High Precision X-Ray Multilayer Mirrors For Customized Solutions

S. Niese[1], M. Krämer[1], T. Holz[1], P. Krüger[2], S. Braun[3], E. Zschech[2,4] and R. Dietsch[1]

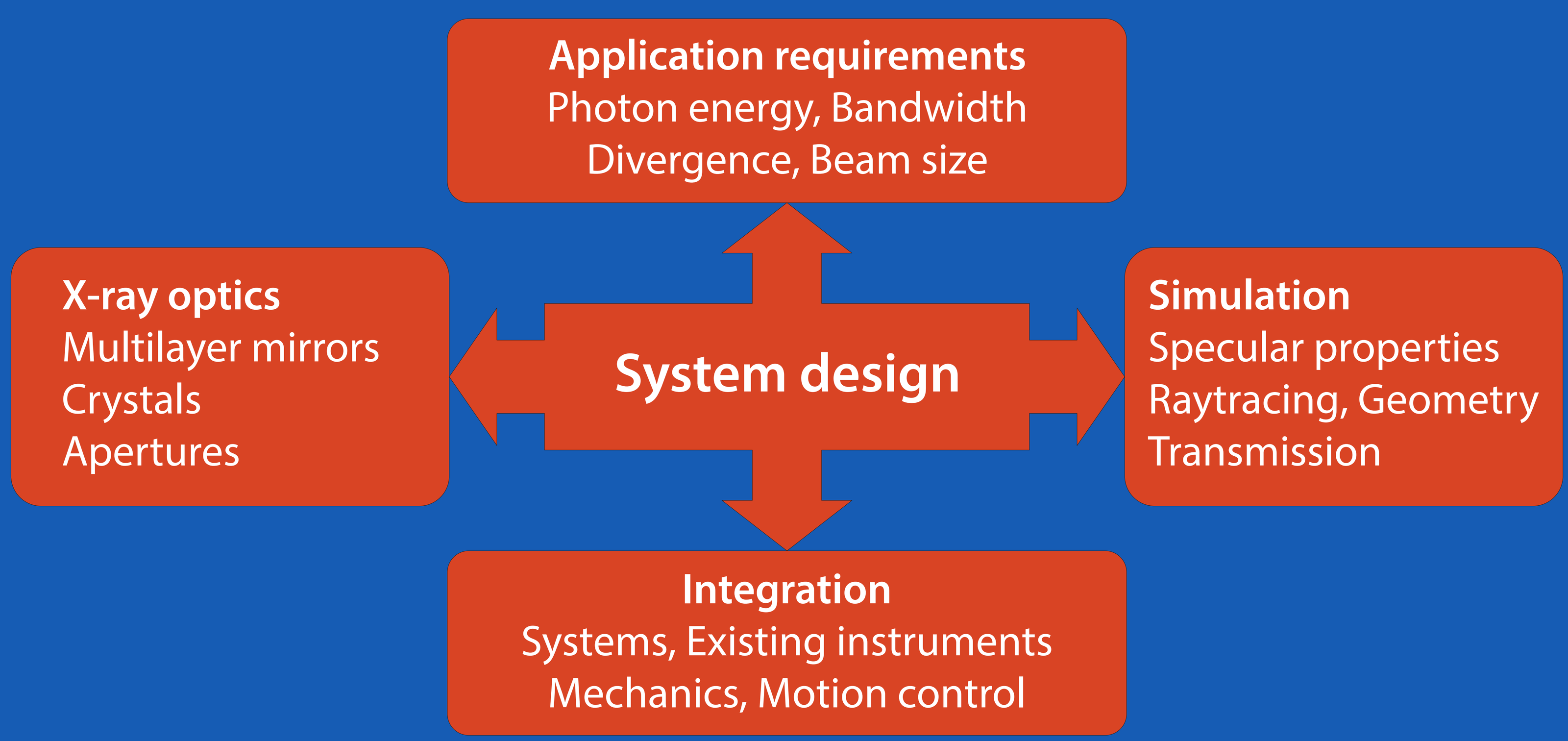
1) AXO DRESDEN GmbH, Gasanstaltstr. 8b, 01237 Dresden, Germany; contact@axo-dresden.de
2) Fraunhofer IKTS-MD, Maria-Reiche-Str. 2, 01109 Dresden, Germany
3) Fraunhofer IWS Dresden, Winterbergstr. 28, 01277 Dresden, Germany
4) Technische Universität Dresden, Dresden Center for Nanoanalysis, Helmholtzstr. 18, 01187 Dresden, Germany

Introduction

The analysis of materials with X-rays is well introduced in science and industry. Two major applications are the characterization of specimens by various X-ray diffraction methods, and non-destructive inspection of heterogeneous structures with X-ray imaging techniques.

In most cases, the X-ray beam needs to be tailored with suitable X-ray optics to enhance the performance and to allow for suitable working distances. X-ray multilayer mirrors are often first choice for the application at typical laboratory X-ray sources since a beam with a requested dimension and divergence can be provided and a sufficient monochromatization is achieved.

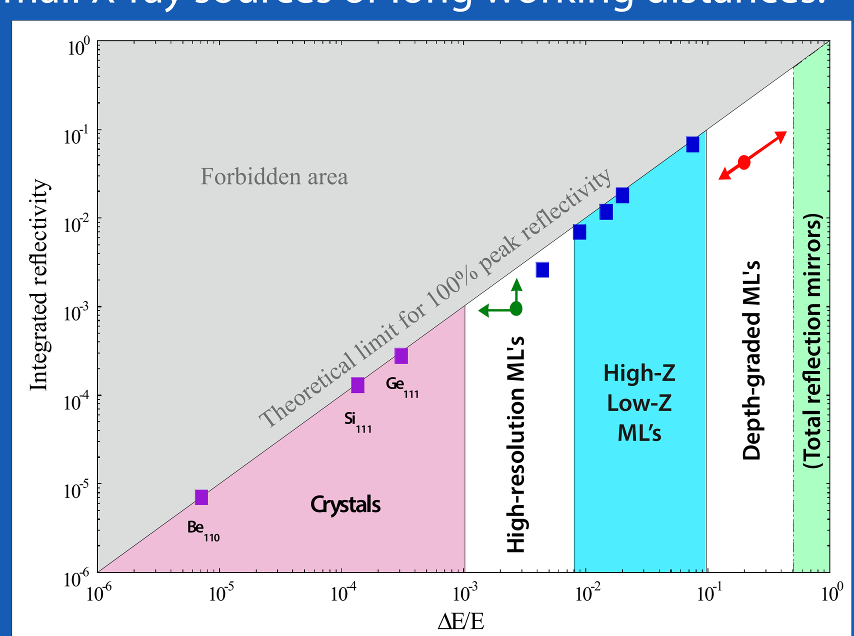
We show typical aspects of the optimization and examples from the fabrication of X-ray multilayer mirrors for specific applications.



Design and simulation

Various parameters can be adjusted to match the X-ray optic to the application:

- **Illumination:** Focusing and collimating, one- and two-dimensionally operating mirrors with requested focal lengths and convergence angles are possible.
- **Substrate:** Precisely bent wafers stripes are a common solution for most applications. Existing substrates can be smoothened or contoured. Prefigured substrates are used for applications with high demands, such as small X-ray sources or long working distances.
- **Multilayer:** The multilayer defines the specular properties. Various possibilities exist to adjust its reflectivity and bandwidth $\Delta E/E$. A lateral thickness gradient is necessary on concavely shaped mirror surfaces to fulfill the Bragg condition.
- **Performance:** The optical properties are simulated with realistic parameters of the multilayer and the geometry for all photon energies of interest. Thus, different designs can be compared and optimized.



Adapted from: Ch. Morawe et al., ESRF, Grenoble, F.

References & Acknowledgment

[1] J. Maser et al.: Multilayer Laue lenses as high-resolution x-ray optics. Proc. SPIE vol. 5539, p. 185, 2004.
[2] S. Niese et al.: Full-field X-ray microscopy with crossed partial multilayer Laue lenses. Optics Express, 22, p. 20008, 2014.

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Condenser optics for full-field XRM with MLLs

Full-field imaging with multilayer Laue lenses (MLL) [1] was recently demonstrated in a laboratory X-ray microscope (XRM) using the hollow cone illumination of a capillary condenser and one-sided imaging [2]. Current restrictions are background due to Cu-Kβ radiation and bremsstrahlung, the limited numerical aperture, and a short working distance caused by the pinhole. A proof-of-principle XRM setup using a two-dimensionally focusing X-ray multilayer mirror was built up to study its feasibility as condenser optics, particularly for photon energies above 8 keV.

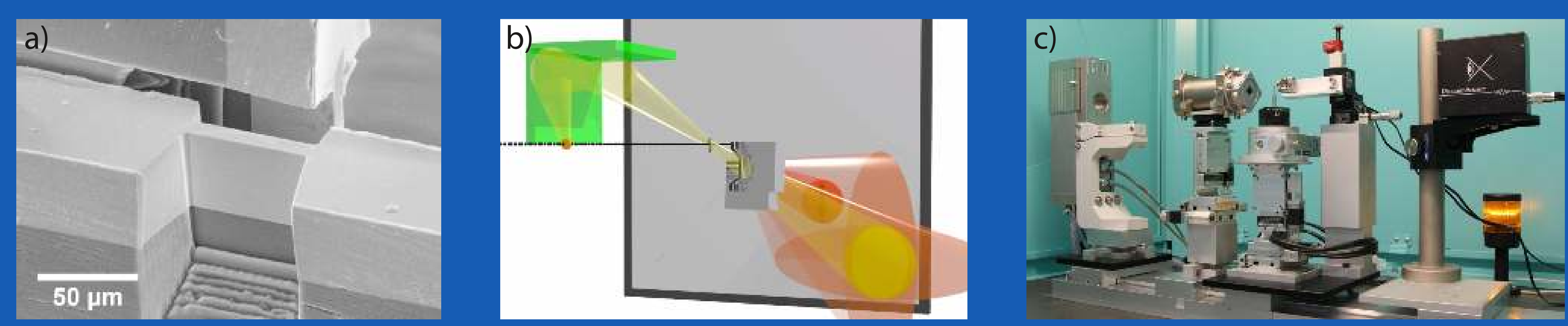

Fig. 1: (a) An MLL can be understood as linear zone plate consisting of several thousand individual layers. Two MLLs are assembled to achieve a 2D focusing or imaging behavior. (b) Optical path of a full-field XRM with a multilayer mirror and crossed MLLs. The image generated by first order diffraction separates in the image plane from other orders. (c) Experimental setup with a conventional X-ray microfocus source and X-ray detector.

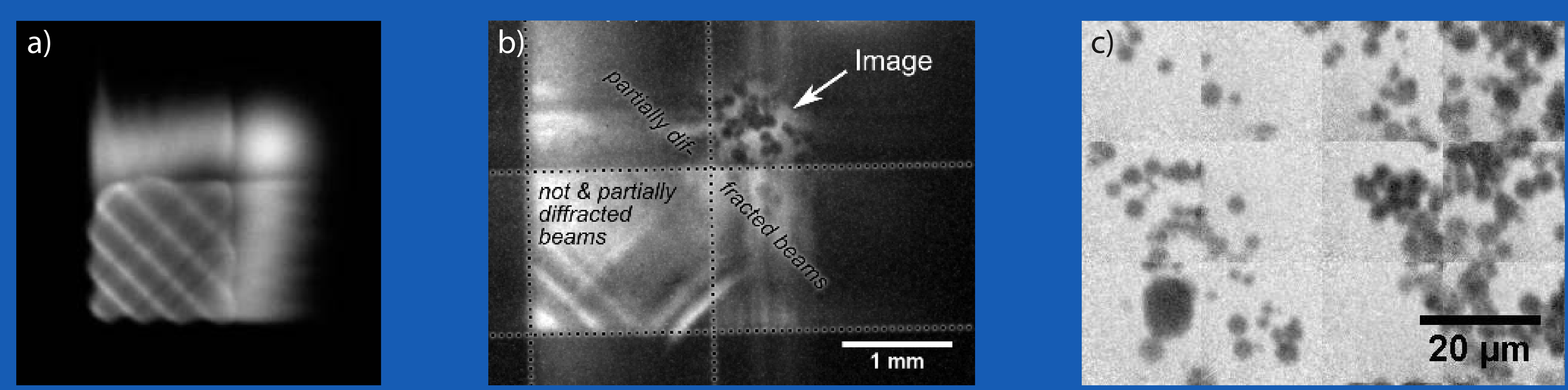

Fig. 2: (a) simulated and (b) measured images in the image plane. The simulation does only consider zero and first order diffraction of the MLL, but the general shape of the illumination is well predicted. (c) A stitched radiograph of a particle array demonstrates the suitability of the condenser optics for full-field XRM.

Multilayer mirrors for high photon energies

X-ray multilayer optics for photon energies $E > 15$ keV face two issues. First, the difference of the photon energies ΔE of the respective $K\alpha_1$ and $K\alpha_2$ radiation increases significantly. It is $\Delta E = 20$ eV for Cu-Kα, but $\Delta E = 173$ eV for Ag-Kα. Second, the angular bandwidth for the same kind of multilayer decreases. Thus, only a fraction of the X-ray source might be accepted by the mirror. If both effects superimpose, partially overlapping regions with $K\alpha_1$ and $K\alpha_2$ radiation do appear, which can complicate the analysis of the experimental data.

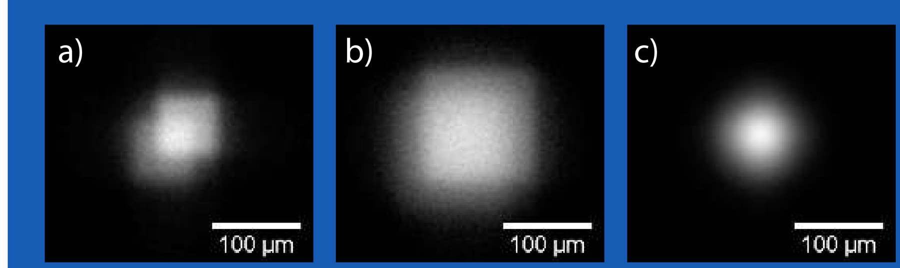

Fig. 3: (a) A Ag microfocus tube, source FWHM = 70 µm combined with a focusing multilayer mirror with a low bandwidth leads to a partial $K\alpha_1$ and $K\alpha_2$ overlapping in the focus. A better performance can be achieved with (b) a different multilayer with a higher bandwidth and (c) the use of a smaller source size, e.g. FWHM = 20 µm.

Multilayer polarizers for synchrotron radiation

Polarizers for synchrotron radiation are special high-resolution multilayers. They feature low period thicknesses and several hundred individual layers to achieve a high R_s/R_p ratio. Polarization is used to study e.g. the O-K line or magnetic materials such as Fe, Co, and Ni.

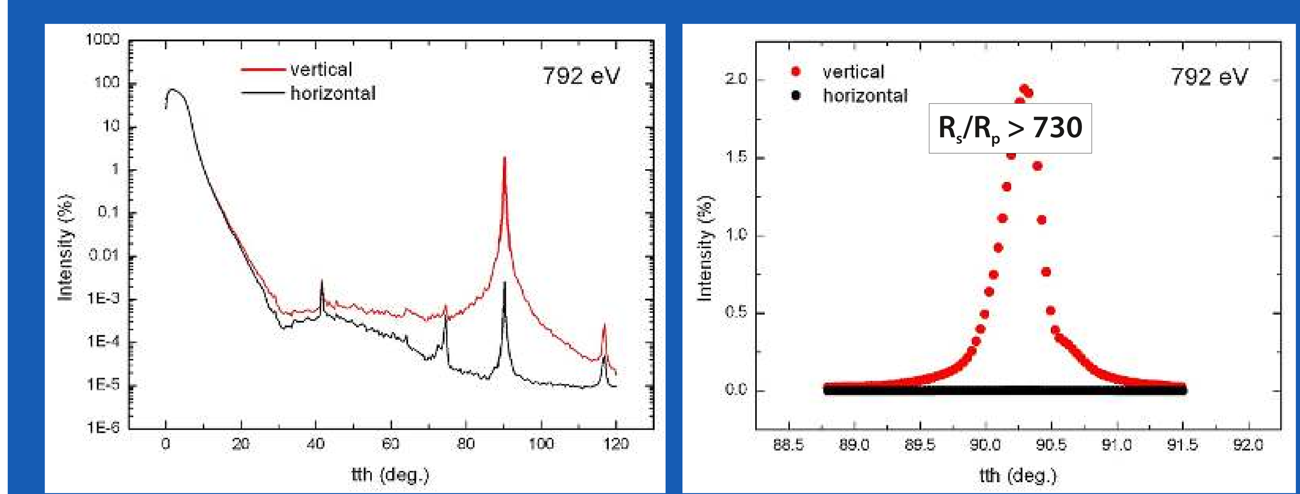

Fig. 4: Characterization of the fabricated mirrors at 792 eV. To obtain the Brewster angle of $2\theta \approx 90°$ at this photon energy, a multilayer period of d = 1.1 nm is required. An excellent R_s/R_p ratio of > 730 was achieved.

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