ESRF	**Experiment title:** Focusing Properties of Crossed Wedged Multilayer Laue Lenses	**Experiment number**: MI 1177
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Introduction

Multilayer Laue lenses (MLL) are one of the most promising approaches for hard x-ray optics to achieve high efficiency focusing [1]. Theoretical work was done to find optimal geometries for subnanometer spot sizes [2]. First steps were conducted in order to obtain spot sizes significantly below 10 nm by producing the necessary wedged geometry to obtain layer interfaces aligned individually to fulfill their respective Bragg condition [3]. However the manufacturing process depositing a steep layer thickness gradient on a substrate is not trivial. Recently, we proposed to deposit a stress layer on a flat MLL to elastically bend the structure to obtain a wedged geometry [4]. This allows the adaption to the particular energy of a particular MLL independently of the used multilayer.
We have tested pairs of crossed MLLs with a stress layer for point focusing at the ESRF beam line ID 13. The multilayer was deposited using magnetron sputter deposition on a commercially available flat 6” Silicon substrate. Subsequently pieces of about 5 mm × 80 µm were extracted and Focused Ion Beam milling was applied to shape the lens element to a flat MLL. An additional stress layer can be deposited afterwards on one side to obtain a wedged geometry. Two MLLs with matched focal lengths have to be arranged in close proximity and perpendicularly to each other to enable point focusing. The device can be installed in an existing x-ray microscopy setup.

Single flat vs. wedged Multilayer Laue Lens characterization

Several lenses with varying geometry were made from the identical deposition. The design of the multilayer is according to Table 1. The difference in local diffraction efficiency is shown for a flat MLL in tilted geometry and a wedged MLL in Figure 1. Both lenses have the same outer dimensions. For the flat MLL only one dark band of extinction is visible on the lens. This corresponds to a specific d-spacing, which is

tilted according to its Bragg condition. In the diffraction pattern, only the area representing the corresponding part shows significant intensity.
The transmission through the wedged MLL is much more homogenous; similarly the diffraction pattern representing the lens shows nearly the same intensity for all d-spacings. Only the lowest part of the diffraction pattern representing a section with a very significant zone-layer placement error is dark due to the highly oscillating phase. The zone-placement error was known after the deposition and the area was truncated for focusing experiments.

Table 1:
Design of the multilayer

Energy	Focal length	Thickness	Zones	Smallest zone width
10.5 keV	6.7 mm	53 µm	850-7850	5 nm

The comparison of diffraction patterns shows the significant difference expected between a flat and a wedged MLL, which were made from the same deposition. Hence, the proposed method produces a wedged geometry for the whole area and aperture of the lens.

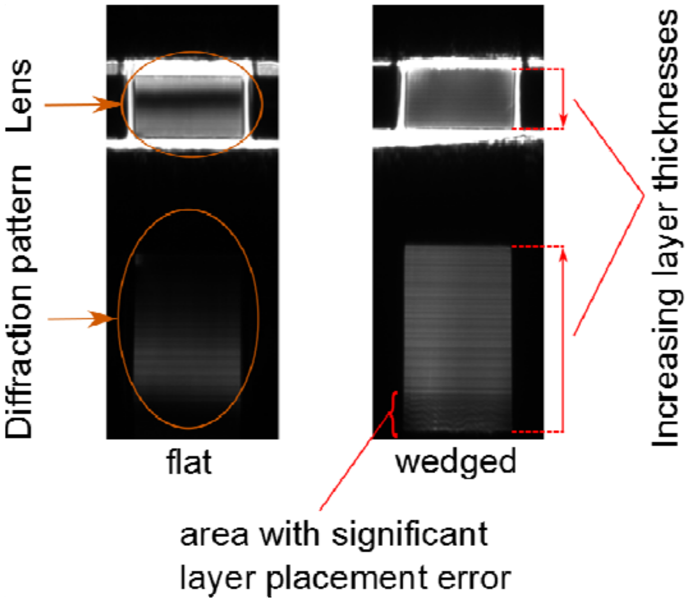

Figure 1:
Transmission trough and diffraction of a tilted flat and a wedged MLL with thicknesses in beam direction of 8 µm acquired by a PCO high resolution camera placed approx. 20 mm behind the line focus. In contrast to the flat MLL, the transmission and diffraction is nearly homogenous across the aperture of the wedged MLL.

Crossed flat and wedged Multilayer Laue Lens characterization with Ptychography:

The MLLs were mounted into the existing optics setup at ID13. Most of the coarse alignment of each MLL was done using a PCO high resolution CCD camera. Precision alignment of the pinhole, the crossed MLL, and the slits was done with a MAXIPIX pixel detector in the far field. Far field diffraction patterns of overlapping regions of a test sample (Siemens star) were acquired by that detector. This information was used to reconstruct information about phase and amplitude of sample and the illumination of the sample using ptychography [5]. Results are the caustic and properties of the focal spot.
For a flat MLL in tilted geometry the smallest focus size determined was 33 nm × 28 nm (FWHM) for an aperture of 23 µm × 23 µm (see Figure 2), which is nearly diffraction limited. Side lobes are present due to the existing zone-placement error of the multilayer.
For the wedged MLL using an aperture of 15 µm × 15 µm, we obtained a diffraction limited focal spot size of 43 nm × 44 nm without any major distortion. The measured efficiency for the crossed MLL is 19.8 % for the system and thus 44.5 % for a single MLL; this is nearly the maximum efficiency expected for this geometry at 10.5 keV. The reconstructed and propagated focus is shown in Figure 3. A further increase of the

illuminated region on the lens up to 30 × 30 µm² results in a slight decrease of the focal size for both lenses; on the other hand the intensity of side lobes caused by imperfections of the deposition increases.

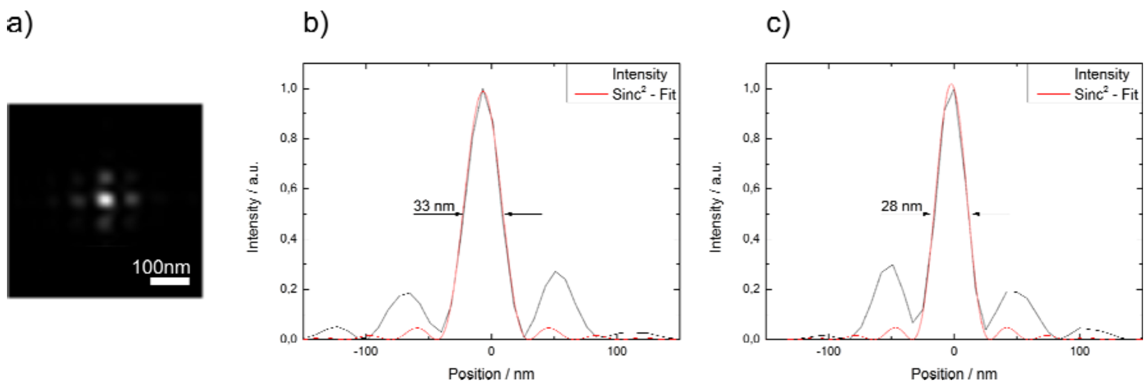

Figure 2:
a) Intensity of the reconstructed wave field in the focal plane for the crossed flat MLL in tilted geometry. b) Beam profile in horizontal direction. c) Beam profile in vertical direction.

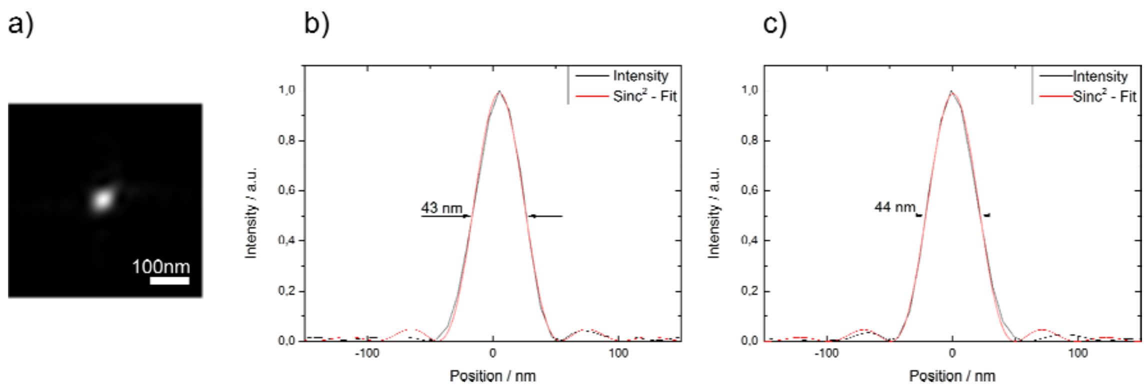

Figure 3:
a) Intensity of the reconstructed wave field in the focal plane for the crossed wedged MLL. b) Beam profile in horizontal direction. c) Beam profile in vertical direction.

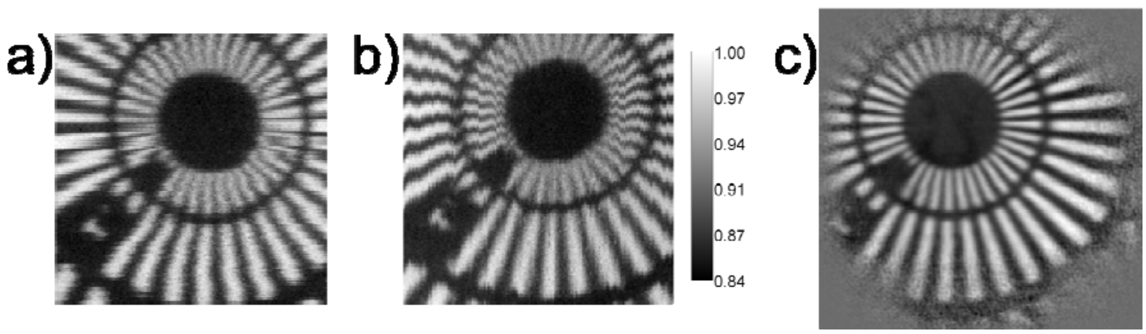

Figure 4:
a) STXM image of the inner region of the Siemens star test sample. Fast scanning axis: horizontal. b) Same image with exchanged slow and fast axes. c) Ptychographic reconstruction of the same region of the sample.

Figures 4 a) and b) show the results of scanning transmission X-ray microscopy (STXM) measurements; the signal was acquired by a PIN diode. The Siemens star test pattern has 50 nm lines and spaces at the center. Between a) and b) fast and slow scanning axes were switched in order to estimate the influence of the sample movement in a particular direction on the measurement. Though time constraints limited a proper settlement of all axes leading to some distortions; no evidence for further side lobes is visible and sharp contrast edges were obtained in both, horizontal and vertical scanning direction.

Summary

We tested MLLs, which were fabricated using the proposed method to obtain the wedged geometry by depositing a stress layer. A nearly homogenous diffraction of such a lens in comparison to an otherwise identical flat MLL in tilted geometry is shown. A pair of pre-assembled crossed wedged MLLs was able to generate a nearly diffraction limited focus with a size of 43 nm × 44 nm and an efficiency of 20 %; this is nearly the maximum achievable efficiency for this energy.We conducted STXM measurements with these lenses, where the smallest features of the test sample consisting of 50 nm lines and spaces are visible. We did not use the whole aperture of the lens due to a known zone placement error, which was caused by a drift in the multilayer deposition process. These errors need to be reduced to a tolerable level in future.
To our knowledge, this is the first experiment showing point focusing with MLLs that have an improved geometry, where all layers are tilted with respect to their individual Bragg condition.

References

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