# Multilayer Monochromators

**A.T. Macrander**
Optics Group , XSD

XIS Workshop, Jan. 10, 2011

# OUTLINE

- Multilayer basics
- Survey of planned DMMs: Petra III, ESRF upgrade
- DMM implemented 2-BM
- Sagittal focusing implemented at CHESS
- Lateral Grading
- Depth grading
- Lateral and depth grading
- Multilayer R&D topics: stripe contrast, grown-in stress

# Acknowledgments

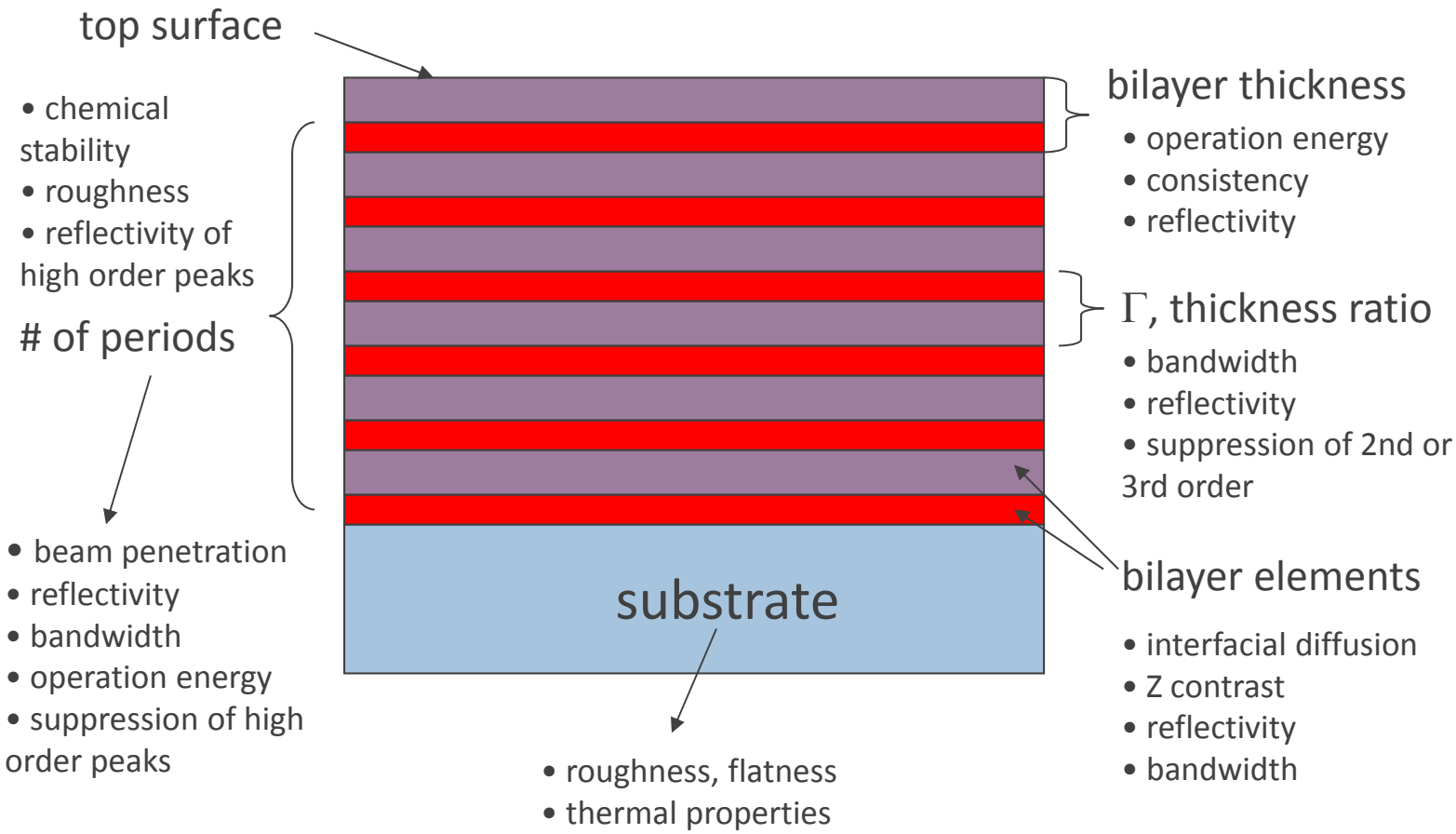

XSD Optics:

- Chian Liu
- Bing Shi
- Lahsen Assoufid

Collaborations:

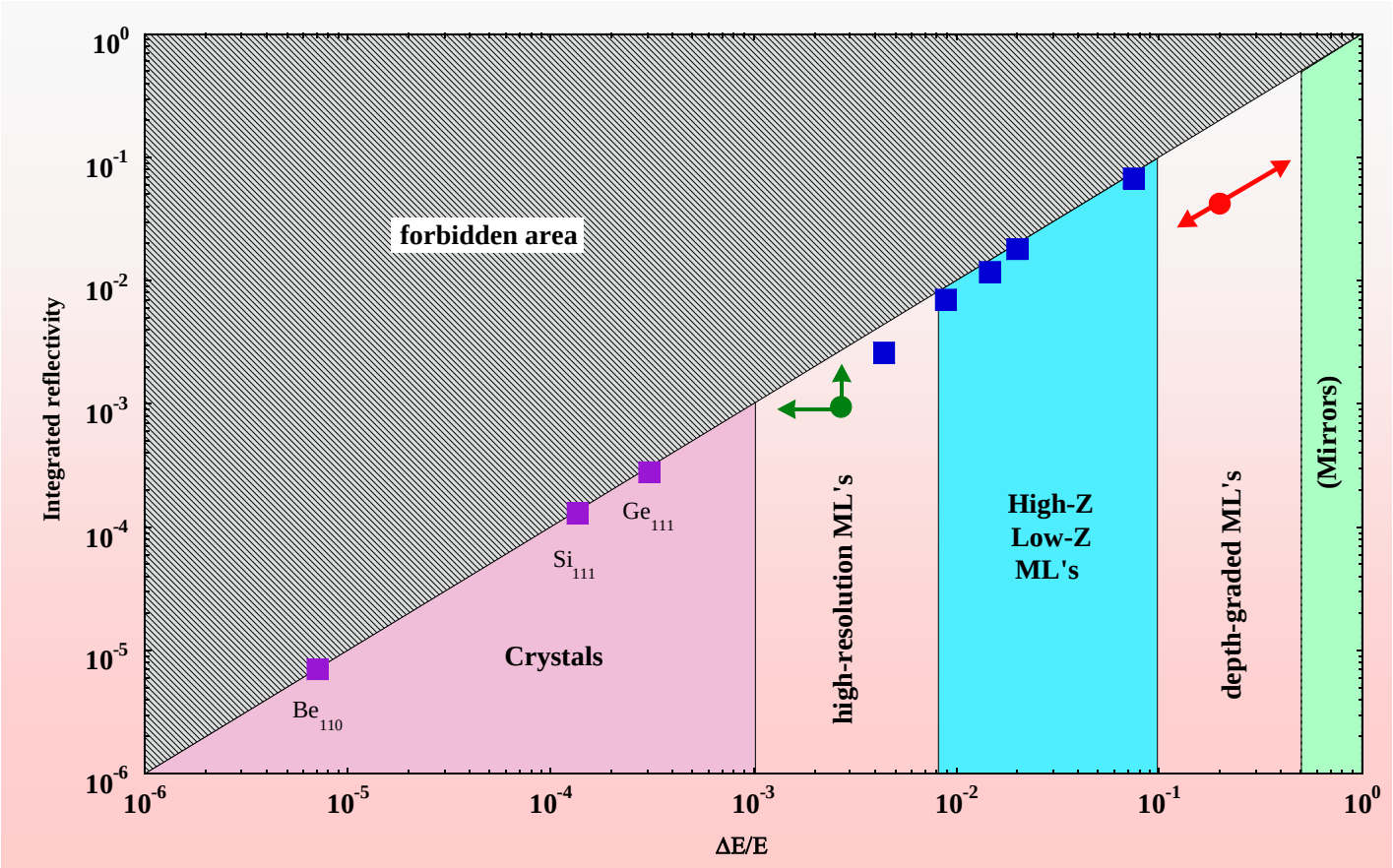
- Yong Chu
- Ray Conley
- Christian Morawe
- Eric Dufresne
- Randall Headrick
- Jens Als-Nielsen

# Important Parameters for Multilayer Mirror




*Slide by Yong Chu*

## Bandpasses: Crystals, Multilayers, Mirrors

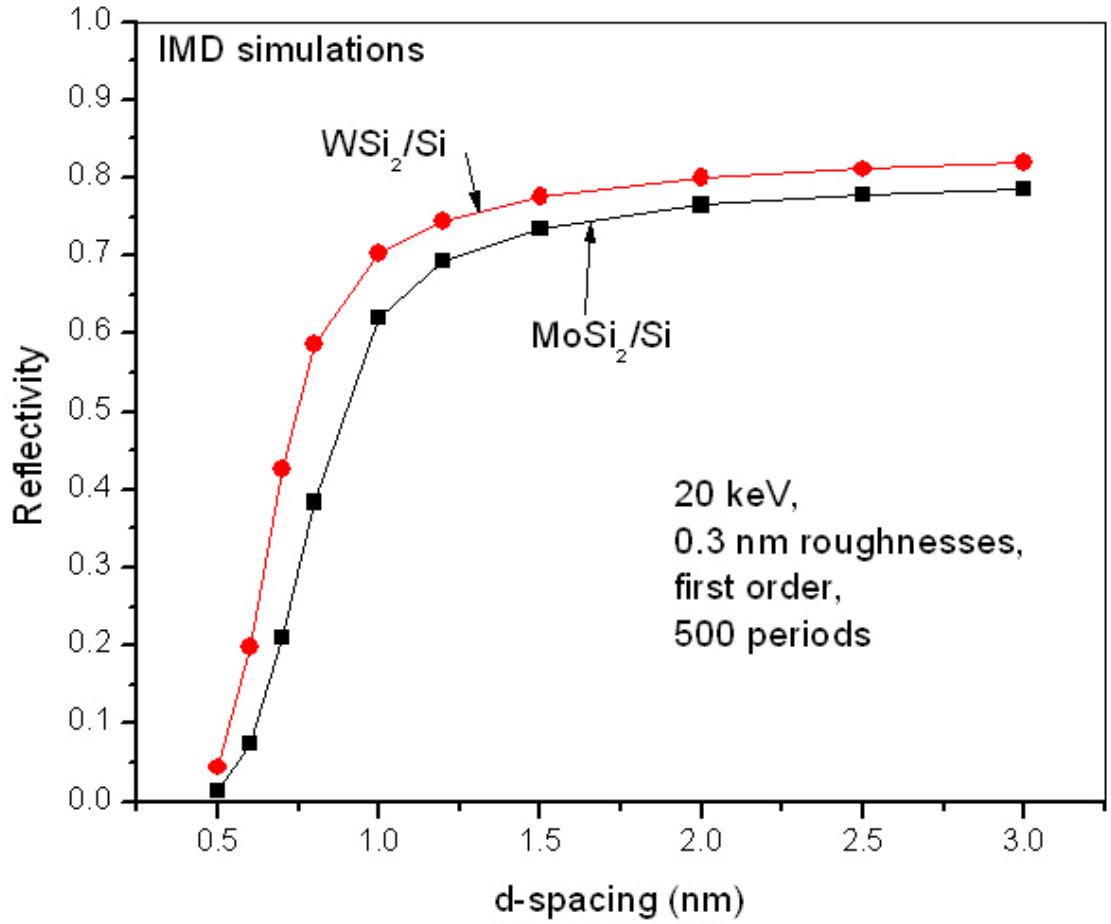



**Double gradient multilayers for broadband focusing**

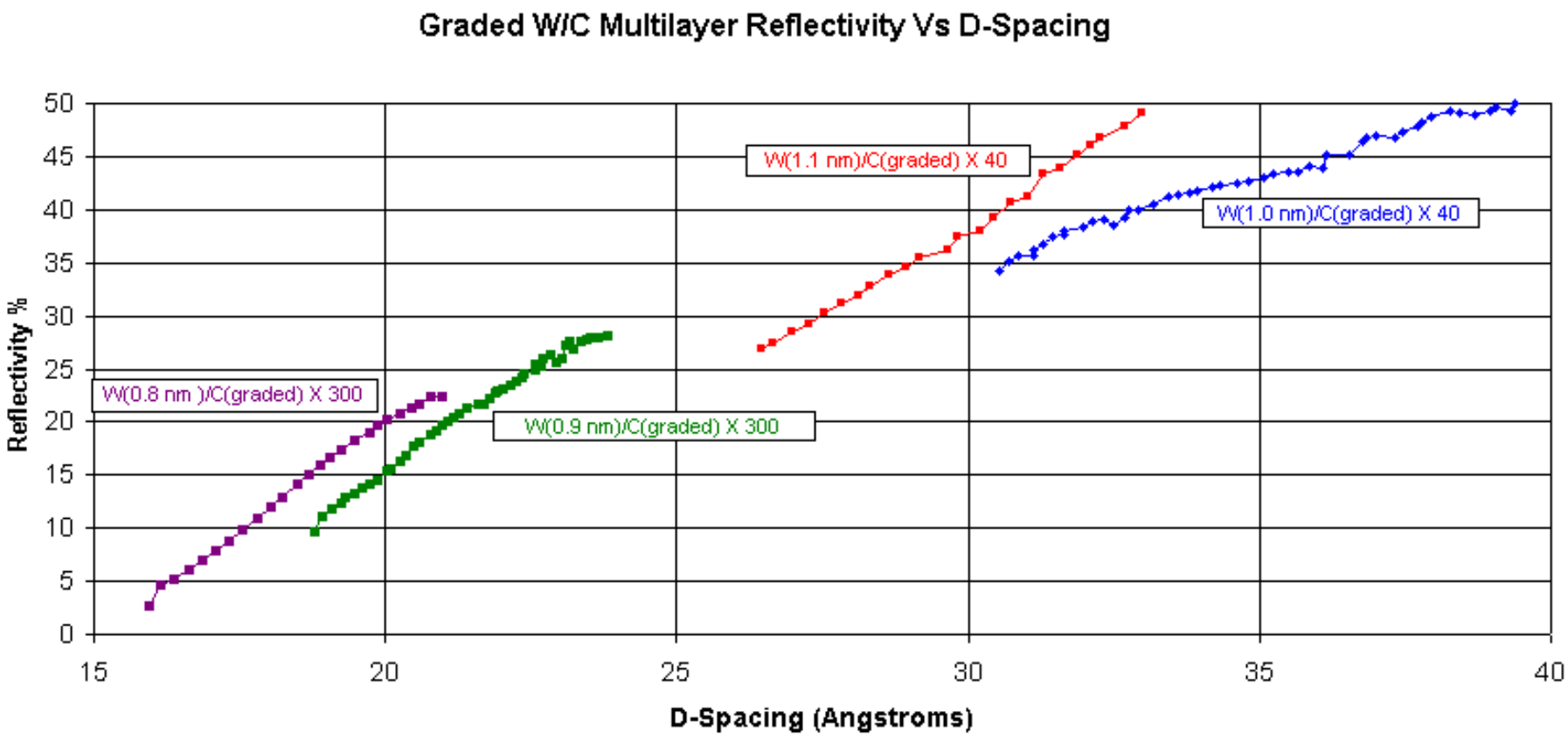
Christian Morawe*[a], Jean-Christophe Peffen[a]
Eric M. Dufresne[b], Yong S. Chu[c], Albert T. Macrander[c]

SPIE Proc. Vol. 5195, p.1 (2003)

## *Reflectivity as a function of d-spacing ($\Gamma$=1)*



# Small d-spacings cause a drop in intensity




Slide courtesy of Ray Conley

## *Planned Double Multilayer Monochromators Worldwide*

| Facility | | | | | |
|---|---|---|---|---|---|
| Petra III | P02 µSAXS/WAXS | P03 Nano-focus | P05 cryocooled | P06 Nano-probe | P12 bioSAX |
| ESRF (Upgrade) | ID-15 buried interfaces | ID-16 IXS | ID-22 nano-imaging | | |
| Soleil | Nanoscopium | | | | |
| Diamond | ID-16 | | | | |

# *Two interesting planned Hi-E DMMs*

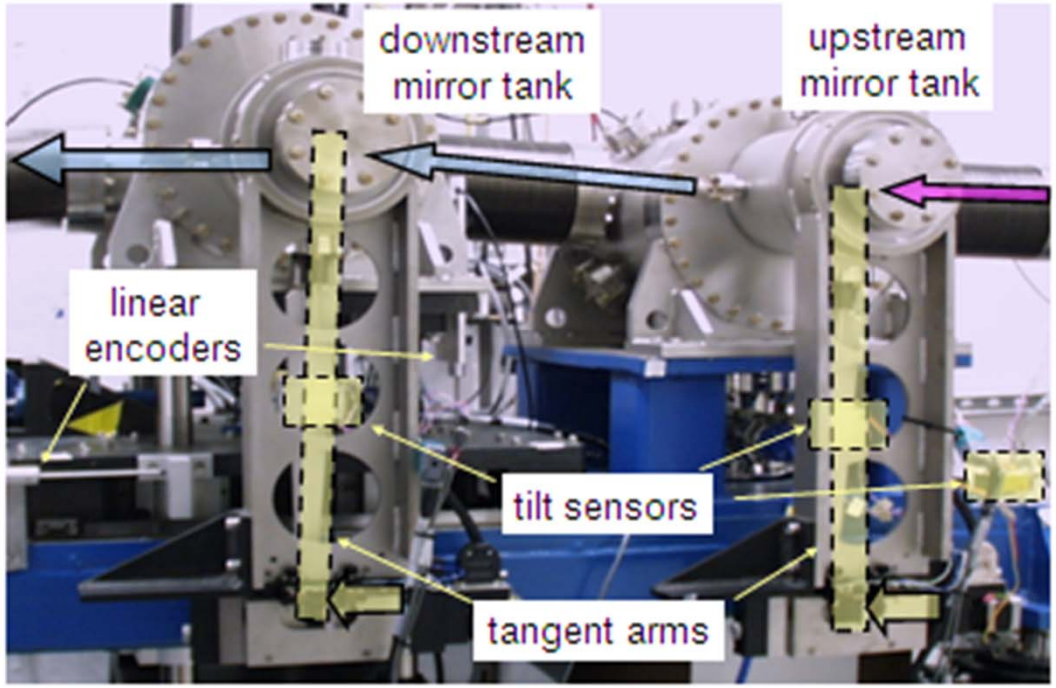
Petra III:
P05 Imaging Beamline for Micro- and Nano-tomography

- Fixed exit
- Bent substrates
- Coated by GKSS
- Liquid Nitrogen Cooled

ESRF Upgrade:
ID-15 High Energy Beamline for Buried Interface Structures and Materials Processing Beamline (also liquid-liquid interfaces)

- 50 - 150 keV
- 0.3% bandpass
- dynamically bent to a parabola
- 10 mm offset
- fixed exit

# Double Multilayer Monochromator at 2-BM



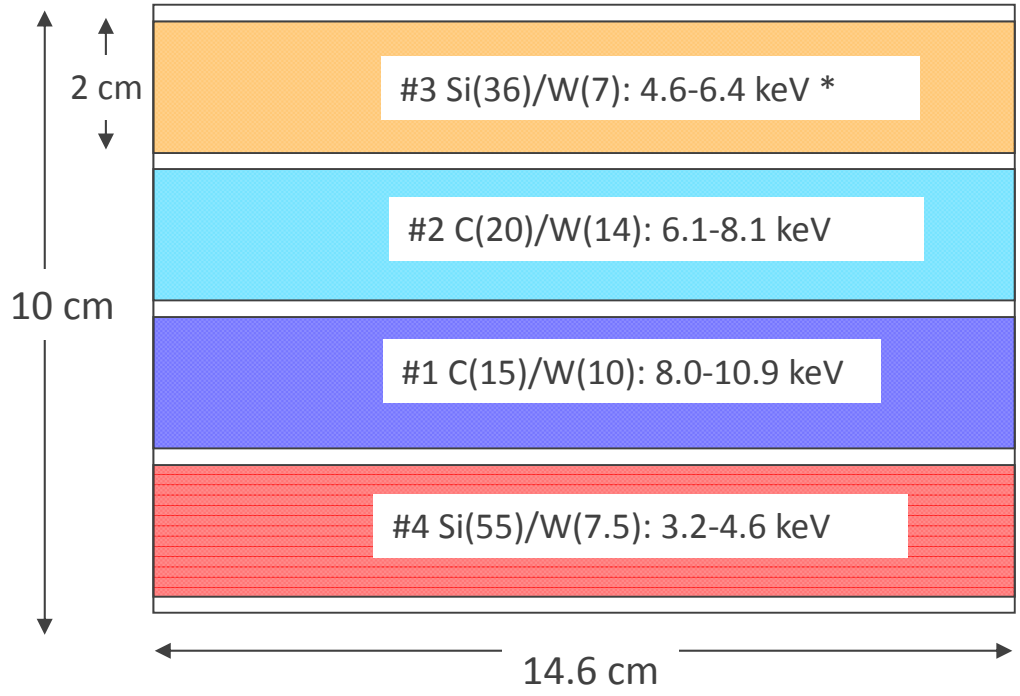

**Performance of a double-multilayer monochromator at Beamline 2-BM at the Advanced Photon Source**

Y. S. Chu,[a] C. Liu, D. C. Mancini, F. De Carlo, A. T. Macrander, B. Lai, and D. Shu
*Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439*

RSI 73, 1485 (2002).

# APS 2-BM

Multilayer optics at 2-BM




* Operation energy ranges based on the incident angular range of 1.35 to 1.89 °

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RSI 73, 1485 (2002).

# APS 2-BM

| multilayer | Nominal operation energy range | Measured reflectivity at 10 keV | Calculated reflectivity based on fit parmeters | Measured bandwidth |
|---|---|---|---|---|
| C(14.8)/W(9.7)x100 | 8.0-10.9 keV | 65% | 65% at 10 keV | 2.5 % at 9.7 keV |
| C(19.5)/W(14.2)x50 | 6.1-8.1 keV | 85% | 77% at 7 keV | 5.5% at 6.7 keV |
| Si(36)/W(6.8)x60* | 4.6-6.4 keV | 86% | 70% at 5.5 keV | 3.4% at 8.53 $2^{nd}$ order |
| Si(55.0)/W(7.5)x35* | 3.2-4.6 keV | 79% | 42% at 4 keV | 2.5 % at 7.1 keV $2^{nd}$ order |

* ~ 20 A SiO2 on the surface
narrower W thickness and ~50% larger interfacial roughness/diffuseness
--> formation of $WSi_2$ suspected

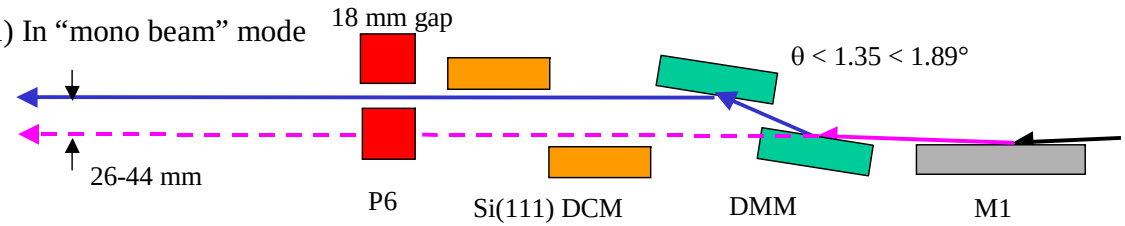
- Constancy (~ 0.5 A or better) of layer thickness over ~40 bilayers.
- Inter diffusion less than ~ 3 A between the layers.
- Flux increase of ~ 40 times at 8keV compared with Si(111) DCM
- Flux increase of ~ 200 times at 20 keV compared with Si(111) DCM using 3rd order.

Tomographic acquisition of 10 Frames/sec now possible.

*Slide by Yong Chu*

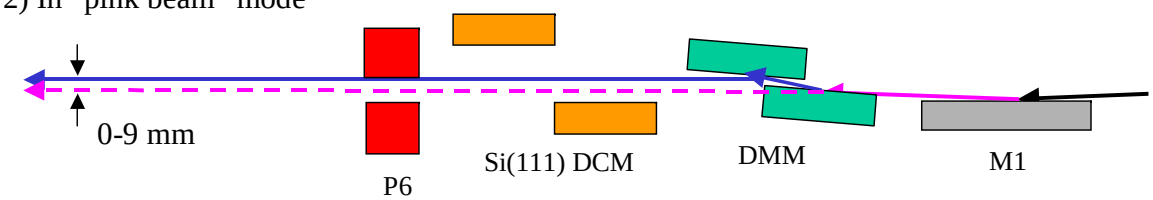
# Two Modes of Operations for DMM

1) In "mono beam" mode




Originally proposed operation mode
Accessible energy range: 3 keV to 11 keV
K edge: Ar through Ga L edge: Tc through Lu

2) In "pink beam" mode




Additional operation mode
Accessible energy range: 15 keV to 30 keV: useful for imaging

**Performance of a double-multilayer monochromator at Beamline 2-BM at the Advanced Photon Source**

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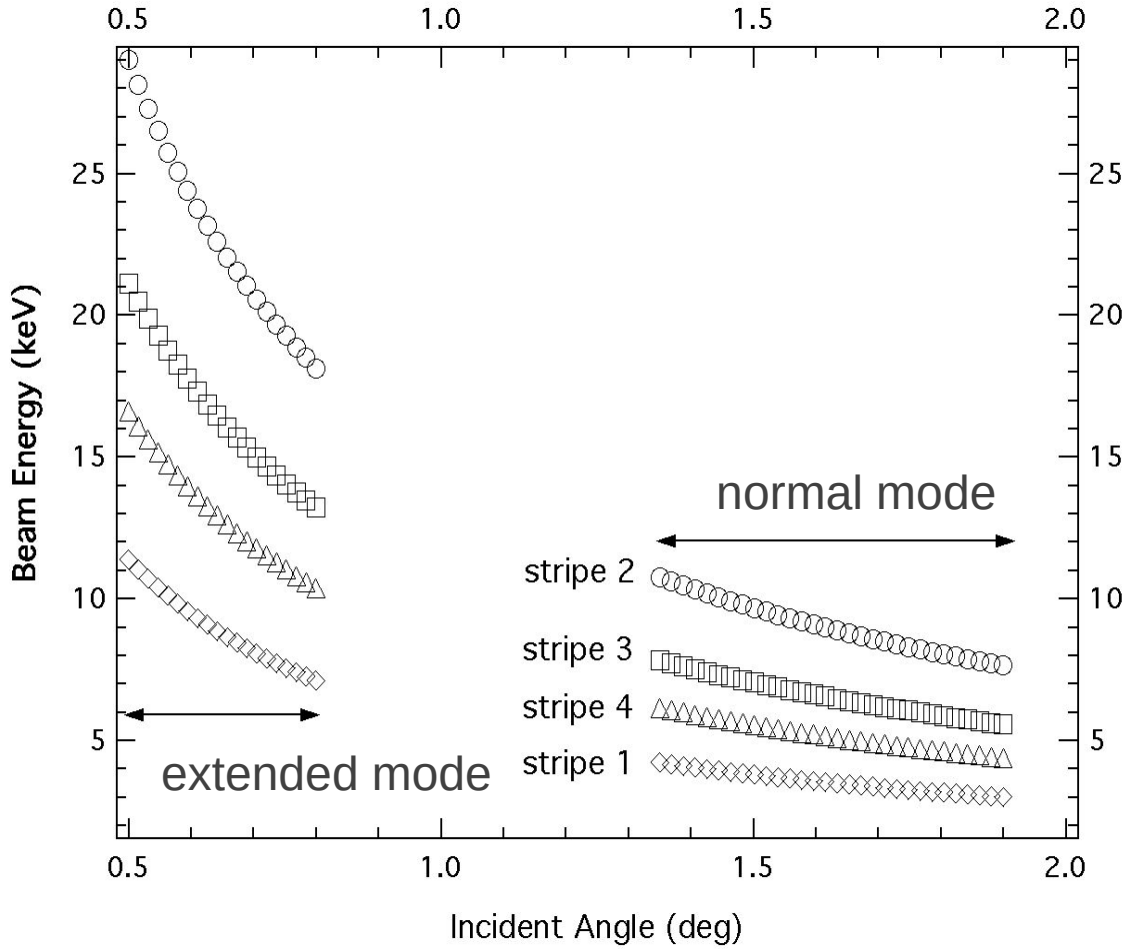
*Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439*

RSI 73, 1485 (2002).

# Available Energies




**Performance of a double-multilayer monochromator at Beamline 2-BM at the Advanced Photon Source**

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*Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439*

RSI 73, 1485 (2002).

# Sagittal Focusing

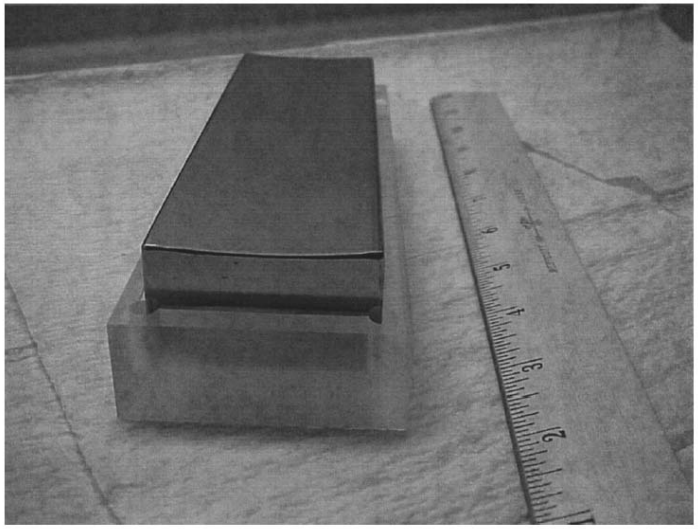

FIG. 1. Cylindrically figured second crystal, used for sagittal focusing. The silicon substrate is 150 mm×50 mm×20 mm thick. The scale on the ruler in the photograph is in inches.

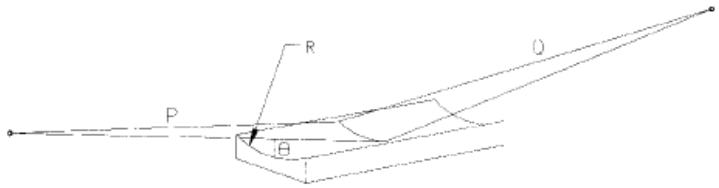


FIG. 3. Optical layout of the sagittal optic. *P* is the distance from source to optic, *Q* is the distance from optic to image.

TABLE III. Summary of multilayers produced and tested.

| Multilayer sample | Coating | Average reflectivity | Average bandwidth |
|---|---|---|---|
| Flat ML 1 (cooled)—APS | 18 Å C/9 Å W | 62% | 2.5% |
| Flat ML 2 (cooled)—Osmic | 15 Å $B_4C$/7.5 Å W | 62% | 2.5% |
| Flat 3 (uncooled)—Osmic | 15 Å $B_4C$/7.5 Å W | 74% | 1.3% |
| Flat ML 4 (uncooled)—APS | 18 Å C/9 Å W | 74% | 1.8% |
| Cylindrical ML—APS | 18 Å C/9 Å W | 45% | 1.4% |

## Multilayer optics for a wiggler beamline (invited)

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Chian Liu and Albert T. Macrander
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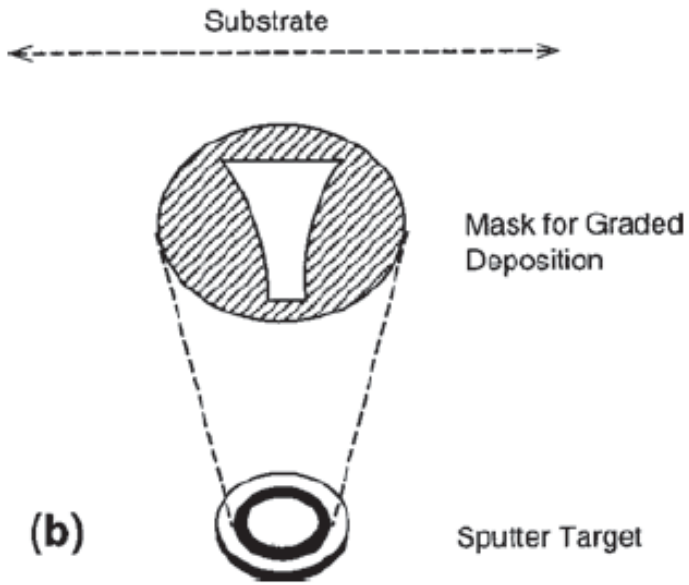
RSI 73, 1476 (2002)

# Lateral Grading



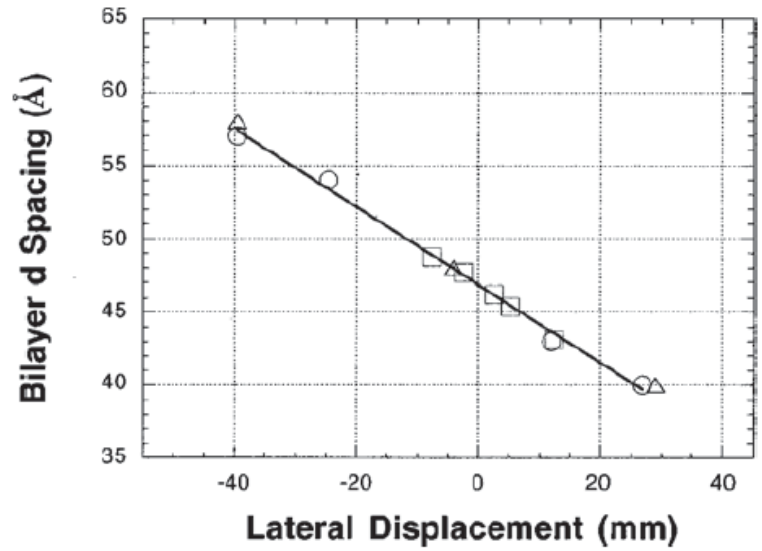




FIG. 3. Bilayer $d$ spacing of a pair of W/C graded multilayers as a function of lateral displacement as obtained from x-ray diffraction measurements. Three sets of data are shown: data from a rotating anode diffractometer on both multilayers (circles and triangles) and data from a synchrotron beam-line on sample 2 (squares). The straight line is a least-squares linear fit to the data.

## Laterally graded multilayers and their applications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JVST A19, 1421 (2001)

# Stanford Synchrotron Radiation Laboratory

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- Publications
- Safety
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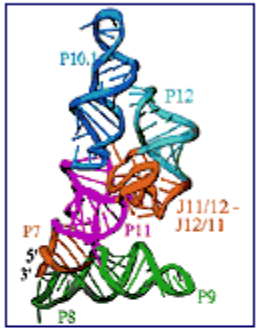
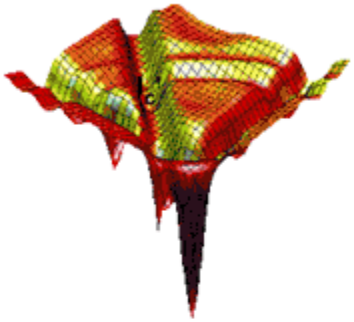
- Staff Resources



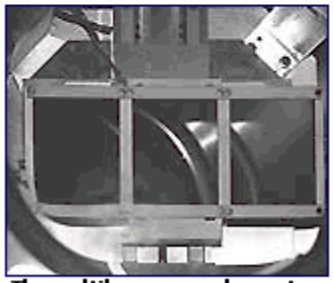

**Specialty Domain of Bacterial RNase P**
Science Highlight Apr '03



**Exploring the Folding Landscape of a Structured RNA by SAXS**
Science Highlight Mar '03

**SPPS experiment begins at SLAC**

The multilayer elements are flat silicon crystals with many alternating layers of tungsten and carbon precisely deposited on the surface. They select an x-ray energy of about 9 keV with a bandwidth of about 1%, matched to the bandwidth of the SPPS undulator fundamental energy. Three successive reflections from the three multilayer elements deflect the x-ray beam sideways by 8.5 degrees; it then passes in a beam pipe out through the accelerator hall shielding and into the SPPS experimental area.



**The multilayer monochromator for the SPPS**

- Special Safety Alert
- Monthly Headline News
- Events
- SPEAR3 Upgrade
- LCLS
- Beam Line Upgrades

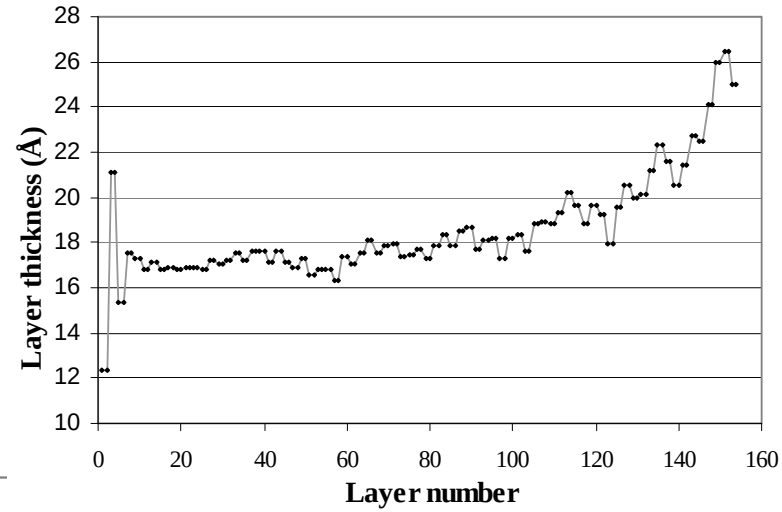
# Depth-graded wide bandpass multilayer

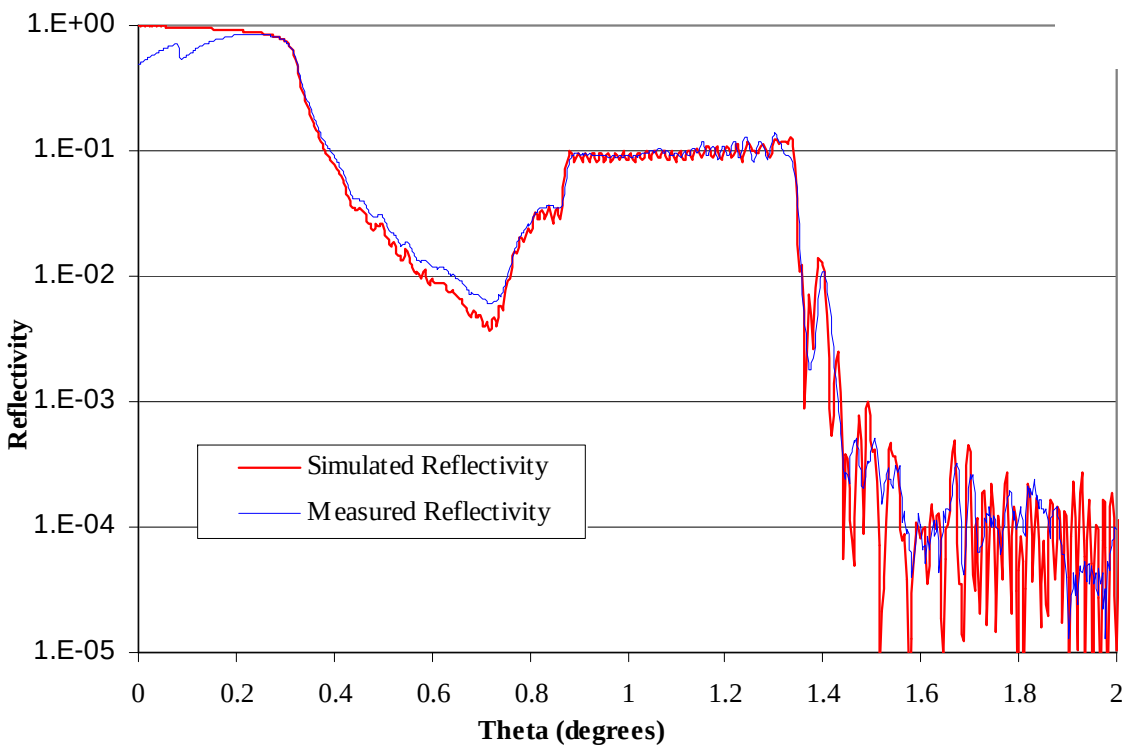
•Computational method employed for multilayer design can be used to calculate the required multilayer stack parameters for arbitrary reflectivity profiles, within reason.

•77 bilayers of $WSi_2$ and Si

• Bilayer spacing from 2.2 nm to 5.5 nm

• Relatively flat-topped reflectivity = 9.5%, Bandpass = 42.6%

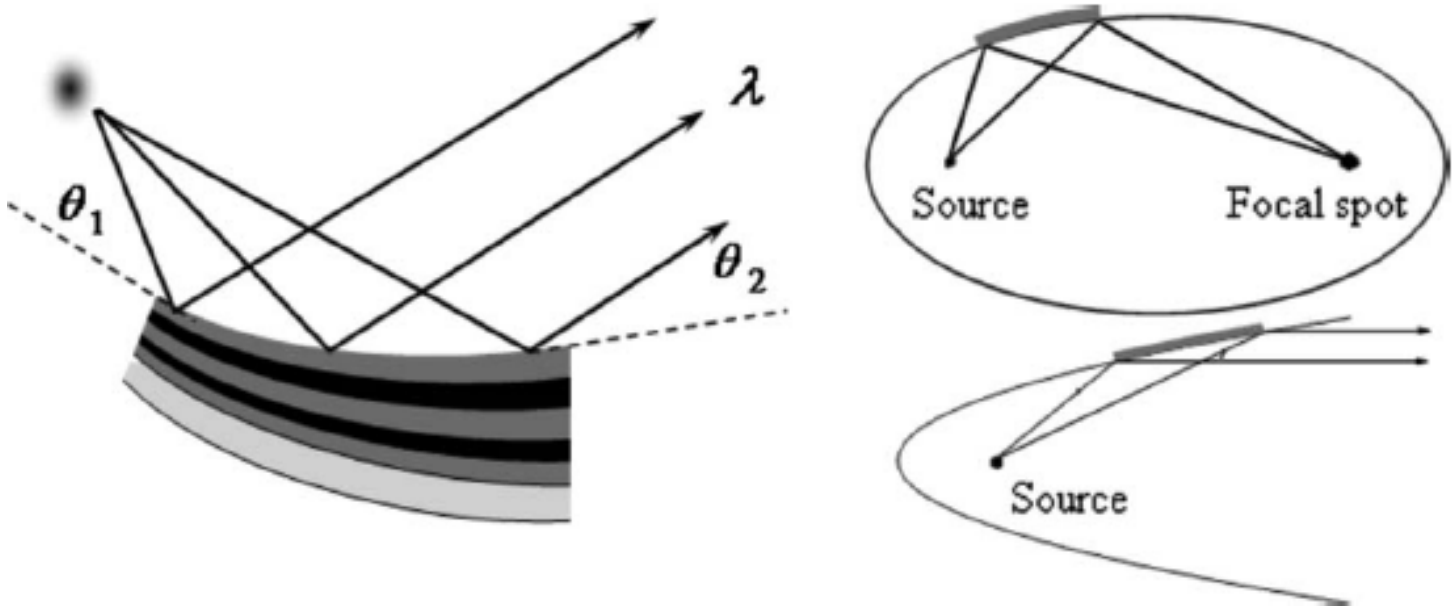



Erko Et. Al., JSR 1998
Kozhevnikov Et. Al., NIMA 2001
Morawe Et. Al., NIMA 2002
Conley et. al., SPIE 6705, 670505 2007.

Slide courtesy of Ray Conley

## *Focusing or collimation by lateral depth grading on a curved substrate*

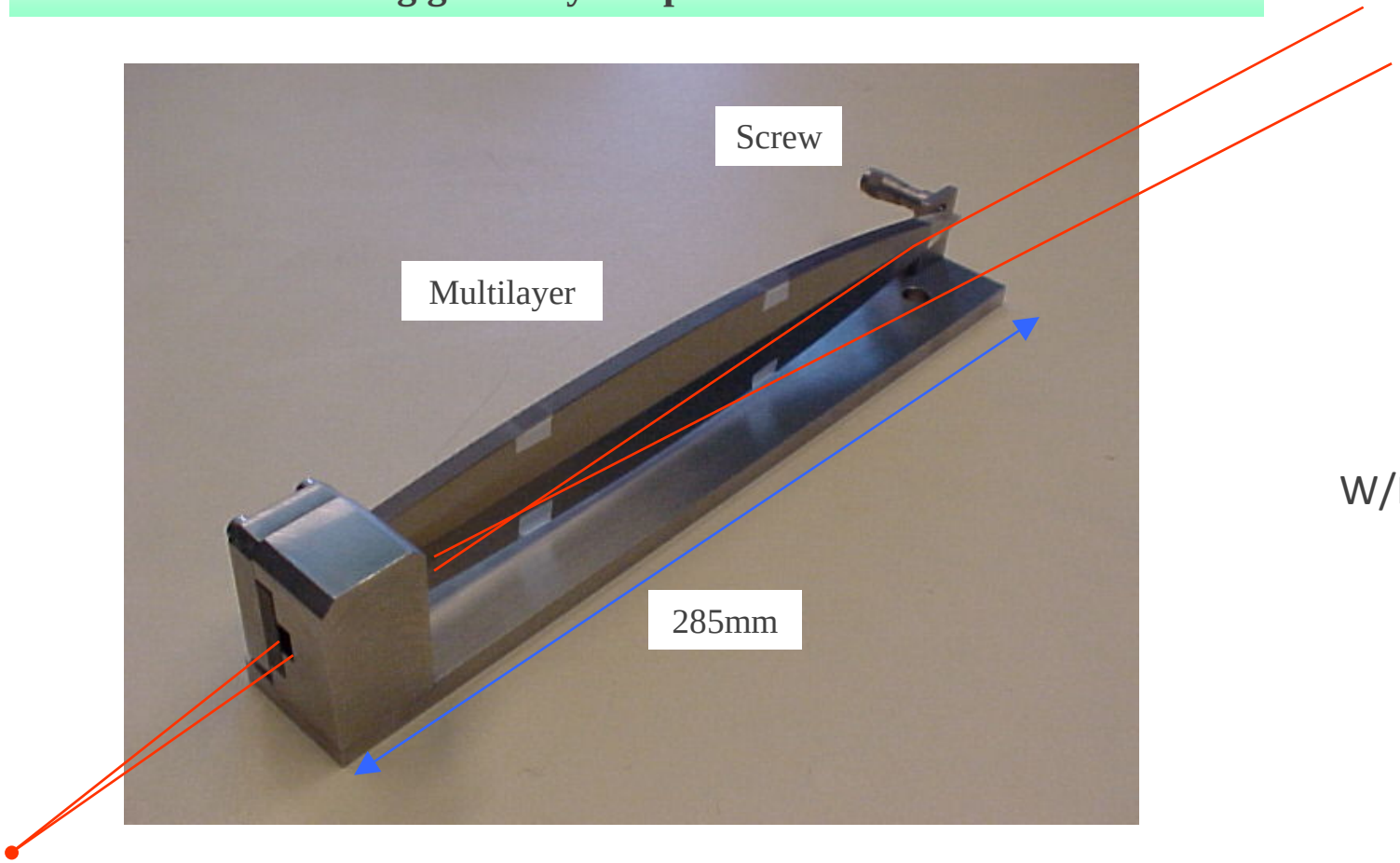



**Application of a single-reflection collimating multilayer optic for X-ray diffraction experiments employing parallel-beam geometry**

M. Wohlschlögel,[a] T. U. Schülli,[b] B. Lantz[b] and U. Welzel[a]*

J. Appl. Cryst. 41, 124 (2008)

## Horizontal focusing geometry – experiment on ID7 MHATT CAT



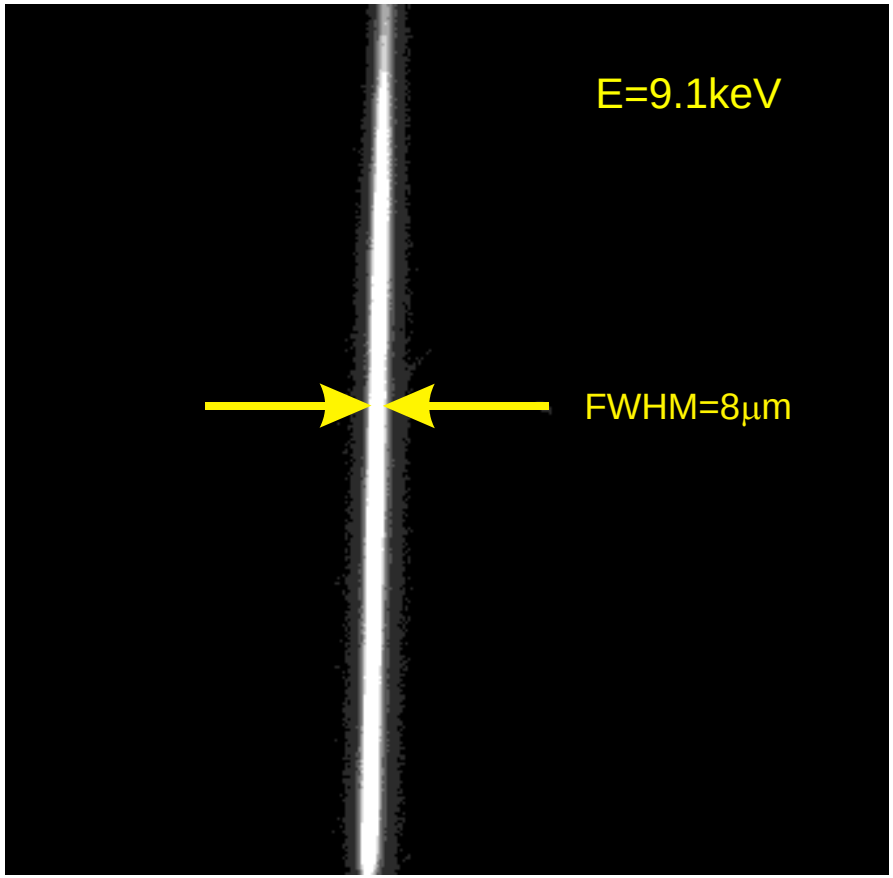

$W/B_4C$

**Double gradient multilayers for broadband focusing**

Christian Morawe*[a], Jean-Christophe Peffen[a]
Eric M. Dufresne[b], Yong S. Chu[c], Albert T. Macrander[c]

SPIE Proc. Vol. 5195, p.1 (2003)

## *Obtained focus at ID 7*




Incident beam width = 1.5 mm
Flat response over 10%
Reflectivity = 50%

**Double gradient multilayers for broadband focusing**

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Eric M. Dufresne[b], Yong S. Chu[c], Albert T. Macrander[c]

SPIE Proc. Vol. 5195, p.1 (2003)

# Problem: Stripes

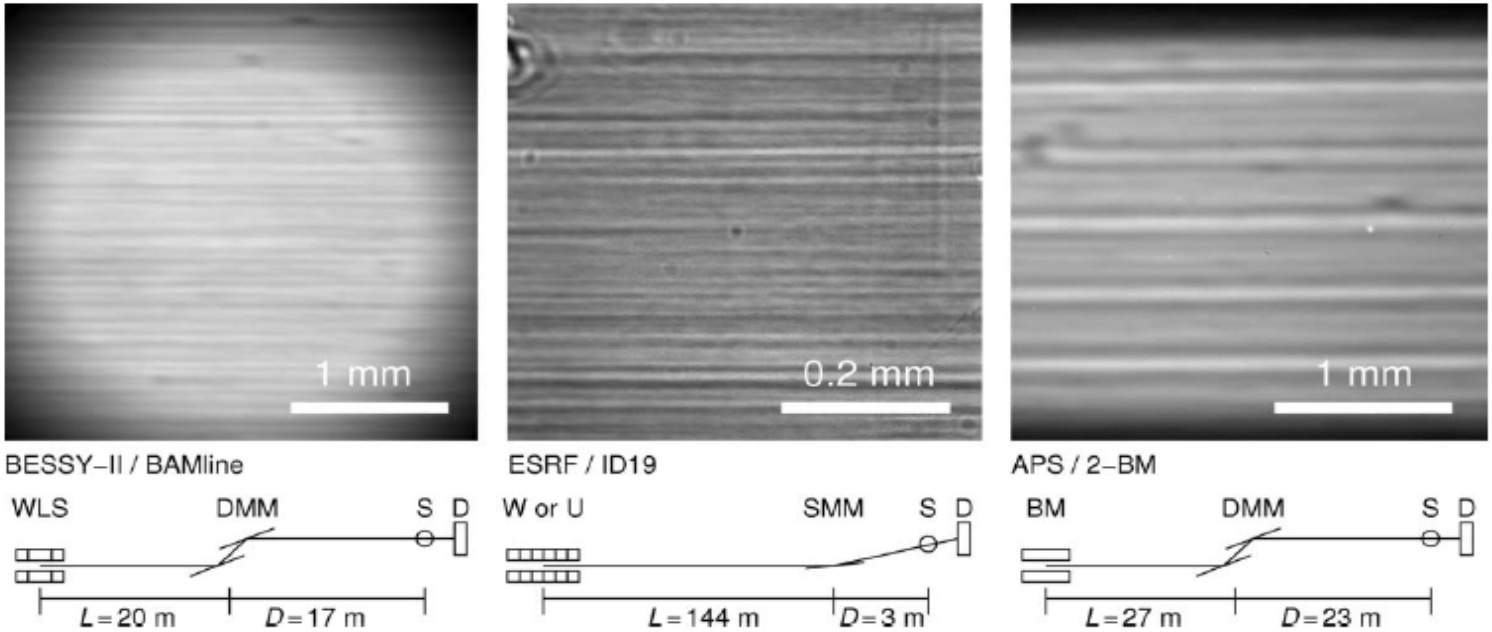
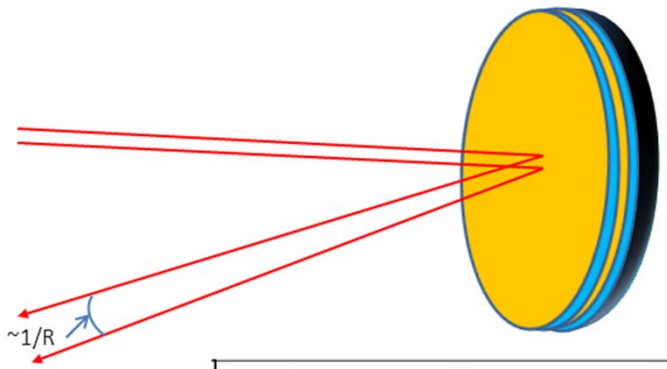


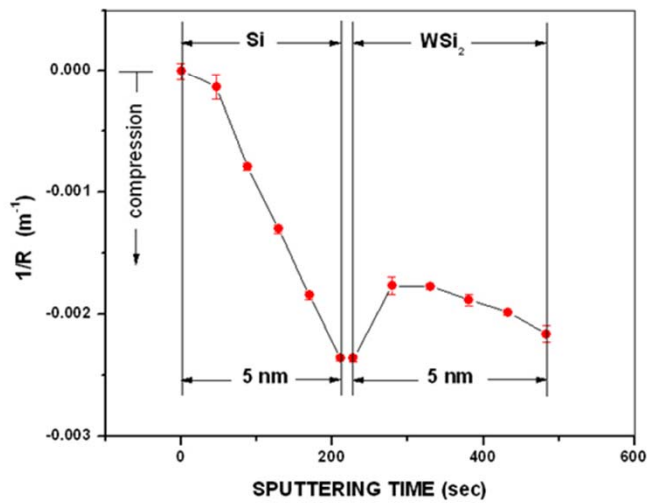

**Figure 1**
Examples of stripe modulations in the flat-field image after reflection by multilayer mirrors of different materials, period $d$ and number $N$ of bi-layers, in use at different beamlines around the globe. (Note that these are not the multilayer samples which are under investigation in this paper.) The sketches below show the essential layout elements of each beamline: source (WLS: wavelength shifter; W: wiggler; U: undulator; BM: bending magnet), monochromator (DMM: double multilayer monochromator; SMM: single multilayer monochromator), and the distances $L$ and $D$ between source, multilayer and experimental station (S: sample; D: detector). The sketches do not show filters, windows, *etc*. Left: W/Si, $N = 150$, $d = 2.88$ nm at the BAM*line*, BESSY-II. Center: Ru/$B_4C$, $N = 65$, $d = 3.92$ nm, at ESRF beamline ID19. Right: W/$B_4C$, $N = 200$, $d = 1.38$ nm, at APS beamline 2-BM.

A. Rack et al., JSR 17, 496 (2010)

# *There may be grown-in stress*




convex bending
for multilayer in compression,
bending radius = R




APPLIED PHYSICS LETTERS **99**, 081905 (2011)

**Periodic variation of stress in sputter deposited Si/$WSi_2$ multilayers**

Kimberly MacArthur,[1,a)] Bing Shi,[1] Ray Conley,[1,2,b)] and Albert T. Macrander[1,c)]
[1]*Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois 60439, USA*
[2]*NSLS-II, Brookhaven National Laboratory, Upton, New York 11973, USA*

# Thank you for your attention