Multilayer Optics for X-ray Analytics and Synchrotrons

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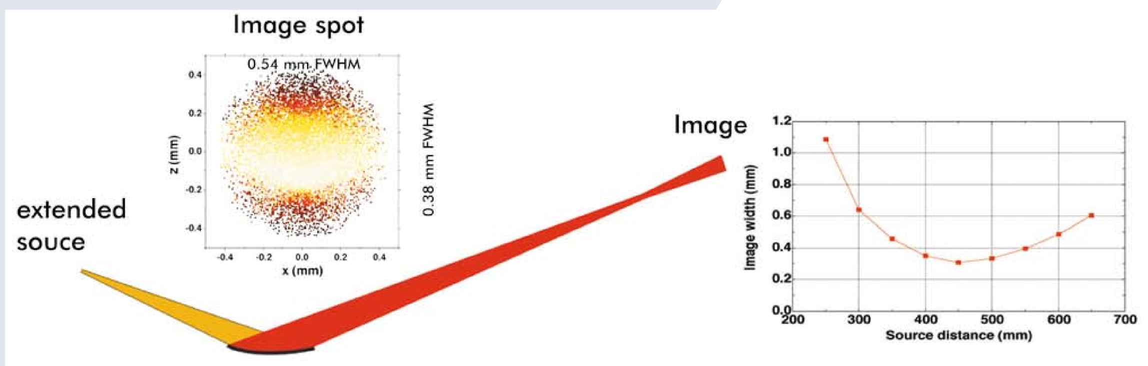
Multilayer Optics Production

At Incoatec we design, manufacture and characterize X-ray optics with optimized properties for specific applications. By simulating the optical properties and by ray-tracing of the complete beam paths we are able to choose the best multilayer materials and the optimum layer thickness profiles and substrate shapes.

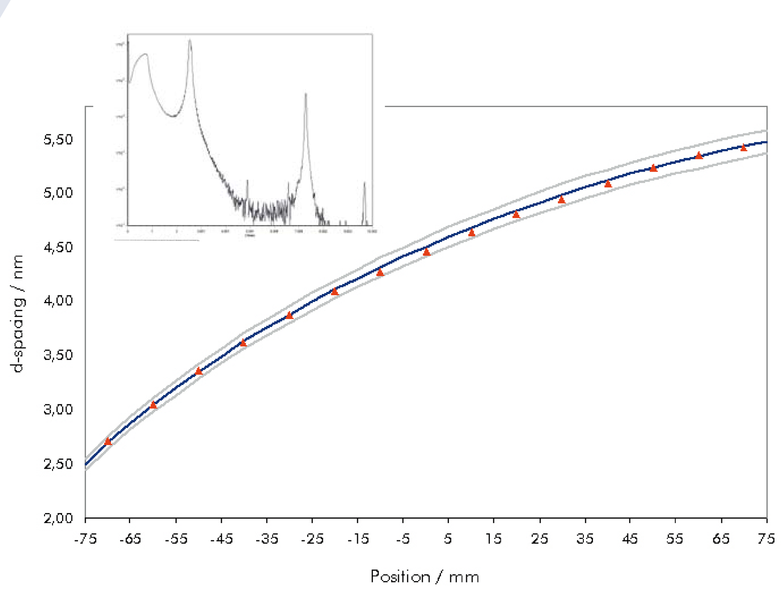


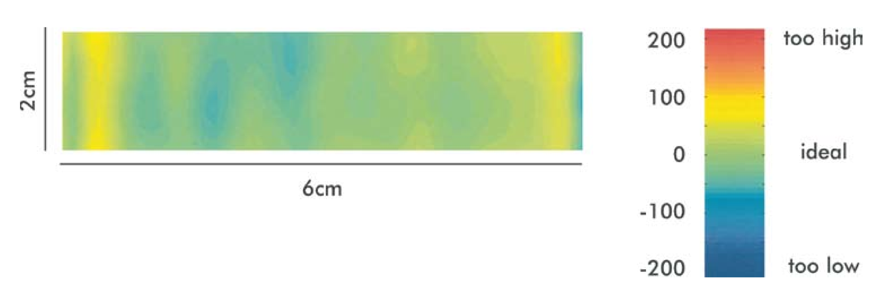
Ray tracing of a 2D focusing optics: the plotted spot shows the distribution of intensity at the image position; the diagram on the right shows the beam width along the beam path.

Our X-ray optics are produced with a homogeneity of ± 0.2 % on 6″ wafers by the very reliable and reproducible deposition method of magnetron sputtering. Coatings on up to 150 cm in length are possible. The most important part of the optics production is the deposition of thin layers for total reflection (single layer) and multilayer (2 materials, up to several 100 pairs of layers) optics.

Characterization

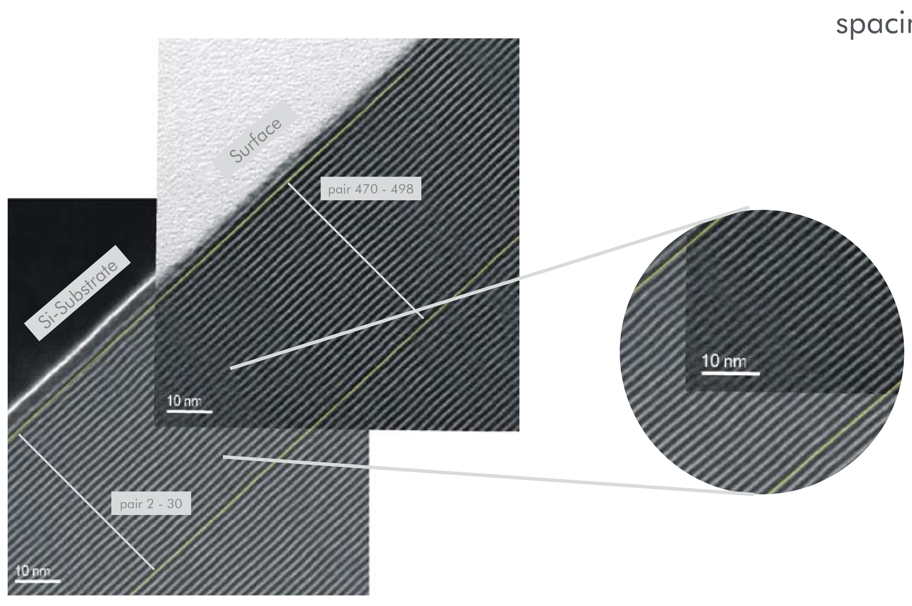
The manufacturing process of most of the optics for lab-instrumentation includes the preparation of shaped substrates by bending silicon wafers. Their quality is tested with optical profilometry methods. The vertical resolution of our profile is well below 10 nm, and the angular resolution is below 1 arcsec. Typically, silicon wafers which are bent and glued onto backing plates show slope errors of about 5-10 arcsec. For some applications in high resolution XRD we use prefigured substrates which achieve slope errors below 1 arcsec (1/3600 deg). Each optics is characterized by X-ray reflectometry to check the quality of the grown film. The reflectometry measurement demonstrates that this optics has been produced well within the required specification of ±1%. The uniformity of the coating is shown in the TEM image.





Profilometry measurement of a parabolic substrate: The shape deviation on the 6 cm substrates is within ±100nm. This is comparable to a deviation of 1 cm to 6 km.

Left: Typical film thickness accuracy for graded multilayers determined by X-ray reflectometry: for optics with d-spacing gradients the precision is within ±1%; for optics with uniform d-spacing we reach a precision below ±0.2%.



Left: TEM micrograph of a Mo/B_4C multilayer with 500 pairs of layers. The magnification shows a perfect correspondence of the layer thickness in all pairs (by courtesy of Prof. Jäger, Uni Kiel).

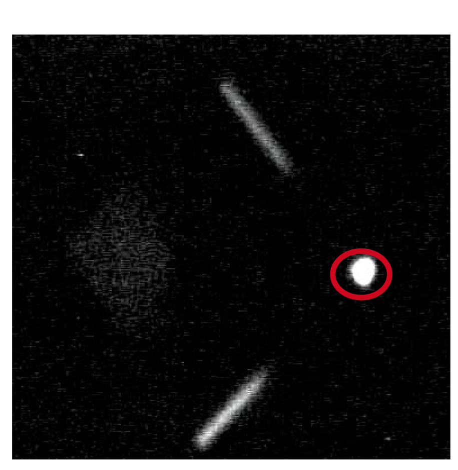
Beam shaping in 2D with Montel Optics

In the 1950s M. Montel introduced a side-by-side optical scheme for 2D focusing or collimating X-rays by mounting two X-ray mirrors side by side and mutually perpendicular. Incoatec's Montel optics consists of two elliptical or parabolic optical surfaces that are coated with laterally graded multilayers.

The quality of the beam shaping due to the optics is demonstrated by the beam properties in the focus. Flux and divergence of the reflected beam are measured with 2D detectors or pin diodes.

Optical scheme of a Montel multilayer mirror (Incoatec GmbH). Brand names such as Helios, Quazar, or MX are also in use.

A typical image of the beam in the focus is marked in the figure on the right. Beams which are reflected on both parts of the L-shaped optics are focused in a very sharp spot. The optics concentrate a lot of flux within a well-shaped, gaussian-like spot of expected size.



X-ray beam: right double reflection, useable beam (single reflection (above and below) and direct beam (left) are shielded)

Conclusion

2D beam shaping multilayer optics are available with a very high quality and for a growing number of instrumental set-ups. The optics show their full strength in combination with high-brilliance sources with a small X-ray spot which is the case for IµS, metal-jet or laser plasma sources. As the optics shape a beam with high flux densities and small spot sizes in the 10..500 µm range they meet the requirements for various applications in X-ray diffractometry.

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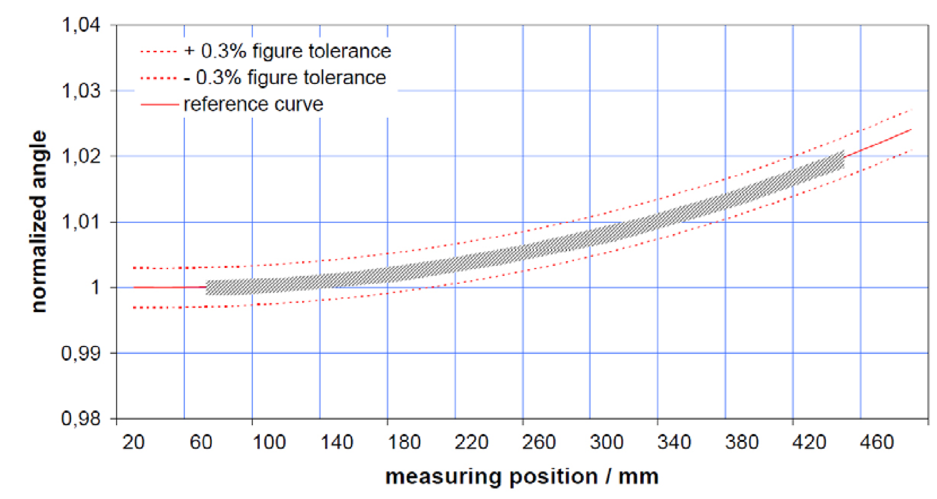
Applications

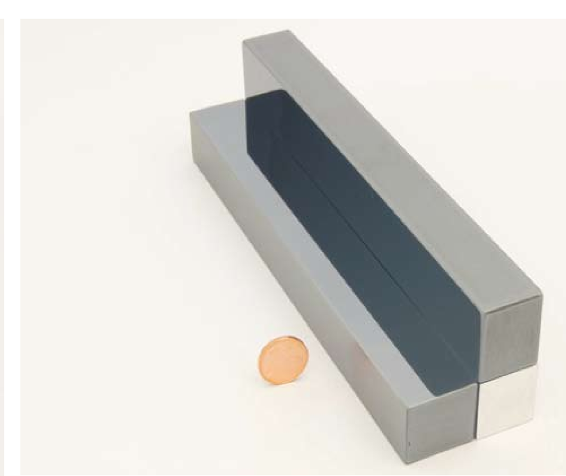
500 mm in length Multilayer Coating with 200 Pairs



The diagram shows a graded multilayer coating designed over 500 mm. The customer specified a gradient of the 1st Bragg peak in the longitudinal direction with a deviation of less than ±0.3 %. The optimum angle of reflection along the multilayer is shown in the solid line. We measured the reflectivity and bragg peak shape at 11 positions directly on a 500 mm substrate. As the results are within the grey area we clearly meet the specifications. First optics were sold to the US.

Montel Optics for Synchrotron

The left picture shows the two mirror parts of a Montel optic. The right picture shows the mounted Montel optics without apertures. The slope error with < 2 arcsec is up to 5 times better than for lab-optics. The first two optics for inelastic scattering beamlines were sold to NSLS and Diamond.



Montel Optics for fs-diffractometry

In a very recommendable publication Dr. Matias Bargheer investigated different kinds of focusing optics used with ultra short-pulse X-ray sources: Appl. Phys. B80 (2005), p. 715-719. He compared the characteristics of capillaries, multilayer optics and toroids (see Figure right).

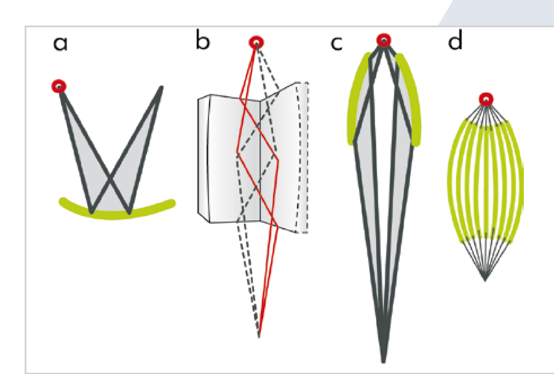


Figure: Scheme of
a) toroidally bent crystal,
b) multilayer optics,
c) elliipsoidal capillary and
d) polycapillary

These optics were used for a laser plasma source with a beam size of 10 µm. The resulting beam profiles are shown below:

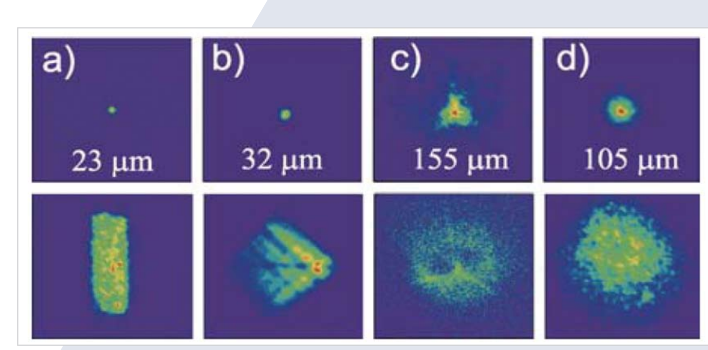


Figure: Beam cross sections and spot sizes in the focus (upper panel) and behind the focus (lower panel) for the different optics toroid, multilayer, mono-cap and poly-cap (left to right)

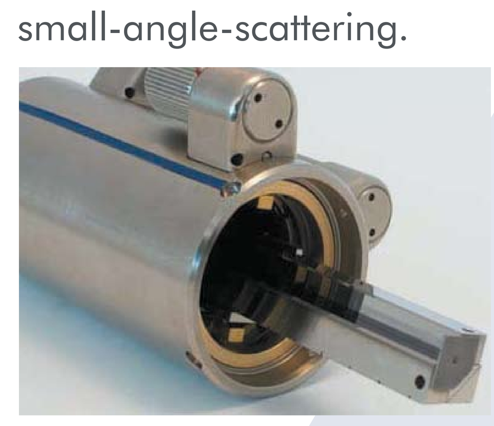
Both the spot sizes and the beam distribution are very different behind the focus. The small foci of the toroid and the multilayer indicate close-to-perfect surfaces.

	Ge (444) DCC	multilayer	monocap	polycap
focal size (µm)	23	32	155	105
flux density (a.u.)	1.30 E-07	1.72 E-07	1.33 E-08	8.98 E-08
brightness (a.u.)	5.80 E-08	8.49 E-07	3.33 E-07	7.33 E-09
brightness in %	6.8%	100.0%	39.2%	0.9%
spectral purity	good	very good	poor	poor
temporal broadening (fs)	90	90	10	1000

Table: Parameter for the optics and the reflected X-ray beam

Montel Optics for lab sources for X-ray Diffractometry

We produce collimating and focusing Montel optics for our Incoatec Microfocus Source IµS for numerous different applications like powder diffraction, biological & chemical crystallography and small-angle-scattering.



Montel Optics mounted in our high-stability housing

Incoatec Microfocus Source IµS for high-brilliance diffractometry in the lab

For more information see our other poster nearby and our web-site.