AXO DRESDEN GmbH Applied X-ray Optics Röntgenoptik und Präzisionsbeschichtung

APPLIED X-RAY OPTICS

X-ray optics for high lateral resolution

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Introduction

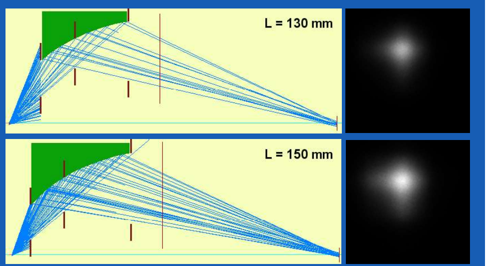
The performance of an X-ray optical device is defined by two main aspects. The mirror geometry (size, shape, contour, slope, slope errors, roughness) has the largest influence on beam size and convergence. On the other hand, the mirror coating (usually a multilayer) not only affects the flux, monochromaticity, spectral resolution, peak reflectance and angular bandwidth. Due to its inherent selectivity it also defines how much of the source is "seen" (and thus used) and can suppress unwanted parts of the spectrum or radiation emitted from areas outside the main focal spot on the anode. Thus, only an optimized combination of mirror geometry and multilayer coating can provide sufficient beam performance for challenging measurement tasks.

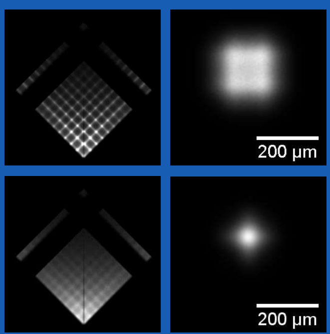
Theory and simulations

When high resolution optics for hard X-rays are required various parameters can be optimized yielding different benefits and problems.

Especially for short wavelength sources, longer mirrors are advantageous as they provide larger collection angles and thus higher beam intensity. On the other hand, the focal spot on the sample position becomes bigger and fabrication gets more challenging. Here, high contour accuracy (HCA) substrates can help with their inherently lower slope errors.

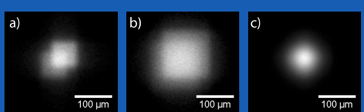
Sketch of the beam path and raytracing results of the focal spot size for comparable two-dimensionally focussing mirrors of different lengths. The extra length of 15% can lead to total flux increase of up to 80%. The focal spot size (FWHM) rises by 10%-30% depending on the multi-layer coating.





Comparison of the beam for a conventionally fabricated mirror with "typical" slope errors (upper row) and an HCA mirror with significantly reduced slope errors. Strong oscillations in the beam profile in the near-field (left column) are the result of assumed sinusoidal slope errors. In the focal plane (right column) these oscillations are not visible, but the focal spot size decreases significantly for the HCA mirror.

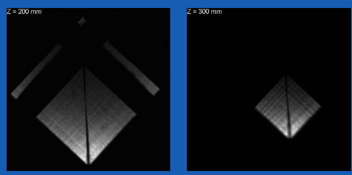
At photon energies above ~15 keV X-ray multilayer optics face two further issues. First, the difference ΔE of the photon energies of the respective $K\alpha_1$ and $K\alpha_2$ emission lines rises significantly. While it is ΔE = 20 eV for Cu-Kα, it becomes ΔE = 173 eV for Ag-Kα. Second, the angular bandwidth of a given kind of multilayer decreases with E. 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.



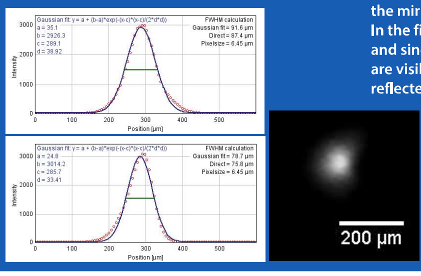
(a) A Ag microfocus tube, source FWHM = 70 µm, combined with a focusing multilayer mirror with a low bandwidth leads to a partial $K\alpha_1$ and $K\alpha_2$ overlapping in the focus. A better performance can be achieved with (b) a different multilayer with higher bandwidth and (c) the use of a smaller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

Tests of 2-dimensional focussing mirror

The properties of a 2-dimensional focussing mirror based on HCA substrates were evaluated with CCD measurements of the beam shape. A hard X-ray source with 20 µm spot size was used.



Images taken in the near-field (85/185 mm from the mirror center, 200/300 mm from the source). In the first image, remains of the direct beam (top) and single reflections (upper left and right lines) are visible next to the two sections of the beam reflected on both mirror sections

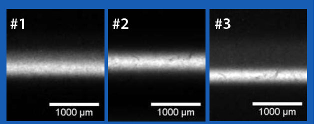


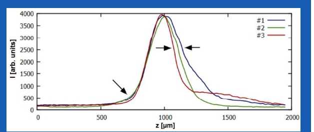
CCD image at the focal position. Horizontal and vertical line profiles give spot dimensions HxV of ~80x90 µm^2 in good accordance with the f_1/f_2 ratio.

Measurements and CCD images courtesy of Excillum AB, Kista, Sweden

Tests of 1-dimensional focussing optics

Three different mirrors were fabricated for a SAXS set-up with very long focal distances (400 mm / 1600 mm) with mirrors 1 and 2 being bent Si wafer stripes (applying different glueing techniques) and mirror 3 on an HCA substrate (reducing the slope error by roughly one order of magnitude). Measurements of the beam profile show a reduction of the beam width from 295 µm to 230 µm for mirror 3 as well as the suppression of a shoulder on the right side of the peak and the steepest slope on the left side (cf. arrows in the graph). Thus, HCA substrates can improve the mirror performance (spot size) significantly.

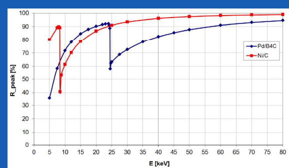




Optics developed in cooperation with A. Gutsche, KIT, Karlsruhe, Germany

3-stripe synchrotron monochromator

A double multilayer monochromator (DMM) with three stripes was fabricated for beamline P06 (HASYLAB at DESY) to work in the energy range from 5 keV up to 80 keV. Due to absorption edges of coating materials, different material combinations were used. A Pd/B_4C multilayer covers medium and high energies while a Ni/C multilayer can be used for lower and higher energies. A third coating (an Ir single layer) can be applied in total reflection mode mainly in the low energy region.



Simulated peak reflectance for a Pd/B_4C and a Ni/C multilayer between 5 keV and 80 keV.

Optics developed in cooperation with G. Falkenberg, HASYLAB/DESY, Hamburg, Germany

Properties of the flat Si<100> mirror substrate:
Size: 200 x 24.8 x 30 mm^3
Flatness: R > 125 km
Slope error: 0.15 µrad rms (tangential)
0.5 µrad rms (sagittal)
µ-roughness: 0.1 nm rms

3-stripes multilayer monochromator with Pd/B_4C (blue), Ir (light grey), Ni/C (dark grey).

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