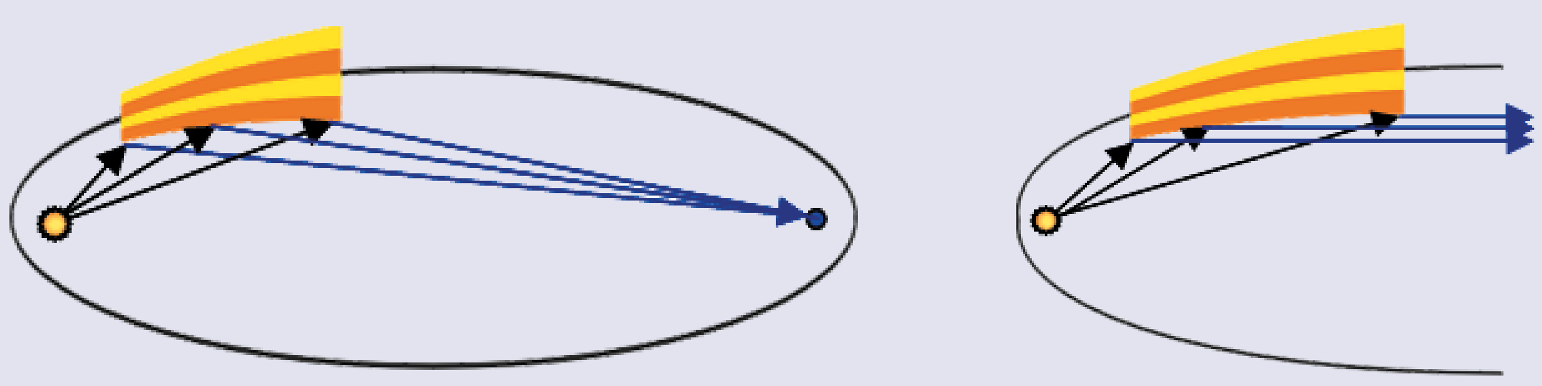
State-of-the-art Multilayer Optics for Modern X-ray Analytics

Introduction

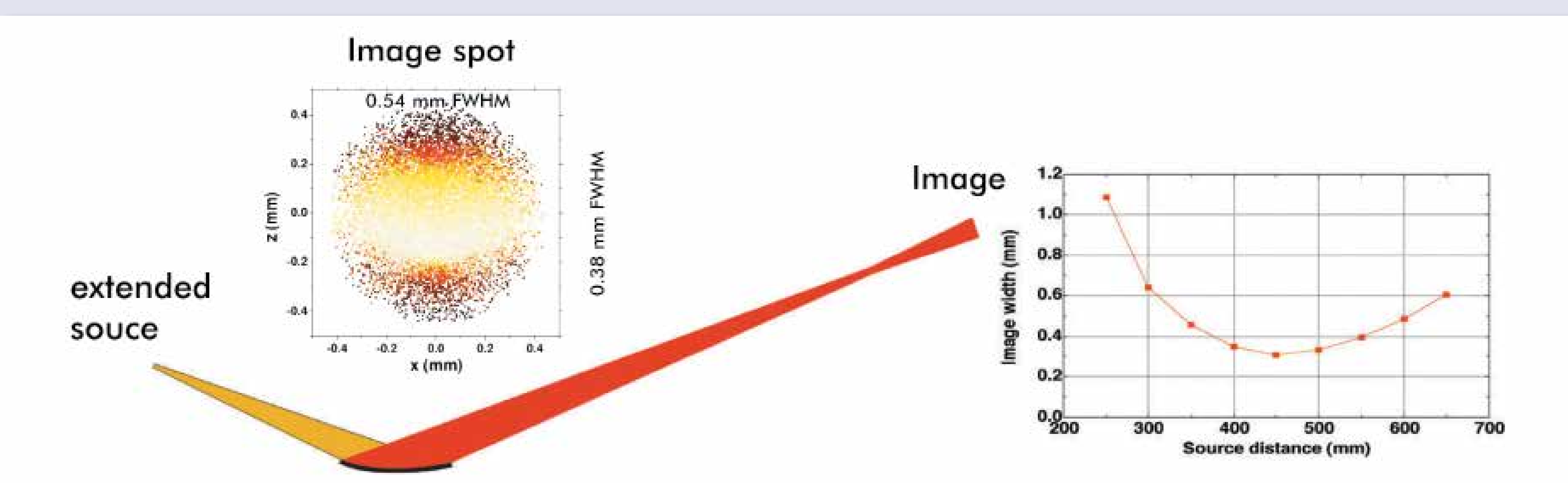
Multilayer optics are suitable and important for the manipulation of X-ray beams. The beam shape is influenced by the curvature of the mirror as this determines the divergence of the reflected beam. While a parabolically shaped mirror is collimating, an elliptically shaped mirror is focusing the beam (figure below). As the incident angle of the X-ray beam varies locally on the mirror, the layer pair thickness needs to vary accordingly in order to fulfill Bragg´s equation. In summary, these beam shaping optics are graded multilayers on precisely curved substrates.



Beam path of an elliptical multilayer mirror (left) and a parabolic mirror (right).

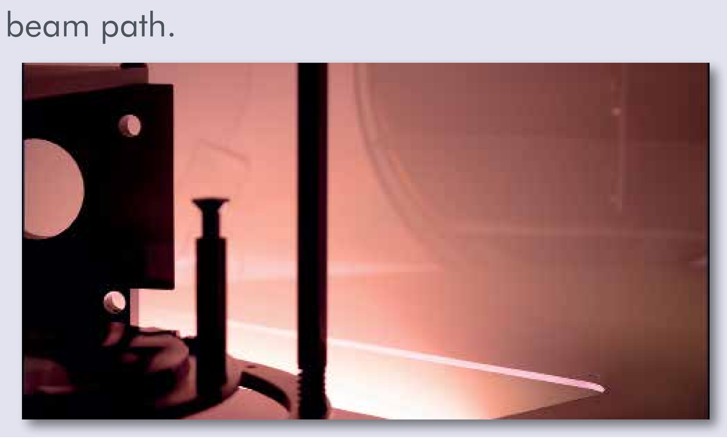
Multilayer Optics Production

At Incoatec we design, manufacture and characterize X-ray optics with optimized properties for customized applications. Optical properties are simulated with the so-called ray-tracing method in order to find the best multilayer materials. This method further enables the optimization of the layer thickness profile and the substrate shape. It is even possible with ray tracing to simulate complete beam paths with a typical outcome shown in the figure below.



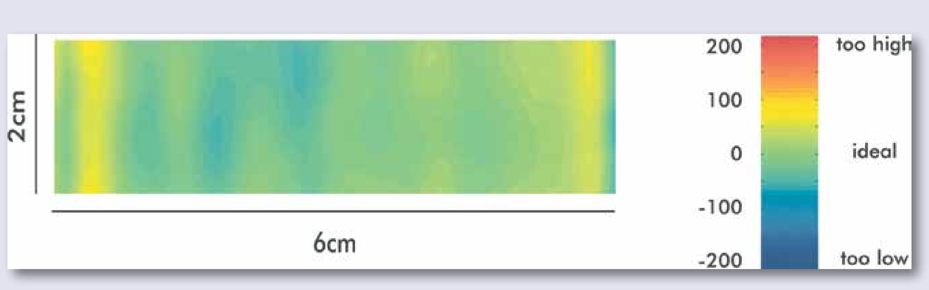
Ray tracing of a 2D focusing optics: the plotted spot above shows the distribution of intensity at the image position; the diagram on the right shows the beam width along the beam path.

Our X-ray optics are graded multilayers which are deposited by magnetron sputtering, a very reliable and reproducible deposition method ensuring homogeneities of ± 0.2 % on 6″ wafers and allowing coatings on up to 150cm in length. Thin, single layer optics are produced for total reflection applications. We have experiences with more than 40 different types of layer materials.

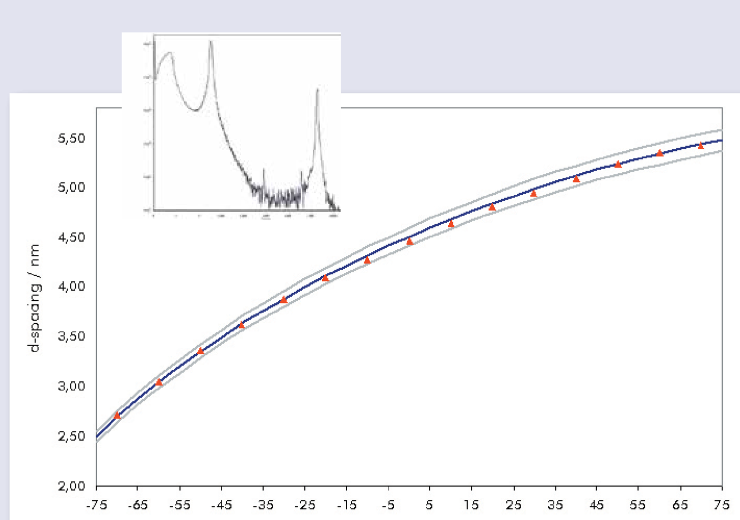


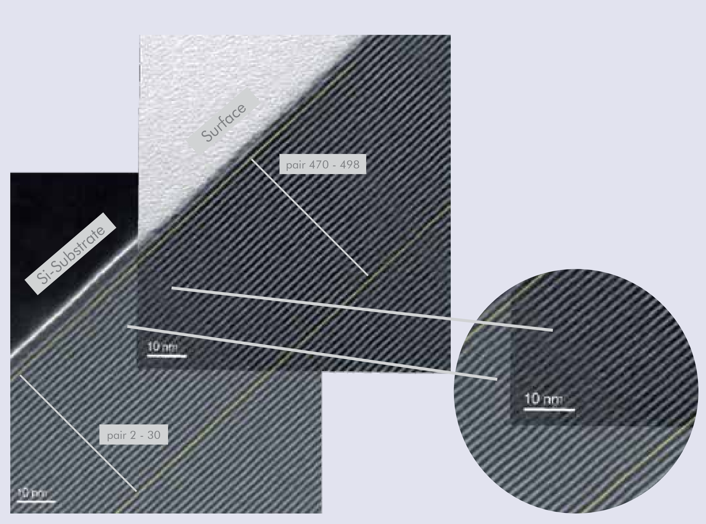
Characterization

The manufacturing process of most of the optics includes shaping 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 high-end applications in high resolution XRD we use prefigured substrates which achieve slope errors below 1 arcsec or 1/3600 deg. We test the quality of the grown thin films by X-ray reflectometry. With transmission electron microscopy (TEM) images we can further show the perfect stacking throughout the multilayer.



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.

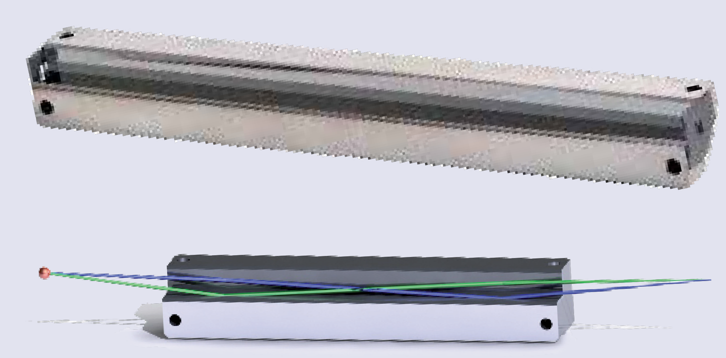


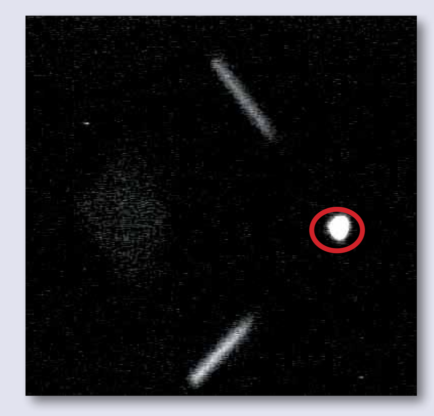


Typical layer pair thickness accuracy for graded multilayers determined by X-ray reflectometry: we achieve a d-spacing gradient accuracy of <±1%; in the case of a uniform d-spacing we reach an accuracy <±0.1% (left). TEM image (right) of a multilayer with 500 pairs of layers. The magnification shows a perfect correspondence of the layer thickness in all pairs. TEM image: Prof. Jäger, University of Kiel

Beam Shaping in 2D with Montel Optics

In the 1950s M. Montel introduced an optical scheme enabling a 2-dimensional beam shaping by mounting two mirrors side-by-side in an L-shape. A Montel optics with two elliptically shaped mirrors is point focusing, whereas two parabolic mirrors enable a collimated beam. A line focus is created with a hybrid optics, a combination of an elliptical and a parabolic mirror. The quality of the beam shaping due to the optics is demonstrated by the beam properties in the focus. The flux and divergence of the reflected beam are measured with 2D detectors or pin diodes. A typical image of the beam in the focus is shown in the figure on the right. Those X-rays which are reflected on both parts of the L-shaped optics are focused in a very sharp spot. The Montel optics accumulate a lot of flux within a well-shaped, gaussian-like spot of expected size. They are now also used at synchrotrons, where they substitute the KB (Kirkpatrick-Baez) mirrors achieving a more compact design.

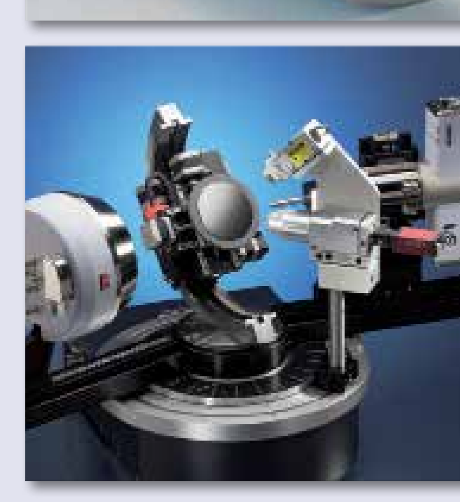




Montel optics (above right) and corresponding optical scheme (middle) of a focusing multilayer mirror. Besides Montel optics brand names such as Helios or Quazar are also in use. Detector image of a X-ray beam (below). The marked bright spot is the double-reflected, useable beam. The direct beam is shielded whereas the single reflections are shown above and below.

The Incoatec Microfocus Source IμS^High Brilliance

Five years after the successful launch of the IμS, we are introducing the next generation of Microfocus Sources: the new Incoatec Microfocus Source IμS^High Brilliance. This new source includes the latest type of Montel optics and is available for Cu, Mo and Ag radiation. When compared to the original IμS the new IμS^High Brilliance delivers an increase in intensity of about 30% for Cu, 50% for Ag and 60% for Mo due to an improved heat management. The IμS^High Brilliance includes all the familiar advantages of the previous IμS system: air-cooling, no moving parts and long lifetime without maintenance. It combines all advantages of a sealed-tube system with the superior data quality of conventional rotating anode systems. Furthermore, memory chips are integrated into the tube, the tube mount and optics, thus allowing the recording of the real-time status of the components. This simplifies considerably the installation and change of components and enables assessing the system online, making remote diagnostics faster, better and easier. The IμS^High Brilliance is available as a component of diffractometers of Bruker AXS such as the new D8 DISCOVER or VENTURE.



The source

- up to 60 % more intensity
- < 50 μm spot size
- air cooled
- Cu, Mo, Ag, Cr and Co available
- component recognition
- improved safety features
- fully compliant with Machinery Directive 2066/42/EC

The optics

- collimating, focussing or collimating + focusing (hybrid)
- patented housing for high stability

Useful accessories

- detectors for beam characterization
- collimators
- pumps + vacuum gauges for monitoring the beampath

Optics	Divergence (mrad)	Focal size (μm)	Flux (10^8 ph/s)	Flux density (ph/(s mm²))
Cu	5.1	250	> 7.8	> 6.5 x 10^9
MX (Cu)	7.6	110	> 3.4	> 18 x 10^9
Cu	1.0	800	> 2.1	
Cu	0.5	2000	> 4	
Mo	4.9	110	> 0.30	> 1.9 x 10^9
Ag	4.9	95	> 0.10	> 0.9 x 10^9
Cr	5.1	330	> 5	> 1.5 x 10^9
Co	5.1	280	> 2	> 3 x 10^9

Standard models of the IμS (others available on request).

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