ACTOP08

October 9-11 2008, Trieste Italy

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Zizak	Ivo	Bessy GmbH

ACTOP08 program

Wednesday Oct. 8		
17:00 – 19:00	Registration	AGH terrace
18:00 – 20:00	Welcome drink	AGH terrace

Thursday Oct. 9		
8:30 – 9:10	Registration	Conference hall
9:10 – 9:20	Opening Remarks (D. Cocco)	Giambiagi hall
9:20 – 9:35	Welcome Address (A. Franciosi)	"
Section 1. Free Electron Laser needs Chair M. Roper		
9:40 – 10:10	K. Tiedtke *The Quest for the perfect focus for high power density XUV and X-Ray beams: Experience from FLASH*	Giambiagi hall
10:10 – 10:30	H. Sinn *Requirements for bimorph mirrors at the European XFEL*	"
10:30 – 11:00	M. Zangrando *The FERMI@Elettra beamlines. From diagnostics to microfocusing.*	
11:00 – 11:40	Coffee break	AGH Terrace
Section 2. Bimorph mirrors on SR beamlines Chair R. Signorato		
11:40 – 12:10	P. Quinn *Bimorph mirrors: Performance and optimization on the microfocus spectroscopy beamline at Diamond*	Giambiagi hall
12:10 – 12:40	R. Fischetti *Automated Focusing of X-ray beams with Bimorph Mirrors*	"
12:40 – 13:00	A.J. Dent *Overview of Bimorph Mirrors at Diamond Light Source*	"
13:00 – 14:40	Lunch	AGH Terrace
Section 3. Sponsor section Chair I. Cudin		
14:40 – 15:00	F. Ciceri, P.I. S.r.l. *From piezo actuators to piezo walk drives, PI solutions serving active optics designers*	Giambiagi hall
15:00 – 15:20	F. Hertlein, Incoatec GmbH State-of-the-art thin film X-ray optics for synchrotrons and FEL sources	"
15:20 – 15:40	H. Thiess, Carl Zeiss Laser Optics GmbH *Fabrication of freeform mirrors: metrology and figuring*	"
15:40 – 16:00	Bruno Touzet, Horiba Jobin Yvon SAS *New Tunable Blaze Diffraction Gratings for EUV Applications*	"
16:00 – 16:20	M. Maeda JTEC *Ultra-precise figuring of KB mirrors*	"
16:20 – 17:00	Coffee Break	AGH Terrace
Section 4. Metrology 1 section Chair K. Sawhney		
17:00 – 17:30	V.V Yashchuk *Bendable X-Ray Optics at the ALS: Design, Tuning, Performance and Applications*	Giambiagi hall
17:30 – 17:50	F. Polack *Simultaneous estimation of the surface shape and the instrument error function from a highly redundant set of LTP data*	"
17:50 – 18:10	S.G. Alcock *Using the slope measuring profiler to optimize the shape of Adaptive Bimorph Optics*	"
18:10 -19:00	Discussion time	"
19:15	Bus departure	AGH entrance
19:30 – 23:00	Dinner at Gaudemus restaurant, Duino	Gaudemus
23:00	Bus departure to AGH	

Friday Oct. 10		
Section 5. Metrology 2 section Chair F. Polack		
8:50 – 9:20	A. Rommeveaux *ESRF Optical Metrology Applied to bent optical surfaces*	Giambiagi hall
9:20 – 9:40	J. Nicolas *The Optics Laboratory at ALBA*	“
9:40 – 10:00	F. Siewert *Characterization and Calibration of Slope Measuring Instruments*	“
10:00 – 10:50	Coffee break	AGH Terrace
Section 6. Astrophysics applications section Chair B. Ramsey		
10:50 – 11:20	S. O'Dell *Optics Requirements for the Generation-X X-Ray telescopes*	Giambiagi hall
11:20 – 11:40	C. Atkins *Smart X-ray Optics for the next generation of X-ray telescopes*	“
11:40 – 12:00	D. Spiga *X-Ray Imaging Telescopes: Prediction of the Expected Image Quality from Surface Roughness Metrology data.*	“
12:00 – 12:20	R. Canestrari *Hot Press Direct Slumping: An option to manufacture deformable optics*	“
12:20 – 14:00	Lunch	AGH Terrace
Section 7. Wavefront preservation and characterization Chair F. Siewert		
14:00 – 14:30	K. Yamauchi *At-wavelength measurement and on-site compensation of wavefront error for hard X-ray nanobeam*	Giambiagi hall
14:30 – 14:50	T. Kimura *Development of adaptive mirror for wavefront correction of hard X-ray nanobeam*	“
14:50 – 15:10	R. Signorato *Adaptive Optics and Wavefront control in the Hard X-ray Domain – Past, Present and Future*	“
15:10 – 15:40	M. Idir *X-ray active mirror coupled with a Hartmann wavefront analyzer*	“
15:40 – 16:20	Coffee Break	AGH Terrace
Section 8. Devices for laboratory Laser and SR beamlines Chair M. Idir		
16:20 – 16:40	F. Frassetto *Bidirectional Membrane deformable mirror*	Giambiagi hall
16:40 – 17:00	M. Cautero *New high voltage control system for bimorph bending mirrors Performance and applications*	“
17:00 – 17:20	S. Kalbfleish *A Waveguide-based Imaging setup for Petra III*	“
17:20 – 17:40	R. Reininger *Correcting Heat Load Induced Deformations on a XUV Beamline*	“
17:40 – 18:00	U. Flechsig *The SLS Optics Beamline - Performance Measurements and Status*	“
18:00 – 19:00	Discussion and closing remarks	“

Saturday Oct. 11 Round table on Bimorph mirrors system and technology		
08:45	Bus departure from AGH	
10:00 – 12:00	Round table	Rocca Bernarda Castle, Ipplis
12:00 – 13:30	Visit at the castle, wine yard and cantinas	“
13:30 – 15:00	Lunch	“
15:00 – 17:00	Round table	“
17:30	Bus departure to AGH	“

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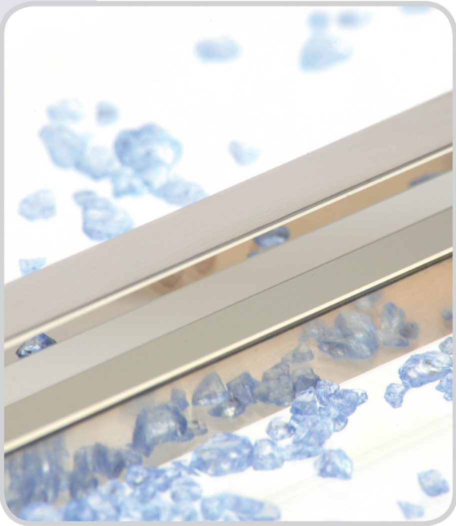
Your Partner for X-ray Optics and Microfocus Sources



Incoatec GmbH is a spin-off company from the GKSS Department for Coating Technology. The company was founded early 2002 by scientists from GKSS together with Bruker AXS in Karlsruhe, one of the leading producers of X-ray analytical equipment worldwide.
Incoatec produces ultra precise thin films according to client-specific requirements using modern technology (Innovative Coating Technologies). Our main products include multilayer X-ray optics for varying applications and microfocus source solutions. Computerized optics simulation, production of various types of substrates as well as characterization of films round off our service profile. Our main business is upgrading analytical X-ray equipment with new optics and X-ray sources. You will also find our products in new diffractometry and spectrometry equipment made by our partner company Bruker AXS.

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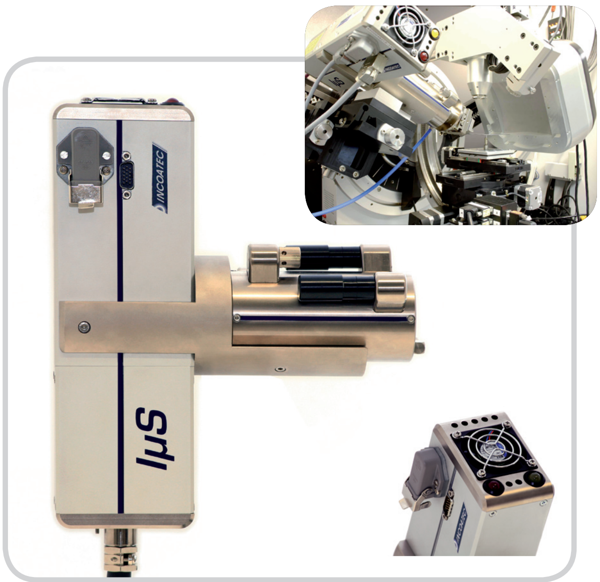
- 30 W air-cooled sealed tube
- New Quazar™ multilayer optics for 2D focusing or collimating
- For Cu and Mo
- Unprecedented flux density
- Low maintenance
- 3 years warranty
- Backup system for beamlines during shutdowns
- For Protein and Small Molecule Crystallography, Small Angle X-ray Scattering, Powder, μ Diffraction, Stress, Texture, ...



Deposition Technology - Thin films and more

We are prepared for customer-specific solutions:

- Monolayer, Multilayer, Multi-stripe coatings
- Metals - Alloys - Ceramics
- Large variety of materials - experienced with > 50 types of targets
- Ultra-homogeneous (< 0.1% on 6")
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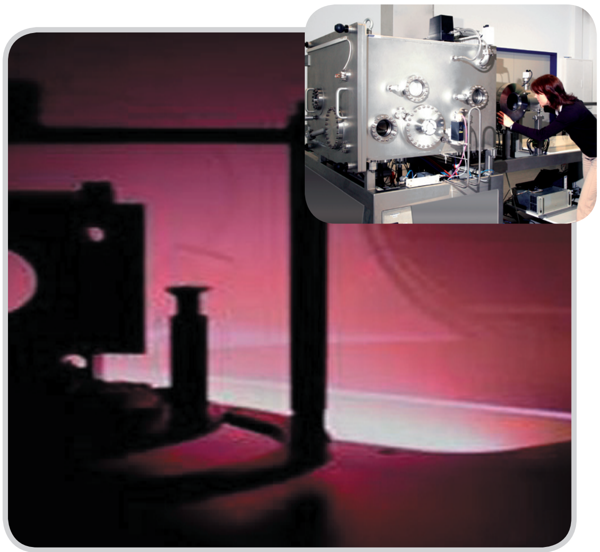
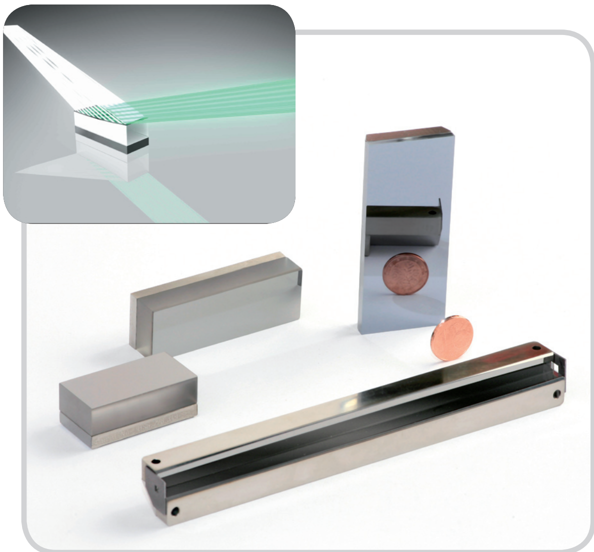
- Development of new deposition and process technologies
- Industrial partner for R&D projects
- Specialist for X-ray characterization





X-ray Optics - Göbel and Montel Mirrors

- Optics of varying lengths, focal distances and divergencies
- Client specific optics
- More than 10^8 photons/sec with sealed tubes
- Divergence of 0.5 mrad, other divergencies on request
- Suited for Cr, Fe, Co, Cu, Mo, Ag, ... radiation

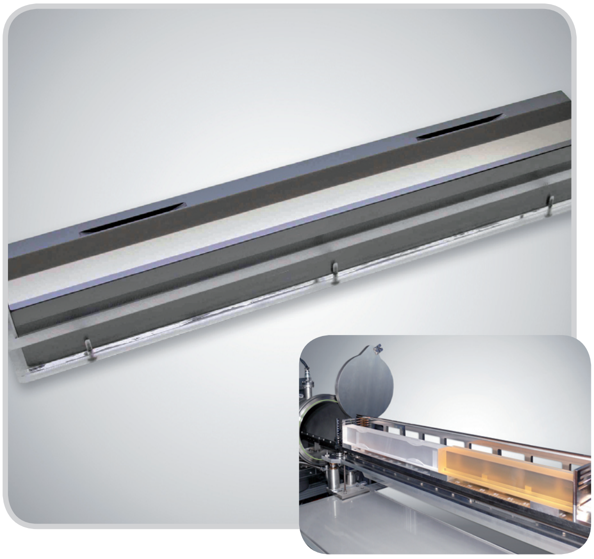
- Göbel mirrors for 1D collimation and focusing
- 3rd generation optics for highest resolution XRD

- Montel mirrors for 2D collimation and focusing
- For SCD and SAXS

Synchrotron Mirrors - Made in Geesthacht

- Total reflection mirrors
- Special carbon coatings for VUV and FEL
- Optics for imaging beamlines
- Multistripe monochromators
- X-ray waveguides

- Coatings up to 150 cm long



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Piezo • Nano • Positioning

Research areas

- Conforcal Microscopy, Scanning Probe Microscopes, AFM, SNOM
- Nanoindentation
- Nanifabrication
- Nanolithography
- Nanometrology
- Optical Tracking
- Optical Tweezers
- Test on Nanomaterials
- Imagine Steering, Enhancement and Stabilization
- Mechatronics
- Surface Analisys
- Nanotribology

Instrumentations

- Scanning systems based on piezoelectric technology with nanometric resolution and up to 6 D.O.F. and 1000µm stroke
- Analogic and state of the art digital multichannel driving systems for piezo-stages
- PZT Actuators with strokes up to 300µm, driving voltage 100V or 1000V, forces up to 80 tons
- Adaptive optics
- Piezo motors with ultrasonic (up to 600mm/sec velocity and 20g acceleration) and piezo-walk (up to 20 mm stroke with nanometric resolution) technology

Characteristics

- Solid state technology, Multilayer Encapsulated PIezo-Actuators, long life-time
- FEA designed high guidance accuracy flexures for zero friction zero stiction motion
- Capacitive sensors with 10pm resolution
- Parallel Cinematic
- Parallel Metrology

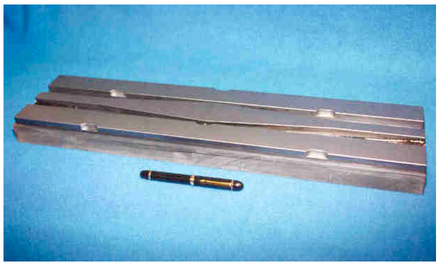
EUV AND X-RAY OPTICS

. 4 Cylinders bender, U Bender, Supports …

. X-Ray mirrors

SILICON CARBIDE MIRRORS

Length = 60 cm Slope error = 0.5"

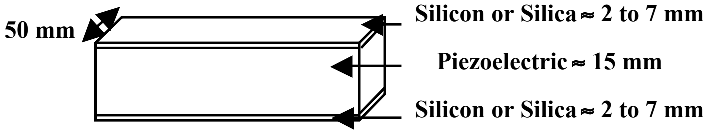


. U shape mirror and Bender Assembly

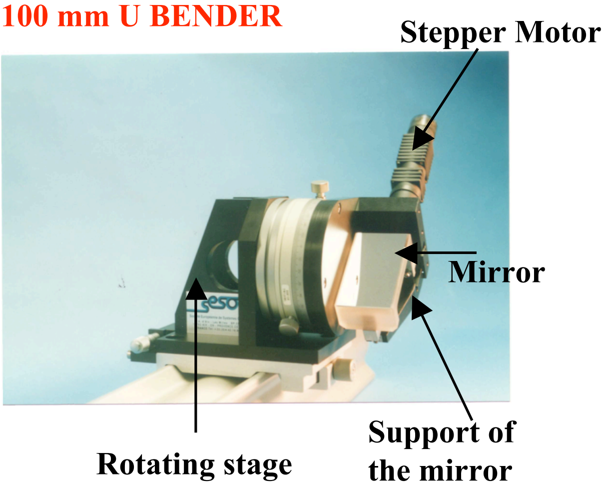
. X-Ray Special Products

BIMORPH MIRRORS

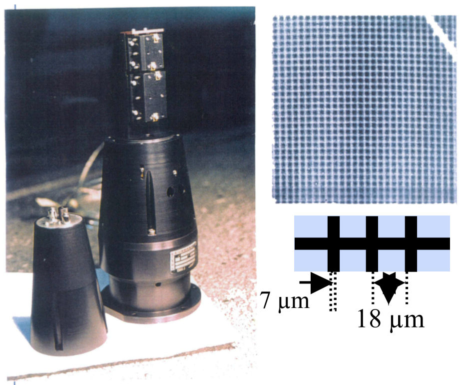
Made with piezoelectric ceramic and two layers of Silicon or Silica
Bendable by applying a voltage to both sides of the piezoelectric



. 100 mm U BENDER

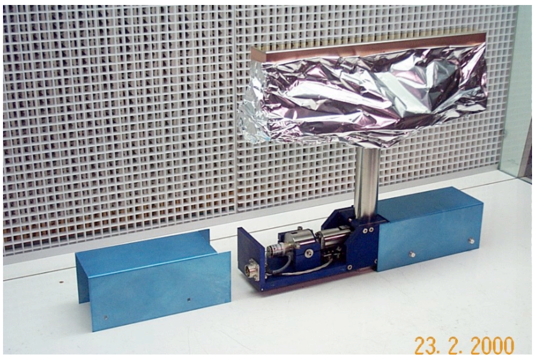


. X RAYS MICROSCOPE

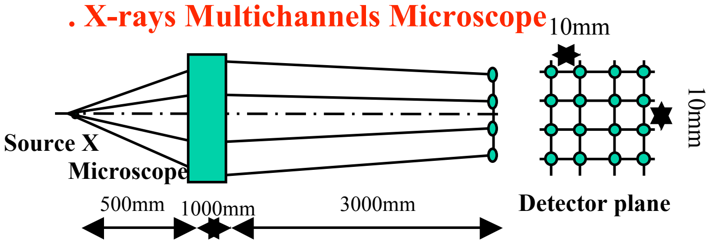


- Resolution : 3 µm
- Field of view : ≥ 0.4 mm x 1 mm
- Collecting angle : 1 mrad
- Magnification : x17 à x40
- Energy bandwidth : 1 à 5 keV

. KB (A1) with focusing and elliptical (A2) Shape driven by stepper motors



. X-rays Multichannels Microscope



CHARASTERISTICS
- Collecting aperture : diameter 0.5 mrad
- Detector : tube shutter with pulsed microchannels slice
- Number of channels : 16
- Magnification : 8
- Resolution in the source plane : 2 to 10µm in a field of 1 mm
- Energy : 0.5 to 5 KeV
- No chromatism due to the use of mirrors in grazing incidence

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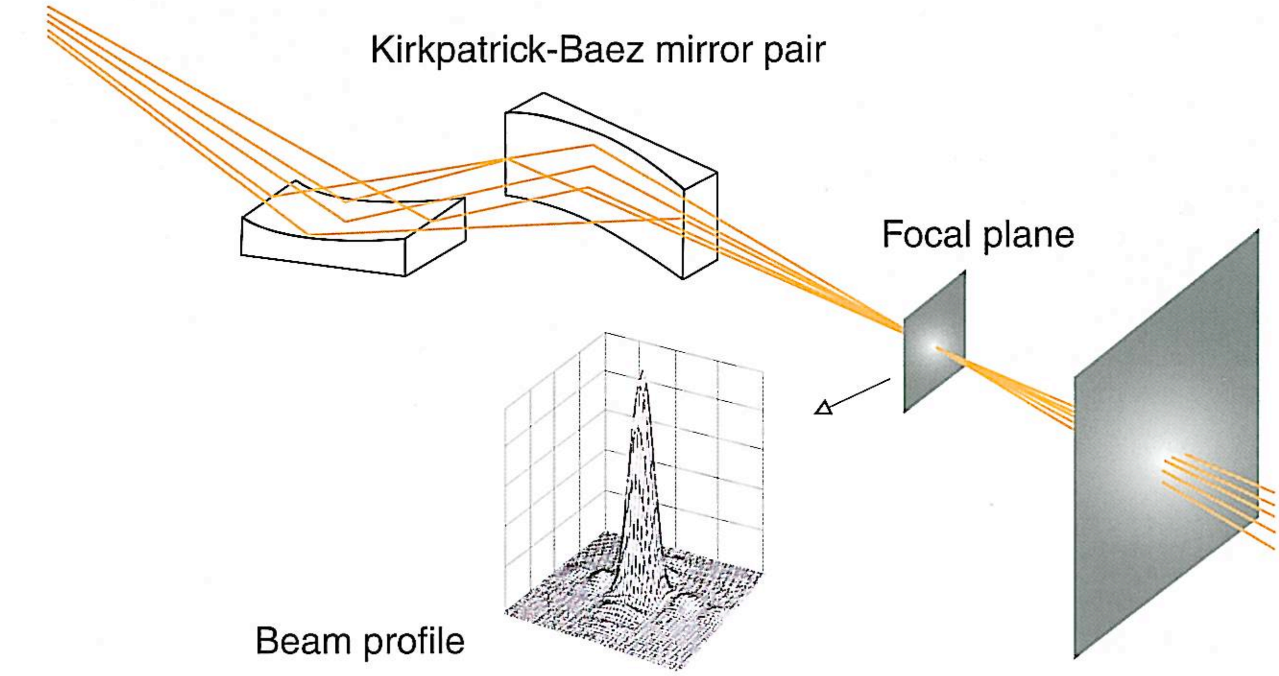
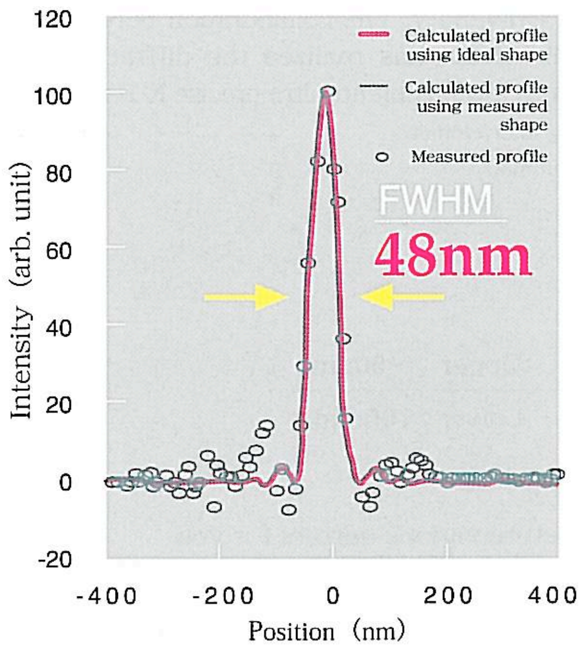
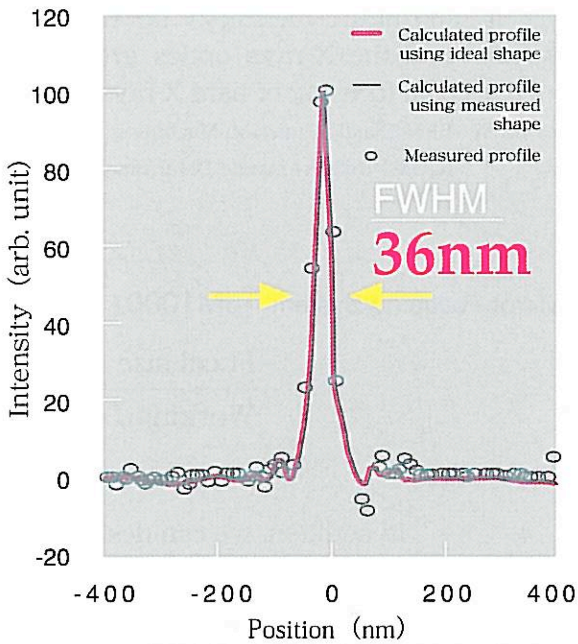
Focusing System for Synchrotron Radiation

Hard-X-ray diffraction-limited nanofocusing





Vertical Focusing
(f =254mm)



Horizontal Focusing
(f=150mm)

At the 1km-long Beamline of SPring-8; E=15 keV

Data from Osaka University

ABSTRACTS

The Quest for the perfect focus for high power density XUV and X-Ray beams: Experience from FLASH

K. Tiedtke
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In mid 2005 the Free electron LASer in Hamburg (FLASH) has started regular user operation [1], providing uniquely intense, short-pulsed radiation that up to now was tuned from 47 nm to 7 nm. Peak and average brilliance of this new user facility exceed both modern synchrotron and laser plasma sources by many orders of magnitude. The XUV output possesses the unprecedented flux of 10^{13} photons per pulse with durations of 10-50 fs, that, when focused into a spot size of a few micrometers in diameter, can achieve peak irradiance levels of more than 10^{16} W/cm^2 [2]. Here, photon matter interaction is affected by non-linear processes. Generally, the key point in the understanding of such non-linear effects is their dependence on irradiance. Therefore techniques to measure the pulse energy, duration, temporal and lateral distribution of the focused radiation are mandatory.

Besides these challenging demands for photon diagnostics, the requirements for the optical components for beam transport and focusing are extreme in terms of figure errors, roughness, stability, and radiation hardness in order to preserve the time structure, coherence, and other important properties of the FEL beam.

This paper will report on concepts for focusing the FLASH beam down to µm or sub-µm dimensions as well as diagnostic tools to determine the lateral and temporal intensity distribution, and the pulse energy.

References

[1] Ayvazyan V et al., , Eur. Phys. J. D **37**, 297 (2006)
[2] A.A. Sorokin et al., Phys. Rev. Lett. **99**, 213002 (2007).

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Requirements for bimorph mirrors at the European XFEL

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X-ray free-electron laser (XFEL) will generate ultrashort and very intense X-ray radiation in the wavelength domain reaching from the XUV all the way to the hard X-ray domain of one Angstrom. The European XFEL near Hamburg relies on super-conducting technology for the linear accelerator, which will enable more than two orders of magnitude increased average photon flux and three times higher peak brightness compared to other X-ray laser projects in the hard X-ray regime. First commissioning activities of the linear accelerator are scheduled for 2013 and user operation under SASE (Self-Amplified Spontaneous Emission) conditions will start in 2014 [1]. In full operation, the European XFEL will have ten or more experimental stations at five different beamlines. Experiments with SASE radiation between 250 eV and 12.3 keV with 10^{12} - 10^{14} photons in a 100 femtosecond pulse will be possible. Spontaneous synchrotron radiation up to 100 keV will be available with about 10^{9} photons per pulse. The proposed experimental stations enable a variety of experiments on ultrashort time scales like coherent X-ray imaging, X-ray photon correlation spectroscopy and plasma physics.

One consequence of the high X-ray peak power in the range of 20 GW is an instantaneous heat load that can easily reach melting conditions for beamline components exposed to the beam. At the European XFEL this problem is addressed by up to 1 km long photon beamlines, where sensitive optical components like mirrors can be placed at several 100 meters distance from the end of the undulators. In this way, the X-ray beam is widened to several 100 micrometers in diameter and the heat load can be managed by small grazing incidence angles and low-Z coating materials like carbon.

On the other hand, long beamlines and the desire to preserve the almost perfect transverse coherence properties of the beam put a stringent set of specifications on slope errors and mechanical stability of X-ray optical components. Estimates show that slope errors of mirrors better than 0.1 microradian rms or about 2 nm height error over 1 m lengths are required in the hard X-ray regime to minimize wavefront distortions of the beam. Bimorph mirror technology could help to fulfil these stringent requirements, if radiation hardness problems can be solved.

References

[1] M. Altarelli, et al. (Eds.) XFEL, The European X-ray Free-Electron Laser, Technical Design Report, 2006, (DESY 2006-097) http://xfel.desy.de/tdr/index_eng.html

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The FERMI@Elettra beamlines: From diagnostics to microfocusing

M. Zangrando, A. Abrami, D. Bacescu, D. Cocco, I. Cudin, C. Fava, D. Giuressi, R. Godnig, D. Lonza, F. Parmigiani, L. Rumiz, R. Sergo, C. Svetina

Sincrotrone Trieste ScpA, S.S. 14 Km 163.5 in Area Science Park, 34012 Trieste, ITALY

The FERMI@Elettra free electron laser (FEL) user facility is currently under construction at the Sincrotrone Trieste laboratory in Trieste (Italy). It will cover the wavelength range from 100 to about 3 nm (by using higher harmonics). In this presentation we will report the layout of the photon beam diagnostics section, the radiation transport system to the experimental area, and the experimental hall. A particular emphasis will be given to the refocusing section involving the use of multi-actuators active elliptical mirrors in Kirkpatrick-Baez configuration.

Due to the peculiar characteristics of the emitted FEL radiation (high peak power, short pulse length, statistical variation of the emitted intensity and distribution) the realization of the diagnostics system is particularly challenging. The final users are interested in parameters like the radiation pulse intensity and spectral distribution, as well as in the possibility to control the intensity. In order to accomplish these tasks a Photon Analysis, Delivery, and Reduction System (PADReS) is now under development and construction, and will be presented here. This system will work on-line producing pulse-resolved information, and will let users have under control the photon beam parameters during the experiments.

The Active optics involved into the refocusing section will use a hybrid system made by standard stepping motors and piezo actuators. The preliminary results show a very good stability and large range of focal distance variation. Those mirrors have to produce a very large demagnification as well as a collimated beam. A brief description of the proposed experiments will be also shown.

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Bimorph mirrors: Performance and optimization on the microfocus spectroscopy beamline at Diamond

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The microfocus spectroscopy beamline at Diamond has been operational since January 2007 and uses bimorph KB mirrors to routinely deliver a 3 micron beam to users. To initially optimize the mirrors in-situ the "pencil-beam" method of Hignette is employed [1]. This involves scanning a narrow pair of slits before the mirror to selectively illuminate sections of the mirror and observing the position of the reflected beam on an x-ray beam position monitor. The voltage of each element on the bimorph is incremented and the scans repeated to build a correction matrix. This technique has been used on the beamline to focus the incoming beam to 5-8 microns but to achieve further improvements to the focused beam size an iterative non-linear optimization scheme was developed. This approach uses knife-edge scans to obtain the beam profile and adjusts the voltages on the bimorph mirror until a satisfactory beam shape is achieved. Using this technique the beam size can be further reduced to 3 microns.

From the design specifications and initial slope errors of the vertically focusing KB mirror (0.9 μrad slope error uncorrected, 0.5 μrad corrected) a 1 micron beam spot should be obtained but this was never achieved in practice. To understand the problems achieving this focus the mirror was recently removed from the beamline and studied at the Diamond metrology lab. The mirror is 200 mm long with a 175mm active area and is designed with a central 150mm long piezoelectric stack with additional 25mm long piezoelectric sections attached at each end. The mechanical junctions between the central and outer piezoelectric sections were found to exhibit very large slope errors (~15μrad) and the uncorrected slope error in the central region is now 2.6 μrad, reducing to 1.5μrad with voltage correction. The potential causes for this degradation in performance will be discussed.

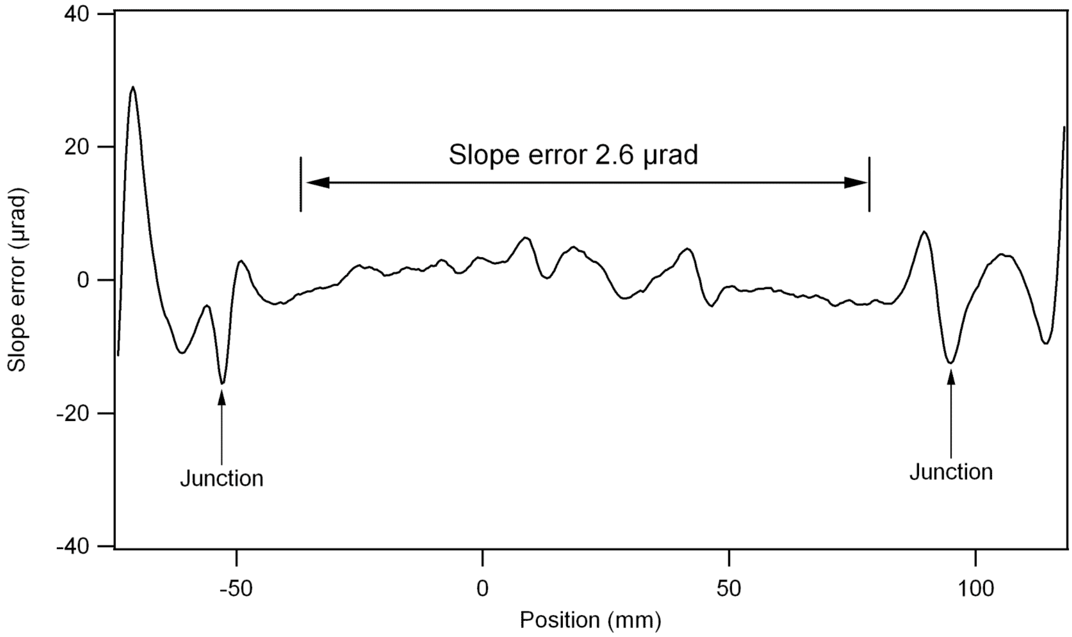

Figure 1. Slope errors measured from the vertical KB mirror at zero volts

References

[1] O. Hignette, A.K. Freund and E. Chinchio, *Proceedings of SPIE* **3152**, (1997) 188

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AUTOMATED FOCUSING OF X-RAY BEAMS WITH BIMORPH MIRRORS

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Adaptive optics such as bimorph mirrors provide the capability to focus X-ray beams by minimizing the slope error of a mirror installed in the beamline. However, achieving the minimal slope error can be quite challenging given the large number of degrees of freedom. We are operating two canted-undulator beamlines at the APS (23-ID-B and 23-ID-D) for macromolecular crystallography with bimorph mirrors arranged in a Kirkpatrick-Baez geometry. The vertical and horizontal focusing mirrors have 16 and 14 electrodes, respectively. Achieving the minimal focused beam size requires determining the optimal applied voltage for each electrode. We have automated the focusing process via a tcl user interface and a library of perl scripts whichinteracts with the mirror controller (developed at Elettra) via EPICS. The scripts collect all the data necessary to determine the interaction matrix of a mirror. Then, the matrix is uploaded to the controller, which inverts the matrix and calculates the optimal voltage for each electrode. GM/CA has used these mirrors and techniques in our beamline layout to create focused beams of approximately 25 µm × 70 µm, which retain a pseudo-Gaussian shape at off-focal locations up to 850 mm away. In addition, we have developed related measurements to determine in situ the slope error of the mirror. These results will be compared to those obtained through LTP methods.

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OVERVIEW OF BIMORPH MIRRORS AT DIAMOND LIGHT SOURCE

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As a new 3rd Generation synchrotron facility Diamond has taken a key decision in investing in bimorph mirrors for a large number of X-ray beamlines. Currently 10 are in use, with a further 8 in commissioning. The reasons for choosing bimorphs over conventional mirrors and benders will be described along with recent commissioning and operational results.

From piezo actuators to piezo walk drives, PI solutions serving active optics designers

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PI Physik Instrumente, the world leading company in Nanopositioning and Piezo Technology is proud to present a comprehensive panorama of solutions and products suitable for your applications of adaptive and active optics. PI defines since more than 35 years the state of the art of the precision positioning equipment by means of piezo technology offered at different levels of integration from the simple components to the newest piezo walk drives: NexAct® and Nexline® are the up to date solutions for designers, engineers and physicists with the most demanding exigencies in terms of performances, environmental conditions and integration:

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- ionizing radiations proof
- open and closed loop versions available for easy integration

Technology, catalogue and customized products and specifications will be presented with stress on applicative examples.


STATE-OF-THE-ART THIN FILM X-RAY OPTICS FOR SYNCHROTRONS AND FEL SOURCES

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Incoatec GmbH, Geesthacht, Germany

Incoatec develops and manufactures sophisticated multilayer and total-reflection X-ray optics as well as microfocus X-ray sources for in-house crystallography and synchrotron applications. Computerized optics simulation by ray-tracing, shaping of various substrate types as well as characterization of films by X-rays and optical profilometry complete our service profile. For Synchrotron Beamlines we especially offer ultra-stable total reflection optics for FEL's, multi-stripe multilayer optics and deposition of thin films on substrate lengths up to 150 cm.

Fabrication of freeform mirrors: metrology and figuring

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Carl Zeiss has a long-lasting expertise in the field of optical manufacturing and material processing for reflecting and refracting optical systems [1][2]. In particular optical mirrors of various geometries ranging from small flats to large freeform mirrors are subject to the extensive research and development activities. Exceedingly stringent specifications are placed on the optical components used in these newly designed systems. Extremely high heat loads demand cooling of these optics and thus material with high heat conductivity and low thermal expansion. The increased quality of radiation sources calls for higher-quality optics: Typical requirements are slope errors significantly below 1 arcsec for aspheric elements and below 0.1 arcsec for flats or spheres. Carl Zeiss uses state-of-the-art tooling and metrology devices in order to serve his customers with highest quality optical devices made from a wide range of substrate and coating materials. In order to achieve the desired surface quality, a very close interaction between metrology and polishing is mandatory.

Testing and manufacturing are complementary tools for fabrication of highly defined optical surfaces. Carl Zeiss has available metrology devices to cover the entire spatial error range from several nm to above 1 m. Full aperture interferometry is best suited for plane and spherical surfaces with dimensions below 12". Therefore 3D profilometry steps into focus when it comes to large complex surfaces. For this purpose Carl Zeiss has developed its 3D ultrahigh-resolution coordinate measuring machine M400. This device is able to measure surfaces up to 550 mm with a resolution < 10 nm.

Interferometric metrology devices are not stricly limited to plane or spherical surfaces. Cylindrical or weak freeform aspheres can be well measured by interferometric setups. One brief example is given below (see fig. 1). It shows the capability of measuring a cylindrical specimen of 70x70 mm^2 optical surface and a cylinder radius of about 2 m. In order to record the large radius with a limited table setup a combined CGH and reference mirror setup has been used. This setup however needs careful calibration of the optical system errors from the reference mirror and CGH. Note the agreement of measurements in the order of few nm that indicates the proper system calibration in this example. Since interferometric metrology (compared to scanning profilers) is an instantaneous method the value for the application of given technique to active optics is straightforward. Even time resolved measurements of optical manipulators for dynamic and drift measurements are feasible.

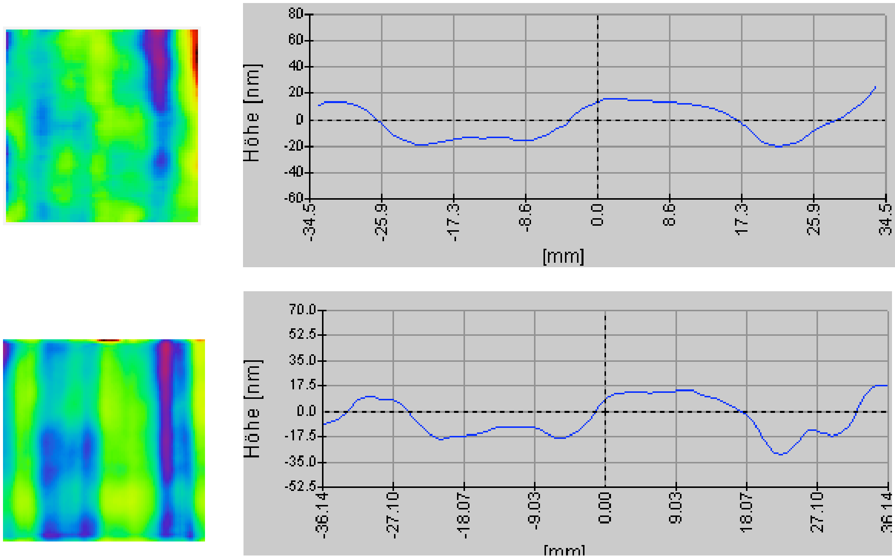

Fig.1: Comparison of tactile and interferometric measurements of a cylindrical optical surface. Quasi intererogram (top) from multi profile scan and intererogram (bottom) are shown. Note the good agreement in the order of few nm.

Future applications such as FEL and 3rd generation diffraction limited synchrotron sources implie further improvement of the achievable quality. New challenges concern the fabrication with advanced specifications of residuals for slope (< 0.05" rms) and pitch (< 0.5 nm rms) that are increasingly out of reach without proper interferometric methods. However the process technology for the manufacturing of surfaces in given precision range cannot be achieved without close cooperation with our customers.

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NEW TUNABLE BLAZE DIFFRACTION GRATINGS FOR EUV APPLICATIONS

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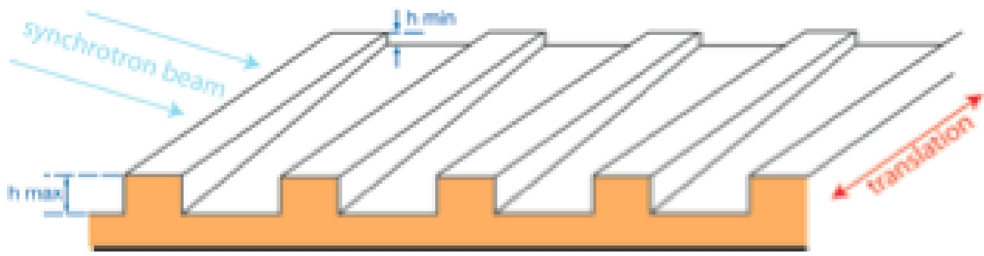
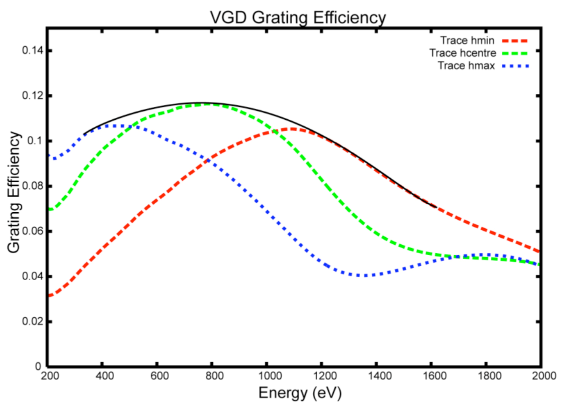
This new type of diffraction grating, called VGD Grating (VGD for Variable Groove Depth), is produced in such a way that the Groove Profile Depth is continuously variable from one side to the other side of the grating. As the blaze efficiency depends directly of the groove profile depth, the VGD grating gives the unique opportunity to get a much wider spectral range thanks to a simple grating translation along its width.



When such blaze adjustment is combined with monochromator scanning movements and narrow beam, the VGD offers to perform ON BLAZE scan and/or to minimise harmonics contamination over wide spectral range.



One Single VGD grating provides efficiency properties of several classical gratings.

Jobin Yvon VGD grating technology is compatible with:

- ✓ Silicon and Fused Silica high polished blanks
- ✓ Holographic Recording Process
- ✓ Constant, Aberration Corrected, VLS groove distribution
- ✓ Ion Etching Process
- ✓ XUV Reflective Coatings

The VGD grating technology, developed as a collaboration with Soleil Synchrotron teams, is usable with most of the recent synchrotron beamline designs that provide mm size synchrotron beam onto the grating. Replacing classical or multi track gratings by a VGD grating will open new experimental opportunities with optimised flux performances over the whole beamline spectral range.

Most of Soleil's extreme-UV monochromators have been designed to take advantage of the VGD potential (for example, the TEMPO,CASSIOPEE and PLEIADES beamlines).

Example of VGD Gratings

blank size (mm)	useful arera (mm)	grooves density (l/mm)	Nominal depth variation over 25 mm		
			h min (nm)	h centre (nm)	h max (nm)
40x100x30	35x90	1800	4.5	10	15.5
40x100x30	35x90	600	18	35	52
40x100x30	35x90	300	42.5	80	117.5

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BENDABLE X-RAY OPTICS AT THE ALS:
DESIGN, TUNING, PERFORMANCE AND APPLICATIONS

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We review the development at the Advanced Light Source (ALS) of bendable x-ray optics widely used for focusing of beams of soft and hard x-rays – Fig. 1.

Figure 1: An example of a bendable optic used at ALS beamline 5.0.2. The mirror with a 900mm long substrate is shown on the Long Trace Profiler (LTP) optical table to be adjusted to the desired spherical shape with radius of curvature of about 2300 m.

Typically, the focusing is divided in the tangential and sagittal directions into two elliptically cylindrical reflecting elements, the so-called Kirkpatrick-Baez (KB) pair [1]. Because fabrication of elliptical surfaces is complicated, the cost of directly fabricated tangential elliptical cylinders is often prohibitive. This is in contrast to flat optics, that are simpler to manufacture and easier to measure by conventional interferometry. The figure of a flat substrate can be changed by placing torques (couples) at each end. Equal couples form a tangential cylinder, and unequal couples can approximate a tangential ellipse or parabola.

We review the nature of the bending, requirements and approaches to the mechanical design, and describe a technique developed at the ALS Optical Metrology

Laboratory (OML) for optimal tuning of bendable mirrors before installation in the beamline [2].

The tuning technique adapts a method previously used to adjust bendable mirrors on synchrotron radiation beamlines [3]. However, in our case, optimal tuning of a bendable mirror is based on surface slope trace data obtained with a slope measuring instrument - in our case, the long trace profiler (LTP). We show that due to the near linearity of the bending problem, the minimal set of data, necessary for tuning of two benders, consists of only three slope traces measured before and after a single adjustment of each bending couple. We provide an algorithm that was used in dedicated software for finding optimal settings for the mirror benders. The algorithm is based on the method of regression analysis with experimentally found characteristic functions of the benders. The resulting approximation to the functional dependence of the desired slope shape provides nearly final settings for the benders. Moreover, the characteristic functions of the benders found in the course of tuning, can be used for retuning of the optics to a new desired shape without removing it from the beamline and re-measuring with the LTP.

The result of practical use of the developed technique to precisely tune a KB mirror used at the ALS for micro-focusing is also presented. We also describe a simple ray trace using the profiler data which shows expected performance in the beamline and compare the simulation with experimental data.

In summary, we also discuss the next steps in the systematic improvement of optical performance for the application of KB pairs in synchrotron beamlines at the ALS.

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Simultaneous estimation of the surface shape and the instrument error function from a highly redundant set of LTP data

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The accuracy of slope measurement with LTPs depends on the radius of the surface under test (SUT). It is clearly shown by the results of the recent COST P7 Round Robin[1] where the level of discrepancy between different instruments increases with the curvatures of the measured reference surfaces. The most obvious reason for this influence is that the optics of the LTP is not perfect and induces systematic errors that are dependant on the position of the return beam on the optics elements. The systematic error therefore depends of slope being measured.

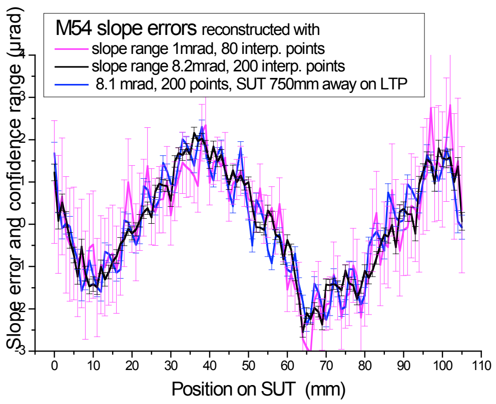
The situation is even worse with strongly curved surfaces, having a slope range larger than the measuring range of the LTP, which require tilting the surface in several steps and applying a stitching procedure. In such a case, the systematic errors of the instrument are propagated and amplified by the stitching procedure and can yield serious distortions of the measured shape. A common work-around is to limit the individual amplitude of the measured segments, thus limiting the amplitude of the defect but increasing the number of segments, i.e. the number of tilted positions of the SUT[2]. This raises the following questions: why restrict the measuring range? Couldn't the instrument error function be extracted from the high redundancy of highly overlapped full range measurements and subtracted from the data?

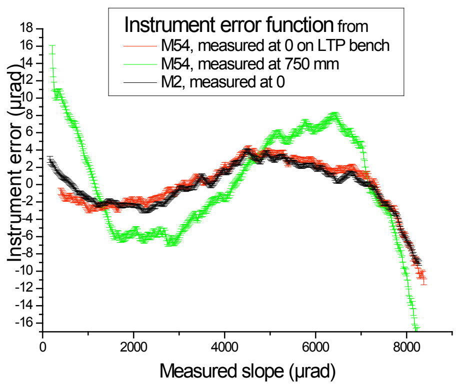
Reformulating the stitching problem to introduce the instrument error function lets give a positive answer to the last question. To the usual variables of the stitching problem, that are the surface slopes at the measured steps and tilt offset values, we add the instrument error function defined as the difference between the actual and measured slopes versus the measured one. As the measured slopes are continuous, this error function needs to be modeled by an interpolation function defined by a discrete set of parameters. A global solution of the problem is then searched as a best fit of the model defined by this extended set of parameters to the recorded data.

The stitching algorithm was implemented under Origin and applied to the processing of data of a two different mirrors called M2 (R=21.4m, L=190mm) and M54 (R=7.77m, L=110mm). Several recording configurations have been tested on mirror M54, varying the tilt step between individual traces, and the position of the mirror on the LTP bench. Reconstructions have been done varying the slope range used and the number of spline segments interpolating the instrument error.

The figures below show some of the results. The short range oscillations of the reconstructed surface slope and uncertainties are reduced by a larger overlap of the recorded data sets either by increasing the number of tilt steps either by increasing the used slope range, but the general shape is not affected. The error function is similarly affected by the data redundancy but is scaled with the position of the SUT on the LTP bench revealing its link to the spherical aberration of the LTP lens.

Extension of the procedure to mirrors that in principle do not require stitching is likely to improve the accuracy of the LTP.





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USING THE SLOPE MEASURING PROFILER TO OPTIMIZE THE SHAPE OF ADAPTIVE BIMORPH OPTICS

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A suite of four, high precision instruments [1] are used in the temperature controlled, Optics & Metrology cleanroom, to characterize the surface topography of synchrotron optics before they are installed and used on the beamlines at Diamond Light Source (DLS). One such instrument is the Slope Measuring Profiler (SMP), inspired by the "NOM" machine [2] and designed in collaboration with staff from the BESSY synchrotron. The SMP is a non-contact instrument, which utilizes a high grade pentaprism, and computer controlled air bearing stages, to scan a narrow beam of visible light across the surface under test. An electronic autocollimation telescope measures the angular deviation of the light reflected from the surface under test. Height information, with nanometre scale resolution, is extracted by integrating the angular slope data over the entire 2D surface of the optic. Optics, and associated mechanics, up to 1.5m in length and weighing hundreds of kilograms, can be mounted on the SMP. Lateral spatial errors in the range of 1mm to 1500mm are obtained by operating in "flyscan" (continuous) or "step scan" (discrete) mode. Slope errors <0.3µrad r.m.s have been routinely measured using the SMP, and repeatability (the angular difference between two similar scans, separated by a period of ~40 hours) has been recorded at 68nrad r.m.s (see Figure 1). Further technical details about the performance of the SMP, and the stability of its environment, will be presented. The SMP has now successfully measured numerous synchrotron optics, and we will show how the SMP was used to characterize a vertically focusing, thirty two piezo element, bimorph optic [3], purchased from ACCEL GmbH. This bimorph optic, and associated high voltage power supply, will be installed on the "Surfaces and Interfaces" (I07) beamline at DLS. An iterative, correction matrix algorithm, developed by R. Signorato & staff at the Elettra synchrotron, was employed, whilst the SMP actively monitored the shape, stability, and repeatability of the bimorph optic. Using this technique, the r.m.s tangential height error, over the 550mm active surface, was reduced from 83.7nm to 9.5nm; the corresponding r.m.s slope error was minimized from 1.54µrad to 0.6µrad.

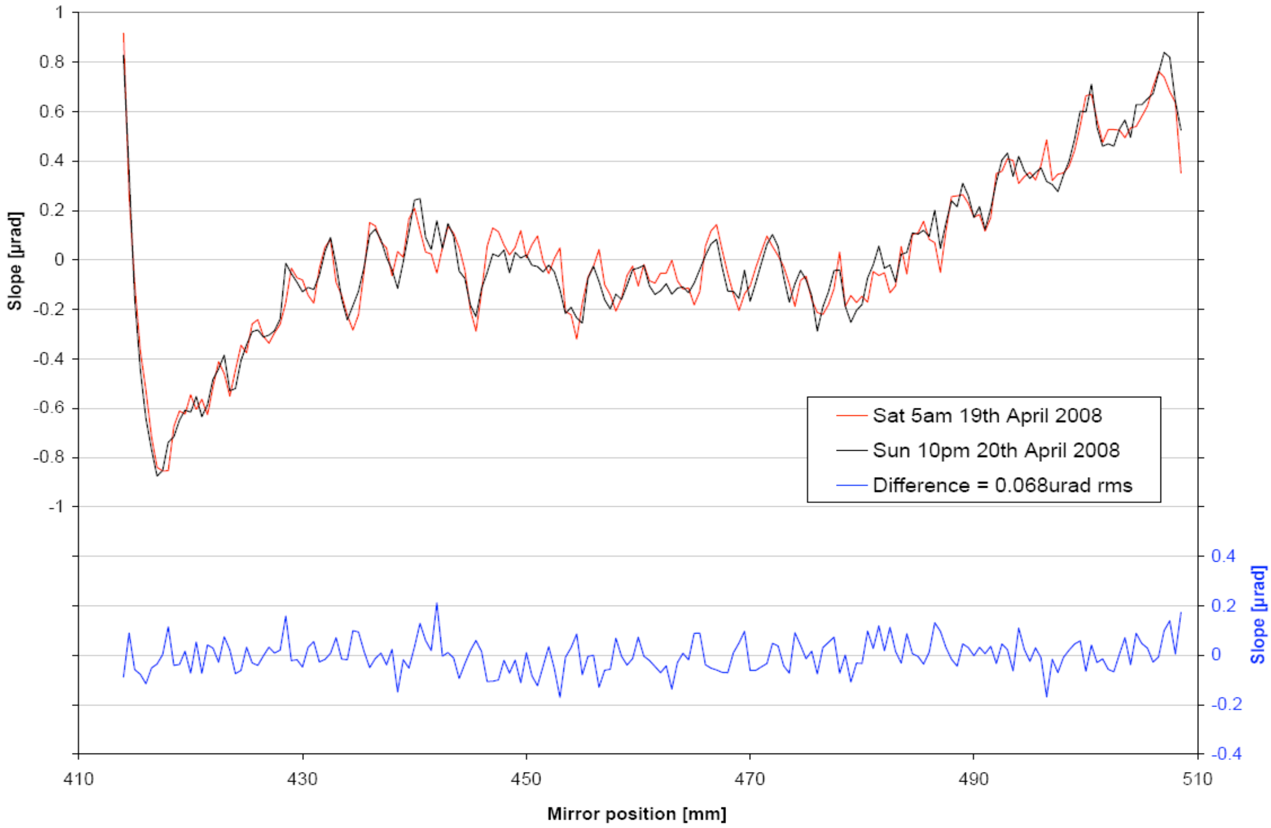

Figure 1: The repeatability of the DLS Slope Measuring Profiler

Acknowledgments

The authors wish to thank and acknowledge F. Siewert, T. Zeschke, F. Senf, and associated staff at the BESSY synchrotron, for their expert knowledge and support in helping to develop the SMP.

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ESRF OPTICAL METROLOGY APPLIED TO BENT OPTICAL SURFACES

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The ESRF mirror metrology laboratory was created 17 years ago. One of its tasks is the mirror-bender assembly calibration and acceptance tests which are carried out with the Long Trace Profiler. We will give a short overview of the long mirror bendable devices delivered from the beginning of the ESRF operation. Then we will focus on the Kirkpatrick-Baez (K-B) systems developed at the ESRF which are used on over half of its beamlines. We will illustrate how optical metrology has become a key point in the development and the production of these devices.

More recently, new requirements to focus X-ray beams down to the nanometre scale have revealed new challenges for the LTP metrology due to the steep slope variation of the optical mirror surface. We will describe the new LTP stitching measurement procedure developed to overcome this difficulty.

Finally, the most recent compact nano-focusing K-B systems (a fixed curvature and the latest ESRF design bendable K-B) will be presented.

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THE OPTICS LABORATORY AT ALBA

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The laboratory of optics of ALBA, the synchrotron radiation facility currently being installed near Barcelona, is being equipped with the optical instruments required to perform the acceptance tests of the optics for the beamlines. The main instruments are a 4 inch Fizeau interferometer, with variable spatial coherence, and a long trace profilometer (LTP). However, given the late delivery and long commissioning time foreseen for the LTP, many of the mirrors for the phase 1 beamlines will be characterized using the Fizeau interferometer. For that, 2 flats and 5 different convex reference mirrors have been purchased. This allows us to characterize 76 out of the 80 optical surfaces of the beamlines in Phase one with the interferometer.

The Fizeau interferometer is being commissioned in a temporary laboratory, in the facilities that ALBA has in the university. The laboratory is under overpressure, and the air conditioning provides temperature stable within ±0.4ºC in 24h. The limiting factor for the temperature stability is the poor isolation of the laboratory.

The interferometer measures the mirror profile with a repeatability 0.4nm RMS point to point. In well isolated environment it is limited by the noise of the CCD. The measure of the radius of curvature of mirrors provided by the interferometer is stable within a 0.47% during 8 hours of continuous measurements and is correlated to temperature variations.

In order to improve the accuracy of the Fizeau, which is limited by the errors of the reference surface, we have implemented the lateral shearing technique to the measurements provided by the interferometer [1][2]. It consists on measuring the sample mirror at two different positions, and then reconstructing the mirror surface from the differences of the two acquisitions. In this case the error of the references can be completely removed, and then the accuracy of the measurement is mainly limited by the uncertainty in the motion of the mirror between measurements: positioning errors, and parasitic angles during the translation. We propose algorithms that allow estimating these errors and reconstructing the mirror profile with accuracies in the order of the one nanometer.

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Characterization and Calibration of Slope Measuring Instruments

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Transferring and manipulating Synchrotron light from the highly brilliant source to the experimental station without significantly loss of brilliance and coherence is a challenging task in X-ray optics and needs optical elements of utmost accuracy. Thus optical elements, either fix focus or adaptive, require the characterization and optimization of shape by use of ultra-precise metrology instruments. Without accurate calibration an absolute exactness allowing for the determination of slope deviations of significantly curved surfaces smaller than 0.25 μrad rms will be doomed. Results obtained with a suitable calibration tool for slope measuring profilers, the Vertical Angle Comparator (VAC) developed at the BESSY optical metrology laboratory will be presented.

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OPTICS REQUIREMENTS FOR THE GENERATION-X X-RAY TELESCOPE

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US, European, and Japanese space agencies each now operate successful X-ray missions—NASA's *Chandra*, ESA's XMM-*Newton*, and JAXA's *Suzaku* observatories. Recently these agencies began a collaboration to develop the next major X-ray astrophysics facility—the *International X-ray Observatory* (IXO)—for launch around 2020. IXO will provide an order-of-magnitude increase in effective area (Table 1), while maintaining good (but not sub-arcsecond) angular resolution.

Table 1. Comparison of X-ray telescopes

Mission	Status	Launch	Aperture area	Resolution
Chandra (*nee* AXAF)	Operating	1999	0.08 m^2	0.5″
XMM-*Newton*	Operating	1999	0.43 m^2	15″
Suzaku (*nee* Astro-E2)	Operating	2005	0.18 m^2	120″
International X-ray Observatory (IXO)	Planning	≈ 2020	3.5 m^2	≤ 5″
Generation-X	Concept	≈ 2035	50 m^2	≈ 0.1″

X-ray astronomy beyond IXO will require optics with even larger aperture areas and much better angular resolution. We are currently conducting a NASA strategic mission concept study to identify technology issues and to formulate a technology roadmap for a mission—*Generation-X* (*Gen-X*)—to provide these capabilities.

Achieving large X-ray collecting areas in a space observatory requires extremely lightweight mirrors. For (2-reflection) X-ray optics with graze angles of order 0.01 radian, the mirror surface area is about 200 times the aperture area. Thus, the Gen-X requirement for 50 m^2 aperture area implies 10000 m^2 of mirror surface area—i.e., 10 tonne of mirrors at an areal density of 1 kg m^{-2}. NASA's plan for the Ares V heavy-lift capability will enable the insertion of *Generation-X* into an Earth-Sun L2 (second Lagrange-point) orbit, in a single launch of a single observatory (Figure 1).

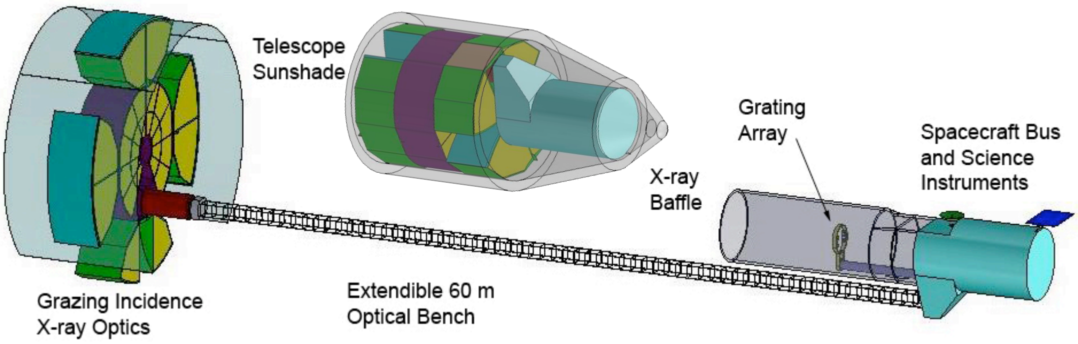

Figure 1. Conceptual configuration of the *Generation-X* telescope. The diagram shows the telescope stowed within an Ares-V 10-m-diameter shroud and deployed for in-space operation.

Achieving 0.1″ X-ray imaging with lightweight mirrors presents a major technological challenge. Accomplishing this will require excellent mirror surfaces (≤0.1 μradian RMS deviations), precise alignment, and exceptional figure control to compensate for mounting stresses. Very likely, achieving and maintaining alignment and figure control will involve active X-ray optics (Figure 2).

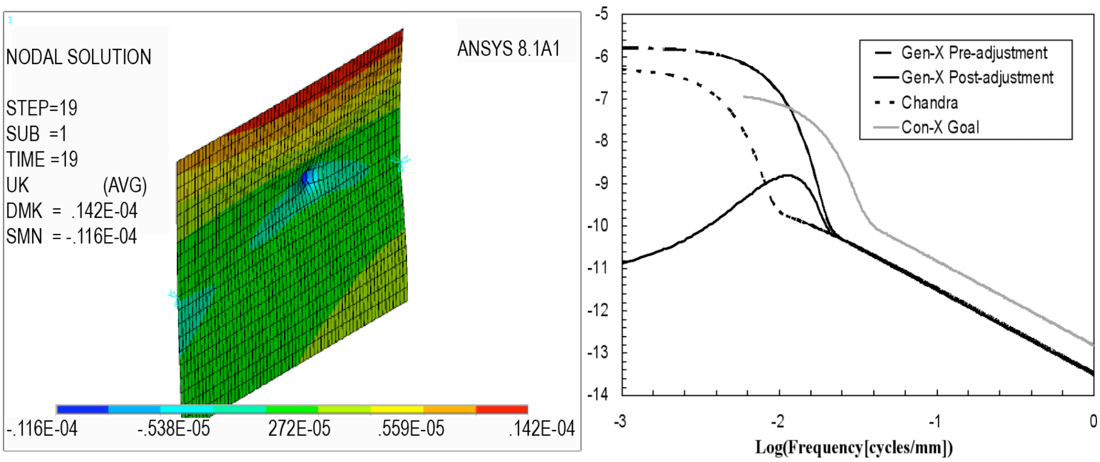

Figure 2. (Left) A finite-element analysis of the influence function for a piezoelectric bimorph zone on a thin mirror; (Right) schematic illustration of the suppression of low-frequency figure errors to correct a mounted mirror to meet the Gen-X requirements on imaging quality.

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Smart X-ray Optics for the next generation of X-ray telescopes

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The Smart X-ray Optics (SXO) project is a UK based consortium consisting of seven UK institutions investigating the application of active/adaptive optics to traditional grazing incidence X-ray optics. Research is being undertaken both on large and small scales, with intended applications for the next generation of X-ray telescopes and medical research respectively.

The current state of X-ray telescope technology is being driven by the need for large collecting area/high sensitivity across the full X-ray spectrum, for example, IXO (a combined ESA and NASA mission previously called XEUS and Constellation-X respectively), Simbol-X and NeXT. However looking beyond the next decade of X-ray telescope development, proposals have been made for an X-ray telescope capable of high sensitivity coupled with high angular resolution, NASA's Generation-X mission. It is envisioned that Generation-X would be able to achieve an angular resolution of 0.1 arc-seconds by using an active/adaptive piezoelectric actuator system, achieving a factor of five improvement on the Chandra X-ray Observatory [1].

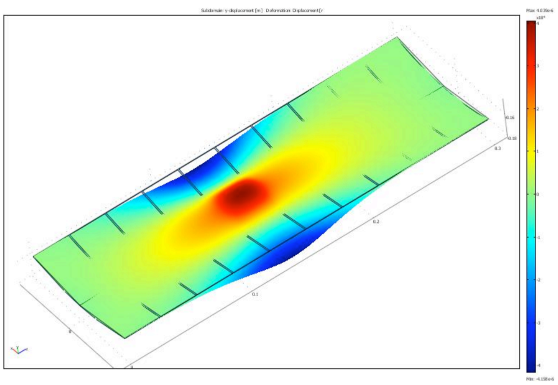
With Generation-X in mind, the SXO project is developing a large scale active X-ray prototype capable of being tested in the X-ray beam facility at the University of Leicester. The active optic is a nickel ellipsoidal shell (optic dimensions 300mm x 100mm, with a thickness of 0.4mm), the back of which will be populated by a grid of 30 curved piezoelectric actuators (actuator dimensions 29mm x 32mm x 0.2mm).

The prototype optic has been produced at University College London, using a nickel sulphamate electroforming procedure; the actuators are manufactured at the University of Birmingham and are then bonded on the reverse of the nickel shell using a low shrinkage adhesive. The actuators are controlled using a 32 channel voltage output drive, connected in series to a high voltage amplifier, providing a possible voltage range of -200V to 200V.

Deformations of the thin optical shell are expected due to the effect of gravity and handling/mounting stresses. The control algorithms that will ultimately determine the form of the optic, includes deformations due to gravity and the actuator influence functions calculated using finite element analysis (FEA). These algorithms will accurately predict the voltages required for each actuator to precisely correct the optic's form.

The piezoelectric actuators will be controlled by an iterative algorithm based on the detected full width half maximum (FWHM) or half energy width (HEW). With each iteration it is hoped that the FWHM will be reduced and the angular resolution of the optic will be improved. A series of basis patterns, created using a fast Fourier transform method, will be used and implemented by the piezo actuators in the algorithm.

Research will be presented on the continuing efforts to produce the SXO's first active X-ray focusing prototype. This will encompass: software development for the actuator control, manufacturing of the shells and theoretical computer simulations of the proposed prototype.



An FEA simulation of a central actuator at 10V, the displacement range is from -2.7 microns (blue at the wings) to 2 microns (red in the centre).

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X-RAY IMAGING TELESCOPES: PREDICTION OF THE EXPECTED IMAGE QUALITY FROM SURFACE ROUGHNESS METROLOGY DATA

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Grazing incidence mirrors optics, coated with wideband multilayer films, are envisaged in the X-ray astronomical instrumentation of the future. For SIMBOL-X[1], the required focal spot size is of the order of 15 arcsec HEW (*Half-Energy-Width*): however, the imaging quality can be severely affected by X-ray Scattering as the photon energy increases, therefore the surface roughness of the mirrors will have to be kept at a few angstroms level. The need of very smooth mirrors and of a sensitive, advanced metrology to assess the compliance of the mirrors to the imaging requirements is an important topic in all the X-ray optic field. Diagnostic methodologies involving surface topography (Atomic Force Microscope, optical profilometers like LTPs…), and X-ray scattering (XRS) techniques can be used to measure the surface roughness PSD (*Power Spectral Density*) in different, complementary spectral windows.

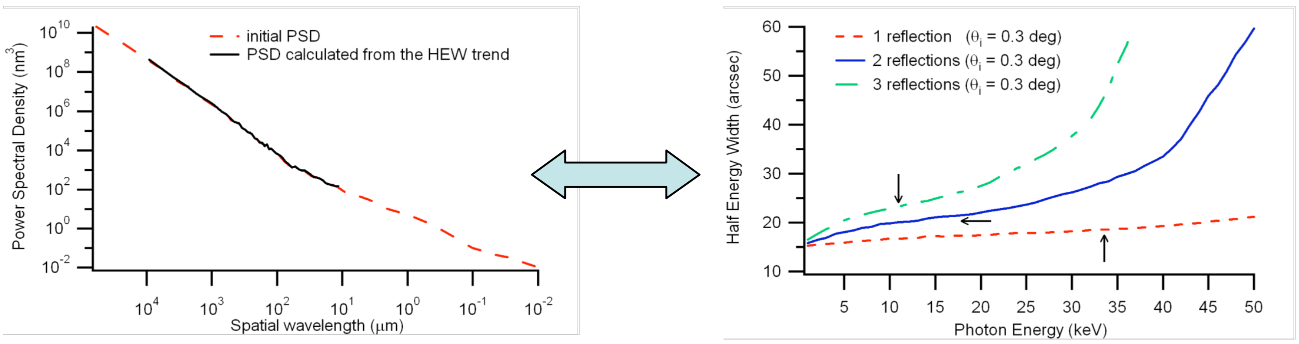

Fig. 1: an example of computation of the HEW scattering term (right panel) from the PSD (left, dashed line) of the surface of an hypothetical X-ray optical system with 1,2,3 reflections at the same grazing incidence angle of 0.3 deg, and vice versa.

However, the prediction of the optical performance from the roughness PSD usually requires a considerable amount of computation, and the calculation cannot be easily reversed (i.e. from the required HEW(λ), as a function of the photon wavelength λ, one cannot derive the needed PSD). In this work (Fig. 1) we expose an analytical approach useful to directly derive the HEW(λ) function from the sample PSD characterization the expected optical performances of the mirrors. More precisely, we assume that the "figure contribution to the HEW, H_0, and the X-ray scattering term of the HEW, $H(\lambda)$, can be combined as follows:

$$HEW^2(\lambda) \approx H_0^2 + H^2(\lambda)$$

to return the measured (or tolerable) HEW, as a function of the photon wavelength. Then, we directly relate the $H(\lambda)$ function to the mirror surface *PSD(f)*, as a function of the surface spatial frequency *f*, along with simple analytical formulae[2], based on the well-known theory of X-ray scattering from rough surfaces. The results are particularly interesting when applied to the particular case of fractal surfaces, whose roughness PSD fits a power-law model. The method is also applicable to multilayer-coated X-ray mirrors with a slowly-varying reflectance with the photon energy. Furthermore, it can also be reversed in order to translate a HEW(λ) trend requirement into a PSD tolerance (Fig. 1). The exposed formalism can be used to set roughness tolerances for future hard X-ray telescopes from the required angular resolution of the telescope[3], but it can be employed also in other sectors of X-ray optics.

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HOT PRESS DIRECT SLUMPING: AN OPTION TO MANIFACTURE DEFORMABLE OPTICS

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Here is illustrated a possible approach for the realization of deformable mirror shells. This study derive from an experience gained from an ongoing R&D program at INAF-OAB on the thermal slumping of thin glass sheets. This investigation has been financed by ESO ("E-ELT Design Study" contract) for adaptive optics for the next generation of ground based optical telescopes.

The approach developed in INAF-OAB is shown in fig. 1 and named "Hot Press Direct Slumping"[1, 2]. It foresees the use of a convex ceramic mould having a good microroughness and acting essentially as a "master". The optical surface of the glass sheet is placed in contact with the mould and pressed actively, with an uniform pressure, against it during a part of the thermal cycle in which the glass is plastic and can change its shape permanently. The overall process is done using a muffle to remove the air and to reduce the convection in order to reach a better temperature distribution homogeneity. Also, it protects the mould and the glass from the dusty environment of the oven. Afterward, a slow and controlled cooling down phase is applied and then the slumped glass sheet is released from the mould, optically characterized and integrated in an ad-hoc supporting structure.

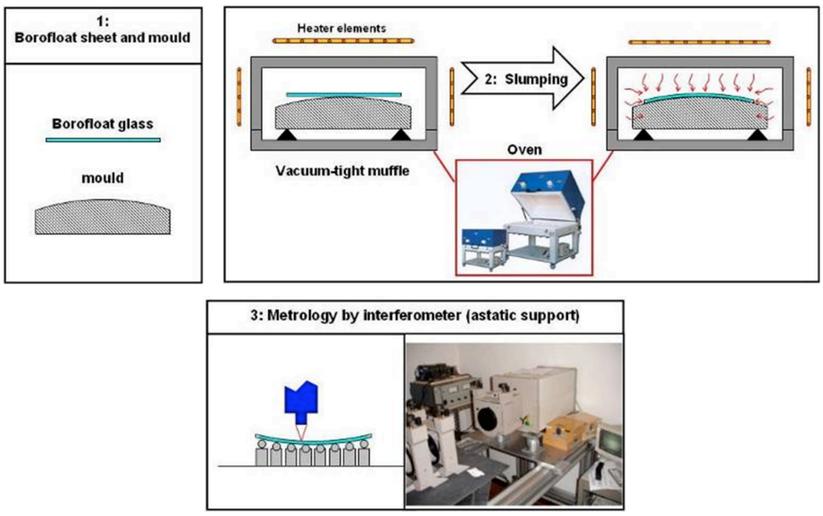

Fig. 1: Concept scheme for the "Hot Press Direct Slumping" process developed in INAF- OAB

As a brief review of some results obtained during the past two years, in fig. 2-left is shown a slumped Borofloat 33 glass segment having a diameter of 130 mm and thickness 2 mm placed onto a spherical convex mould made in Zerodur K20, having a radius of curvature of 4000 mm. The pattern of interference fringes generated from Sodium light depicts the shape difference between mould and glass: it is quite circular and regular that means that no high spatial frequencies are present and almost no dust was trapped between glass and mould. In fig. 2-right instead is shown an interferometric measure of the same slumped segment on a diameter of 80 mm that gave a residual error respect to a sphere of 57 nm rms. This means that the optical surface that was slumped had a quality of $\lambda/11$. On the overall size of 130 mm the optical quality was $\lambda/3$.

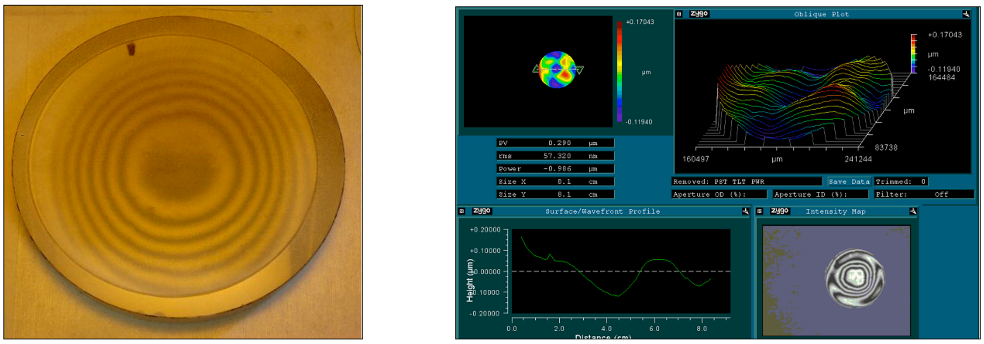

Fig. 2: (left) Interference fringes between mould surface and slumped glass. (right) Interferometric measure of a typical slumped glass shell.

During the last months we have started to scale-up the process to produce a demonstrative 50 cm diam. concave spherical mirror, with a radius of 5 m and thickness of 1.6 mm. The first tests were to fix some problems related to the larger dimension and the results are quite promising.

Ending, even if the mould shape adopted (spherical surface) and probably the thickness of the glass used are not useful for the application in the field of the X-ray optics, the investigation has permitted to INAF-OAB to gain precious experience and to put the “hands” on the slumping technique and on the related problems. In the next months we have planned to start an R&D program dedicated to X-ray optics for the next generation of large X-ray telescopes like IXO of NASA/ESA/JAXA [3].

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At-wavelength measurement and on-site compensation of wavefront error for hard X-ray nanobeam

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We developed a surface-figuring method to realize 0.1nm (RMS) level figure accuracy over the large area of several 100s mm range, and applied it to fabricate hard X-ray nano-focusing mirrors [1, 2, 3]. A total-reflection mirror fabricated was tested at the 1km-long beamline (BL29-XUL) of SPring-8 and found to realize the nearly diffraction-limited focusing with the spot size of 25 nm at the X-ray energy of 15keV.

We are now trying to form a sub-10nm X-ray beam, the wavefront perfectibility in which should be controlled with an unprecedented accuracy. We proposed novel methods to measure and correct the wavefront shape. The proposal is based on an adaptive compensation concept. An at-wavelength interferometry using a phase retrieval technique was established for the wavefront-shape measurement [4]. The intensity map near the beam waist was precisely measured by a special knife-edge method and processed to recover the phase information of the reflected X-ray beam [4, 5]. To remove the phase-error, an adaptive mirror placed upstream is employed. An on-site phase error compensation system developed was demonstrated at BL29-XUL of Spring-8 and showed good enough performance in a nano-focusing system, the diffraction-limited spot size of which was 12nm [6, 7].

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Development of adaptive mirror for wavefront correction of hard X-ray nanobeam

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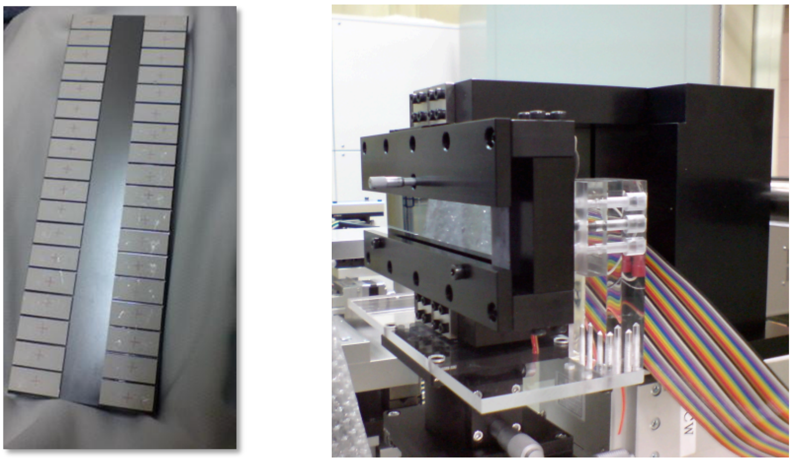
Extremely high surface figure accuracy is required for hard X-ray nanofocusing mirrors, which demands an ideal spherical wavefront in a reflected X-ray beam. For example, in the case of the realization of sub-10-nm focused beam at 20 keV, a PV figure error height of lower than 1 nm is necessary. An effective way to overcome these obstacles is to analyze and compensate wavefront errors during experiments. In the hard x-ray region, adaptive mirror is currently used to add flexibility to beamline systems [1-3]. Piezoelectric bimorph mirrors are employed to enable the adjustment of its optical properties to different beamline geometries or to variations in the grazing angle.

In this study, we developed a new adaptive mirror having unprecedented accuracy in the control of the wavefront of X-rays. The developed adaptive mirror is shown in Figure 1. Taking such high deformability and stability into account, we monitored the surface profile of the mirror continuously using a Fizeau interferometer. In the system, the degree of curvature can be adjusted at each position on the mirror at a sub-nanometer level, and maintained for a long time by feedback control. Figure 2 shows the results of the deformation test of arbitrary shape.

The intensity profiles of X-rays reflected on the mirror with several curved profiles were measured and compared at the 1-km-long beamline at SPring-8, and the measurement results of intensity profiles of reflected X-rays were shown to be in good agreement with the wave-optically simulated profiles. This indicates that ideal wavefront correction was performed and the wavefront modulation ability for the mirror is better than wavelength order. These results will contribute to the development of hard X-ray coherent science.



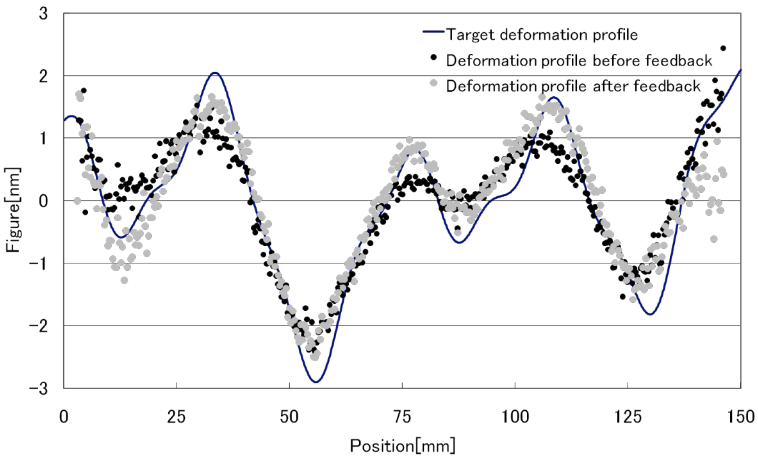


Figure 1 Adaptive mirror and wavefront correction unit.

Figure 2 Results of the deformation test of arbitrary shape.

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ADAPTIVE OPTICS AND WAVEFRONT CONTROL IN THE HARD X-RAY DOMAIN - PAST, PRESENT AND FUTURE

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Since their first presentation at SRI 1997 in Himeji, Japan, modular bimorph mirrors have undergone a complete upgrading and characterization program and have nowadays become an established, proven and reliable device, being currently used at all major third generation SR sources worldwide. More than 50 such mirrors have been built and the majority of them are already routinely used at beamlines in users service mode. The available optical lengths range from 150 mm up to 1000 mm and focusing lengths from hundred of mm to tens of meters are already implemented.

A customized, dedicated, high stability High Voltage Bipolar Power Supply system has been designed and built in collaboration with ELETTRA and is currently routinely used at several beamlines. An user-friendly GUI allows simple, reliable and safe operation of the adaptive mirrors and also offers the possibility to interface to the beamline control system via EPICS or TANGO..

This overview talk will review the main results obtained by several different users of bimorph mirrors and will report examples of adaptive wavefront correction in the hard X-ray regime. I will report experimental data showing how bimorph mirrors can be uniquely used not only to optimize the beam focusing and the Strehl ratio, but also the X-ray beam properties outside of the focal plane. It has been proven that the effect of striations (intensity modulations) in the measured beam profile can be strongly reduced, if not totally eliminated, by a proper setting of the adaptive mirror. This unique capability of bimorph mirrors has proven to be of uttermost interest to operate X-ray beamlines either with variable focal spot size or to perform experiments where the sample may be located far from the mirrors focus.

I will also briefly report experimental results showing demonstrating the possibility to perform the focusing/wavefront optimization procedure of the adaptive mirrors by using a simple Beam Position Monitor, a set of slits and a correction algorithm based on the use of the interaction/control matrix of the (mirror + photon beam) system. This straightforward process can be simply automated and is of great help in optimizing the beamline performances while making full use of the powerful capabilities offered by the adaptive bimorph mirrors hardware.

Finally, some possible R&D strategies for the near future involving both the mirror hardware/software and the substrate polishing will be outlined.

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X-ray active mirror coupled with a Hartmann wavefront analyser

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This paper reports on the design and performances of a test prototype active x-ray mirror which has been designed and manufactured in collaboration with the French SME mechanical company ISP System for the national French storage ring SOLEIL (see figure 1). Coupled with this active x-ray mirror and also in collaboration with a French SME (Imagine Optic) a lot of efforts have been done in order to design and fabricate a wavefront x-ray analyzer based on the Hartmann principle (see figure 2).

During the talk I will present the main results obtained with these two devices. I will also present some results on a developed tool for simulation of coherent wavefront propagation on X-ray optical components and wavefront phase recovery from 2D intensity distributions.

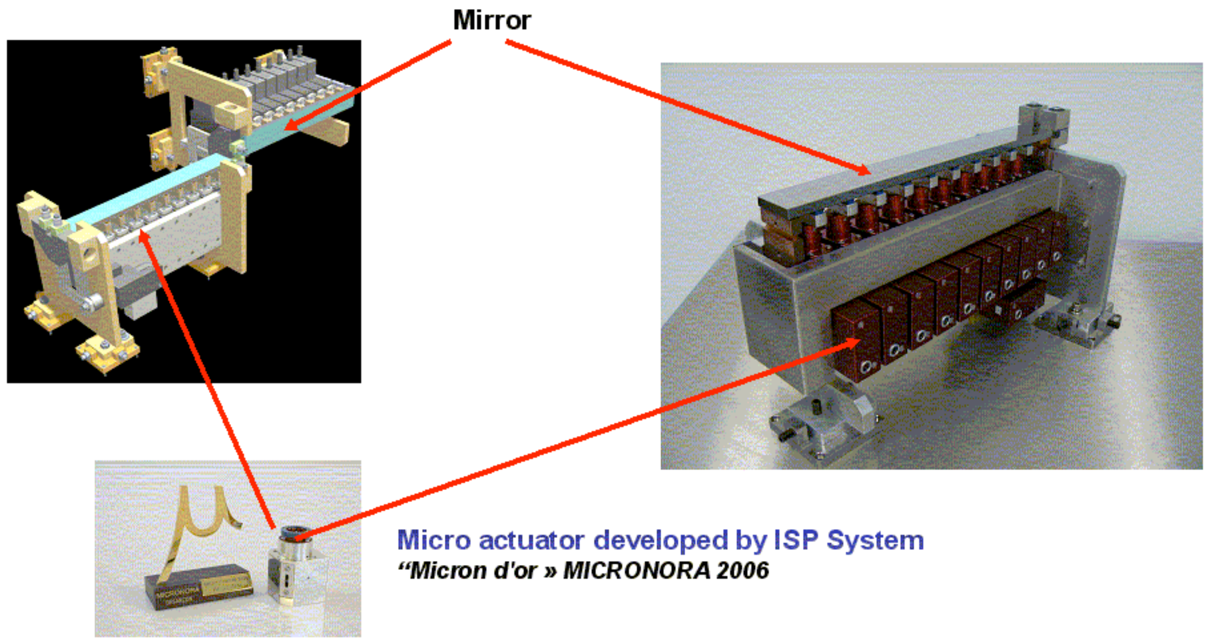

Figure 1 : X-ray active mirror (length 350 mm 14 actuators)

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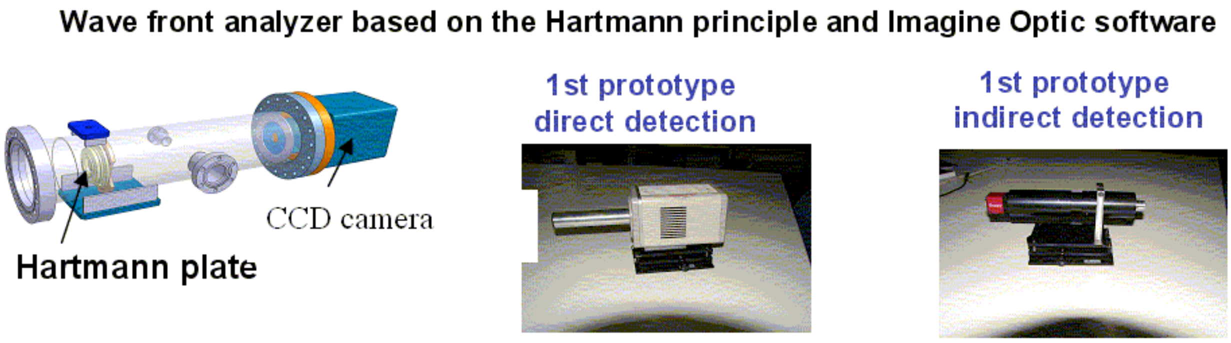

Figure : X-ray Hartmann wavefront sensors

Bidirectional membrane deformable mirror

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We present a membrane electrostatic deformable mirror which can operate bidirectionally. The electrostatic actuation of membranes is a well known class of deformable mirrors. They became popular because of their properties of good optical power, limited power consumption, achromaticity, a good dynamic behavior and low cost. Nevertheless, their major limitation is the limited optical power which limits their use in some applications. Moreover, the electrostatic actuation is unidirectional allowing the membrane to be pulled, again limiting the optical power of the mirror.

We overcame these drawbacks with a unique mirror design that comprises actuators on both sides of the membrane. Moreover, the electrodes on the top side are conductive and transparent. We propose two different membrane mirror configurations which improve the typical performances: the first device has a transparent electrode on the top side[1] (see Fig.1) and a second device with electrodes transparent patterned in the top side active region. The advantages compared to the state of the art technique for electrostatic mirror are measured and presented. The operating wavelengths are from 300nm to the infrared region.

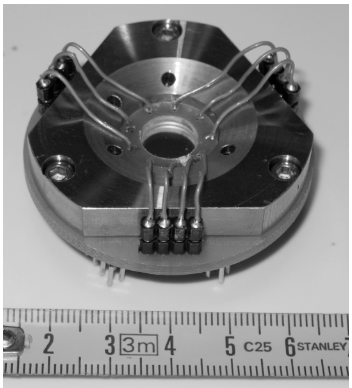

Fig 1: Prototype of bidirectional actuated membrane mirror.

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NEW HIGH VOLTAGE CONTROL SYSTEM FOR BIMORPH BENDING MIRRORS PERFORMANCE AND APPLICATIONS

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DIGITAL POWER SUPPLY CONTROLLER

The power supply system used to drive this mirror is composed by a 3U high rack containing four output cards with four high voltage outputs each, one main controller board and one power supply board. The main controller board is connected via Ethernet to a rugged industrial computer interfaced to any computer of a Local Area Network (Wi-Fi or Ethernet). All four high voltage outputs are terminated with standard high voltage SHV connectors. There are two more SHV connectors for adjacent channel hardware daisy chain protection, as mirrors have stringent electric specifications on adjacent channels. All connections come from a backplane carrying all needed signals to the boards installed. Controlling commands can be issued through a LabVIEW™ client or some of the most popular synchrotron facility control systems (Epics, Tango). System control can also be done through a web page.

AD/DA CONVERSION

Voltage monitoring is achieved by sensing the real outputs of all four channels after high stability, high voltage resistive dividers and feeding four true 24-bit delta-sigma ADC converters. The effective resolution of this converter for full speed conversion rates goes down to 19-bit, which allows grabbing 16-bit noise free data. These values are then loaded to the DSP and processed with a PID algorithm. The regulation outputs of the PID controller are then sent to the four 16-bit DAC converters closing the loop.

DIGITAL CONTROLLER

The heart of the system is a Texas TMS320F2808 100MHz DSP mounted on each output card. It performs the digital control of the four channels included on the board. One eeprom memory keeps all calibration data of the high voltage channels on board. A cubic polynomial has been used to correct the non linearity of the high voltage resistive dividers with respect to the working voltage. Four coefficients are used to get the best fit of the voltage readout. On this memory there is plenty of room to put other coefficients in order to increase the order of the polynomial or to use other methods like look up tables. Main program is written in the internal DSP flash memory, automatically loaded into its fast ram memory to speed up operation and work at full power. The firmware is completely written in C-code. All the devices controlled by the DSP (like ADCs, DACs, Eeprom) have a serial SPI interface working at a speed of 8MHz, thus taking not more than 2us time to transfer 16-bit data.

The regulator is a standard PID controller with anti-windup.

The discrete control equation is: $u(k)=u_p(k)+u_i(k)+u_d(k)$ where:

1) $u_p(k)$ is the proportional part, $u_p(k)=K_p\, e(k)$ (e(k) is the error variable)
2) $u_i(k)$ is the integral part, $u_i(k)=K_i \sum_{i=0,k} [e(i)]$
3) $u_d(k)$ is the derivative part, $u_d(k)=K_d[e(k)-e(k-1)]$

V_{err} is computed as the difference between V_{ref} (set point) and V_{out}, so the proportional output is simply evaluated as $V_p=K_p*V_{err}$.

The integral part is computed as $V_i=V_{i-1}+(K_i*V_p)+(K_c*V_{saterr})$ where the last addendum is the anti windup term. This value is evaluated as the difference between the output value after and before limiter. The derivative part is simply $V_d=K_d*(V_p-V_{p-1})$.

The digital control loop is working at 40 kHz ensuring enough bandwidth for this application, as the mirror itself has a limited bandwidth, and higher frequency components of the driving voltage are intrinsically rejected. Further developments will insure increasing the bandwidth of the controller by using faster SPI devices (higher data rate), and recoding some time crucial parts of the firmware directly in assembler.

RESULTS

Figure 1 shows the block diagram of the power supply. Both rails are controlled by the DSP via a D/A converter, in order to get adaptive voltage settings. This means that there is no need to keep the negative rail up to its maximum voltage and dissipate energy while the output is completely positive. The maximum drain and source capabilities are fixed up to 500uA per channel

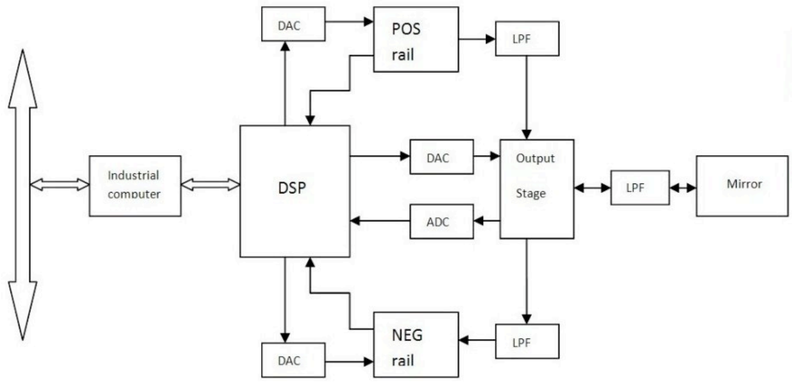

Figure 1

On a 2kV bipolar module the maximum resolution achieved for a set voltage is about 60mV.Actual noise and residual peak values at the output of these modules are better than 15ppm/FS and their long term stability is better than 100ppm/FS. These results can be improved by filtering the outputs.

If the system is thermo-statised, stability improves. Metrology and experimental results in laboratory with a long trace profiler in a thermo-statised (0.2C/week) room have shown medium and long term stability improved by a factor of two. After a week of applying the same voltage at the electrodes, the same profile (within the LTP sensibility) was measured.

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A WAVEGUIDE-BASED IMAGING SETUP FOR PETRA III

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Recent results in the field of X-ray waveguides have successfully demonstrated the imaging capability [1] and high resolution in object localization [2]. In combination with improved waveguide fabrication techniques [3] waveguide-based holographic microscopy can become a powerful tool for life sciences and nano sciences. An important advantage of holographic imaging compared to coherent X-ray diffractive imaging (CXDI) results from a deterministic and unique one-step object reconstruction. To fully exploit the potential of waveguide-based holographic imaging, we are designing and constructing a dedicated waveguide imaging endstation at the coherence beamline P10 of PETRA III.

We will present the requirements and current development status for the waveguide imaging setup, including prefocusing optics, positioning accuracy for waveguide and sample, detector resolution, overall stability and a tomography option.

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Correcting Heat Load Induced Deformations on a XUV Beamline

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A major problem affecting the performance of XUV monochromators is the impairment in resolution and/or spot size due to the power absorbed on the optics. A common approach to reduce the effect of heat load on the resolution in a vertical dispersing monochromator without an exit slit is to use a horizontally deflecting mirror as the first optical element. However, for high resolution beamlines this is not enough and it also increases the horizontal spot size.

We have recently proposed a beamline design [1] that is flexible enough to preserve both the very high resolution and small spot size at the sample even when the absorbed power densities in the first (M1, deflecting horizontally) and second (M2, deflecting in the dispersion plane) optical elements are as high as 0.92 and 0.36 W/mm^2, respectively. The beamline is based on a variable line spacing (VLS) plane grating monochromator illuminated with collimated light along the dispersion direction [1] and is the basis for the soft x-ray undulator beamlines planned for NSLS-II [2]. In this design the beam is focused at all photon energies by illuminating the VLS at the required angle of incidence with the help of the plane pre mirror (M2).

The centerline deformation and slope error along the M2 mirror length obtained from finite element analysis when the power density absorbed by the water cooled mirror is 0.36 W/mm^2 (236 W total) are presented in Figure 1. As seen in the figure, the slope error is almost linear in the region illuminated by the central cone (<40 mm). From this slope one obtains an approximate constant convex radius of curvature equal to 16 km.

With this beamline design one can correct the defocusing induced by the absorbed heat load along the dispersion direction via a modification of the *c* value ($\cos\beta/\cos\alpha$)

as demonstrated in the ray tracings seen in Figure 2. Clearly, the original spot size, i.e., same resolution, is recovered.

Similarly, the use of a horizontally deflecting bendable plane elliptical mirror allows canceling the five-fold increase in the horizontal spot size at the sample due to the deformations induced on M1.

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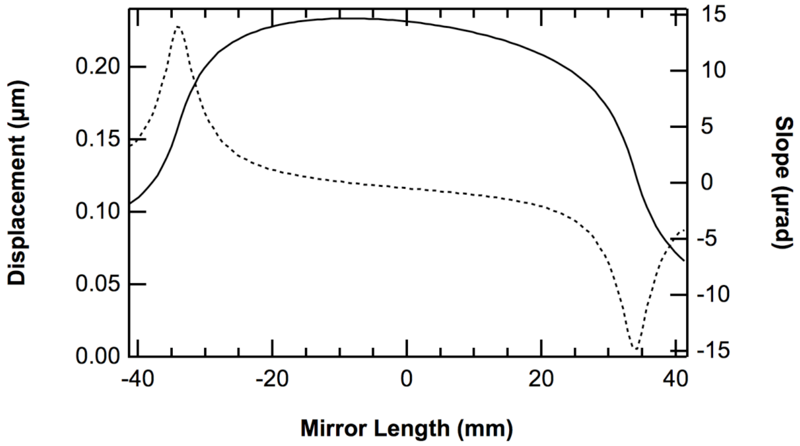

Figure 1: Displacement (solid line) and slope error (dashed line) along the M2 mirror length at half its width.

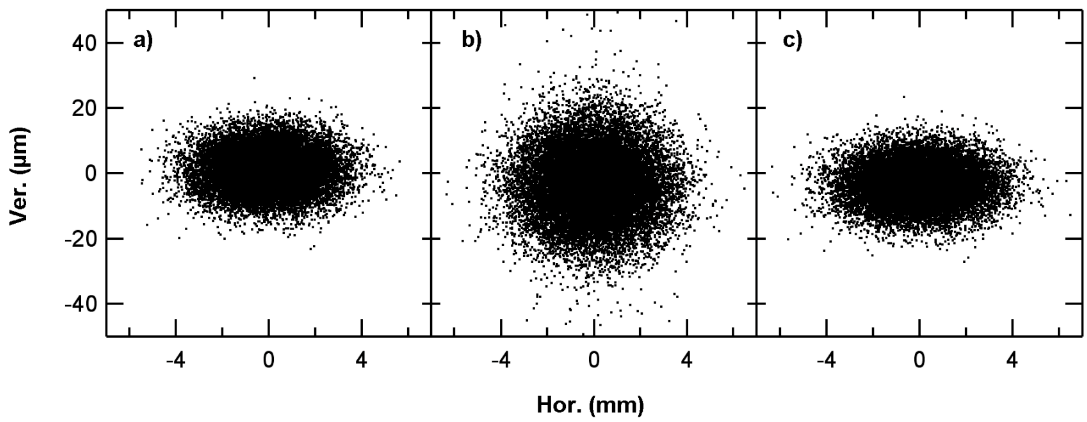

Figure 2: Spot patterns at the exit slit. a) Perfect optics; b) With slope errors on M1 and M2 due to the absorbed power on the mirrors; c) As b) after correction done by monochromator tuning.

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The SLS Optics Beamline - Performance Measurements and Status

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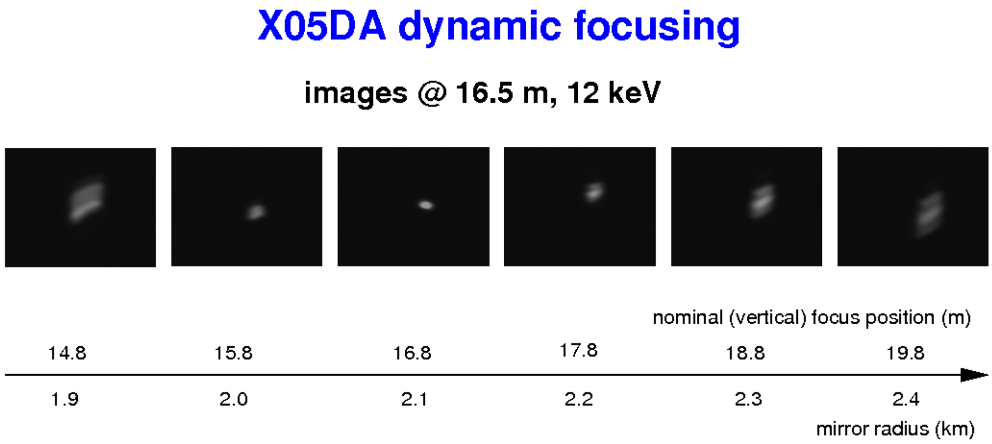
A beamline for experiments and developments in the field of X-ray optics and synchrotron radiation instrumentation in general has been installed and commissioned at the Swiss Light Source (SLS) bending magnet X05DA.

The beamline covers a photon energy range of about 5.5 to 22 keV with a cryogenically cooled channel cut Si(111) monochromator and a bendable 1:1 toroidal focusing mirror. The basic principle of the beamline has been taken over from the x-ray diffraction beamline at the Advanced Light Source (ALS BL 11.3.1) [1]. The details of the design and the hardware can be found in [2]. The monochromator and focusing mirror can be individually retracted to allow focused and unfocused monochromatic and pink beam respectively.

Since the first light in fall 2006 a basic experimental infrastructure has been installed and the beamline has been extensively characterized. Some characteristic measurements with focused monochromatic light are: a photon flux of 1.7×10^{11} photons/s at 10 keV with a resolving power $E/\Delta E$ of about 3000, a higher order contamination of 3% at 18 keV and a focus of (70 x 140) µm (v x h) @ 12 keV. The bender allows to shift the vertical focus along the beam path, alternatively one can collimate the light or defocus as shown in the figure. The mirror radius has been varied while the screen remained at a fixed position. Out of focus we see a not uniform intensity distribution which indicates residual slope errors of the focusing mirror.

In the unfocused pink beam mode we measured the power directly with a thermopile sensor. We received 10.6 W which is in very good agreement with the expectation. The horizontal opening of the beamline was 1 mrad and matched to the sensor acceptance (10 mm in diameter).



The focused pink beam mode has not been further investigated so far. The expected power density is 1.6 kW/mm^2. Tests showed- the 50 μm thick Kapton window which terminates the beamline melts within a few seconds i.e. to use this mode the experiments have to be inside vacuum.

The results of the performance measurements will be presented for the fist time. Possible applications of the beamline for "at wavelength" metrology and detector calibration will be discussed.

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