PROVIDER OF EXCELLENCE

Ion surfacing of X-ray mirror optics for XFEL and synchrotron applications

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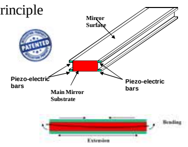
ABSTRACT

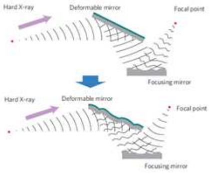
An ion beam surfacing process [1-2] has been adapted for realizing a set of X-ray mirrors manufactured at Thales SESO. The developed fabrication-metrology protocol is proved to tailor simultaneously both figure and finish and it allows correcting deterministically arbitrary mirror shapes including optics for future XFEL experiments. The manufacturing sequence is discussed and applied in two specific case: a bulky monolithic mirror for X-ray nano-focusing (elliptical cylinder) with dimensions 150x30x60 mm3, and, a 2nd generation deformable (bimorph) mirror driven by 16th piezoelectric actuators evenly distributed over a length of 0.890 m. An X-ray wavefront curvature sensing technique is presented as a possibility to combine these optics and to optimize the beamline performances [4] .

Mirror Optics for Synchrotron Radiation and XFELs

II generation Bimorph

Principle





NANOFOCUSING scheme proposed to achieve sub-10 nm focusing

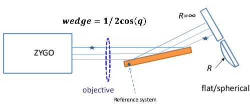
Mimura et al., Nature Phys. 2009

Elliptical Cilnder for nanofocusing

2° generation Bimorph device

Ion Beam Profiling (IBP) & Metrology

Clean room environnent
Grazing Incidence Phase Shifting Interferometry



flat/spherical Reference

TESTING Layout HFM (Horizzontal Focusing Mirror)

Phase shifting interferometry →1 shot measurements

Grazing geometry (angle q~4-20 deg)→ simulate final SR use

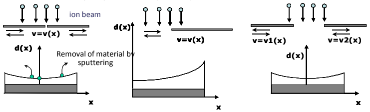
Gravity does not play a role (difficult with LTP instruments [3])

Double-pass reduces reference errors

Useful technique in phase of integration adjustement of deformable mirrors

Bimorph testing (grazing PSI)

IBP schemes for "1D" grazing incidence X-ray mirror optics (Silicon, SiO2 and Zerodur), see Ref. [1]



Off-set scan
- Sample/spot moving
- Slow process
- High resolution

Single Blade Scan
- Sample/slit moving
- Slow process
- Interesting for coating

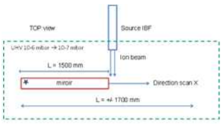
Gap Scan
- Sample Stationary
- very fast
- Requires Broad Beams

1D →Tight slope error specification along the longitudinal direction (< 500 nrad)
Non-contact polishing method → possibility to use in-situ metrology

Typical processing scheme

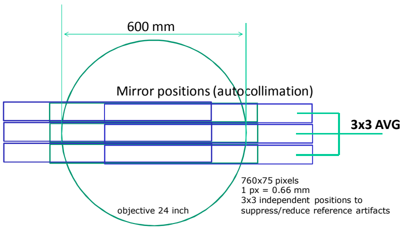
Substrate scanning - offset scan

Mirror prepared by traditional polishing



Surfacing and control of a 2nd generation bimorph for XFELs

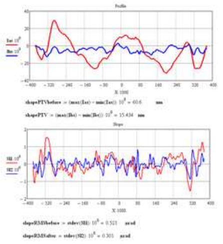
for large area stitching (wavelength shifting interferometry)



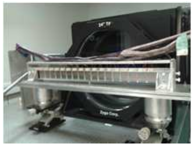
760x75 pixels
1 px = 0.66 mm
3x3 independent positions to suppress/reduce reference artifacts

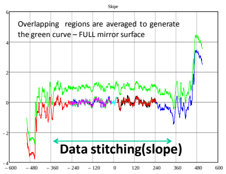
Surface errors before/after IBP

Figuring obtained in 1 correction step from grazing incidence PSI data (double pass + 3x3 position + stat. averaging to suppress the cavity)



Bimorph testing (autocollimation)





Overlapping regions are averaged to generate the green curve – FULL mirror surface

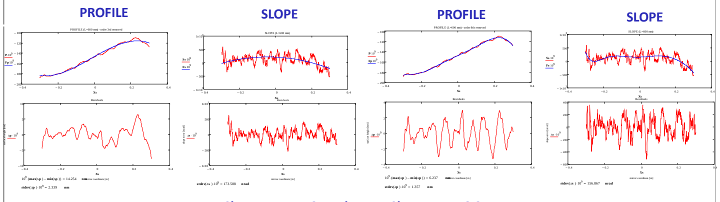
Shape PTV= 15,4 nm (L=0,75 m)

Slope rms = 301 nrad (L=0,75 m)

Radius ~ 2000 km

3rd order polynomial removed (L=0,6 m)

8th order polynomial removed (L=0,6 m)



Shape PTV= 14.3 nm

Slope rms = 173 nrad

Shape PTV= 6,2 nm

Slope rms = 157 nrad

REFERENCES

[1] L. Peverini et al., Ion beam profiling of aspherical X-ray mirrors, NIM A, 616, (2010)
[2] E. Ziegler et al, Evolution of surface roughness in silicon X-ray mirrors exposed to a low-energy ion beam, NIM A, 616, 188-92 (2010
[3] F. Siewert et al, "The Nanometer Optical Component Measuring machine: a new Sub-nm Topography Measuring Device for X-ray Optics at BESSY," AIP Conf. Proc. 705, 847–850 (2004)
[4] F. Roddier, Appl. Opt. 27, 1223–1225 (1988)

Fabrication and testing of elliptical cylinders for nanofocusing

KB-mirror holder

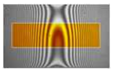
SPECIFICATIONS
slope errors r.m.s. < 0,1-0,2 µrad
Shape errors r.m.s. < 0,5 nm
Long Spatial Periods p>1 mm

The strong aspheric shapes required for nanofocusing required the development of specific protocols to adapt our polishing capabilities to these peculiar shapes. Due to the large thickness involved, the amplitude of high order terms (h4→h6) and low slope errors specification we decide to operate with a flat superpolished down to 150 nrad instead of a stresspolished mirror (see e.g. below). This choice allowed us in particular to define the limit of our IBF technology in terms of:

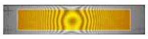
- **Roughness preservation** proved for large removed thicknesses **(> 10 µm)**
- **IBP convergence** to the absolute ellipptical shape specified
- **Metrology** at Grazing and normal incidence are combined to infeer low/middle/high frequency dependencies of the real mirror profile

AXOC project – nanoprobe BL SOLEIL
Monolithic nanofocusing mirrors (L= 0,15 m)
p = 73 m
q = 0,34 m
theta = 3,1 mrad
Magnification M =208

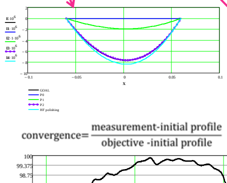
Autocollimation PSI to determine the elliptical parameters



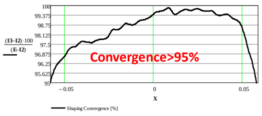
Grazing incidence PSI (20°) to infeer the high frequency errors



~20-30 fringes are resolved in a single shot

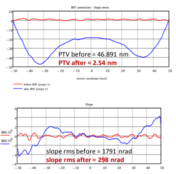


$$\text{convergence}=\frac{\text{measurement-initial profile}}{\text{objective -initial profile}}$$

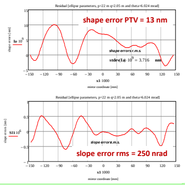


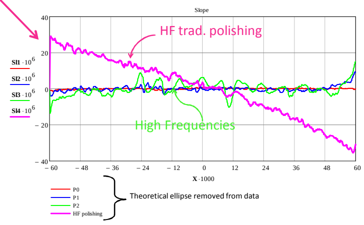
Commercial mirrors for nanofocusing

Example of a KB mirror (torpedo) for nanofocusing polished by IBP (nanoprobe BL -SOLEIL)



Example of stress-polished ellipse polished by IBP (beamline Syrius-SOLEIL)



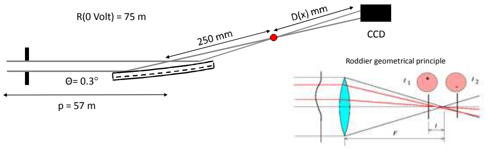


The protocol investigated lead to HF errors probably due to long terms instabilities of the ion beam profiling process involved removing large substrate thicknesses. This type of errors could be hardly removed by IBF only. We idetified thus a set of possibilities and conclusions (work in progress):

a) iterating IBP and traditional polishing seems to be necessary to guarantee a convergence to the exact elliptical shape and suppress HF corrugations
b) Use of pre-polished cylindrical mirror instead of flat is a simple technical solution to reduce the thickness removed by IBP

→ Both approaches promise to be a valuable approach to polish very thick and compact focusing mirror needed for high heatload (pink SR beam) , XFEL applications and nanofocusing.

Beamline wavefront optimization using curvature sensing (Roddier)

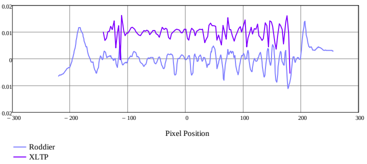


CCD camera
SENSICAM 1376x1040 16 bit
Resolution 1.3 µm
Pixel size 0.645 µm

X-ray Beam
Source Size 25 µm
Energy E = 10 keV
∆E/E ~ 0.001 (Si 1 1 1)

X-ray Validation - Roddier vs XLTP

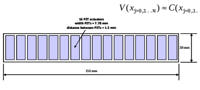
Cylindrical wavefront data using pencil beam deflectometry data, the so-called X-LTP and curvature calculated from the analysis of the Roddier signal. The XLTP data are translated in local curvature by simply deriving the normalized slope.



Ultra-thin bimorph 1st gen. prototype (naked)

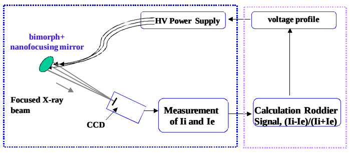
Signorato et al. JSR, 5, 797 (1998)

$$V(x_{j=0,1..N}) \approx C(x_{j=0,1..N}) = \frac{d^2P(x)}{dx^2}$$



Closed loop wave-front compensation for SR & XFEL beamlines

1. Compact design and flexible beam shaping –> nanofocusing
2. On-line wavefront diagnostic and fast compensation with high contrast and spatial resolution
3. Technique compatible with large sample environnements
4. Easy relationship between Roddier signal and voltage distribution



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