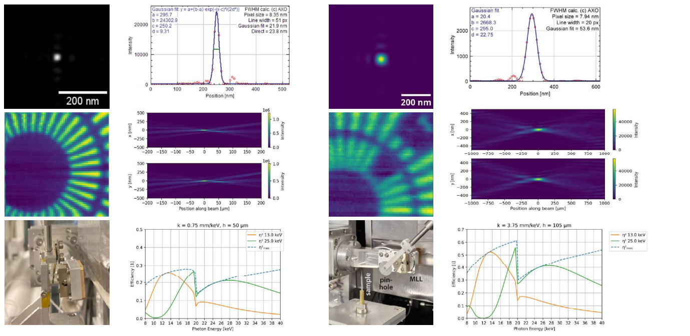

Fig. 5: MLLs developed at IWS exhibited ≈ 22 nm (LWD design, left) and 53 nm (VLWD design, right) focus size at ESRF, ID13 (*preliminary result*).

MLLs for structural analysis

VLWD MLLs were used to focus the synchrotron beam at ID13, ESRF and investigate stress and structural properties in transistors. A cross-sectional nano-XRD setup as in-situ micromechanical experiments is shown in Fig. 6 (a), where a sample is scanned with an MLL focused X-ray beam with ≈ 75 nm FWHM [7]. A notched cantilever with Pt dots as markers is shown in Fig. 6 (b). Local defect density and stress distributions were investigated under load, see in Fig. 6 (c).

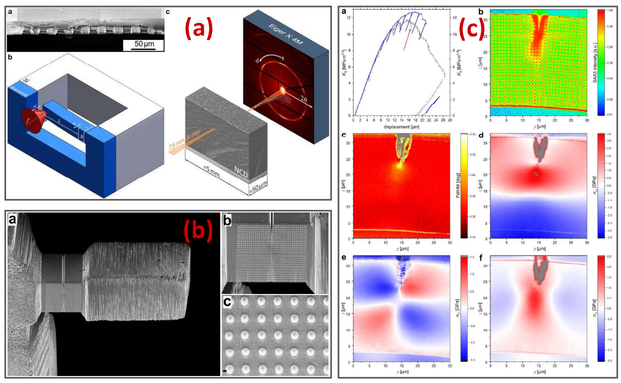

Fig. 6: Results from in-situ micromechanical experiments [7].

Conclusion

- MLLs address the limits of traditional X-ray lenses such as limited resolutions and diffraction efficiencies particularly for hard x-rays
- MLLs enable high-resolution X-ray studies with nm-scale focusing
- Three designs with increasing working distance were successfully developed
- MLLs can be tailored to specific applications offering flexibility in terms of energy range, focal length and working distances
- The integrated MLL mount allows an easy and safe integration to the beamline

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