Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Synchrotron-radiation based EUV metrology at PTB

Michael Kolbe, Victor Soltwisch, Frank Scholze

Michael.Kolbe@ptb.de, Victor.Soltwisch@ptb.de, Frank.Scholze@ptb.de

https://www.ptb.de/cms/en/ptb/fachabteilungen/abt7/fb-71/ag-712.html

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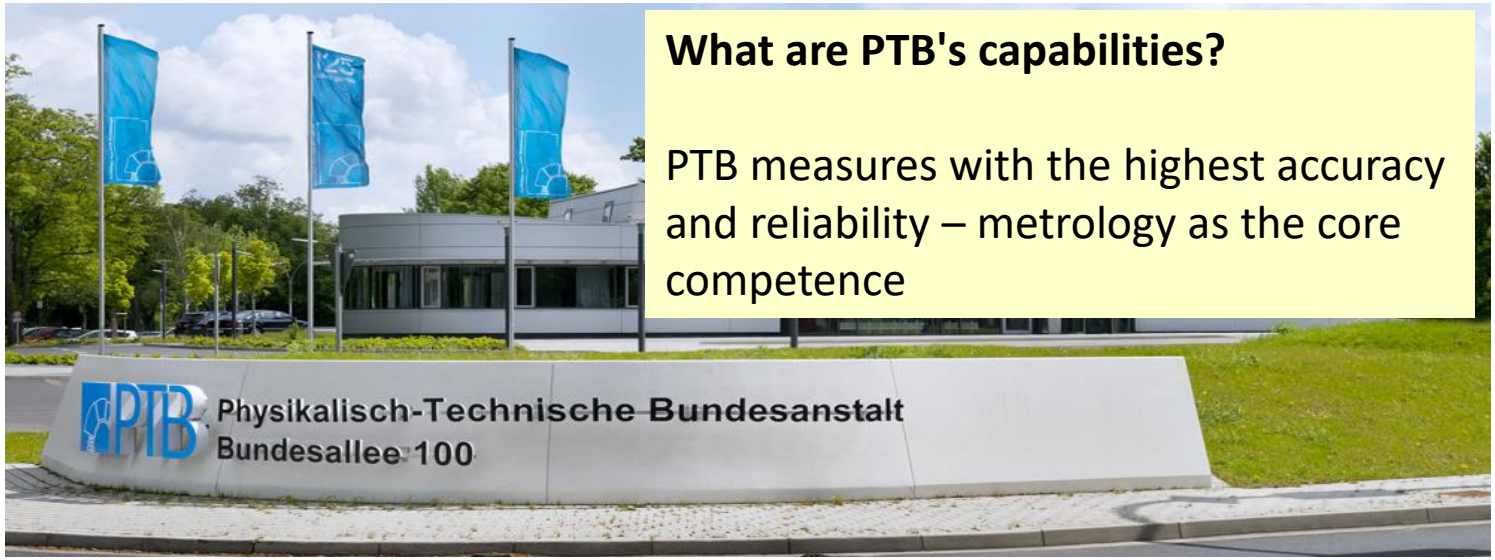
National Metrology Institute
of the Federal Republic of Germany



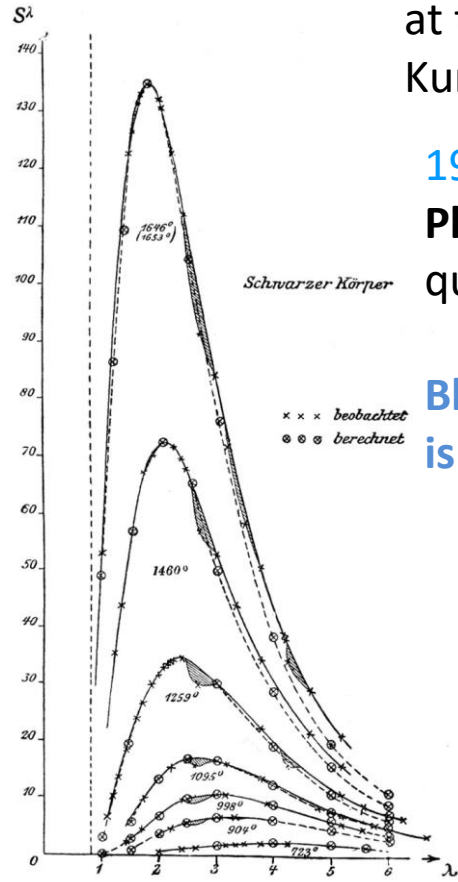
What are PTB's capabilities?

PTB measures with the highest accuracy and reliability – metrology as the core competence

Bundesministerium für Wirtschaft und Energie

Physikalisch-Technische Bundesanstalt (PTB) is a scientific and technical higher federal authority within the portfolio of the Federal Ministry for Economic Affairs and Energy.

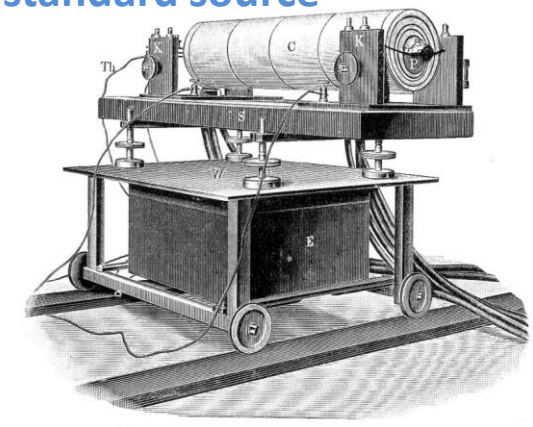
National Metrology Institute



Early 1890‘s:
precision measurements of black body radiation
at the PTR (Lummer, Wien, Kurlbaum, Pringsheim)

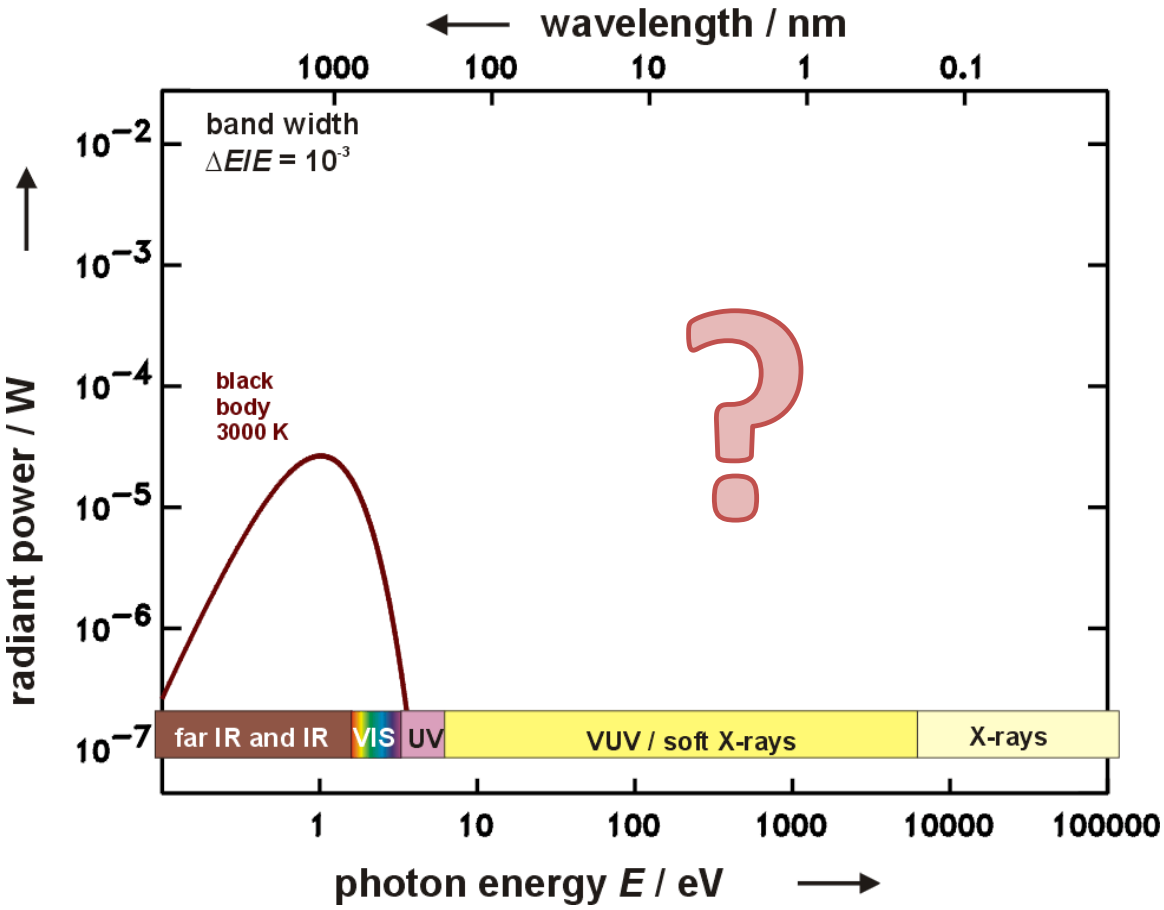
1900:
Planck‘s law – the birth of quantum theory

Black Body Radiator is a standard source



The cradle of quantum mechanics

Metrology with SR: Radiometry beyond UV



Black Body Radiatior

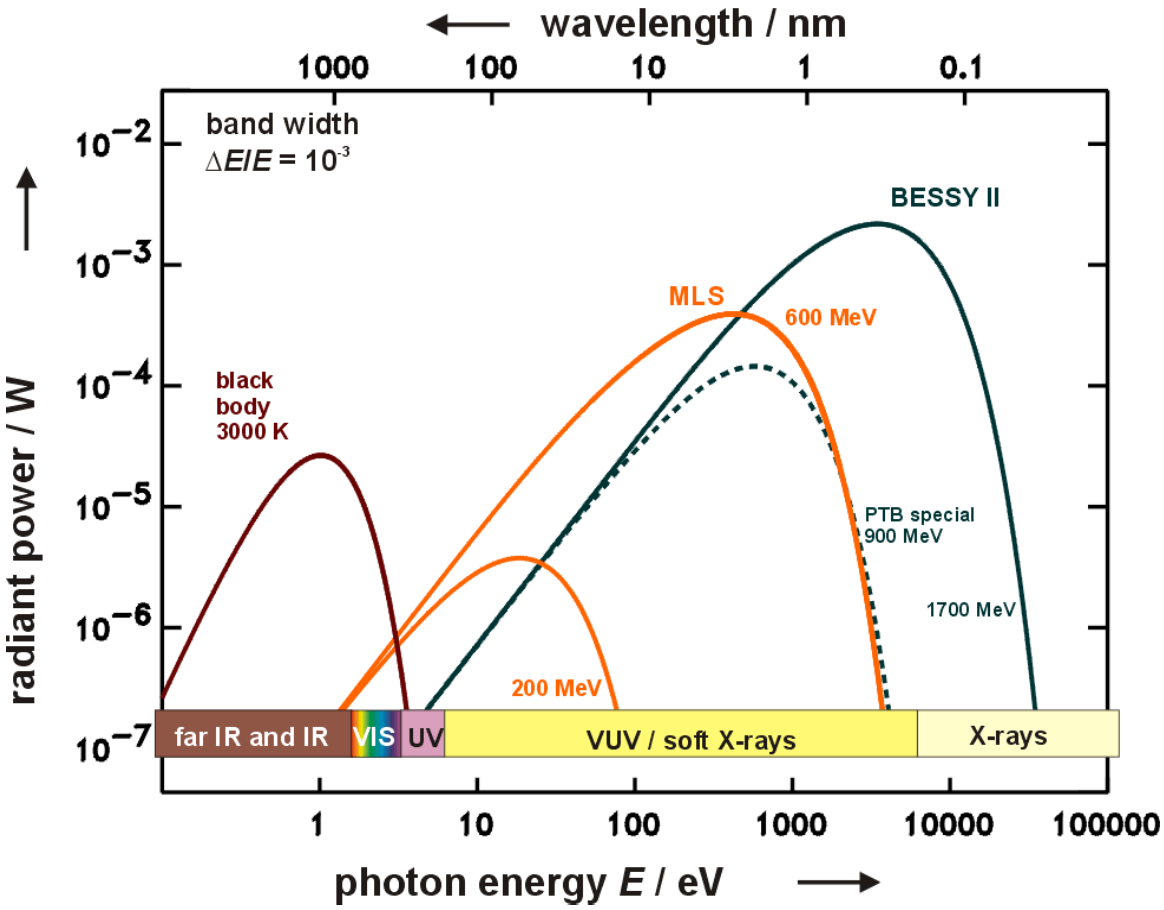
Planck's Radiation Law:

- Temperature

$$\Phi = \Phi(T)$$

Emission calculable from basic physical principles

Metrology with SR: Radiometry beyond UV



Black Body Radiatior

Planck's Radiation Law:

- Temperature

$$\Phi = \Phi(T)$$

Emission calculable from basic physical principles

Electron Storage Ring (Synchrotron radiation)

Schwinger Equation:

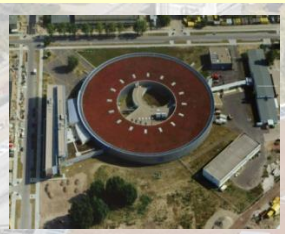
- Storage ring parameters
- Geometry

$$\Phi = \Phi(W, B, I, \Sigma\gamma, \psi, d, r)$$

PTB @ BESSY I, II, MLS

1982 – 1999: BESSY I

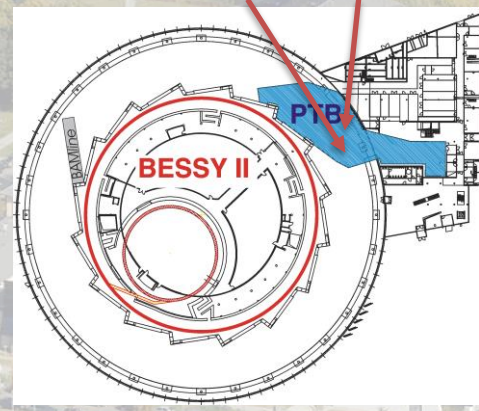
since 1999: BESSY II



since 2008: MLS

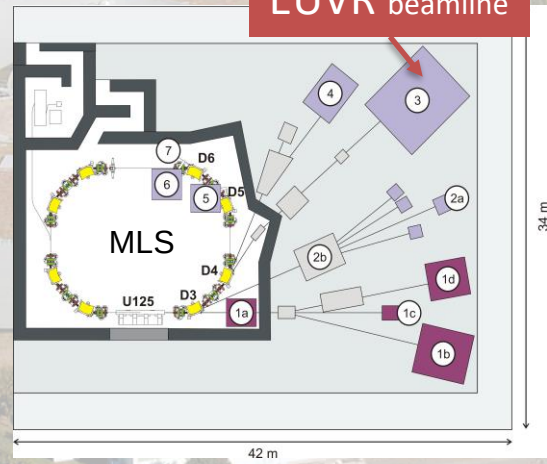
SX700 beamline

DWL beamline



BESSY II

EUVR beamline



BESSY II:
circumference 250 m
electron energy 1.7 GeV

PTB:
10 beamline branches
from 400 nm (3 eV)
to 0.02 nm (60 keV)

UV EUV X-ray

MLS

Metrology Light Source MLS
circumference 48 m
electron energy 100 - 630 MeV

8 beamlines
from 8 mm
to 4 nm (300 eV)

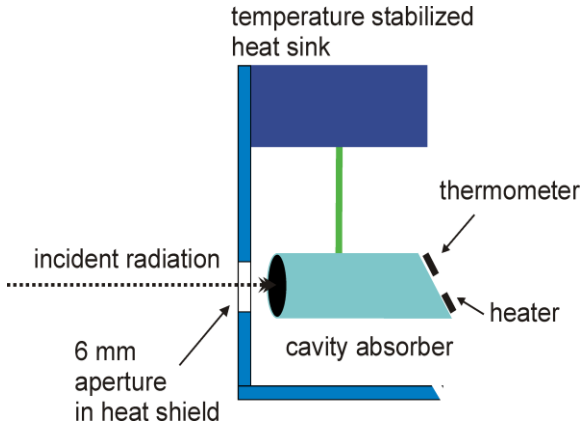
THz UV EUV

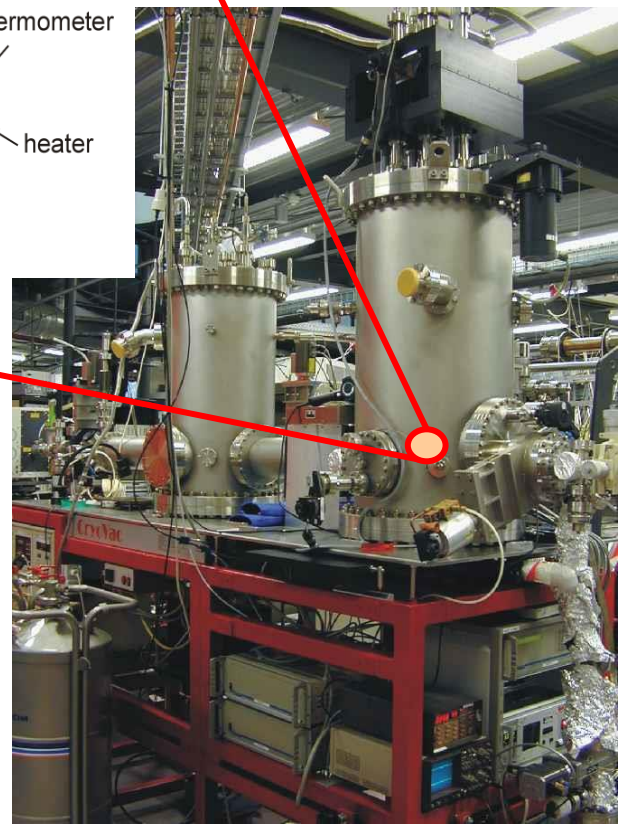
Methods

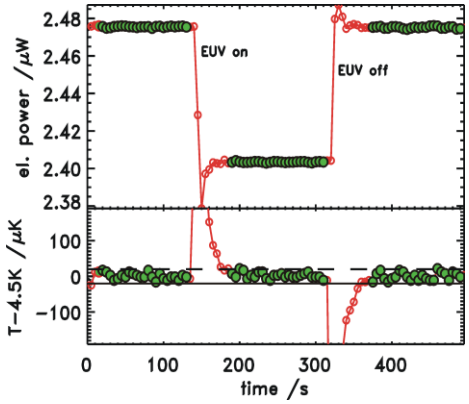
- Source calibration
- Detector calibration
- X-ray Spectrometry
- Layer thickness determination
- EUV Reflectometry
- EUV Scatterometry

Detector calibration

Cryogenic Electrical Substitution Radiometer

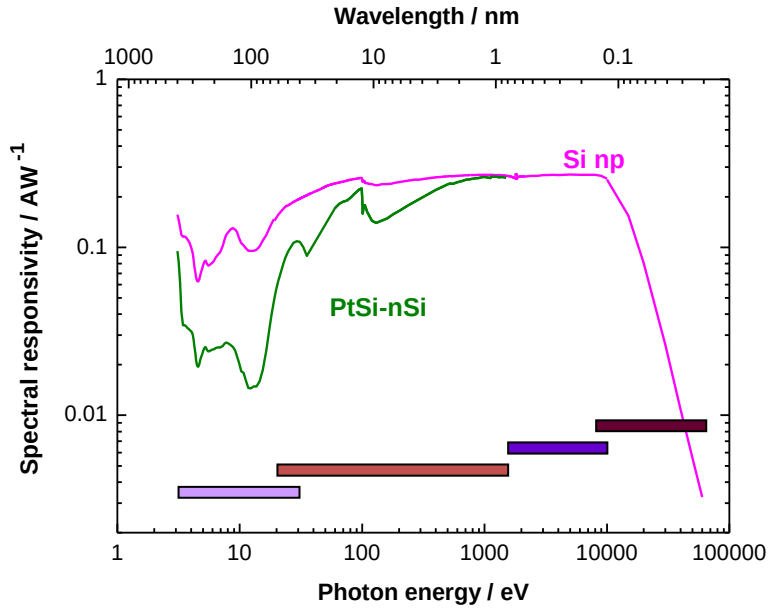






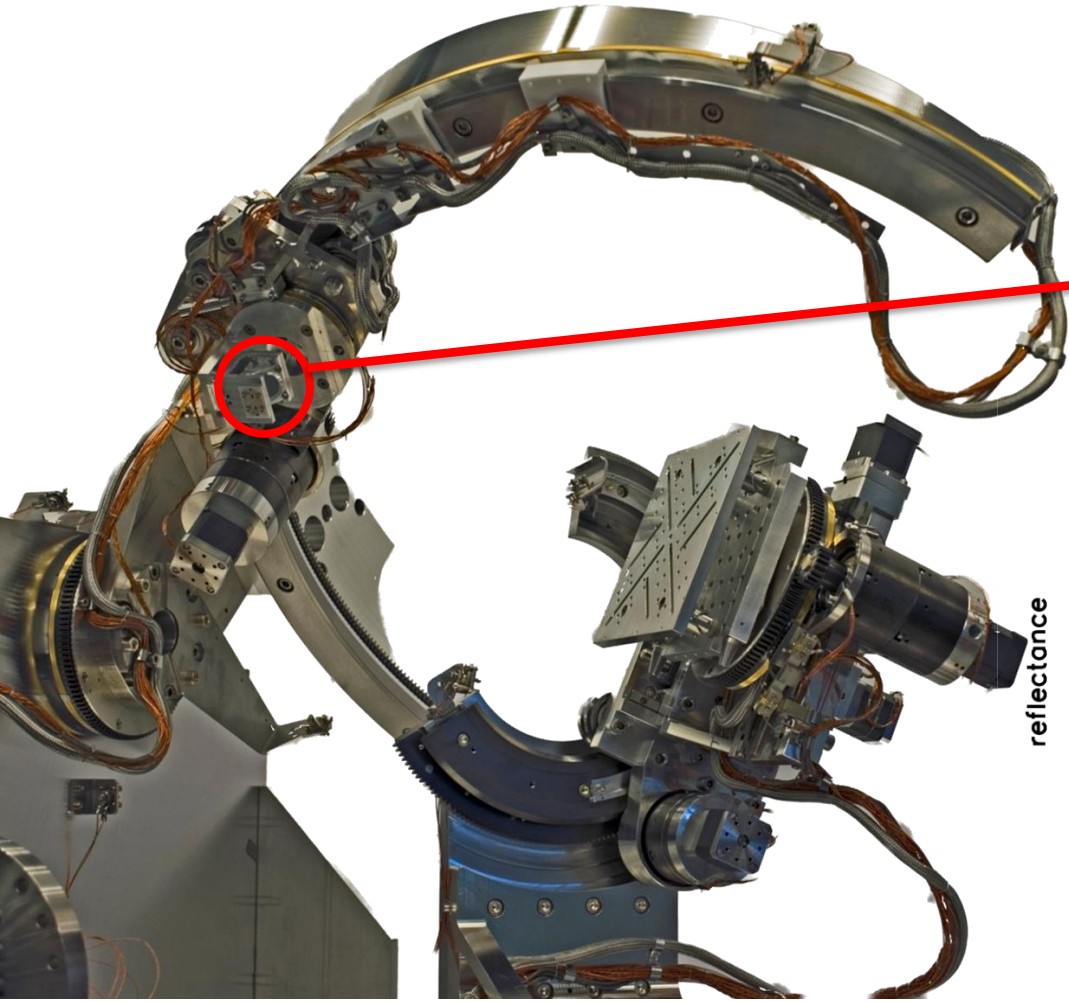
semiconductor photodiodes, type depending from energy range due to

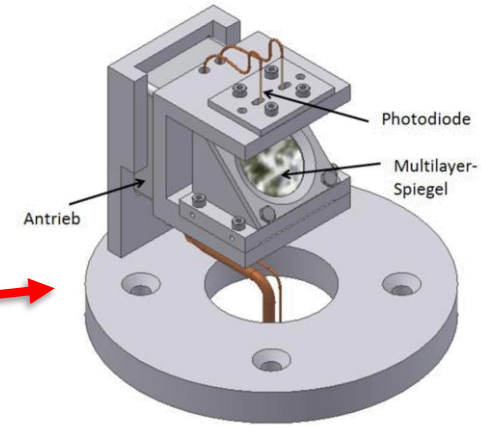
- stability
- linearity
- spatial uniformity

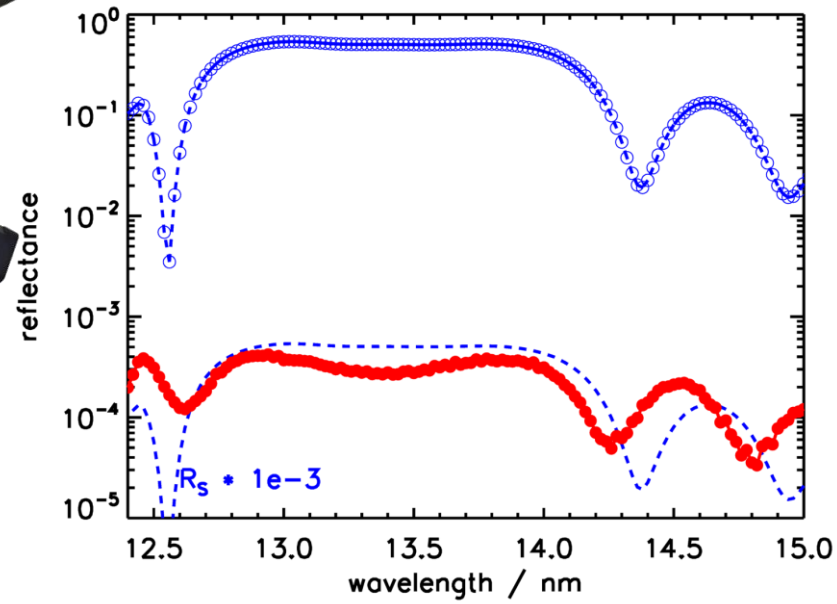


Relative standard uncertainty of detector calibration: < 1.2 % … 0.3 %

EUV-Ellipso-Scatterometer

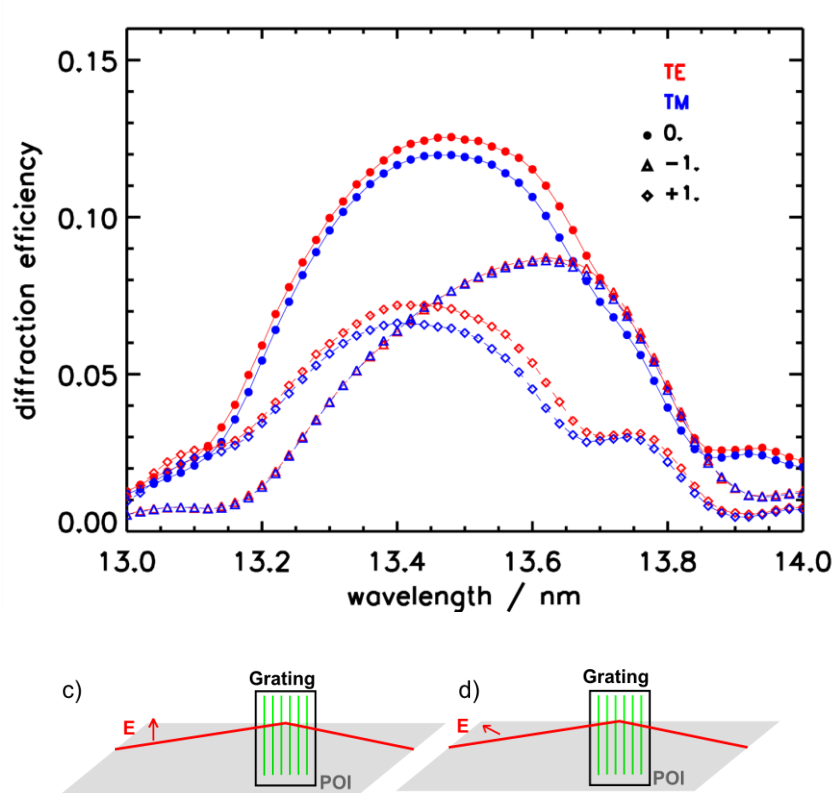




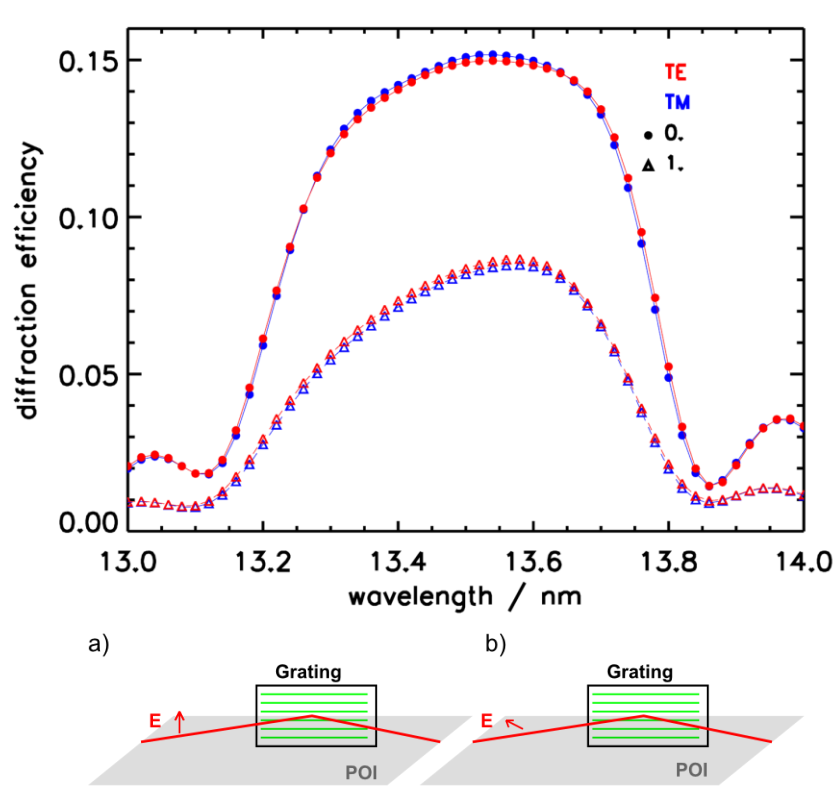


Selectivity of Brewster-analyser

Polarisation effects at EUV reticles



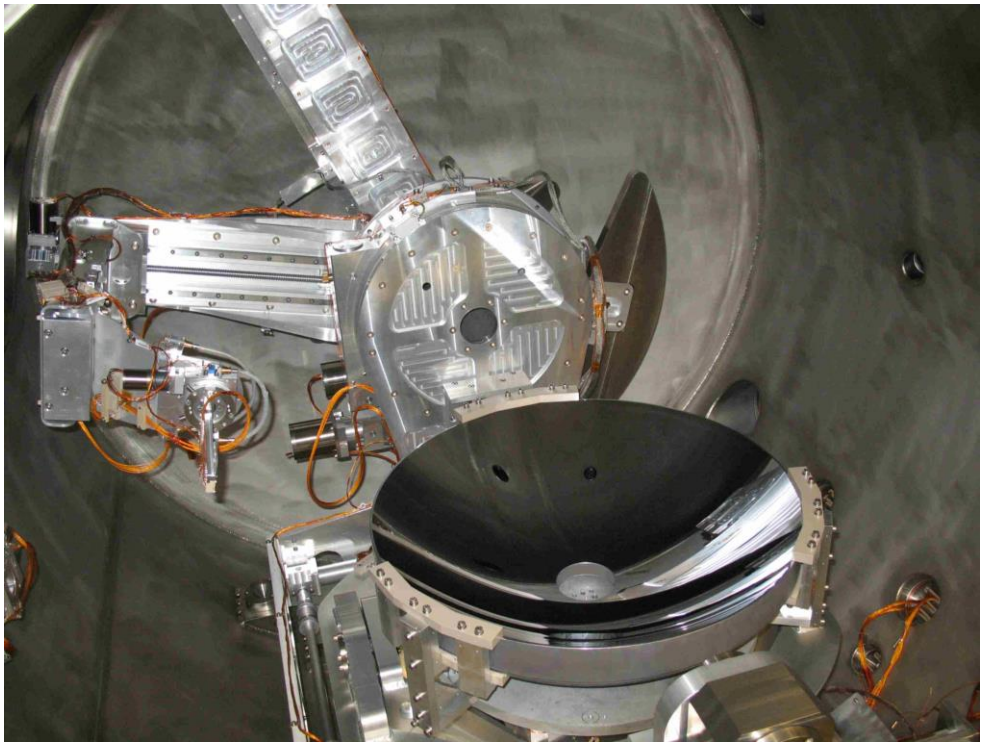
"horizontal lines"



"vertical lines"

V. Soltwisch, et al., Proc. SPIE **9422** 9422-38 (2015)

Optics for EUV Sources



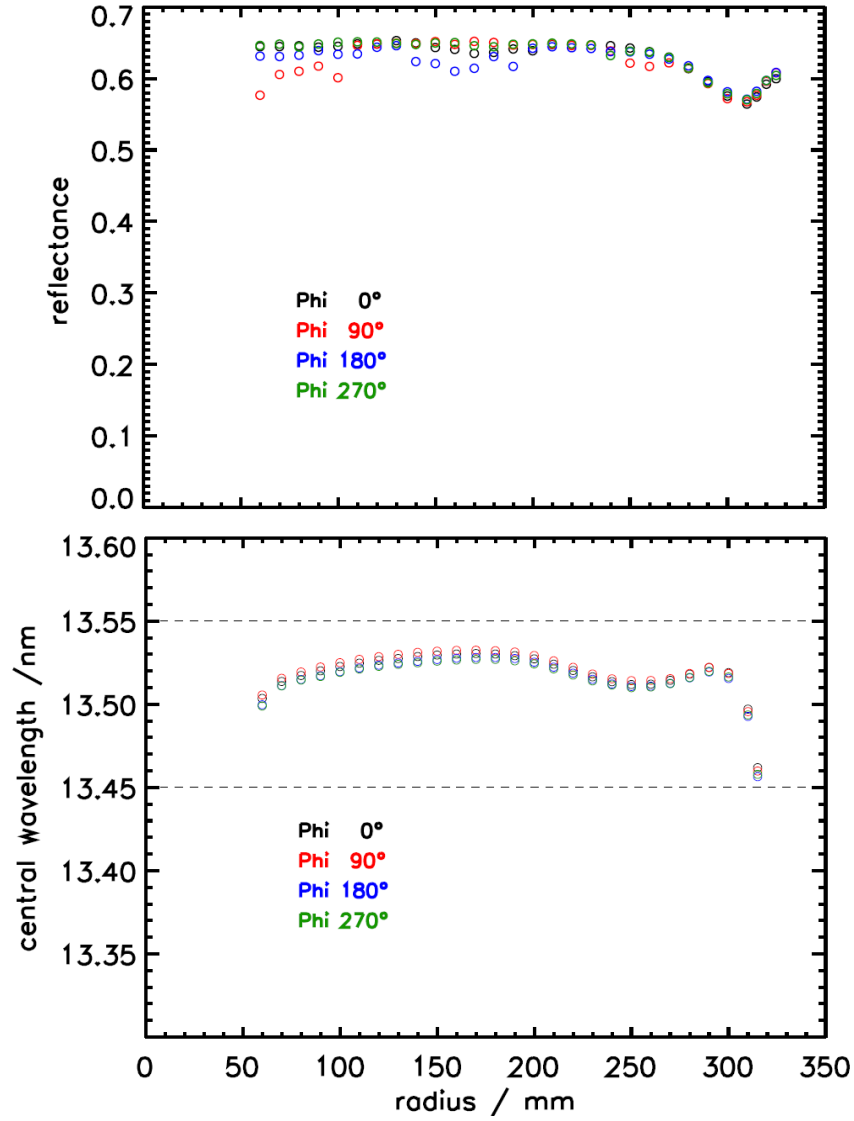
5 sr collector, 670 mm outer diameter design

CYMER®

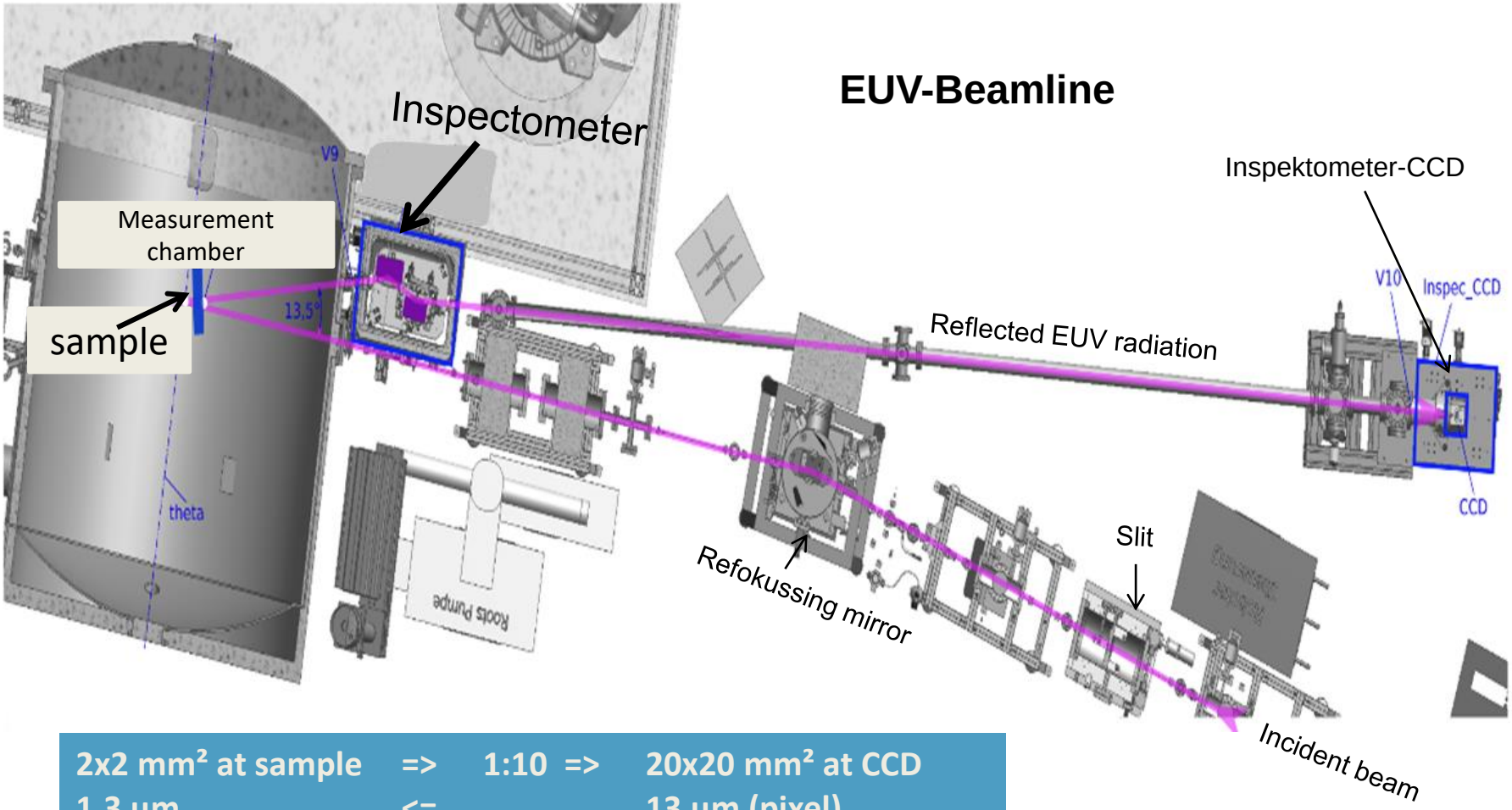
coating

Fraunhofer IOF Institut Angewandte Optik und Feinmechanik

mounted for measurements at PTB



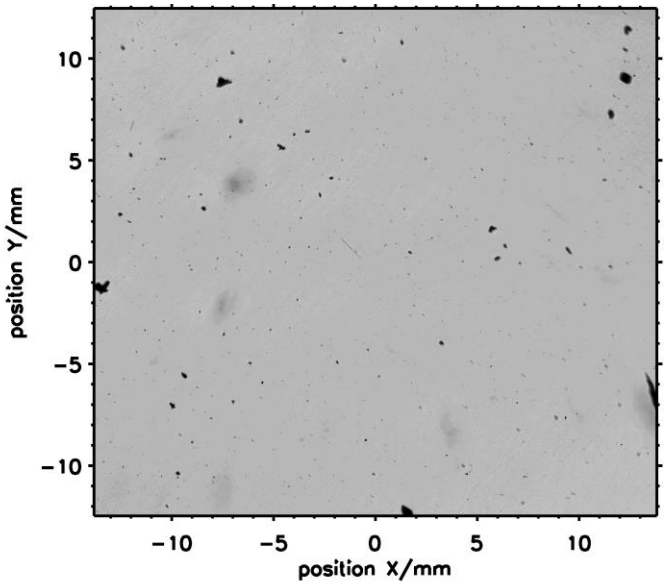
Spatially resolved reflectometry

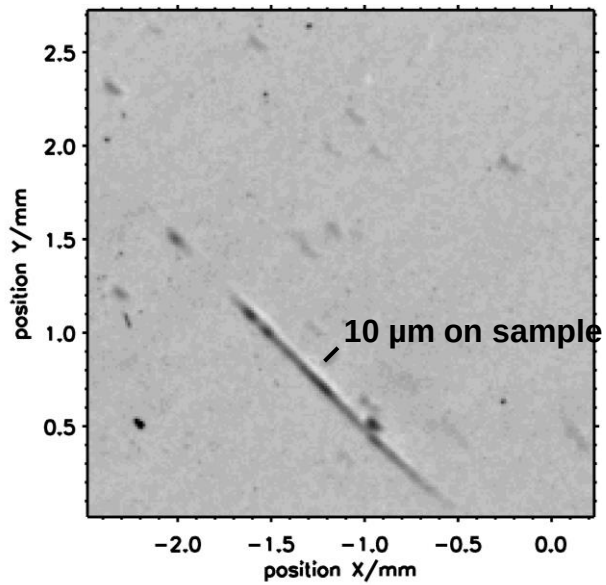


2x2 mm² at sample	=>	1:10	=>	20x20 mm² at CCD
1.3 µm	<=			13 µm (pixel)

Scheme of EUV reflectometer extension with 1:10 magnification EUV-telescope
Optical scheme (modified Wolter III): ellipsoid / hyperbola, operated under grazing incidence

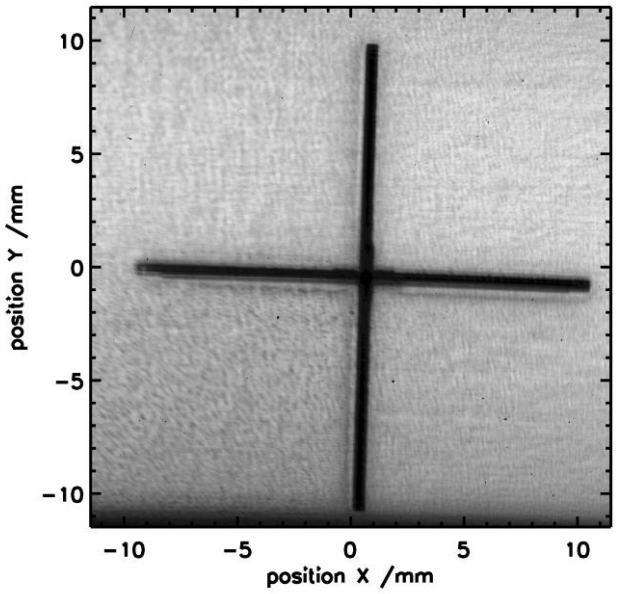
Operation examples: CCD images

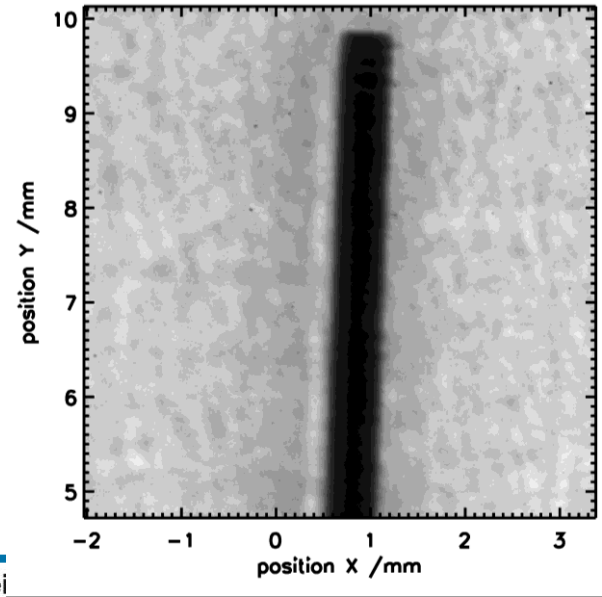




surface of an EUV

Mo/Si mirror with dust and scratches





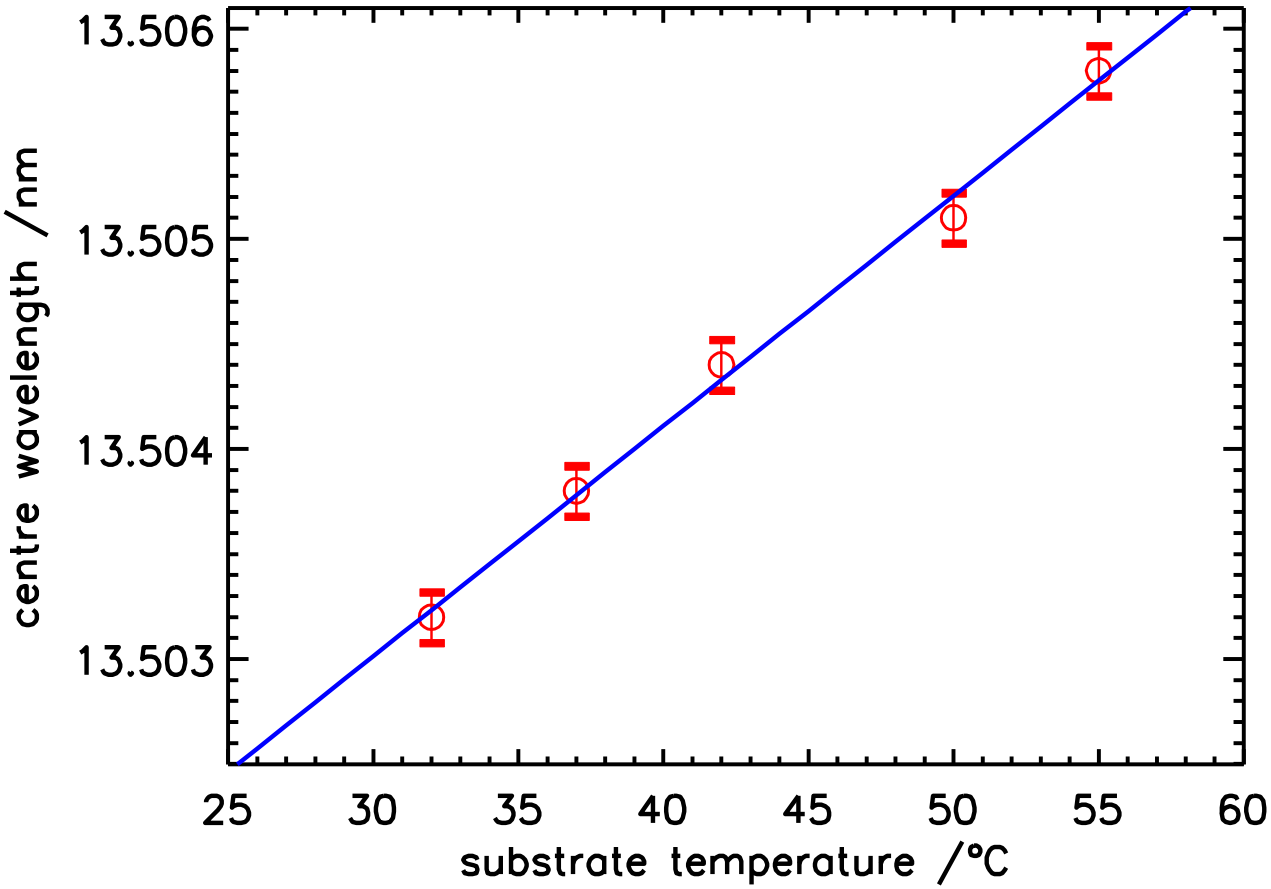
laser-written cross mark at EUV-reticle

2 mm long, 50 µm wide bars

scale on detector

Repeatability of Wavelength

measured shift of the center wavelength as function of substrate temperature



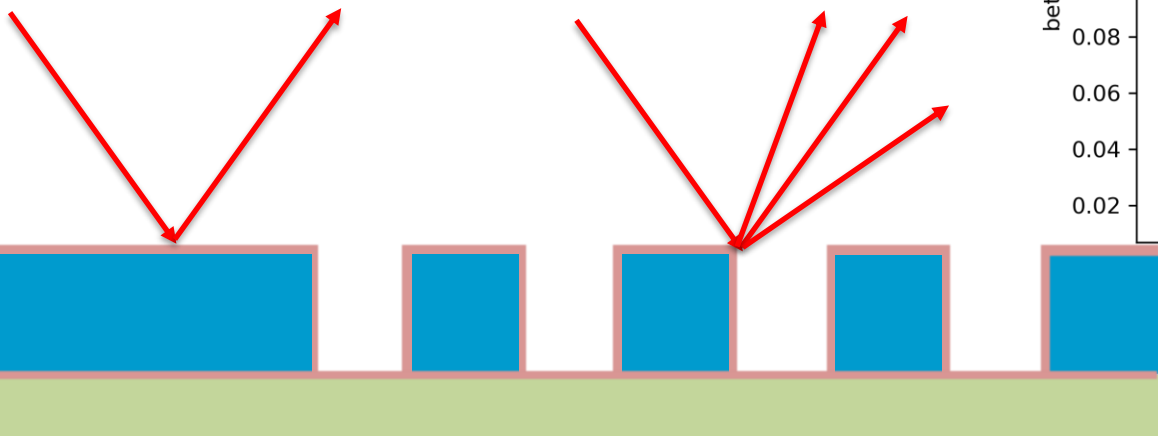
error bars:
signal statistics,
0.12 pm (2σ)

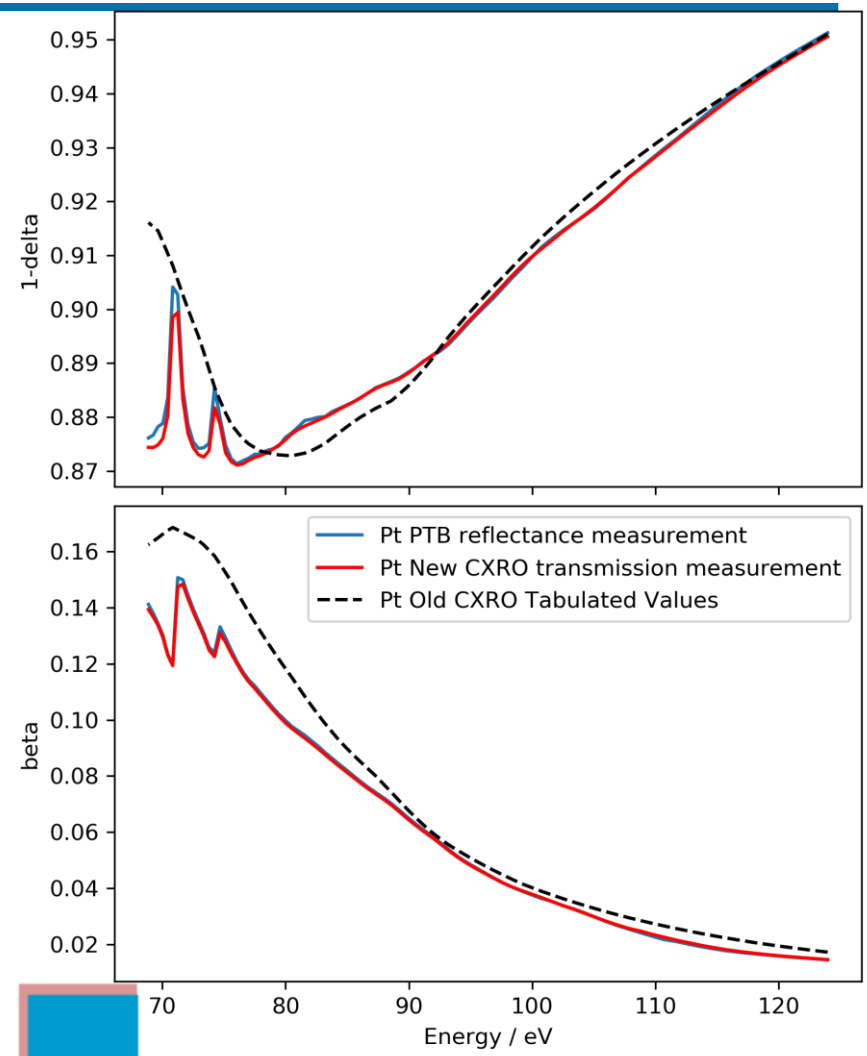
line:
linear fit with a thermal expansion coefficient of $8.1(4)10^{-6}$ K^{-1}.

Evaluation of optical constants

In the soft X-ray range

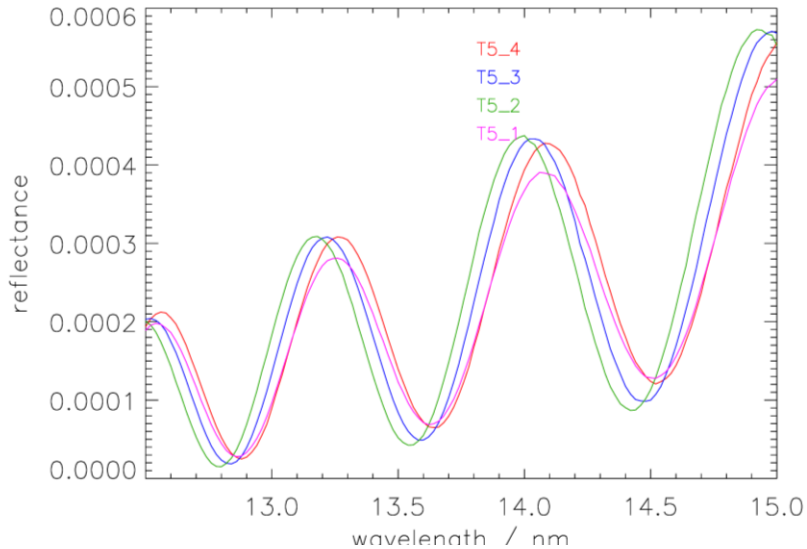
- Reconstruction of the optical constants from reflectometry measurements of well-defined thin films
- For structured samples, optical constant determination in the surrounding unstructured area





arXiv:2103.11868v1
doi.:10.1107/s1600576720016325

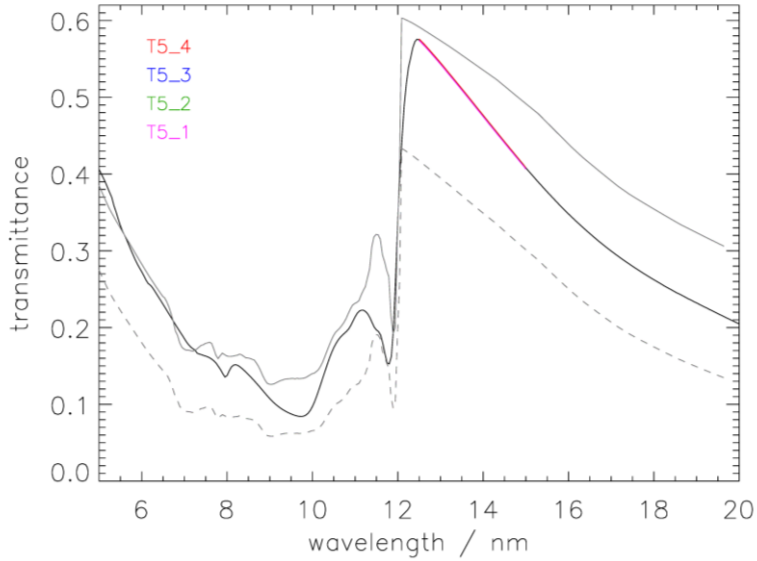
EUV measurement of membrane samples



reflectance of reference membranes

=> clear thickness oscillations

=> minor differences between fields



transmittance of reference membranes

=> rather SiN instead of Si_3N_4

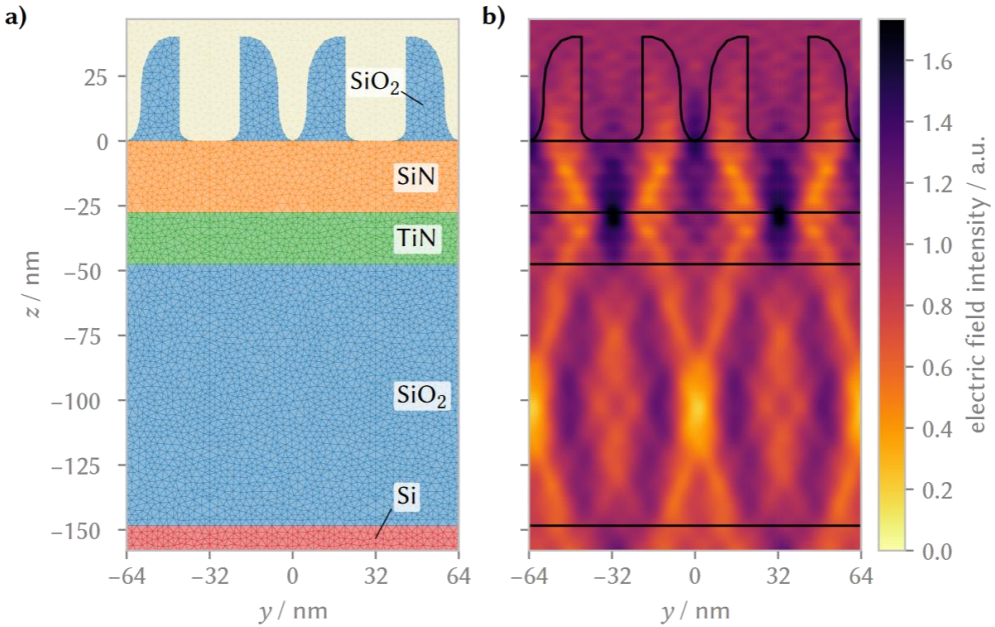
transmittance broad spectral range
grey curves: CXRO data
solid line: SiN
dashed line: Si_3N_4

CXRO data shifted by 0.36 nm to account for chemical shift

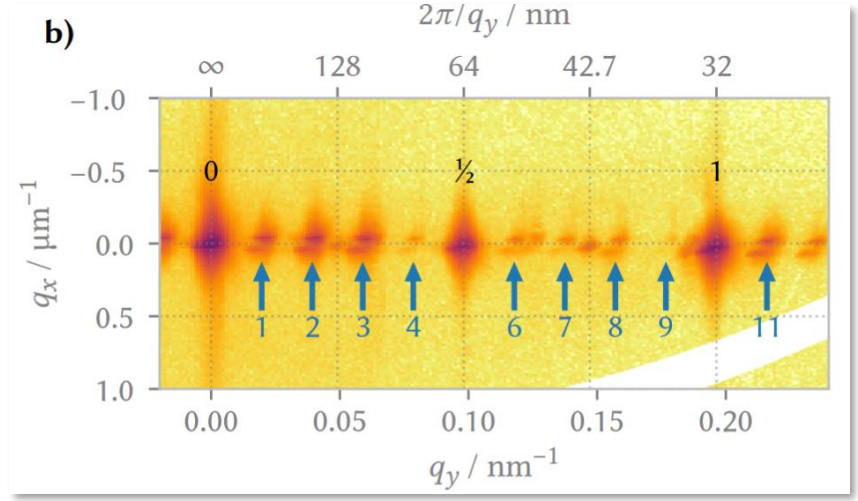
EUV Scatterometry

The Challenge: modern structures

Structures on wafer: e.g. SAQP pitch walk

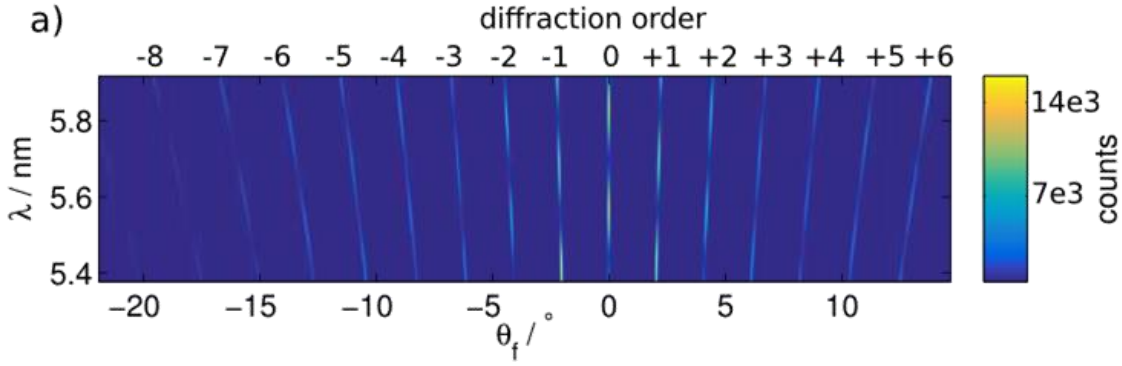


- Different materials, huge computational domain, ML, pitch walk …
- Small target field, signal is disturbed by surrounding structures
- Pitch 32 nm



satellite peaks (numbered)
=> fingerprint of asymmetry & pitch walk

EUV Scatterometry



Comparison of X-ray (6keV) and EUV (0.2 keV) reconstruction

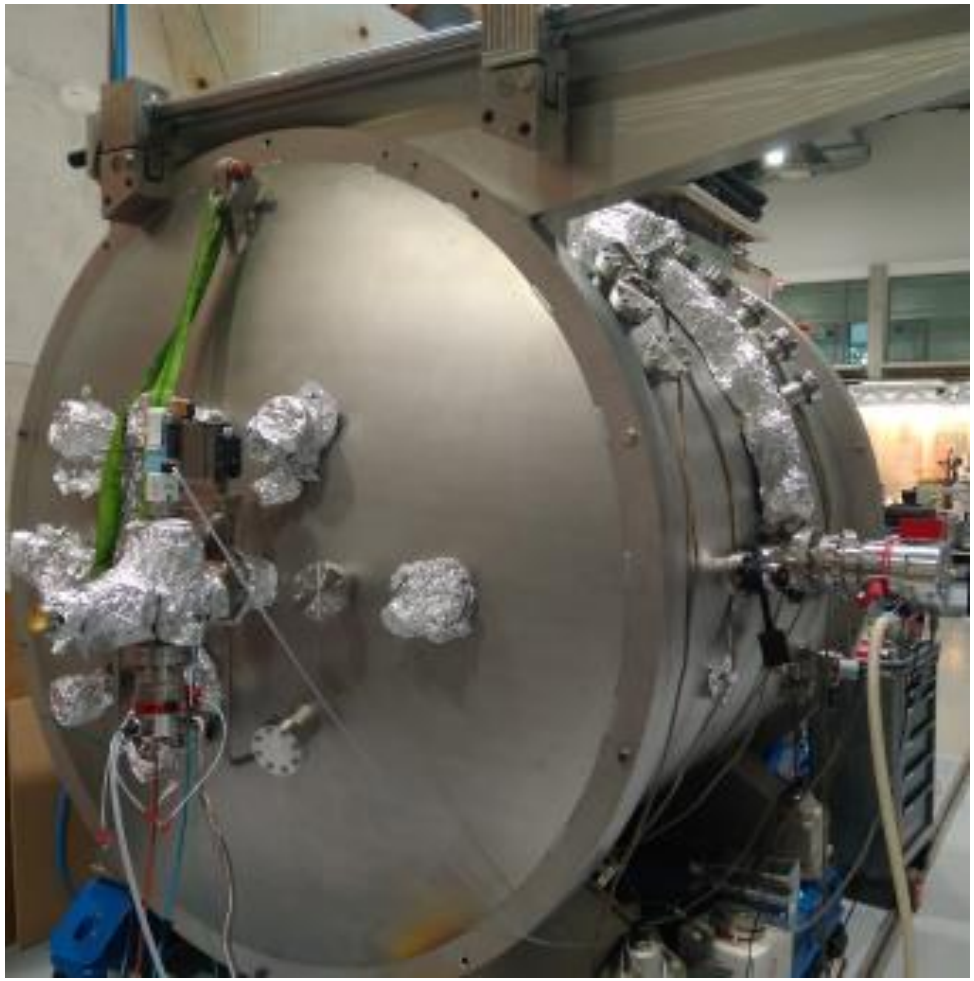
Parameter	GISAXS	EUV-SAS
h/nm	119.50 ± 0.11	121.5 ± 0.5
h_{Oxide}/nm	-	7.1 ± 0.1
cd/nm	67.30 ± 0.31	64.6 ± 0.9
$\omega/°$	84.73 ± 0.33	87.9 ± 0.6
ξ_{DWF}/nm	1.87 ± 0.14	1.3 ± 0.2

X-ray: established technology **but** shallow incidence
➡ long footprint on sample ☹

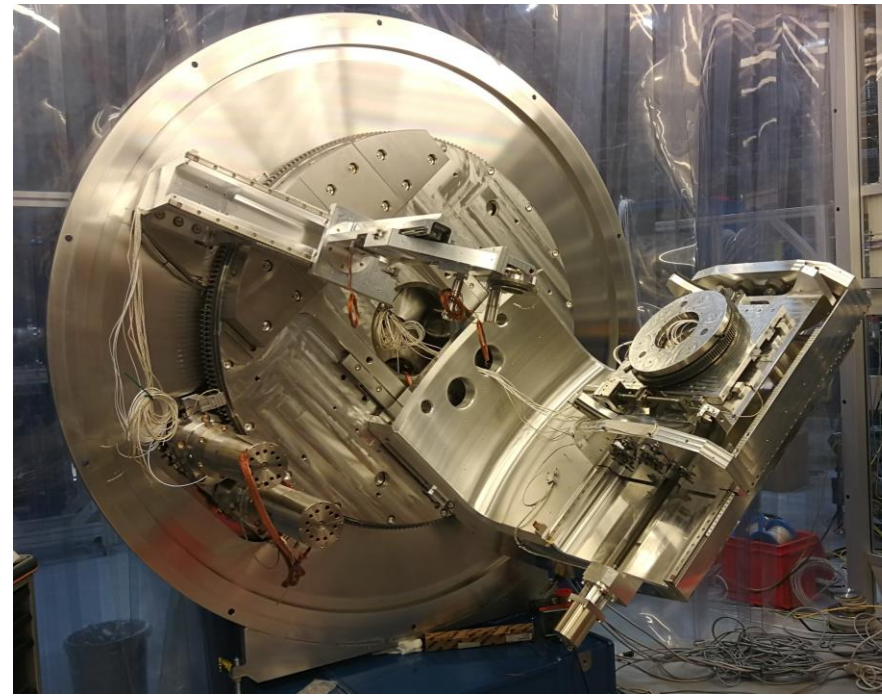
EUV: new approach ➡ steeper incidence angles
➡ smaller footprint ➡ same information ☺

Analía Fernández Herrero et al., On uncertainties in the reconstruction of nano-structures in EUV scatterometry and GISAXS
arXiv:2103.03334v1

New instrumentation

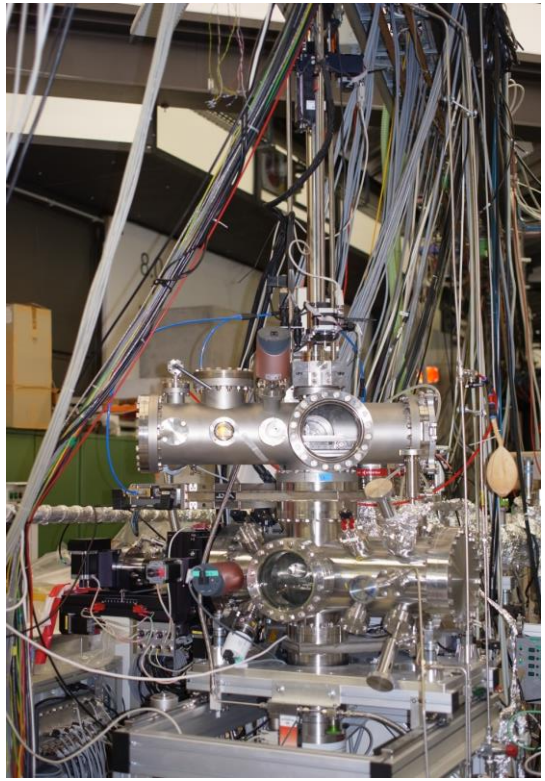


lubricant-free big reflectometer for samples even big like collector mirrors samples of up to 150 kilograms can be measured.



Start of operation expected Jan 2022

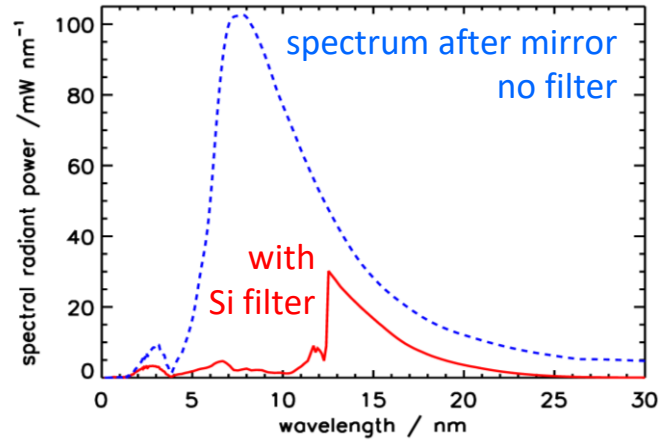
Irradiation beamline: Experimental chamber



Experimental chamber with gas supply system and load lock

Gases available:
H_2 and others,
3 Pa total pressure can be handled by differential pumping

Spectral distribution



integral power :

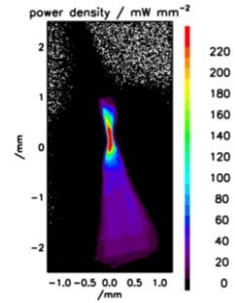
0.9 W (no filter)	2.5 nJ / pulse
0.15 W (Si-Filter)	0.4 nJ / pulse

Power density and spatial distribution adjustable by varying the sample to focus distance

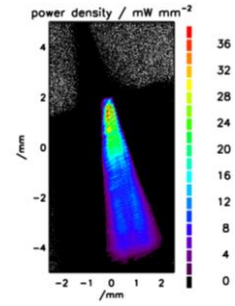
⇒ power 1 W/cm² … 23 W/cm²

⇒ Dose 1 J/cm² (~1s) feasible (no fast shutter)
… 650kJ/cm²(~8h)

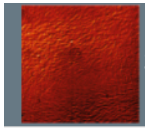
Pos 1



Pos 2



PTB seminar on VUV and EUV Metrology



317. PTB-Seminar
VUV and EUV Metrology

Home | Important dates | Registration | Organizers | Contact

Scope

The seminar, the sixth in a series launched in 2011, is a forum for interdisciplinary exchange between basic and technology-oriented researchers and industrial users. The topics cover latest results from industrial applications of EUV radiation for lithography and measurement technology to developments for space-based VUV and EUV spectroscopy and the investigation of nano-structured surfaces.

Previous seminars: 2011, 2013, 2015, 2017, 2019

Questions about further information may be addressed to: euv2021

Dates

19 - 20 October 2021 full day: oral and poster sessions
on-site *) and as an online web conference

18 October 2021 afternoon: PTB Adlershof Laboratory visit *)
19 October 2021 evening: Get together Dinner *)
*) only if in accordance with the rules and measures against the corona virus

www.euv2021.ptb.de

Venue

The meeting will take place in the Helmholtz-Building of the Berlin-Charlottenburg campus site of PTB (Abbestr. 2-12, 10587 Berlin). The historical PTB campus is located within walking distance from Kurfürstendamm and Bahnhof Zoologischer Garten, right in the heart of Berlin's 'City West'.

Confirmed invited speakers

M. van de Kerkhof, ASML H. Enkisch, Carl Zeiss SMT V. Philipsen, imec T. Feigl, optiXfab

S. Gissot, ROB K. Tiedtke, DESY J. Feikes, HZB S. Danylyuk, ILT A. Szelghemi, IAP H. Stiel, MBI

We thank all our colleagues in Berlin-Adlershof and you for your attention

Michael Kolbe
EUV radiometry group

Victor Soltwisch
EUV nanometrology group

Frank Scholze
Department Radiometry with Synchrotron Radiation

Abbestr. 2-12
10587 Berlin
Germany