

Large area nanopatterning and industrial resist testing with an in-lab EUV Dual Beamline

EUVL Workshop, June 5th - 10th 2021

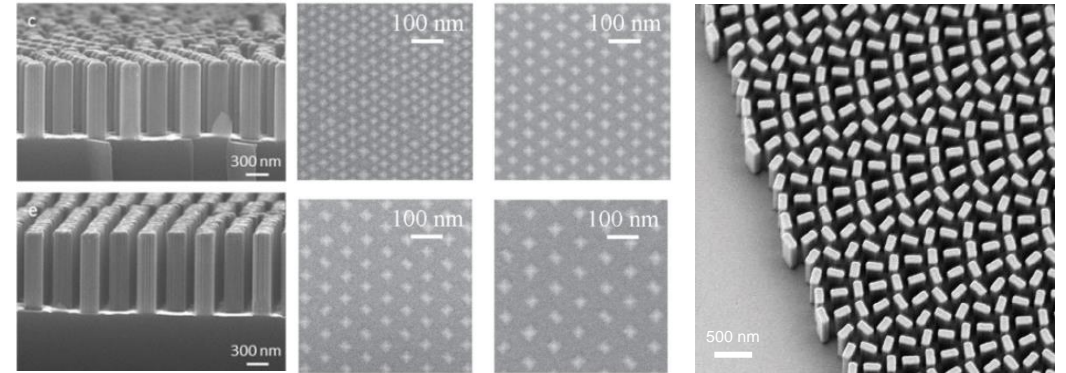
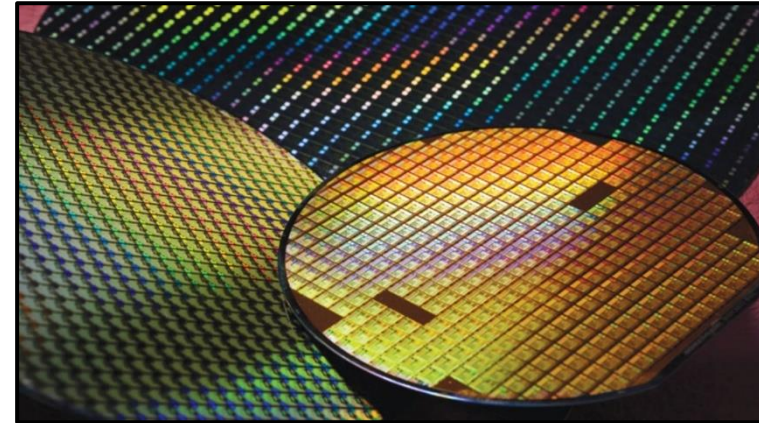
Bernhard Lüttgenau, Sascha Brose, Jochen Stollenwerk
RWTH Aachen University TOS - Chair for Technology of Optical Systems

Serhiy Danylyuk, Peter Loosen
Fraunhofer ILT - Institute for Laser Technology

Industrial and scientific need for EUV patterning tools

- In recent years, EUV has entered high-volume manufacturing in the semiconductor industry
- Compact setups offer small to medium enterprises and research institutions access to EUV technology
- Exemplary application fields:
 - 1) Industrial EUV photoresist development and qualification
 - 2) Large area nanopatterning for prototyping or small-batch production

Photograph of processed wafers [1]



Various nanopatterns for scientific applications [2,3,4]

[1] <https://photos5.appleinsider.com/gallery/39316-75230-36740-68650-tsmc-wafers-xl-xl.jpg>

[2] J. Veerbeek et al., *Chem. Nano. Mat.* 4, 874–881 (2018)

[3] J. Tempeler et al., *Nanotechnology* 29, 275601 (2018)

[4] B. Chen et al., *Nano Lett.* 17, 6345-6352 (2017)

EUV Dual Beamline



EUV Dual Beamline in research configuration (footprint: 2.5 x 1.5 m²)

Specifications EUV Dual Beamline	$\lambda = 10.9 \text{ nm}$	$\lambda = 13.5 \text{ nm}$
Intensity @ 2.5 kHz (mW/cm ²)	2.0	0.1
Wafer diameter (mm)	up to 100	
Single exposure field (mm ²)	2 x 2	5 x 5
Total exposure area (mm ²)	up to 64 x 64	
Demonstrated resolution (nm)	28	35

- Compact in-lab setup for high-resolution nanopatterning at two EUV wavelengths:
 - 1) Industrial photoresist qualification at 13.5 nm
 - 2) Large area nanopatterning with high throughput at 10.9 nm

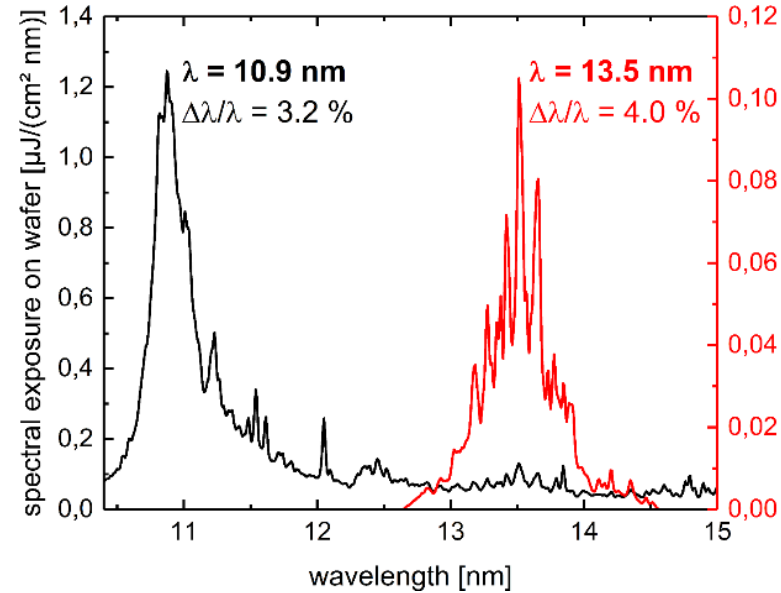
- Serves as a basis for industrial prototype development:
 - Optimized source operation
 - Lithographic interference scheme
 - Transmission mask technology

Optimized source operation

Commercial EUV source (FS5440, Fraunhofer ILT)



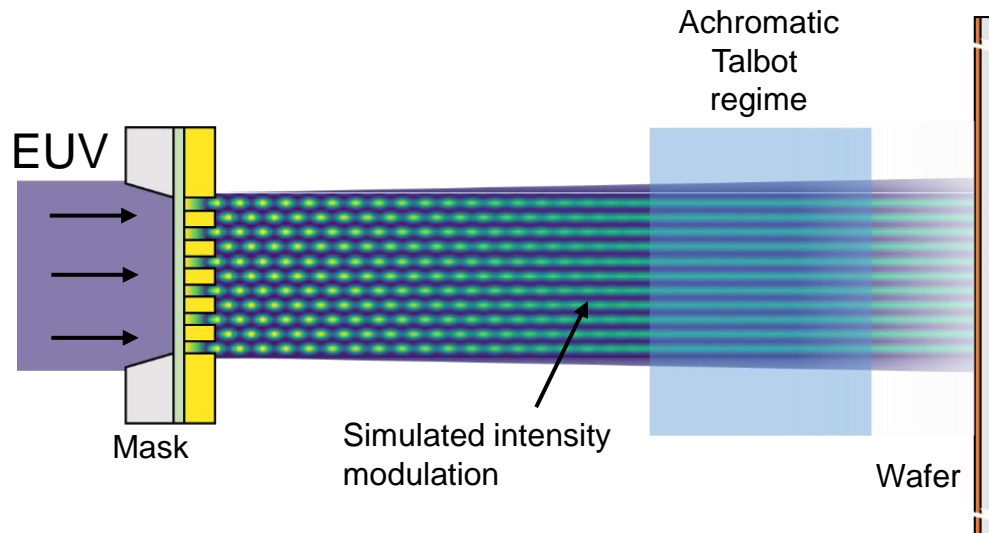
Spectral exposure for lithographic applications



- Compact discharge-produced plasma EUV source
- Spectral exposure optimized for lithographic applications:
 - 1) Main wavelength
 - 2) Relative spectral bandwidth
 - 3) Sufficient intensity

Lithographic interference scheme

Schematic drawing of achromatic Talbot lithography



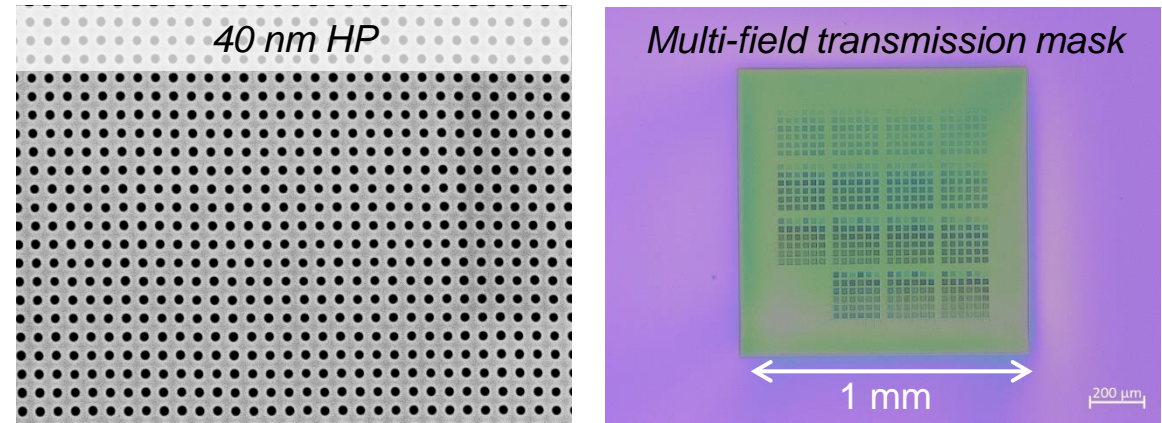
- Achromatic Talbot lithography:
 - High-contrast intensity modulation
 - Up to two times pattern demagnification
 - Efficient use of EUV radiation
- Intensity modulation predictable by rigorous simulation models
- Enables optimization of transmission mask design

Transmission mask technology

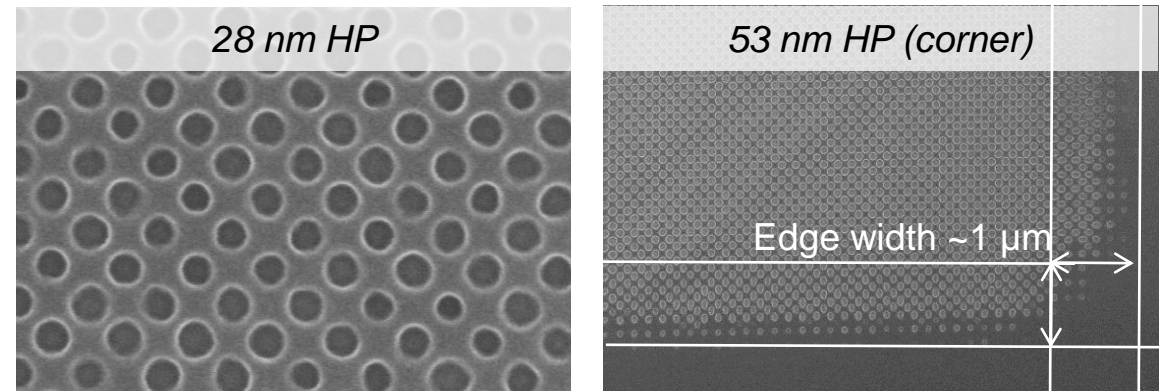
- Established mask fabrication process:
 - Sub-40 nm half-pitch (HP) periodic structures
 - Up to 2 x 2 mm² mask area
 - Single or multi-field transmission masks

- High-resolution nanopatterning:
 - Sub-30 nm half-pitch demonstrated (theoretical resolution limit < 10 nm)
 - Single exposure fields are stitched together to cover even larger areas

Fabricated mask patterns



Exemplary exposure results



→ **High-resolution patterning technology for industrial and scientific applications**

Thank you for your attention

Feel free to check out our poster or contact me directly

Bernhard Lüttgenau, M.Sc.
 RWTH Aachen University TOS – Chair for Technology of Optical Systems
 Steinbachstraße 15
 52074 Aachen
 Phone: + 49 241 8906-301
 bernhard.luetzgenau@tos.rwth-aachen.de

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B. Lüttgenau^{1,2}, S. Brose^{1,2}, S. Danylyuk³, J. Stollenwerk^{1,2,3}, P. Loosen³
¹RWTH Aachen University TOS – Chair for Technology of Optical Systems, Steinbachstr. 15, 52074 Aachen, Germany
²JARA – Fundamentals of Future Information Technology, Research Centre Jülich, 52425 Jülich, Germany
³Fraunhofer ILT – Institute for Laser Technology, Steinbachstr. 15, 52074 Aachen, Germany



*corresponding author's email address: bernhard.luetzgenau@tos.rwth-aachen.de

The EUV Dual Beamline is a versatile exposure tool equipped with a compact discharge-produced plasma (DPP) EUV source and can be operated either at an exposure wavelength of 10.9 nm or 13.5 nm, depending on the application. By operating the source with an Ar/Xe gas mixture, a narrow-band spectrum with a main wavelength of 10.9 nm is created without the need of spectral filtering. The resulting intensity of up to 2 mW/cm² in wafer plane allows large area patterning with highest throughput of several mm²/min. Qualification of industrial photoresists regarding sensitivity, contrast and resolution at 13.5 nm is enabled by operating the DPP source with pure Xe. The resulting broadband emission is spectrally filtered to 13.5 nm in-band radiation by a customized multilayer mirror. For partially coherent radiation as provided by the DPP source-based illumination setup, the (achromatic) Talbot lithography has proven to be the most suitable lithographic scheme with a demonstrated resolution in the sub-30 nm regime and theoretical resolution limit below 10 nm. To create high-resolution nanopatterns on the wafer, efficient phase-shifting transmission masks need to be carefully designed and fabricated. Single and multi-field resolution masks can be created to either enable large-area nanopatterning or efficient resolution testing for industrial EUV resists.

EUV DUAL BEAMLINE

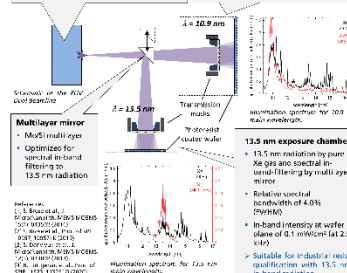


- EUV Dual Beamline:**
- Discharge produced plasma EUV source
 - Large-area patterning with sub-30 nm resolution at 10.9 nm wavelength [1]
 - Customization of EUV photoresist sensitivity, contrast, resolution at 13.5 nm wavelength [2]
 - Interfero- and Interference lithography

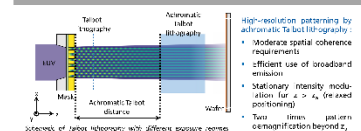
UVI dual beamline for nanopatterning at 10.9 nm and 13.5 nm.

MAIN COMPONENTS

- DPP EUV source**
- High-temperature ionized plasma (up to 100,000 K)
 - Small radiation volume by pinch effect (< 0.500 µm)
 - Pulse duration ~100 ns and up to kHz-frequency
 - Utilization of different fuel gases optimized for lithographic applications [1]
- Compact DPP source developed for in-lab use:**
- Comparative low debris due to operation with noble gases
 - Reduced number of optical elements
 - Efficient use of radiation
 - Suitable for small enterprises or research groups
- 10.9 nm exposure chamber**
- 10.9 nm radiation by Ar/Xe gas mixture
 - Relative spectral bandwidth of 1.2% (FWHM)
 - High intensity in wafer plane (2.0 mW/cm² at 2.5 kHz)
 - High throughput achievable (1 mm²/min)
 - Suitable for large area nanopatterning



ACHROMATIC TALBOT LITHOGRAPHY



PHASE-SHIFTING TRANSMISSION MASKS

- Phase-shifting mask**
- Phase-shifting transmission masks for efficient use of radiation
 - Fabrication process developed for resist based and metal based masks
 - Dense periodic structures down to 40 nm half pitch
 - Up to 2 x 2 mm² mask area
 - Single and multi-field transmission masks
- Sub-30 nm half-pitch mask**
- Sub-30 nm half-pitch mask
 - Multi-field transmission mask

HIGH-RESOLUTION NANOPATTERNING

- 10.9 nm (Ar/Xe)**
- Single exposure fields > 1 x 1 m²
 - Spacing of structures flexible possible (edge width of ~1 µm for 53 nm half-pitch)
 - Low-defectivity patterns due to interference
 - Suitable for large-area nanopatterning
- 13.5 nm (Xe)**
- Sub-30 nm half-pitch resolution demonstrated (contact mask)
 - Theoretical resolution limit: down to 10 nm half pitch [4]
 - Suitable for resist qualification for future technology nodes

EUV Dual Beamline for high-resolution nanopatterning

- Compact in-lab setup for nanopatterning at two different EUV wave lengths
- Interfero- and interference lithography with high resolution at 13.5 nm
- Large-area nanopatterning with high throughput at 10.9 nm
- Versatile nanopatterning tool for scientific and industrial applications

