Beamlines at MAX IV – optical design and commissioning

Andreas Lassesson
Beamline Project Coordinator
Outline

Overview of MAX IV beamlines

Beamline design philosophy

Commissioning & early users
The 14+ funded Beamlines

1. FemtoMAX (2015)
   - Ultra-fast processes in materials

   - Imaging, spectroscopic & scattering with nanometer resolution

3. BALDER (2016)
   - X-ray absorption spectroscopy in-situ and time resolved

   - Highly automated macromolecular crystallography

5. VERITAS (2016)
   - RIXS with unique resolving power and momentum resolution

6. HIPPIE (2016)
   - High-pressure photoelectron spectroscopy

7. BLOCH (2017)
   - Angle resolved photoelectron spectroscopy

8. FinEstBeAMS (2017)
   - Estonian-Finnish Beamline for Materials Science

9. SPECIES (2017)
   - VUV High-pressure photoelectron spectroscopy and RIXS

10. FlexPES (2018)
    - Photoelectron Spectroscopy and NEXAFS

11. MAXPeem (2018)
    - Photoelectron microscopy

    - Small angle scattering

    - Coherent Soft X-Ray Scattering, Holography...

14. DanMAX (2019/20)
    - Paper and pulp

MicroMAX
   - Frontier MX

ForMAX
   - Paper and pulp

DiffMAX
Beamline timeplan

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Beamline timeplan

1. Time resolved experiments (<100 fs)
2. Nano/micro diffraction and imaging
3. X-ray absorption spectroscopy
4. Protein crystallography
5. RIXS
6. High pressure photoemission spectroscopy
7. ARPES


Phase I – 7 beamlines

Phase IIa – 6 beamlines

Phase IIb – >2 beamlines
Beaml ine timeplan

- SAXS
- Imaging; STXM, CXI
- Photoemission spectroscopy
- RIXS
- XPEEM
- Gas phase spectroscopy

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Beamline timeplan

- Imaging; tomography
- Diffraction
- SAXS
- Micro-crystal protein crystallography


**Phase I** – 7 beamlines

**Phase IIa** – 6 beamlines

**Phase IIb** – >2 beamlines
Commissioning status

- 4 beamlines with external or expert users in 2017
- 2 beamlines have commissioned optics & are finishing endstations
- 3 beamline is about to commission optics with endstations mostly in place
Low emittance: high flux, small source, low divergence

Energy resolution
Spatial resolution
Coherence

Small spot with low divergence:

Micro diffraction w/ high resolution

Energy resolution

PRL 104, 193002 (2010)

Optical design

- The optics in MAX IV beamlines are designed to meet scientific design targets while exploiting the properties of the MAX IV sources.

- Simulations are typically done by beamline project managers with assistance of experts in various simulation software:
  - Ray – ray tracing, Rami Sankari
  - XRT – ray tracing & wavefront propagation: Konstantin Klementiev
  - MESH - ray tracing and heat load calculations: Peter Sondhauss

- Output:
  - Beamline layout
  - Shape & type of optical elements
  - Min. slope errors & roughness
  - Spot size, beam divergence etc.
Optical design – soft X-ray beamlines

- Standardized design criteria
- cPGMs – blazed and laminar gratings
- 8 beamlines
Stability – optical systems

- Stiff (high spring constant) & light (low mass): high eigenfrequencies
- Design process in collaboration with vendors

Mirror chamber: FMB (Prototype)
- FEA: 112Hz
- Measured: 95Hz

Grating monos: Toyama
- FEA: 119Hz
- Measured: 100-120Hz

Stability responsible: Brian N Jensen
Gratings

Blazed and laminar gratings from HZB are used at all 8 soft X-ray beamlines at MAX IV

Substrates:
- Plane & curved
- Slope errors <0.02 arcsec substrates

Specifications:
- Blaze angles: 0.5 – 6 degrees
- Line density: <100 – 4000 l/mm
- Length: 120 – 300 mm
- Energy: <5 - 2000 eV
- Coatings: 40nm Au, Rh
Gratings - design

Example 1:
“Work horse” grating for the BLOCH beamline:
• Blaze angle: 2 degrees
• Line density: 800 l/mm
• Length: 140 mm
• Energy: 10 - 1000 eV
• E/dE: 1E4
• Flux: 1E13 ph/s

Example 2:
High energy resolution at low energies at the BLOCH beamline:
• Blaze angle: 6 degrees
• Line density: 2400 l/mm
• Length: 140 mm
• Energy: 10 - 200 eV
• E/dE: 1E5
• Flux: 1E11 ph/s
High energy resolution (VERITAS)

- RIXS beamline
- Energy range 250 – 1600 eV at 3 GeV ring
- Team:
  - Marcus Agåker (Uppsala U)
  - Conny Såthe
  - Shih-Wen (Winnie) Huang
  - Nial Wassdahl
High energy resolution (VERITAS)

Resolution contributions:
- Source size (diffraction limited)
- (slope errors of the) optics
- Slit size
- Mono: (moderately) high resolution, high flux, small spot
- Gratings: 1200 l/mm & 2400 l/mm

Early commissioning results:
- Approx. 30000
The VERITAS spectrometer

- 10 m long, Rowland type
- > 35 000 resolving power
- 980 mm long collimating mirror to increase collection efficiency
- 2 cylindrical gratings
- MCP based detector with 2D DLD readout (150 ps time resolution)
High spatial resolution (SoftiMAX)

- Imaging beamline
- Beam size: ≥10 nm (STXM) - 20 μm (CXI)
- Energy range: 275 – 2500 eV
- First users: 2019
- Two branchlines for:
  - Scanning Transmission X-ray Microscopy (STXM)
  - Ptychography (STXM)
  - Fourier Transform Holography (CXI)
  - Resonant soft X-ray scattering (CXI)

SoftiMAX – optical design

Simulations by:
- Karina Thånell
- Rami Sankari
- Konstantin Klementiev
- Walan Grizolli

Using:
Ray & XRT

where to put FZP?
what is the result if finite beam emittance?
what are the coherence properties?
how to isolate the coherent part?
How to isolate the coherent part? - XRT

Simulations by: Konstantin Klementiev
Using XRT: https://pypi.python.org/pypi/xrt
High spatial resolution (NanoMAX)

- 5 – 30 keV (3rd-17th harmonic from undulator)
- SSA: Tune coherence / flux for KB, ZP and different wavelengths

Ulf Johansson
Gerardina Carbone
Sebastian Kalbfleisch
Alexander Björling
Ulrich Vogt, KTH
Anders Mikkelsen, LU
NanoMAX – commissioning:
ZP test setup (11/2016)
NanoMAX - KB endstation

- Hyperpolished mirrors in KB configuration
- Focal spot: 40-200 nm
- Sample holder: Goniometer, <5 kg
- 2D pixel detector on robot arm
- Fluorescence detector
NanoMAX – commissioning KB setup

Ptychography at 9.5 keV

Imaging of Siemens stars

Beam properties close to focus

Spot size and phase

Beam sideview
NanoMAX – first user results at KB endstation

Nano wires: Jesper Wallentin, NanoLund, Lund University

Direct resolution: XRF map:

Preliminary 2D reconstructions:
## HIPPIE

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<tr>
<td>Energy</td>
<td>110 – 2,000 eV (LP)</td>
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<td>Resolving power</td>
<td>30,000 – 40,000</td>
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<td>Flux (500 mA)</td>
<td>&gt; $10^{12}$ @ $R = 10,000$</td>
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<td>Spot size</td>
<td>50 x 50 µm²</td>
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- **Catalysis cell**
- **Liquid Cell**
- Retractible sample compartment
- Pump
- Pump
- Pump

**Beamline Manager**: Andrey Shavorskiy
**Beamline Scientist**: Jan Knudsen
**Research Engineer**: Suyun Zhu
**Spokes Person**: Joachim Schnadt
HIPPIE - AP XPS endstation

- General Purpose/Catalysis cell available
- Electrochemical/Liquid/Jet cell testing 2018
- AP-XPS up to 30 mbar (N2) tested
- Gas dosing system for up to 8 individual gases and their mixtures
- 4 user groups so far, more to come in 2018!
MAX IV Laboratory is a national research infrastructure hosted by Lund University

- Accelerators and basic lab infrastructure:

- Beamlines

- International beamlines:
Thank you!