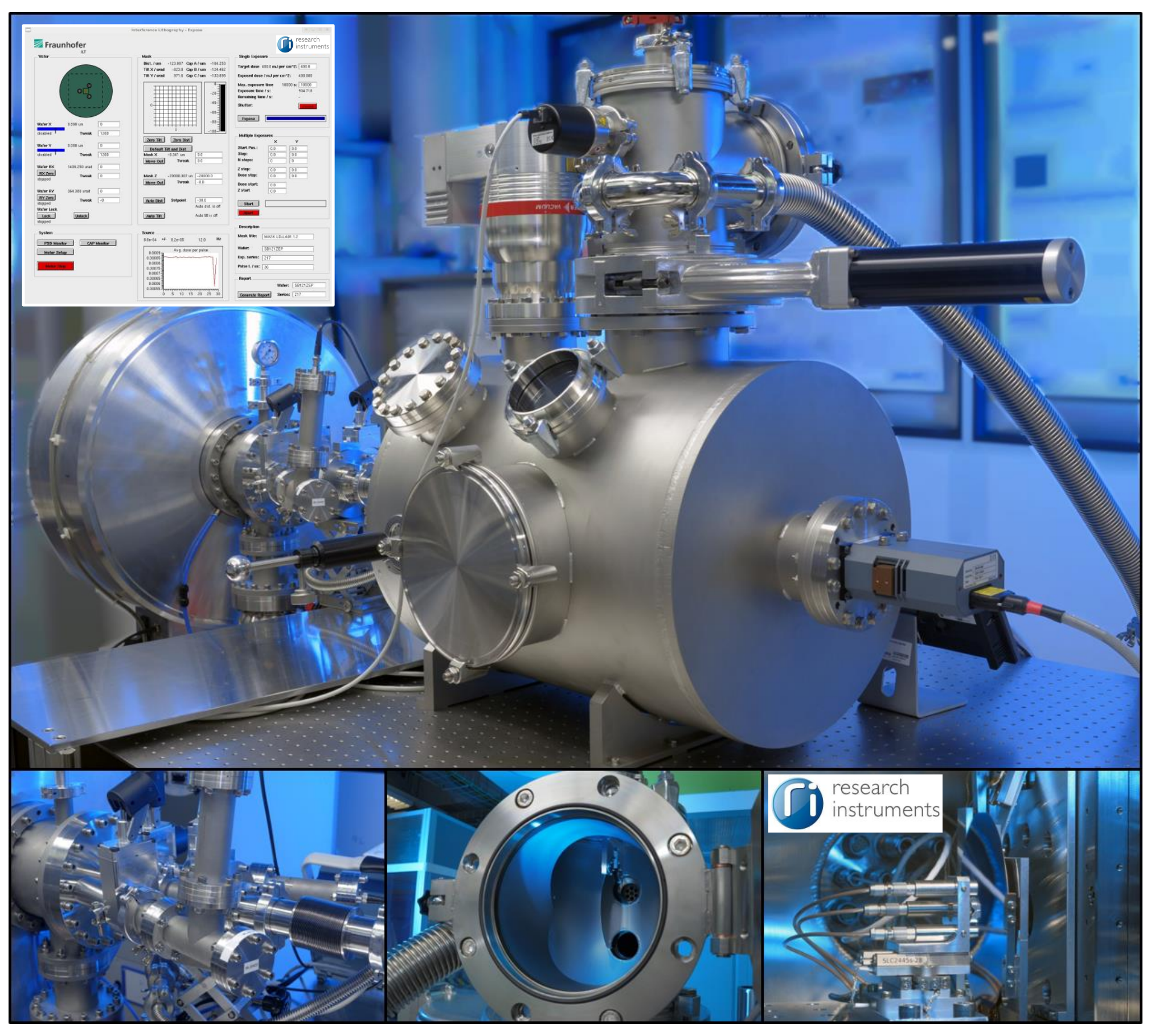
EUV LABORATORY EXPOSURE TOOL (EUV-LET)

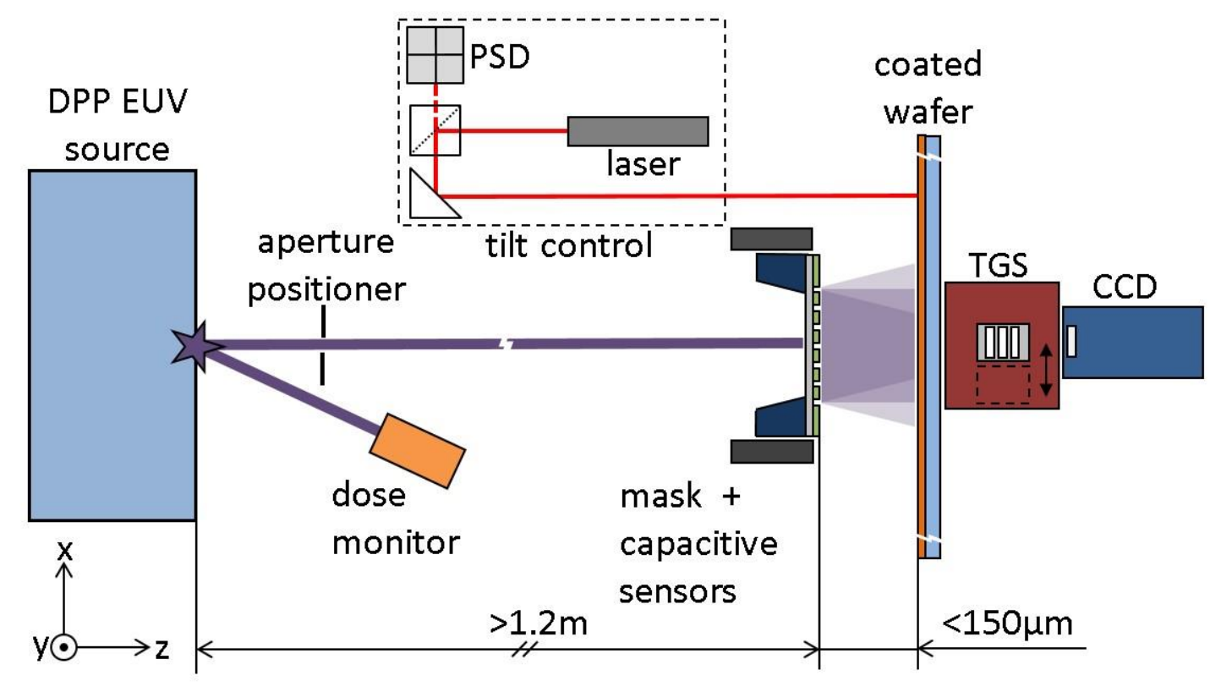
ACHROMATIC TALBOT LITHOGRAPHY WITH PARTIALLY COHERENT EUV RADIATION

Sascha Brose[1,3]*, Jenny Tempeler[1,3], Hyun-su Kim[2,3], Serhiy Danylyuk[1,3], Larissa Juschkin[2,3], Peter Loosen[1,3,4]
[1] RWTH Aachen University, Chair for Technology of Optical Systems, Steinbachstr. 15, 52074 Aachen, Germany
[2] RWTH Aachen University, Experimental Physics of Extreme Ultraviolet, Steinbachstr. 15, 52074 Aachen, Germany
[3] JARA – Fundamentals of Future Information Technology, Research Centre Jülich, 52425 Jülich, Germany
[4] Fraunhofer Institute for Laser Technology, Steinbachstr. 15, 52074 Aachen, Germany
*corresponding author's email address: sascha.brose@tos.rwth-aachen.de

In this contribution we present the EUV laboratory exposure tool. It is a versatile tool suited for applications in academia and industrial research, reaching from pre-patterning of substrates to resist and pellicle characterization. The setup consists of a discharge produced plasma source with a direct beam path to a phase-shifting transmission mask, the photoresist coated wafer and the positioning system. High throughput is enabled by the utilization of the achromatic Talbot effect that is suited for broadband emission, since all radiation contributes to the interference pattern. The method also allows for a up to two-times demagnification of the mask features, leading to more relaxed mask fabrication requirements. For process window identification, systematic exposure series were performed varying the mask-wafer distance and the exposure dose. The depth of field is found to be 20 µm in close proximity to the transmission mask. Optimization of the exposure parameters resulted in 35 nm half-pitch wafer features with low defectivity level. The process window can be extended by spatial filtering techniques, leading to sub-30 nm wafer half-pitches.

EUV LABORATORY EXPOSURE TOOL





Technical Specifications	
Discharge argon/xenon based EUV source	
Wavelength for lithography:	10.9 nm (or 13.5 nm)
Single exposure field:	up to 2 x 2 mm²
Bandwidth at 10.9 nm:	3.2%
Photon flux at mask @ 1kHz:	1.0 mW/cm²
Spatial coherence in mask plane:	10 to 20 µm
Theoretical resolution:	10 nm
Demonstrated resolution:	35 nm

Top (left): Photograph of EUV-LET. Inset: GUI of control software.
Top (right): Working scheme of the EUV-LET.

DPP EUV SOURCE

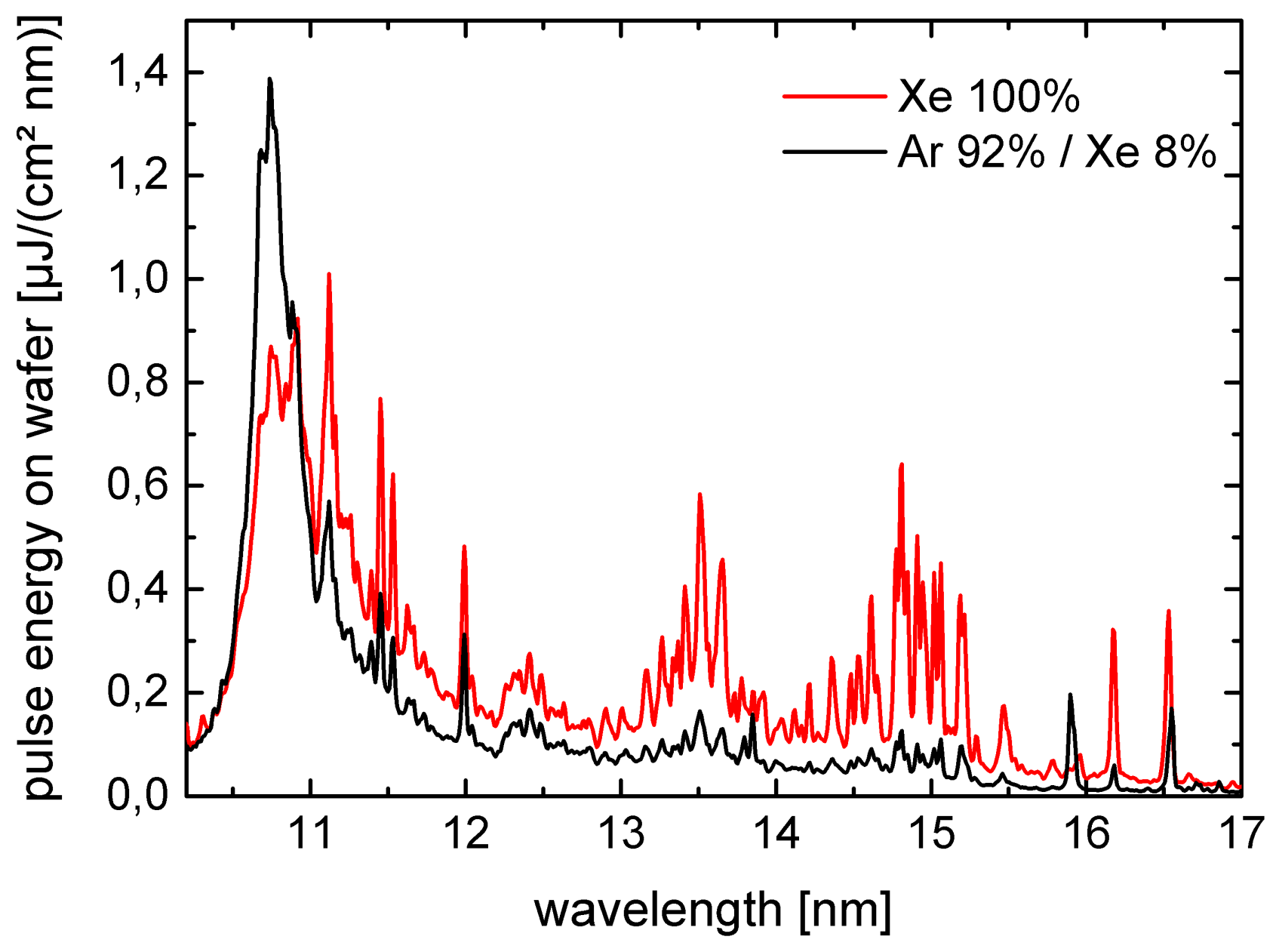
- Standard Operation

In-band power	:	**20 W/2πsr**
EUV pulse energy	:	2,2 mJ/sr
Repetition rate	:	1500 Hz
Peak brightness	:	8 W/mm²sr

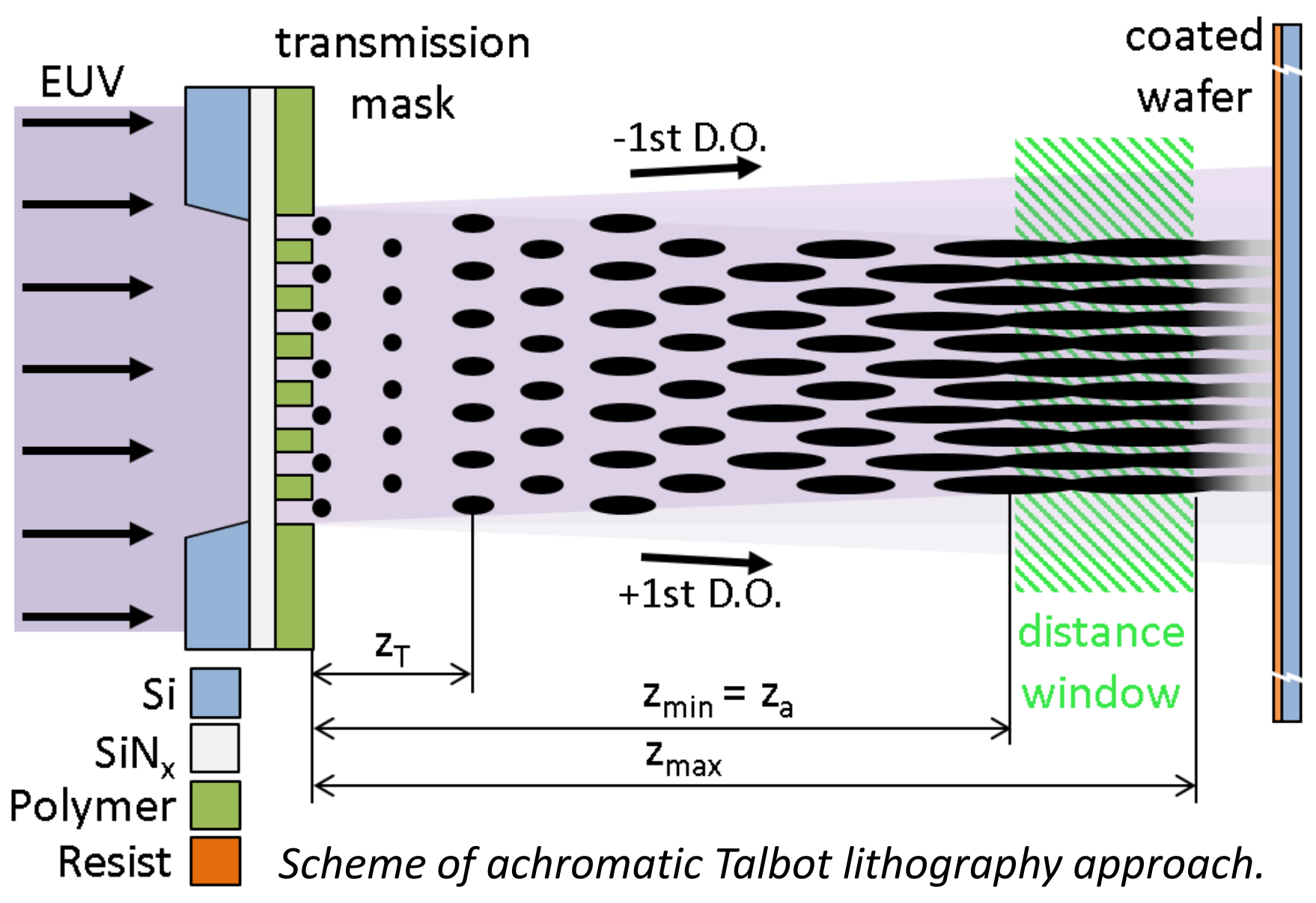
- High Pulse Energy Option

In-band power	:	<10 W/2πsr
EUV pulse energy	:	**> 4,0 mJ/sr**
Repetition rate	:	< 400 Hz

Right: Typical xenon and argon/xenon emission spectrum [1].

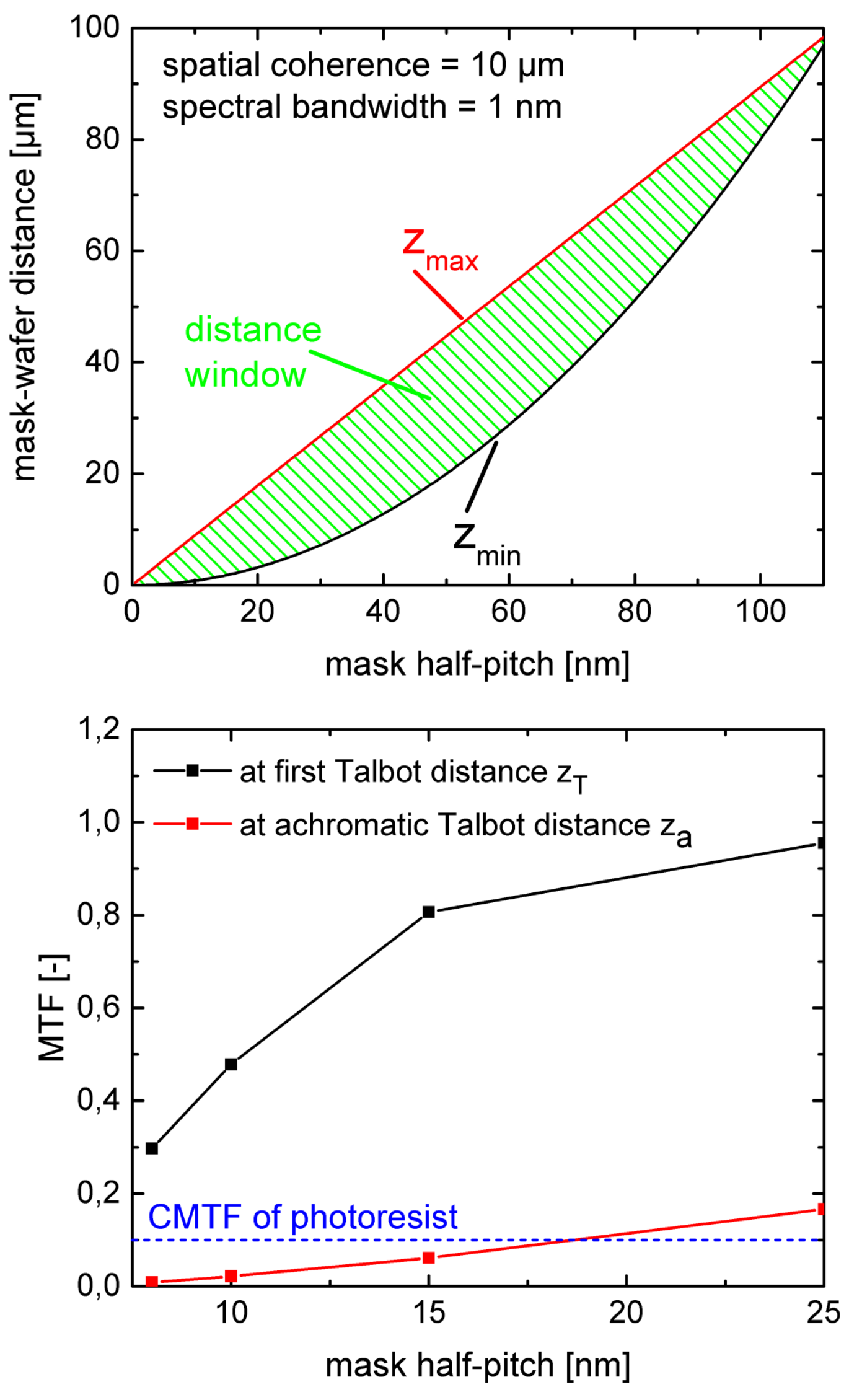


ACHROMATIC TALBOT LITHOGRAPHY



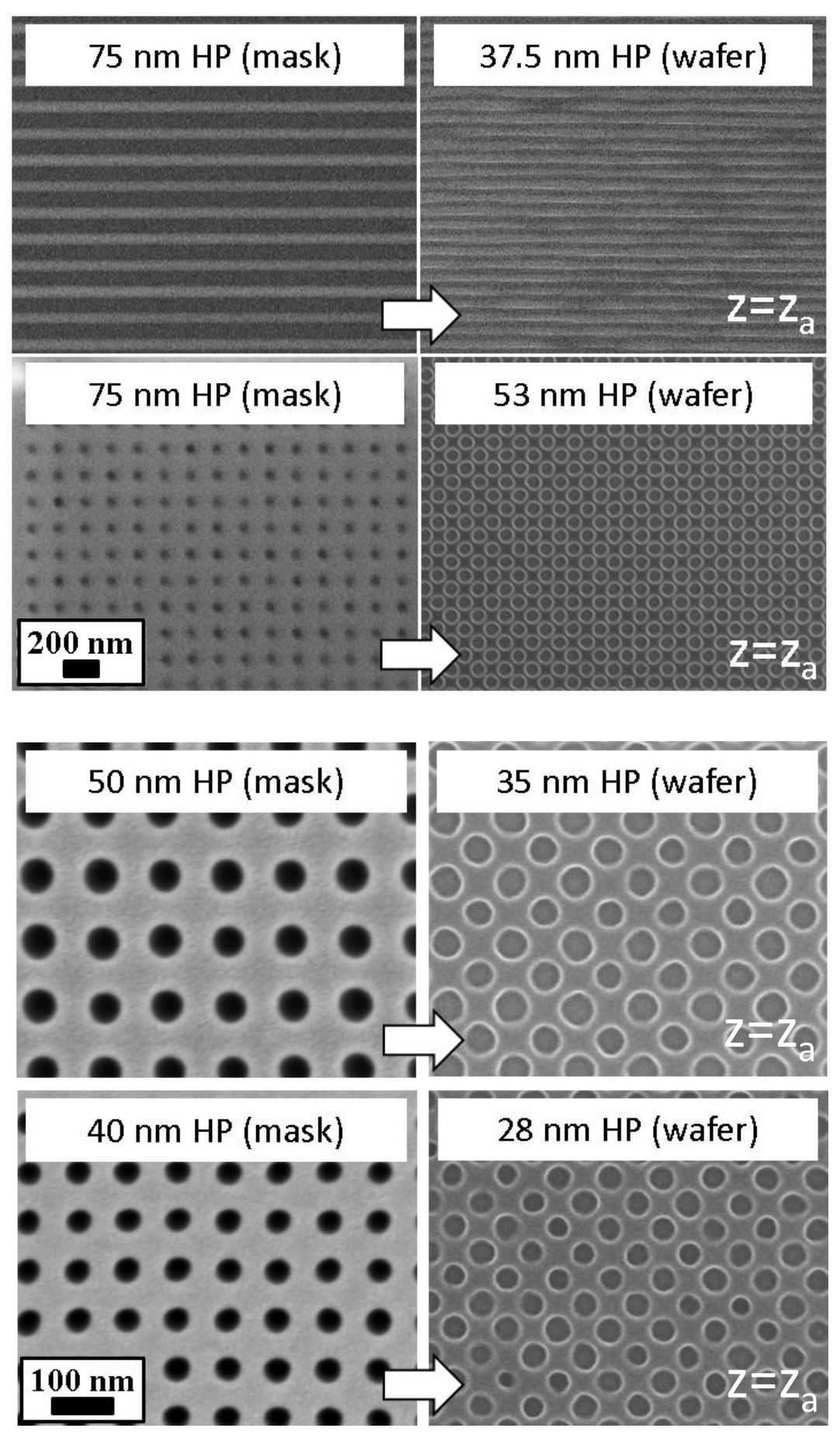
Scheme of achromatic Talbot lithography approach.

- Efficient use of broadband emission
- Up to 2x demagnified mask-patterns in the exposure result
- Non-contact exposure mode
- Stationary achromatic intensity distribution within distance window (spatial coherence limited at z_{max})
- Depth of field of 10 to 20 µm [2]
- Theoretical resolution limit of 10 nm half-pitch [3]



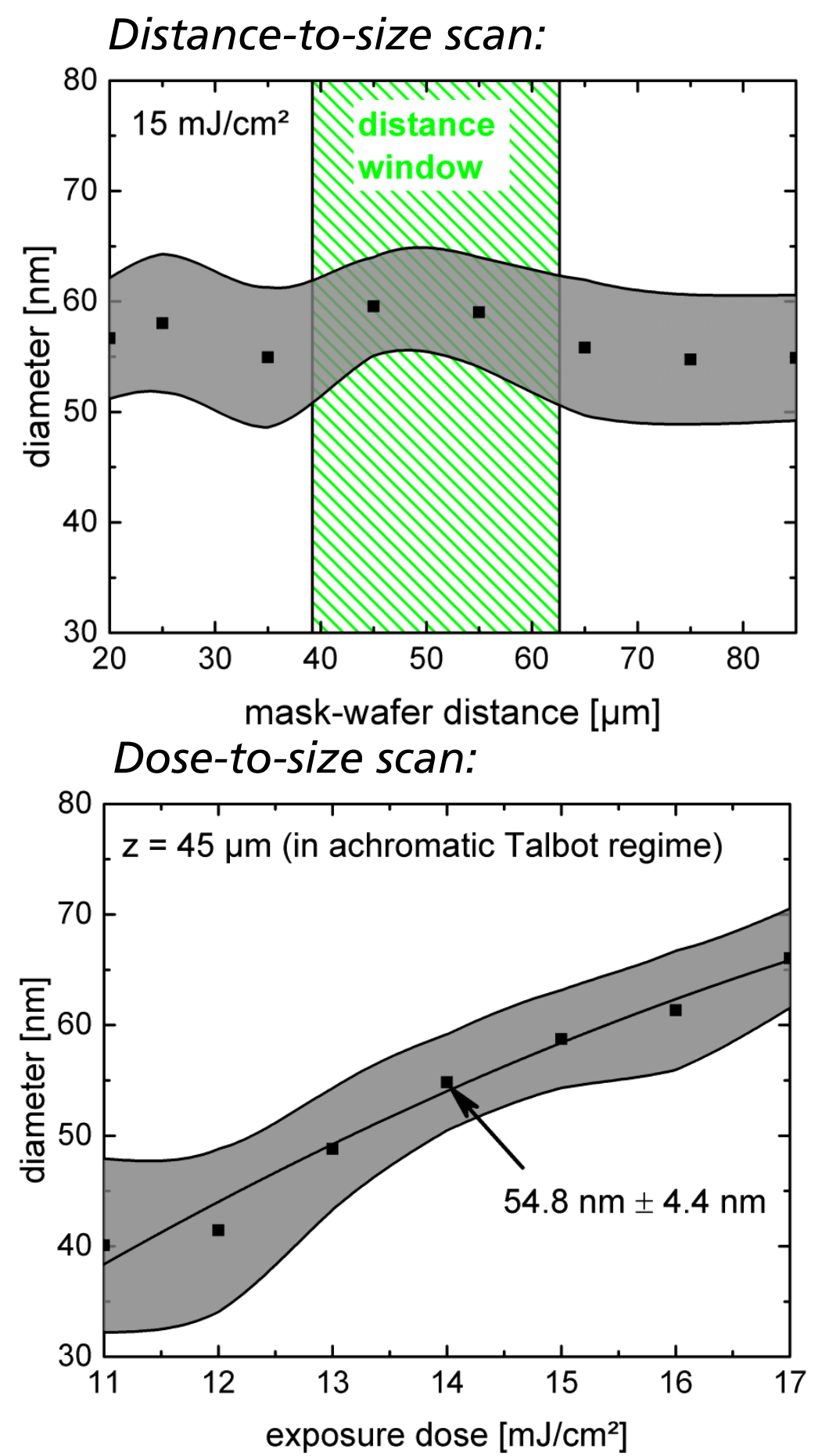
Calculated distance window for EUV-LET (top) and simulated aerial image contrast for Talbot lithography approach (bottom).

HIGH RESOLUTION PATTERNING



Typical exposure results in achromatic Talbot distance. Compared to the mask half-pitch the wafer half-pitch is reduced up to two times (for lines and spaces).

- High quality, low defectivity interference patterns
- Established fabrication processes for amplitude [4] and phase-shifting masks [5]
- Single exposure fields up to 2 x 2 mm² (stitching to larger fields possible)
- Exposure time less than 60 s (for 15 mJ/cm² EUV resist)
- Various applications in academia and industry

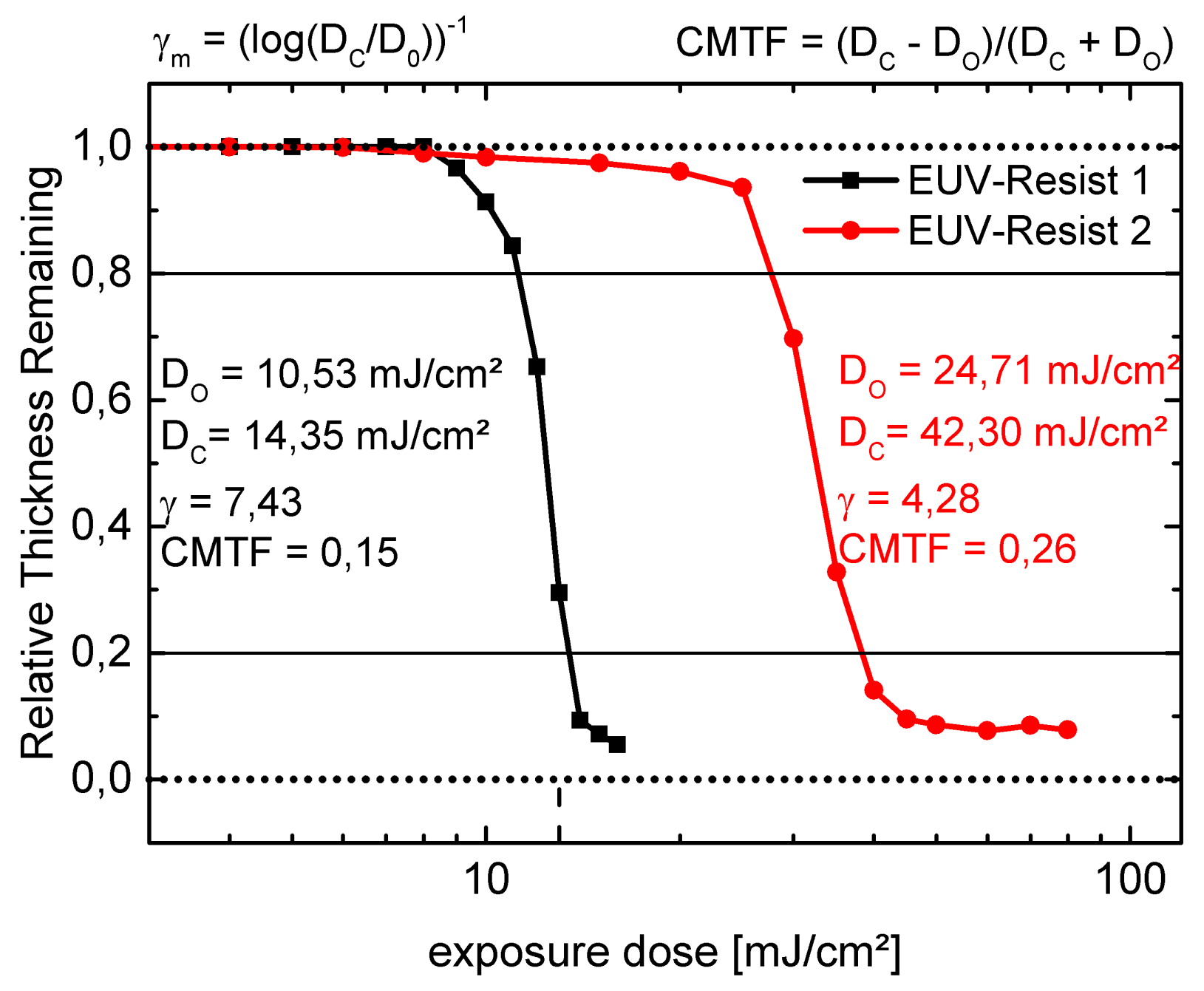


Process window analysis for 50 nm half-pitch structures.

RESIST CHARACTERIZATION

- Open frame exposures for resist screening [4]
- Determination of sensitivity (dose-to-clear D_C) and contrast γ (or CMTF)
- Enabled by precise dose control (±5 µJ/cm² dose precision)
- Evaluation method for resist pre- and post-processing optimization

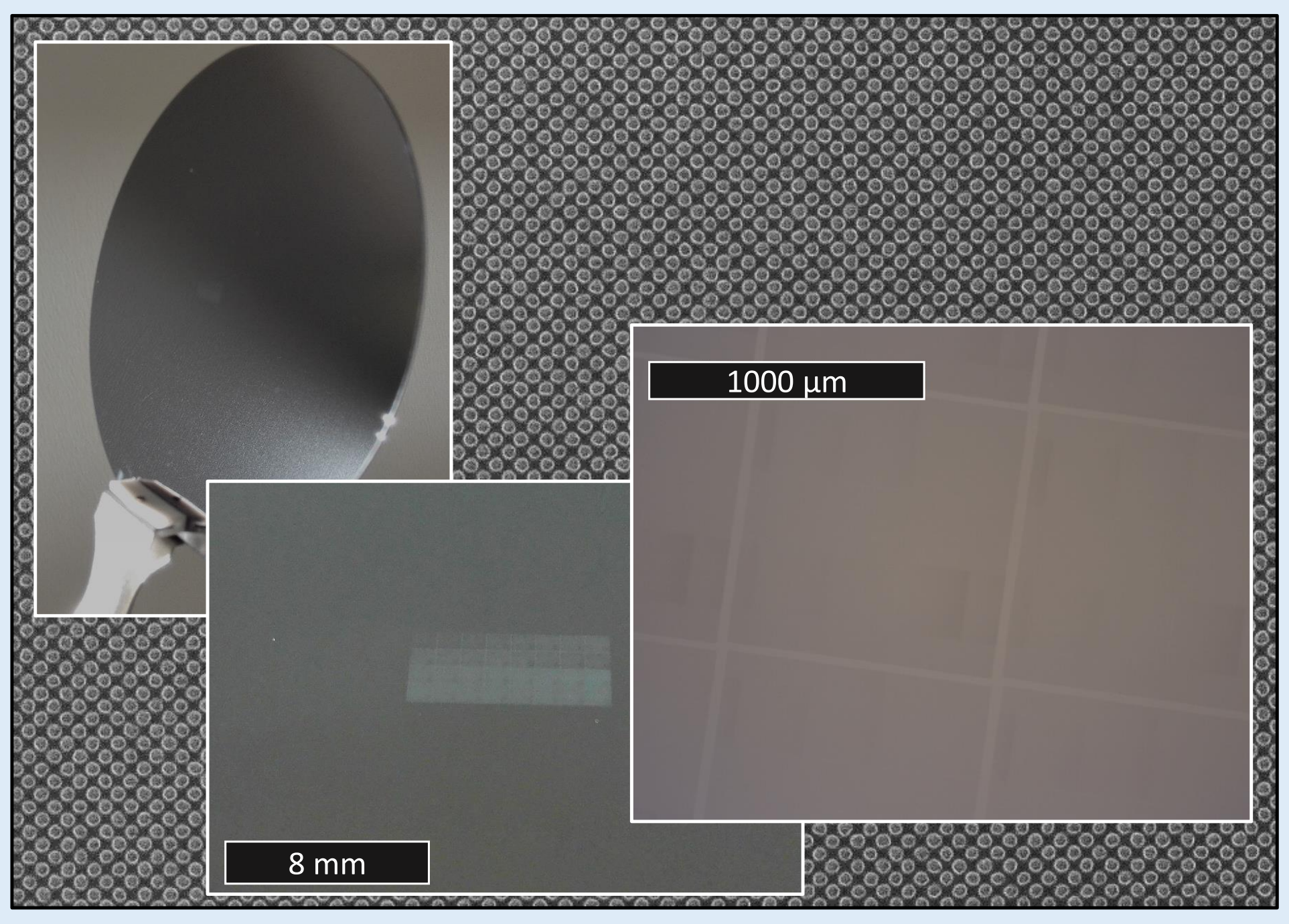
Right: Typical characteristic curve plot for two different EUV resists.



APPLICATIONS IN R&D

Versatile in-lab exposure tool:

- Filter/Pellicle characterization (transmission & uniformity). Resolution better than 50 µm (not shown here).
- Resist characterization (sensitivity, contrast, resolution, outgassing).
- In-lab patterning of periodic sub-30 nm half pitch structures (dots, lines and spaces).
- Simple and robust mask fabrication technology (spin-on polymer on SiN_x membrane).
- Record resolution of 28 nm with achromatic Talbot lithography.



Photograph of exposed 100 mm wafer (left); close-up of exposure result of 4 x 8 single exposure fields (center); microscopic image of stitched 1 x 1 mm² single exposure fields (right); SEM image of low-defectivity 50 nm half-pitch structures (background).

[1] K. Bergmann et al., J. Appl. Phys. 106, 073309 (2009)
[2] S. Brose et al., J. Micro/Nanolith. MEMS MOEMS 15(4), 043502 (2016)
[3] S. Danylyuk et al., J. Micro/Nanolith. MEMS MOEMS 12(3), 033002 (2013)
[4] S. Brose et al., Thin Solid Films 520, 5080 (2012)
[5] S. Brose et al., Proc. SPIE 9776, Extreme Ultraviolet (EUV) Lithography VII, 97760R (2016)

Fraunhofer ILT
JARA | FIT Fundamentals of Future Information Technology
RWTH AACHEN UNIVERSITY