Table-top EUV/XUV source

Generating 2-20 nm wavelength radiation

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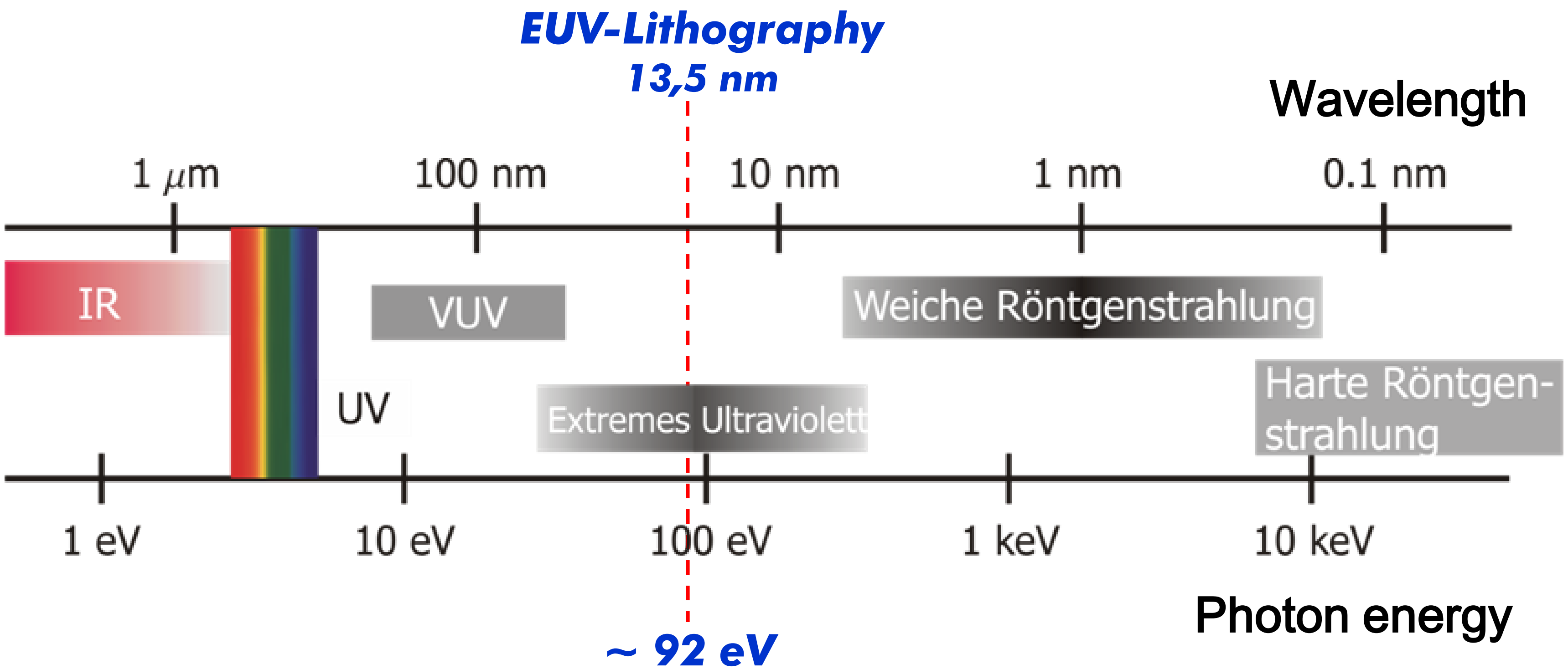
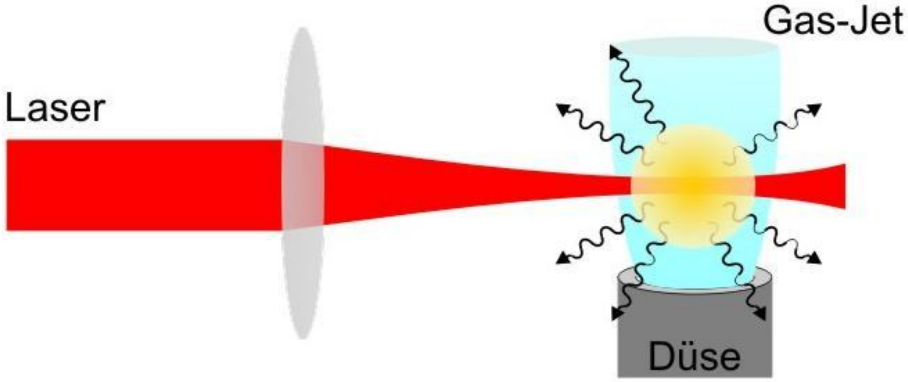
Laboratorium
Göttingen e.V.

Spectrum of electromagnetic radiation

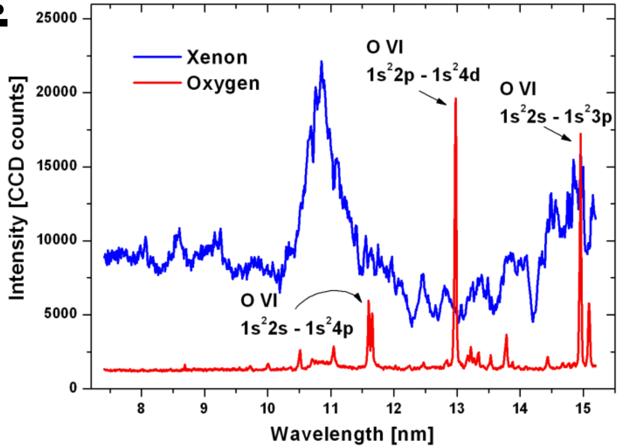


Principle of laser-produced plasma

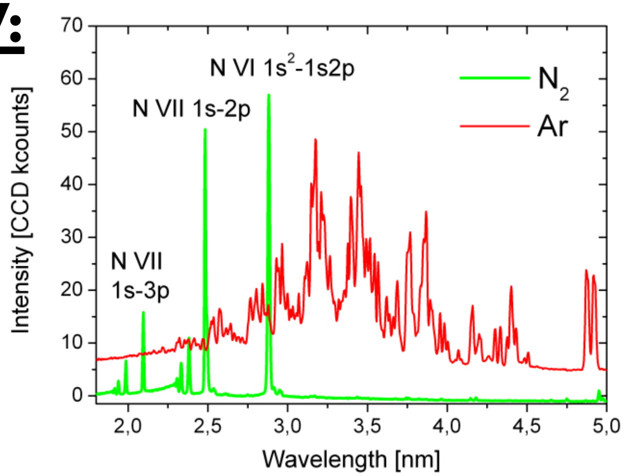


- **High-energy laser focused on gaseous target**
- **Emission spectra depending on target gas**

EUV:

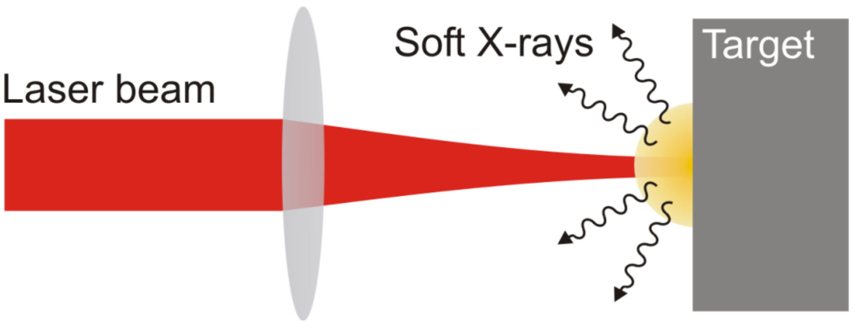


XUV:

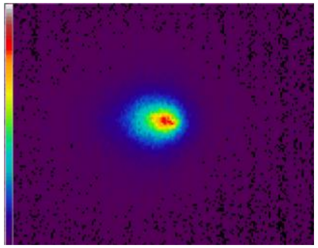


Principle of laser-produced plasma

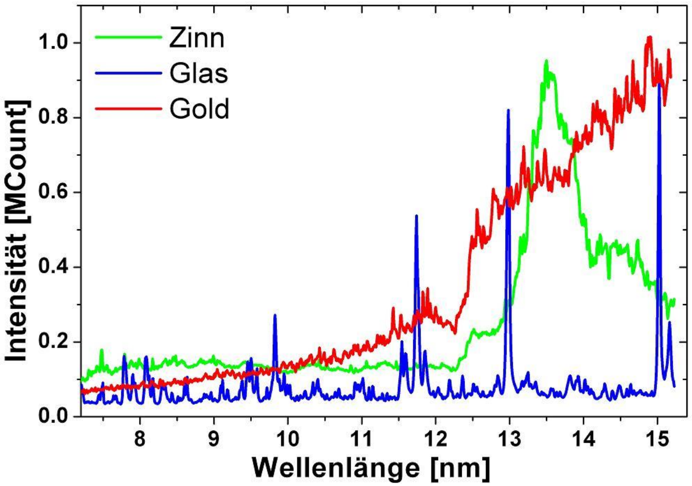
Laser-Laboratorium Göttingen e.V.



- Solid target for high-brilliant plasmas
- Emission spectra depending on target material



- Image of EUV plasma
- Diameter ~ 50µm (FWHM)



Laser-produced plasma

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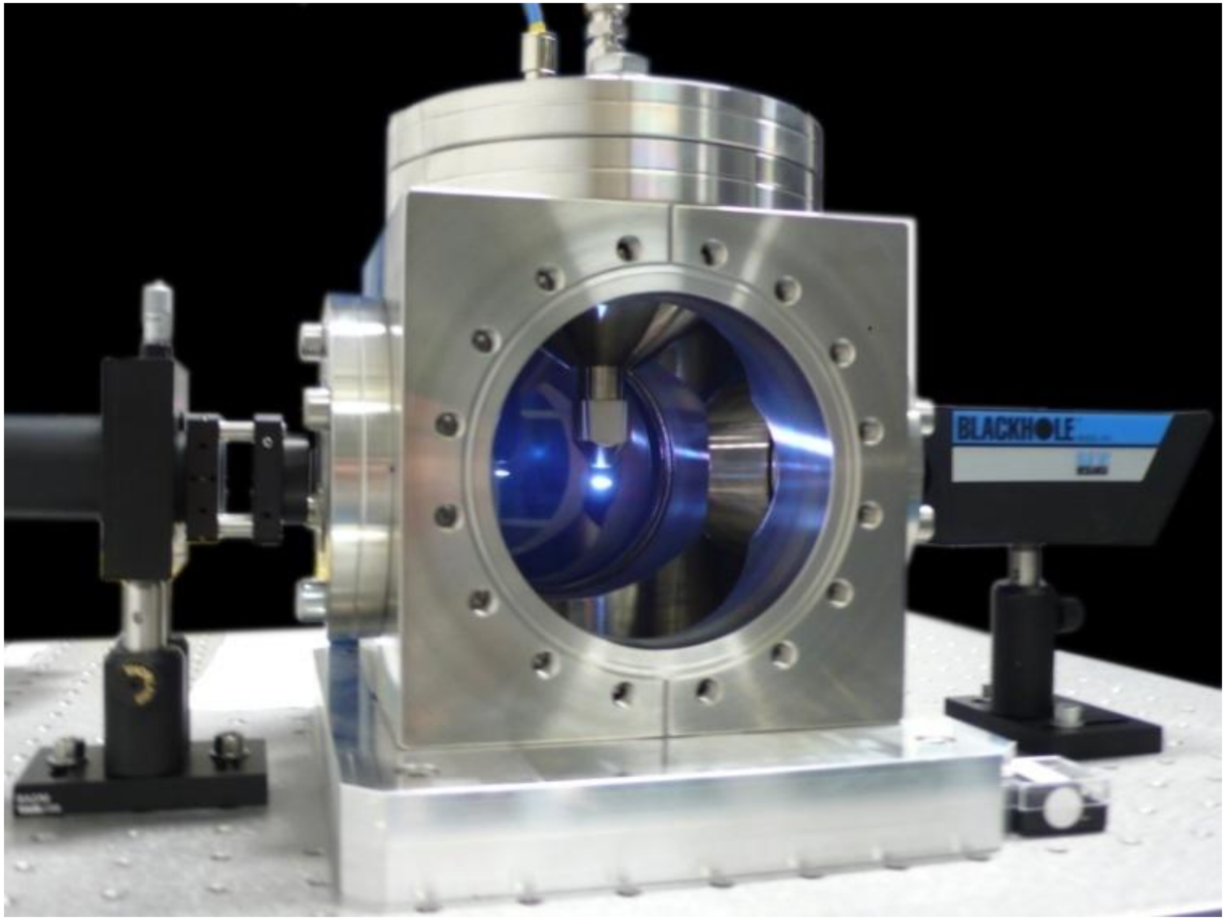

NEXAFS spectroscopy

Near-edge x-ray absorption
fine-structure spectroscopy

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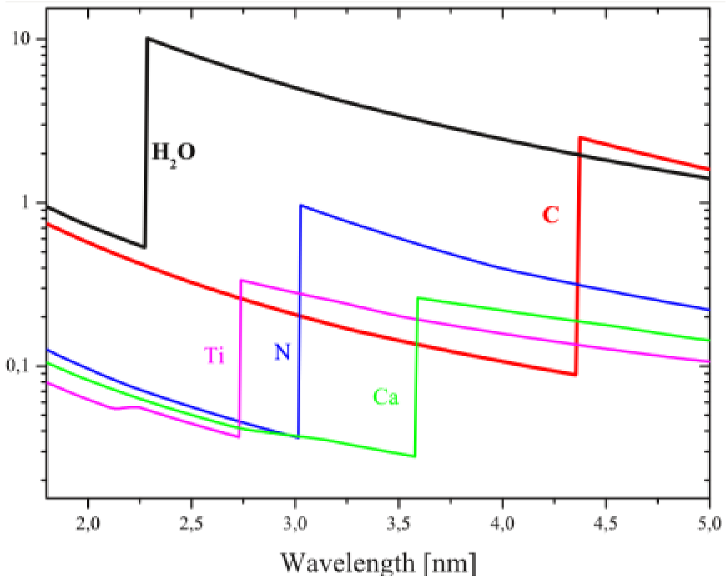
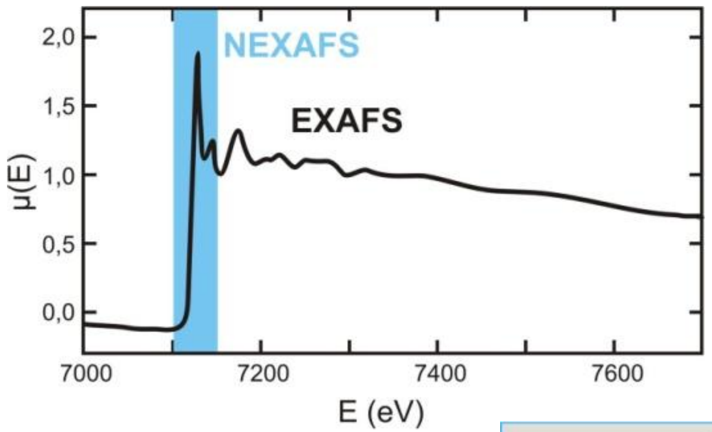
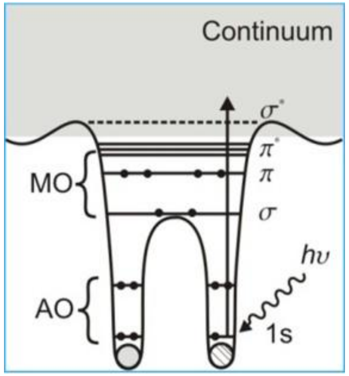
NEXAFS - Principle



➢ **Absorption-edges in the XUV wavelength range (selected elements)**



- Fine-structure at absorption edge
  - molecular orbitals
  - oxidation states
  - coordination of an absorbing element



NEXAFS - Setup

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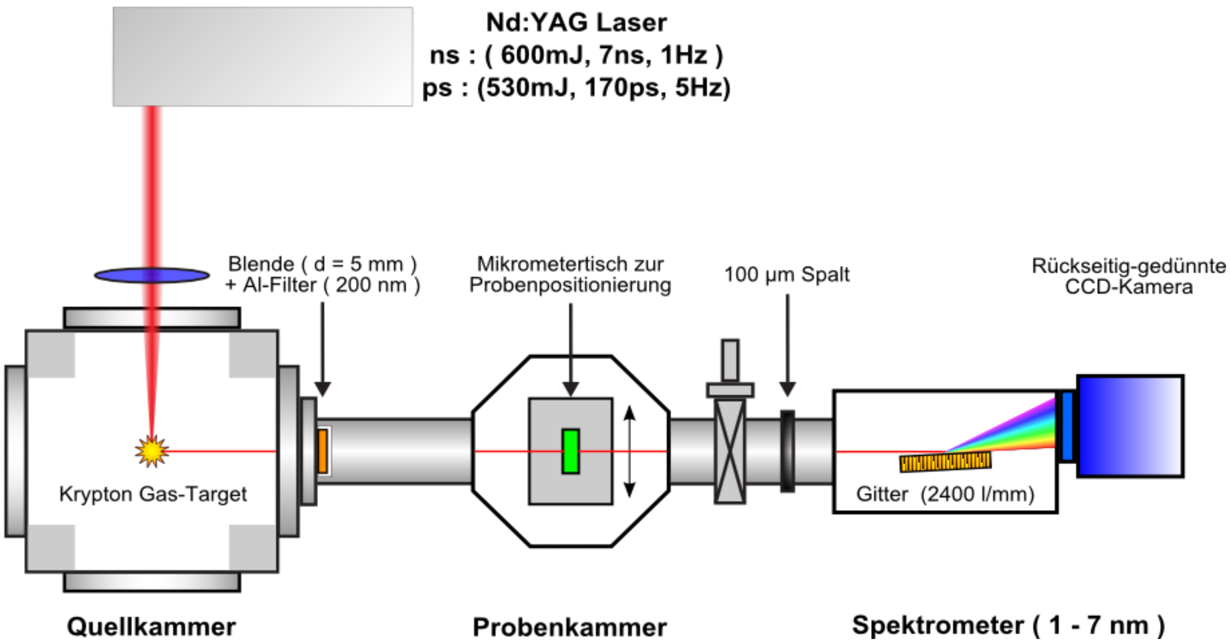
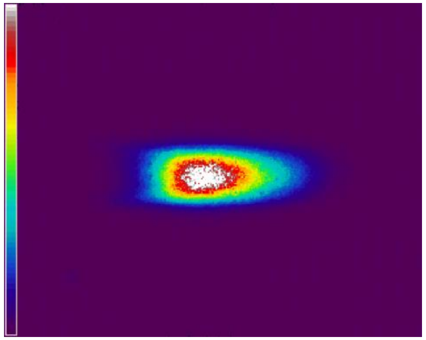
- Table-top system
- „Single-shot“
- Pump-probe exp.

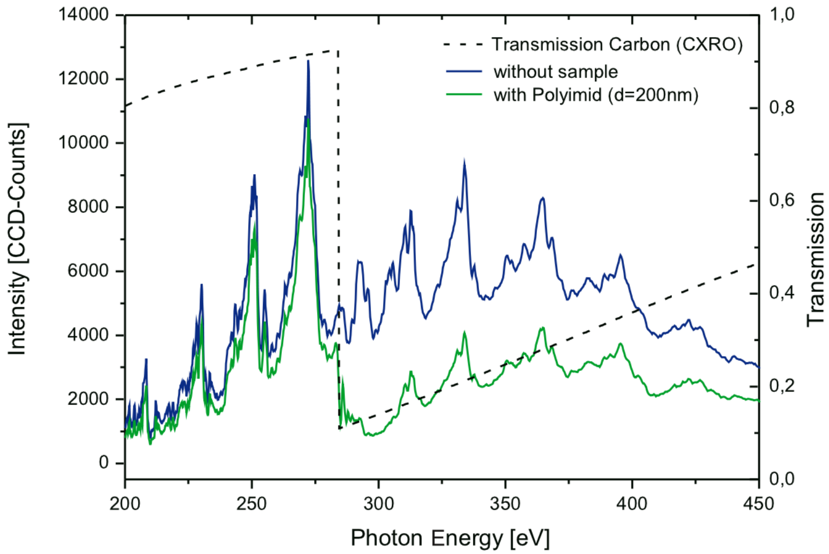


$$\frac{\lambda}{\Delta\lambda} \approx 400$$

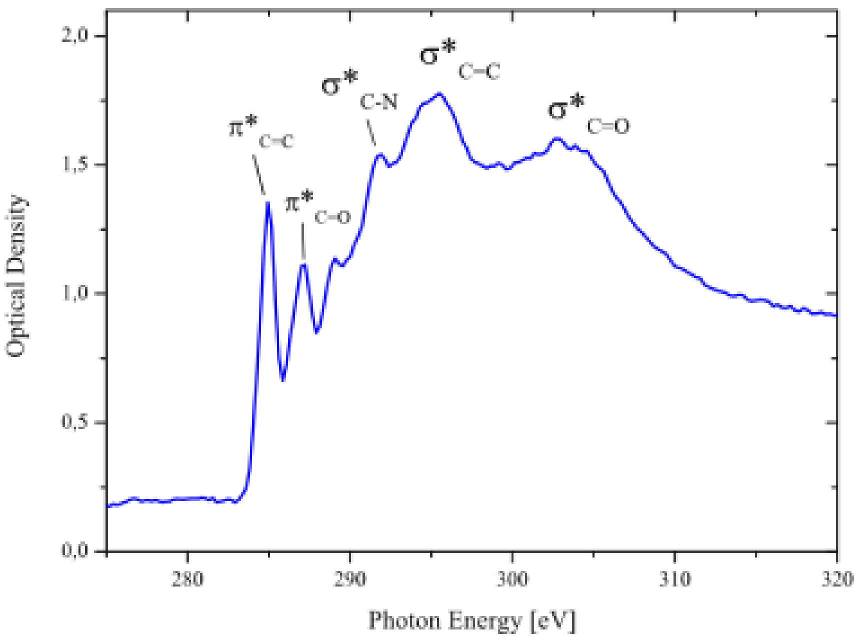
XUV plasma (Kr)
with pinhole camera



NEXAFS - Measurement

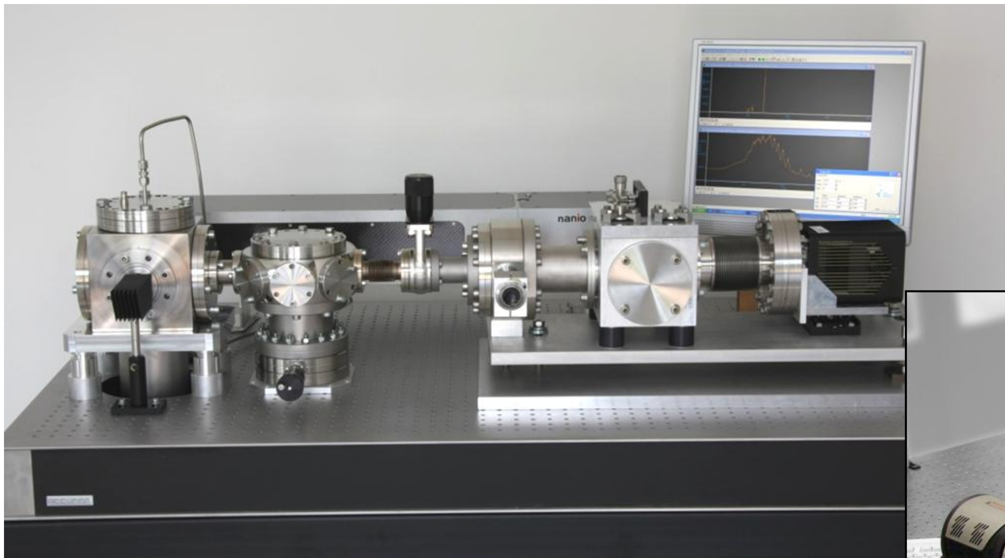


- **Emission spectra of Krypton with and without sample**

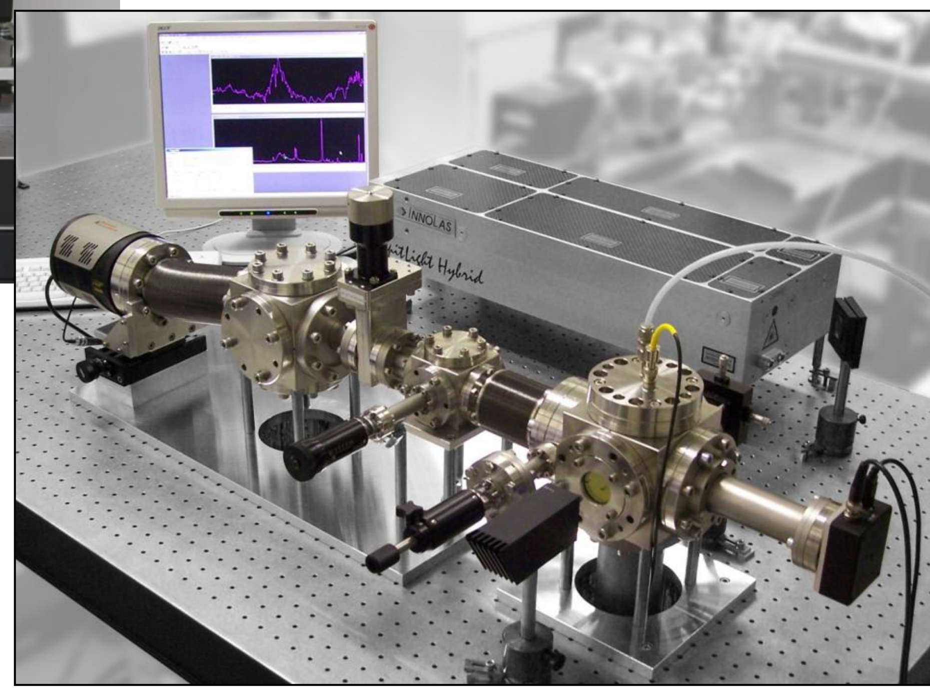


- **NEXAFS spectrum of Polyimide**

Setup of NEXAFS Spectrometer



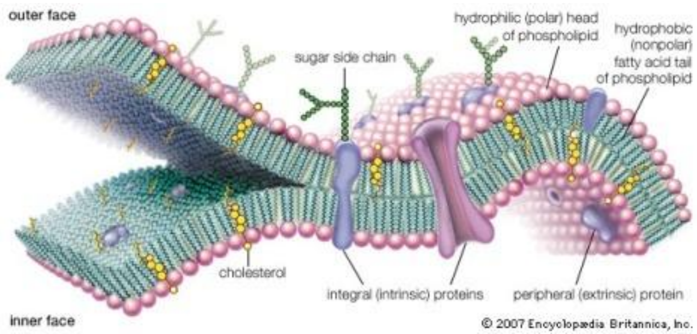
- **XUV – NEXAFS (2-5 nm)**

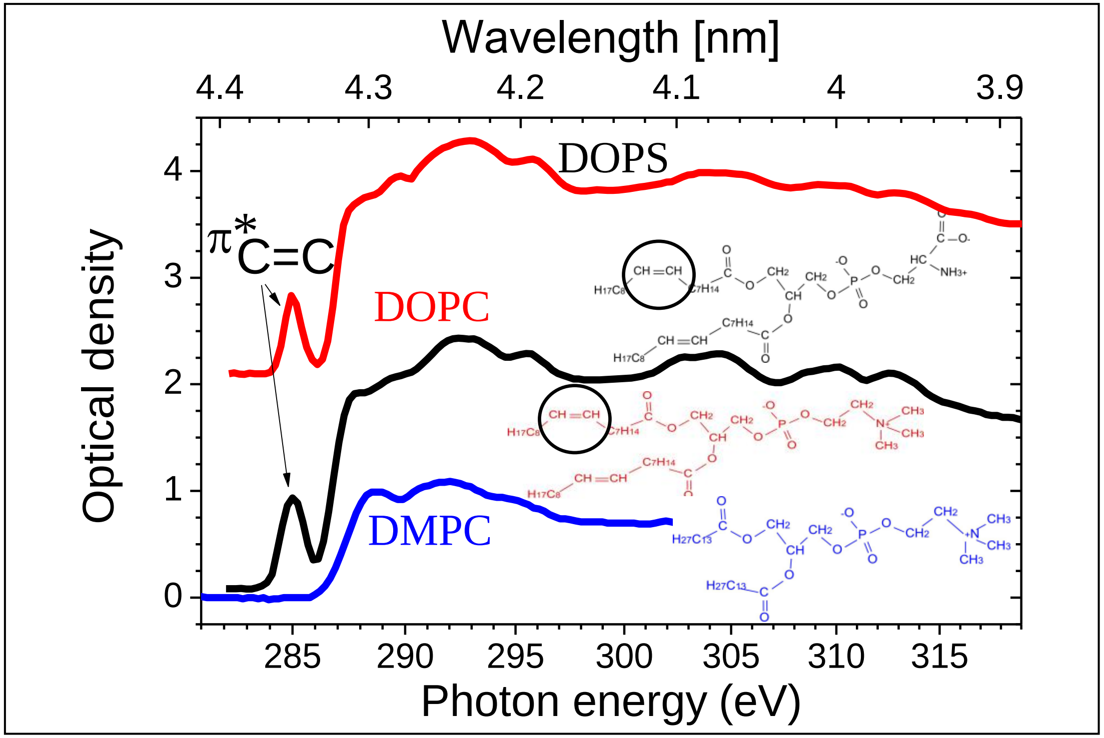


- **EUV – NEXAFS (7-16 nm)**

NEXAFS - Results I

- Lipid membranes (carbon K-edge)





E. Novakova, C. Peth, K. Mann, T. Salditt et al.: Biointerphases, **3** (2008) FB44

NEXAFS – Results II

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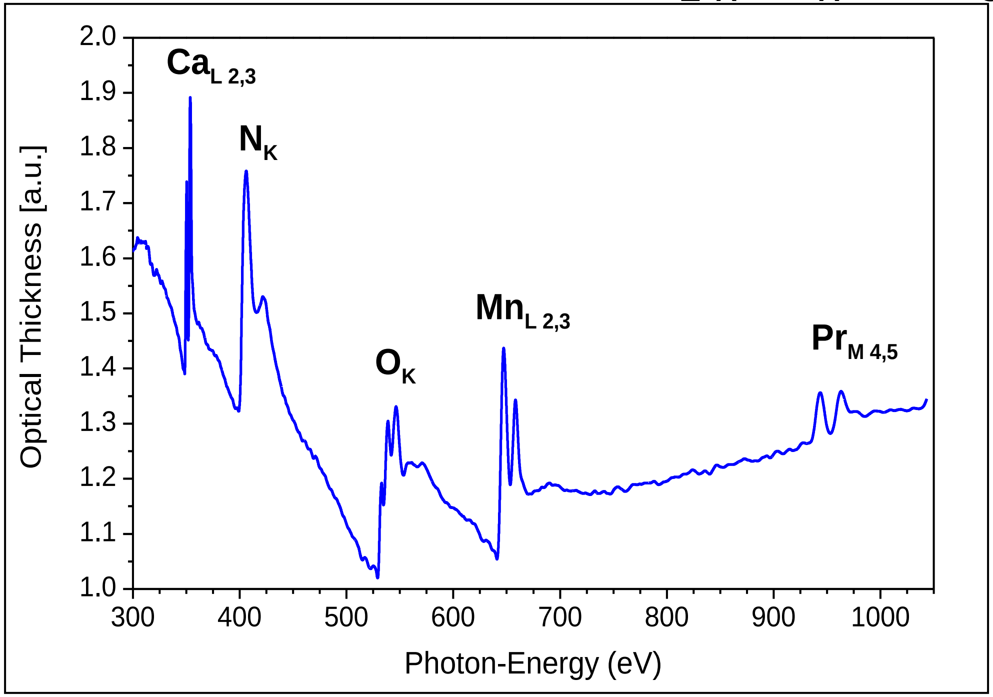
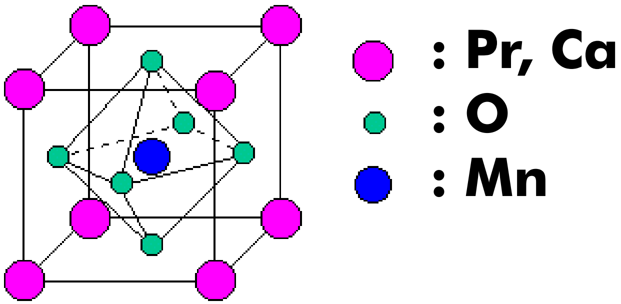
- PCMO (Perovskite-type manganate)

$Pr_{1-x}Ca_xMnO_3$





- Every element visible (single shots)
- Pump-probe experiments

E. Novakova, C. Peth, K. Mann, T. Salditt et al.: Biointerphases, **3** (2008) FB44

EUV damage

Material interaction studies with
13.5 nm radiation

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Motivation for EUV damage

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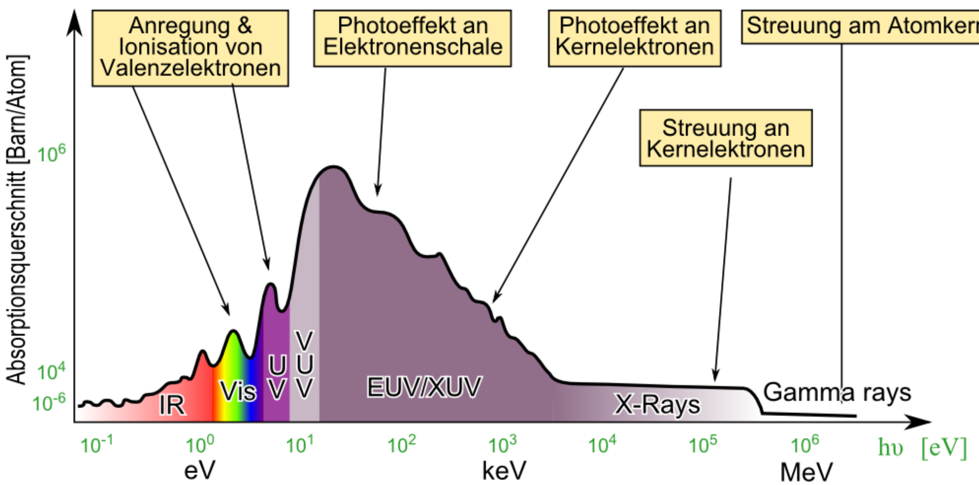
- Higher processor speed
  → need for smaller feature sizes
- Current wavelength: 193 nm
- **Next generation Litography: 13.5nm**

- Highest absorption
- Penetration depths of ~ 10-300 nm only
- **Structuring / surface modification**



EUV Schwarzschild Objective

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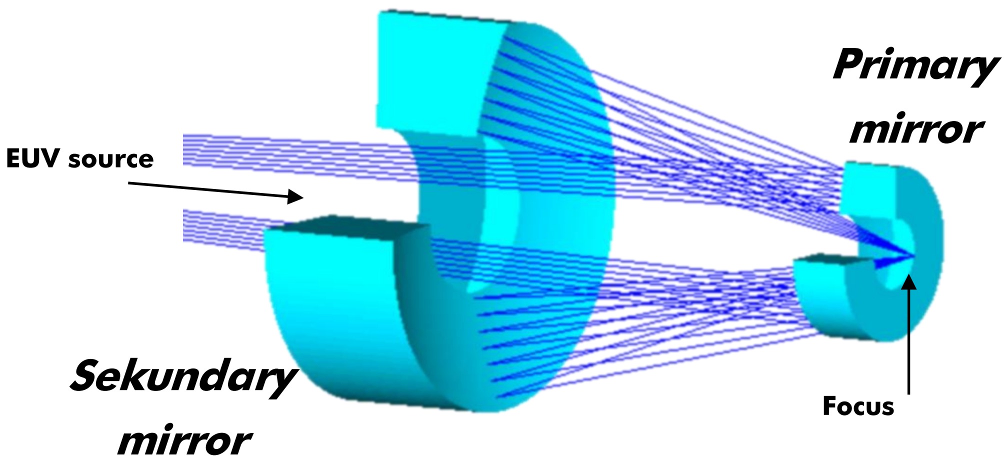
Göttingen e.V.

Fraunhofer Institut Angewandte Optik und Feinmechanik



- Schwarzschild Objective
  - Magnification 10:1
  - High numerical apterture (0.4)
  - Generation of highest energy densities

Setup for EUV Damage: Sketch

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Laboratorium
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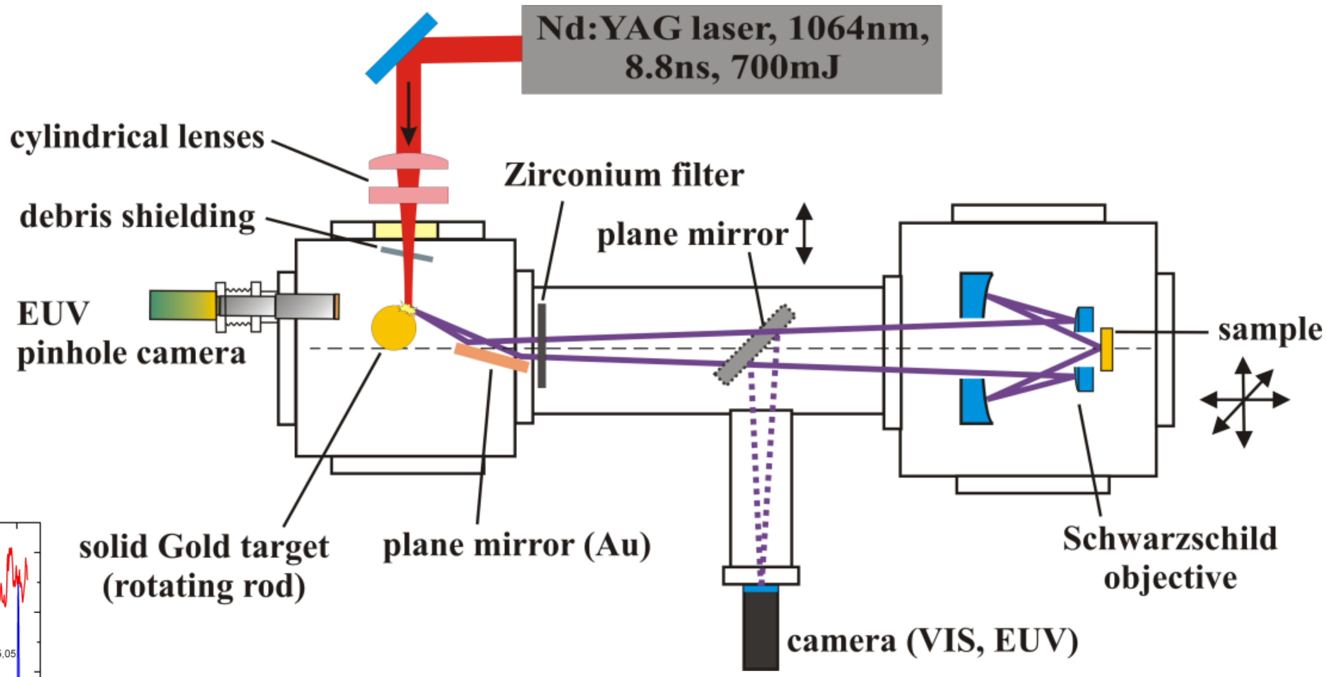
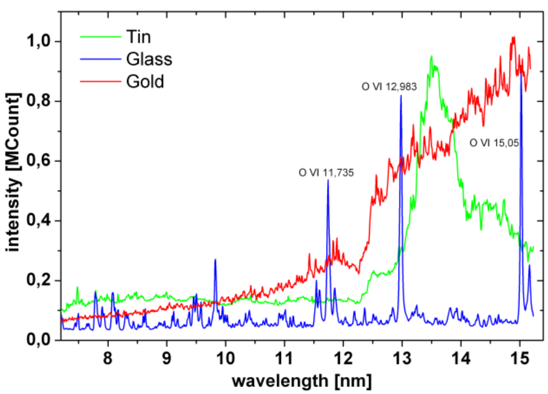
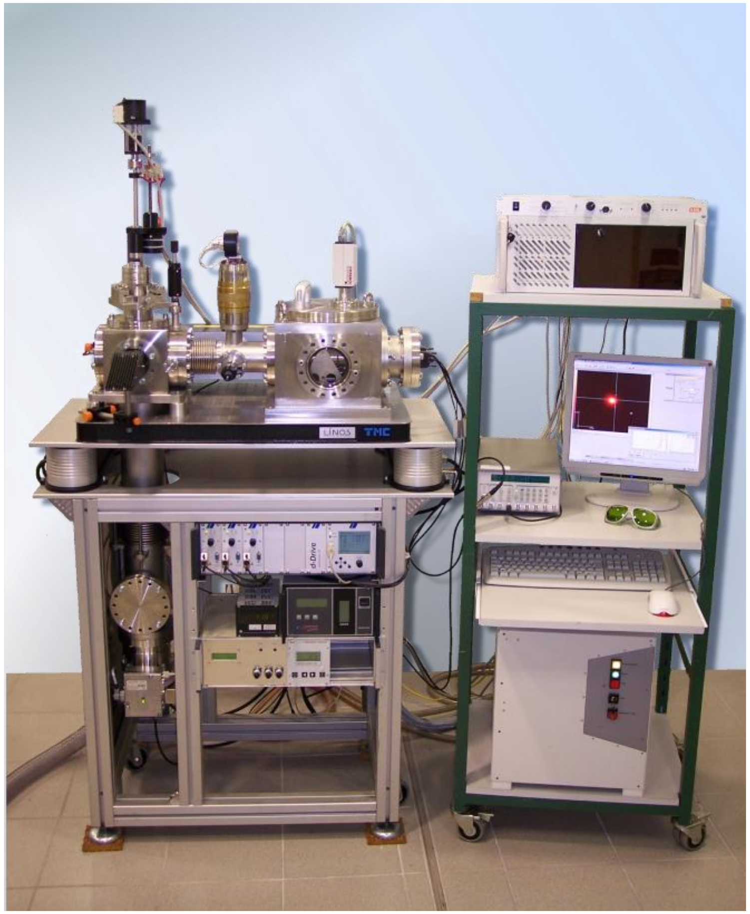


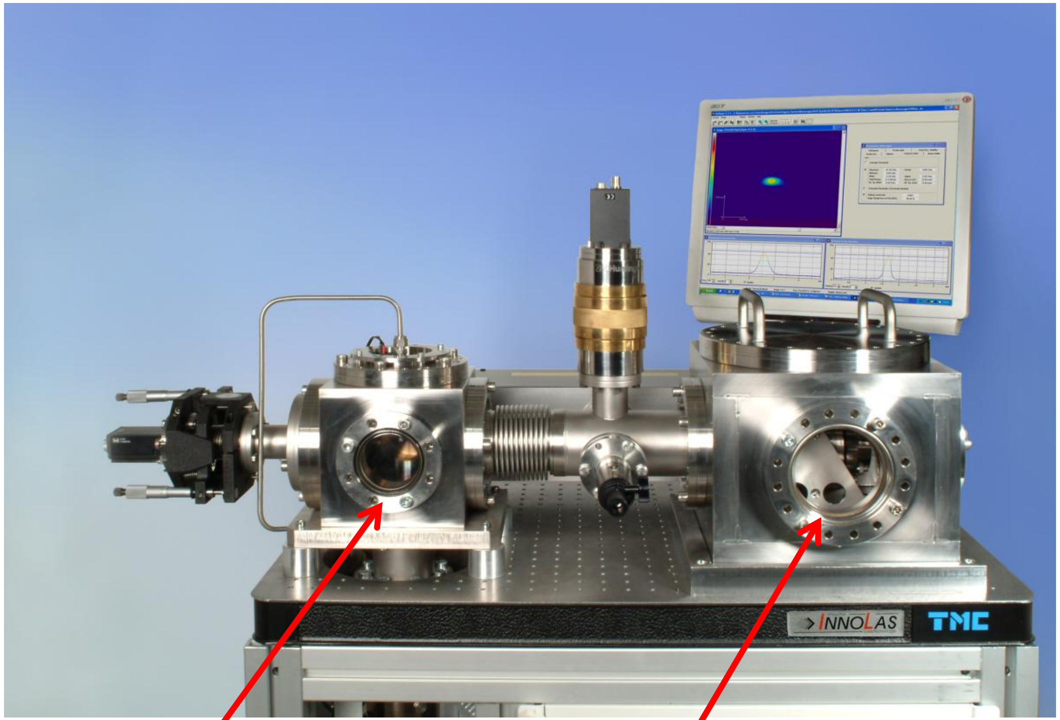


- **Solid state laser-targets for high brilliance plasmas**

Setup for EUV Damage: Picture

Laser-
Laboratorium
Göttingen e.V.





EUV source **Schwarzschild Objective**

EUV-damage: Polymer ablation

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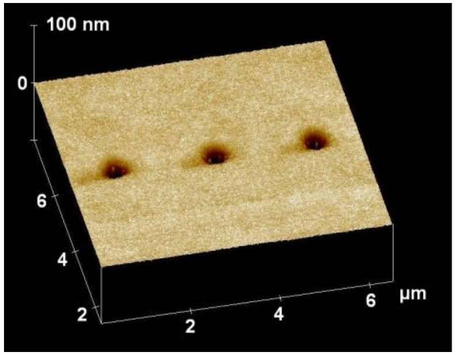
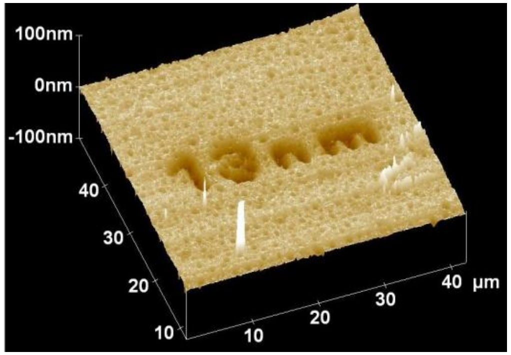
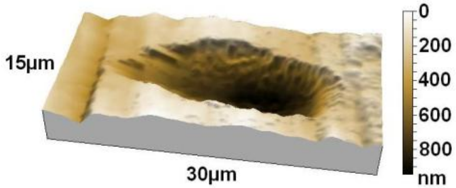


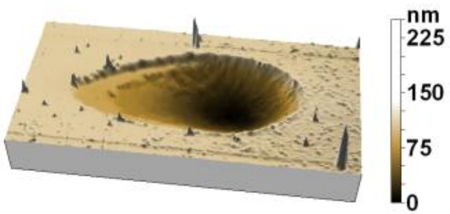


- **High-resolution direct structuring of PMMA**

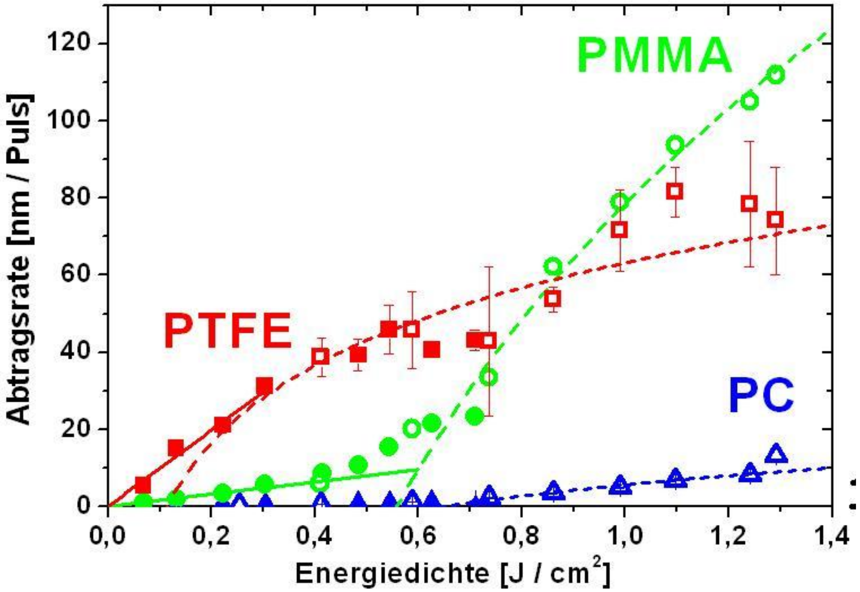
- **Ablation characteristics of Polymers**
- **PMMA, PTFE, PC**



PTFE, 1 pulse, 1.3 J/cm²



PMMA, 1 pulse, 1.3 J/cm²



EUV damage: EUV diffraction

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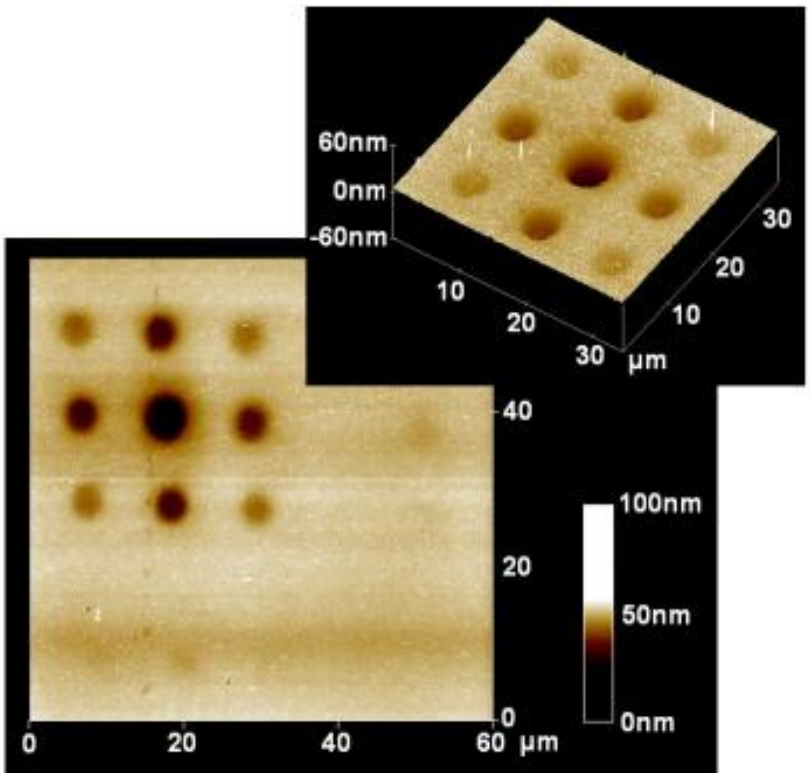
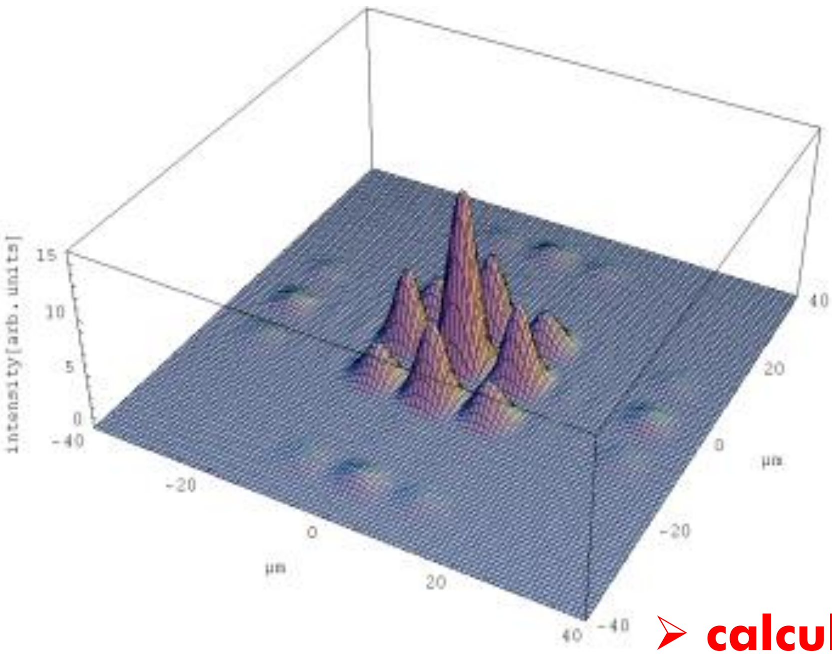
- Diffraction @13.5 nm
  - Verification of EUV wavelength
  - Influence of higher wavelength to ablation
  - Diffractive element : etched mesh

➢ **imprint in PMMA**





➢ **calculated diffraction pattern**

EUV Damage: Optics

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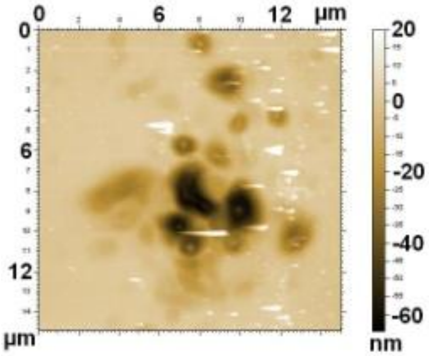
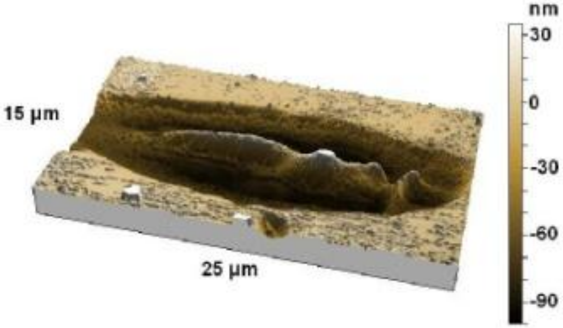
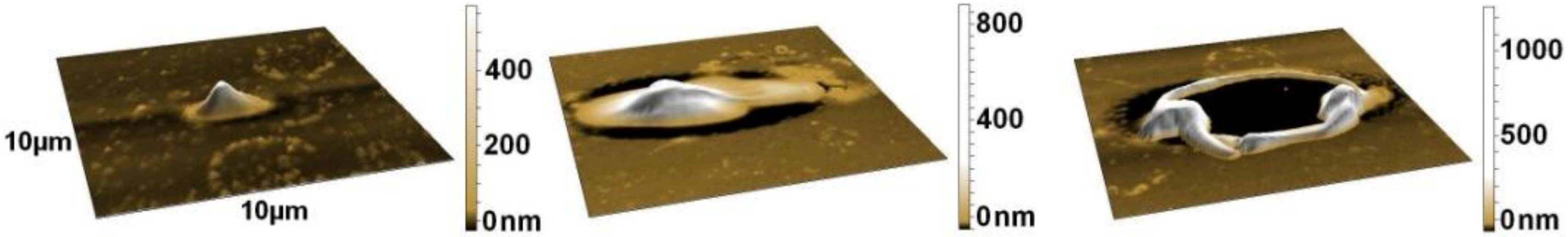
TEM-Micrograph of Mo/Si mirror

Fraunhofer Institut Angewandte Optik und Feinmechanik

- **Damage of Mo/Si multilayer EUV mirrors**







- **Damage of thin gold films (grazing-incidence EUV mirrors)**

EUV Damage: Substrates

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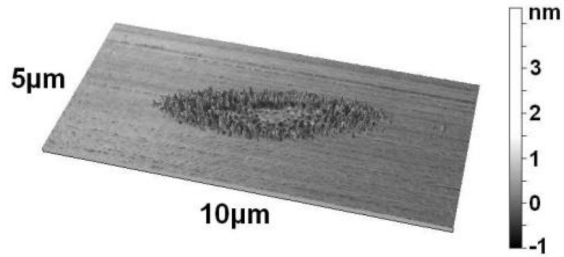
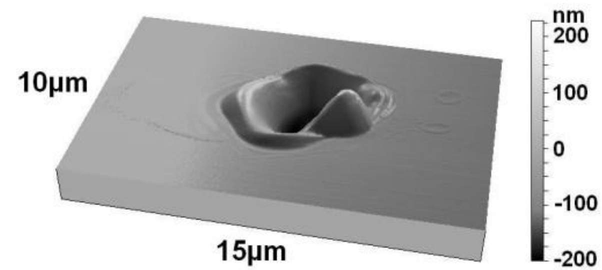
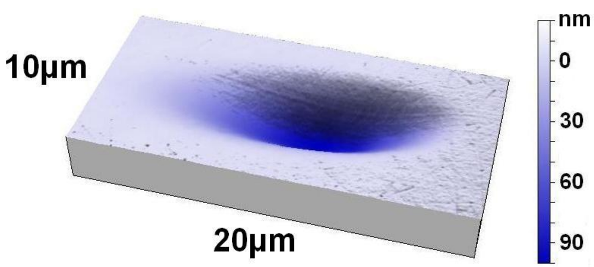
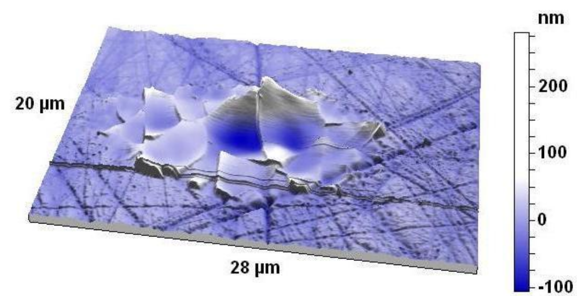
- **Damage of Silicon wafers at different EUV energy densities**

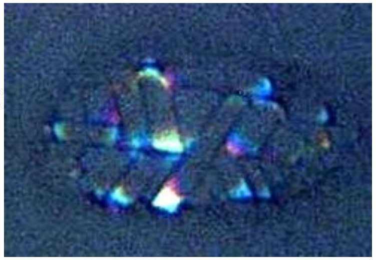






- **Damage of fused silica**





- **Damage of calcium fluoride**


Kurze Wellenlängen
EUV
Kompakte
EUV -
Laborstrahlquelle

EUV reflectometry

Reflectometry @ 13.0 nm wavelength

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EUV reflectometry: Setup

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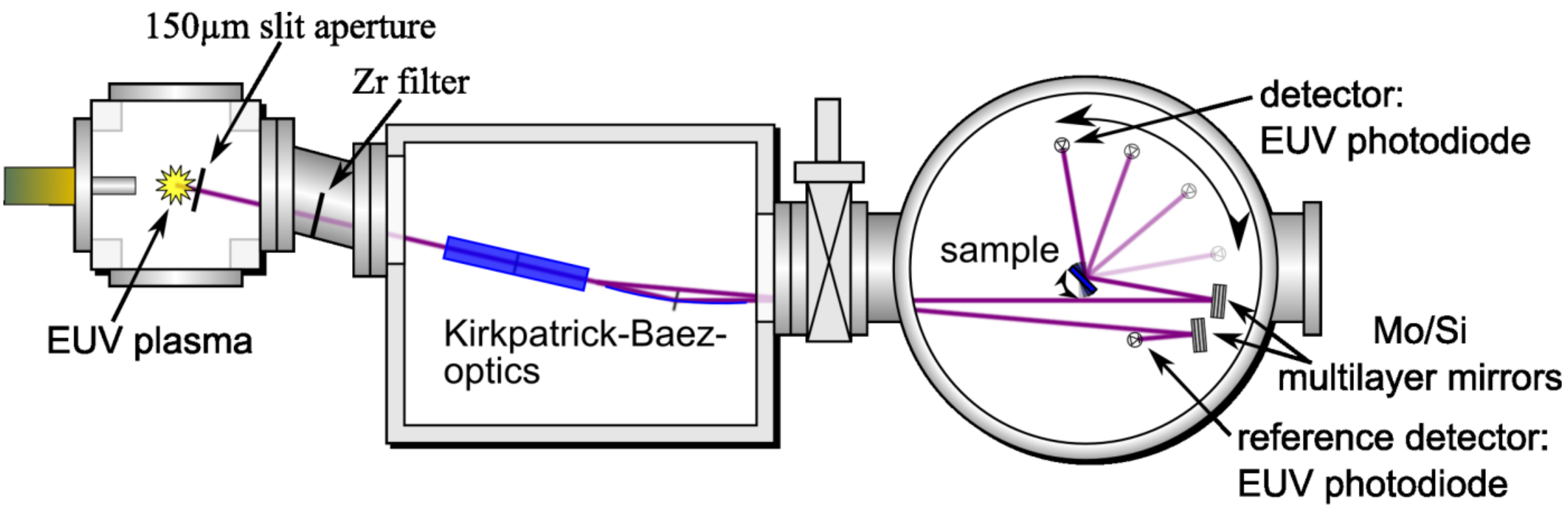
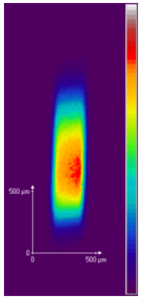


- Reflectivity @ 12.98 nm
  - Oxygen emission line
  - Angular resolution 0.3°
  - Angular range 1°- 85°



EUV spot
on sample

EUV reflectometry: Optics

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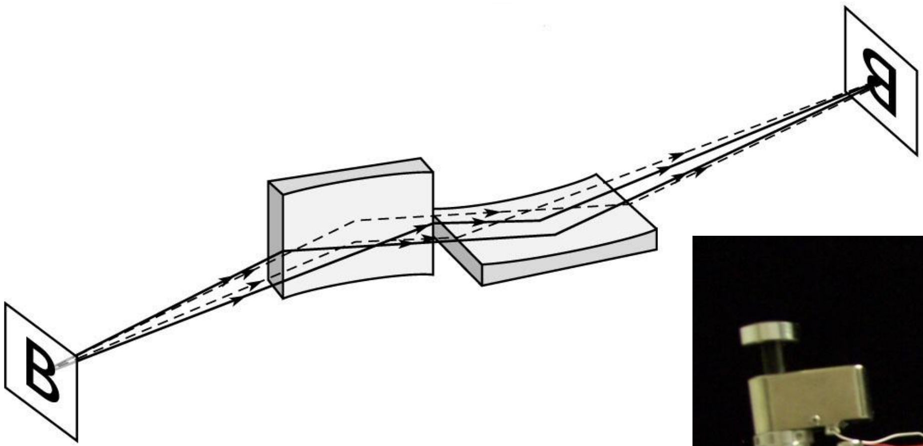

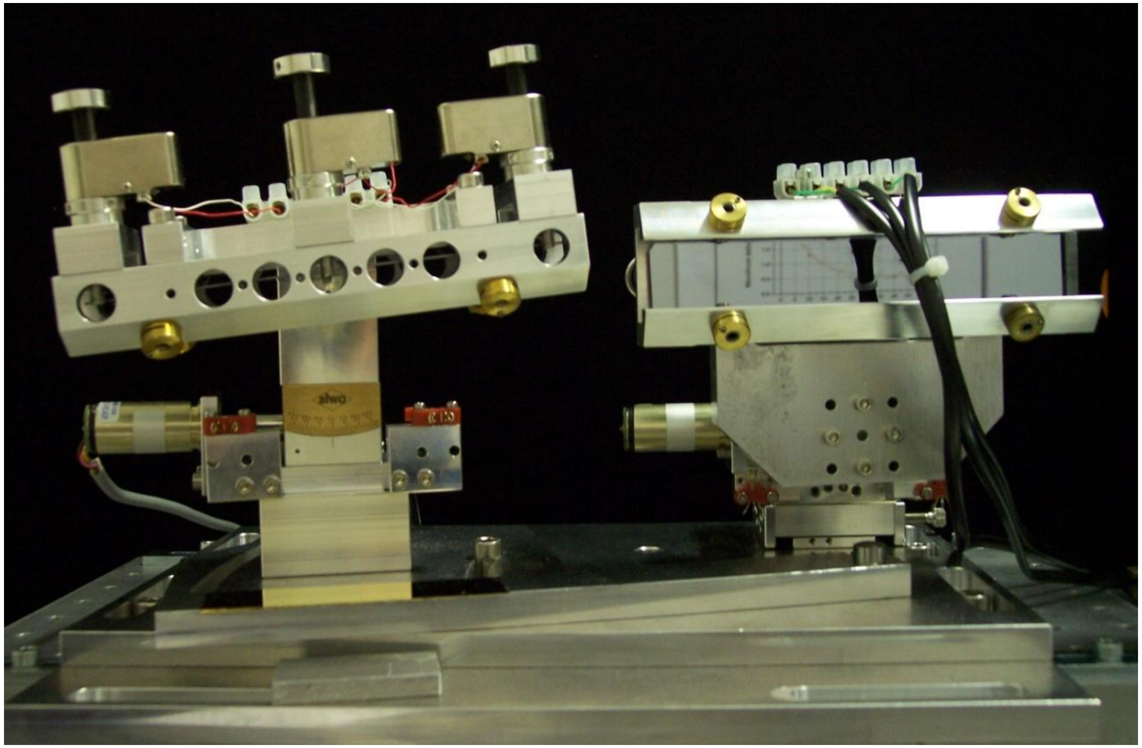

- Kirkpatrick-Baez
  - 2 cylindrical mirrors
  - Shape by bent wafers
  - Gold / Carbon layer mirrors

EUV reflectometry: examples

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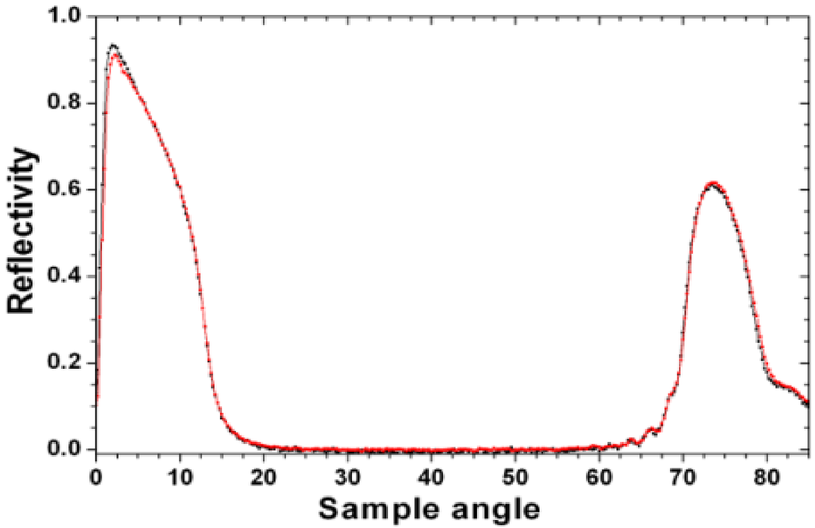
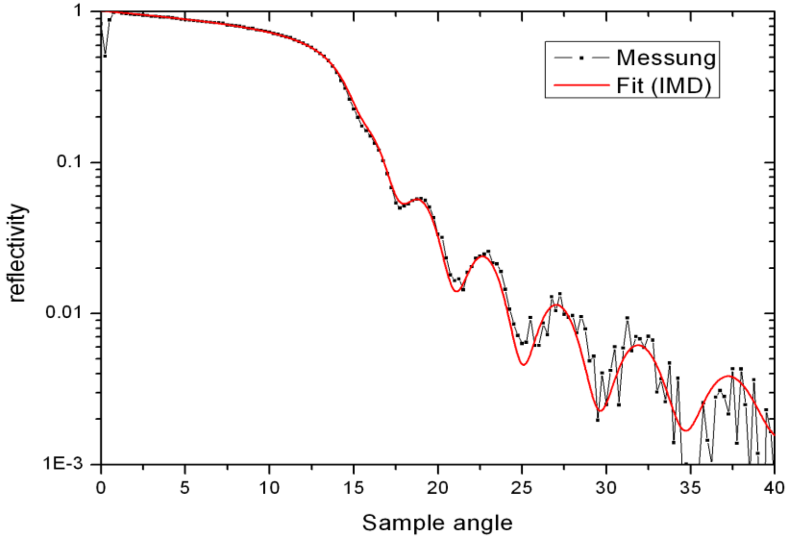
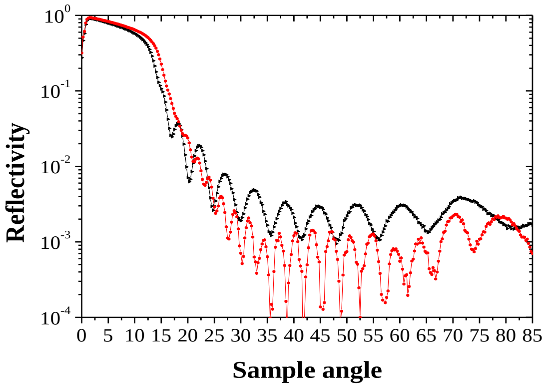


Carbon layer,
thickness 75nm



Mo/Si
multilayer
mirrors



Multilayer-Laue Lenses

Novel optics for soft x-rays

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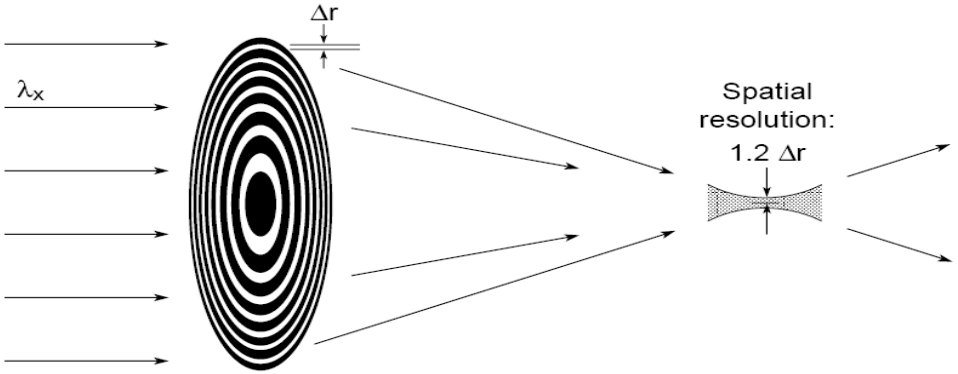

- **Zone-plate**
  - Absorbing / transmitting rings
  - Suitable for EUV/XUV spectral range

- **Multilayer Laue lens**
  - Absorbing / transmitting layers
  - Corresponds to cylindrical lens

absorbing Material (ZrO_2)

transmitting Material (Ti)

Herstellung der Multilayer Laue Lens

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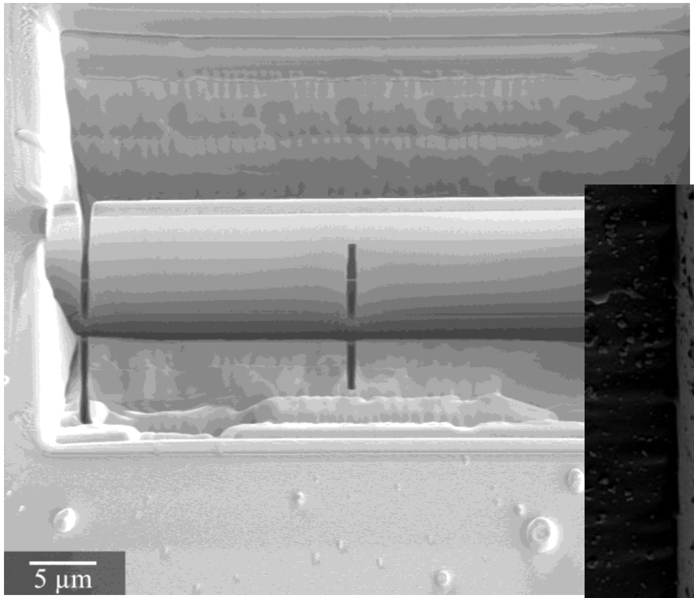
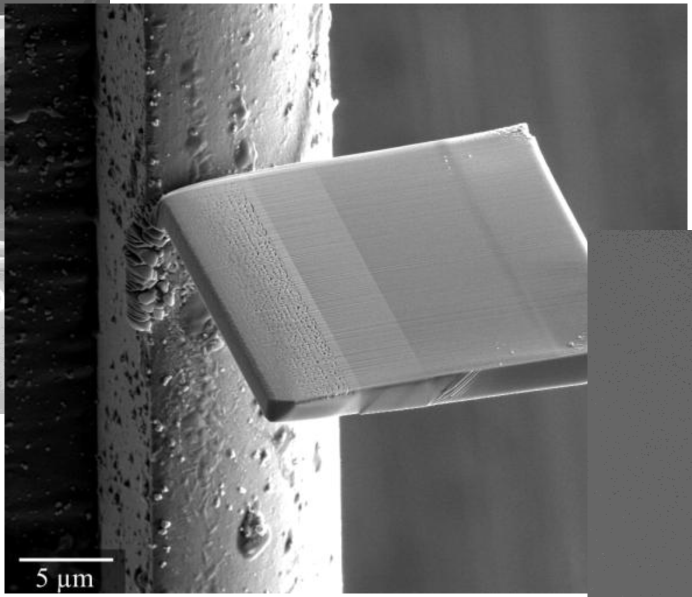
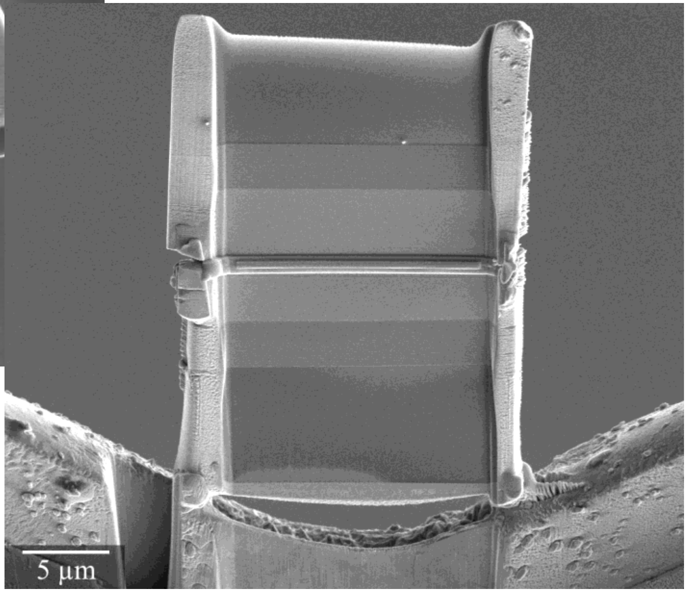
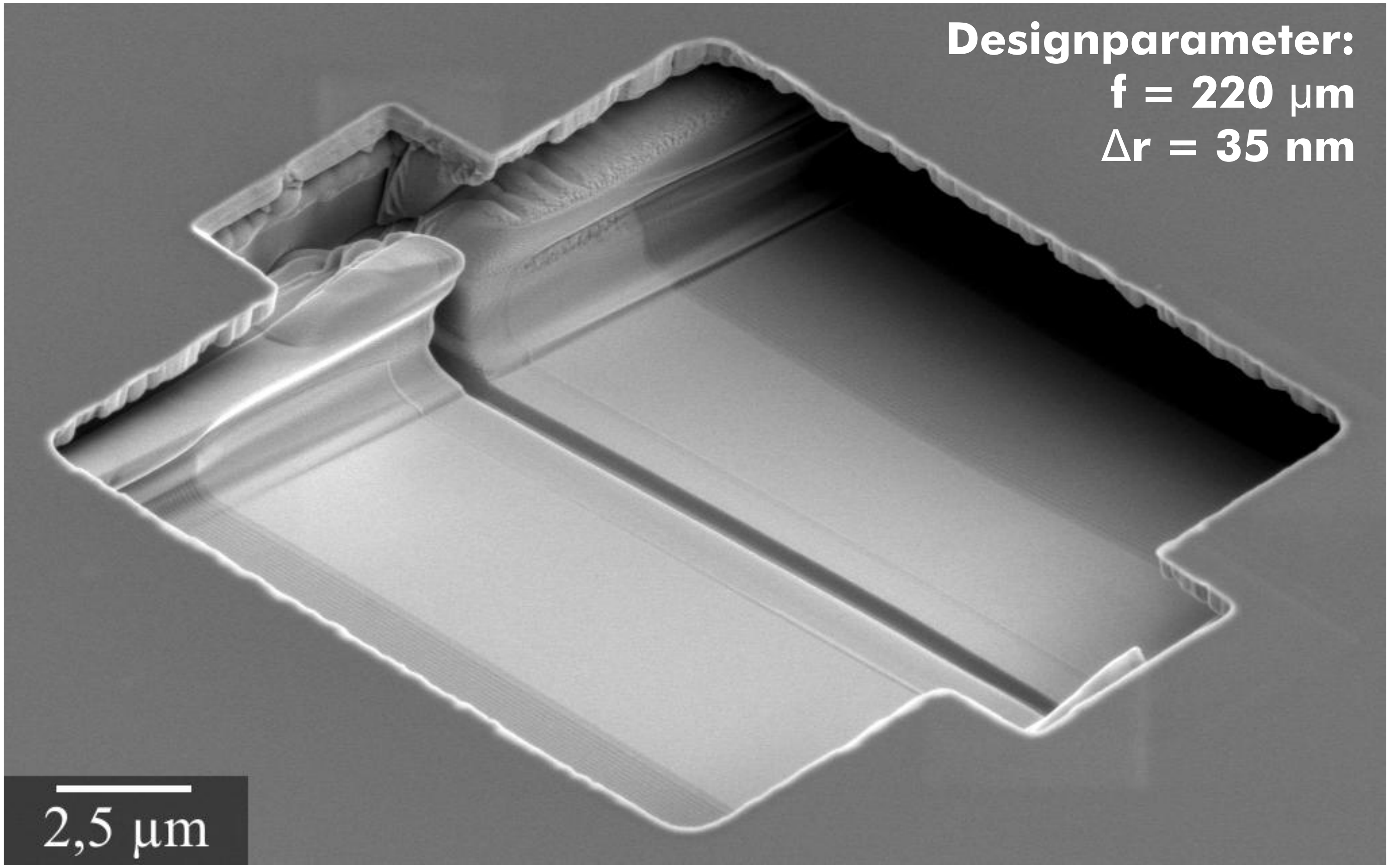






- **Two slices of multilayer**
- **Multilayer, structured by focused ion beam**

Multilayer Laue Lens



Multilayer Laue Lens: @2.88nm

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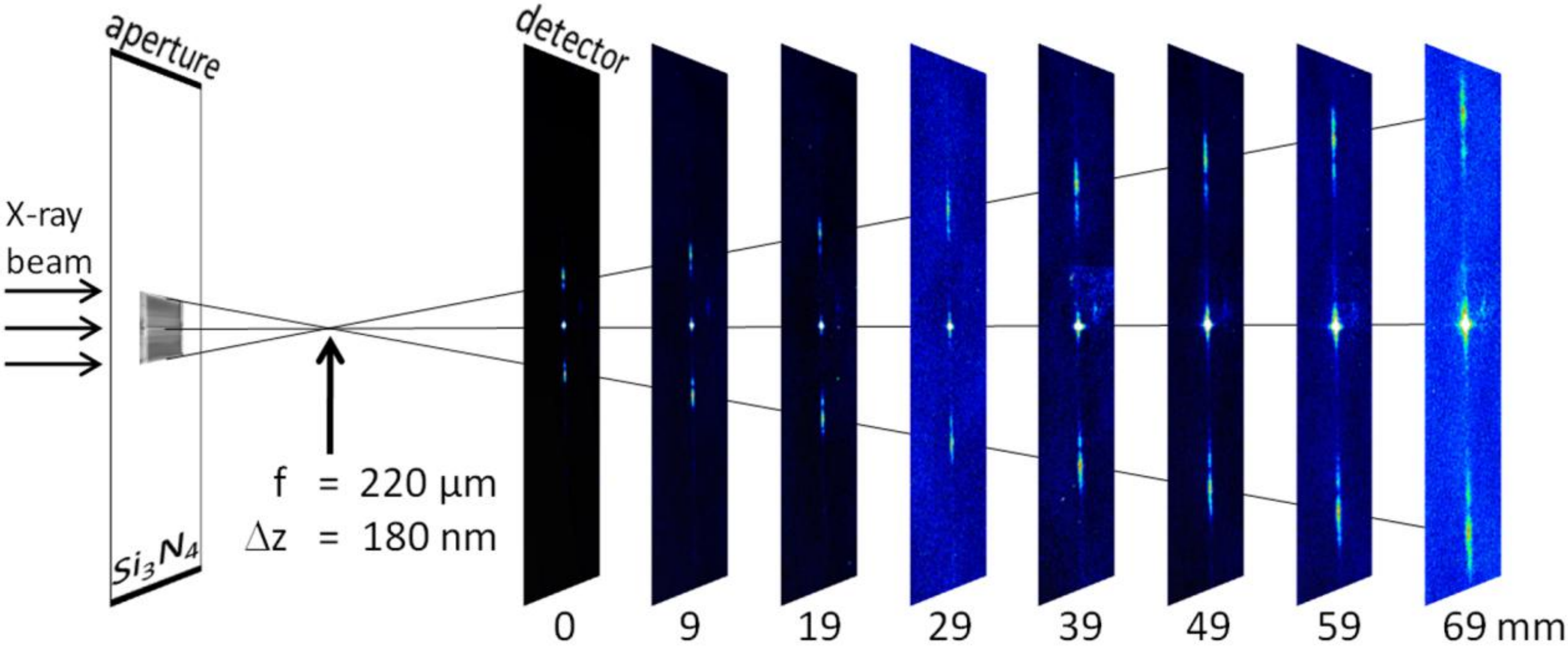
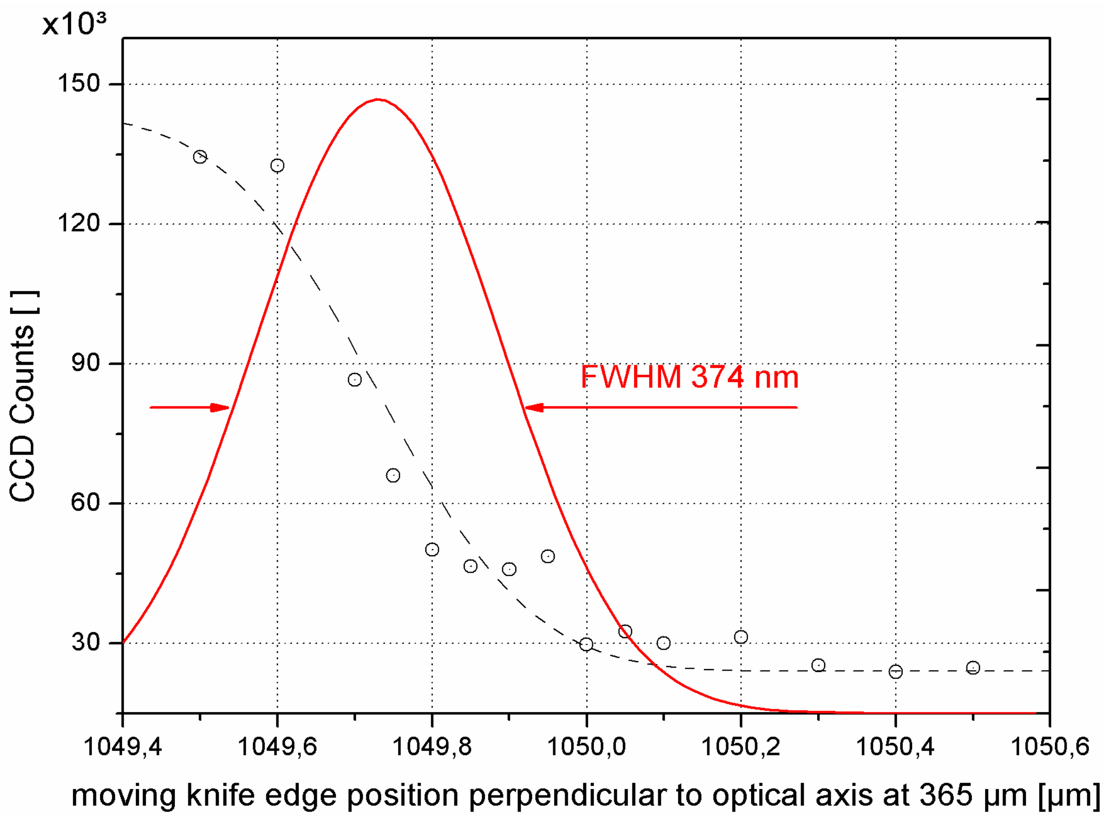
- Far-field measurement (CCD):



M. Reese, H.U.Krebs, K. Mann et al. Appl. Phys . A **102** (2011)

Knife-edge measurement



- **Sub-micron focussing of XUV radiation possible**

MLL: Simulation

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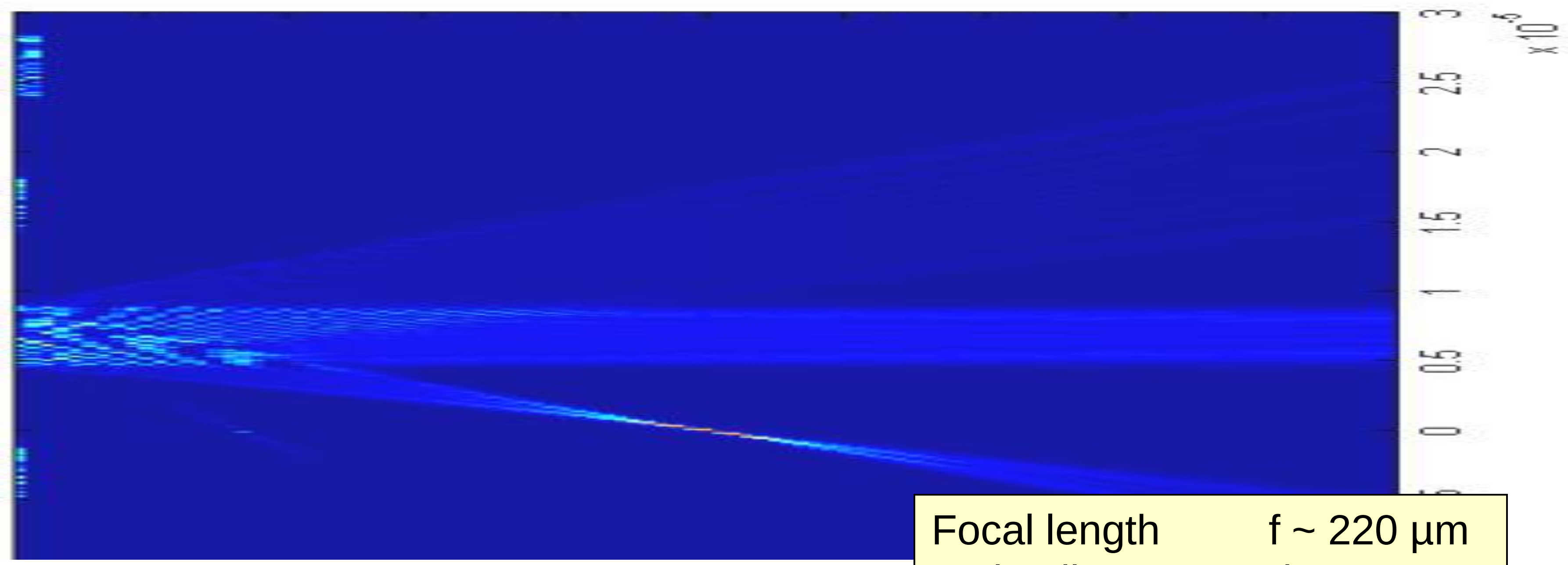
- Numerical simulation of single MLL



Focal length	f ~ 220 µm
Waist diameter	d_0 ~ 370nm

EUV wavefront sensor

Suitable for 2-20 nm wavelength radiation

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Wavefront sensor: Photo

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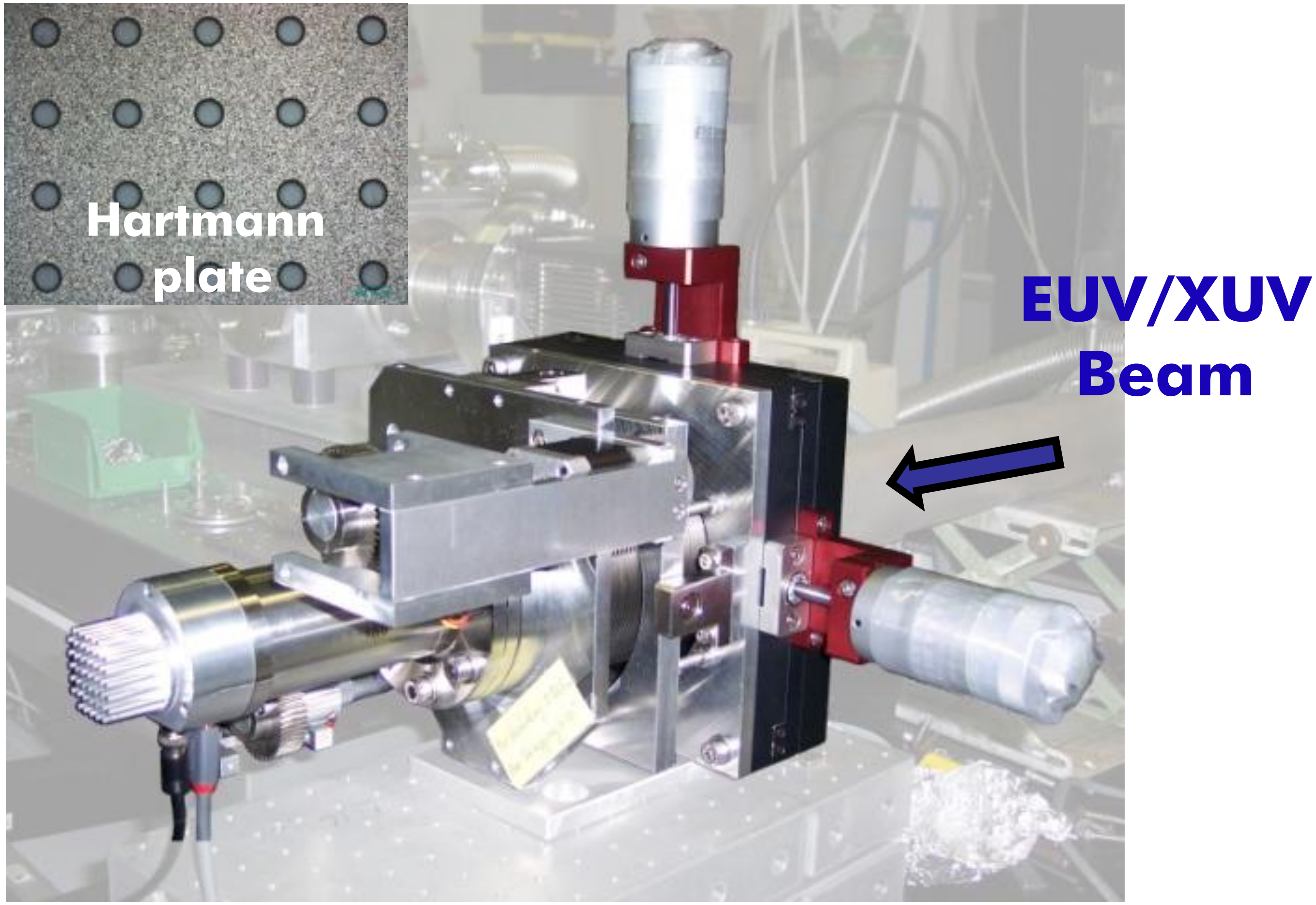
Laboratorium
Göttingen e.V.



Test of EUV wavefront sensor at Free-electron laser (FLASH)

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Laboratorium
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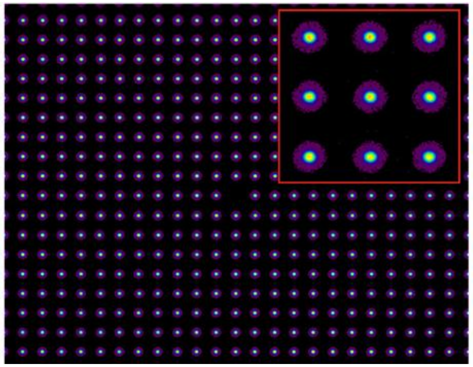
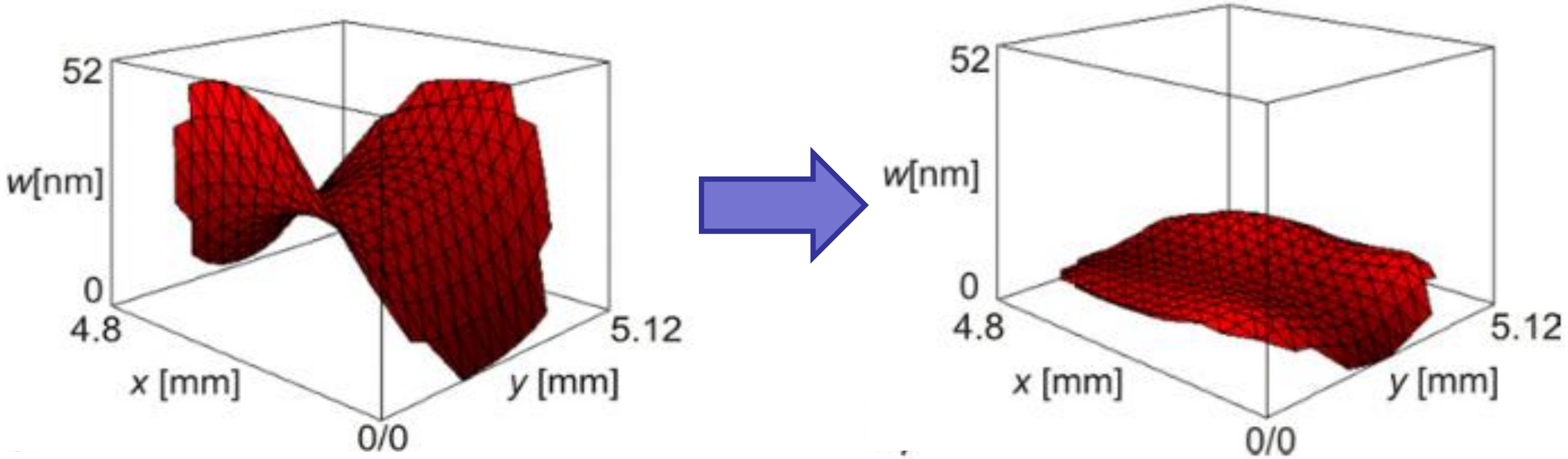
EUV wavefront sensor: Beam adjustment at FLASH

- Spot distribution:



- Adjustment of beam line optics:



B. Flöter, K. Mann, K. Tiedtke et al. NIM **A 635**, S108–S112 (2011)