Characterization of silicon pore optics for the NewATHENA observatory in the PTB laboratory at BESSY II

Michael Krumrey

Physikalisches-Technische Bundesanstalt (PTB)
Outline

1. The NewATHENA observatory
2. The PTB laboratory at BESSY II
3. Mirror module assembly and characterization at the X-ray Parallel Beam Facility (XPBF 2.0)
4. Reflectance measurement on a mirror module at the Four Crystal Monochromator (FCM) beamline
New ATHENA facts and figures

- Two instruments (detectors):
  - X-ray Integral Field Unit (X-IFU), cryogenic imaging spectrometer, 0.3 to 10 keV
  - Wide Field Imager (WFI), silicon active pixel sensor, 0.1 to 12 keV energy range
- Effective area of $>1.1 \text{ m}^2$ at 1 keV, mirror surface $>300 \text{ m}^2$
- Angular resolution of $<9$ arcsec
- Field of view of $>40$ arcmin
- Silicon Pore Optics (SPO) with 12 m focal length
Silicon Pore Optics (SPO): mirror module production

38 plates are assembled to a stack by a stacking robot.

2 stacks are assembled to an XOU (X-ray Optical Unit) for primary and secondary reflection.

2 XOUs form a mirror module (MM).
Silicon Pore Optics (SPO): MM integration in the ‘X-ray lens‘

New ATHENA
- 13 rows
- 492 mirror modules
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PTB laboratory at BESSY II

Main parameters:
- ring circumference: 240 m
- electron energy: 1.7 GeV
- max. ring current: 300 mA, top-up
- beamlines: 50

<table>
<thead>
<tr>
<th>Beamline</th>
<th>Description</th>
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<tr>
<td>B1</td>
<td>plane grating monochromator SX700 30 eV to 1800 eV</td>
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<tr>
<td>B2</td>
<td>four-crystal monochromator (FCM) 1.75 keV to 10 keV (0.7 nm to 0.1 nm)</td>
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<tr>
<td>B3a</td>
<td>undispersed bending magnet radiation</td>
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<tr>
<td>B3b</td>
<td>normal incidence monochromator 3 eV to 35 eV (400 nm to 35 nm)</td>
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<tr>
<td>B3c</td>
<td>deflected undispersed bending magnet radiation, EUV irradiation test station</td>
</tr>
<tr>
<td>B4a</td>
<td>undispersed undulator radiation Compton backscattering</td>
</tr>
<tr>
<td>B4b</td>
<td>plane grating monochromator (PGM) at undulator, 40 eV to 1900 eV (30 nm to 0.65 nm)</td>
</tr>
<tr>
<td>B4c</td>
<td>deflected undispersed undulator radiation EUVL metrology test station</td>
</tr>
<tr>
<td>B4c</td>
<td>X-ray pencil beam facility (XPBF), astrophysics optics characterization</td>
</tr>
<tr>
<td>B5</td>
<td>X-ray parallel beam facility (XPBF 2.0), astrophysics optics characterization</td>
</tr>
<tr>
<td>B6</td>
<td>Tender X-ray microfocus beamline 1.5 keV to 10 keV (multilayer mirror monochromator &amp; DCM)</td>
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<tr>
<td>B7</td>
<td>BAMline, double multilayer and double crystal monochromator (DCM &amp; DMM), 8 keV to 60 keV</td>
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X-ray Parallel Beam Facility (XPBF 2.0)

- Cooperation between PTB and ESA for optics and detector characterization with synchrotron radiation since 1994 (BESSY I)
- X-ray Pencil Beam Facility (XPBF 1) in operation since 2005
- X-ray Parallel Beam Facility (XPBF 2.0) in operation since 2016, upgraded in 2020
**Toroidal mirror**
- Radii: 210 m, 4.3 m
- W/Si multilayer coating, $d$-spacing 4.4 nm
- Grazing incidence angle: 8.5°
Sample chamber of XPBF 2.0

Hexapod for sample (mirror module) positioning
- Travel ranges hor. plane: ± 60 mm, vertical ± 30 mm (+ 85 mm)
- Angular range: 15°, freely selectable pivot point
- Angular positioning accuracy: 0.7 arcsec using feedback from two electronic autocollimators
Detector ‘tower’ of XPBF 2.0

- Vertical translation: 2.1 m
- Translation: in beam direction 1 m, perpendicular 100 mm
- Absolute detector position measurement with laser tracker
- Phosphor screen, tandem optics, CCD camera 2048 x 2048, 13.5 µm pixel size
Available beam at XPBF 2.0

Pinhole beam or large area (typ. 100 µm to 7.5 mm)

Monochromatic, 1 keV

Spectrum measured with SDD

Parallel beam, divergence below 2 arcsec

Raytracing result (RAY)
Assembly of mirror modules at XPBF 2.0

Mirror Module (MM): combination of two XOUs

- Assembled at XPBF 2.0 using 3 hexapods for positioning of the stacks
- X-rays are used for the alignment
Characterization of XOUs at XPBF 2.0

Time evolution of X-ray Optical Unit quality

Silicon Pore Optics
XOU middle-radius performance
34 plates (XOUs since 2021-01)
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Four Crystal Monochromator (FCM) beamline
MM-0061 in the reflectometer at the FCM beamline
**X-ray fluorescence (XRF) scan on part of MM top layer**

- **Photon energy**: 3.6 keV
- **Pencil beam (ap)**: 0.2 mm x 0.2 mm

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**Graphs**

- **XRF Signal / counts vs. Energy (eV)**
  - Peaks for **Ir** and **Si**
  - **O** trace
- **Sample X (mm)** vs. **Ir**, **Si**, and **O** concentrations
  - Peaks at sample positions 90, 92, 94, 96, 98, and 100

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**National Metrology Institute**

Physikalisch-Technische Bundesanstalt - Braunschweig and Berlin
MM reflectance line scan

No reflectance when the beam is hitting the ribs or the underlying plate (due to the curvature)
Reflectance of different MM pores

Photon energy scans through individual pores, double reflection
Very stable beam position required!

- pores on 3 different plates (1, 9, 17)
- 2 off-center pores for plate 1 (± 20 mm)

Raster scans at fixed angle
Double reflection, variation of the incidence angle by $\pm 0.5^\circ$

Earlier measurements from January 2022 on a partly coated MM which has also been measured at the PGM beamline in the energy range from 0.2 to 1.8 keV. Double reflection peaks remain at the same position.
Conclusion and outlook

- NewATHENA will be the largest X-ray telescope ever flown
- Mirror will be based on Silicon Pore Optics
- Mirror Modules are assembled and characterized at XPBF 2.0
- Energy-dependent reflectance has been measured on a Ir coated mirror module at the FCM beamline in the range from 1.75 to 10 keV
- Currently, a (partly modified) copy of XPBF 2.0 (called MINERVA) is being installed at the ALBA synchrotron radiation facility in Spain
- After final mission adoption, two additional beamlines will be installed in the PTB laboratory at BESSY II for the production of the about 500 mirror modules
- The launch of NewATHENA is currently scheduled for 2036, the budget for ESA is 1.3 G€
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