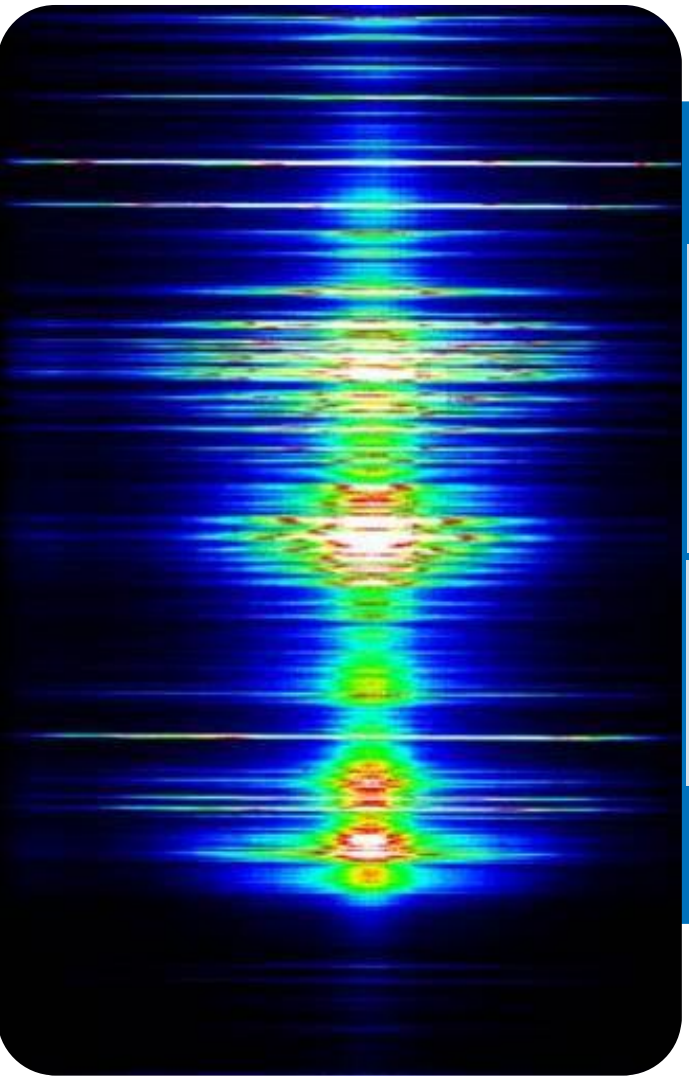

Spatial Resolved EUV Spectrum of EUV-Lamp

XUV Research with Compact DPP and LPP Laboratory Sources: Complementary to Beamlines and Large Scale Industrial Tools

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1 RI Research Instruments GmbH, Bergisch Gladbach

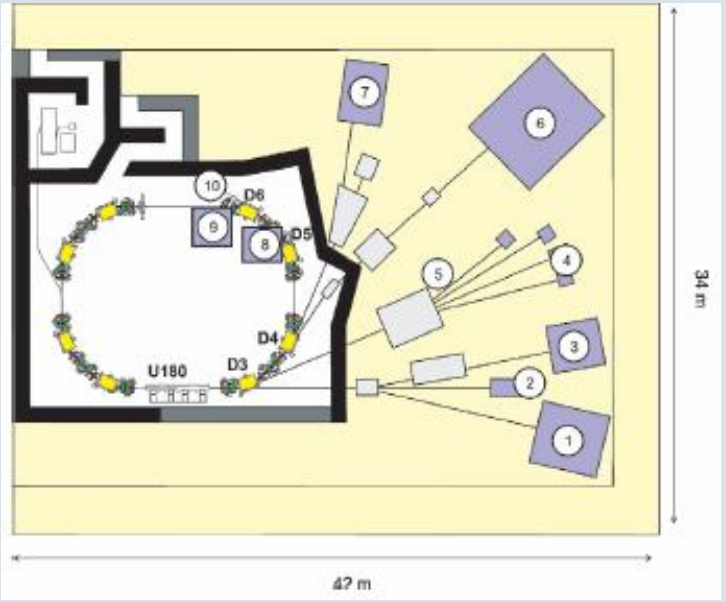
2 Fraunhofer Institute for Laser Technology, Aachen

3 RWTH Aachen, Chair for Technology of Optical Systems, Aachen

4 RWTH Aachen, Chair for Experimental Physics of EUV, Aachen

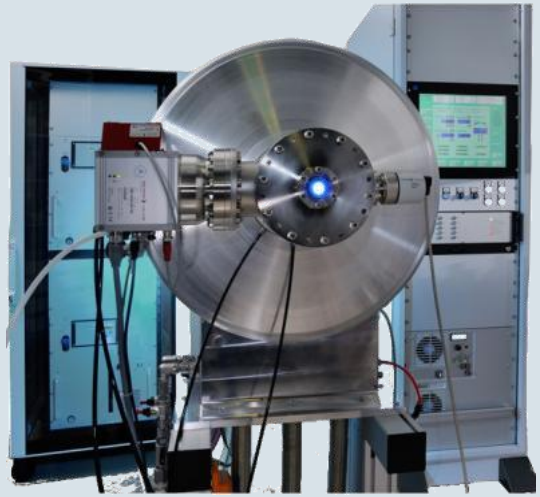
From Storage Ring to Lab Source

Synchrotron based Metrology



EUV SCANNER

Lab Metrology Sources



Path to Realize Solutions With EUV-Lab Sources

research instruments

Solving any task with any process requires:

- Analyze top-level requirements for applied process and target of use (Reflectometry (NI, GI), Transmission, Scatter, Irradiation, Interference, etc.
- Find effective solution of EUV-Source, collection, SPF, optical scheme, sample handling geometry, monitoring and signal detection
- Integrate with high quality periphery and components (vacuum, cleanliness, vibration, safety, operation)

EUV Lab sources are the one key element

In contrast to HVM sources, metrology sources are available in both general forms: DPP & LPP, which allows to select for the required features and can even be selected / tuned to special demands (wavelength range, bandwidth , spectral purity, interaction area (sample), spatial distribution etc.)

Easy Source – Tool vacuum and automation integration has been demonstrated.

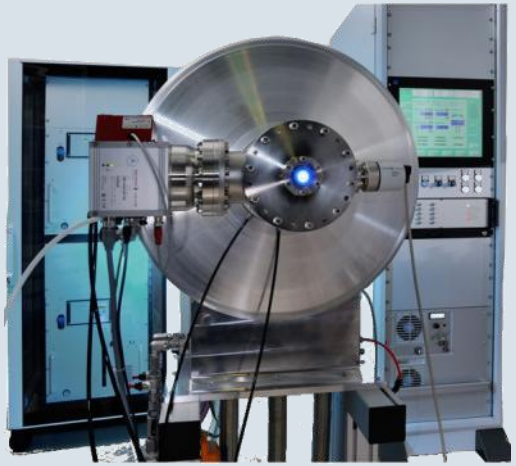
For real industrial and tool use optimization with respect to spectrum, collection geometry, effective debris mitigation and monitoring is designed on case to case basis.

Portfolio of EUV Metrology Sources

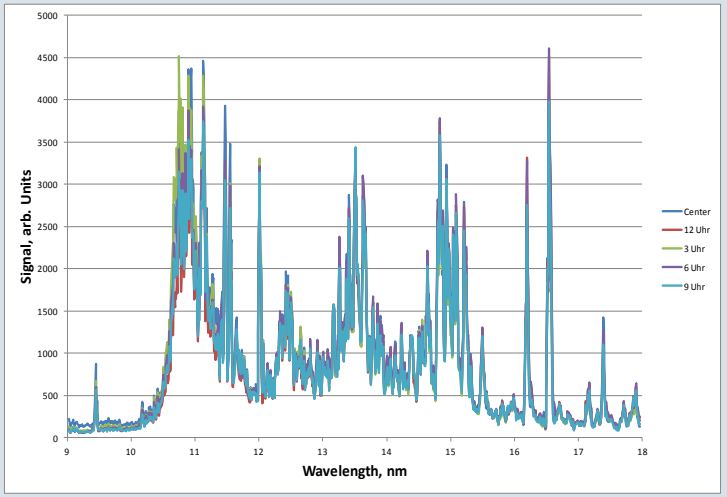
Demands: Power, Brightness, Debris-free, Stability, Cleanliness, Integration

Discharge Produced:

EUV-Lamp < 1 W EUV inband

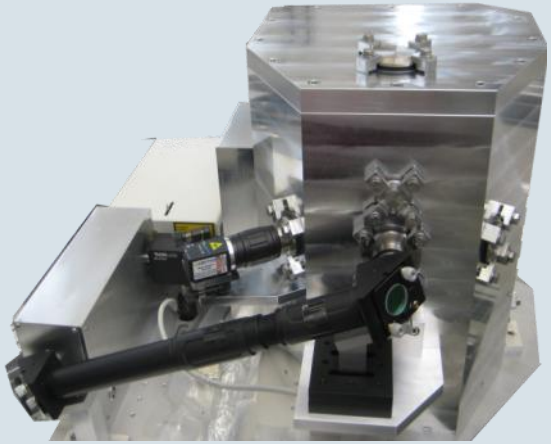


EUV-Source > 20 W EUV inband



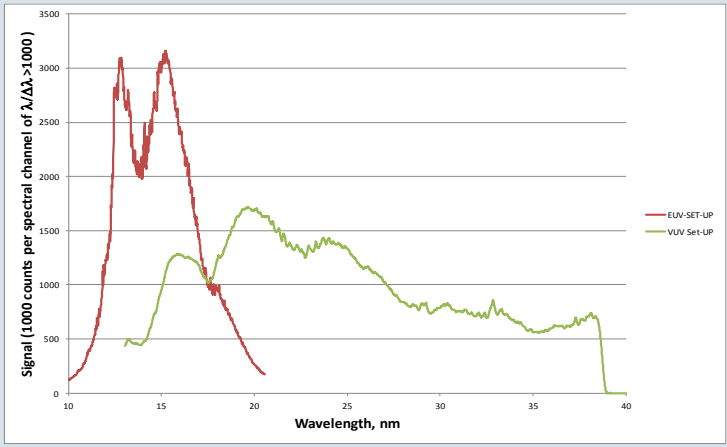
DPP spectrum of Xenon EUV-Lamp under different angles

Laser Produced:



LPP <5 mW EUV inband for spectr.

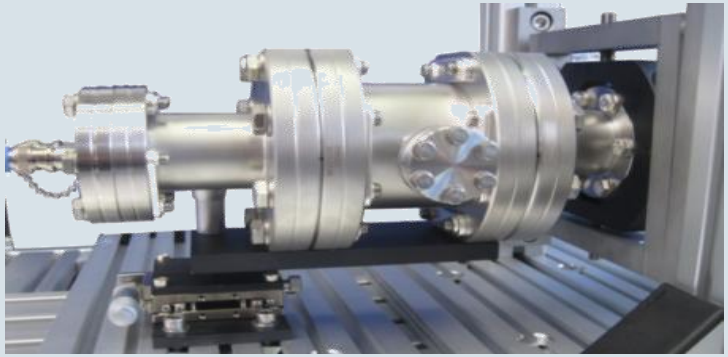
HB-LPP > 200 W/mm²/sr inband



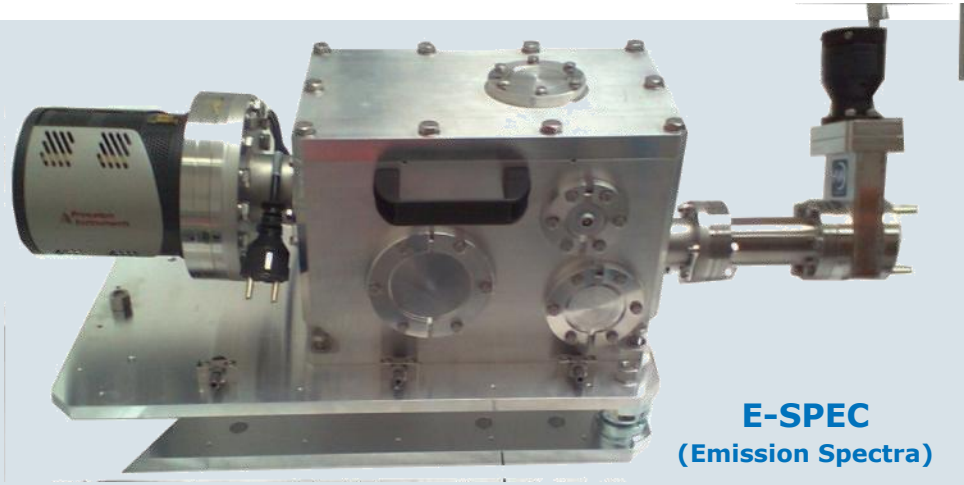
LPP source gold emission

Source Metrology Tools

research instruments

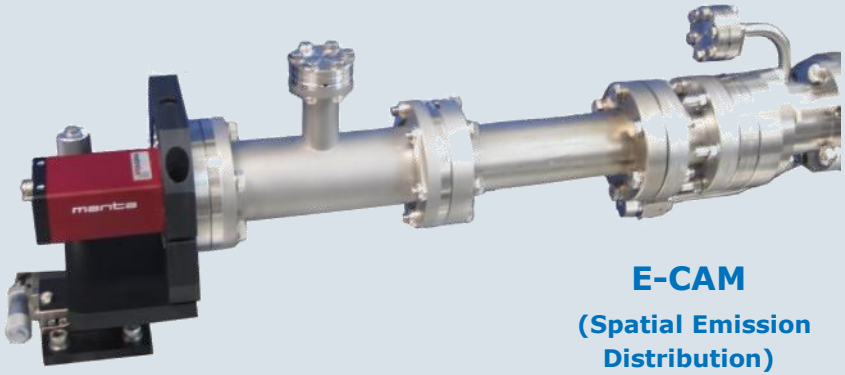


E-MON (inband Pulse and Power)

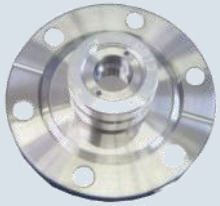


E-SPEC
(Emission Spectra)

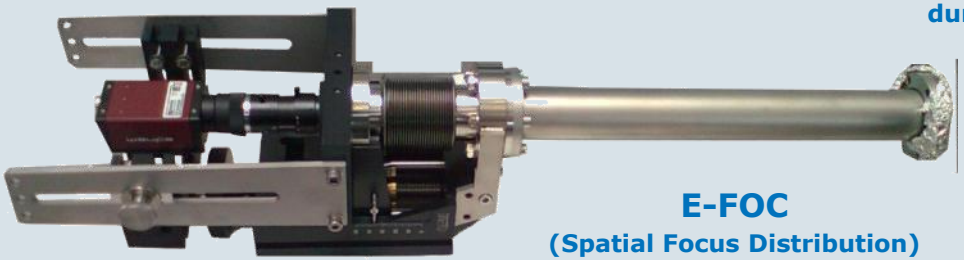
PTB Calibration Support is appreciated !



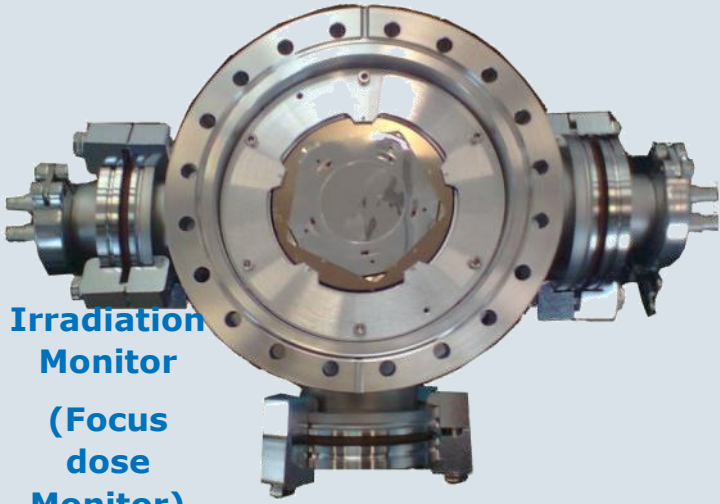
E-CAM
(Spatial Emission Distribution)



E-Diode
(Pulse duration)



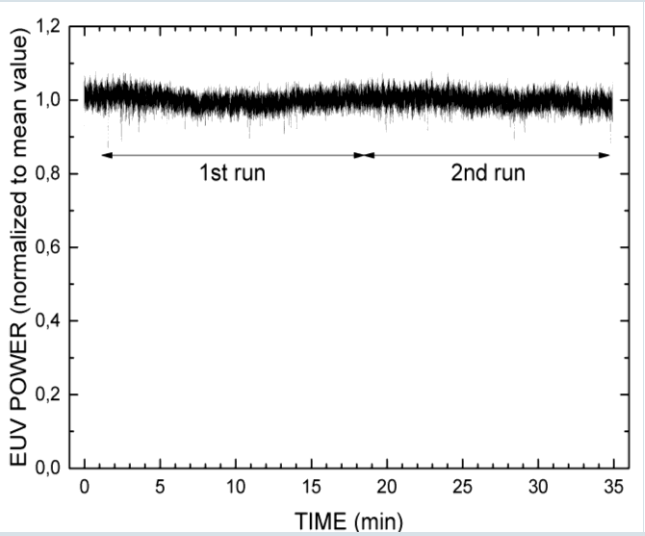
E-FOC
(Spatial Focus Distribution)



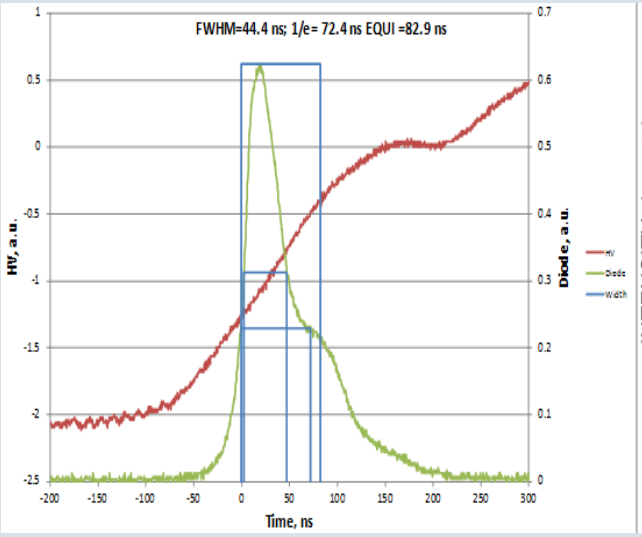
Irradiation Monitor
(Focus dose Monitor)

Scope of Source Qualification: Power, Pulse, Spectrum, Size and Statistics of All

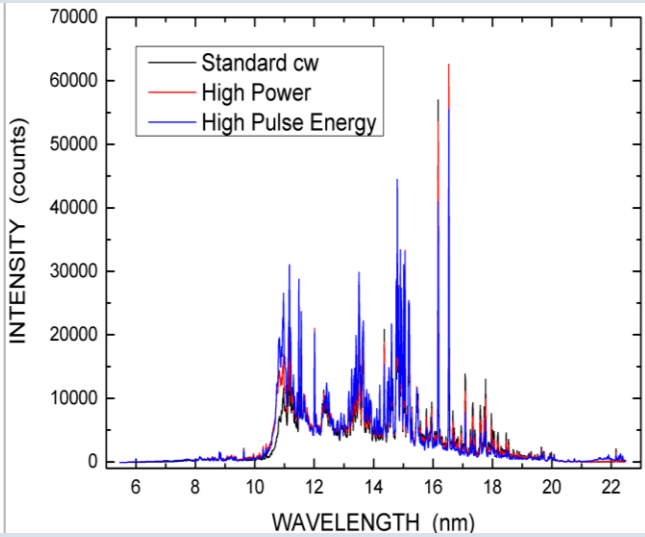
research instruments



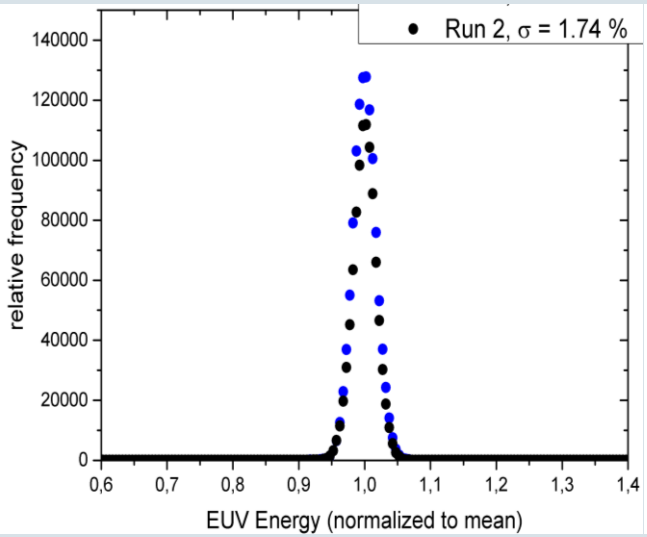
EUV inband Power: E-MON



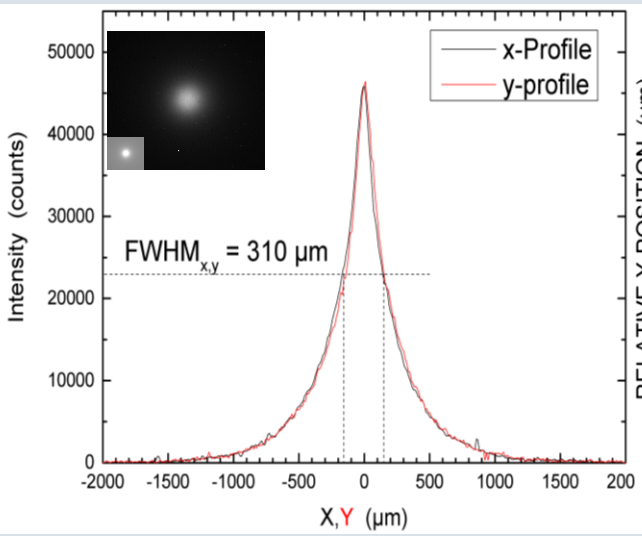
EUV Pulse Duration



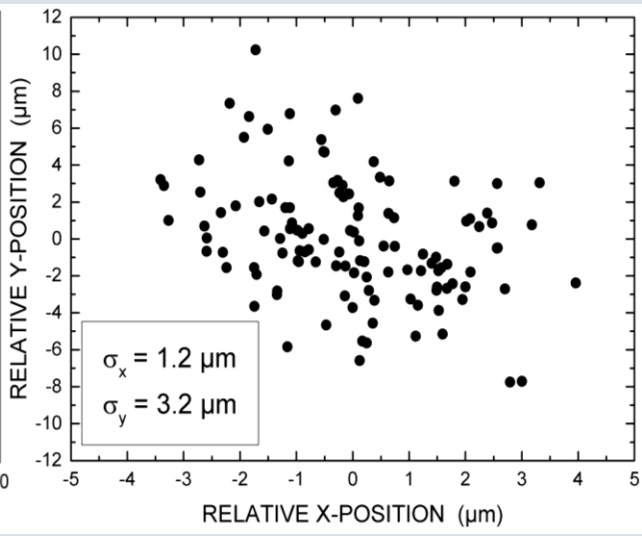
EUV Spectrum: E-SPEC



Pulse Statistics



Source Size



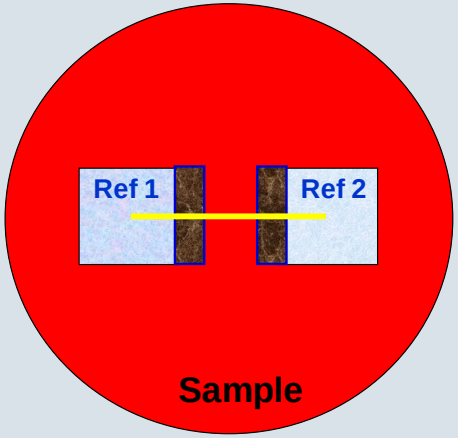
Position Stability

EUV Mask Reflectometry: EUV-MBR

research instruments

Top Level Task

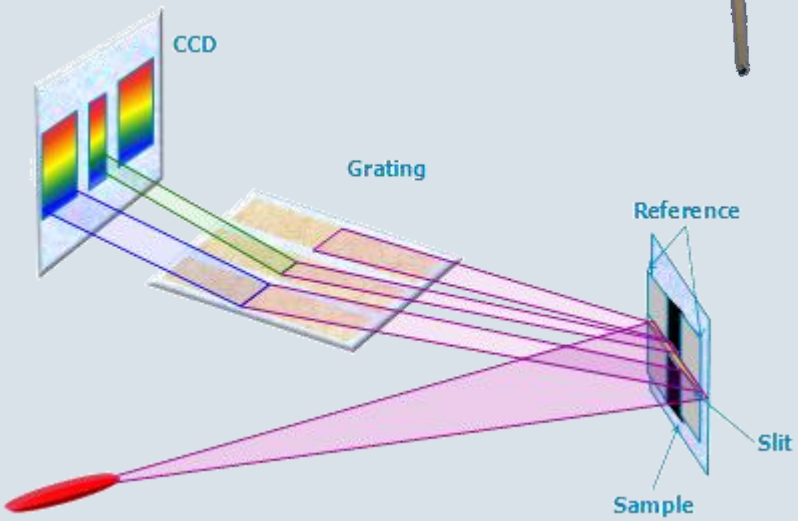
Measure spectral reflectance of multilayer and absorbers with high precision and accuracy (x* SEMI masks) under 6° AOI with high throughput



Experimental Targets

Spectral Reflectometry at 12.5-14.5 nm.

Reproducibility of R_{max}< 0.2 % abs and CWL_50 < 5 pm!



Solving Concept

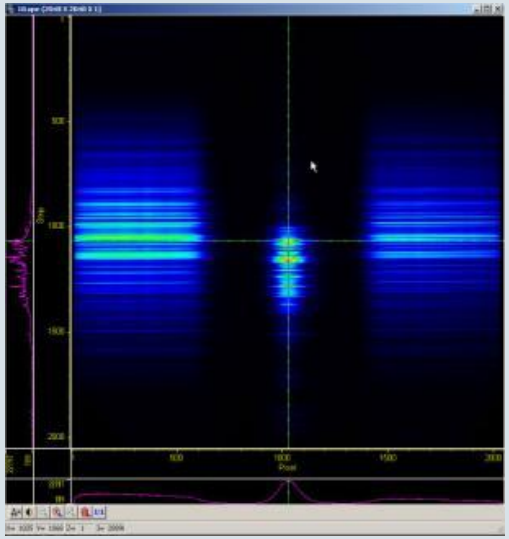
Polychromatic reflectometry relative to reference with $\Delta\lambda/\lambda$ > 2000 resolution

Immanent wavelength calibration with NIST Xe lines

Broadband EUV Spectrum of < 300 mW/2p sr) i.b.

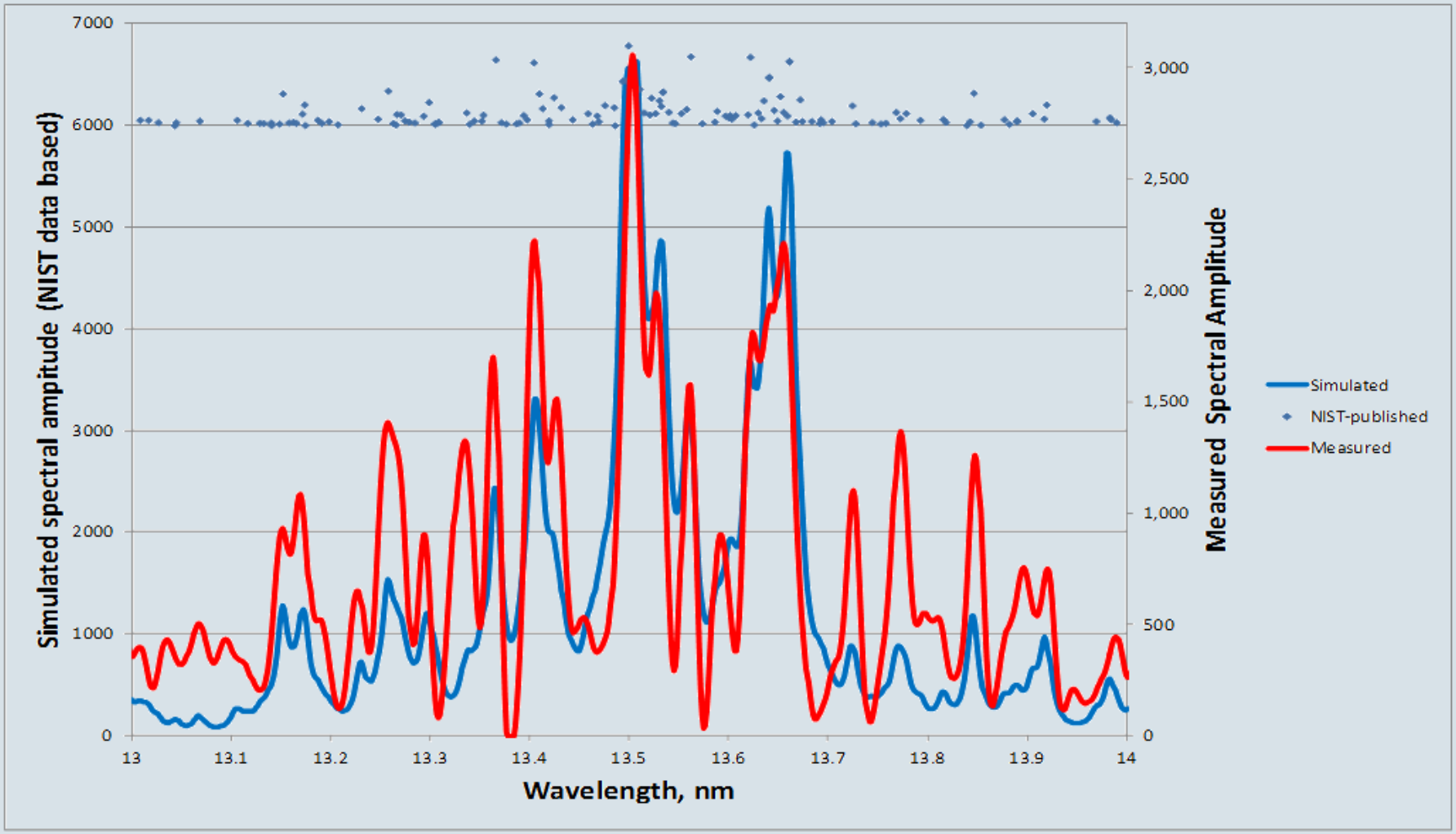
Reliable and stable

Performance:



Spot: 250*100 µm² ; result in 20 seconds; precision σ: 0.2 %, 1 pm

Special Development:
Immanent WL Calibration with by NIST Xe Lines

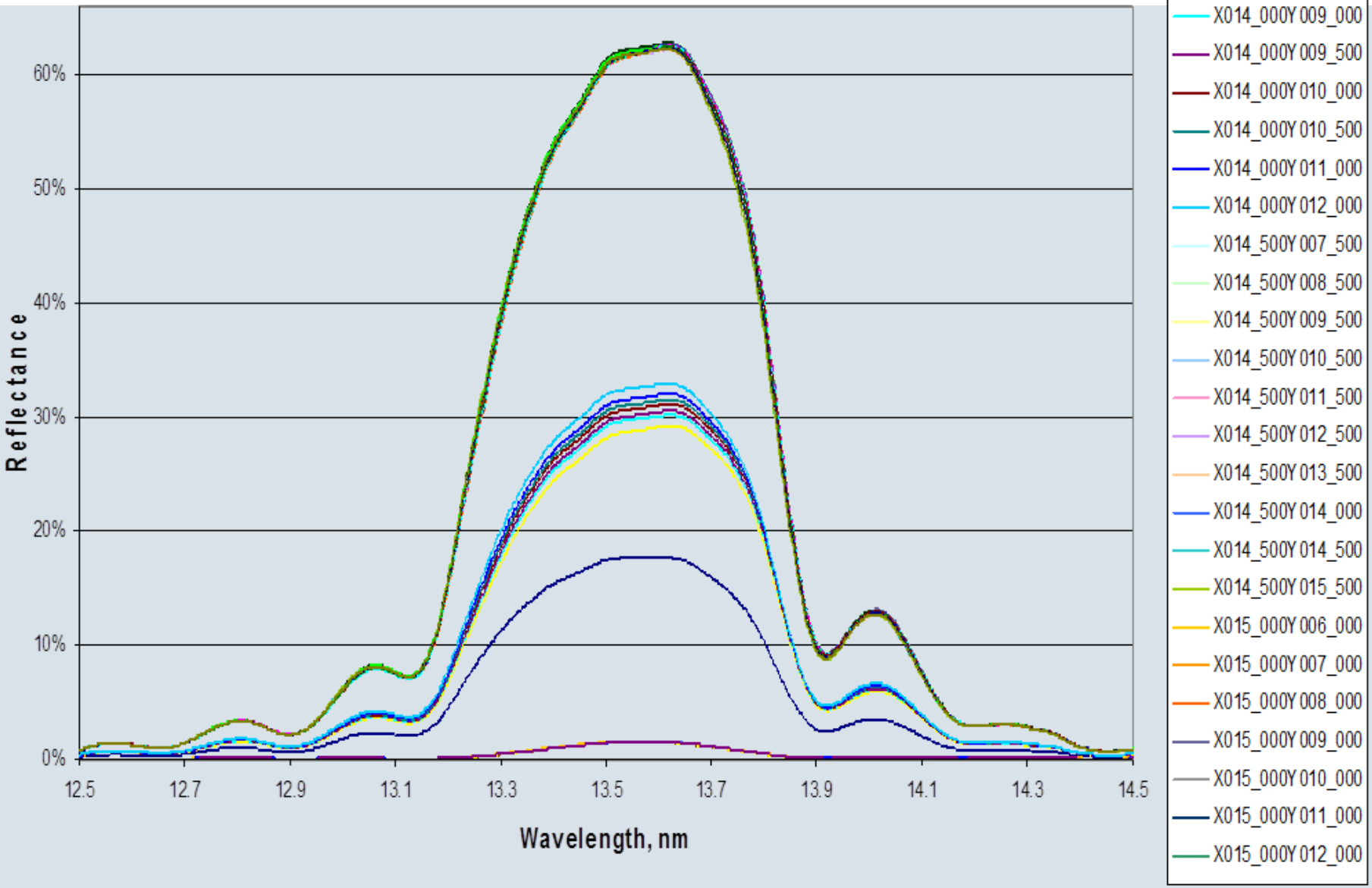


➔Accuracy better one spectral channel

➔ MBR: < 1.6 nm; XUV-SPM < 8 pm @ 13.5 pm ($\lambda/\Delta\lambda$ >8,000 resp. 1,500)

Example: Stepping Measurement over Structured Mask delivers linear superimposed results.

research instruments



XUV Spectrophotometry: XUV-SPM

research instruments

Top Level Task

R&D grade spectral photometry of arbitrary samples (also gases and curved) in arbitrary geometry in spectral range from (2) 8-40 nm

Experimental Target

Spectral characterization of samples under arbitrary AOI: 0° to 85°

Reproducibility of < 0.5 % abs. and < 25 pm !

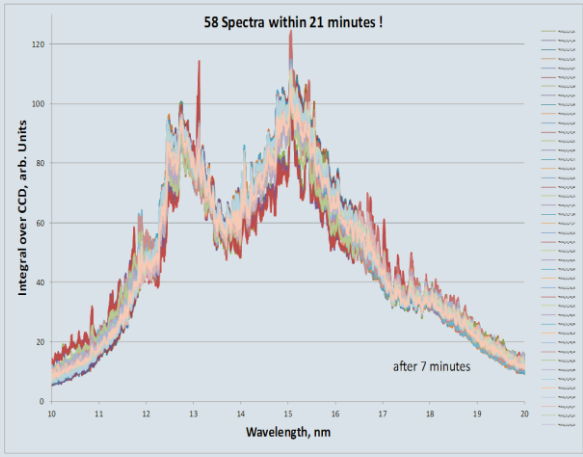
Solving Concept

Demagnify source onto sample

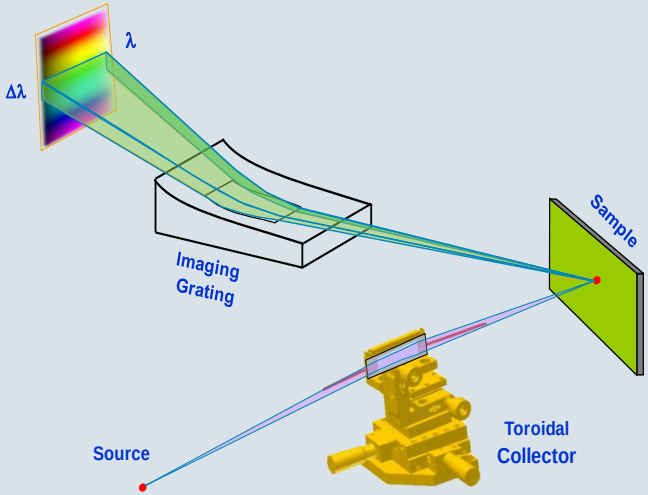
Dose monitored; polychromatic spectrograph with $\Delta\lambda/\lambda > 500$

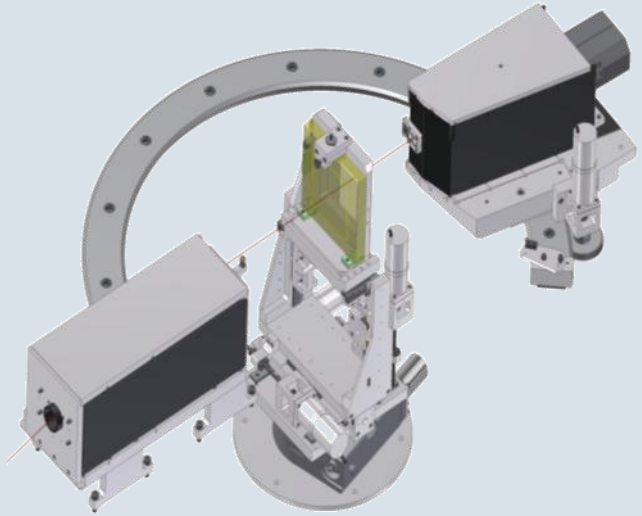
Immanent Xe WL calibration

Low power small size broadband XUV source
➔ gold LPP source



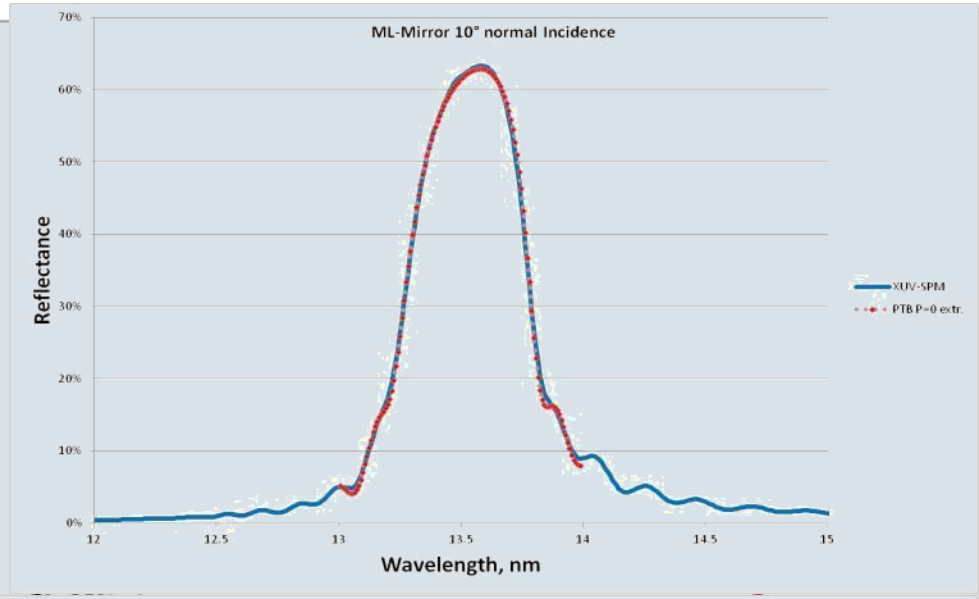
LPP < 5 mW EUV i.b. for spectroscopy

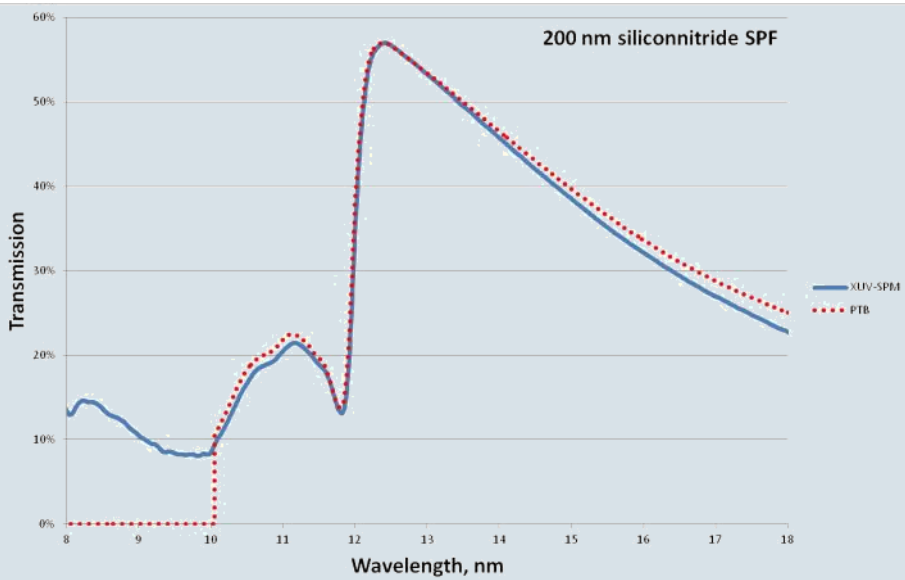


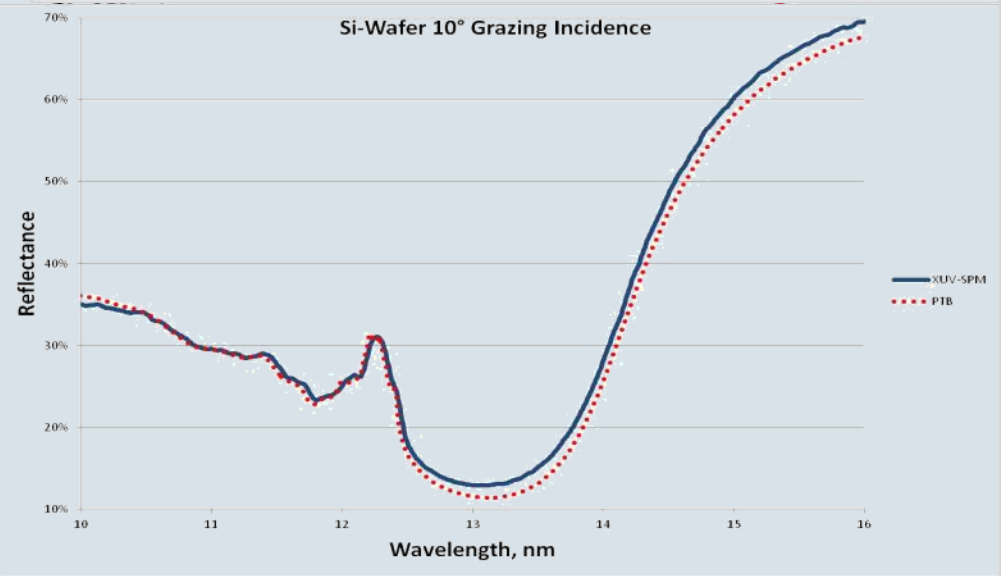


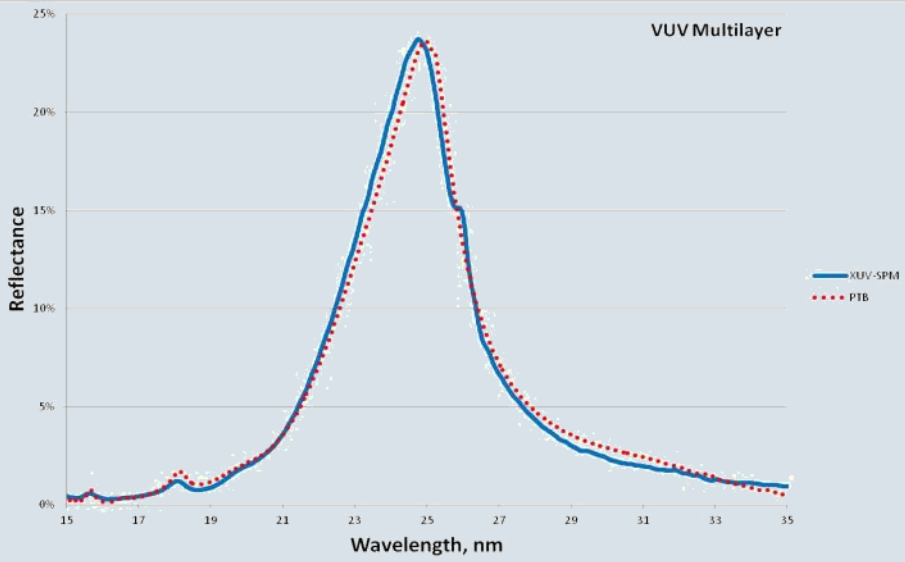
Performance:
Ø≈ 50 µm; one spectrum in 30 seconds; precision σ: 0.5 %, 10 pm

XUV-SPM: Flexibility
GI & NI Reflection, Transmission, VUV, Gases









XUV-SPM Accuracy:
Influence of Polarization to be accounted for

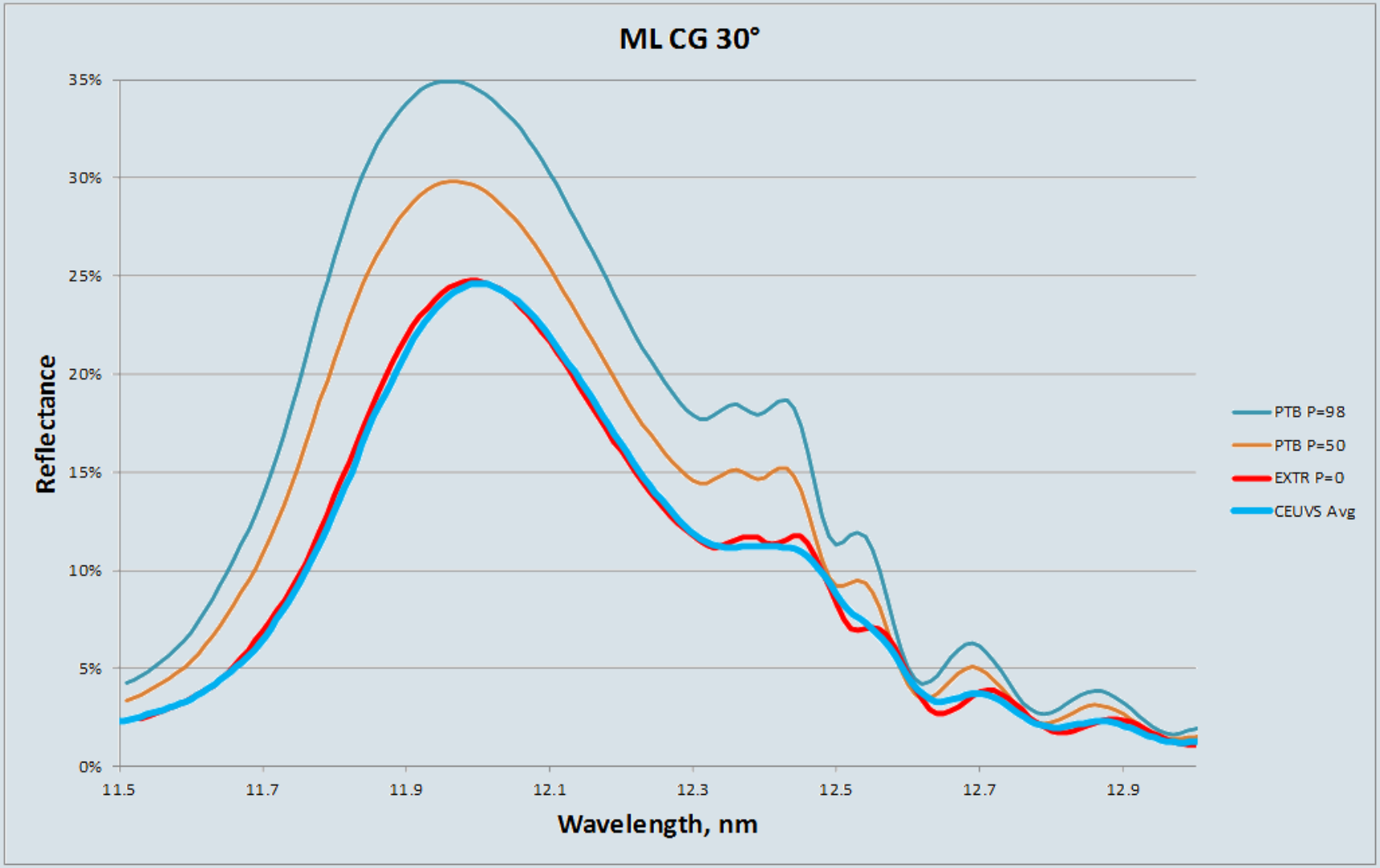


Table top R&D EUV Reflectometer „PANTER“

Top Level Task

R&D grade grazing incidence XUV reflectometry (GIXUVR) for arbitrary thin film analytics (e.g. NEXAFS)

Experimental Targets

AOI from 5-10: variable (two angle measurement ➔ calibration free)

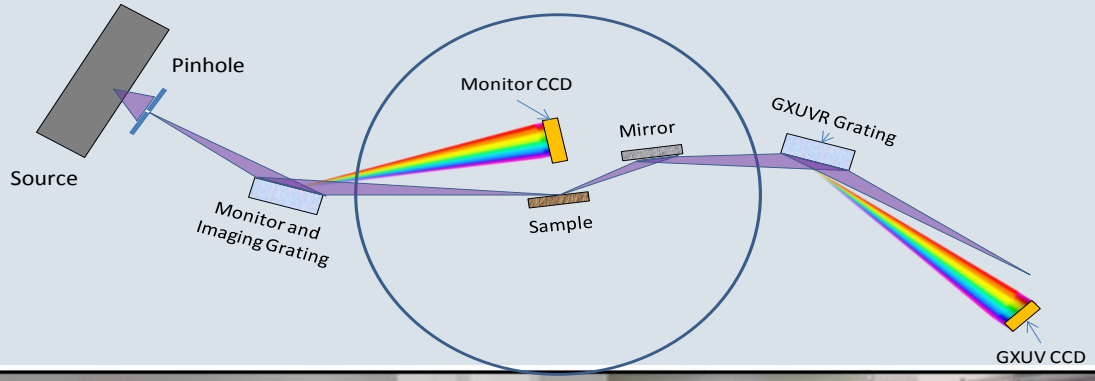
Spectral monitoring for GI !

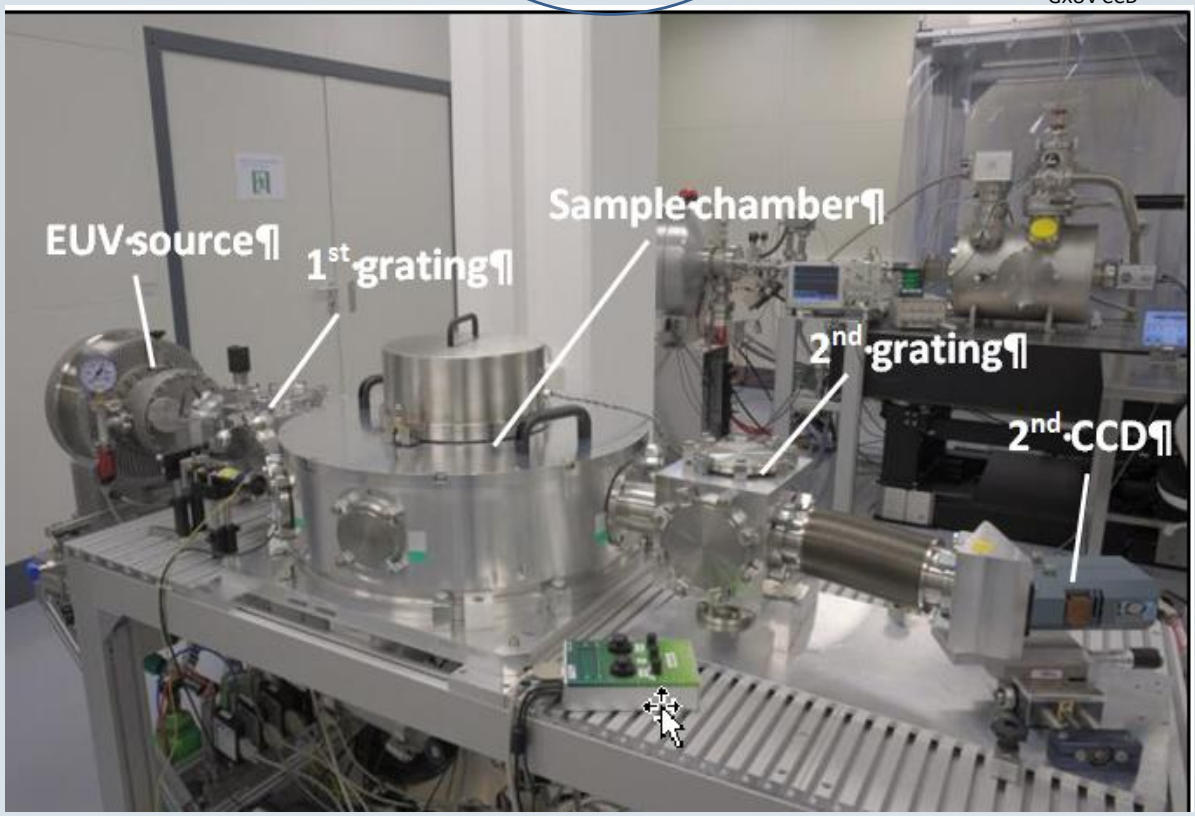
Solving Concept

With “illumination grating” reference spectrum is out-coupled from 1st order.

AOI variation is compensated by deflection mirrors.

Medium Power standard EUV-lamp

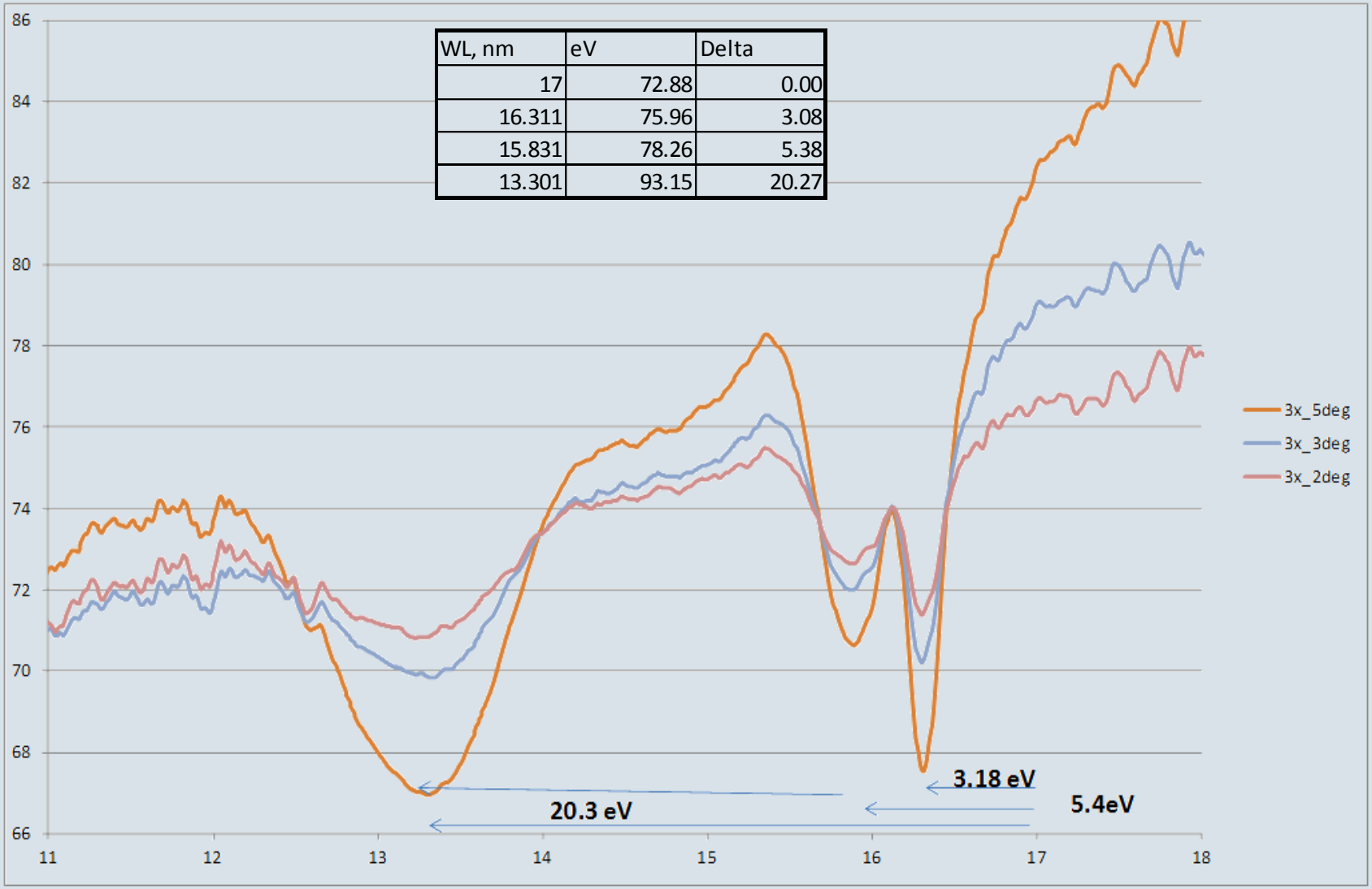




➔ Path to XUV-Analytics (XANES, NEXAFS), e.g.: Al_2O_3: Chemical shift due to amorphous or crystalline

research instruments

WL, nm	eV	Delta
17	72.88	0.00
16.311	75.96	3.08
15.831	78.26	5.38
13.301	93.15	20.27



EUV Resist: Interference Nano-patterning

Top Level Task

Print nanostructures of < 100 nm HP

Experimental Targets

Exploit "near field" polychromatic interference Lithography (Talbot)

Stable position during exposure

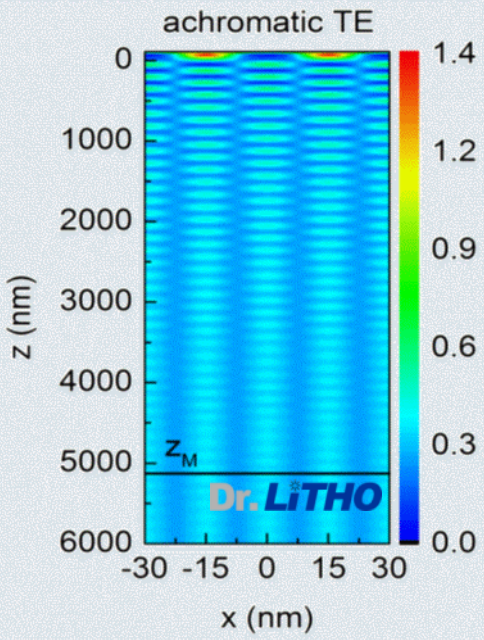
Precise mask-wafer distance

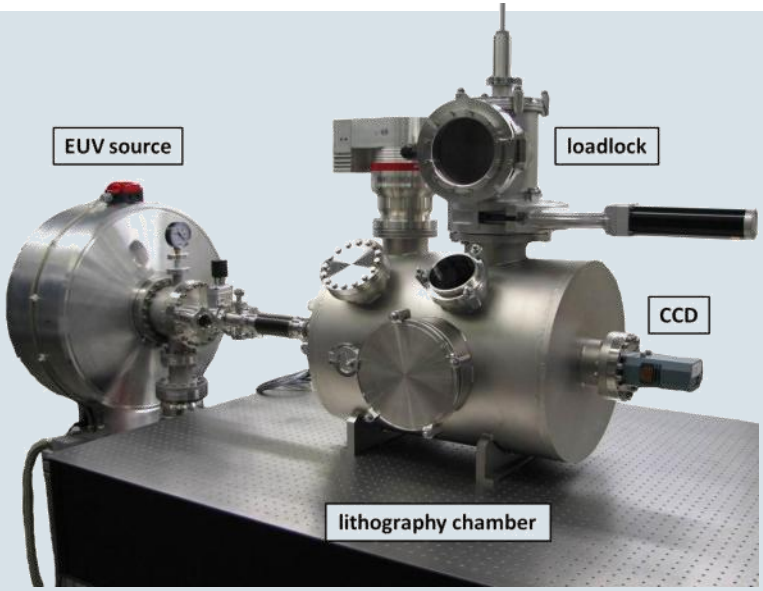
Solving Concept

Tight(< 100 nm) mask-wafer distance and tilt control.

High brightness & high flux DPP EUV source V4

11 nm emission optimized for high brightness

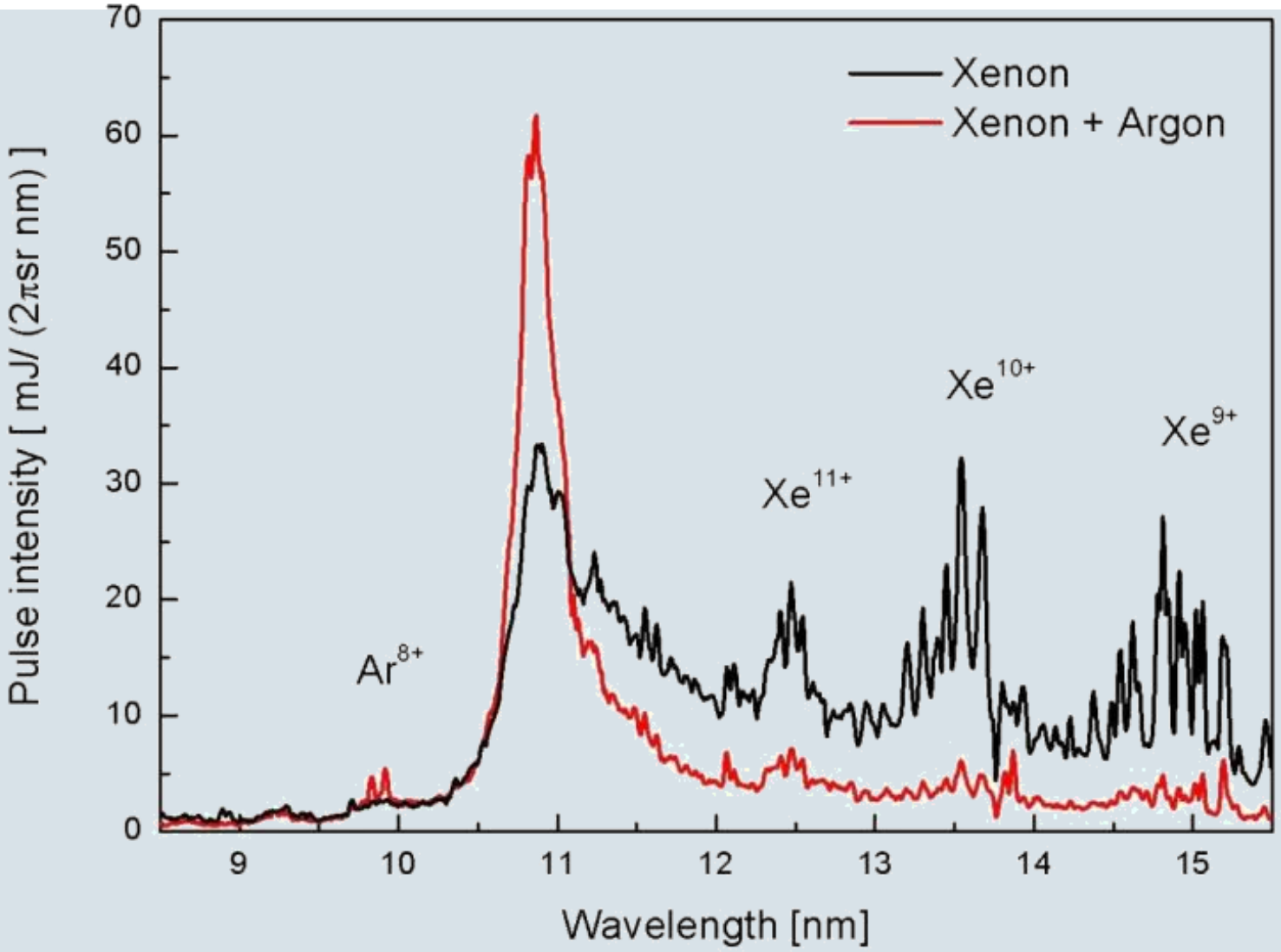




Exposure tool: Up to 100 mm wafers; fields of 4 mm²
Printed in < 60s @ 30 mJ/cm2;
Control: Distance better 100 nm; Dose < 0.1 mJ/cm2

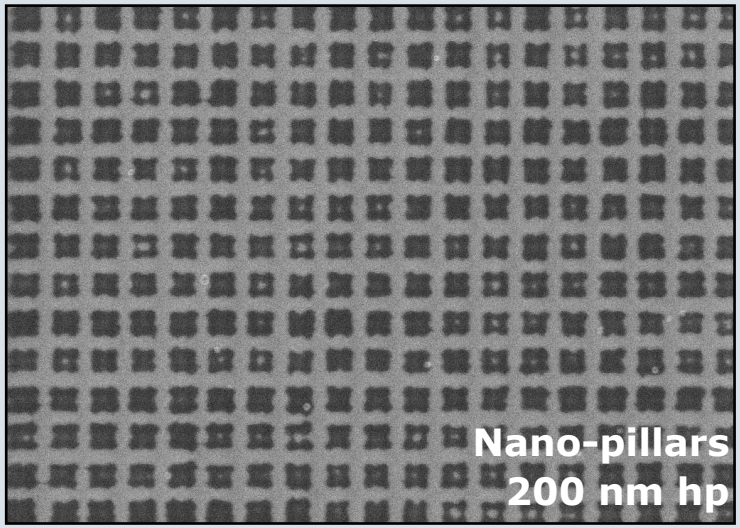
Outlook: Vector simulations show scalability down **to 7.5 nm hp on wafer** with polarized light.

Special Solution: Xenon EUV Source tuned for narrowband 11 nm emission

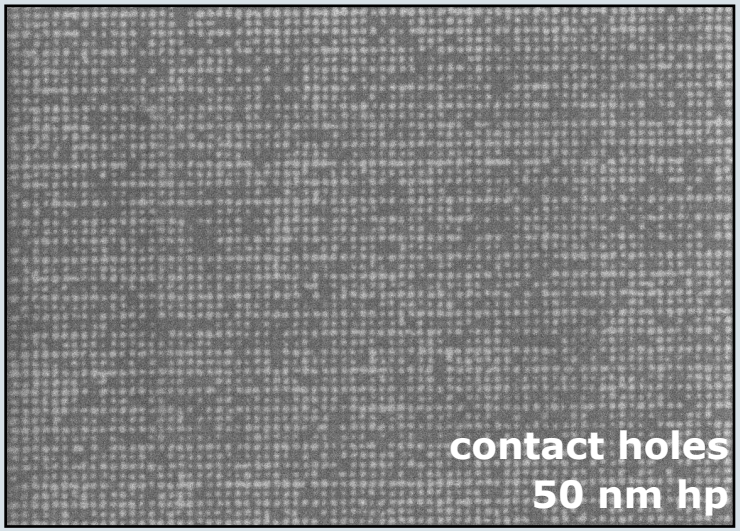


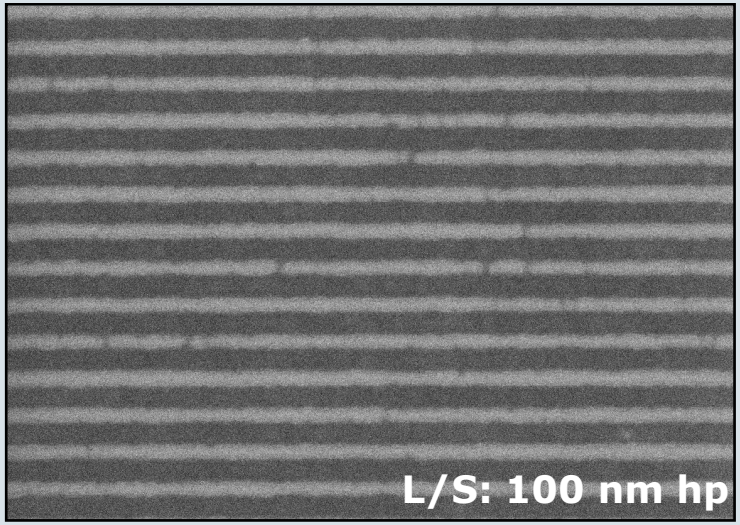
EUV source: Diameter ~250 µm; Brilliance: >100 W/(mm²sr)

Lithography Exposure Results

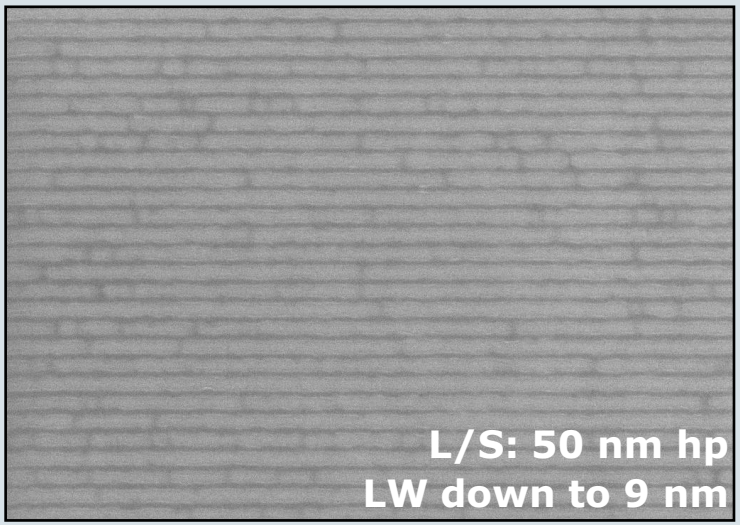


Proximity printing with double patterning





Demagnification with Talbot lithography



All shown exposures are produced in ~30nm thick ZEP520A resist

Actinic Multilayer Scatterometry

Fraunhofer IOF

research instruments

Top Level Target

Quantify and Qualify flare due to scatter from multilayer roughness (actinic)

Experimental Tasks

Spectral filtered and flare clean irradiation on small spot.

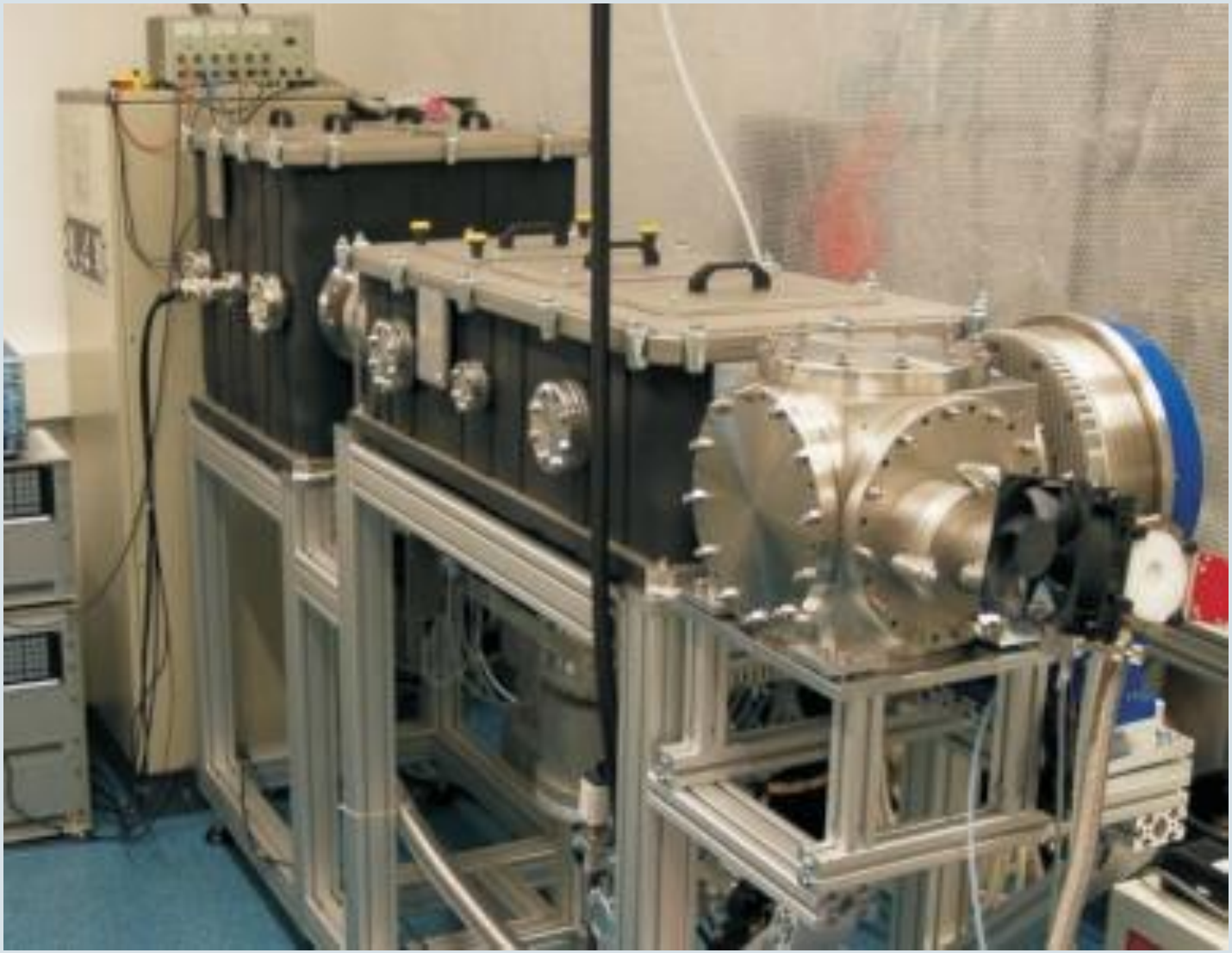
Sensitive wide angle detection

Concept & Source

Medium power DPP Source

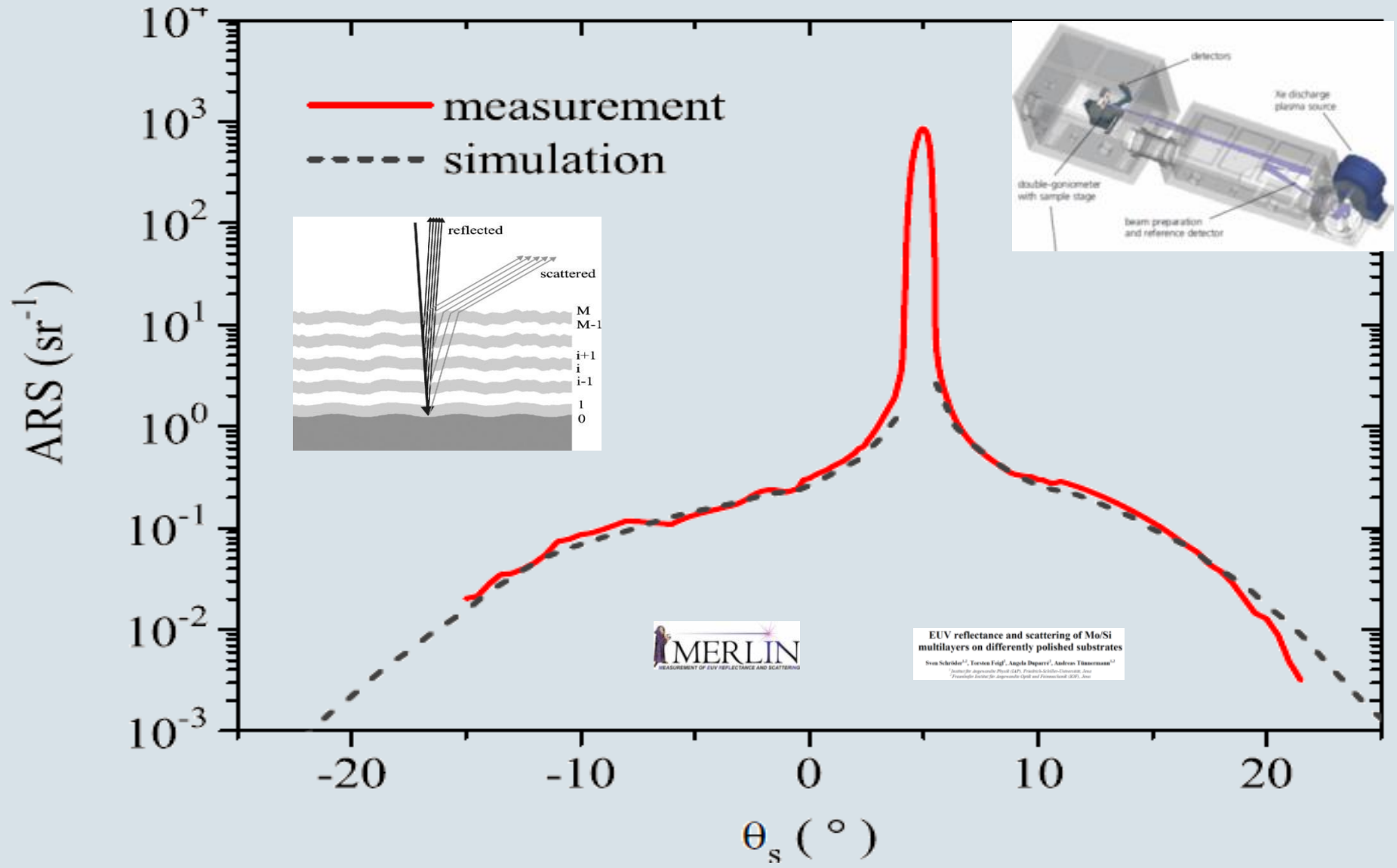
SPF+ML reflection for beam forming and cleaning

Beam Monitor



Instrument for the Measuring of EUV Reflectance and Scattering - MERLIN

Fraunhofer IOF research instruments



"Monochromatic " general Scatterometry: Wide Angle XUV GI Scatterometry

research instruments

Top Level Target

Collect scatter information from arbitrary nano structures for qualification of samples (wafers, masks)

Experimental Tasks

Find best compromise between resolution, wavelength, angle of incidence and number of orders.

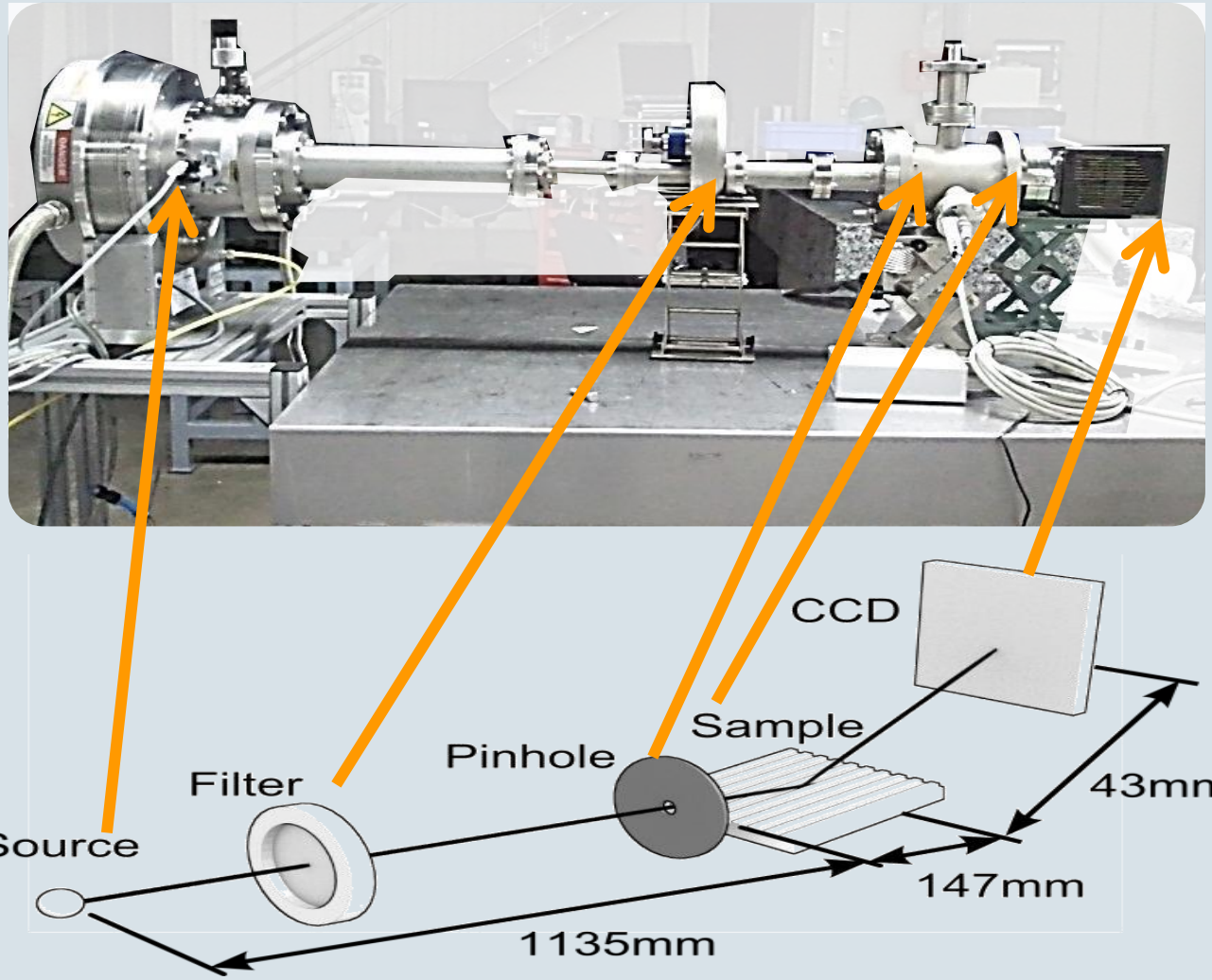
Generate quasi point like, monochromatic irradiation

Solving Solutions

Low power DPP or LPP source spectrally filtered for narrowband and spatially for low divergence.

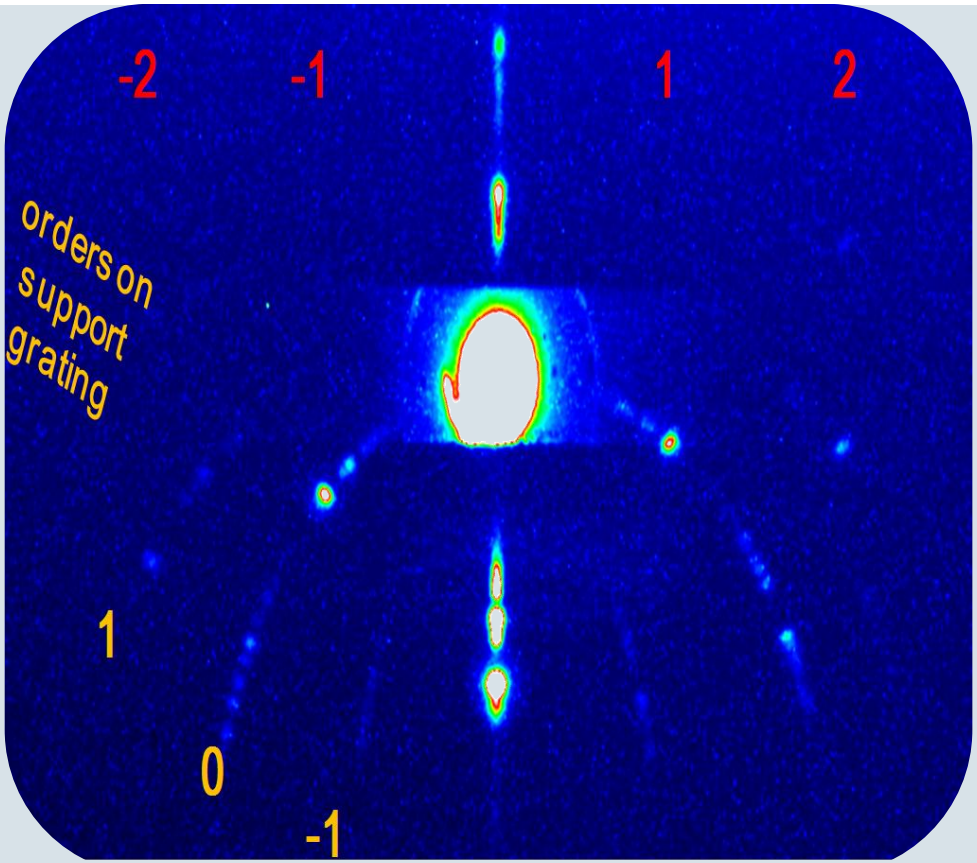
Clean collimated beam

Finite angles (> 5 °)

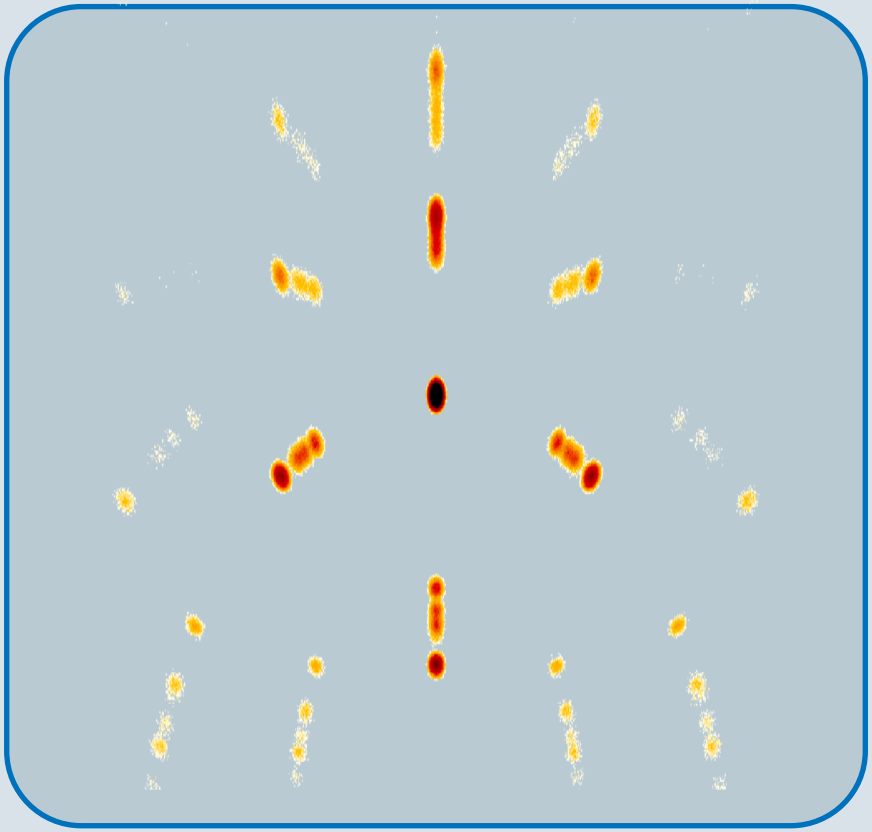


Straight forward compact Proof of feasibility experiment set-up with available lab components at BASC.

CD-WA-XUV-Scatterometry: First results



Typical Result obtained with PoP set-up



Simulation of expected result is in agreement

< 1mm² spot >5° AOI exp.< 10 s per image No beam stop

Spectral distribution exploits flexibility of EUV-Lamp with different working gases

➔ Achieved: Accuracy of CD < ± 2 nm Reproducibility. < 0.06 nm rms < 0.2 nm PV

Actinic CD on masks is straight forward solvable task. Demand ? Specs ?

Nanoscopy (Here Soft-X-Ray)

Top-Level Target

Microscopy with sub-20 nm resolution; Soft-X or EUV

Experimental Tasks

Narrowband emission $\lambda/\Delta\lambda < 100$

High brightness (➔ 100 W/mm²/sr)

Source Size matched

Solution Concept

Single Line optimized

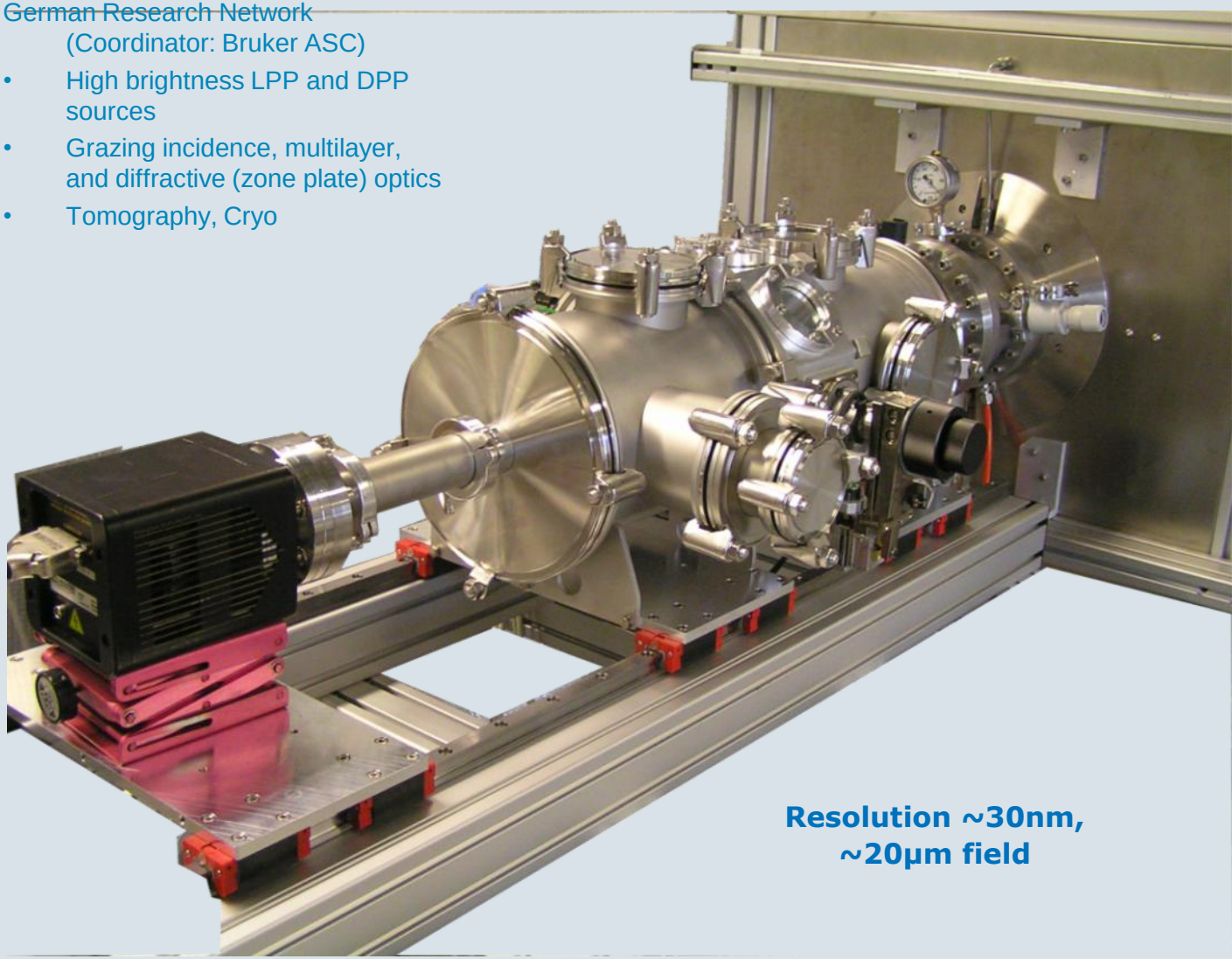
DPP or LPP source

GI-Collector

Zone plate optics

German Research Network
(Coordinator: Bruker ASC)

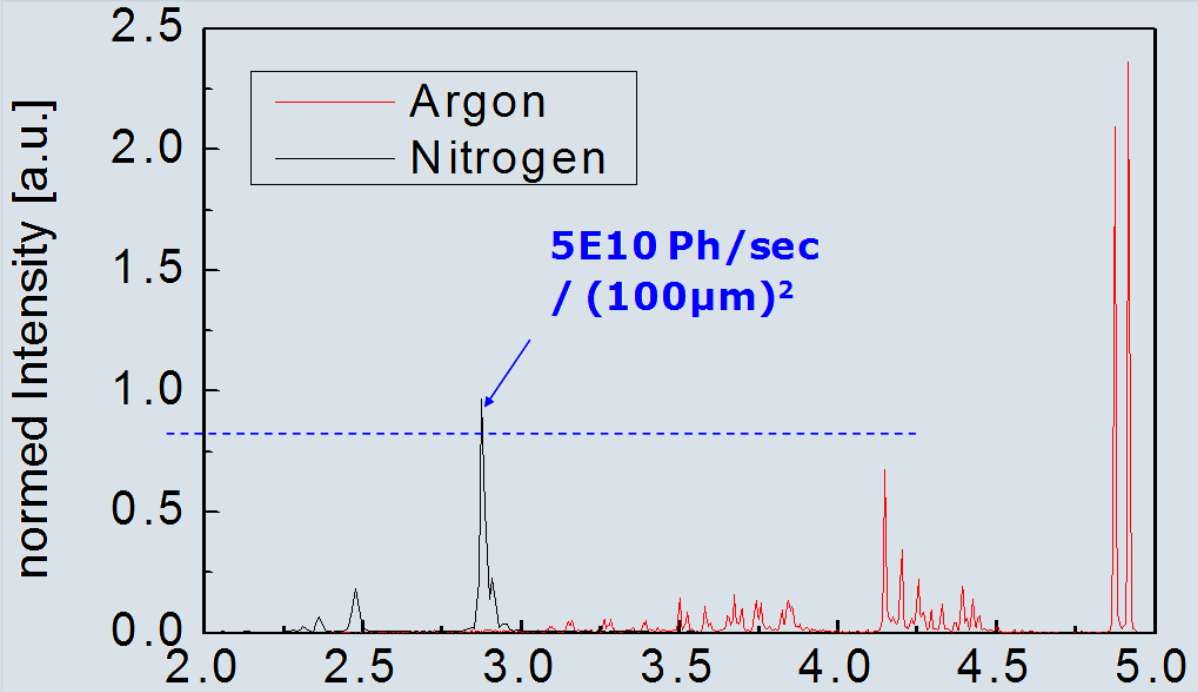
- High brightness LPP and DPP sources
- Grazing incidence, multilayer, and diffractive (zone plate) optics
- Tomography, Cryo



Resolution ~30nm, ~20µm field

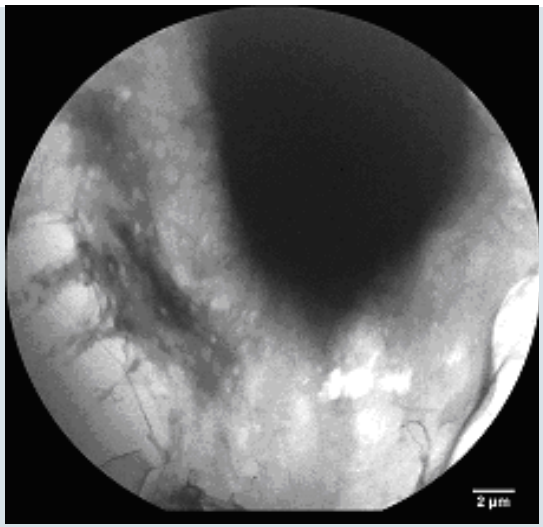
Special Development: High Brightness Monochromatic XUV Source in Water Window

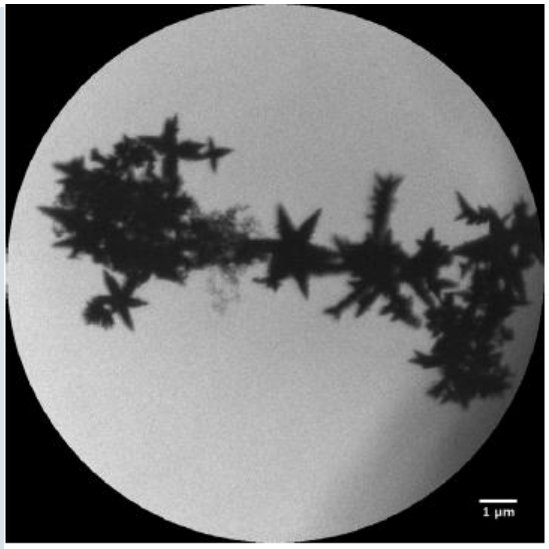
Benk et al., Optics Letters 33 (2008)

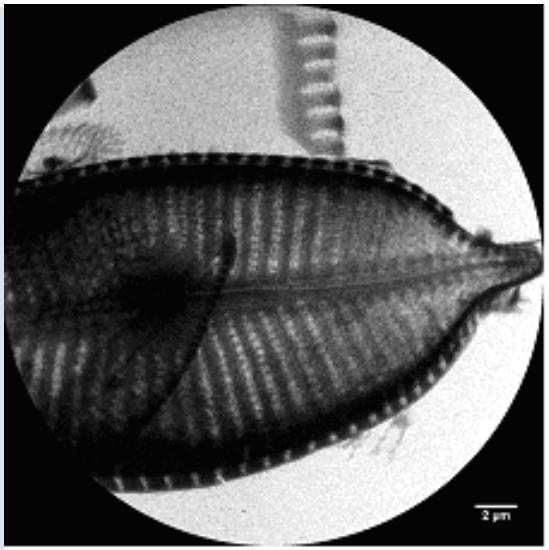


- el. Pulse energy : 12 - 20 J
- Repetition rate : 1- 2 kHz
- Peak current : 15 kA
- Input power : 10 - 20 kW
- source diameter : several 100 µm FWHM
- photon flux : > 10^{14} Ph/(2π sr)/ Pulse
  : > 4.6 W/(2π sr) @ 10 kW

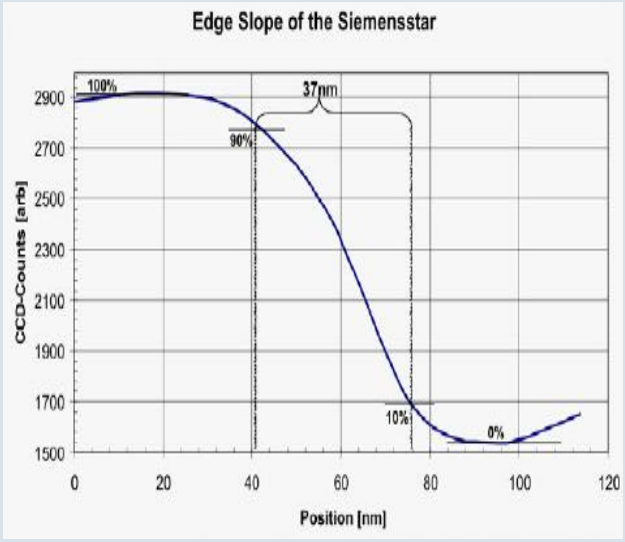
X-Ray Microscopy with DPP source: 40 nm Rayleigh Resolution demonstrated



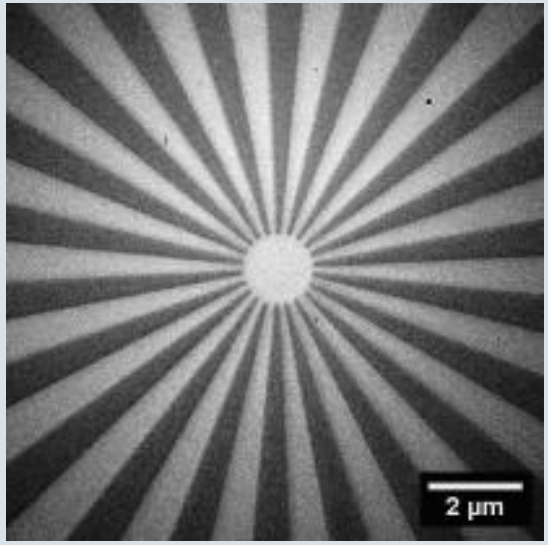




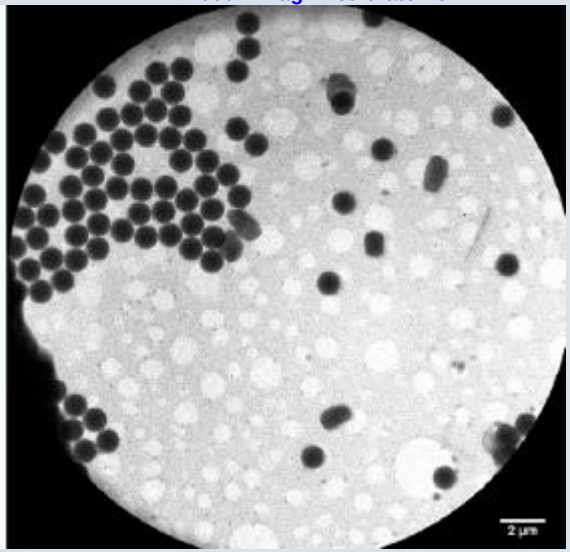
1000 x magnified diatoms



M. Benk, K. Bergmann, D. Schäfer (2008)



M. Benk, K. Bergmann, D. Schäfer (2007)



1000 x magnified diatoms and 80 nm latex spheres

EUV Mask: Actinic Blank Defect Inspection
R&D Grade ABIT in Operation

Top Level Target

Find all printing defects of > x nm on mask blanks. Also purely actinic (Phase)

Experimental Tasks

100 µW irradiated on sample spot of 1*1 mm²

Spectrally and flare clean irradiation

High contrast of defect signal and sample flare (ML roughness !)

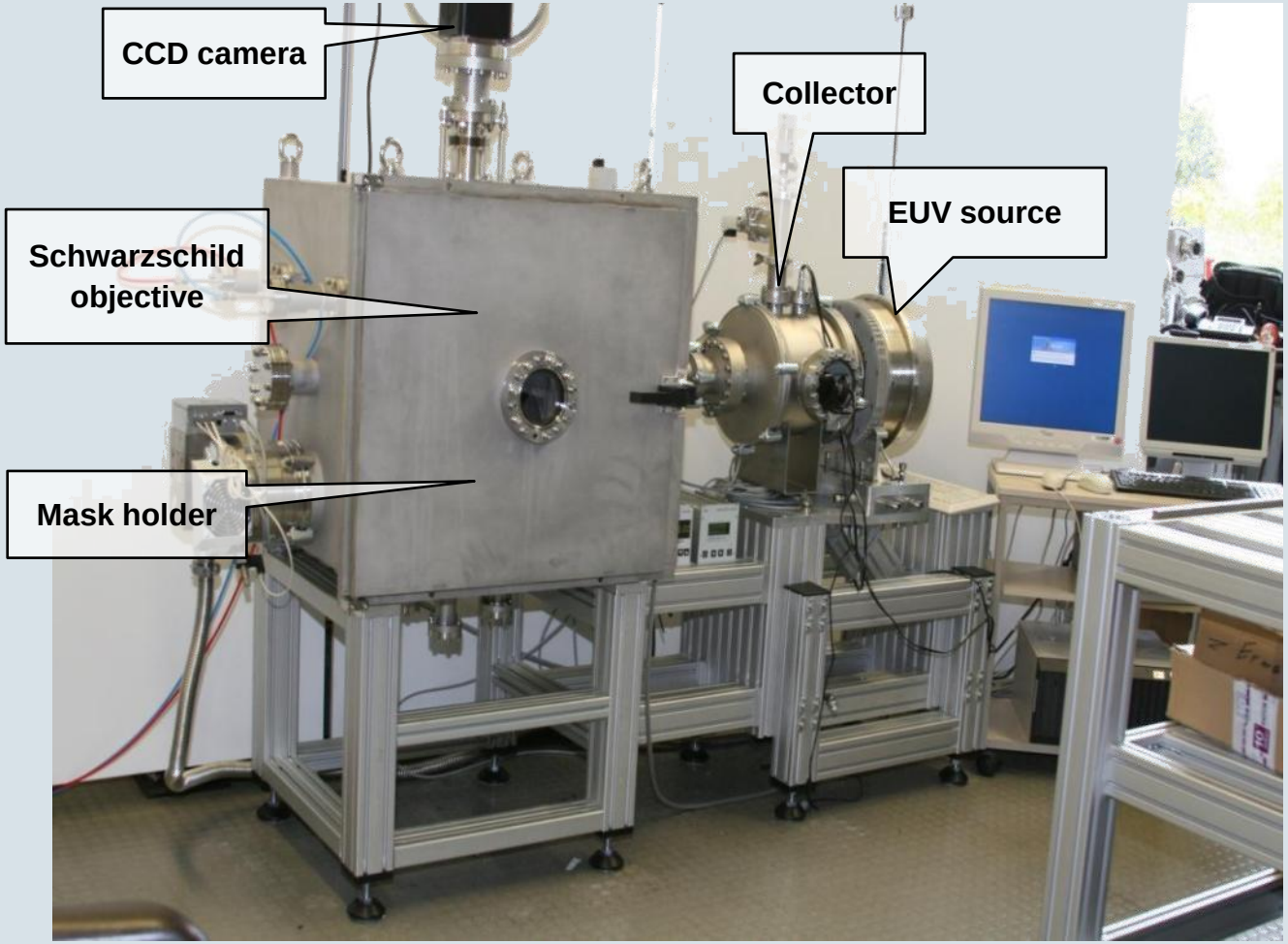
Solving Concept

Dark field EUV microscope

DPP EUV-Source

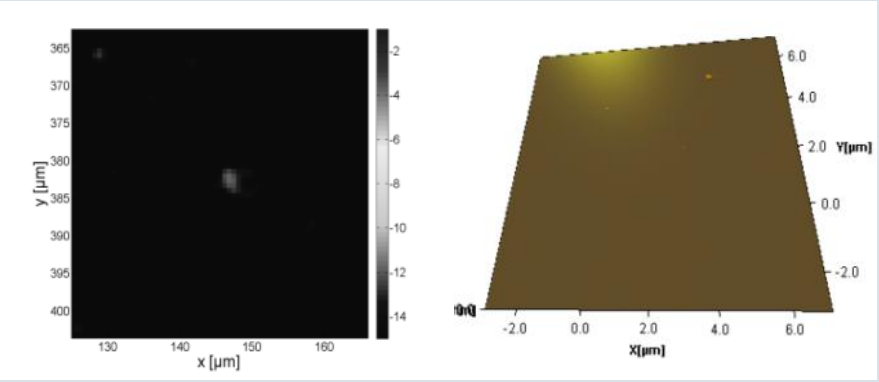
Filtered, magnified , homogen. irradiation

Large scatter collection angle



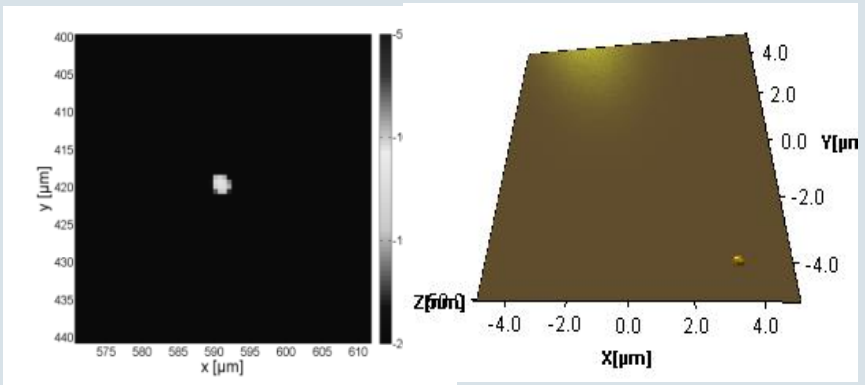
Investigation results:
Natural defects on a multilayer mirror

EUV **AFM**

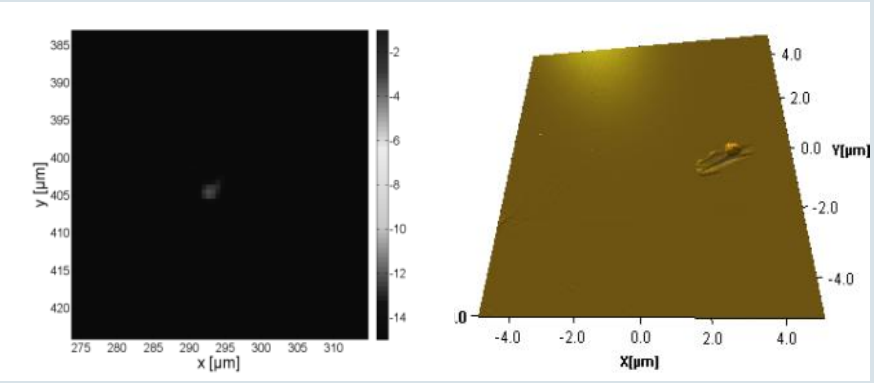


Bump:
Sphere: 220nm
Circle: 250 nm
Height: 160 nm

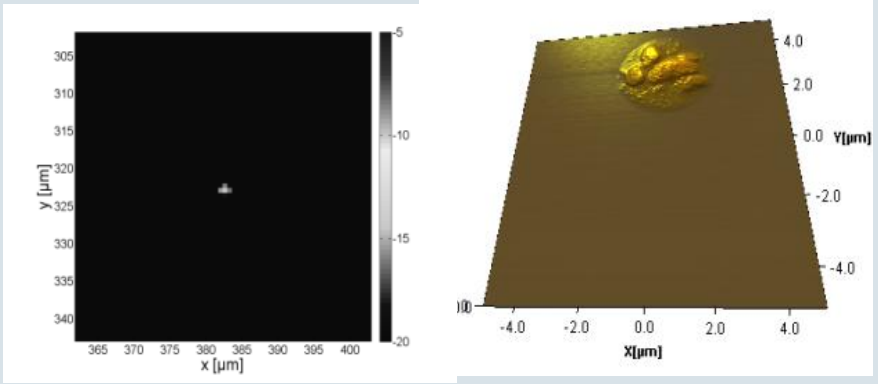
EUV **AFM**



Potential phase defect



Sphere: 81 nm
Circle: 133 nm
Height: 25 nm



Sphere: 720 nm
Circle: 1220 nm
Height: 210 nm

Summary

- Available LPP and DPP Lab sources support a broad range of laboratory based experiments and tooling.
- Most applications relate to actinic mask, optics, pellicle and resist testing, characterization and metrology in EUVL arena .
However, also new options for nanoscopy, nano-printing, thin film analysis are supported.
- Viable solutions are found in concept studies by selecting, adapting and tailoring effective Lab source, matched optical concept and suited components for vacuum, handling, detection and monitoring.
- Proof of concept experiments in our application labs allow to extrapolate to customer tailored solutions.
- Experience in UHV; optics, mechanics, automation, and control design, manufacturing and commissioning allows for offering, up to turn key installations
- ➔ One of a kind realization, is our business and very typical for our accelerator and beamline photon instrumentation contracts.

Thank you for your attention

See you at Poster P 32

We gratefully acknowledge
Collaboration with PTB, xOptFab, Rhein-Ahr Campus Remagen, Helmholtz and MBI Berlin

We also appreciate funding from the BMBF/Catrene (13N10572, CT301), JARA-FIT, NRW (w1001nm016 a,b) and BMBF/ECSEL (16ESE0048).

www.research-instruments.de

From ACCEL and AIXUV to RI

ACCEL

research instruments

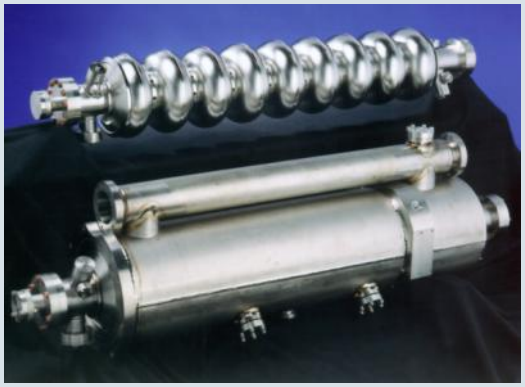
1993-2007: ACCEL grew to Leading Global Accelerator Equipment and Systems Supplier

Accelerator Technology

Linear Accelerators

Special Manufacturing

Insertion Devices



Magnet Technology

Superconducting Magnets

Synchrotrons/Cyclotrons

Proton Therapy Systems

V: Beamline, X-Ray Optics

Beamline Components,

X-ray Optics,

Endstations, UHV

2007 Varian Medical Systems acquires all Accel

VARIAN medical systems

2010 Varian cont. only Proton Therapy

BRUKER Bruker ASC

research instruments

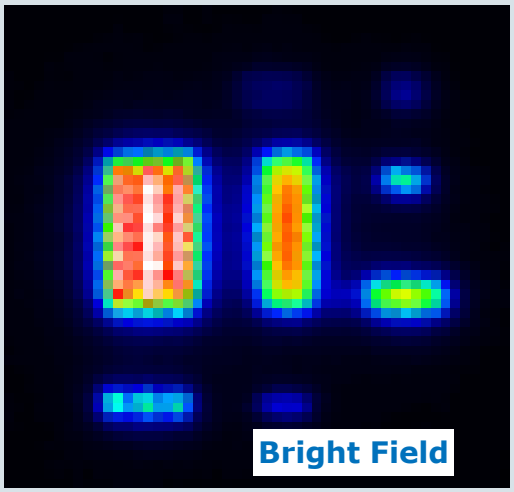
AIXUV EUV-Technology

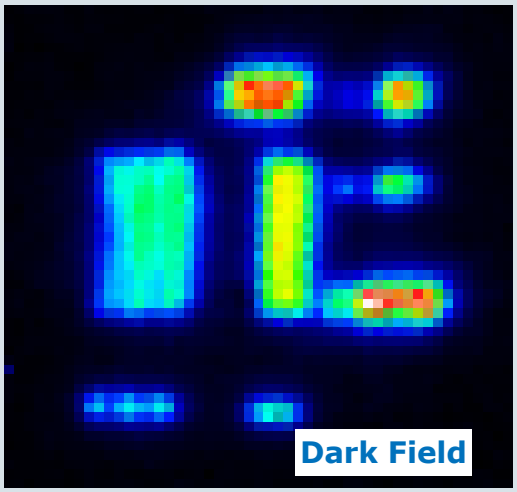
2010 BASC acq. AIXUV

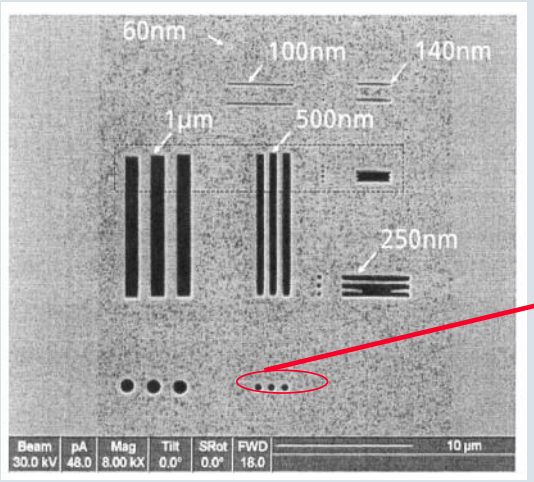
2013 BASC closes M part

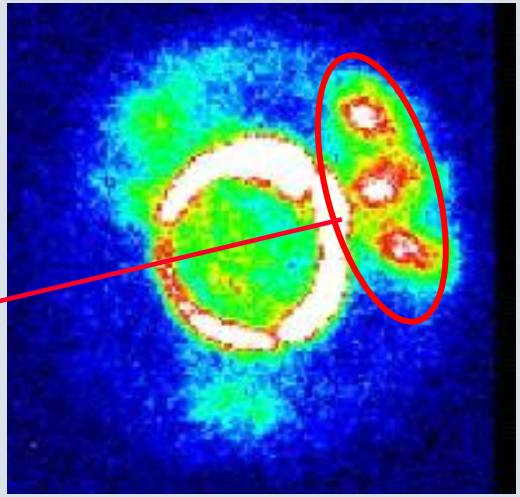
2015 RI and BASC-V "re-merge"

Actinic EUV Microscopy with DPP EUV-Lamp



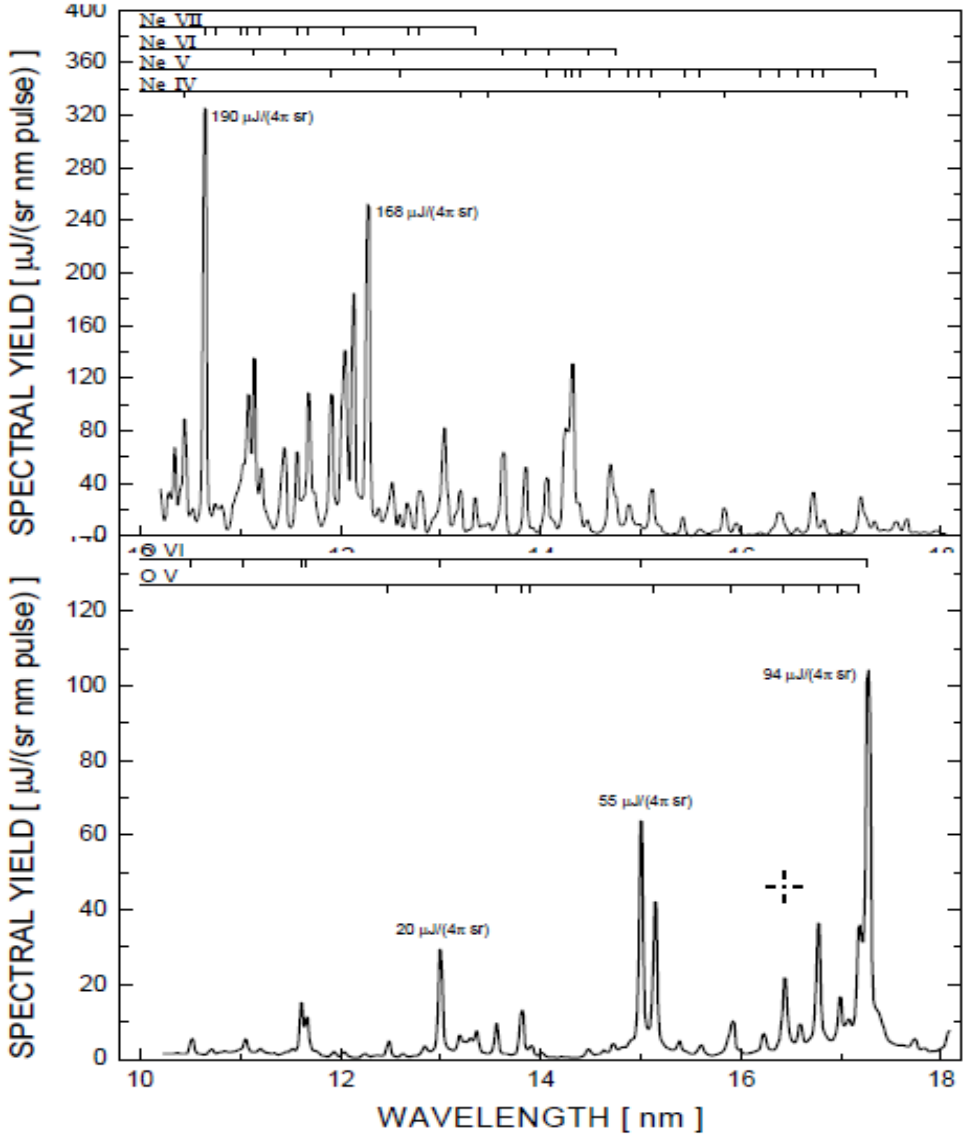


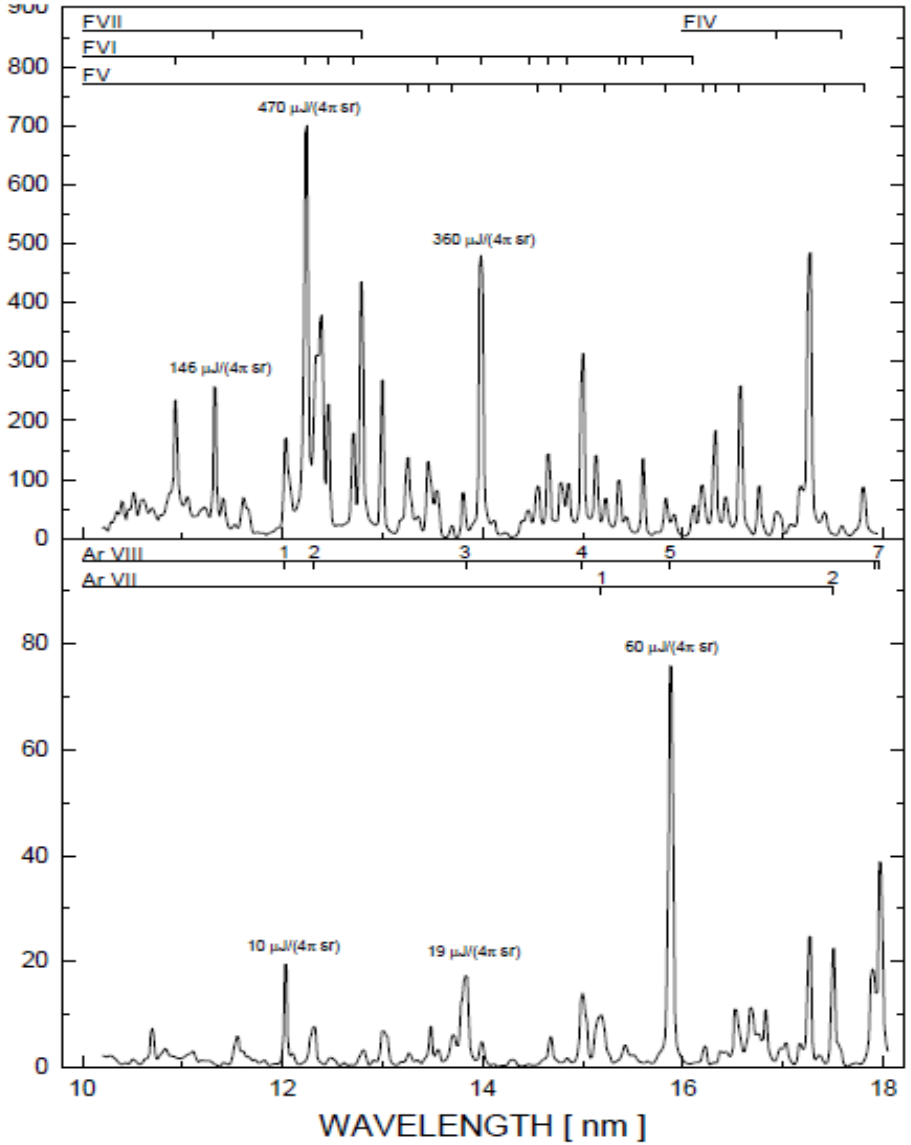




"Three Points" of transmission mask
dist = 100 nm, W = 100 nm, mag = 224

Spectral Flexibility of EUV-Lamp: just change gas !





Lifetime Monitoring for Industrial Sources

At field installed sources, we can supply lifetime monitoring of discharge and operation properties with

- 5 datasets per second for fast parameters and variables
- 1 set every 2 seconds for environmental parameters
- supported by event and error logging.