Multilayer Optics for X-Ray Diffractometry

Bernd Hasse – Incoatec GmbH, Geesthacht, Germany

Agenda

INCOATEC
innovative coating technologies

1. Multilayer Optics – Design and Fabrication

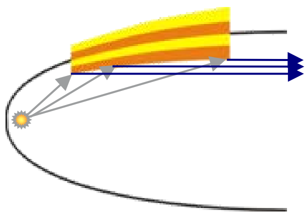
2. XRD-Applications with Multilayer Optics

3. The Past and the Future

Multilayer X-ray Optics for specific applications

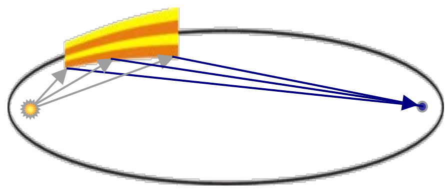
INCOATEC
innovative coating technologies

Diffractometry



1-dimensional

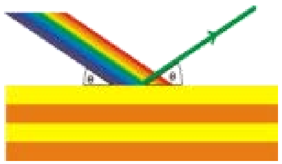
Göbel Mirror
Gutman Optics



2-dimensional

KB mirrors
Side-by-side optics
2-dim shaped optics

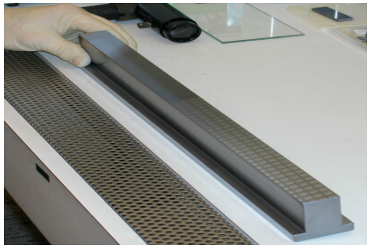
Spectrometry



Plane / Curved

WDXRF - Multilayer Analyser

Others



different types

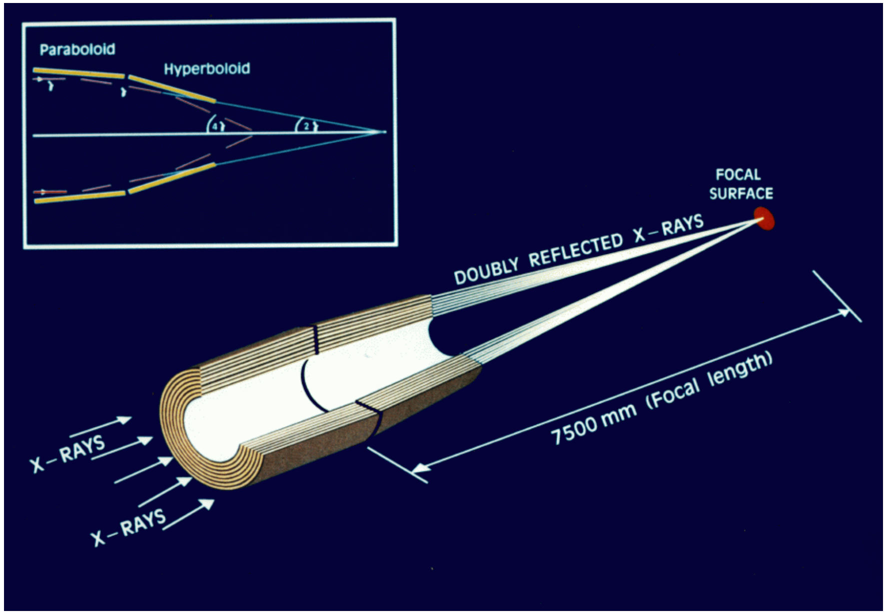
Synchrotron
EUV lithography
X-ray microscopy
Medical equipment
X-ray astronomy

High-End multilayer optics

NuSTAR Spectrocsopic Telescope Array

- 6 – 79 keV
- Pt/SiC and W/Si coating
- Shells spaced apart by graphite,

  held together by epoxy



http://www.nustar.caltech.edu/about-nustar/instrumentation/optics

Parts of Multilayer Optics

Substrate :

- Roughness
- Curvature (or plane)

  in one or two dimensions

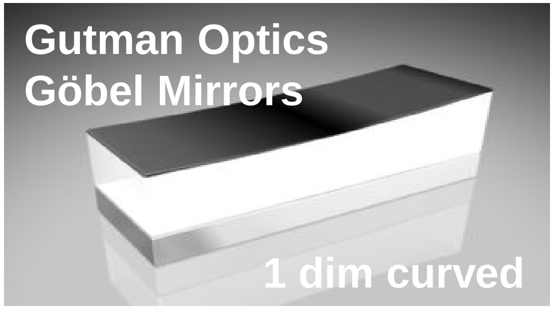
Multilayer film:

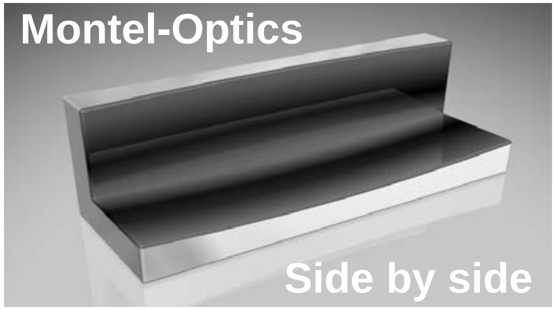
- Materials
- Layer Thickness
- Gradients (lateral and depth)

Mounting:

- combination of several multilayers

1 arcsec = 1/3600 deg = 0.00485 mrad;
for comparison: Bragg peak widths ~ 100 – 200 arcsec



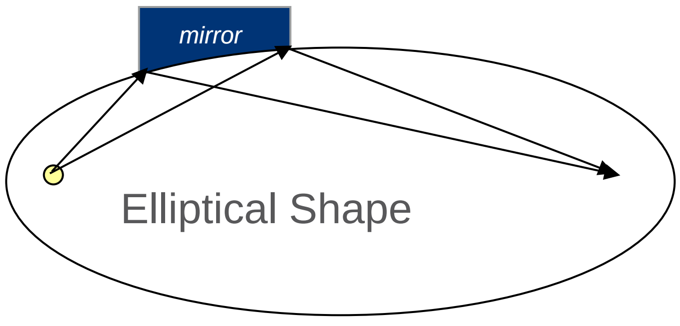


Substrates

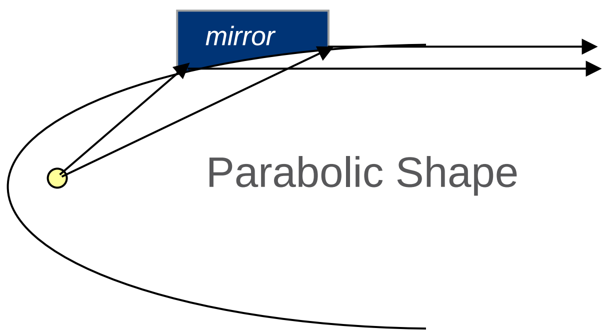
Material: Si, fused silica, quartz, zerodur, …

Properties:

- prefigured or “curved and glued” wafers with
- low roughness (< 3 Å down to 1 Å)
- curved with radii of several meters in beam direction plus several mm curvature for ellipsoids, paraboloids,…
- peak to valley: up to several 100 µm
- length in lab instruments up to 15 cm
- optimum shape: slope errors down to 5 arcsec (curved and glued), down to 0.03 arcsec (prefigured)



Source

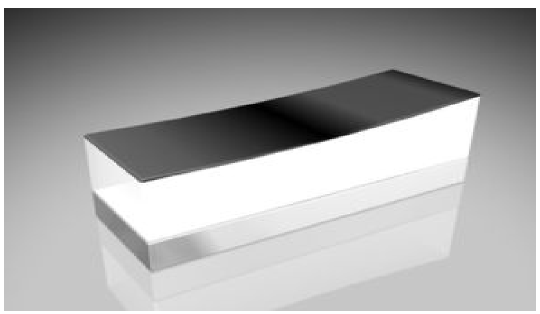


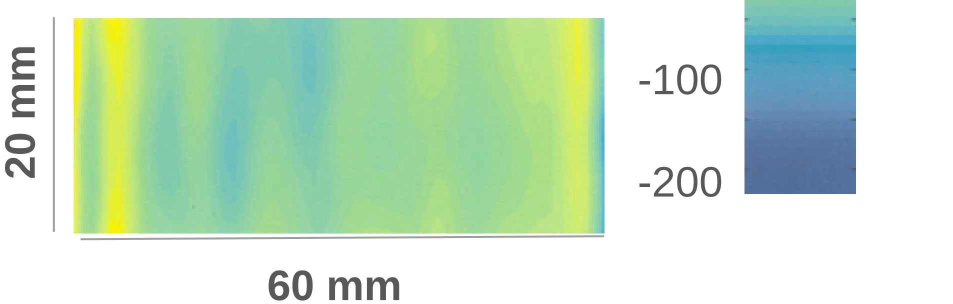
Source

Substrates: Shape characterization

Method: profilometry (e.g. Laser-Interferometry)

Example: 1-dim parabolic mirror





Shape as specified with

errors up to ± 100 nm

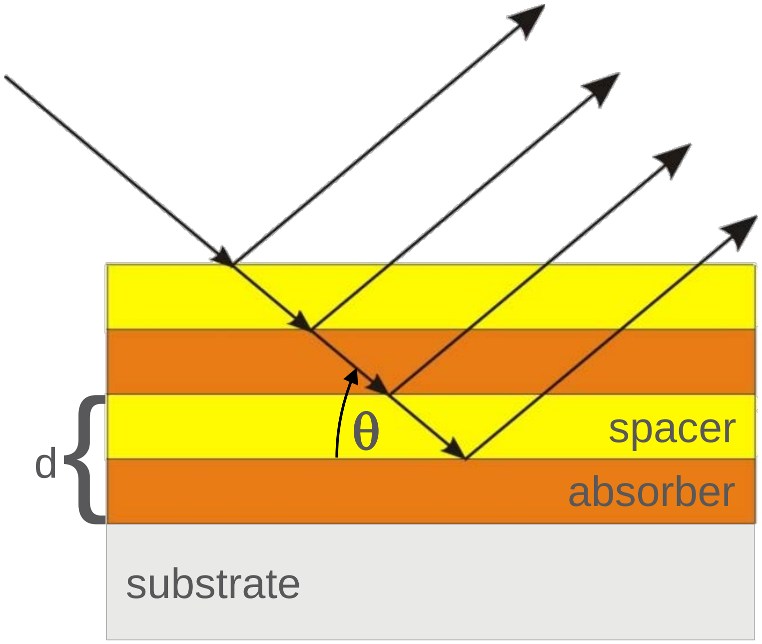
Slope error:

horizontal 3.3 arcsec rms

vertical 0.5 arcsec rms

Multilayer X-ray Optics

- Typical Parameters
  - Reflected Photons:
    λ: 0.01…40 nm / E: 30 eV … 100 keV
  - d: 1…30 nm
  - θ: 0 – 90 °
  - N: 40…1000 (Number of Pairs)
  - Γ-Ratio: 0.1…0.8 ($d_{absorber}/d$)
  - Lengths: 0.15 m (lab)…1.5 m (synchr)



δ: Dispersion of Materials

$$n\lambda = 2d\sin\vartheta \cdot \sqrt{1 - \frac{2\delta - \delta^2}{\sin^2\vartheta}}$$

Magneton Sputtering

INCOATEC
innovative coating technologies

- **area for deposition:**
  up to 150 x 12 cm or 8’’ diameter

- **lateral gradients by substrate moving**

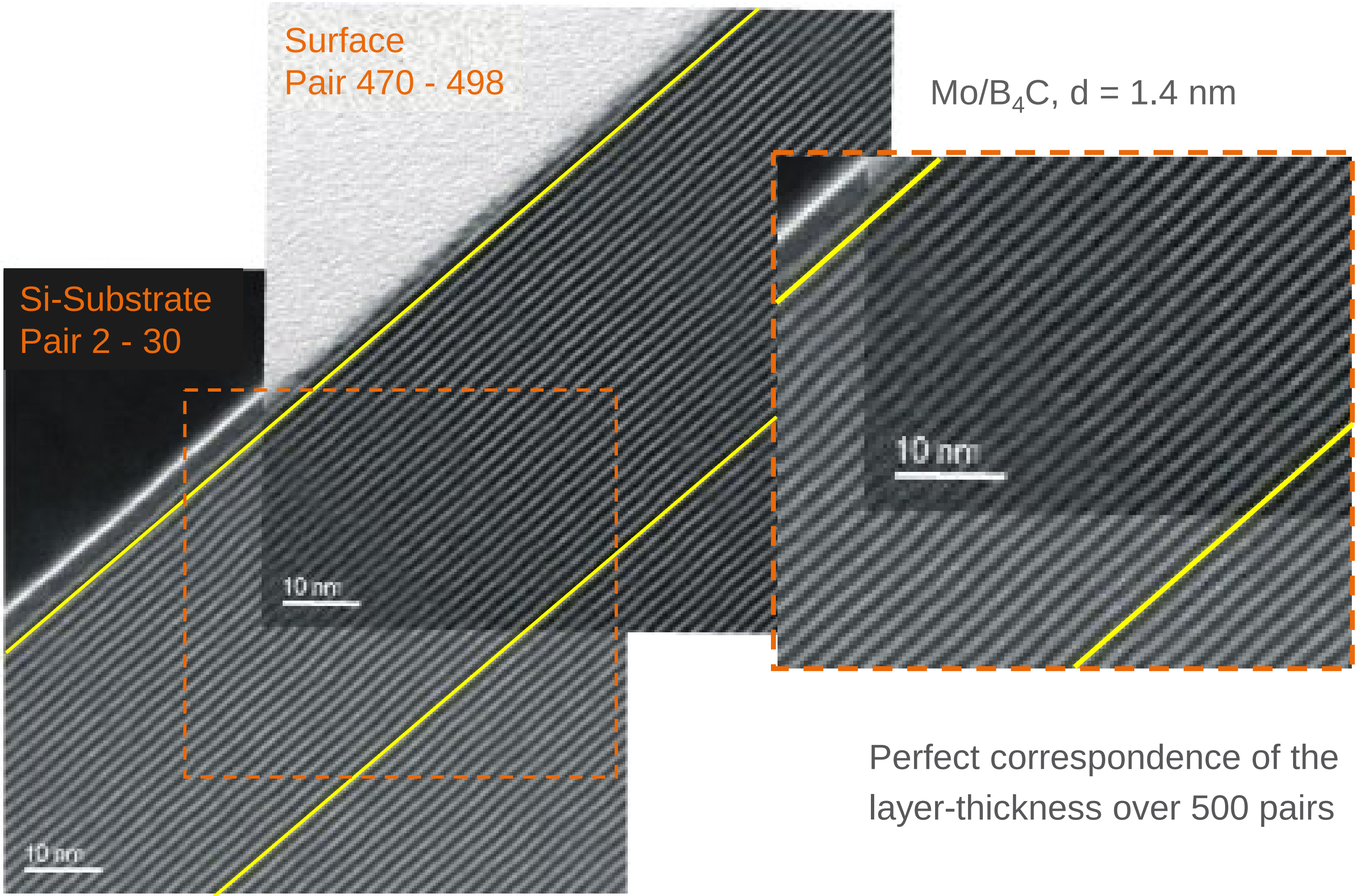
- **Target materials:**
  absorber:
  W, WSi2, Ru, V, La, Mo, TiO2, Ni …
  spacer: C, BN, B4C, Si,…

- **precision:**
  typical ±1%, up to ±0.2%

- **Difference of deposition facilities:**
  sizes, gradients and precision

TEM-Picture of a multilayer coating

INCOATEC
innovative coating technologies



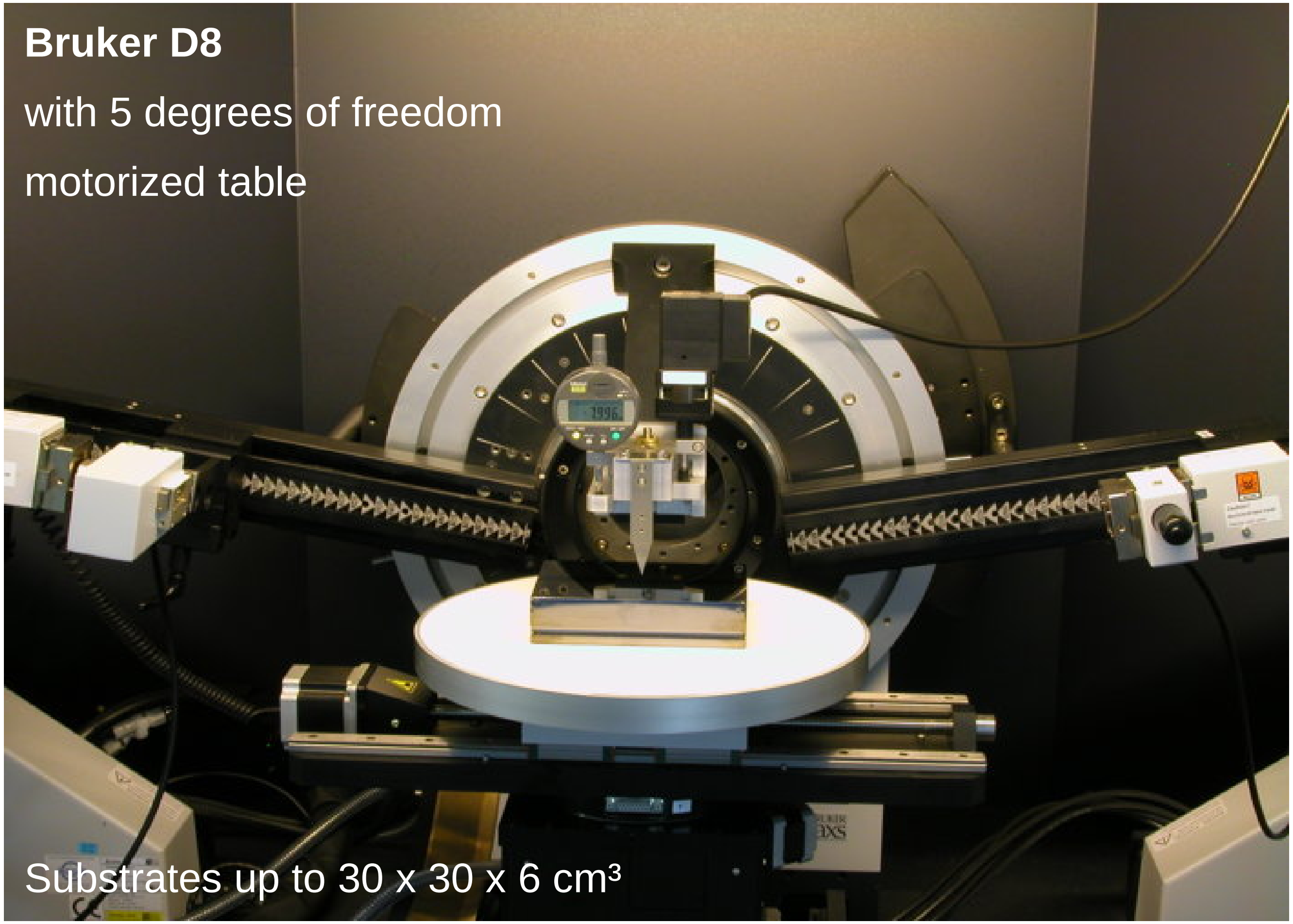
Measured by Prof. Jäger et al., Univ. of Kiel

Mo/B_4C, d = 1.4 nm

Perfect correspondence of the layer-thickness over 500 pairs

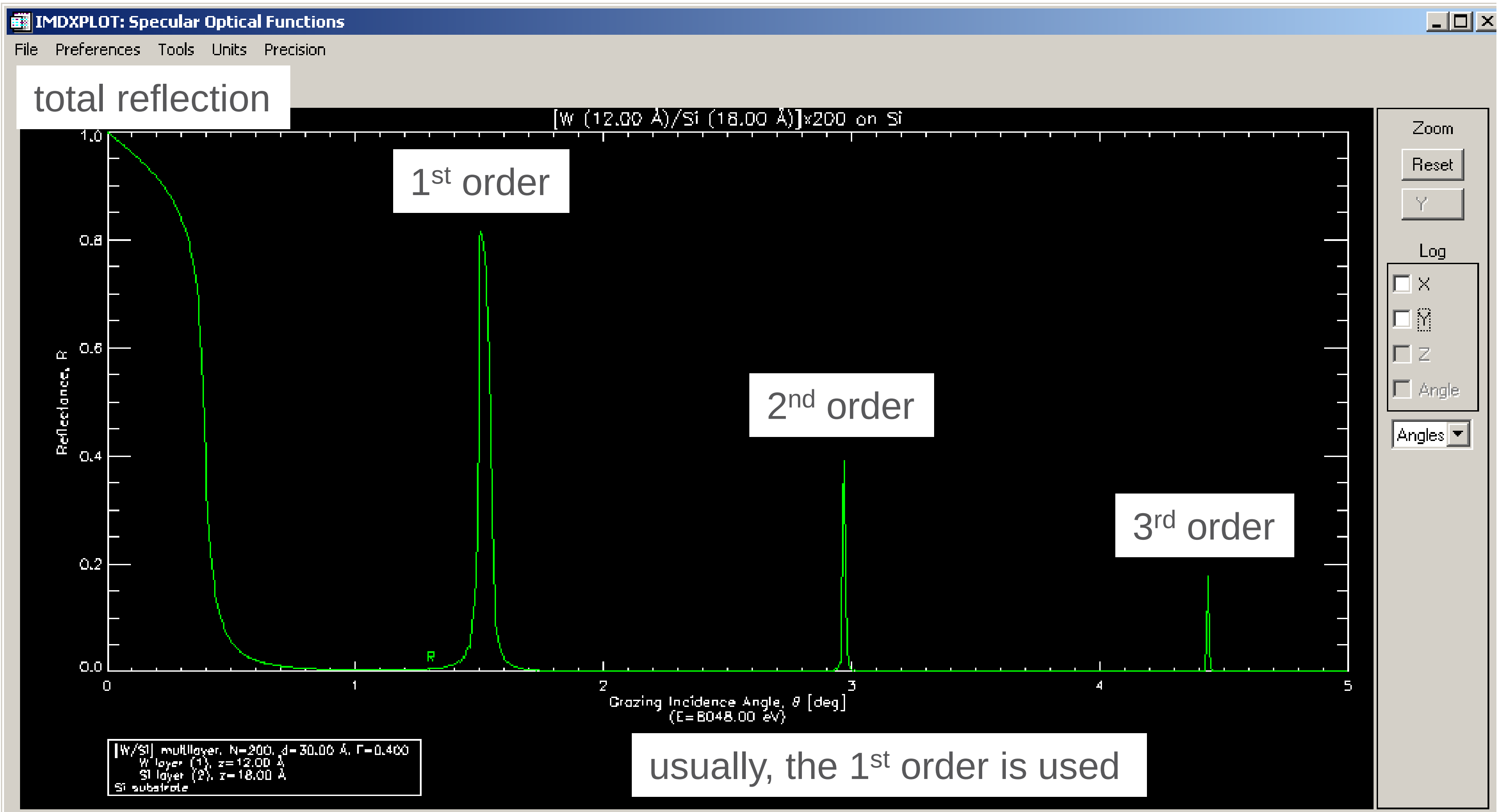
Standard process control: Characterization with X-Ray Reflectometry

innovative coating technologies



Typical reflectivity curve at 8 keV (Cu Kα)

INCOATEC
innovative coating technologies

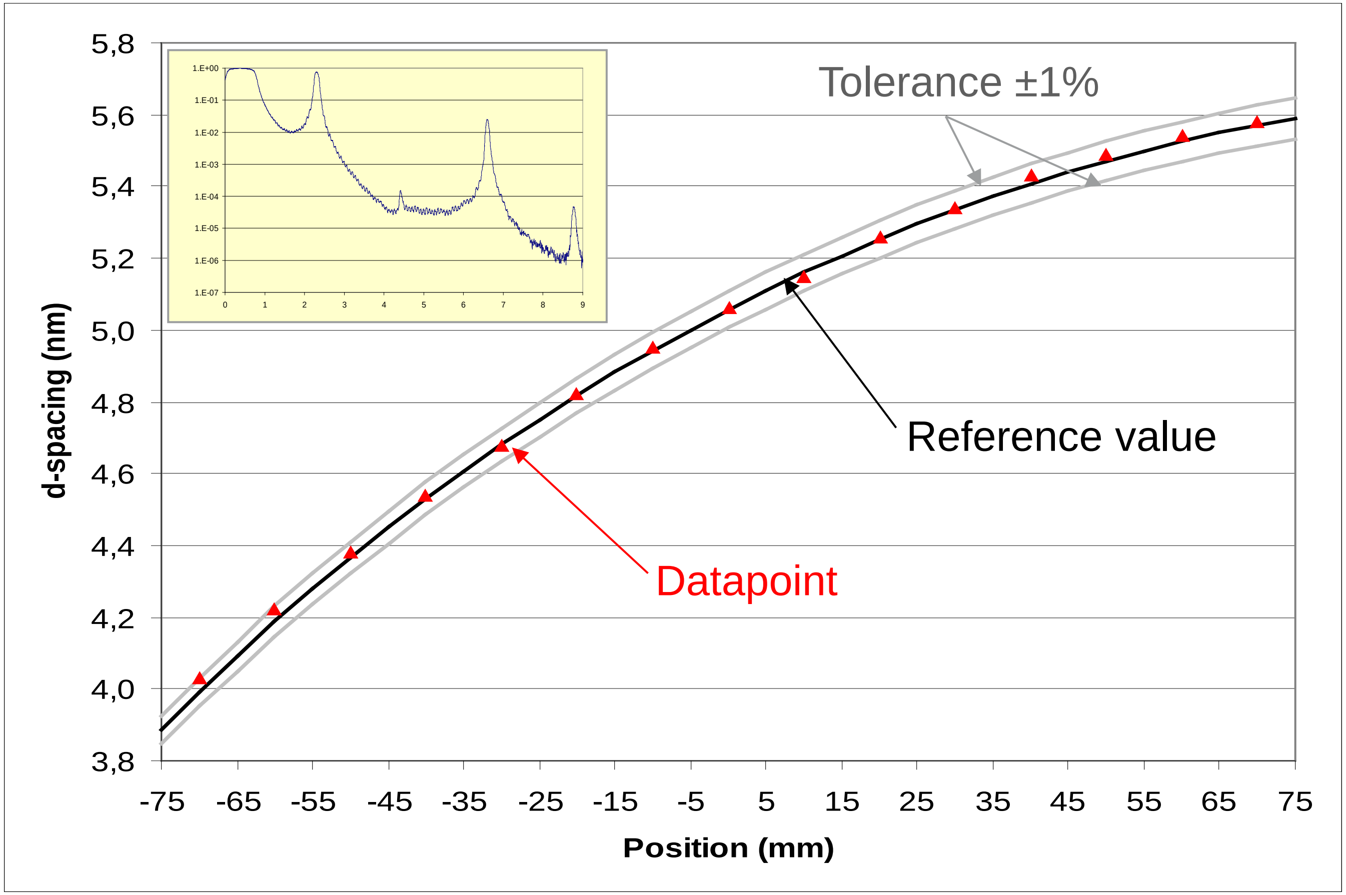


Reflectivity R = 70…90 %, bandpass $\Delta E/E$ = 1…10%

→ Monochromatic beam (> 99% Kα) with high flux

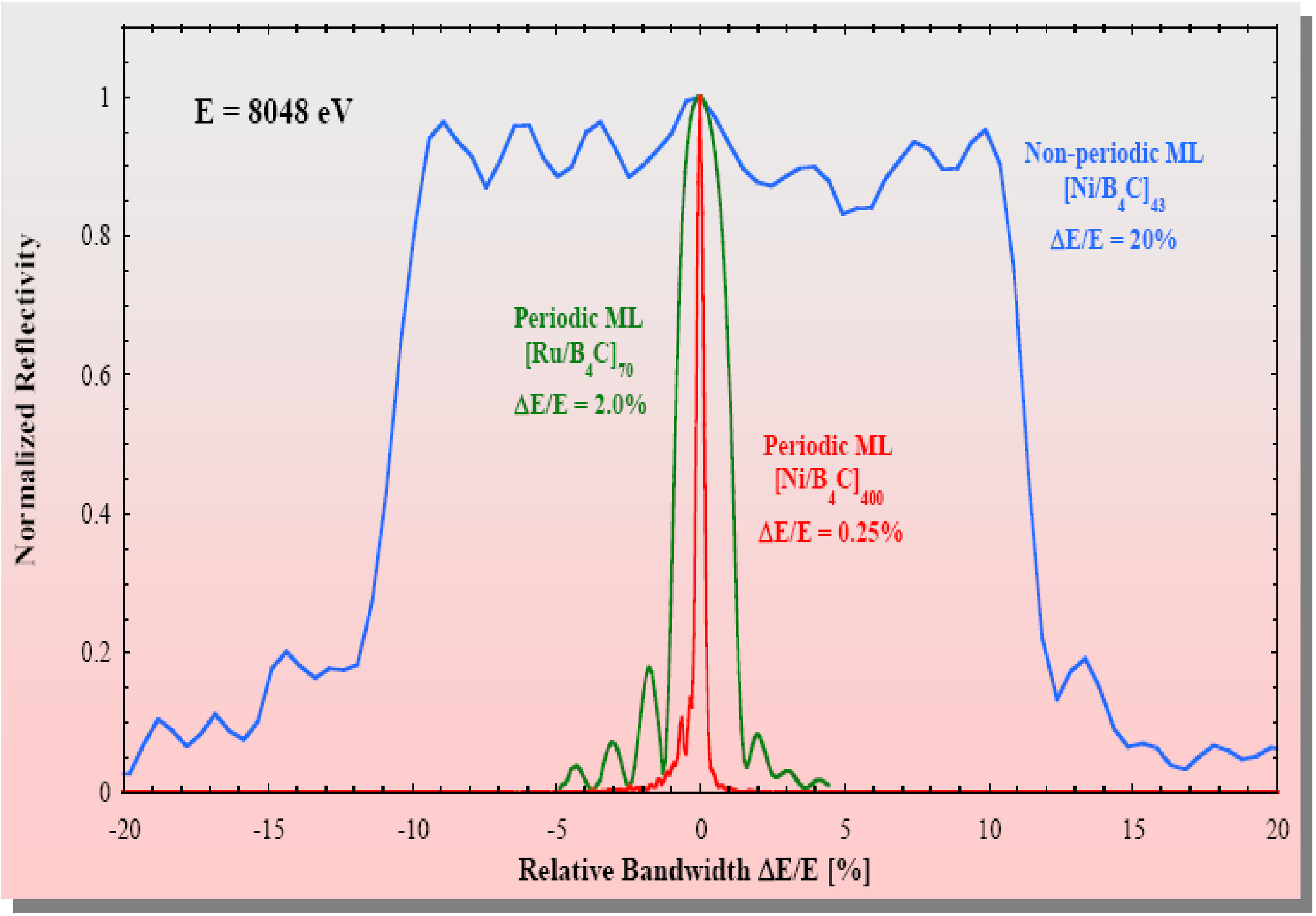
Characterization with XRR

Graded Multilayer



d-spacing accuracy better 1% !

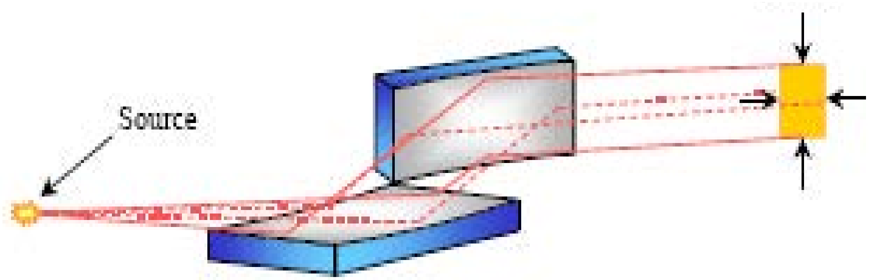
Tailoring the bandwidth at synchrotrons



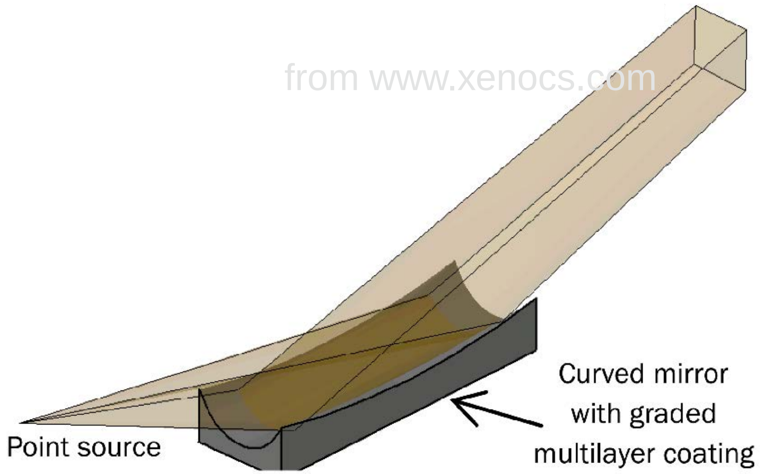
from C. Morawe, ESRF

Concepts for two-dimensional Optics

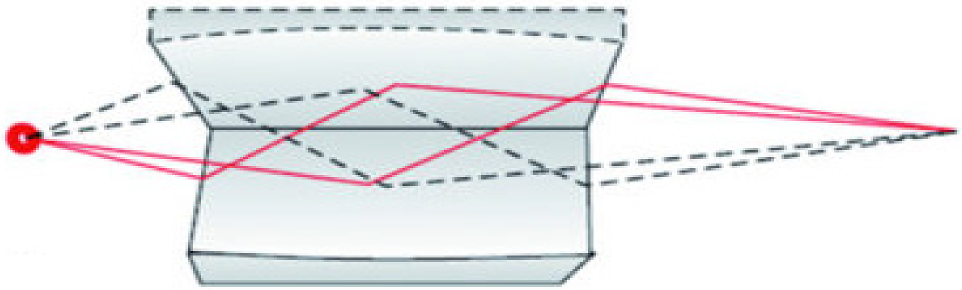
INCOATEC
innovative coating technologies



KB (Kirkpatrick Baez) scheme, also called cross-coupled: two 1-dim optics; used at synchrotrons and few lab instruments



2-dim curved substrate:
Single-reflection Optics

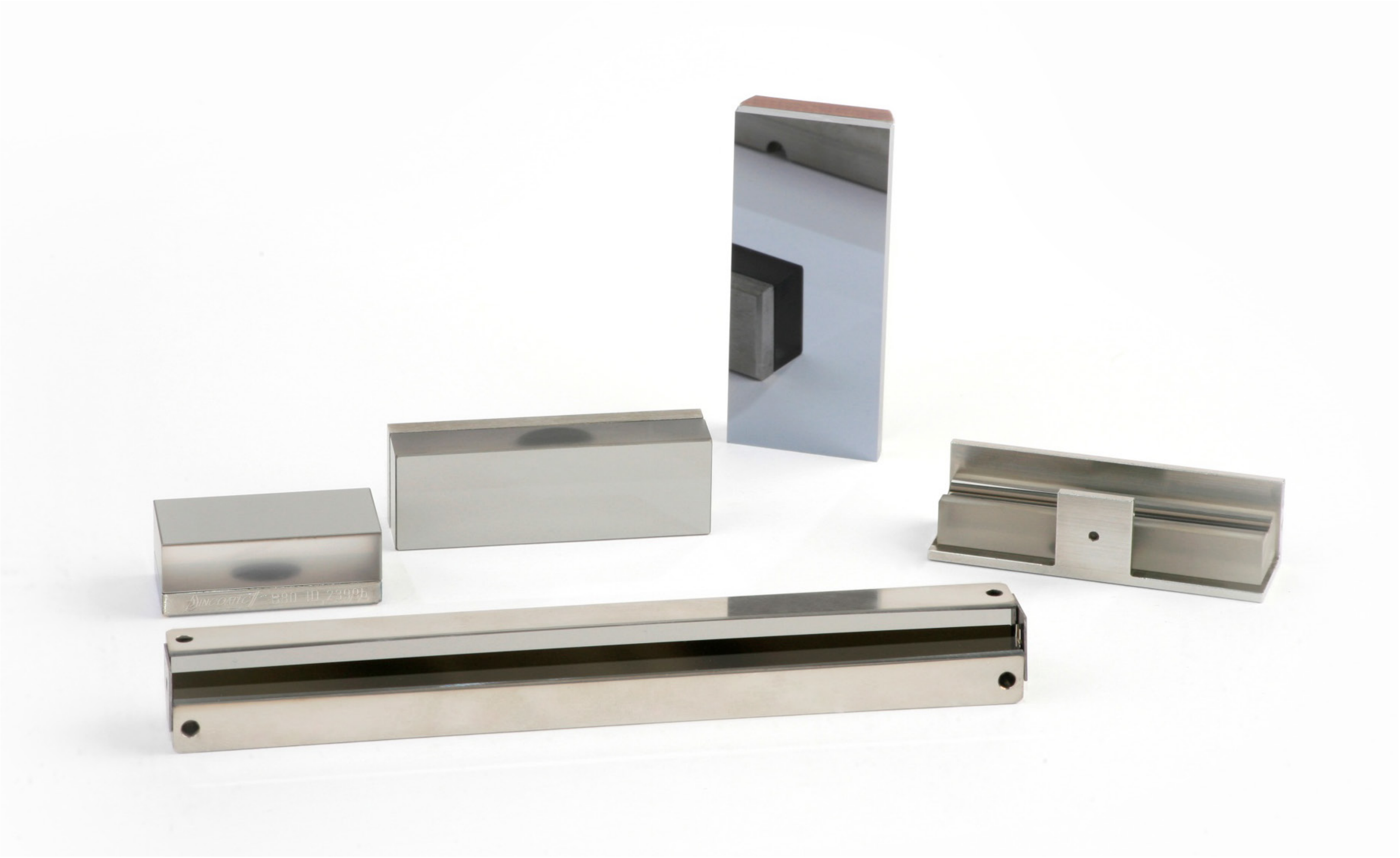


Side-by-side scheme, also called Montel Optics: two 1-dim optics mounted together; state-of-the-art in lab instruments

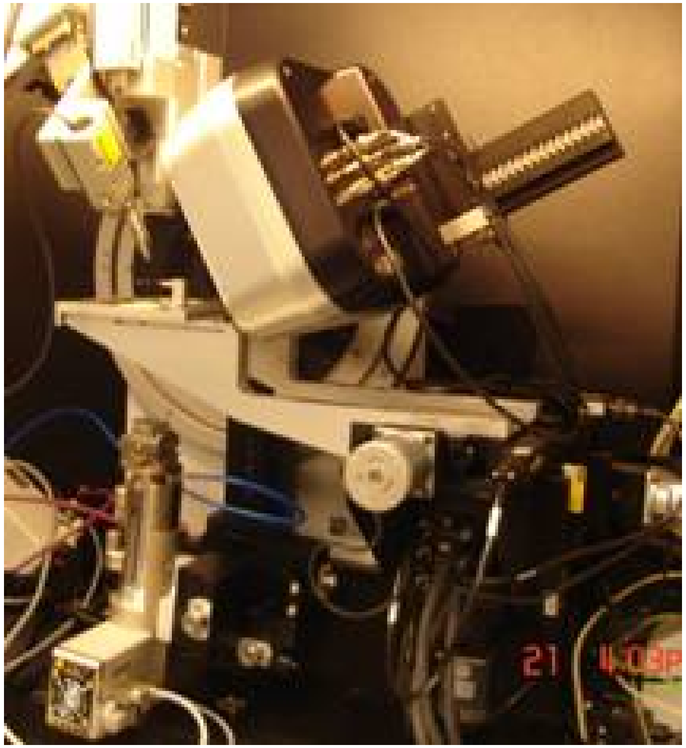
All concepts available for focusing and collimating

Multilayer Optics for Lab-instruments

INCOATEC
innovative coating technologies



Focussing Mirror for XRD



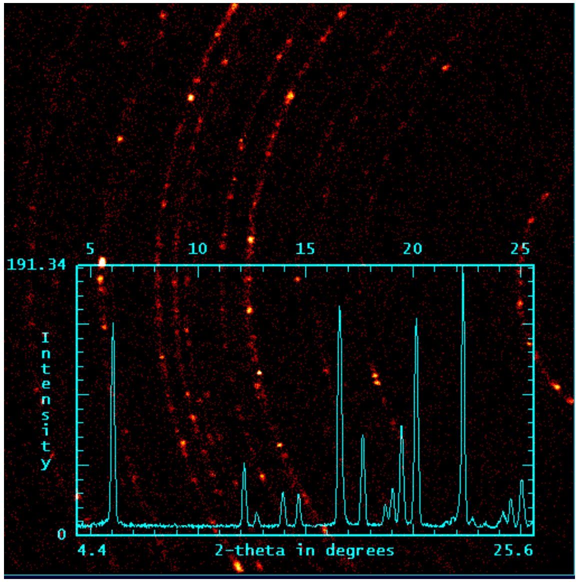
- measurements in transmission
- with Bruker D8 GADDS and VÅNTEC 2000
- Sample: Ibuprofene
- Sample-Detector distance: 290 mm

Focussing Mirror for XRD

Sealed Tube

- 0.3 mm collimator
- cross-coupled mirrors

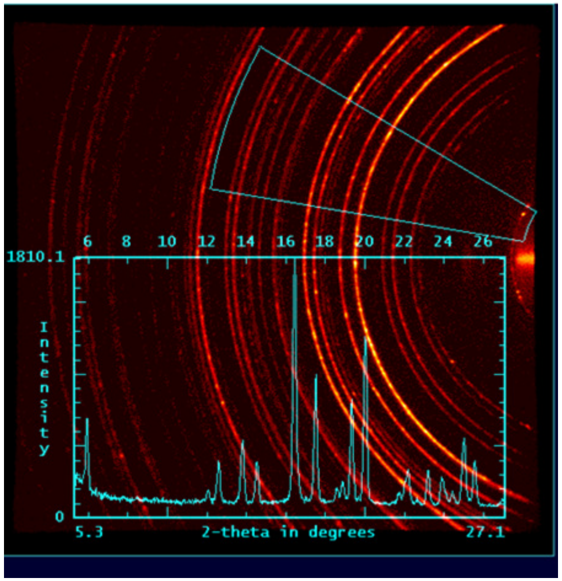
120 sec collection time



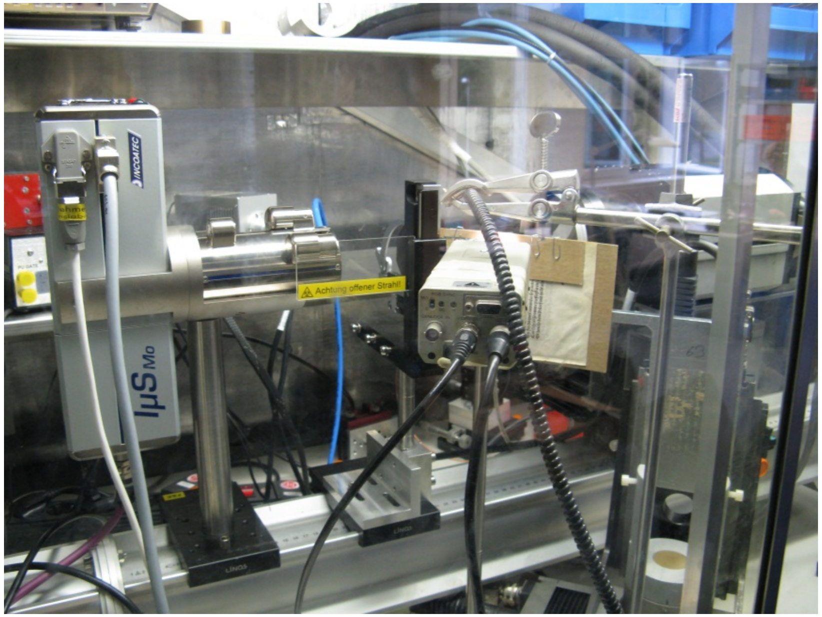
Microfocus source

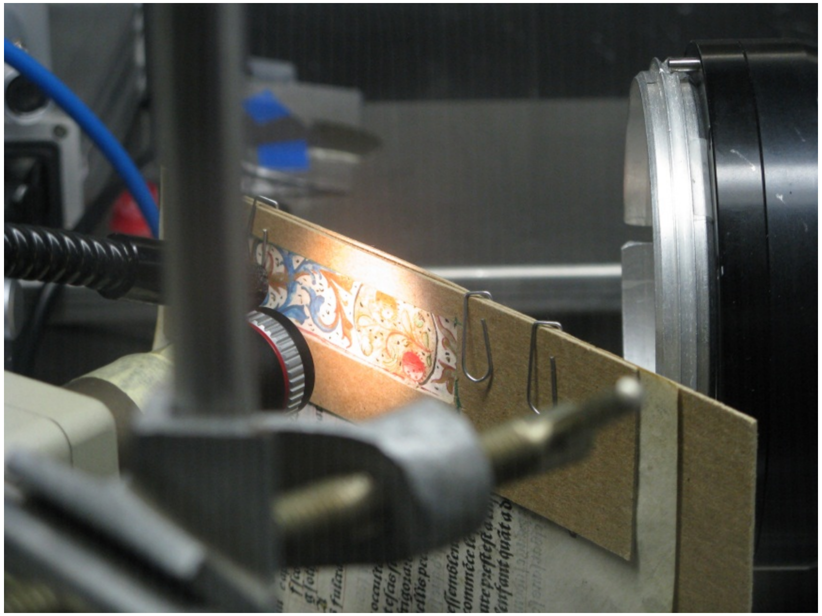
- 0.3 mm snout
- Focussing 2-dim optics
- small slice for integration to obtain better resolution (poor detector calibration)

15 sec collection time



Measurement of a Manuscript





- Simultaneous XRD and XRF measurements
- Position sensitive measurements using focusing Mo-microfocus source
  - Resolution 150 µm

K. Janssens, Antwerpen

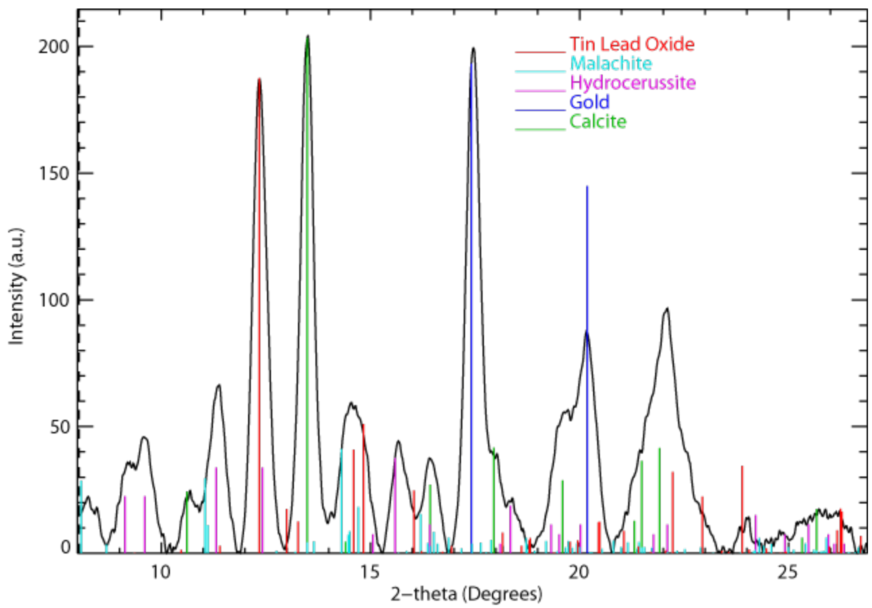
Illuminated Manuscript
Point Measurements

K. Janssens, Antwerpen

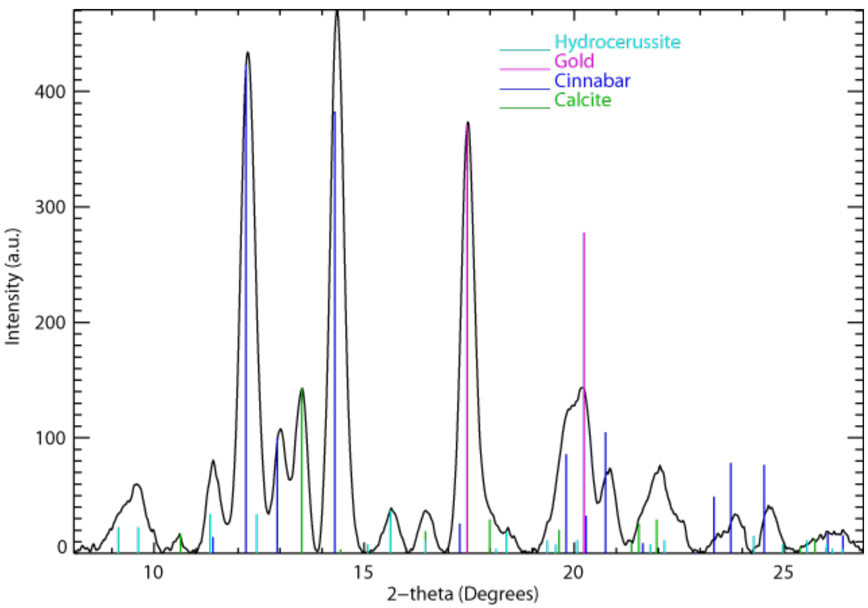
Results

INCOATEC
innovative coating technologies

Green



Red

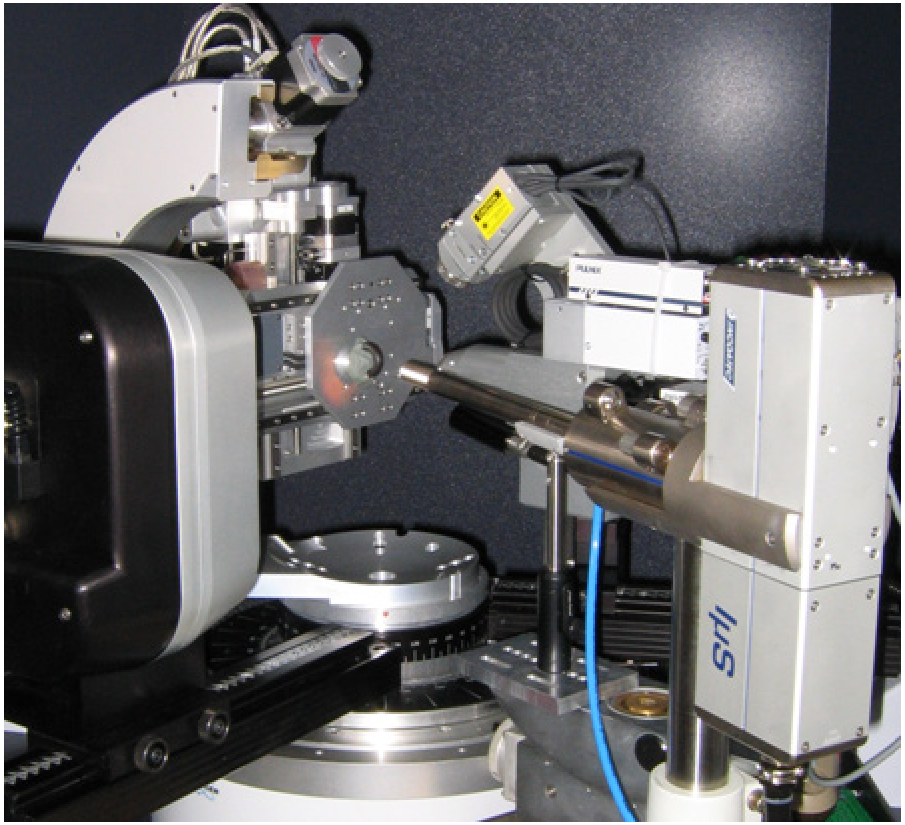


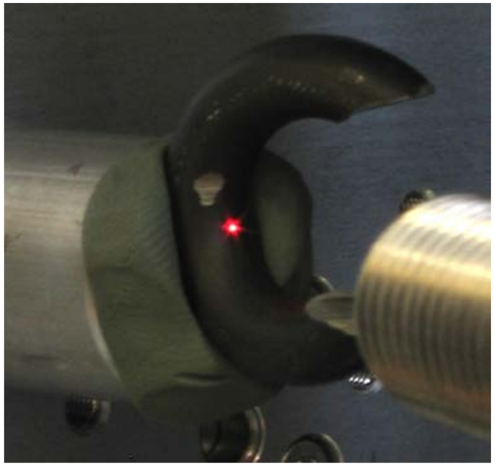
- Mo-microfocus source: 50 kV, 600 µA, 30 sec exposure time
- Scanning Micro diffraction (combined with XRF):

  4 x 4.5 mm², resolution 150 µm, Total measurement time: 18 h
- Measurements and data evaluation by Frederick Vanmeert

K. Janssens, Antwerpen

Fast Stress Analysis: Steel Spring

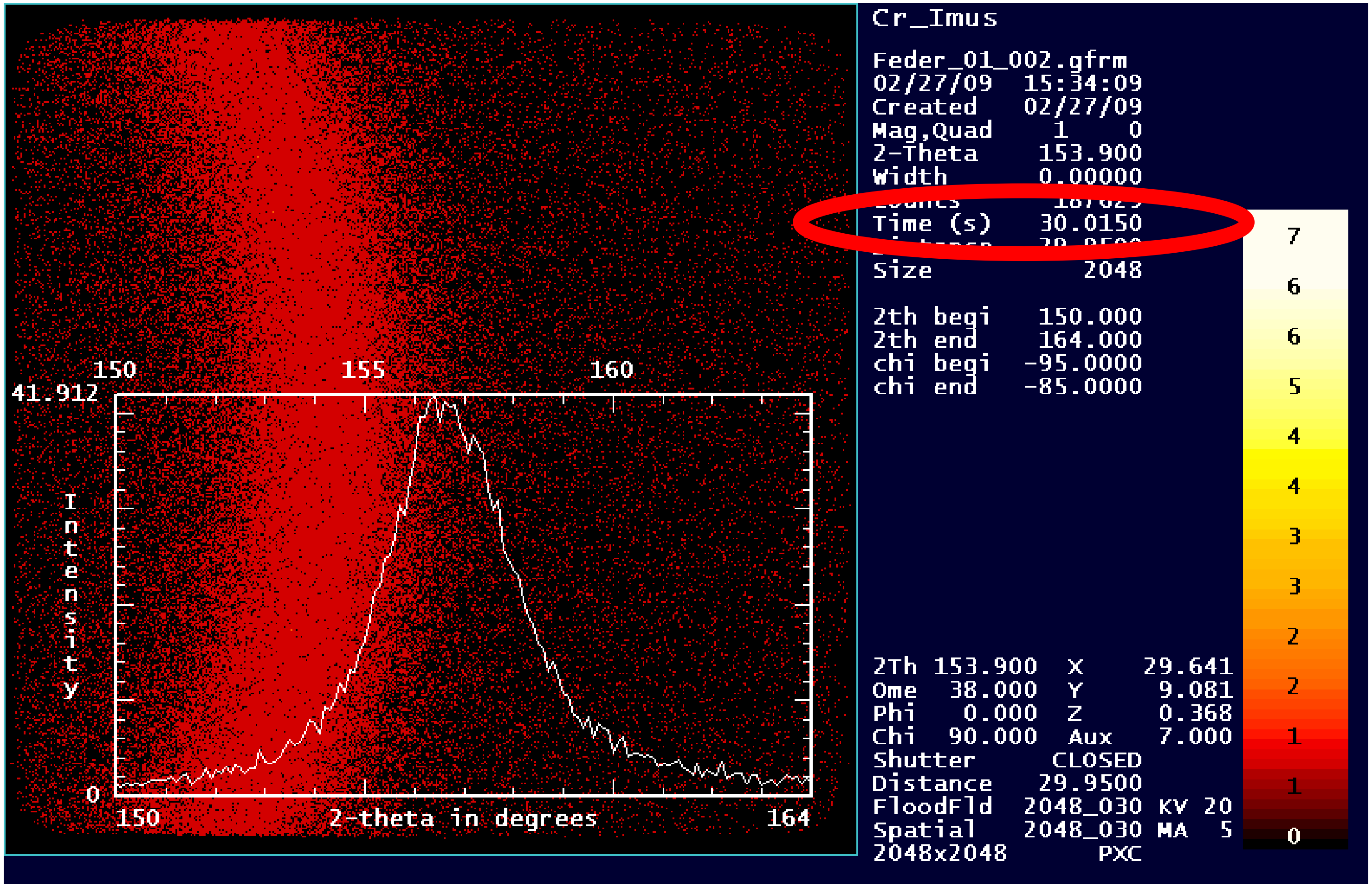




H. and U. Göbel, LabXA and M. Schuster, Siemens, Munich

Steel Spring: Measurement

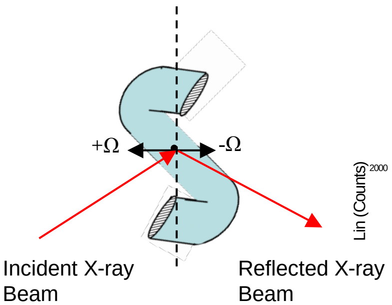
INCOATEC
innovative coating technologies

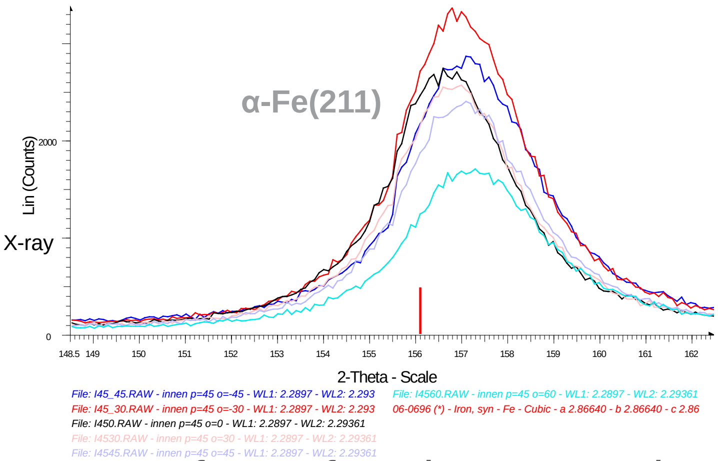


H. and U. Göbel, LabXA and M. Schuster, Siemens, Munich

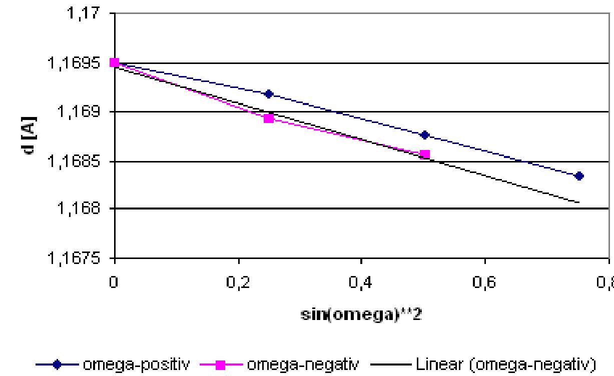
Steel Spring: Results – Tensile and compressive stress at the inner surface

Inner Surface of Spring, +45°-Direction

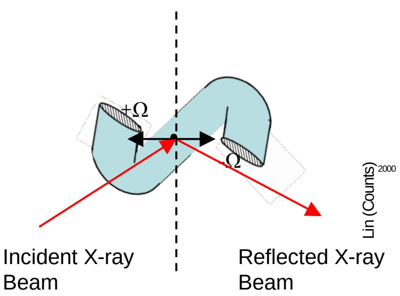


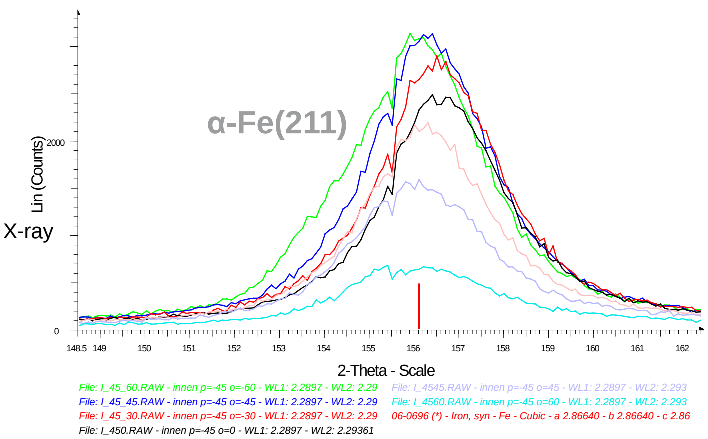


Compressive Stress: -238 MPa

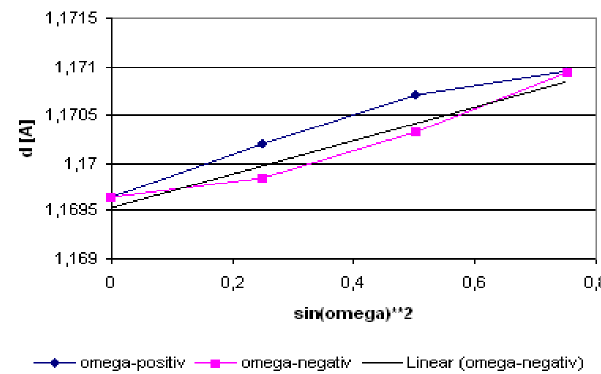


Inner Surface of Spring, -45°-Direction





Tensile Stress: +241 MPa



H. and U. Göbel, LabXA and M. Schuster, Siemens, Munich

The Past and the Future

- Multilayer mirrors for a variety of energies: Cr, Mn, Fe, Co, Cu, Ge, Mo, Ag, and higher energies for synchrotrons
- Large variety of possible material combinations
- Multilayers are stable (except against ozone)

New sources with (sub-) micrometer beams:

- microfocus sources
- liquid metal jet sources
- synchrotron beam lines

Energy range 5 keV to 100 keV

Requirement: Pre-figured substrates with a very low figure error for very small spots of focusing mirrors and very homogeneous spots of collimating mirrors

Acknowledgement

H. Göbel, U. Hermeking-Göbel, LabXA, Munich

M. Schuster, Siemens, Munich

K. Janssens, F. Vanmeert, Antwerpen

All People from Bruker and Incoatec

Thank You

Please contact for more information

Incoatec GmbH

Max-Planck-Str. 2 · 21502 Geesthacht · Germany
Tel: +49(0)41 52 - 88 93 81 · www.incoatec.de