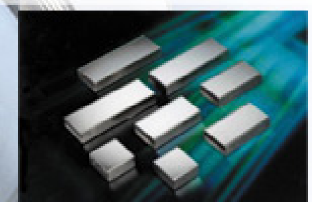
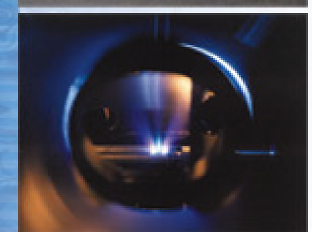
AXO

APPLIED X-RAY OPTICS

Multilayer mirrors – potentials for imaging, monochromating, collimating or focusing optics





R. Dietsch, M. Krämer, Th. Holz,
D. Weißbach
AXO DRESDEN GmbH, Germany

ACTOP 11
April 4th - 5th 2011
Oxford, UK

AXO DRESDEN GmbH – Multilayer X-Ray Optics High Precision Deposition

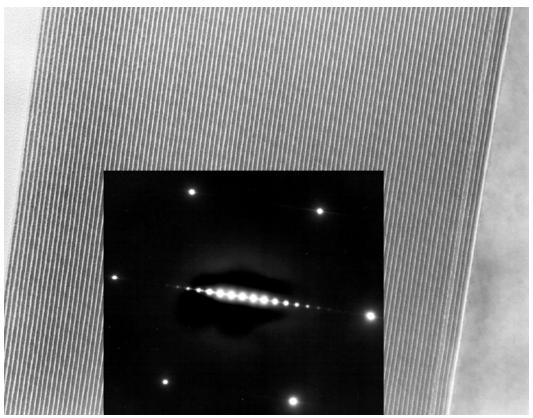
One- and two- dimensional **nanometer multilayer X-ray optics** for XRD and XRR

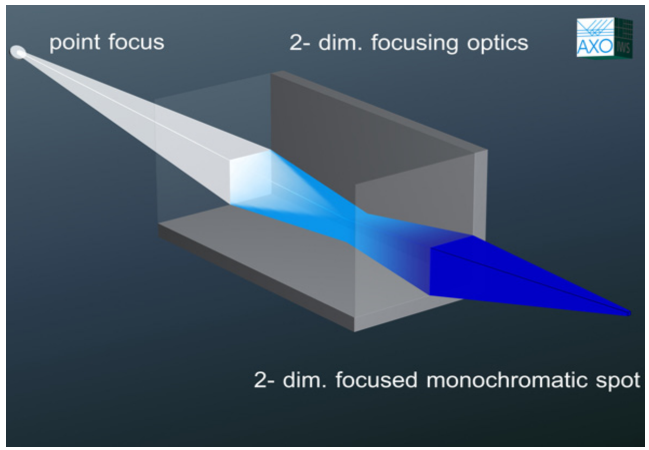
Synchrotron optics from EUV to hard X-rays and **monochromators** for XRF

High precision large area deposition (typical: 8” ∅ / 20” length)

Application and **teaching** in XRD, XRR and XRF

AXO DRESDEN GmbH – Multilayer X-Ray Optics High Precision Deposition





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Outline

Multilayer mirrors – potentials for imaging, monochromating, collimating or focusing optics

- Features and design of multilayer X-ray optics: Energy resolution / divergence
- High precision deposition techniques

- Applications
  - broad band multilayer mirrors
  - multilayer polarizers / high resolution multilayer mirrors
  - multilayers for imaging
  - Reference samples for micro XRF
  - Micro focus X-ray systems / Complete systems for XRR and XRF

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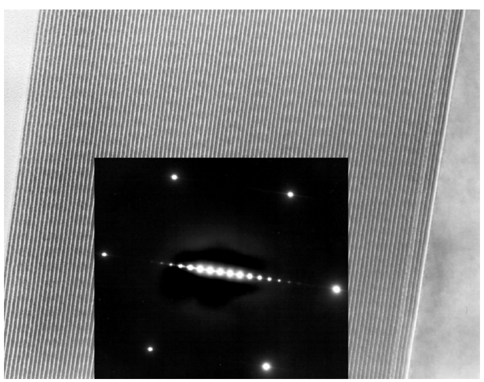
Multilayers:

Artificial periodic structures that can be tailored to specific users‘ demands

Constraints:

- photon energy / wavelength
- incidence angle
- monochromaticity / bandwidth
- photon flux

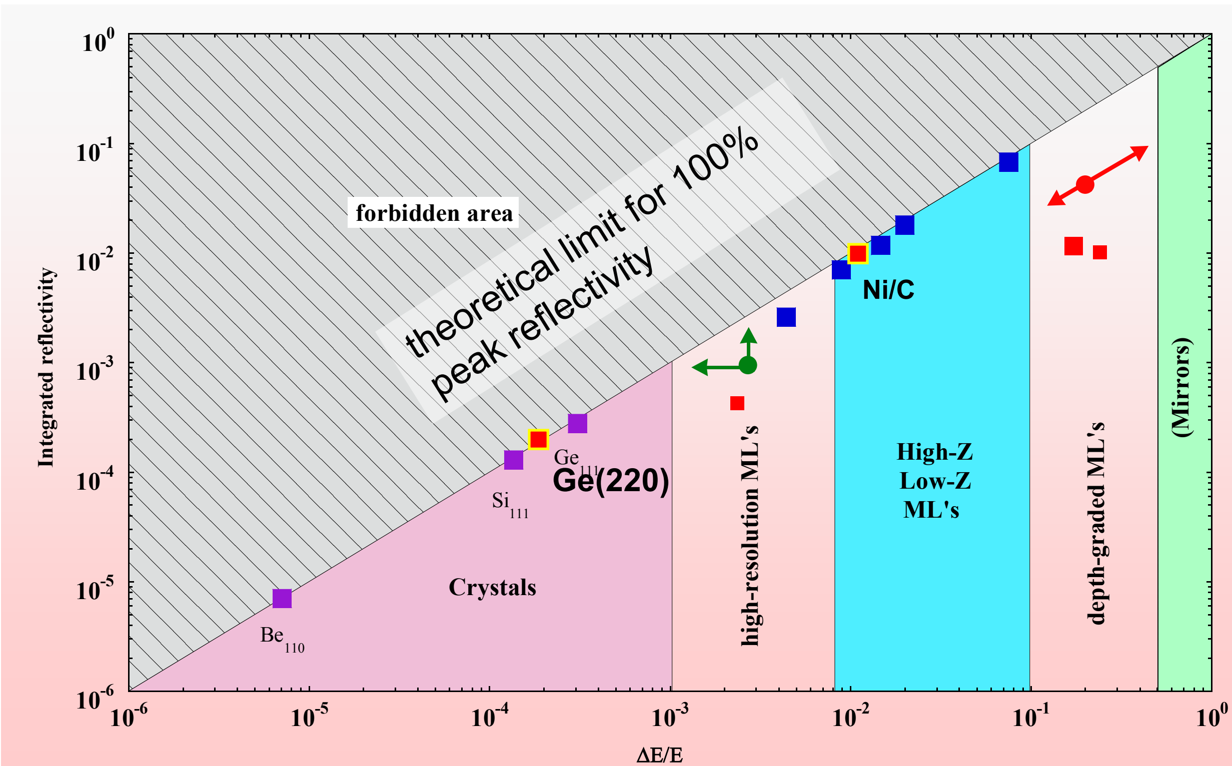


Free parameters:

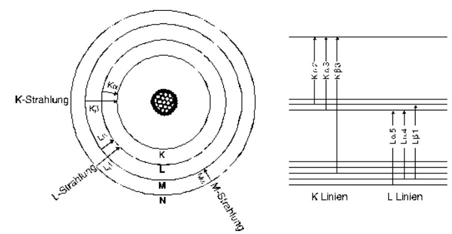
- multilayer materials
- period thickness
- layer thickness ratio
- period number
- gradient of period thickness

energy resolution and divergence

Overview of reflecting hard x-ray optics



BRAGG's law: $\lambda = 2d \sin \Theta$



Lab source: Ep = 8.04 keV

Cu $K\alpha_{1,2}$: $\Delta E/E = 2.5 \cdot 10^{-3}$

Cu $K\alpha,\beta$: $\Delta E/E = 0.11$

Ch. Morawe et al. –
ESRF - Grenoble - France

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High Precision Large Area Deposition of Nanometer Multilayers

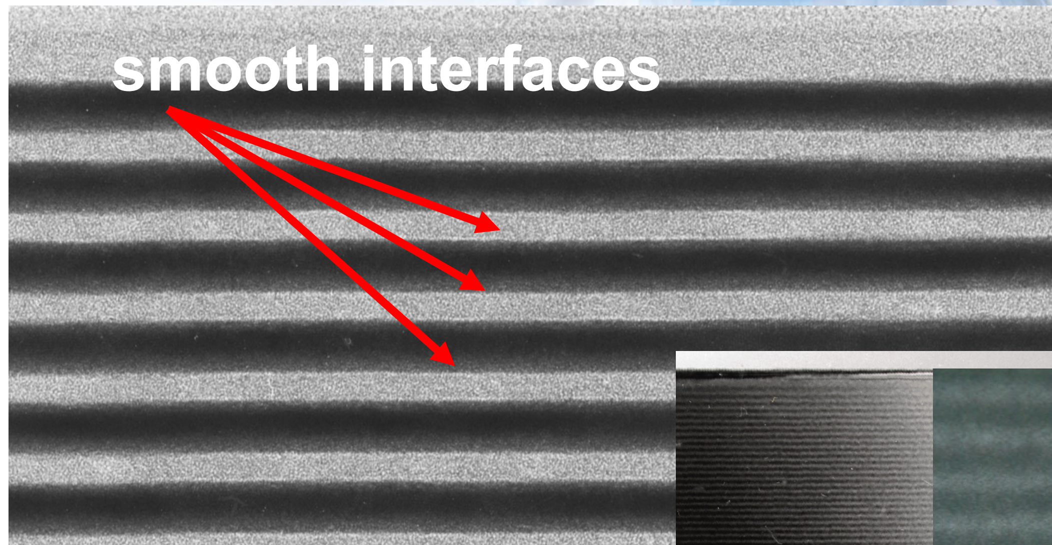
Combination of complementary high precision deposition technologies

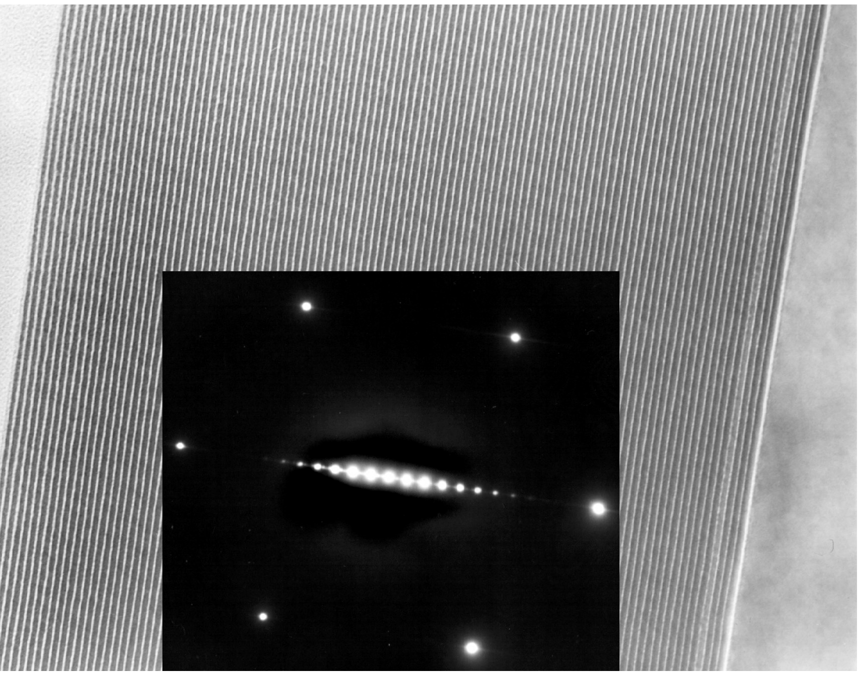
- **magnetron sputtering (MSD)**
- **Dual Ion Beam Sputter Deposition (DIBD)**
- **Large-Area PLD (LA-PLD)**

MSD and DIBD (UHV conditions):
- 8" diameter substrates
- 500mm substrate length

LA-PLD / MSD: UHV cluster-tool system
- 6 " diameter substrates
- automated deposition of nm- ML

possible candidates for these different deposition techniques



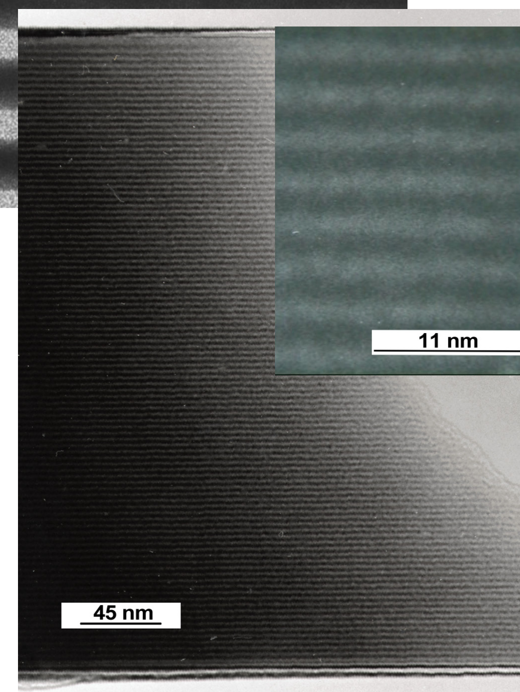


HRTEM of a PLD- Ni/C multilayer (100 layer pairs, d=3.2 nm)
and reciprocal space image of electron diffraction

MSD: W/Si,
Mo/Si ($R_{13.4nm}$= 70.1%)

DIBD: Ni/B4C,
C/C, a-C

PLD: Ni/C,
C/C, a-C



Beam shaping X-ray optics for X-ray analysis

1D

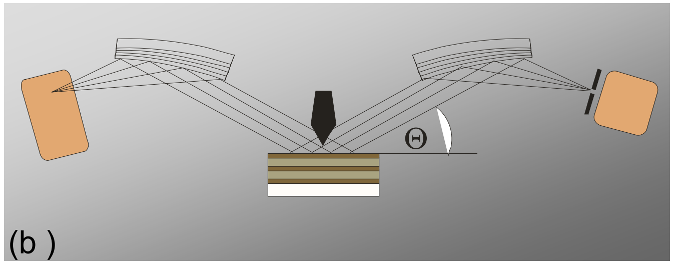
Parallel beam X-ray optics (a)
Twin mirror arrangement (b)
Focused beam X-ray optics

2D

Kirkpatrick-Baez-arrangement
side-by-side optical systems (ASTIX) (c)
single bounce mirrors (d)

(a)

(c)



(b)

(d)

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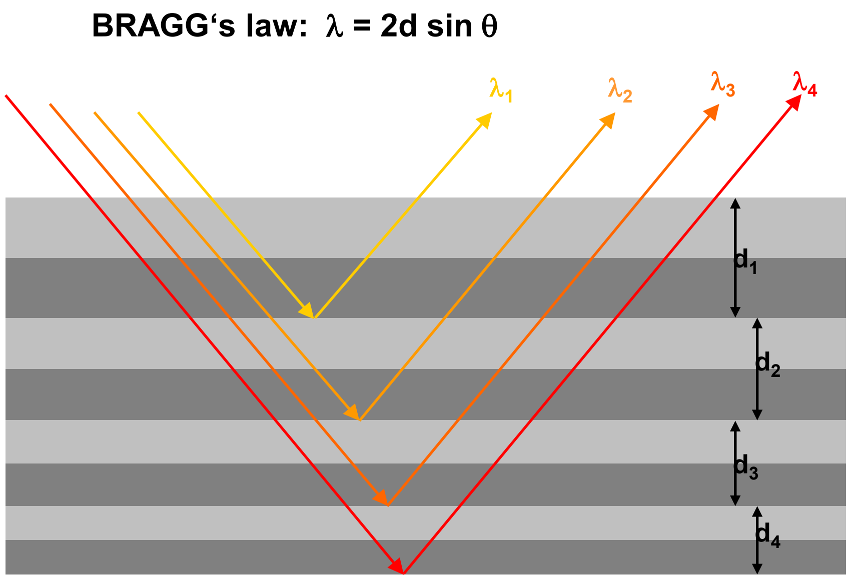
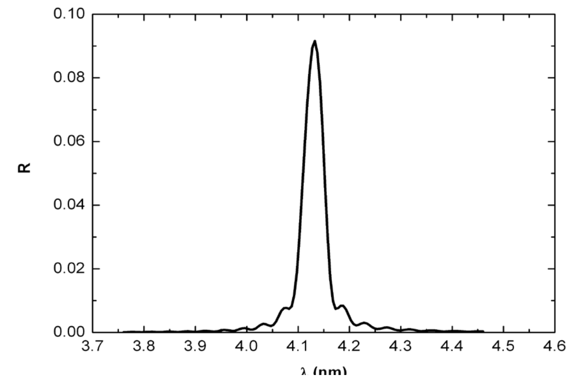
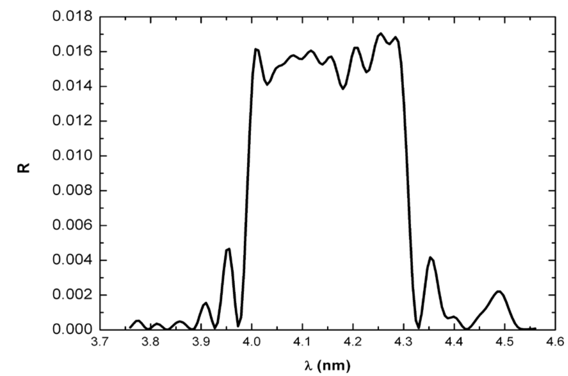
Design of a broadband („depth-graded“) multilayer

Approach: Provide a period thickness for each required wavelength / range







increase number of periods with different thicknesses

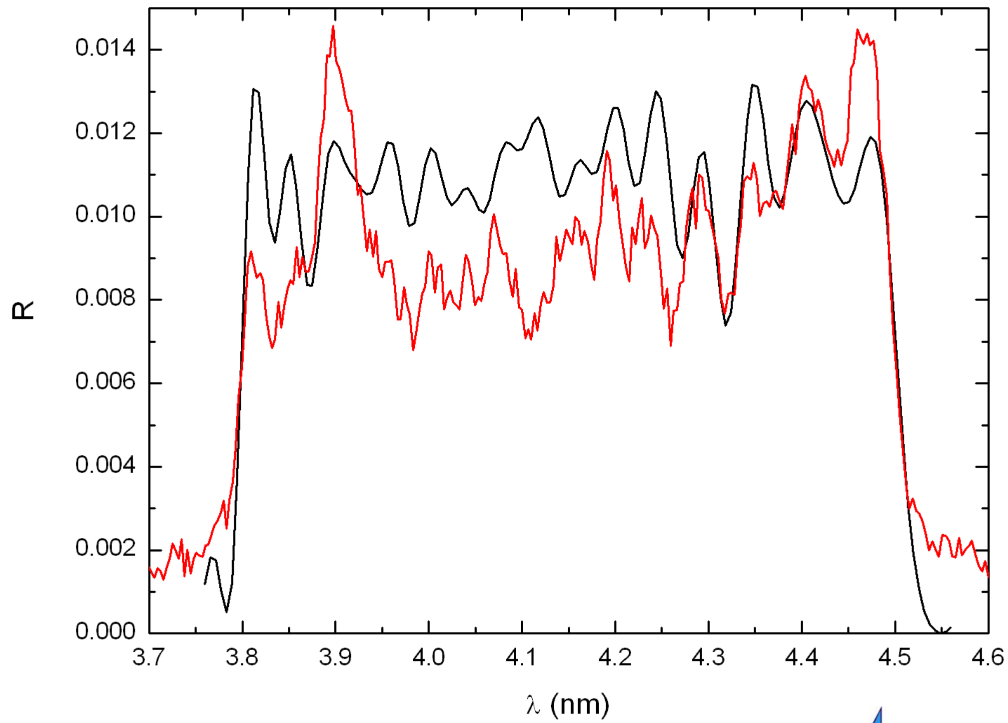
increase of bandwidth

Broadband multilayer polarizer for laboratory LPP-Source @ 300 eV photon energy

Goals

- incidence angle
  45° (Brewster angle)
- high peak reflectivity
  @ 300 eV (4.14 nm)
- Energy bandwidth
  ~ 51 eV (0.7 nm)
  => $\Delta E/E$ = 17 %

Calculated (black) and measured (red, shifted) reflectivity

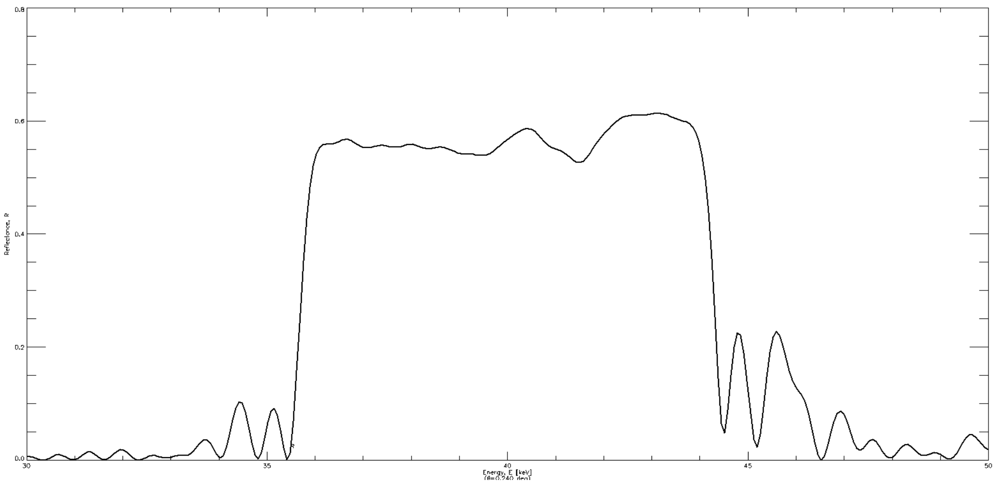


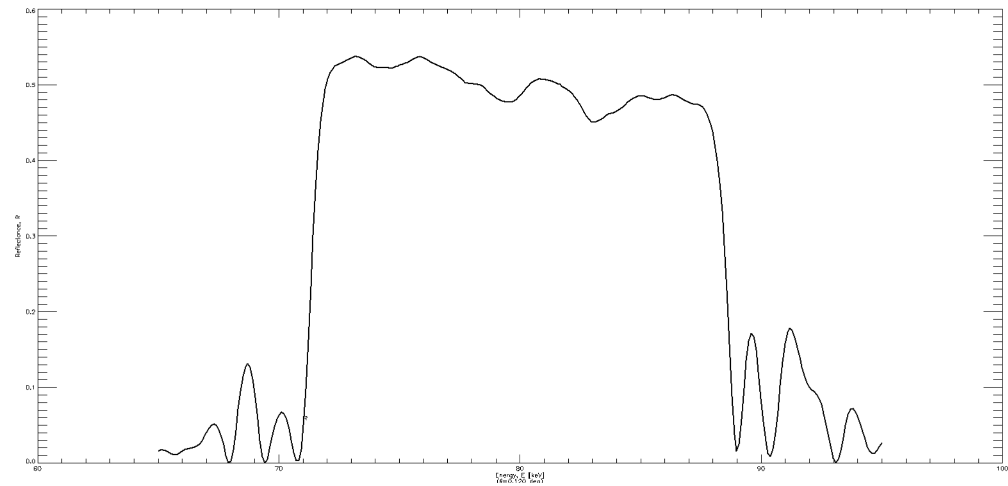
* Measurement:
Reflection coefficient normalized to 1,
λ shifted by 0.07 nm

Laser-Laboratorium Göttingen e.V.

courtesy of K. Mann, Laser Lab. Göttingen

Broadband multilayer mirror for hard X-rays



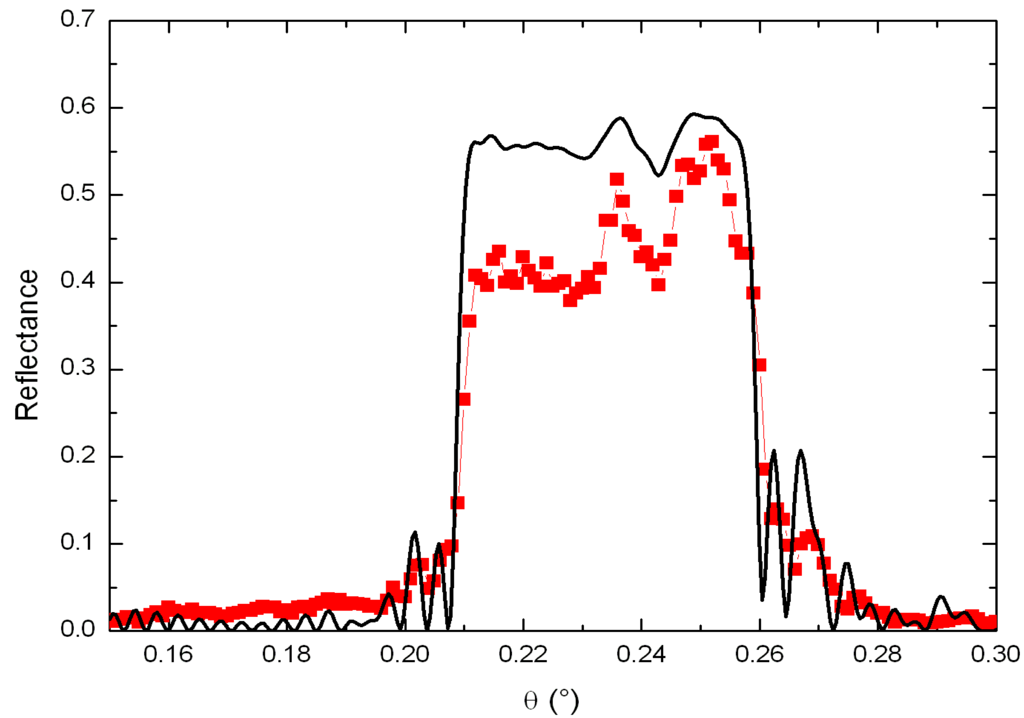


Simulated reflectivity of one depth graded multilayer for broadband reflection in the hard X-ray regime, applied both at 40 keV (left) and 80 keV (right).
Energy bandwidth $\Delta E/E > 20\%$ with $R \geq 50\%$ for both photon energies.
$\Rightarrow$ Only minor changes of performance over a wide energy range

Broadband multilayer mirror at high photon energies: Synchrotron radiation at 40 keV

Photon energy E = 40-41 keV, energy bandwidth ΔE/E ≈ 20-22%, R ≈ 40-60%

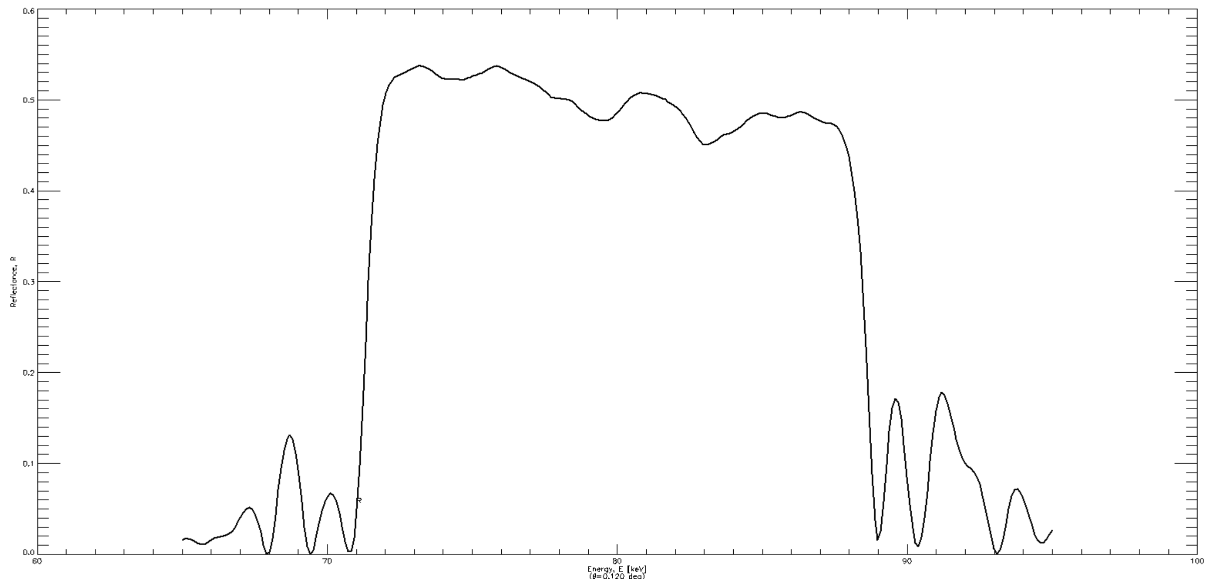
Calculated (-) and measured (•) reflectivity profile for a broadband multilayer reflector, measured at HASYLAB synchrotron at E = 40-41 keV.



courtesy of D. Novikov & H.-P. Liermann, DESY HASYLAB, Hamburg

Broadband multilayer mirror for special applications at extremely hard X-rays at 80 keV:

Simulation: Energy bandwidth at 80 keV ≈ 20%, R ≈ 53%



Calculated reflectivity profile for a broadband multilayer reflector at 80 keV.

Fabricated but not yet tested...

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Multilayer Polarizer designed for the soft X-ray regime

E_p = 582 eV / 792eV / 797eV

$(2\Theta) = 90^\circ$

Challenges:

Deposition of low period thickness multilayers

High reflection coefficient R_s even at low period thicknesses

High ratio R_S / R_P

→ Polarization analysis (for example: O-K line, magnetic materials Fe, Co, Ni)

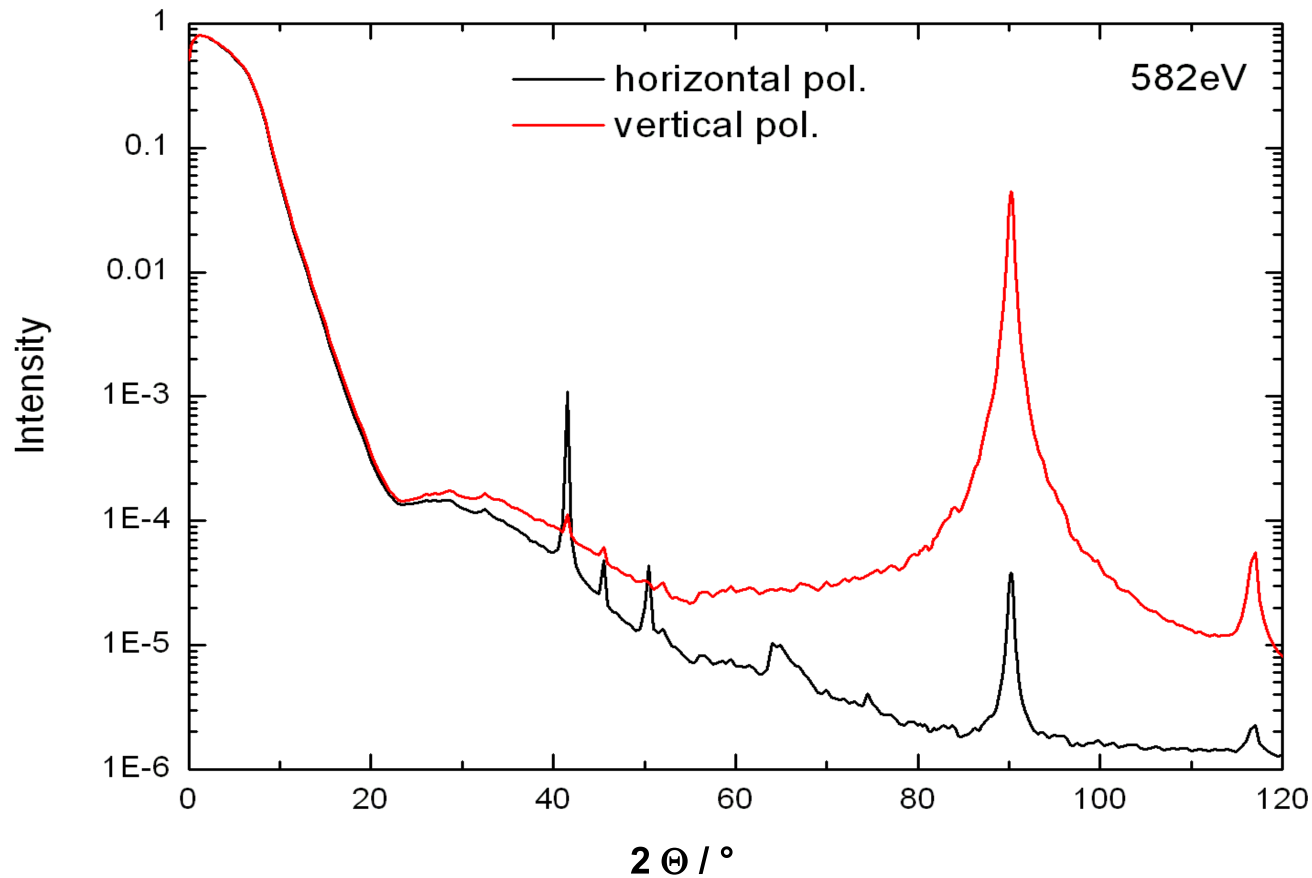
Multilayer Polarizer – Example 1

E_p = 582 eV

d= 1.5nm

R_s = 4.4%

$R_S / R_P > 10^3$



HELMHOLTZ ZENTRUM BERLIN für Materialien und Energie

courtesy of E. Schierle, HZB

Multilayer Polarizer – Example 2

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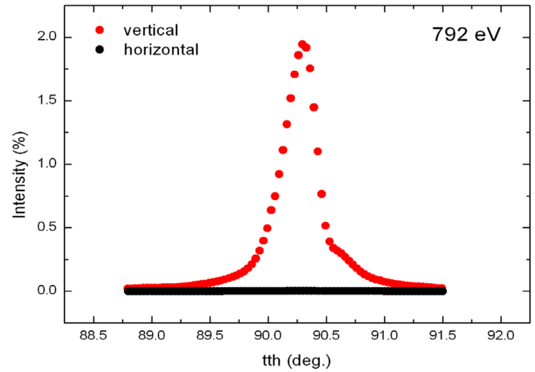
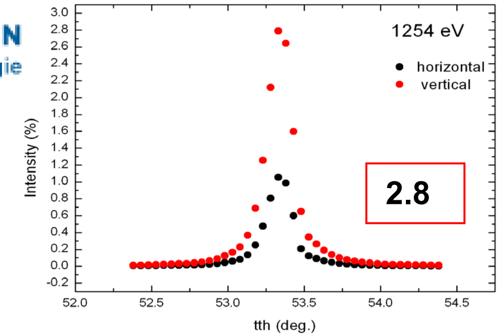
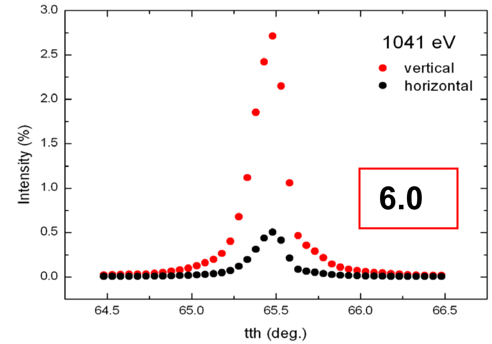
E_p = 792 eV / d= 1.1nm

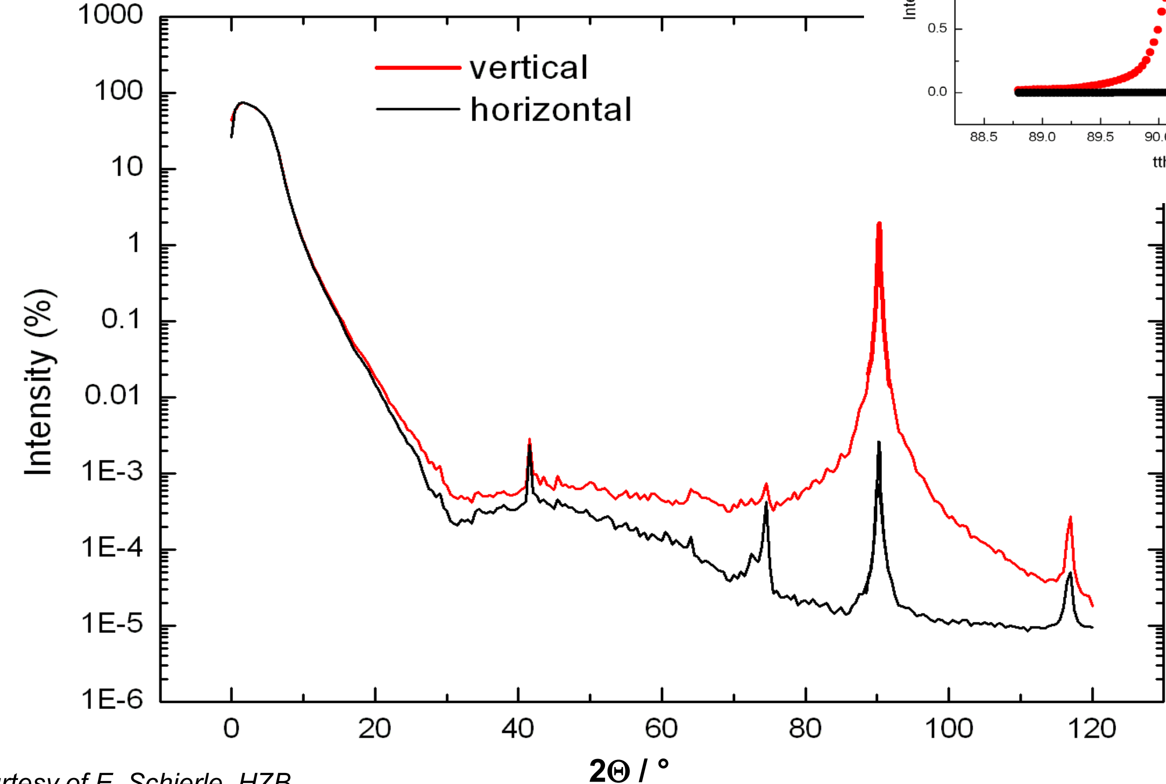
R_S = 2% close to Brewster angle!

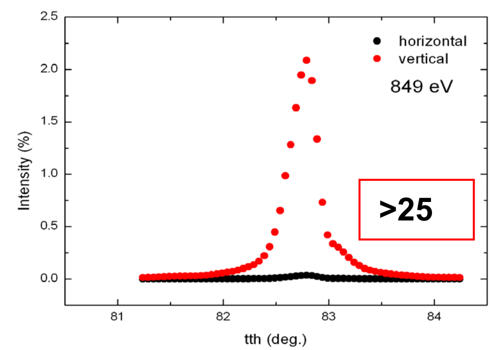
R_S/R_P > 700











courtesy of E. Schierle, HZB

Multilayer Polarizer – Example 3

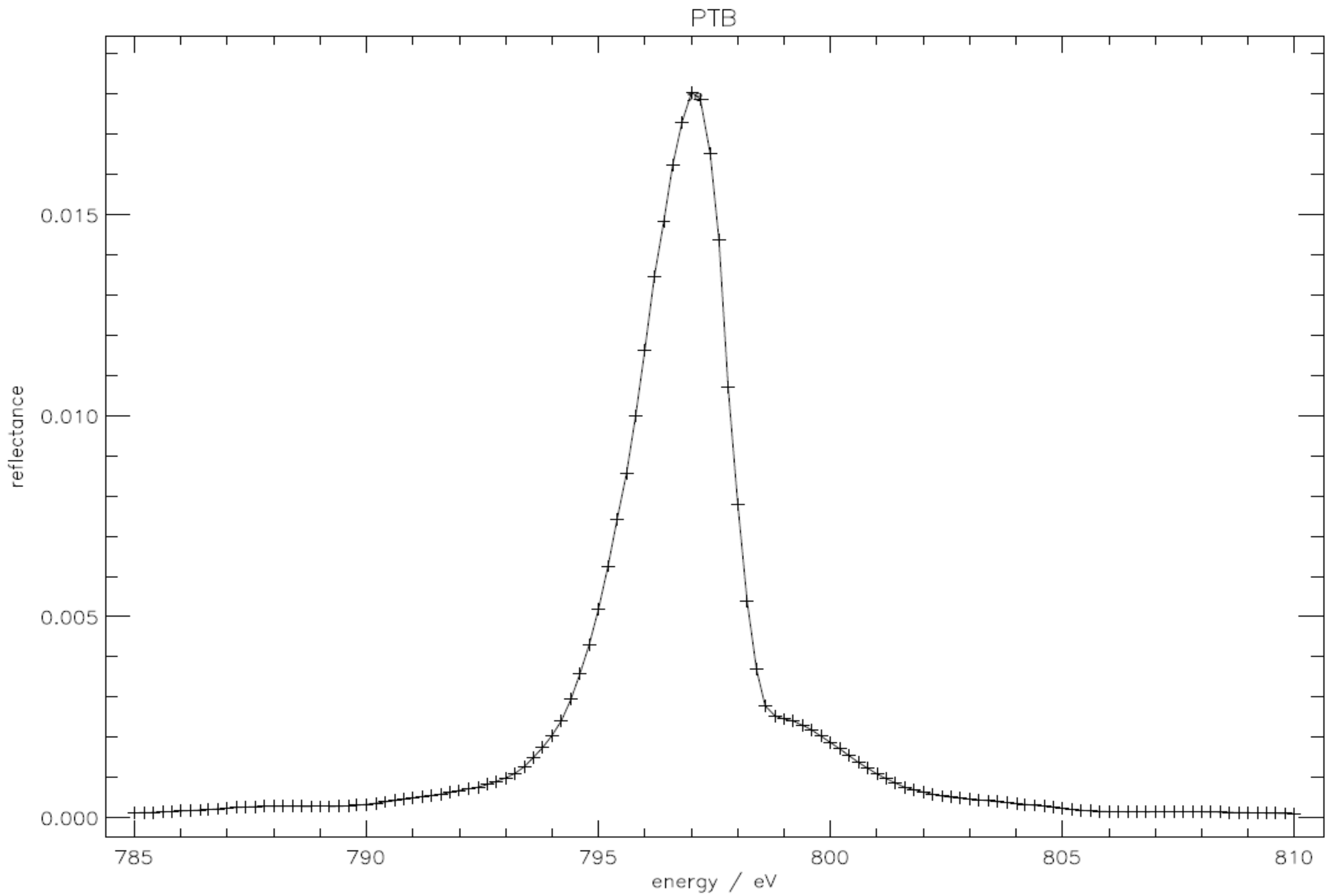
E_p = 797 eV

d= 1.1nm

ΔE = 2.25 eV

=> ΔE/E = 0.28%

R_S = 1.8%



courtesy of F. Scholze, PTB

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Imaging techniques – requirements and challenges

Absorption contrast imaging:

- high photon flux
- lateral homogeneous illumination
- temporal homogeneous illumination

Multilayer properties:

- flux higher than by crystal
- „stripe pattern“ due to inhomogeneities sometimes not correctable with flat field

Phase contrast imaging:

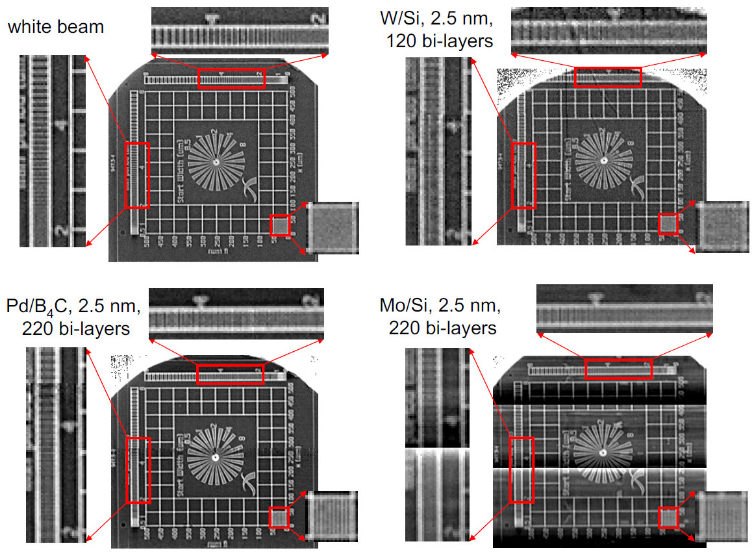
- high photon flux
- partial spatial coherence (large distance to source)

Multilayer properties:

- flux higher than by crystal
- coherence can be degraded

Beam profile and resolution

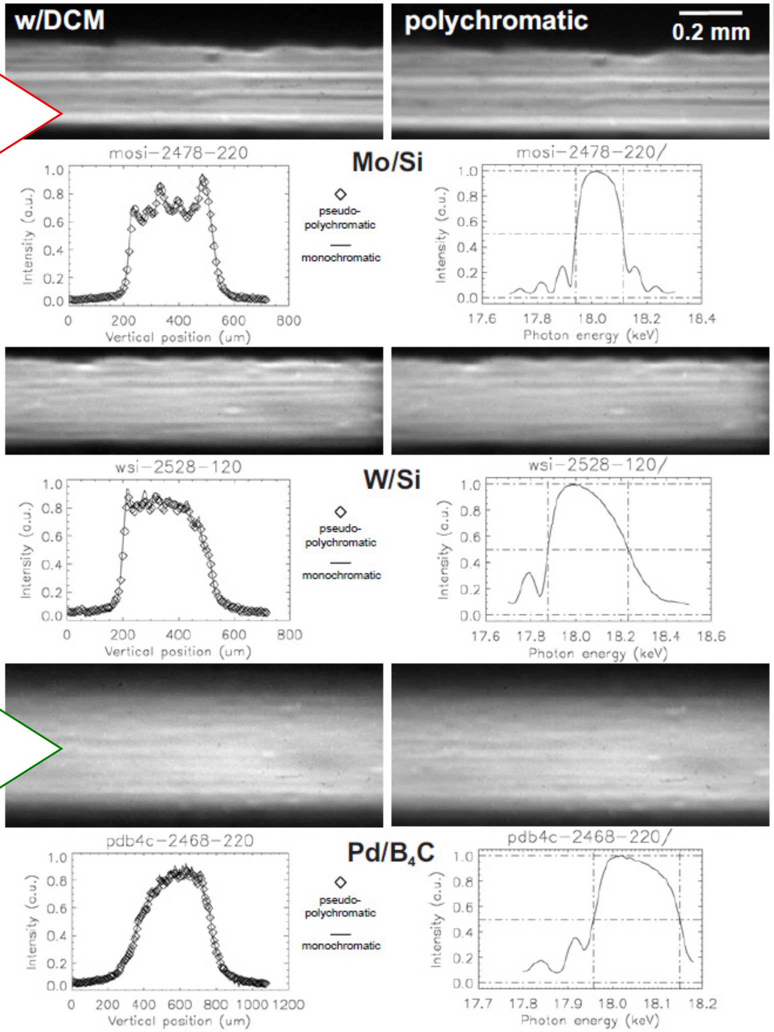
Influence of the multilayer composition on reflected beam profile (right) and reachable spatial (hor/ver) resolution for different multilayers (below).



courtesy of A. Rack, ESRF

stripe pattern

smooth illumination



Beam profile and resolution

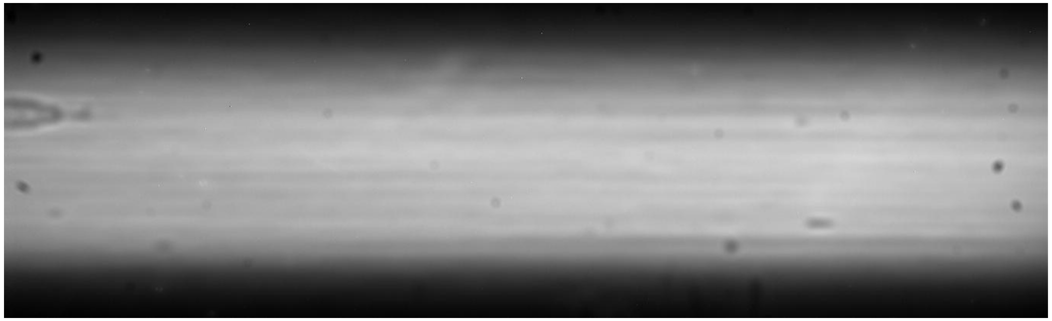
Typical imaging behaviour of the material system Pd/B4C measured at different synchrotron sources:

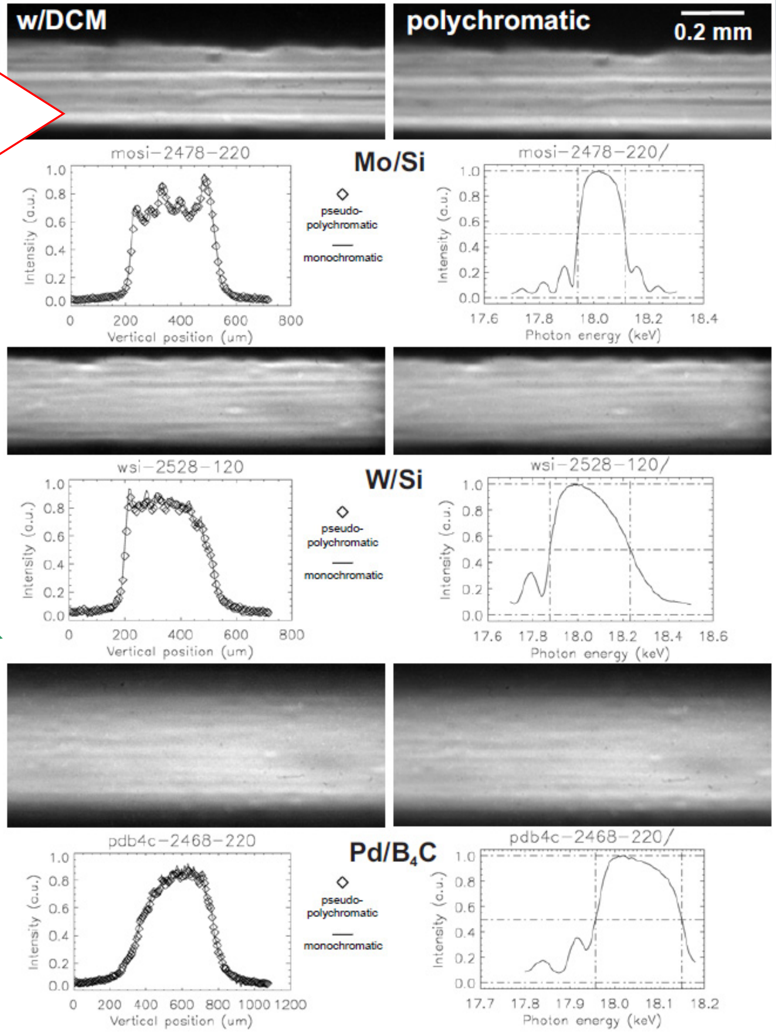
stripe pattern

Smooth illumination

APS 03.2011

ESRF 2009

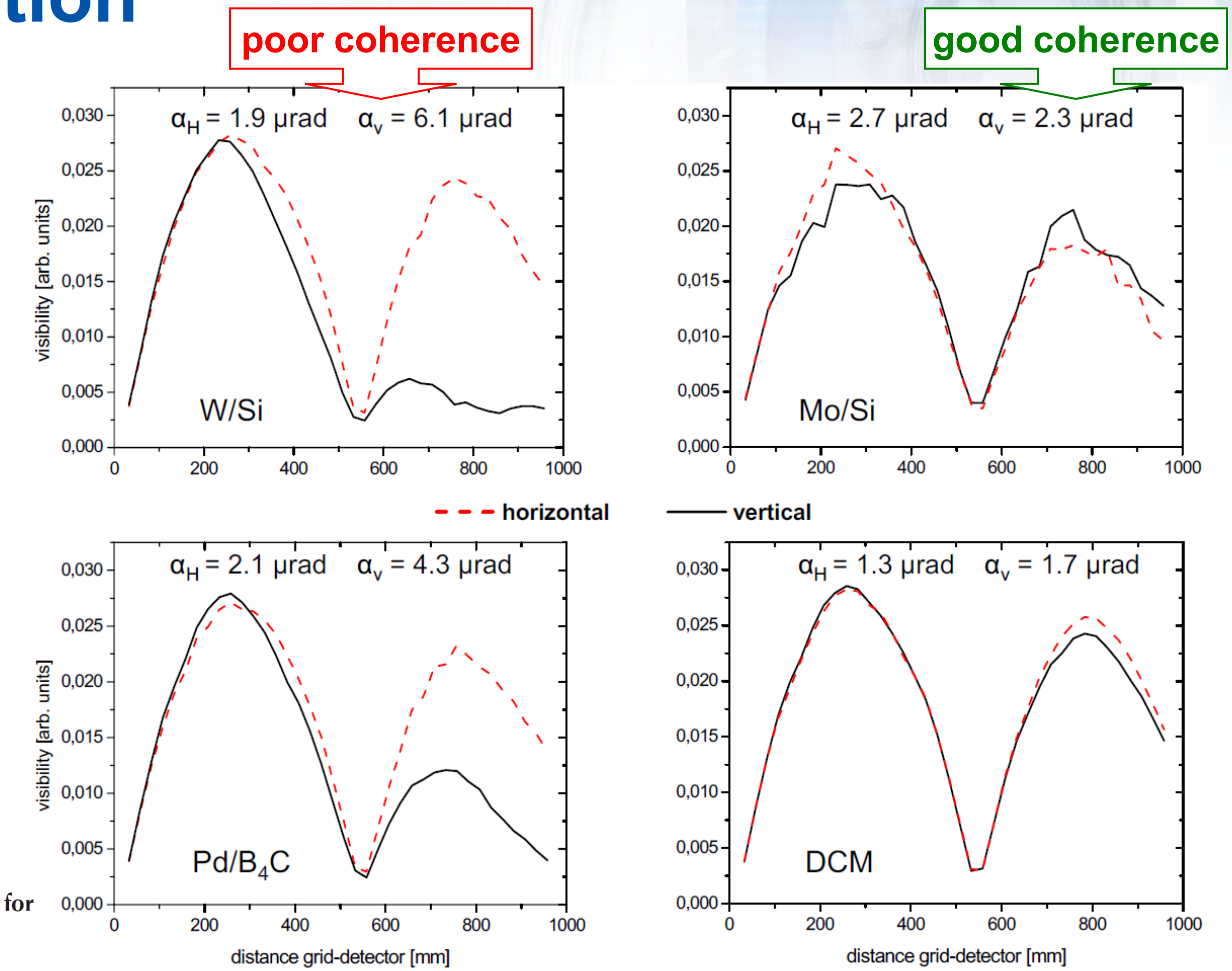


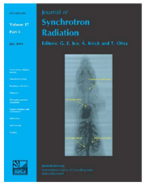


courtesy of A. Rack, ESRF

Coherence preservation

Talbot imaging was used to study the coherence properties of hard X-rays after reflection by the multilayers. Results after reflection by a double-crystal monochromator (DCM) are shown for comparison. The angular source size α is calculated from the two Talbot planes given.





Comparative study of multilayers used in monochromators for synchrotron-based coherent hard X-ray imaging

A. Rack, T. Weitkamp, M. Riotte, D. Grigoriev, T. Rack, L. Helfen, T. Baumbach, R. Dietsch, T. Holz, M. Krämer, F. Siewert, M. Meduňa, P. Cloetens and E. Ziegler

J. Synchrotron Rad. (2010). **17**, 496–510

courtesy of A. Rack and T. Weitkamp, ESRF

Summary / Conclusions

- Complimentary large are a high precision deposition techniques have to be installed to deposit optimized high performance single and multilayer X-ray optics for a wide energy range and different applications

- **Broadband polarizer multilayers** for 300eV can be designed and fabricated

- **Broadband multilayers** for hard X-rays are designed, showing more than 20% bandwidth and high reflection coefficients both at 40 keV and at 80 keV

- **Low period thickness multilayers** (1.5nm - 1.1nm) can be used both as **high resolution** multilayers and as **polarizers** (energy range up to 1000eV)

- **multilayer** performance for **imaging applications** is investigated

- Multi element thin film **reference samples** for µ-XRF are available

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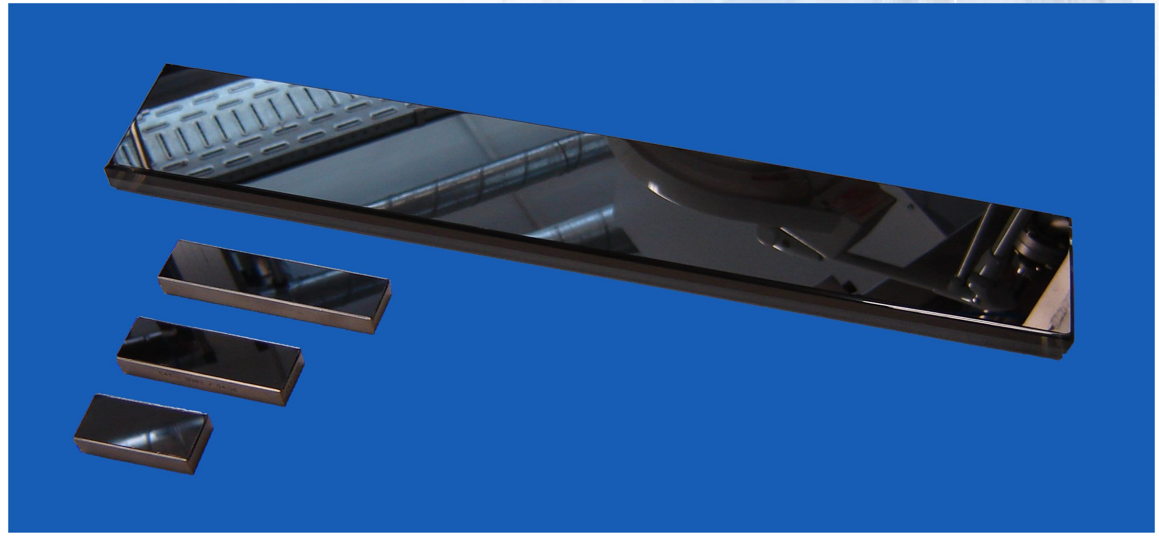
A. Rack, T. Weitkamp (ESRF Grenoble / Soleil, France)

P. Liermann, D. Novikov (HASYLAB at DESY, Germany)

K. Mann (Laser Laboratory Goettingen, Germany)



Thank you very much for your attention !

AXO DRESDEN GmbH
Winterbergstraße 28
01277 Dresden
Germany
www.axo-dresden.de

Applications **monochromators** for laboratory X-ray sources and for synchrotrons, optimized for high reflectivity or tailored resolution
polarizers in the soft X-ray range (O-K, Fe-L, Ni-L)
Typical sizes 500 mm in length or 8 inches diameter
Resolution 0.25 % < ΔE/E < 2 % **(periodic ML)**
ΔE/E > 5% on request **(aperiodic ML)**