

STATUS OF EBL2: AN EUV IRRADIATION FACILITY AT TNO AND UPCOMING UPGRADES

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TNO innovation
for life



OUTLINE

- › **Introduction EUV beamline 2**
- › Status of EBL2
- › A few results
- › Upcoming upgrades
- › Conclusion

EBL2: SECOND EUV BEAMLINE AT TNO

2006: First EUV beam line: EBL

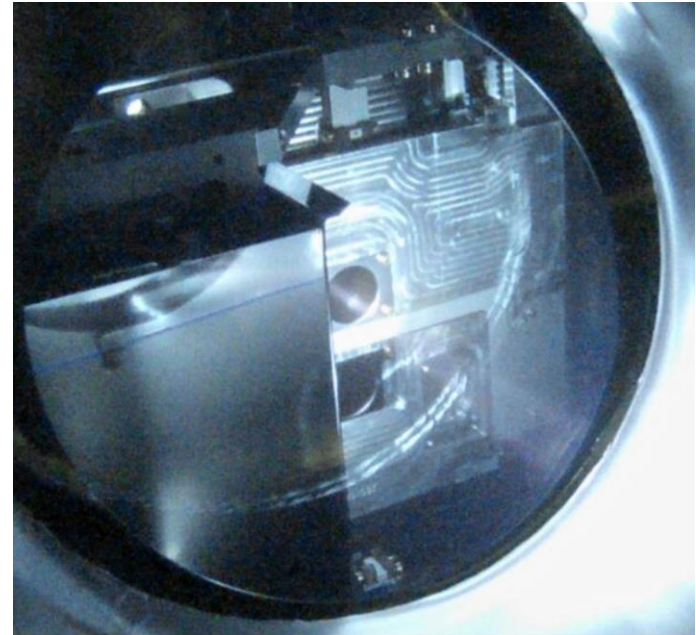


2016: Second EUV beam line: EBL2



INTRODUCTION: WHAT IS EBL2

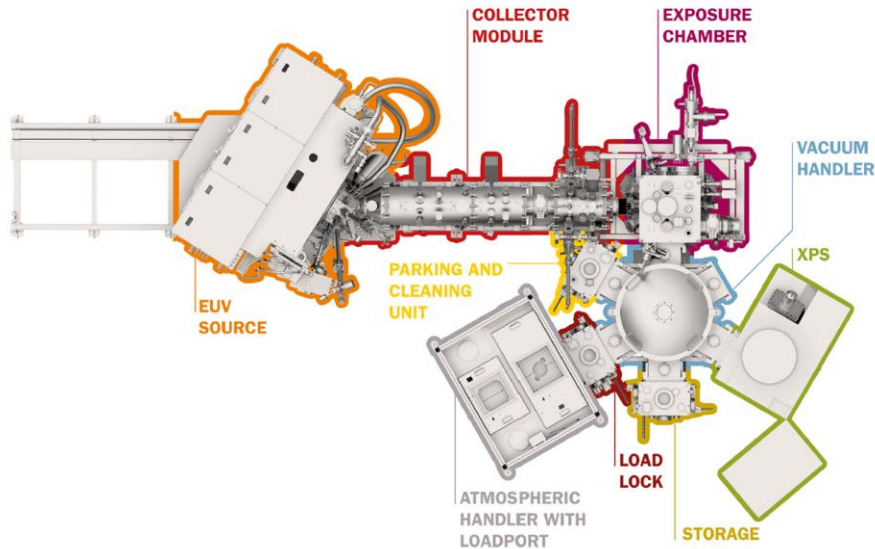
- › EBL2 ⇔ EUV Beam Line #2
- › What it can:
 - › Irradiation of materials with high intensity EUV light (10-20 nm) in a controlled vacuum environment
 - › Samples can be in the form of wafer pieces or other small sizes up to EUV masks
- › What it cannot:
 - › Perform lithography/pattern printing with EUV (yet) → metrology port on source suitable for building second beam line for lithography



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CURRENT EBL2 PERFORMANCE



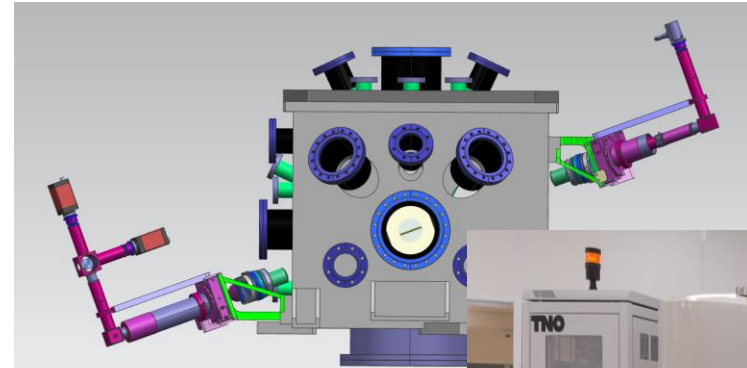
	EBL2
EUV source	Ushio -Sn-LDP
Rep.rate	1-10 kHz
Peak intensity (13.5 nm 2%BW)	0.5 W/mm ² @ 3kHz
Integrated power (on 1"sample) @ 10 -20 nm	4-5 Watt @ 3kHz
Spotsize	1x2 mm ²
Defocussing option	Yes
H2 pressure range	0-50 Pa
Gasses	H ₂ , He, Ar, H ₂ O, XCDA, O ₂ , N ₂ , C _x H _y
Sample size	152x152x20 mm ³

For a 250W EUV source intensity at pellicle ~0.05W/mm² (Zoldesi et al)
 EBL2 can accelerate by factor 10, when degradation is driven mainly by EUV photons

Zoldesi, C., Bal, K., Blum, B., Bock, G., Brouns, D., Dhalluin, F., Dziomkina, N., Arias Espinoza, J.D., de Hoogh, J., Houweling, S., Jansen, M., Kamali, M., Kempa, A., Kox, R., de Kruijff, R., Lima, J., Liu, Y., Meijer, H., Meiling, H., van Mil, I., Reijnen, M., Scaccabarozzi, L., Smith, D., Verbrugge, B., de Winters, L., Xiong, X., Zimmerman, J., "Progress on EUV pellicle development" Proc. of SPIE 90481N (2014)

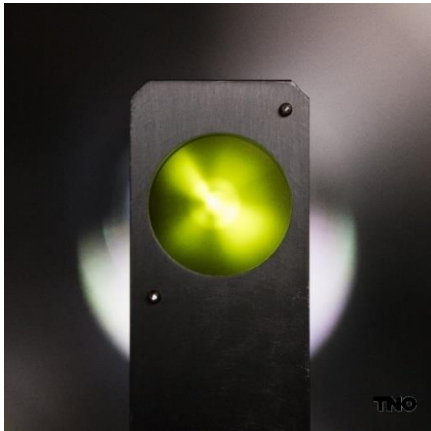
SAMPLE ANALYSIS

- › Online sample analysis: imaging ellipsometry
 - › Used for alignment on sample
 - › Designed by TNO
- › In vacuo sample analysis: XPS analysis and surface mapping, after in vacuum transport to the XPS
- › Other online or in vacuo analysis techniques in preparation
- › Ex vacuo analysis in house:
 - › SEM, XRF, ellipsometry
- › Ex vacuo analysis external:
 - › EUV reflectometry at PTB

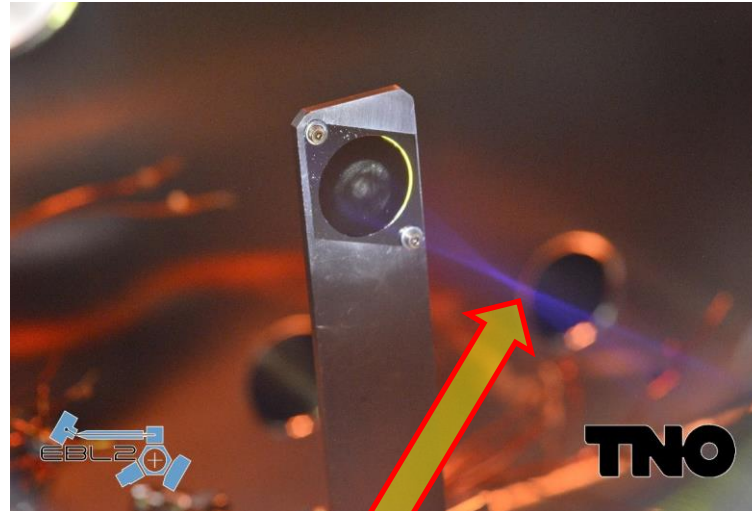


FIRST LIGHT (DEC 2016)

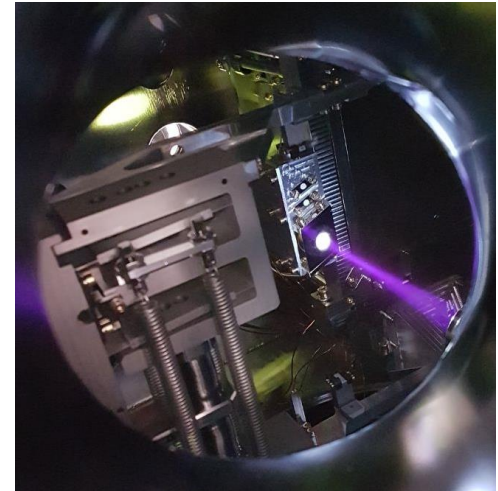
- › With small M1 collector and preliminary M2
- › No alignment optimisation



Fluorescent image with side lobes of M2



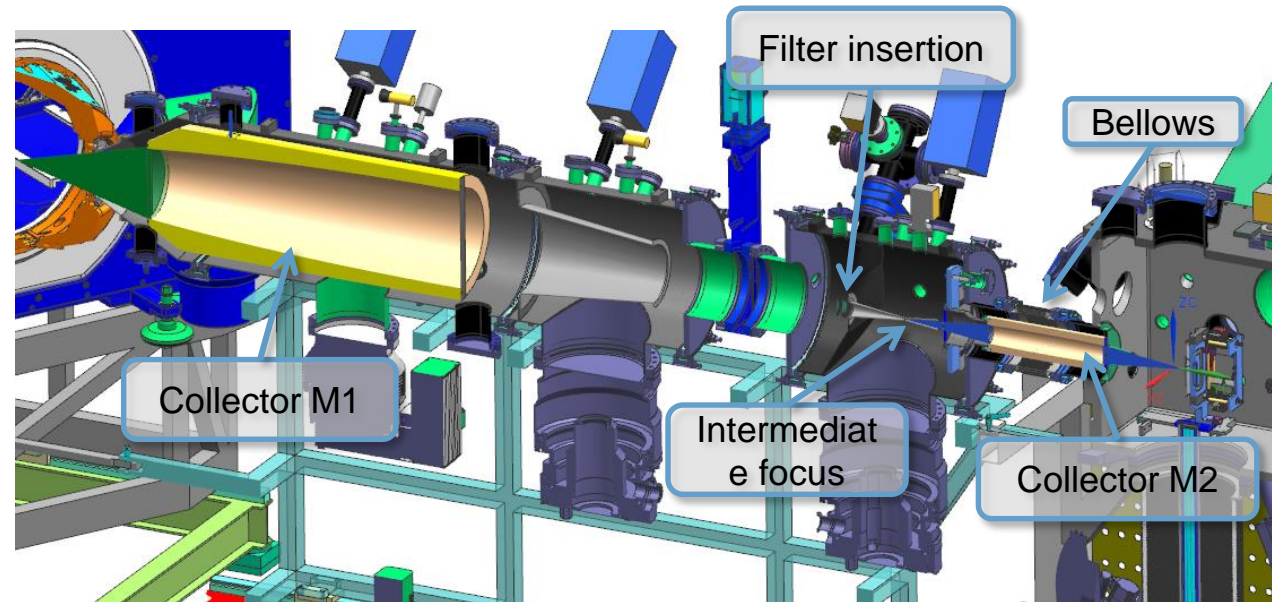
Focal point



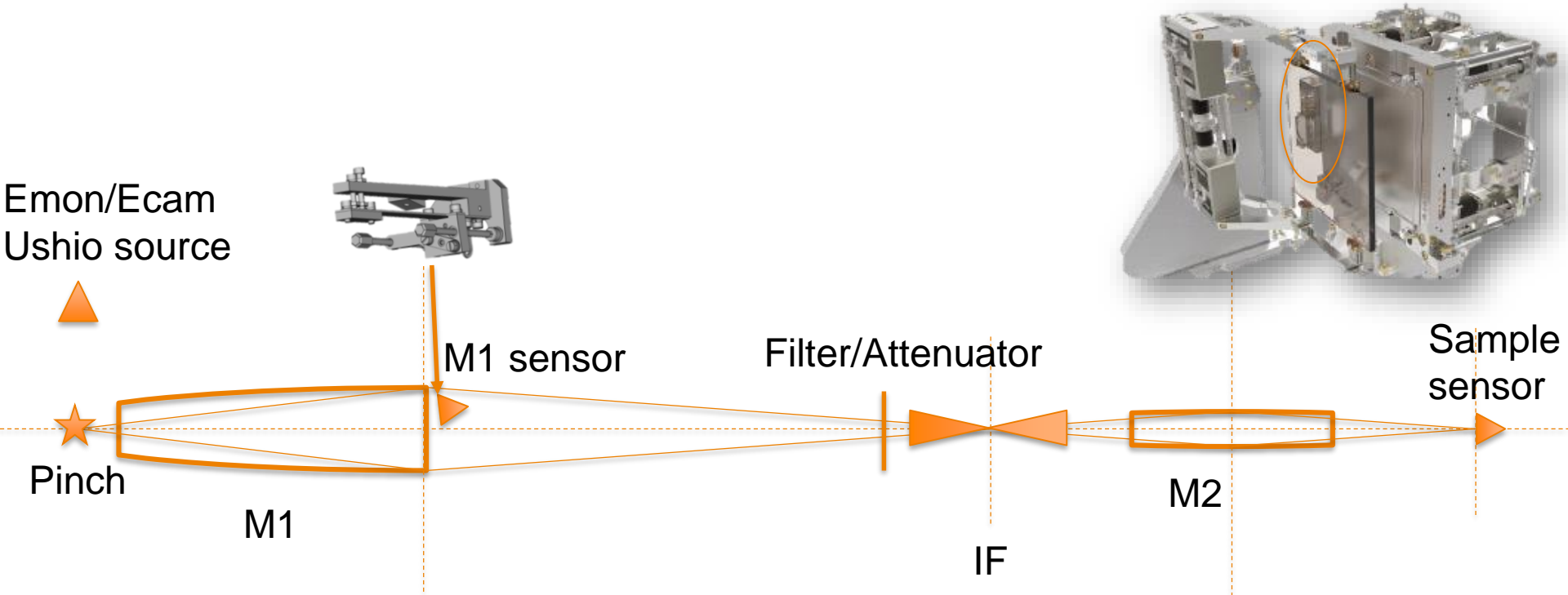
May 2017

COLLECTOR OPTICS

- › 2 mirror design with intermediate focus
- › Integrated differential pumping assembly for gas separation
- › Filter insertion point for spectral filtering
- › (De)focussing by translating source and collectors on track

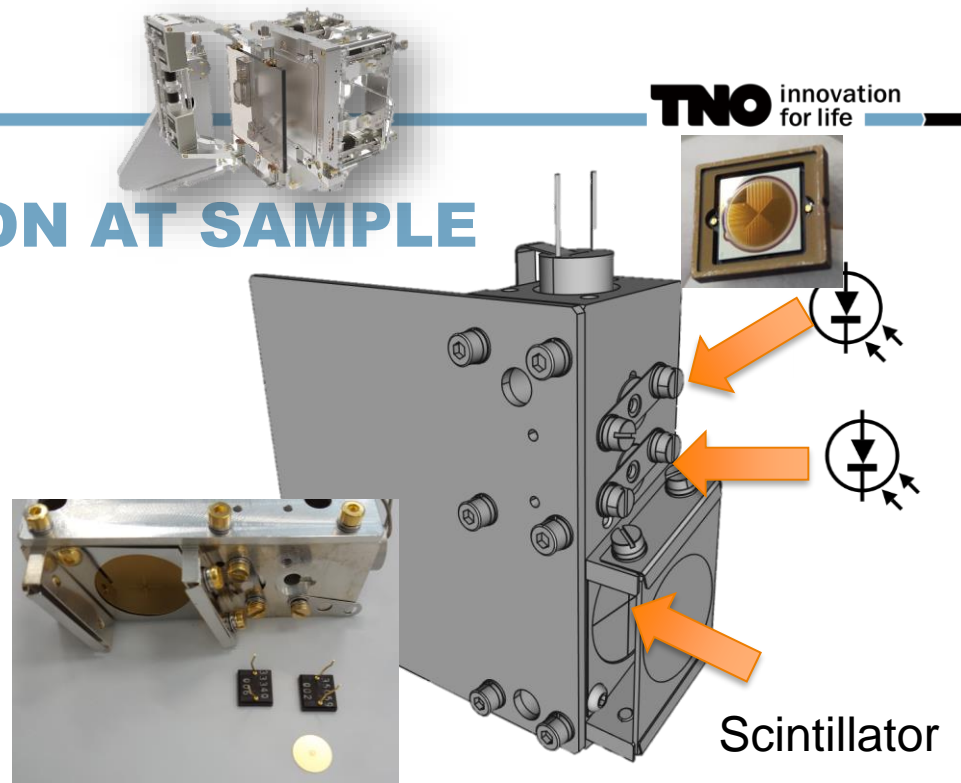


EUV DIAGNOSTICS

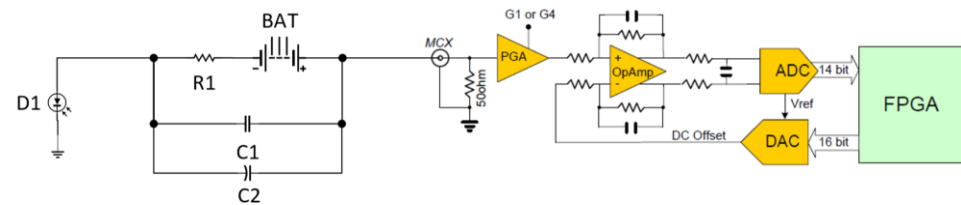


MEASURING IRRADIATION AT SAMPLE

- › Two 1 – 200 nm sensitive photodiodes
- › Custom coating for EUV bandpass filtering
- › Calibrated at PTB
- › Behind 25 and 100 μm pinhole
 - › Intensity attenuation for diode
 - › Spatial resolution for intensity distribution
- › Diode biasing for fast response
- › Photocurrent sampled with 500 MHz digitizer and numerically integrated
- › Scintillator with crosshair
 - › YAG with custom coating for EUV filtering
 - › Converts EUV to 550 nm (green)
 - › Measured using CCD camera
 - › Used for: spot alignment and relative intensity distribution



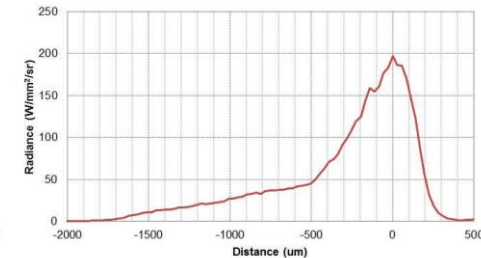
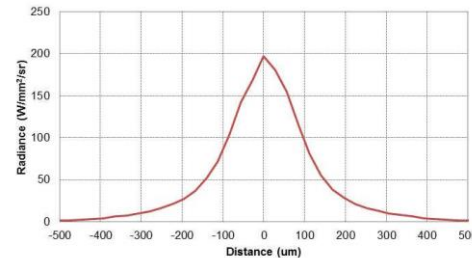
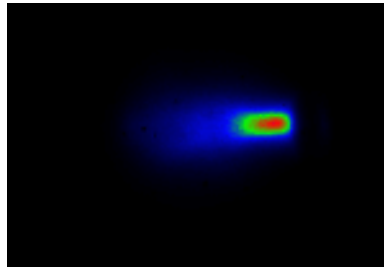
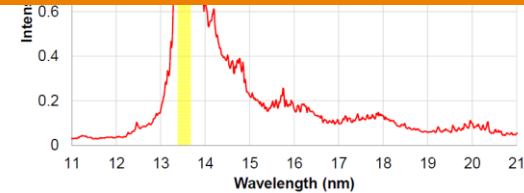
Scintillator



MEASURING PERFORMANCE AT SOURCE

- › Supplied by Technology Partner Ushio
 - › Sn fuelled → Sn spectrum
 - › Rep rate: 3 kHz
 - › Tuneable from single pulse up to 10 kHz
 - › Plasma size: ~0.2*0.6 mm FWHM
 - › Ecam picture (with EUV diode for quantification)

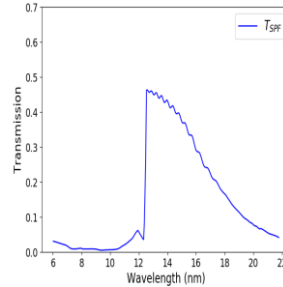
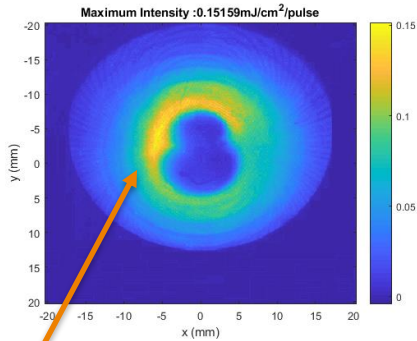
See also: S64 Ushio source update by Yusuke Teramoto



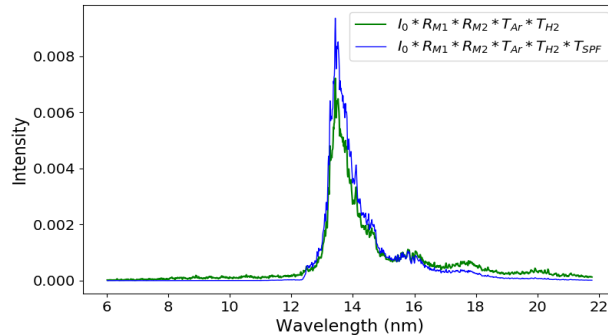
Images courtesy of Ushio; see also Proc. of SPIE Vol. 9422, pp. 94220F-1-9

PERFORMANCE AT SAMPLE

with SPF



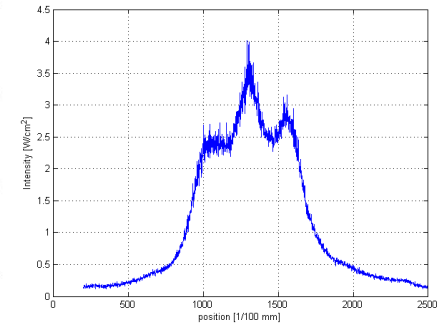
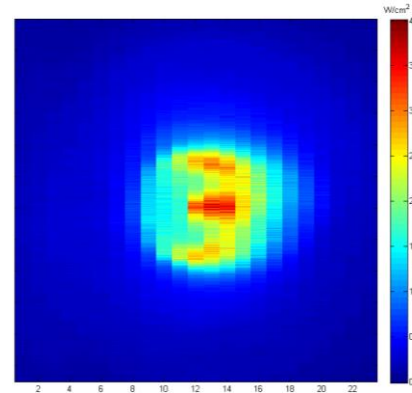
22 mW/mm² peak



no SPF

Diode scan

At 3kHz, unfiltered in-band:
 total power at 3kHz is 2.6 W
 (= 0.546 W filtered)
 peak power at 3kHz is 3.5 W/cm²
 (=0.735 W/cm² filtered)



100 μm (nominal) pinhole, diode 35059-007 (#10), 0.00855 C/J sensitivity (no SPF), 0.00937 C/J sensitivity (SPF)

STATUS UPDATE

- › EBL2 is operational since 2018, serving multiple customers
- › Multiple experiments performed:
 - › Mask lifetime
 - › Material degradation
 - › EUV induced plasma
 - › New absorber test protocol for high k and PSM masks developed in cooperation with ASML
- › M2 collector not up to specification. Replacement is underway as we speak

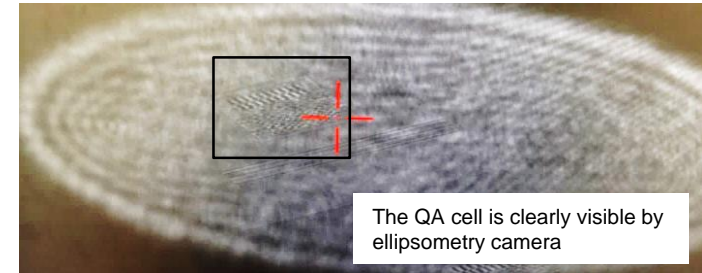
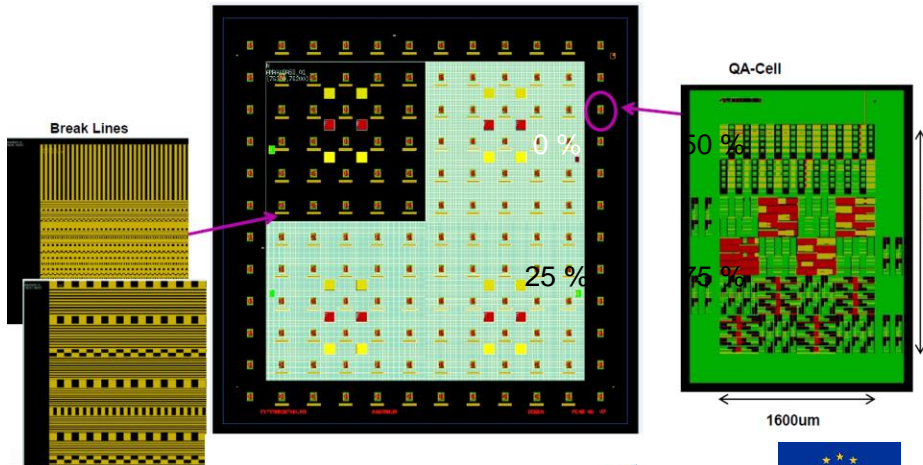
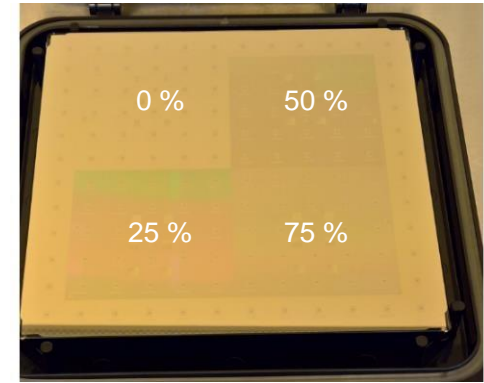
Parameter	Unit	Current	Future
Irradiance IB	W/mm ²	0.45	2
Radiant influx	W	3.3	4
Drift	mm	<0.2	?

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TEST EUV MASK

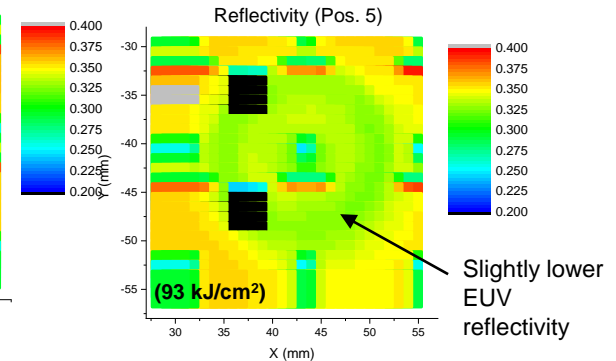
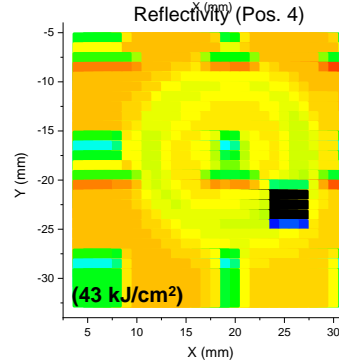
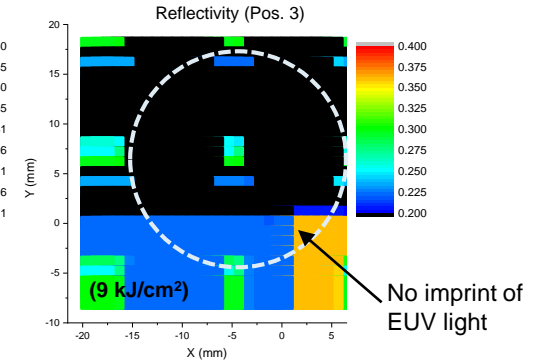
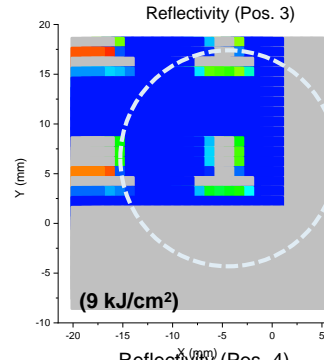
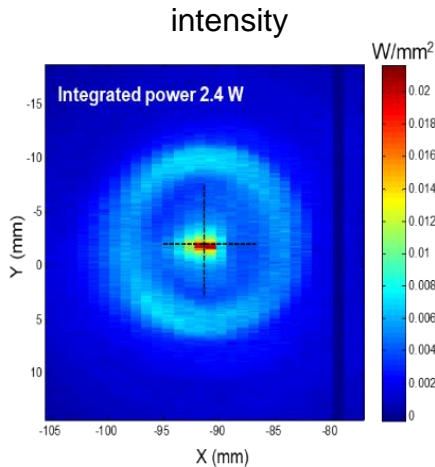
- › Mask with regular grid of Test-clips (QA cells) in 4 different background loadings (0%, 25%, 50% and 75%).
- › QA cell provides different patterns in terms of size, feature types and tones.



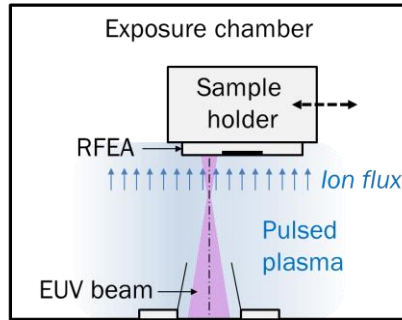
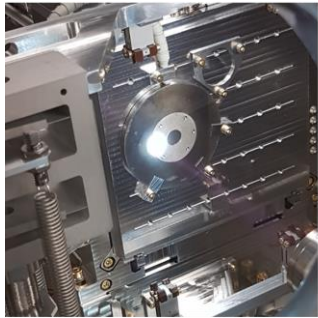
EUVR ANALYSIS (ZOOM-IN)

- › EUVR measurement shows the impact of different EUV dose on sample.
- › Intensity measured using EBL2 EUV metrology (calibrated diode)

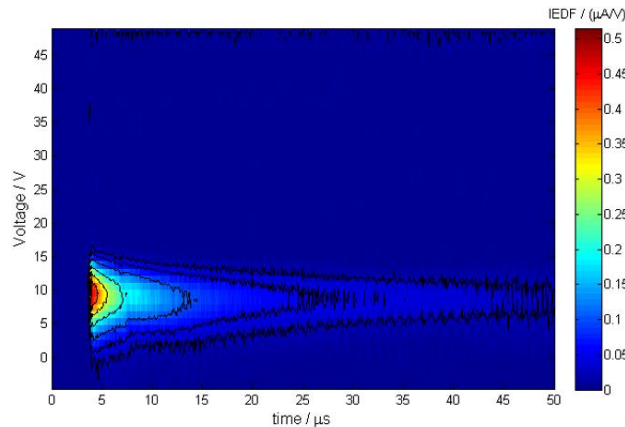
1 corresponds to 100% reflectivity



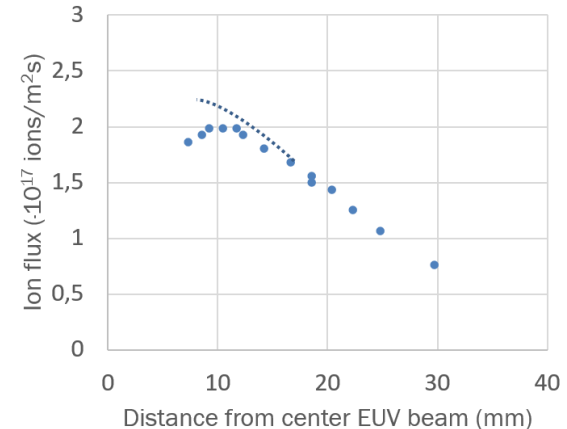
EBL-2 : EUV INDUCED PLASMA MEASUREMENTS



- The ion fluxes and energies were measured using the RFEA in time-integrated and time-resolved modes.
- Typical peak energies: 5–10 eV.
- Typical ion flux $\Phi \approx 2 \cdot 10^{17}$ ions·m⁻²s⁻¹.
- Radial profiles: the ion flux decays ~4 times 30 mm from the beam center.
- The plasma decay time in the afterglow estimated as ~100 μ s and is supposed to be limited by the diffusion to the chamber walls.



RFEA position with respect to EUV beam during the experiments 10 mm left; and time-resolved diagrams of ion energy distributions

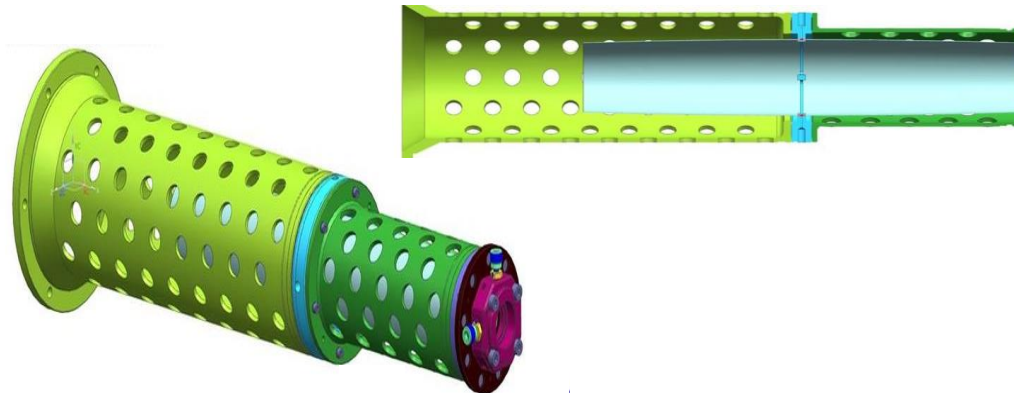


OUTLINE

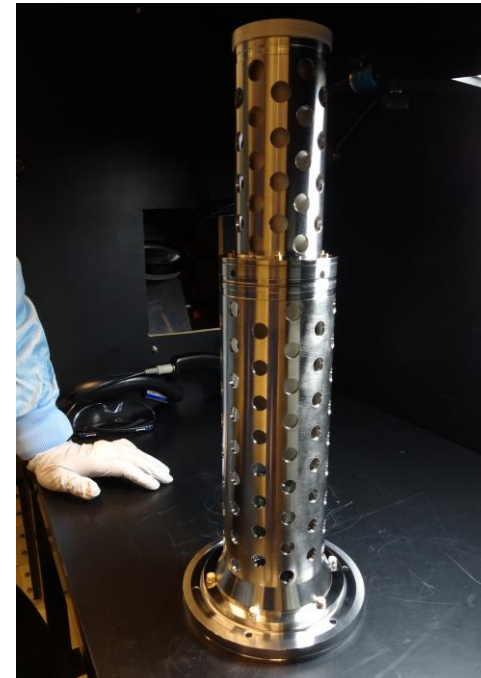
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PRESENT UPGRADE: M2

- › Improvement of intensity to 2 W/mm²
- › Shell design
- › Currently being installed
- › Validation program to start week 46



We make it visible.



FUTURE UPGRADE: EUV REFLECTOMETRY

TAPES3

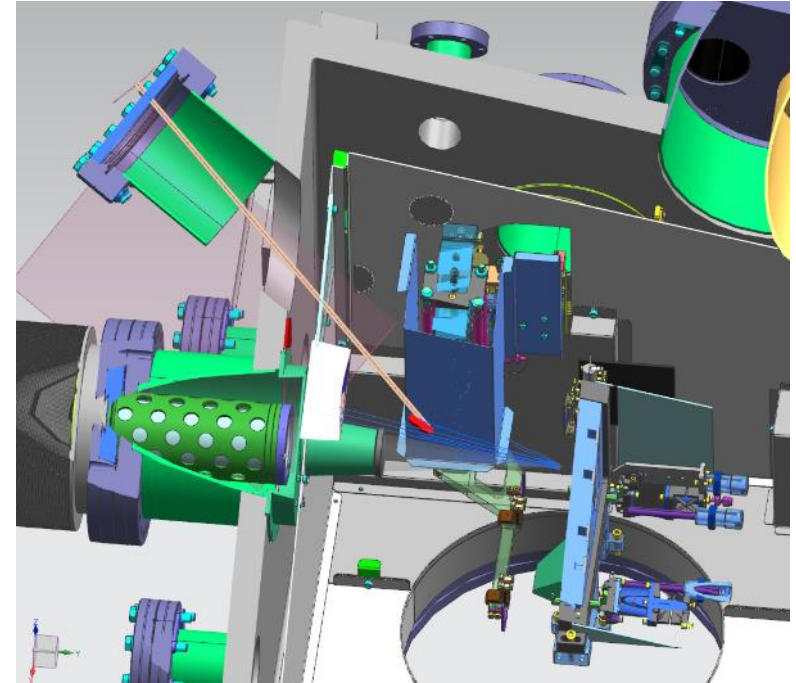
★★★

Requirements finalized

- › Relative reflectometry measurements
- › Pre and post measurements (0.5% accuracy)
- › Wavelength range 12.5-14.5 nm (<0.05 resolution)
- › Fixed angle of 6° CRA
- › No moving parts

Concept design started

- › Permanent in-situ system
- › Spectrometer using grating to resolve spectrum
- › Project within TAPES3 framework



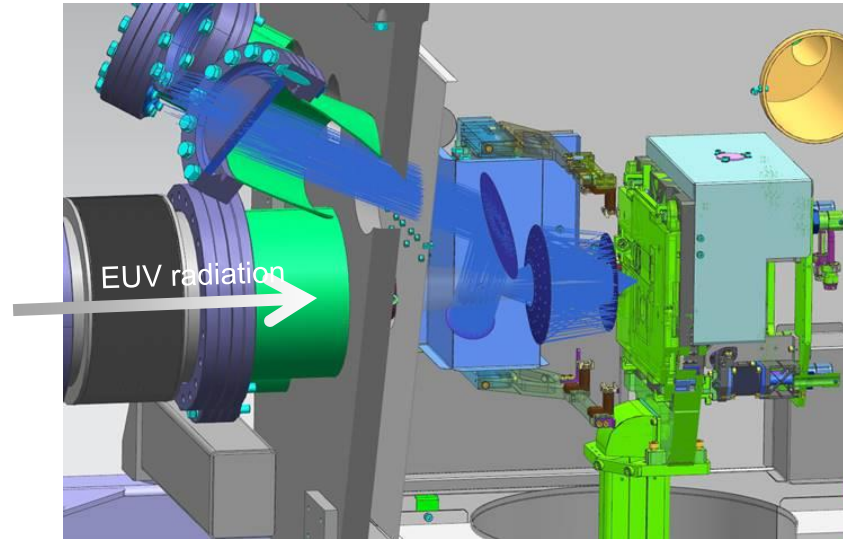
FUTURE UPGRADE: IR MICROSCOPY

Design of first concept

- › No optics inside vacuum
- › Camera and COTS lens in ambient
- › Thermal image of sample with high resolution (0.1 mm) and fast response

Ongoing conceptual design

- › Parts are ordered
- › Project within TAPES3 framework



CONCLUSION

- › EBL2 is an unique facility, accessible to third parties, that enables EUV lifetime research with;
 - › ASML EUV scanner relevant conditions,
 - › Up to EUV mask sample size
 - › High flexibility in environmental conditions
 - › In vacuum surface analysis

ASML

We make it visible.

USHIO Lighting—Edge Technologies**ADVANCED MASK TECHNOLOGY CENTER**
a Joint Venture of GLOBALFOUNDRIES and Toppan Photomasks**TAPES3**
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THANK YOU FOR YOUR
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