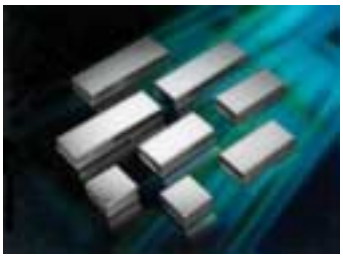
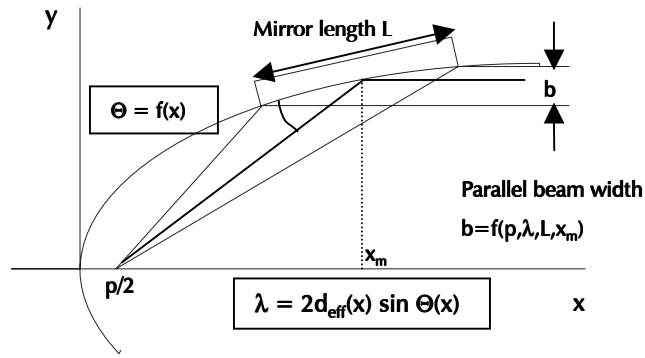


# PARALLEL BEAM X-RAY OPTICS

Fabrication of high precision 60 mm parallel beam optics both on prefigured substrates (right) and on flat substrates, which are glued and bend after deposition (left)




Generation of a monochromatic parallel beam in one dimension

| | |
|---|---|
| Spectral lines: | Cr, Co, Cu, Mo, Ag (others on request) |
| Mean Reflectivity: | R > 70% |
| Monochromasy: | $K\alpha_1 + K\alpha_2$ |
| Divergence: | $\Delta\phi \leq 0.03°$ |
| Mirror length: | 20mm - 80mm (on customers request) |
| X- ray source geometry: | Line focus preferred |
| Parallel beam width b: | dependent on spectral line, geometry and mirror length<br>b=0.8mm (Cu, 40mm, $x_m$ = 90 mm) |
| Geometry: | distance source-mirror (middle pos.- $x_m$ )<br>standard mirror (40mm) $x_m$ = 90mm<br>standard mirror (60mm) $x_m$ = 100mm |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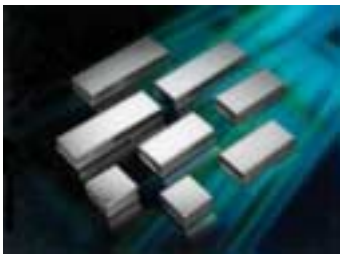
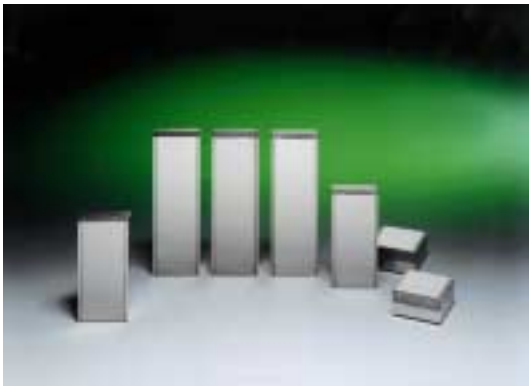
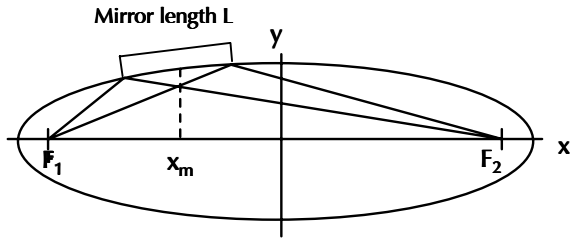


# FOCUSSING X-RAY OPTICS



Parallel beam and focussing X-ray optics with various geometries




Generation of a monochromatic focussing beam in one dimension

| | |
|---|---|
| Spectral lines: | Cr, Co, Cu, Mo, Ag (others on request) |
| Mean reflectivity: | R > 70% |
| Monochromasy: | $K\alpha_1 + K\alpha_2$ |
| Mirror length: | 20mm - 80mm (on customers request) |
| X-ray source geometry: | Line focus preferred |
| Width of focus b: | dependent on spectral line, geometry and mirror length |
| Geometry: | customized |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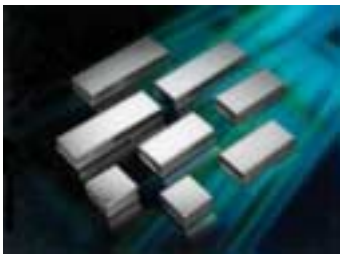
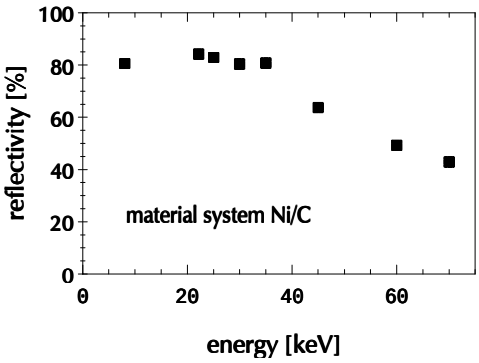
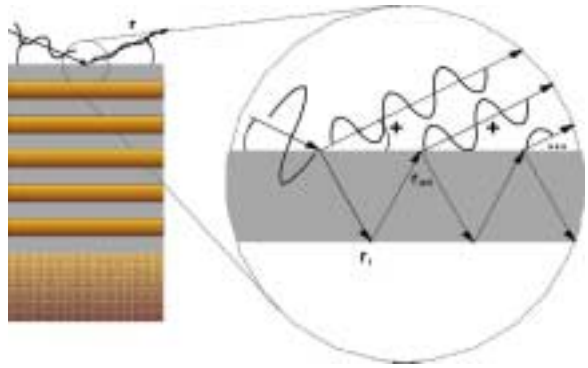


# MONOCHROMATORS



| | |
|---|---|
| Spectral range : | 100 eV – 100 keV |
| Material systems: | optimized on wavelength, on customers request |
| Dimensions: | up to 6“ diameter, others on request |
| Thickness homogeneity: | $\Delta d/d < 1\%$ |
| Applications: | monochromators on laboratory X-ray sources and on synchrotrons |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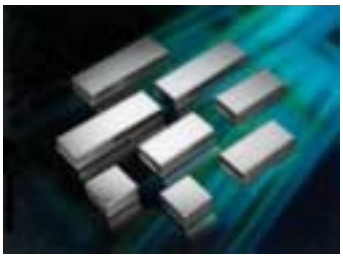
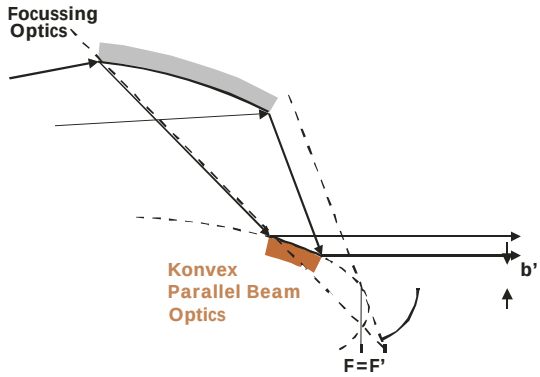


# KONVEX PARALLEL BEAM OPTICS




Generation of a compressed monochromatic parallel beam (width b) in one dimension

| | |
|---|---|
| **Outstanding Feature:** | **Increase of the parallel beam photon flux in combination with a focusing optic by reduction of beam width b compared to conventional parallel beam optics** |
| Spectral lines: | Cr, Co, Cu, Mo, Ag (others on request) |
| Mean reflectivity: | R > 70% |
| Monochromasy: | $K\alpha_1 + K\alpha_2$ |
| Mirror length: | 20mm - 40mm (on customers request) |
| X-ray source geometry: | Line focus preferred |
| Geometry: | customized |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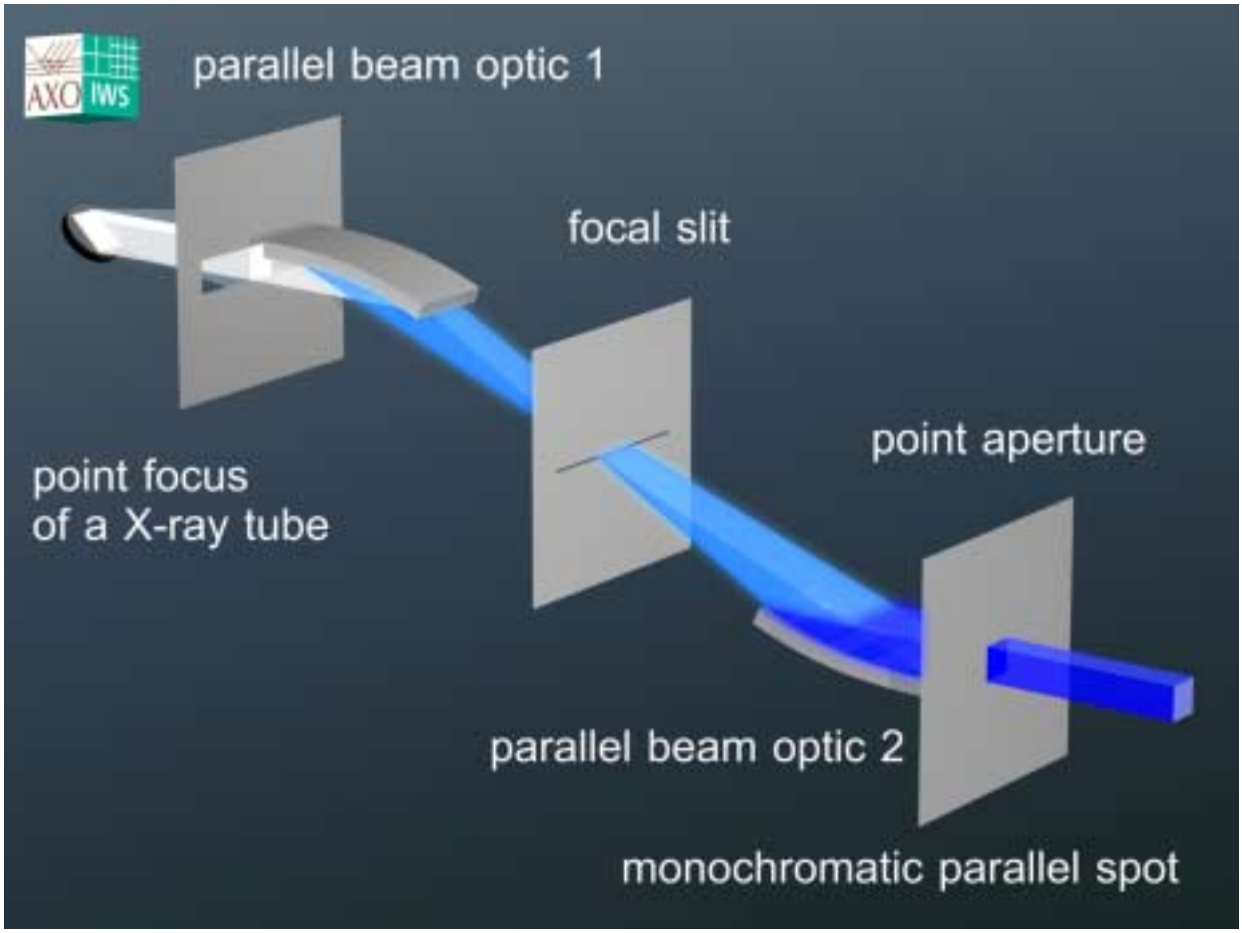
# COLLIMATING MONOCHROMATOR





Two parallel beam optics, aligned
on the same focal point

Acceptance of parallel X-radiation
emitted by a point focus X-ray source
(e.g. 0.3mm x 0.3mm rotating Mo anode)

**Result:**
monochromatic ($K\alpha_{1,2}$) parallel spot

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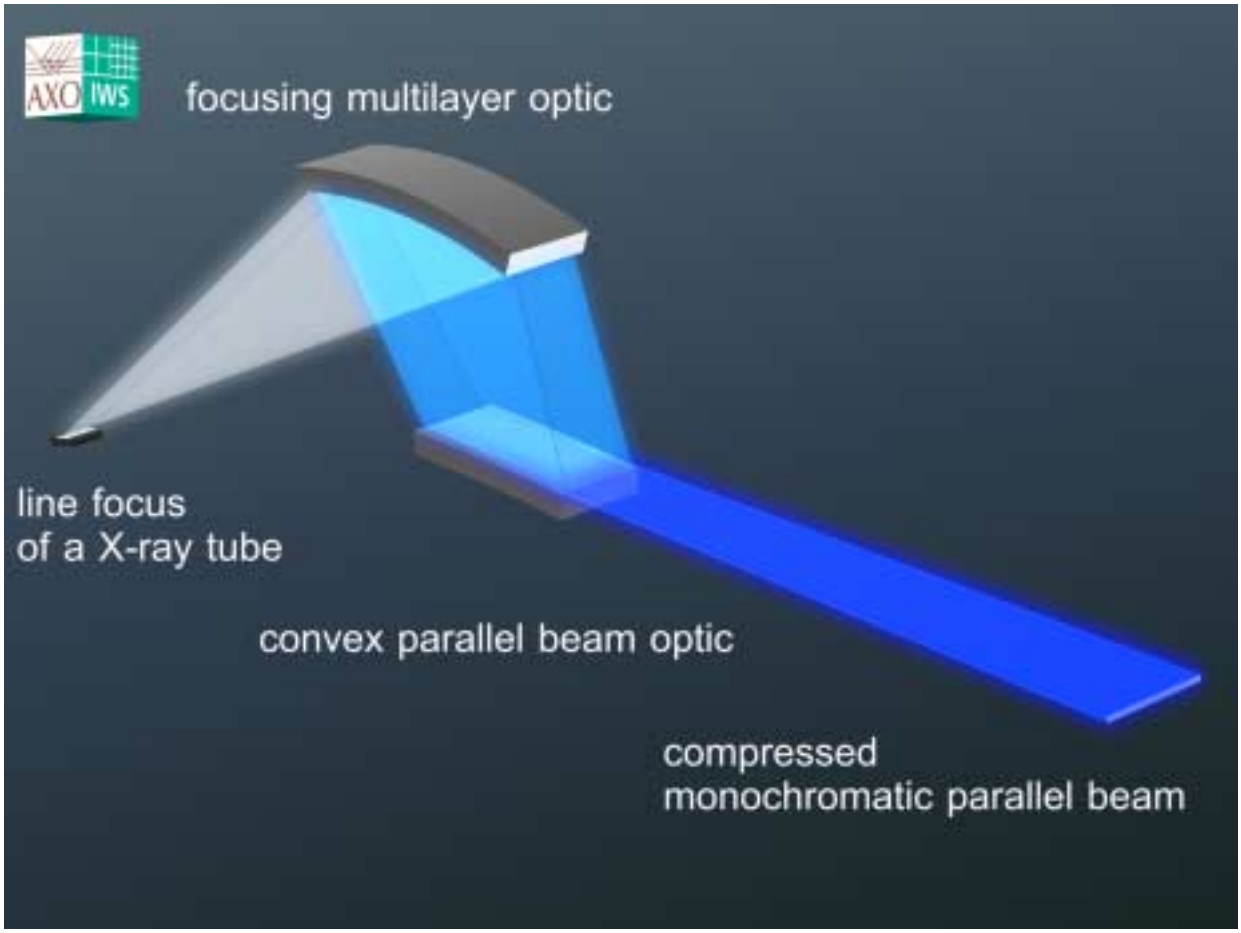
# BEAM COMPRESSOR





Combination of focussing and collimating multilayer optics

Emission of a parallel monochromatic beam

Adjustable beam width b at sample position

Result:
monochromatic ($K\alpha_{1,2}$) parallel spot
with a width b < 0.3 mm

Application: microdiffractometry and -tomography

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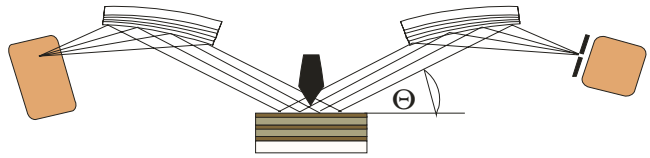
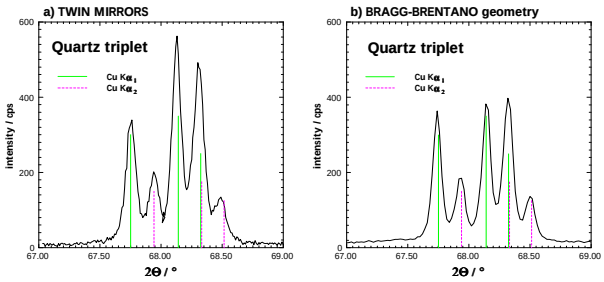
# TWIN MIRROR KIT

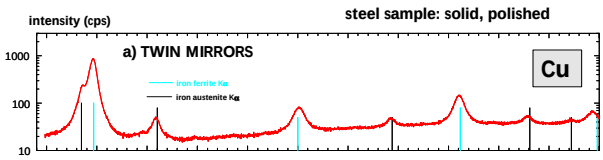



Setup of TWIN MIRROR arrangement

Twin Mirror Kit – left: primary mirror housing,
right: secondary mirror housing with beam tube and slit holder

## A new quality in X-ray diffractometry – secondary parallel beam optics




Better resolution than soller slits because of a more than two times lower angular acceptance ( Cu Kα : $\Delta\phi<0.03°$ )

Transmission higher than 70%

Increased S/N-ratio due to sample fluorescence suppression

Fits best to primary parallel beam optics

Parallel beam geometry:
-simplified sample preparation
-increased accuracy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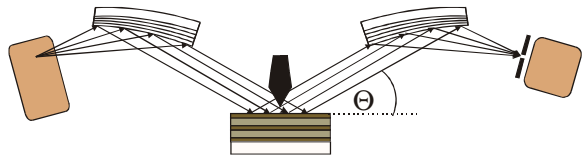
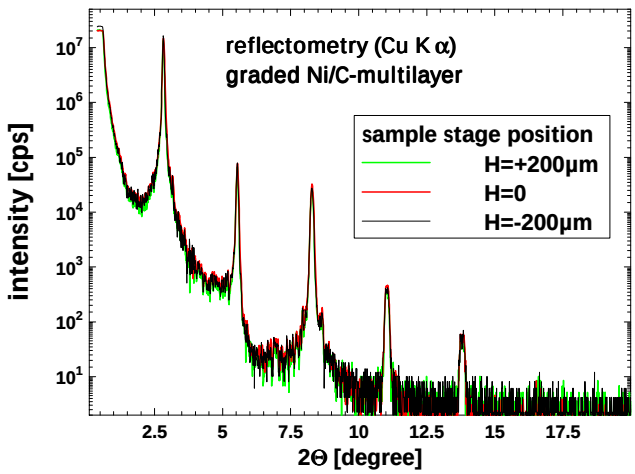
# TWIN MIRROR KIT




Setup of TWIN MIRROR arrangement

Twin Mirror Kit – left: primary mirror housing,
right: secondary mirror housing with beam tube and slit holder

## A new quality in in-house X-ray reflectometry – TWIN MIRROR Arrangement




- No influence of sample displacement errors up to 200 $\mu$m on peak position and intensity
- Sample alignment within 10 seconds
- Dynamic range of more than 7 orders of magnitude
- Low divergence ( Cu Kα : $\Delta\phi < 0.02°$ )
- Detectable thin film thicknesses between 2nm and 270nm

Upgrade available for Cr Kα, Co Kα, Cu Kα, Mo Kα, Ag Kα
Geometry on customer request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# Application of Nanometer-Multilayer Optics for X-ray Analysis

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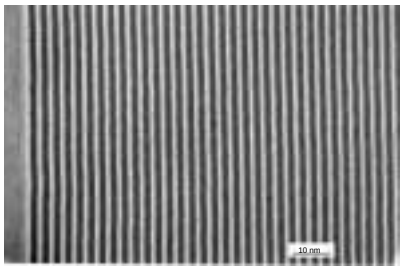
**AXO DRESDEN GmbH, Siegfried-Rädel-Str.31, D-01809 Heidenau, Germany: **www.axo-dresden.de**

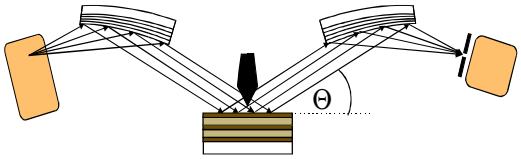
## High performance focusing and parallel beam multilayer X-ray optics



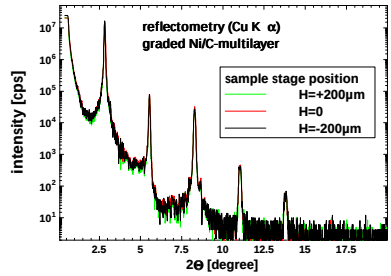

Ni/C multilayer
(d=3.2 nm)
(TEM cross section)

Glued and prefigured focusing and parallel beam X-ray optics with various focal lengths and parallel beam widths, designed for Mo Kα-, Cu Kα-, Co Kα-radiation

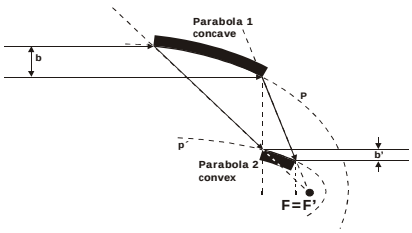
## A new quality of in-house X-ray reflectometry - Twin mirror arrangement

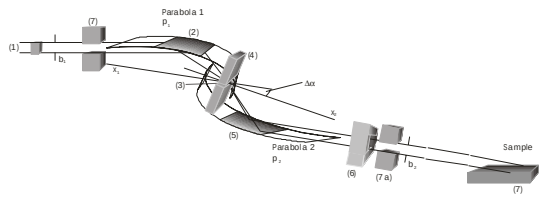



- highest intensity and low divergence
- superior Kβ- suppression
- sample fluorescence suppression
- no influence of sample surface position errors on peak position for reflectometry and diffractometry
- easy and fast sample alignment



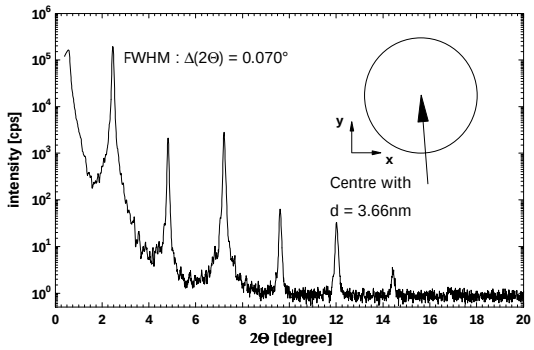

## High brilliance collimating monochromator systems for intense sub-mm X-ray spots X-ray Pointer and Beam Compressor




*Beam Compressor*

*Collimating Monochromator*




**sub-mm Reflectometry**

Thickness Gradient
perpendicular
to beam direction

(Ni/C graded multilayer)

(Beam Compressor spot 0.3mm x 0.6mm (Z x Y); Twin mirror arrangement)

**FUTURE POTENTIALS in**

- Micro-Diffraction, Reflectometry
- X-Ray Micro-Lithography
- Micro-Tomography
- Single Crystal Diffractometry

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# X-ray Pointer and Beam Compressor – high brilliance collimating monochromator systems for intense sub-mm X-ray spots

Reiner Dietsch*/**, Thomas Holz**

*Fraunhofer Institute Material and Beam Technology (IWS), Winterbergstr. 28, D-01277 Dresden, Germany
**AXO DRESDEN GmbH, Siegfried-Rädel-Str.31, D-01809 Heidenau, Germany

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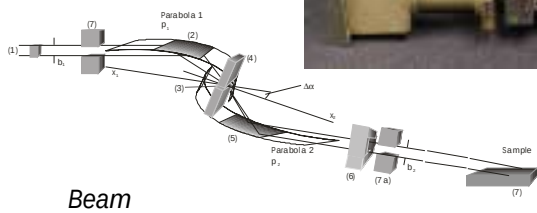
## Modules and Design

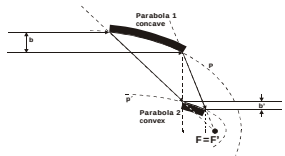
Glued and prefigured X-ray mirrors with different lengths and convex and concave parabolic shape designed for Mo, Cu, Co Kα-radiation

- Two parallel beam optics aligned on the same focal point
- Acceptance of parallel X-radiation emitted by a point focus X-ray source (e.g. 0.3mm x 0.3mm rotating anode)
- Result: a monochromatic ($K\alpha_{1,2}$) parallel spot

*Collimating Monochromator*

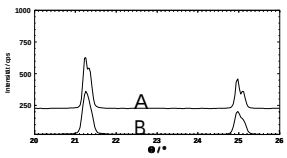



*Beam Compressor*



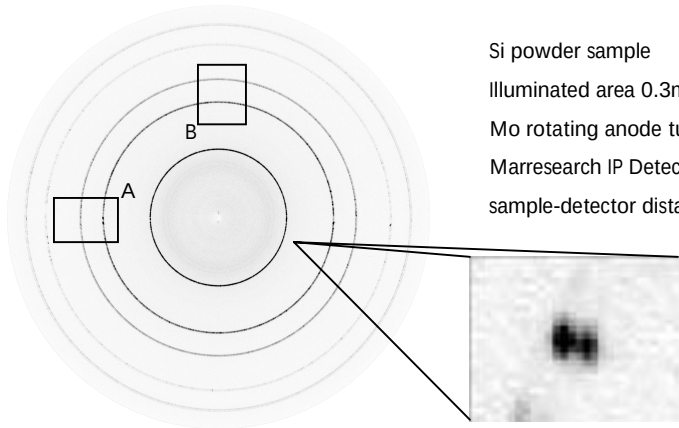

## XRD-Application*

*Ch. Baerlocher, ETH Zurich




integrated intensities of rectangles A and B

comparable resolution by means of parallel beam optics (A) and slits (B)




Si powder sample

Illuminated area 0.3mm x 0.3mm

Mo rotating anode tube 50kV/90mA

Marresearch IP Detector

sample-detector distance 300mm

**Si (111)**

Separation $K\alpha_1$ and $K\alpha_2$ reflection

FWHM:
only 1 or 3 pixel, resp.

## sub-mm Reflectometry

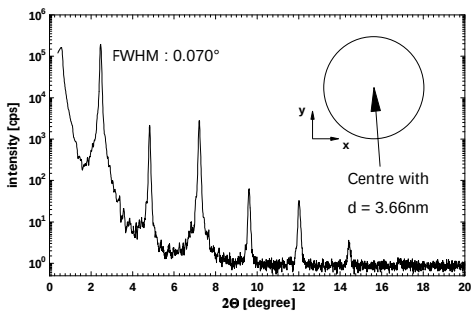
Ni/C graded multilayer on 4" Si-wafer (inset)

Thickness Gradient perpendicular to beam direction

40kV/40mA
Cu fixed anode tube
point fokus 1,2mm x 0.4mm

Beam Compressor spot
0.3mm x 0.6mm (Z x Y)

Geometry: Twin arrangement




## FUTURE POTENTIALS in

- µ-DIFFRACTION, REFLECTOMETRY
- X-RAY µ-LITHOGRAPHY
- µ-TOMOGRAPHY
- SINGLE CRYSTAL DIFFRACTOMETRY

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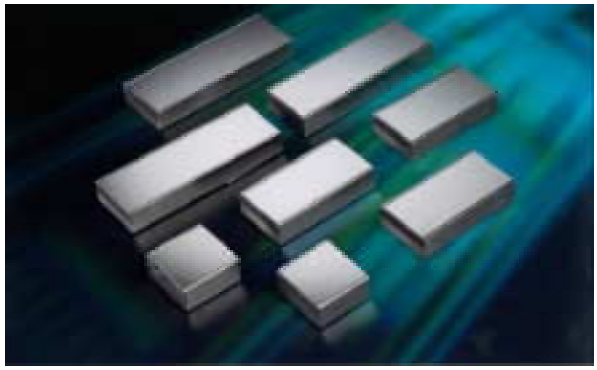
# Parallel beam X-ray optics for CrKα, CoKα, CuKα, MoKα, AgKα radiation



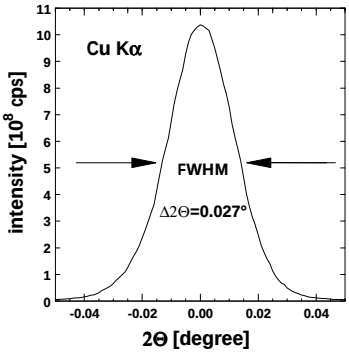
**Various parallel beam optics for single and twin mirror arrangements**

- highest intensity and low divergence
- no influence of sample surface position errors on peak position for reflectometry and diffractometry
- superior Kβ suppression
- sample fluorescence suppression
- easy and fast sample alignment

**Selected results for twin mirror arrangement:**

**cross intensity**

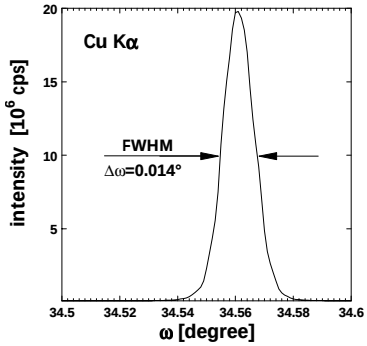
**I > 1.000.000.000 cps**




**2Θ-scan without sample**

**angle resolution**

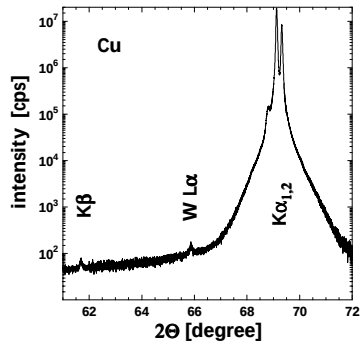
**Δω < 0.02°**




**rocking-scan Si(400)**
**silicon wafer**

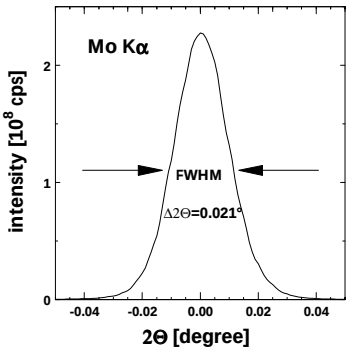
**Kβ - suppression**

**$I_{CuK\alpha 1} : I_{CuK\beta}$ > 1.000.000 : 1**



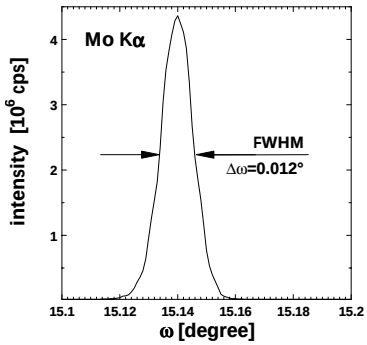

**Θ–2Θ scan Si(400)**
**silicon wafer**

**I > 200.000.000 cps**



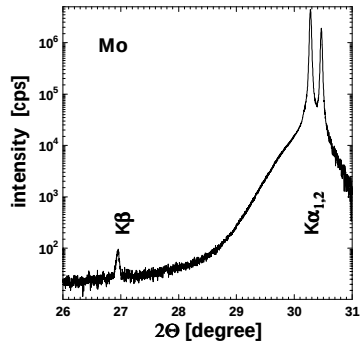

**2Θ-scan without sample**

**Δω < 0.02°**




**rocking-scan Si(400)**
**silicon wafer**

**$I_{MoK\alpha 1} : I_{MoK\beta}$ > 100.000 : 1**




**Θ–2Θ scan Si(400)**
**silicon wafer**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IWS
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# High-precision nm-Coatings for EUV and X-ray Optical Applications

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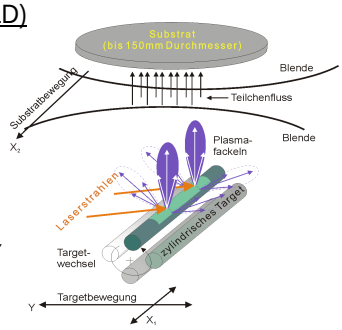
## Preparation of nm Multilayers

### Pulsed Laser Deposition (PLD)

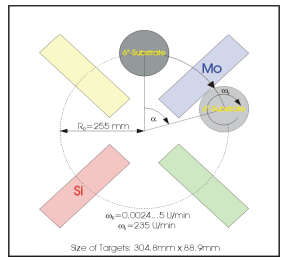
Experimental setup:
- UHV-chamber with 4 targets
- Base pressure: $10^{-8}$mbar range
- Laser-target-interaction
  => Emission of a plasma plume
- Target motion in y-direction
  => Pivoting of the plasma plume, connected with a uniformization in Y direction
- Target-substrate dist.: ≈150mm
- Maximum substrate size: 150mm ∅
- Substrate motion: linear in X-direction with any v-profile




Schematical view of the target-substrate arrangement at the PLD.

### Magnetron Sputter Deposition (MSD)

Experimental setup:
- UHV-chamber with 4 sources
- Base pressure: <$2\cdot10^{-8}$mbar
- Sputtering gas: Ar, stable process conditions at $p_{Ar}$≥$7\cdot10^{-4}$mbar
- Target-substrate dist.: 50-100mm
- Maximum substrate size: 150mm ∅
- Substrate rotation: $\omega_R$=0.0024-5 rpm
- Substrat spin: $\omega_S$=235rpm
- Typical deposition times:
  1 period per minute

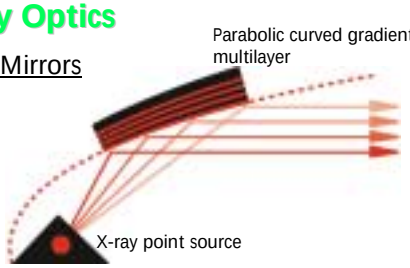



Schematical view of the target-substrate arrangement at the MSD.

## Applications of nm Multilayers

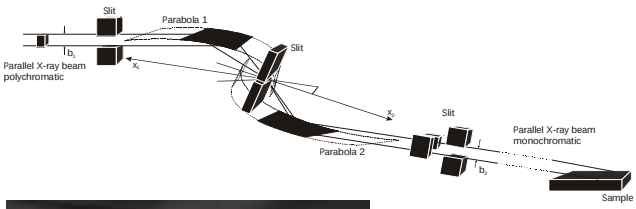
### X-Ray Optics

#### Göbel Mirrors




- Bragg equation nλ=2dsinΘ has to be fulfilled on the whole mirror surface
- Difference of set and actual d-value must be in the range of Δd=±0.03nm…0.06nm on every surface point
- Particularly the deposition on pre-curved substrates is a challenge for every coating technology

#### Beam Collimator




2 parallel beam optics aligned on the same focal point

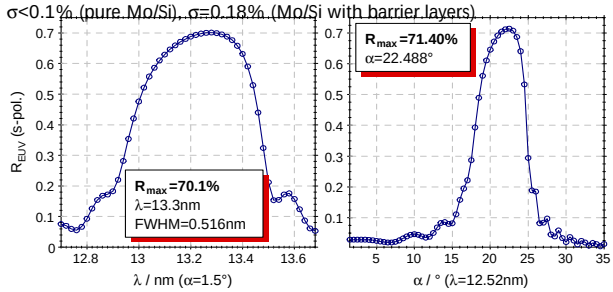
- Acceptance of parallel X-ray radiation emitted by a point focus X-ray source
- Emission of a monochromatic parallel spot

### EUV Optics

#### Mo/Si Multilayer as EUV Reflectors

Specifications:

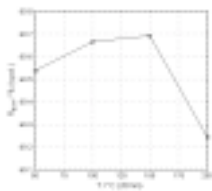
- Reflectance: R=71.4% (λ=12.5nm, α=22.5°), R=70.1% (λ=13.3nm, α=1.5°)
- Uniformity: 99.9% on substrates with 150mm diameter ($\sigma_{Multilayer\ period}$=0.03…0.05%, $\sigma_{EUV\ Reflectance}$=0.05…0.08%)
- Run-to-run Reproducibility:
  σ<0.1% (pure Mo/Si), σ=0.18% (Mo/Si with barrier layers)



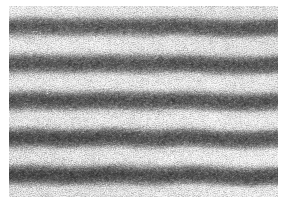

EUV reflectance of interface-optimized Mo/Si multilayers with C und $B_4C$ barrier layers.

#### Thermal Stability

Introduction of C- und $B_4C$ Barrier layers
=> Improvement of thermal and long-term stability



EUV reflectance depending on the annealing temperature. After thermal treatment at 200°C it remains $R_{EUV}$>69%



Mo/Si multilayer with $B_4C$ barrier layers (d=0.5nm) on both interfaces after annealing at 400° for 20 min.

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