PtyNAMi

Ptychographic Nano-Analytical X-ray Microscope at PETRA III
How to achieve sample stability in the nanometer range

Ralph Döhrmann
Paris, 28 June 2018
PtyNAMi

How to achieve sample stability in the nanometer range

Short Overview

• Experimental methods
• Beamline layout
• Experimental setup
• Performed measurements
• Stability considerations
Beamline Layout

P06 Nano Probe Beamline

Hard X-ray
Micro/Nano- Probe Beamline P06

- energy range from 7 to 30 KeV
- Focus size: 30 - 80 nm
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Experimental methods

Why do we need stable conditions for Ptychography
Experimental methods

Ptychography at the P06 Nanoprobe experiment

**Requirements**
- Beam size below 50nm
- Sample scans
- Precise movements
- Precise position information
- Small distances (2-30mm)
- Stable conditions
- Flux hungry
- Fast movements
- Fast detectors
- Can be combined with fluorescence measurements

**Diagram**
- Fast data acquisition
- Sample
- Pinhole
- Nano-focusing optic
- NFL horizontal
- NFL vertical
- Detector
- Sample Scanner
- SR Beam
- 30-50nm beam size
- Reconstructed image
- Reconstruction
- Scan area
- Reconstructed image
Experimental methods

Ptychography at the P06 Nanoprobe experiment

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Ptycho-tomography

- Precise rotation
- Long-term stability
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How to achieve sample stability in the nanometer range

Beamline Layout
For beamline P06 and nanoprobe endstation
Beamline Layout

Overall setup of the Micro- and Nanoprobe beamline

31.75 m distance to source

97.5 m
Beamline Layout

Overall setup of the Micro- and Nanoprobe beamline

- P06 optics
- Distance to source: 31.75 m
- P06 Experimental Control
- Nano probe hutch with PtyNAMi setup
- Multi-layer monochromator
- Double crystal monochromator
- HO suppressing Mirrors
- Pre focusing CRL-System

DESY | PtyNAMi @ PETRA III | Ralph Döhrmann | MEDSI Conference | 28 June 2018
Beamline Layout

Overall setup of the Micro- and Nanoprobe beamline

- P06 optics hutch
- 31.75 m distance to source
- Vacuum chamber with CRL-changer system for pre-focusing

P06 optics

- Multi-layer monochromator
- Double crystal monochromator
- HO suppressing Mirrors
- Pre focusing CRL-system

Micro-focusing CRL-lens system:

- Binary stack arrangement
- Adaptable to energy
- Pre focus size at Nano optics (100-200 µm)
- Increase intensity or coherence at sample
Beamline Layout

Overall setup of the Micro- and Nanoprobe beamline

- **P06 optics hutch**
- **31.75 m distance to source**
- **Nano probe hutch with PtyNAMi setup**
- **Multilayer monochromator**
- **Double crystal monochromator**
- **HO suppressing Mirrors**
- **Pre focusing CRL-System**

**Vacuum chamber with CRL-changer system for pre-focusing**

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**Experimental Control**

- P06 optics hutch
- Vacuum chamber with CRL-changer system for pre-focusing
- Force-amplification by toggle principle
Beamline Layout

Overall setup of the Micro- and Nanoprobe beamline

31.75 m distance to source

P06 optics

Vacuum chamber with CRL-changer system for pre-focusing

Force-amplification by toggle principle

Experimental Control

P06 optics

Nano probe hutch with PtyNAMi setup

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Multilayer monochromator

Double crystal monochromator

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Pre focusing CRL-System

P06 optics hutch

Micro-focusing CRL-lens system:

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- Adaptable to energy
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Force at spring (0.5mm travel)

Force at piezo motor

Pressure chamber with CRL-changer system for pre-focusing

Force-amplification by toggle principle
Beamline Layout

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- P06 optics
- Multilayer monochromator
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- Distance to source: 31.75 m

Vacuum chamber with CRL-changer system for pre-focusing

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- P06 Experimental Control
- Nanoprobe hutch with PtyNAMi setup
- 31.75 m distance to source
- P06 Nano probe experiment (PtyNAMi)
- Sample Position
- Detector bench

P06 optics hutch

Multilayer monochromator
Double crystal monochromator
HO suppressing Mirrors
Pre focusing CRL-System

P06 optics
Experimental Setup

Overall setup of the Nanoprobe experiment

P06 Experimental Control
Nanoprobe hut with PtyNAMi setup

Short term 1-2h ±0.02K
Long term 1-2d ±0.05K

Air conditioning

Temperature stability in the Nano Hutch

P06 Nano probe experiment (PtyNAMi)
Experimental Setup

Overall setup of the Nanoprobe experiment

Sample to Detektor maximal 3300mm

P06 Experimental Control

Nanoprobe hutch with PtyNAMi setup

Sample Position

Detector bench

Air conditioning

P06 Nano probe experiment (PtyNAMi)
Experimental Setup

Overall setup of the Nanoprobe experiment

- Sample position
- Fluorescence detector
- WAXS detectors
- Adaptive flight tube
- Optional position for detectors
- Eiger 4M detector in vacuum
- Detector bench
- Sample Position
- P06 Nano probe experiment (PtyNAMi)
- Detector bench
- Nano probe hutch with PtyNAMi setup

Sample to Detektor maximal 3300mm

97.5m
Experimental Setup

Overall setup of the Nanoprobe experiment

- **Adjustable flight pass**: ca. 1900mm
- **Sample position**
- **Fluorescence detector**
- **WAXS detectors**
- **Adaptive flight tube**
- **Optional position for detectors**
- **Eiger 4M detector in vacuum**
- **Sample Position**
- **Detector bench**

*P06 Nano probe experiment (PtyNAMI)*

*97.5m*

*Nano probe hutch with PtyNAMI setup*

*P06 Experimental Control*
Experimental Setup

Overall setup of the Nanoprobe experiment

- Sample position
- Fluorescence detector
- WAXS detectors
- Adaptive flight tube
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Functionality of the detector bench

Adjustable angle ca. 20°

Nano probe hutch with PtyNAMi setup

P06 Nano probe experiment (PtyNAMi)

97.5m

P06 Experimental Control

97.5m

Overall setup of the Nanoprobe experiment
Experimental Setup

Overall setup of the Nanoprobe experiment

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Nano probe hutch with PtyNAMi setup

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P06 Experimental Control

Sample position

Fluorescence detector

WAXS detectors

Adaptive flight tube

Optional position for detectors

Eiger 4M detector in vacuum

Sample Position

Detector bench

Functionality of the detector bench
Experimental Setup

Overall setup of the Nanoprobe experiment

Sample position
Fluorescence detector
WAXS detectors
Adaptive flight tube
Optional position for detectors

P06 Nano probe experiment (PtyNAMi)

Functionality of the detector bench

Eiger 4M detector in vacuum

Sample Position

Detector bench

Nano probe hutch with PtyNAMi setup

97.5m

Experimental Control

P06

Overall setup of the Nanoprobe experiment
Experimental Setup

Overall setup of the Nano probe experimental hutch

- Sample environment
- Detector bench
- Beamstop Device
- 2D-Detector
- Linear-stage for horizontal and angular adjustment
- Z-stage for vertical and angular adjustment
Experimental Setup

Sample environment

- Rigid titanium frame
- Invar Case can be opened
- Centering stages
- High precision rotation stage
- Sample positioning stages
- Scanner stages
Experimental Setup

Sample environment

- Rigid titanium frame
- Invar Case can be opened
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- High precision rotation stage
- Sample positioning stages
- Scanner stages

Stability considerations
Lowest eigenfrequency 336.8Hz
Experimental Setup

PtyNAMi standard setup

**Nano-focusing optics**
- Precise and independent positioning possibilities of Nano-optics, laser-optics and sample
- Possibilities to assemble components in the limited spaces

**Position monitoring using**
- Laser interferometer and Ball-lens
- Allows for rotation
- Fast and Precise

**Sample**
- Nano-focusing optics
- Laser optics
- Scanner stages 100µm xyz-travel range
- Ball lens

**Fluorescence detector**
- Pinhole

**Ball lens with refractive index n=2, is metal-coated on one side, to increase signal quality**

**Arrangement of lasers for two-dimensional position measurement**

Option to open the bracket
Experimental Setup

PtyNAMi standard setup

- PtyNAMi standard setup
- Option to open the bracket
- Possibilities to assemble components in the limited spaces
- Precise and independent positioning possibilities of Nano-optics, laser-optics and sample
- Position monitoring using:
  - Laser interferometer and Ball-lens
  - Allows for rotation
  - Fast and Precise

**Ball Lens as a retroreflector**

Focal Length $f$ in a Ball Lens

$$f = \frac{nr}{2(n-1)}$$

Our ball lenses:

- $n = 1.955$ @ $\lambda = 1550\text{nm}$  \( r = 5\text{mm} \)
- Usable travel range $d$

Good situation: $\sim 1\text{mm}$ (optimised laser alignment)
Real situation: $\sim 250\mu\text{m}$
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Position stability
Some results, measured with the laser interferometer
Position Stability

Position information from standard setup obtained by the interferometer

Measurement conditions
- Measured with laser 1 and 3.
- Laser 2 is used for correction only.
- Position measurements performed during continuous scan
  - Horizontal deviation 24.7nm (rms)
  - Vertical deviation 9.6nm (rms)
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Position information from standard setup obtained by the interferometer

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- Measured with laser 1 and 3.
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Not bad! But it could be better
Position Stability

Experimental option for an extremely stable setup

How to increase stability

- Removing all sources of vibration
- Reduction of the degree of freedom and increase in stiffness.

Ultra stable scanner setup for 2D-scan experiments.
How to increase stability

- Removing all sources of vibration
- Reduction of the degree of freedom and increase in stiffness.

Position Stability
Experimental option for an extremely stable setup

Ultra stable scanner setup for 2D-scan experiments.

- Blue points: standard Tomography setup.
- Orange points: modified setup deviations horizontal 0.67nm (rms) vertical 1.5nm (rms)

- Blue lines: standard Tomography setup.
- Orange lines: modified setup deviations horizontal 0.38nm (rms)
Position Stability

Comparison between standard setup and modified setup (Flexibility vs. Stability)

RMS may be misleading!
Stability considerations

For further improvements
Stability considerations

To achieve the best measurement conditions

- Vibration-optimised design for experimental hutches
- Rigid construction
- Rigid and stable supports
- Ultra stable setups
- Passive vibration damping
- Passive stability
- Thermal stability
- Materials with low thermal expansion
- Constructive arrangements
- No heat input
- Low vibration background
- No internal vibration sources
- No external vibration sources

PETRA IV Beamlines and Experiments

- Environmental control
  - Precise measurements
  - Precise value adjustment
- Compensation of disturbing influences
  - No internal vibration sources
  - No external vibration sources
- Position control
  - Fast position measurements
  - Precise position adjustment
- Elimination of disturbing influences
  - Vibration extinction (anti noise)
  - Active vibration compensation
  - Active vibration damping
- Fast vibration measurements
- Rigid construction and stable supports
- Ultra stable setups
- Low vibration background
- Vibration optimised design
- Constructive arrangements
- Motors, Lamps, Cameras, Power supplies
- Precise measurements
- Precise value adjustment
- Fast position measurements
- Precise position adjustment
Conclusions

• An overview on the experimental setup was given.
• A new adaptive detector bench and its functionality were explained.
• The PtyNAMi setup with interferometric position detection has been presented.
• Two different scanner setups and its maximum positional stability of 0.38 nm was shown.
• Options for further improvements in position stability have been identified.
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