

Multilayer Optics for Novel Sources in X-ray Analytics

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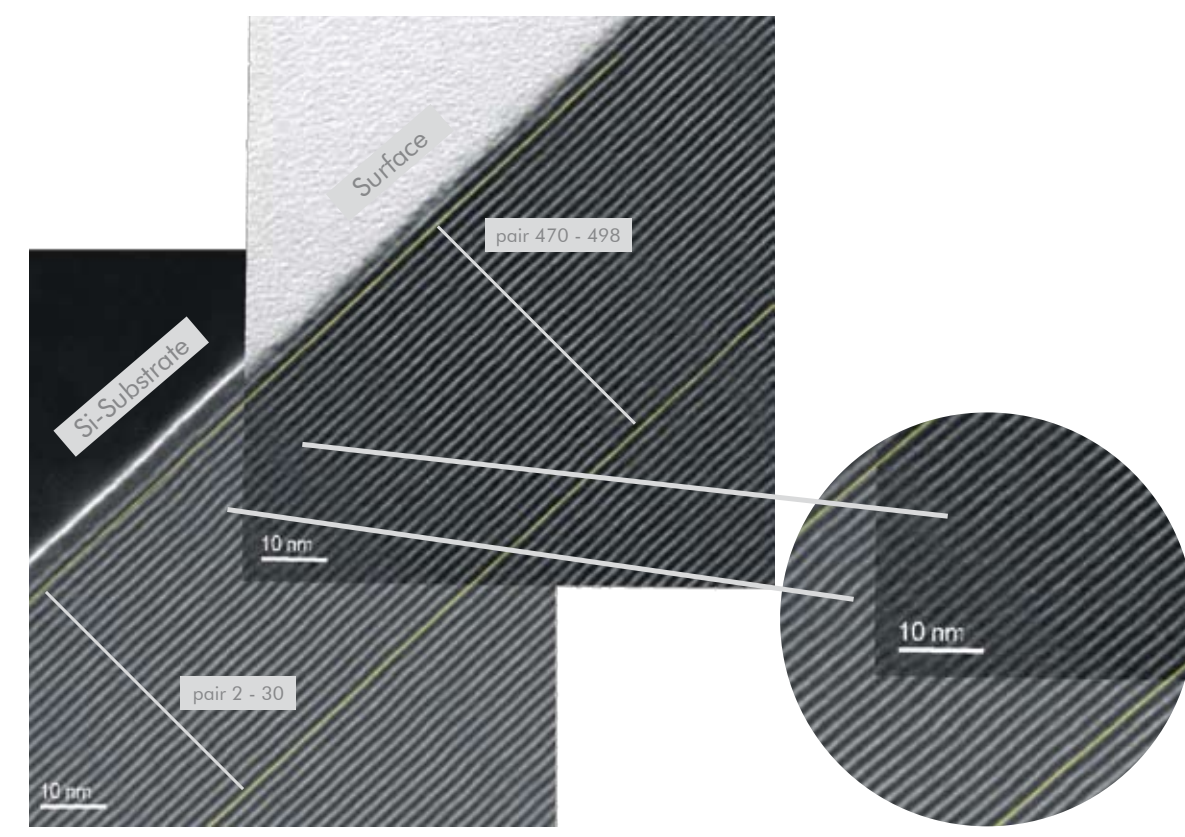
Multilayer Optics Production

At Incoatec we design, manufacture and characterize X-ray optics with optimized properties for customized applications. The multilayer materials, the layer thickness profile, the substrate shape and even complete beam paths are optimized by simulation with the ray tracing method.

Our X-ray optics are graded multilayers which are deposited by magnetron sputtering, a very reliable and reproducible deposition method ensuring homogeneities of $\pm 0.2\%$ on 6" wafers and allowing coatings on up to 150 cm 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

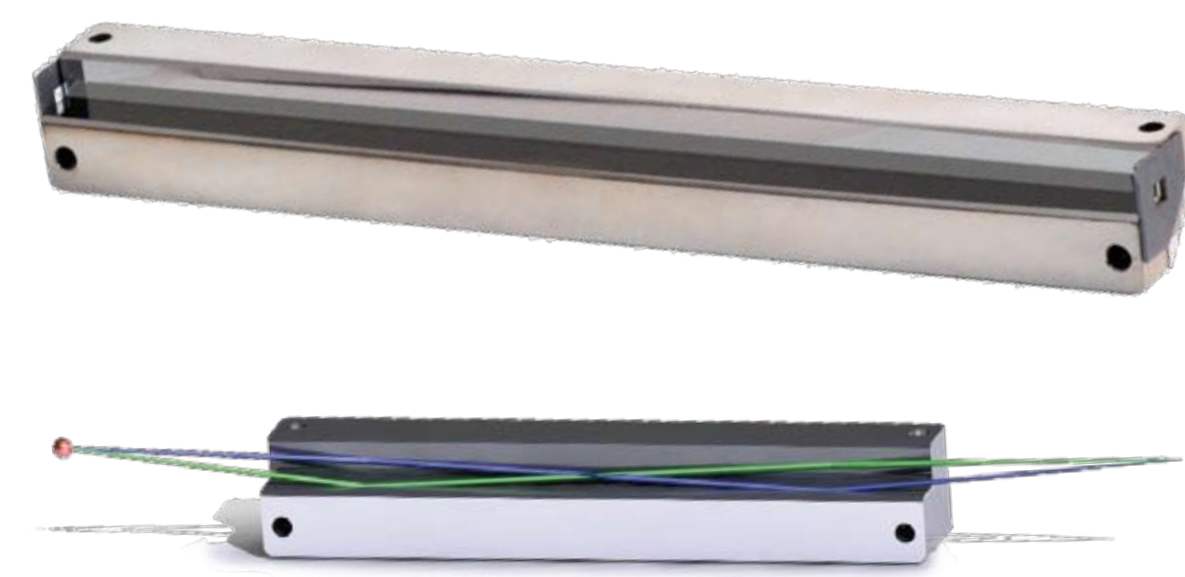
The manufacturing process of most of the optics includes shaping substrates by bending silicon wafers. Their quality is tested with optical profilometry methods. The vertical resolution of our profile is well below 10 nm, and the angular resolution is below 1 arcsec. Typically, silicon wafers which are 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.



TEM image of a multilayer with 500 pairs of layers. The magnification shows a perfect matching of the layer thickness throughout all pairs. (Prof. Jäger, University of Kiel)

Beam Shaping in 2D with Montel Optics

Montel optics are two mirrors mounted side-by-side in an L-shape enabling a 2-dimensional beam shaping. 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 Montel optics accumulate a lot of flux within a well-shaped, gaussian-like spot of expected size measured by 2D detectors or pin diodes. Nowadays, Montel optics are also used at synchrotrons, where they substitute the KB (Kirkpatrick-Baez) mirrors achieving a more compact design.



Montel optics (top) and corresponding optical scheme (bottom) of a focusing multilayer mirror.

The Incoatec Microfocus Source $\mu\text{S}^{\text{High Brilliance}}$

Five years after the successful launch of the μS , we are introducing the next generation: the new Incoatec Microfocus Source $\mu\text{S}^{\text{High Brilliance}}$. This new source includes all familiar advantages of the previous μS system: air-cooling, no moving parts, long lifetime without maintenance and it combines the advantages of a sealed-tube system with the superior data quality of conventional rotating anode systems. The new $\mu\text{S}^{\text{High Brilliance}}$ includes the latest type of Montel optics and delivers compared to the classic μS an increase in intensity of about 30% for Cu, 50% for Ag and 60% for Mo. Furthermore, integrated memory chips enable faster, better and easier remote diagnostics and service.



The source

- up to 60 % more intensity
- < 50 μm spot size
- air cooled
- Cu, Mo, Ag and Cr available
- convenience of sealed-tube
- component recognition
- 3 years warranty
- improved safety features
- compliant with Machinery Directive 2006/42/EC
- available as component for Bruker's new D8 series

The optics

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

Useful accessories

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

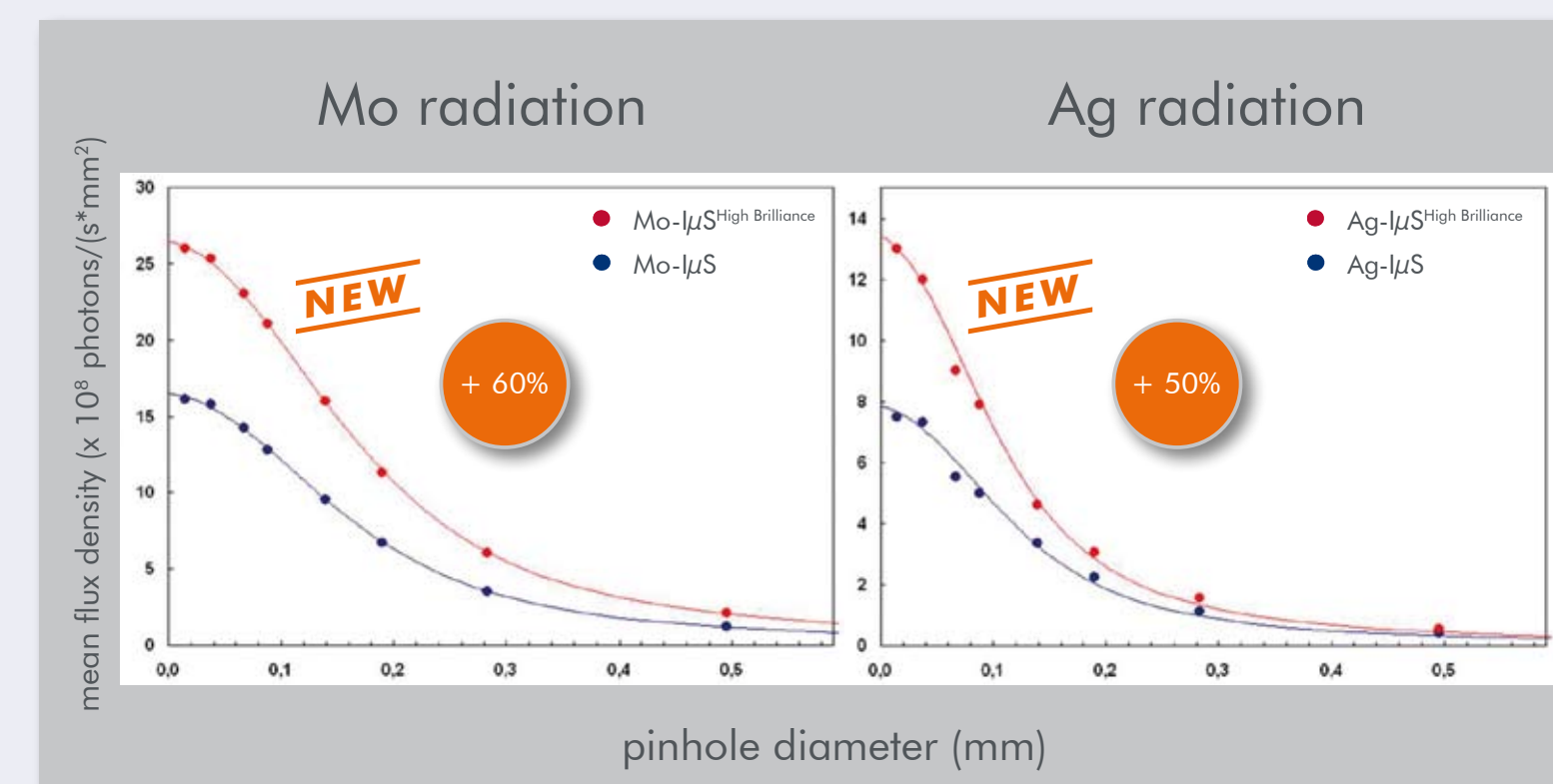
Optics	Divergence (mrad)	Focal size (μm)	Flux (10^{10} ph/s)	Flux density (ph/(s mm^2))
Cu	5.1	250	> 7	> 4.5×10^9
MX (Cu)	7.6	110	> 3	> 19×10^9
Cu	1.0	800	> 2.5	> 4
Cu	0.5	2000	> 4	> 2 $\times 10^9$
Mo	4.9	110	> 0.35	> 0.8×10^9
Ag	4.9	95	> 0.09	> 8×10^8
Cr	5.1	330	> 10	> 8×10^8

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



D8 VENTURE with PHOTON100 CMOS detector and the new Cu- and Mo- $\mu\text{S}^{\text{High Brilliance}}$.

Comparison of the Original μS and the New $\mu\text{S}^{\text{High Brilliance}}$



The figures show a flux density comparison of the original μS and new $\mu\text{S}^{\text{High Brilliance}}$ for Mo and Ag radiation. Due to an improved heat management the new $\mu\text{S}^{\text{High Brilliance}}$ enables up to 60% more intensity. This was shown by measuring the flux through a set of pinholes of varying size with a calibrated pin diode. This is a standard method at Incoatec and allows a direct comparison of intensities as was done here for Mo and Ag radiation.

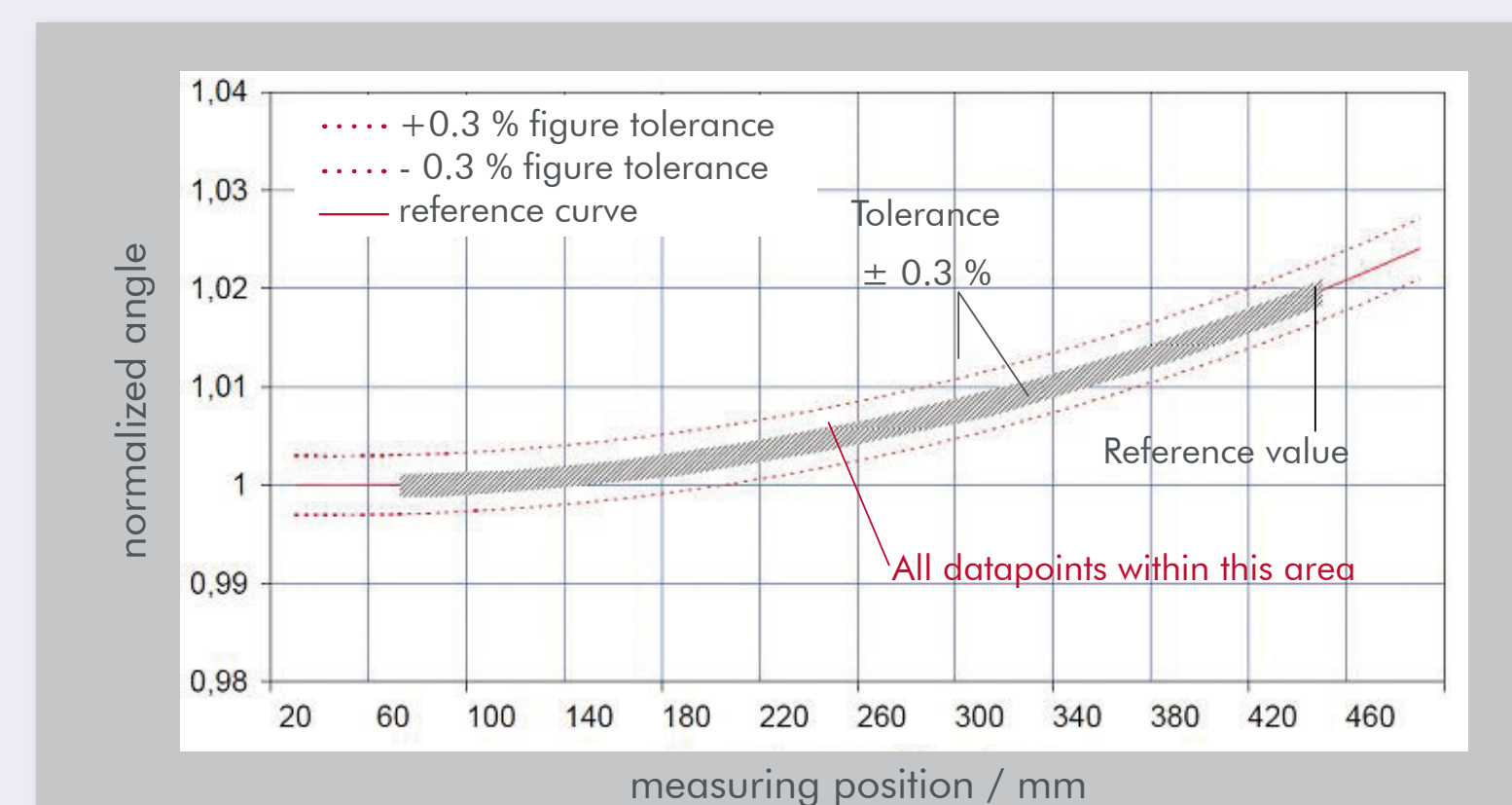
Source	Mo- $\mu\text{S}^{\text{High Brilliance}}$	Mo- μS
Exposure [s/°]	4	4
$\langle I \rangle$	2927.2	1828.5
Resolution [\AA]	0.83 (0.92 - 0.83)	0.83 (0.92 - 0.83)
$\langle 1/\sigma \rangle$	37.9 (8.7)	31.8 (6.5)
$R(\text{int}), R(\sigma)$ [%]	3.39, 1.50	4.17, 1.81
$R1, wR2$ [%]	3.13, 8.80	3.58, 10.00
$d(\text{C7-C8})$ [\AA]	1.368 (3)	1.363 (4)

We have compared both microfocus sources in small molecule crystallography measurements on an ylid crystal of size $0.16 \times 0.12 \times 0.12 \text{ mm}^3$. The results clearly show an enhanced performance of the new Mo- $\mu\text{S}^{\text{High Brilliance}}$. The intensity and the signal-to-noise ratio are considerably larger, thus improving the results of the structure refinement.

Synchrotron Optics

Incoatec offers different types of multilayer optics (see below) for synchrotron applications. We can coat substrates of up to 150 cm in length and we are able to manufacture graded multilayers with less than 0.2 % deviation from the required design.

500 mm Multilayer Coating with 200 Pairs



Graded multilayer coating over 500 mm.

Total Reflection Optics



Total reflection optics are used for beam guidance and alignment. The length often exceeds 100 cm due to small incidence angles.

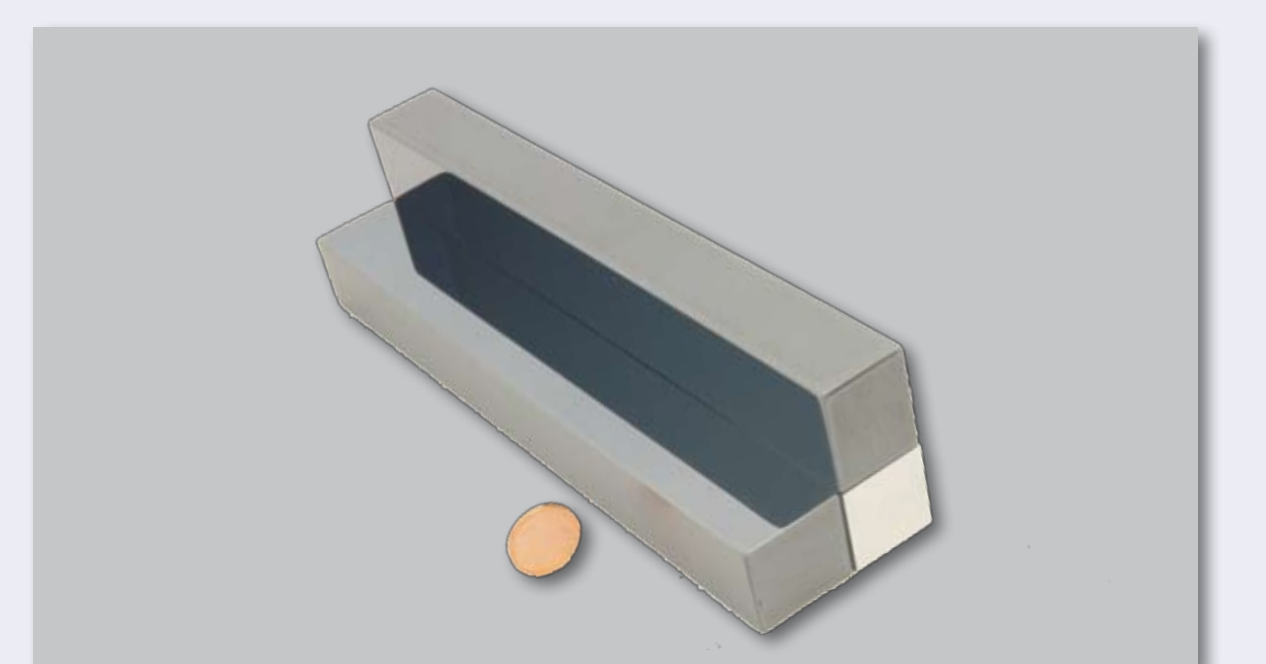
Multi-stripe Multilayer Optics



Stripe A: [Ru/C]100, $d=40 \text{ \AA}$, $y=0.5$,
 $R > 80\%$ for $10 < E < 22 \text{ keV}$
 Midspace: Si<111>, roughness 0.1 nm,
 slope error 0.04"
 Stripe B: [W/Si]100, $d=30 \text{ \AA}$, $y=0.5$,
 $R > 80\%$ for $22 < E < 45 \text{ keV}$

Three-stripe multilayer optics for tomographic microscopy and coherent radiology. The coatings are optimized for different beam energies (TOMCAT at SLS). (M. Stamparoni, PSI)

Montel Optics

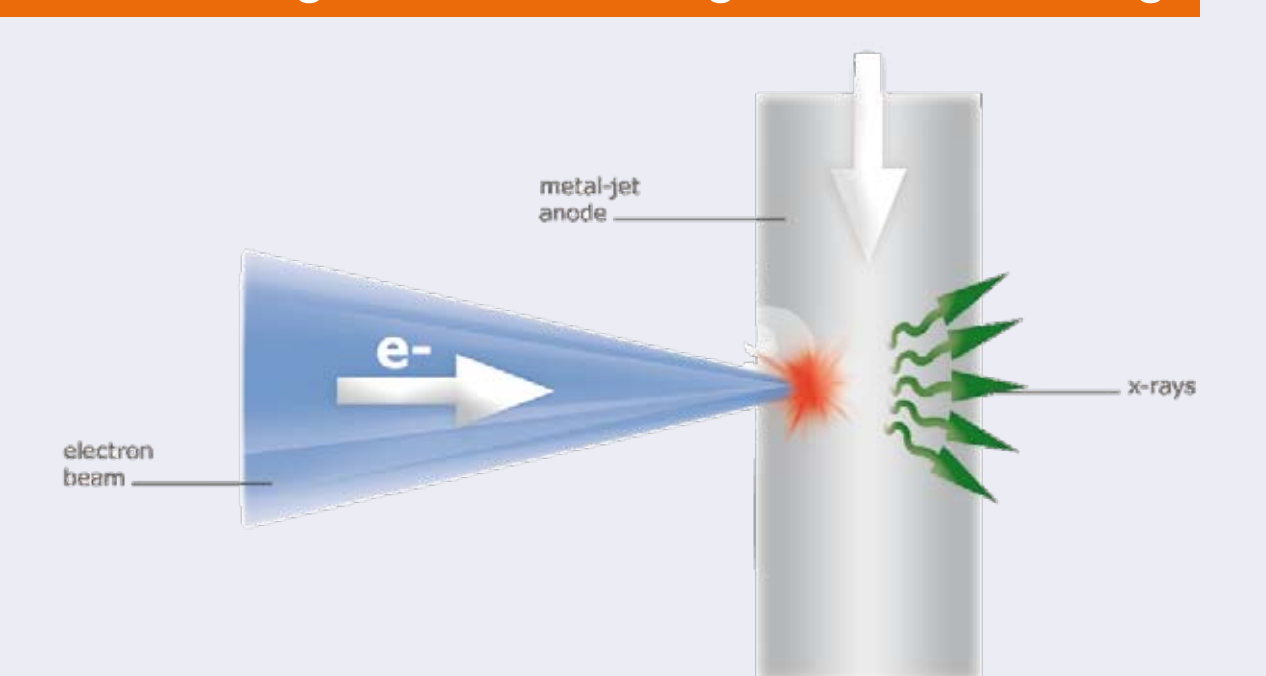


The picture shows a Montel optics without apertures. The slope error is < 2 arcsec and thus up to 5 times better than for lab-optics.

...Coming soon...Coming soon...Coming soon...Coming soon... Coming soon...Coming soon... Coming

Liquid Metal Jet X-ray Source

Liquid metal jet sources use a new technology and have already shown intensities superior to the best microfocus rotating anodes. This innovative technology generates X-rays by an electron beam that is focused on a jet of a liquid metal melt, such as Ga ($K_{\alpha}=9.2 \text{ keV}$), In ($K_{\alpha}=24 \text{ keV}$) or Sn ($K_{\alpha}=25.3 \text{ keV}$). As the anode is a liquid melt jet it is self-healing and has a larger heat capacity compared to a solid metal anode, thus allowing an order of magnitude higher power load. Liquid metal jet sources represent a promising development for future high brilliant sources with the potential to reach intensities of up to 10^{12} photons/(s $\cdot\text{mm}^2$). With our partners Bruker AXS and Excillum we are developing a new generation of diffractometers. Incoatec is designing and manufacturing the multilayer optics and the corresponding housing. So far we have achieved very symmetric, gaussian-shaped beam spots with a FWHM width of $95 \mu\text{m}$ and a brilliance of 7.1×10^9 photons/(s $\cdot\text{mm}^2 \cdot \text{mrad}^2$).



Working principle of a liquid metal jet anode.

