GenISys
Advancing the Standard

September, 2024

LAB

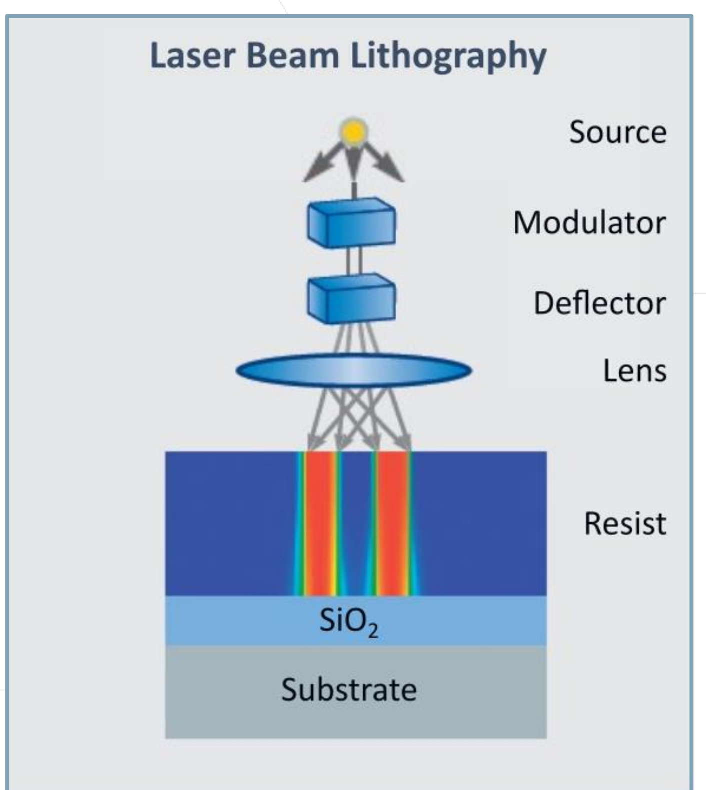
Simulation of Laser Lithography

Outline

- Laser Lithography
- Exposure and Development Simulation
- Application Cases
  - 2D
    - Matrix of Squares
    - Gratings
  - 3D
    - Diffractive Optical Elements (DOEs)

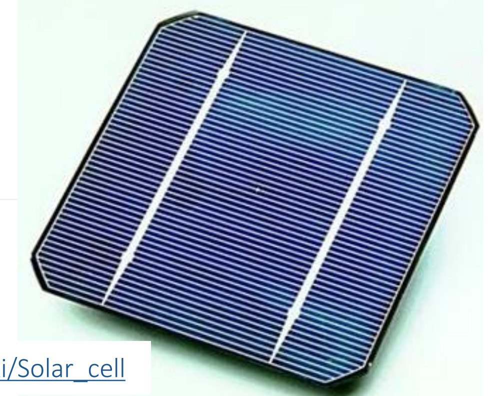
Laser Lithography Basics

- Spatial Light Modulator (**SLM**) used to read layout
- Layout scanned on wafer using a **Deflector + Lens**
- **Direct laser exposure** → No need of a mask
- **Low** and **mid-volume** production (R&D)
- **High-volume** production (Industry)



Laser Lithography Applications

Energy conversion

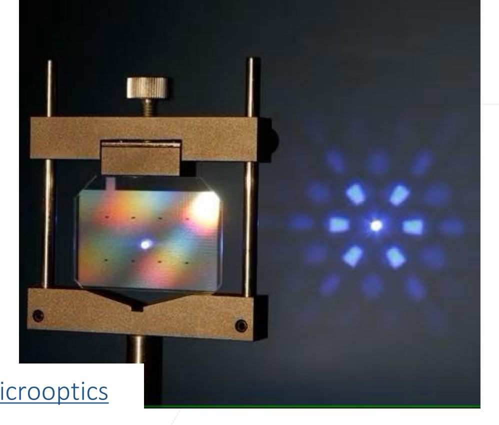


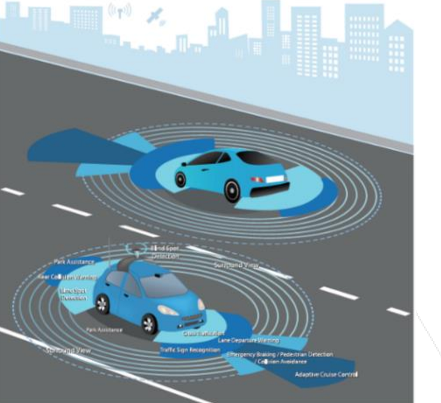
https://en.wikipedia.org/wiki/Solar_cell

Photodetectors

https://www.tech-faq.com/photodetector.html

Diffractive Optical Elements (DOEs)





https://www.jenoptik.com/products/optical-systems/optical-precision-components/diffractive-optical-elements-doe-microoptics
https://www.agc.com/en/products/electoric/detail/doe_and_diffuser.html

Examples of first exposures

2.0000 um

2.42 µm

2 µm

5 µm

2 µm

2um_iso_vert_90mJ_d0_4k | Live Measurement
CD[um]: Mean = 2.4280 Min = 2.3941 Max = 2.48

Internal corners rounded

Structures widening

Shape lost

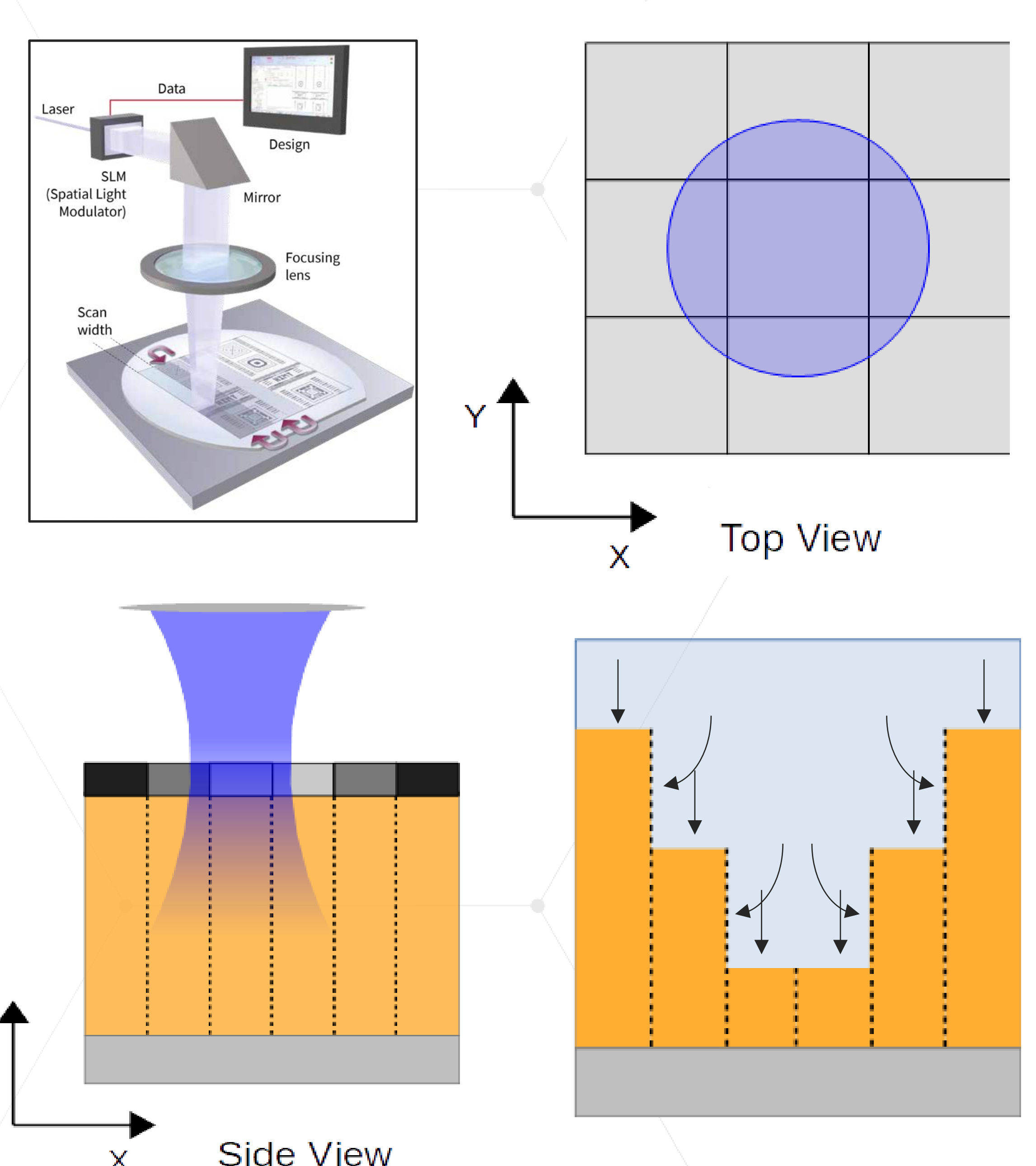
Laser lithography challenges

Tool factors:

- NA and wavelength define imaging performance
- Beam spot larger than pixel size
- Intensity not constant along Z-axis

Processing factors:

- Dissolution rate depends on local intensity (3D impact)
  - Lateral development
  - Depth-dependent development time



LAB to improve the outcome

2.0000 um

2.42 µm

2 µm 5 µm 2 µm

2um_iso_vert_90mJ_d0_4k | Live Measurement
CD[um]: Mean = 2.4280 Min = 2.3941 Max = 2.48

LAB

2.05 µm

2 µm 5 µm 2 µm

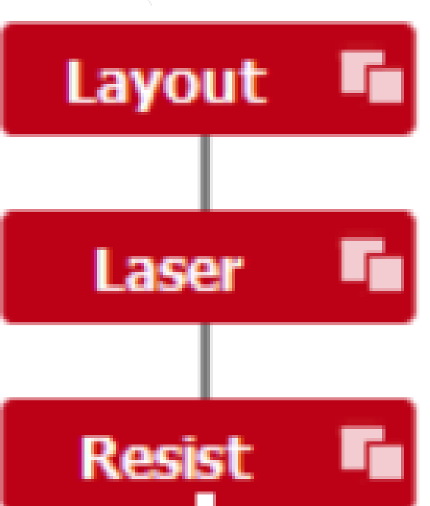
LAB simulation replaces many *experimental iterations*

Outline

- Laser Lithography
- Exposure and Development Simulation
- Application Cases
  - 2D
    - Matrix of Squares
    - Gratings
  - 3D
    - Diffractive Optical Elements (DOEs)

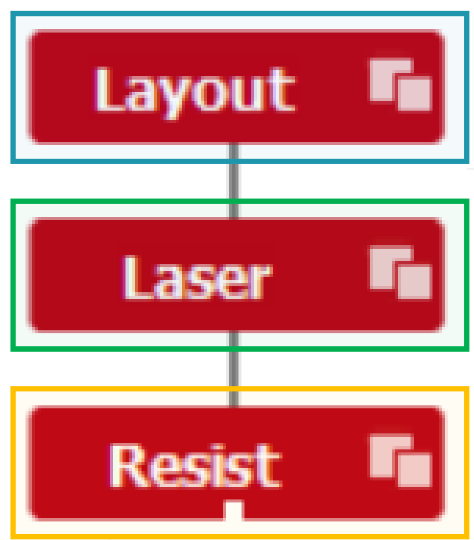
Basic LAB flow

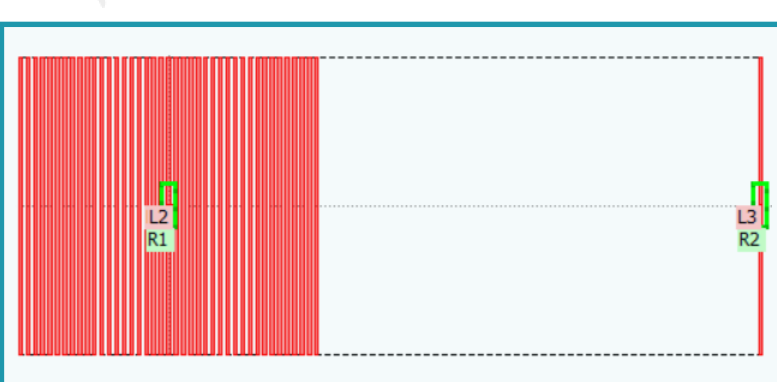
- Import
  - Formats: **gds**, **dxf**, **png**, etc.
- Simulation
  - **Laser Exposure**
- Modelling
  - Resist Models: **Mack-4**, **Development Rate**, and **Threshold**



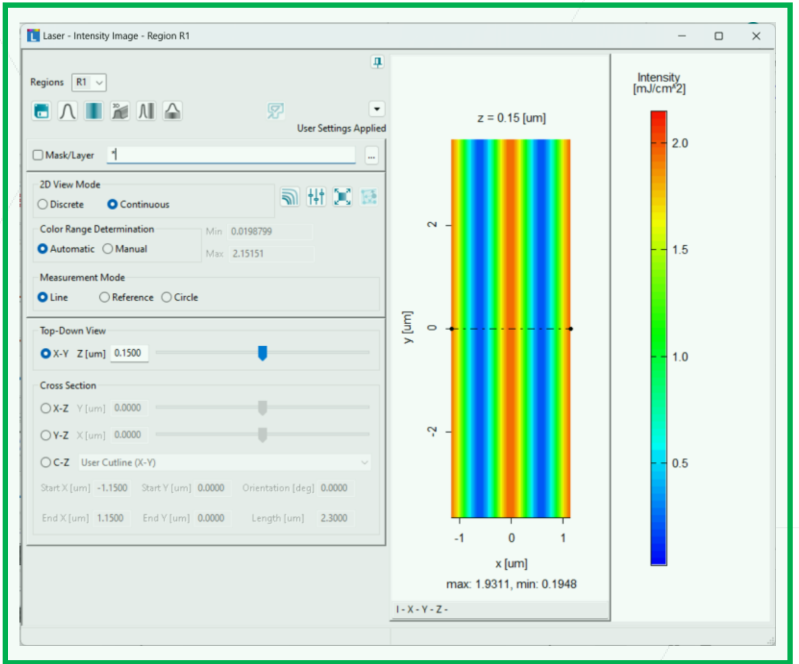
Overview of LAB simulations

LAB easily imports a pattern allowing simulating laser exposure on any photoresist and subsequent development

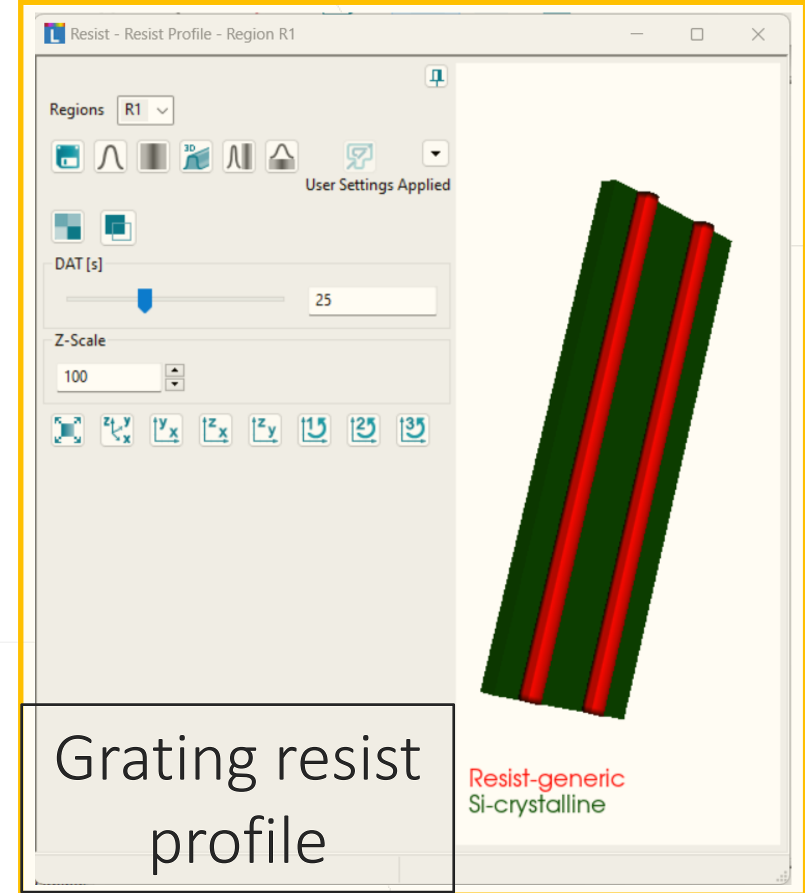




Gratings and iso-line example



Grating 2D intensity image



Grating resist profile

Laser Exposure Settings

- Settings to establish the experimental conditions

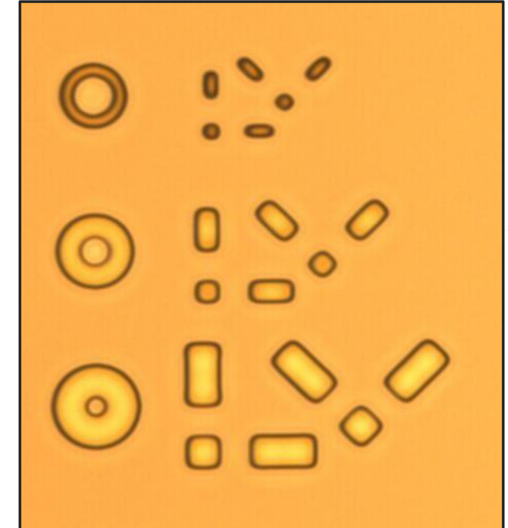
Layout
Laser
Resist

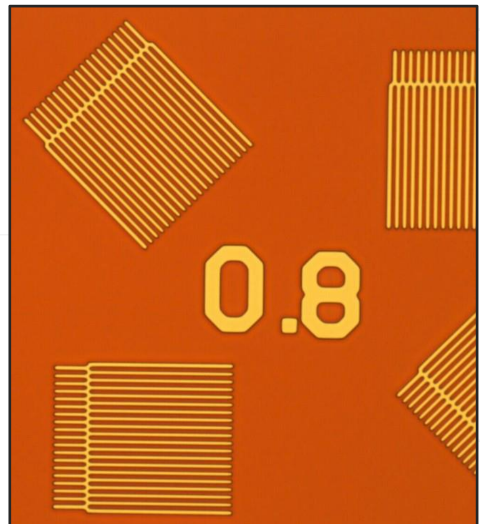
Outline

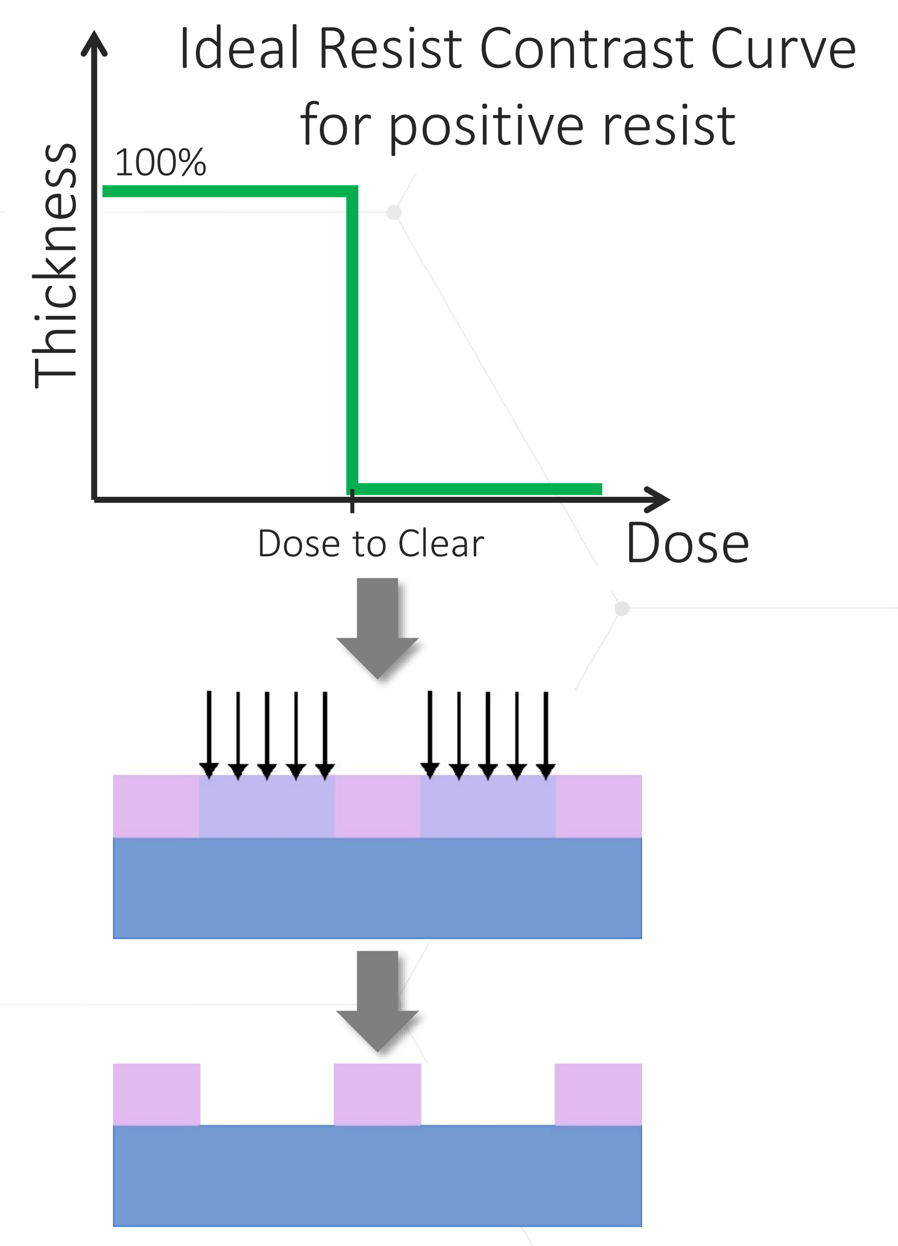
- Laser Lithography
- Exposure and Development Simulation
- Application Cases
  - 2D
    - Matrix of Squares
    - Gratings
  - 3D
    - Diffractive Optical Elements (DOEs)

2D lithography

- Traditional 2D lithography is **Binary**







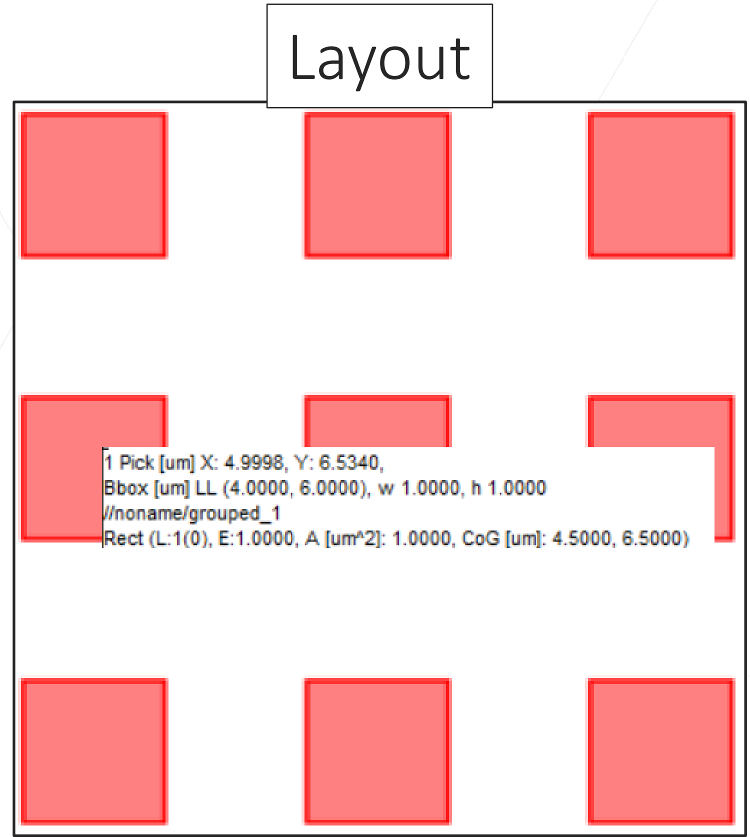
Source: MPI Munich

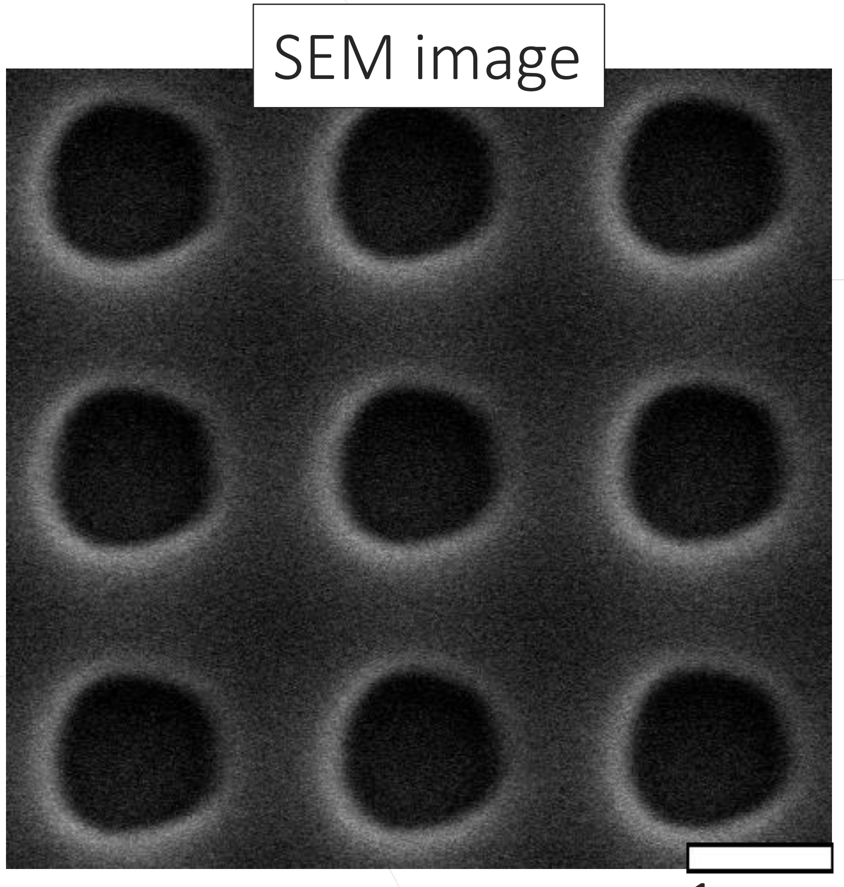
Outline

- Laser Lithography
- Exposure and Development Simulation
- Application Cases
  - 2D
    - Matrix of Squares
    - Gratings
  - 3D
    - Diffractive Optical Elements (DOEs)

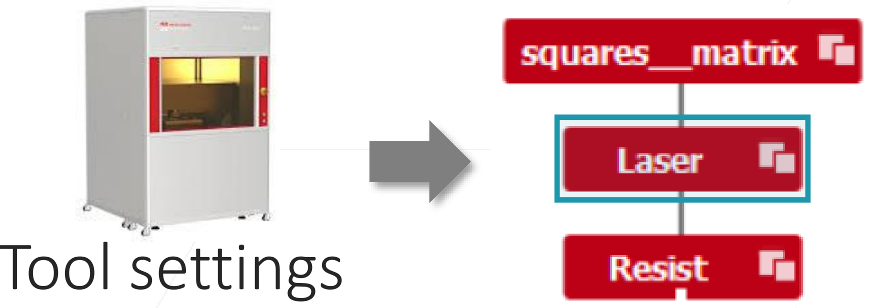
Binary lithography

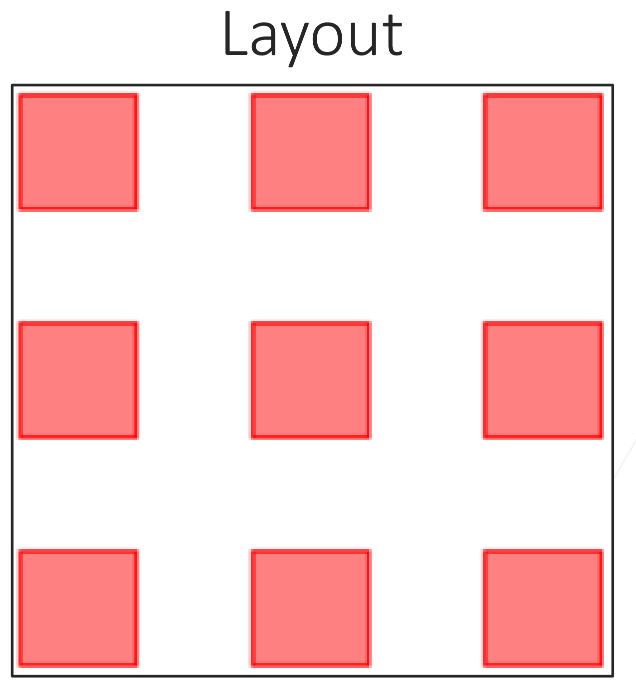
- Layout: Matrix of 1 µm squares
- Substrate: 500 nm of AZ1505 on SiO_2
- Tool resolution: 600 nm

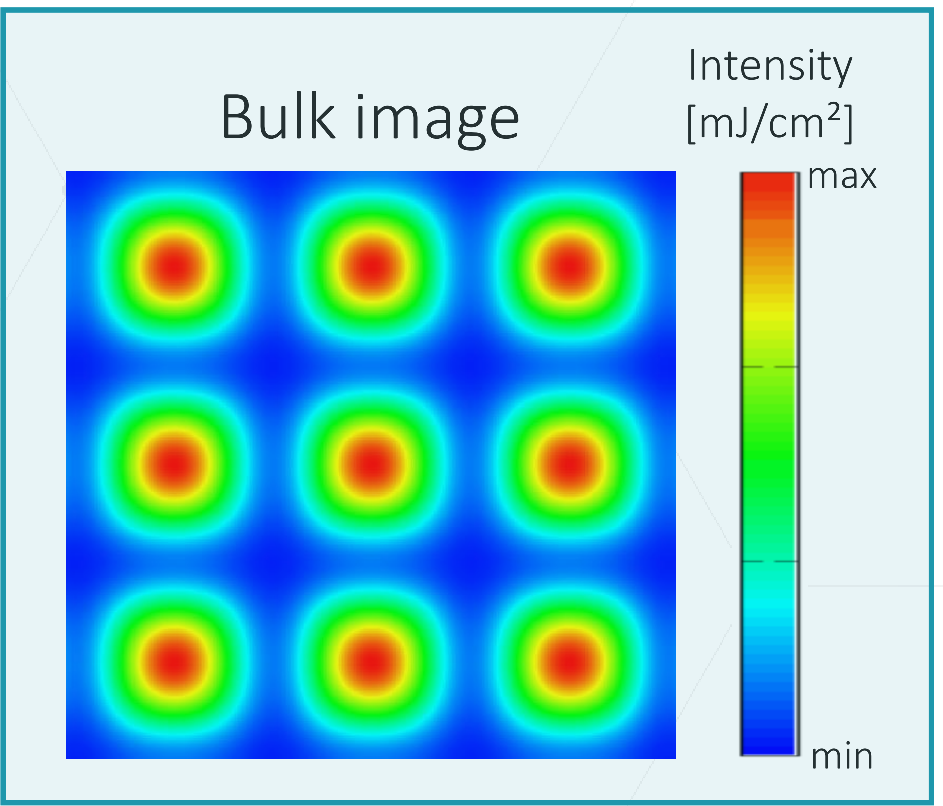


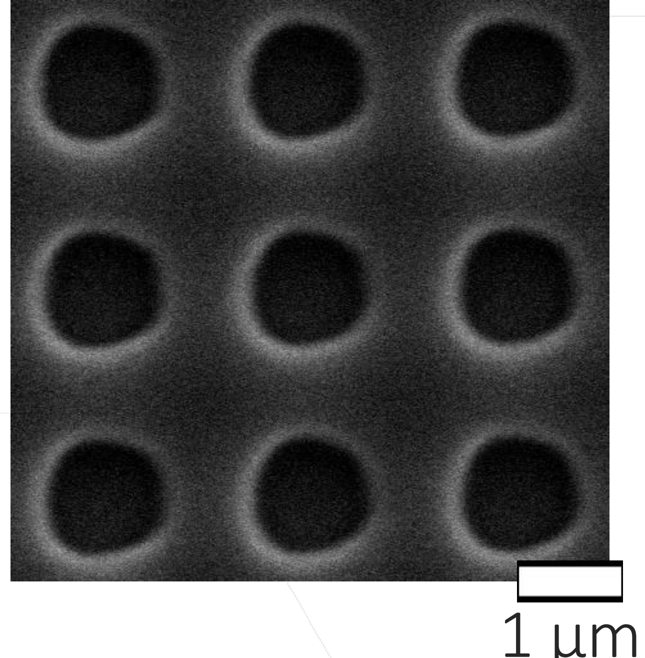


Simulating the Experiment

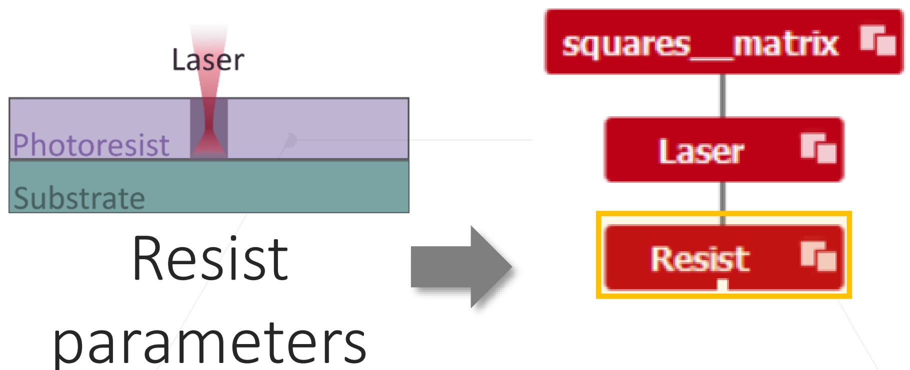








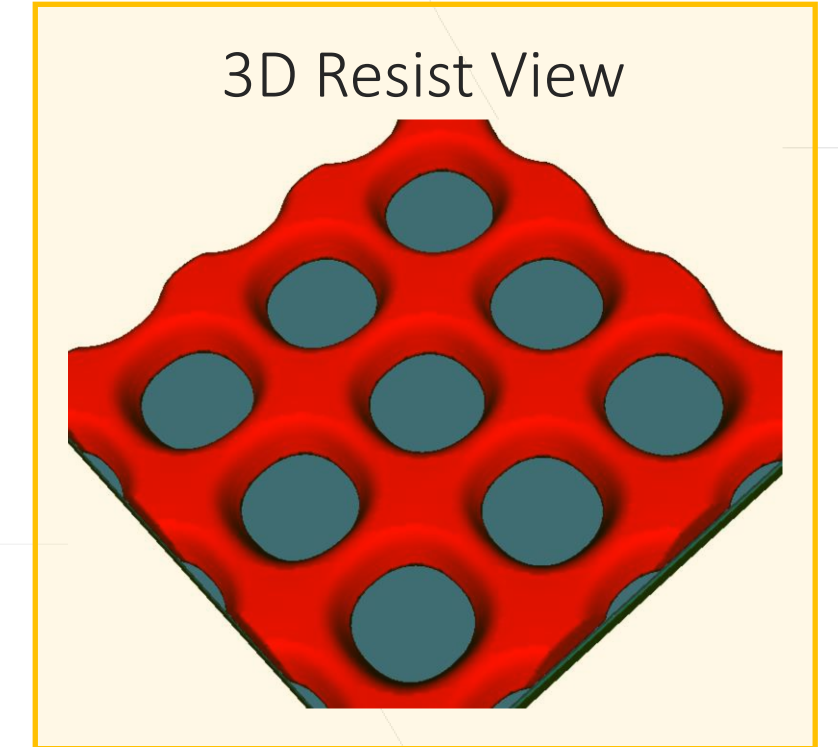
Resist Modelling



Layout

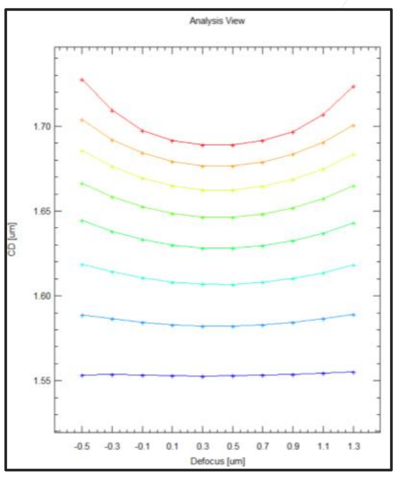
SEM image

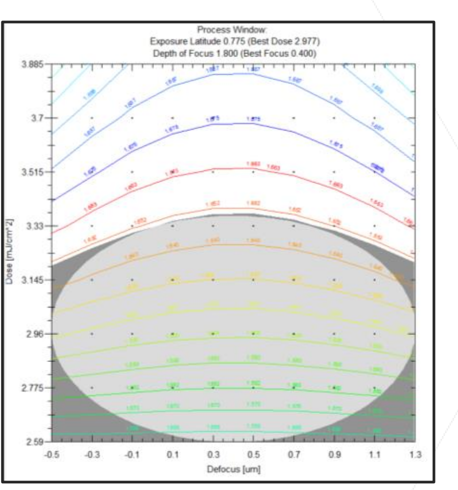
1 µm

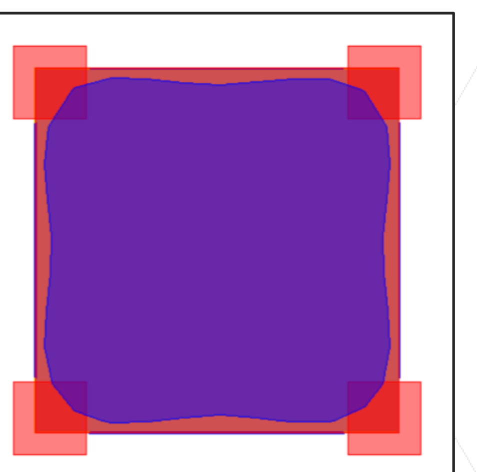


LAB simulations

- **LAB** speeds up finding optimal experimental conditions:
  - Process
    - Bossung curve
    - Process window
  - Pattern
    - Rule-OPC (Optical Proximity Correction)

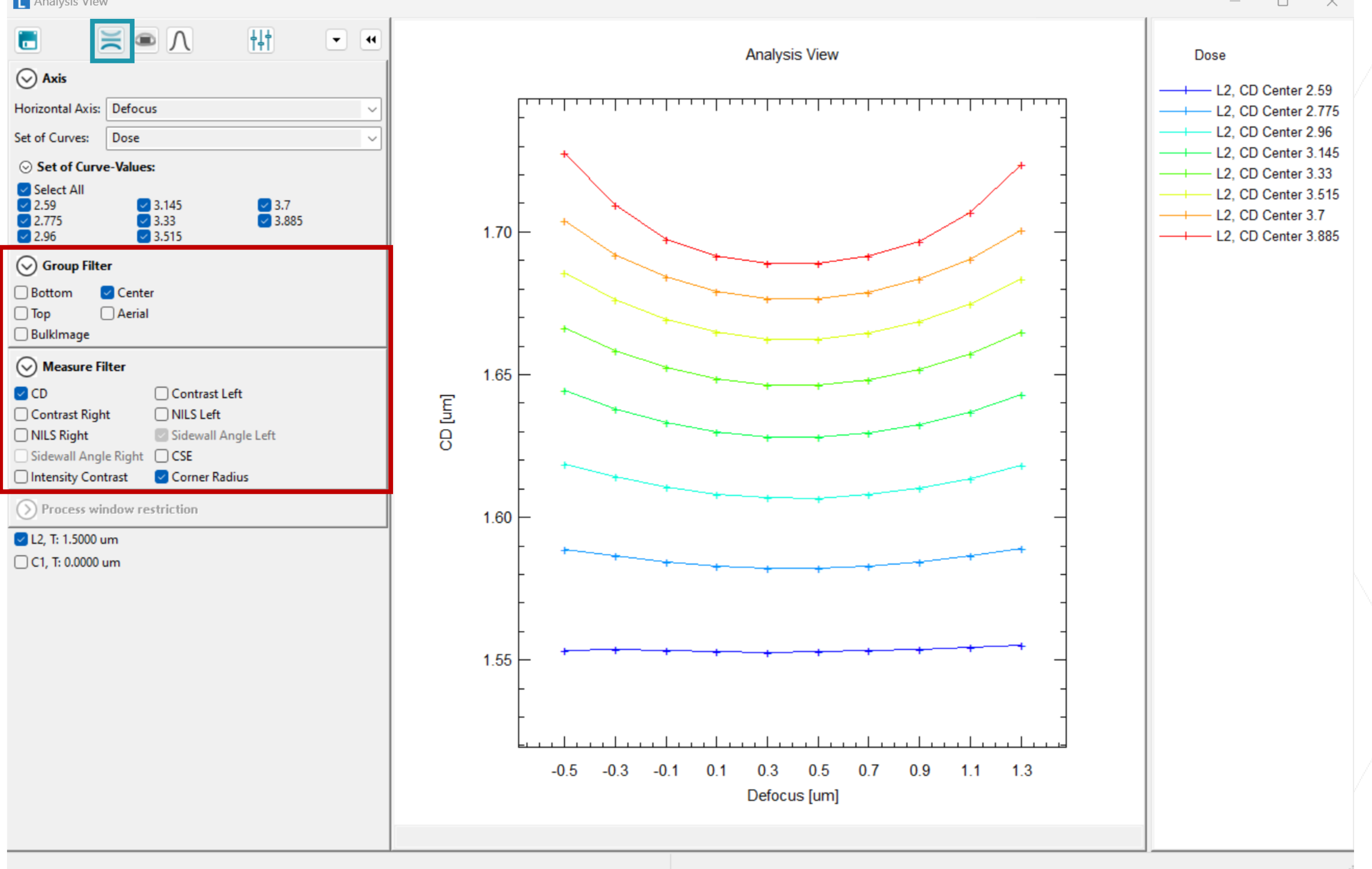






Finding Optimal Exposure Settings

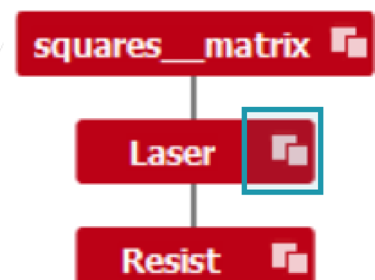
- Laser Exposure ➔ Analysis ➔ Focus Exposure Matrix



- **Group Filter**
  - Select area of interest
    Bottom, Top, BulkImage, Center, Aerial
- **Measure Filter**
  - Select analysis parameter
    CD, Contrast Right/Left, NILS Right/Left...

Plots analysing CD as function of focus and dose are called ***Bossung curves***

Process Window



Analysis View

Axis
Horizontal Axis: Defocus
Set of Curves: Dose
Set of Curve-Values: Select All

Group Filter
Bottom, Center, Top, Aerial, BulkImage

Measure Filter
CD, Contrast Left, Contrast Right, NILS Left, NILS Right, Sidewall Angle Left, Sidewall Angle Right, CSE, Intensity Contrast, Corner Radius

Process window restriction
L2, T: 1.5000 um

Group	Measure	Min	Max	Mode
Center	CD	1.3500	1.6500	Abs

C1, T: 0.0000 um

Process Window:
Exposure Latitude 0.775 (Best Dose 2.977)
Depth of Focus 1.800 (Best Focus 0.400)

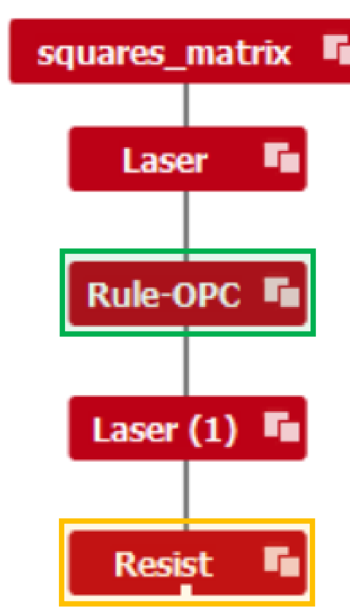
Dose [mJ/cm^2]: 3.885, 3.7, 3.515, 3.33, 3.145, 2.96, 2.775, 2.59
Defocus [um]: -0.5, -0.3, -0.1, 0.1, 0.3, 0.5, 0.7, 0.9, 1.1, 1.3

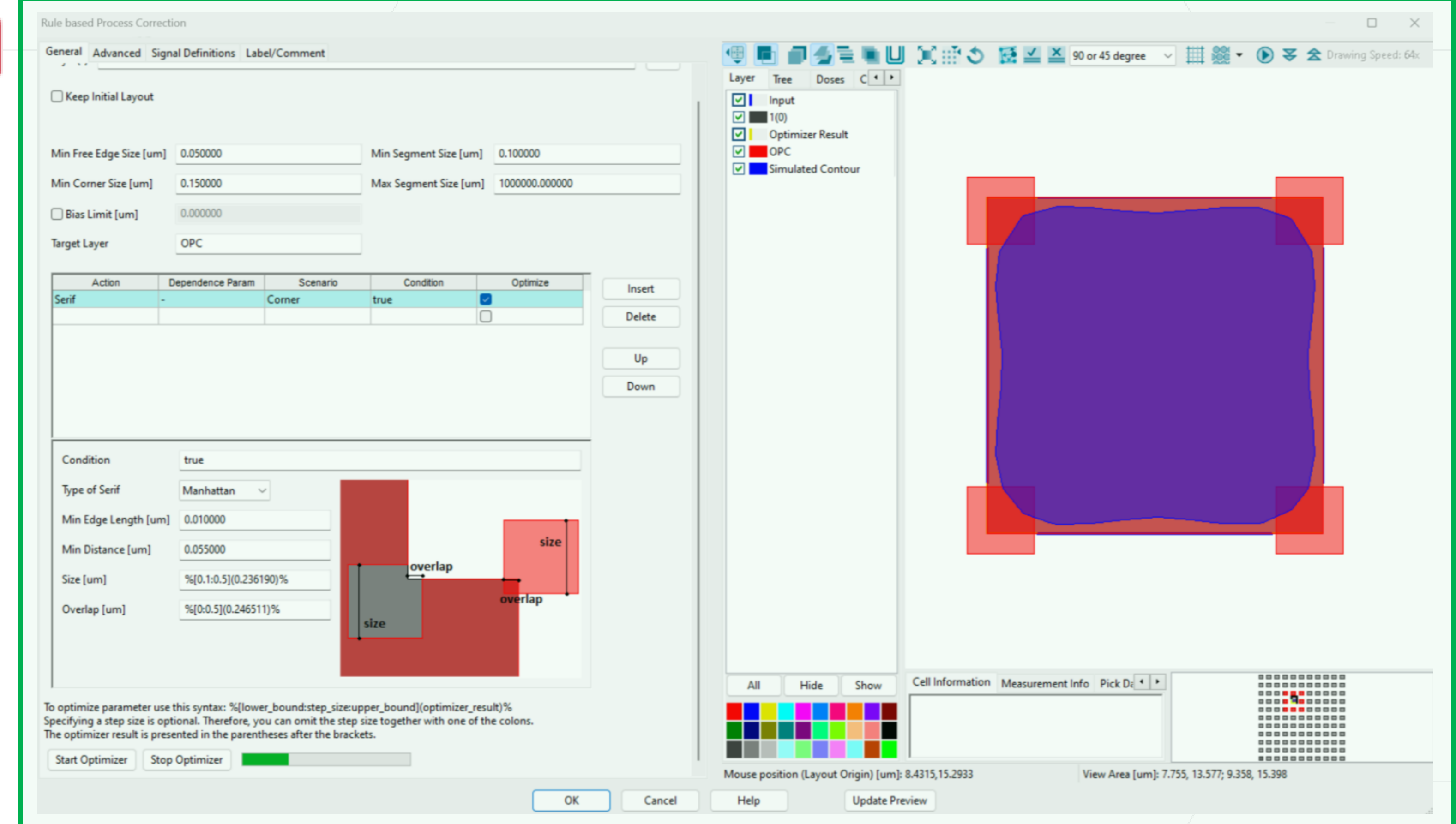
- Range of parameters of the process to yield a desired result
- **Min**, **Max** and **Mode**
  - Acceptability limits for the process

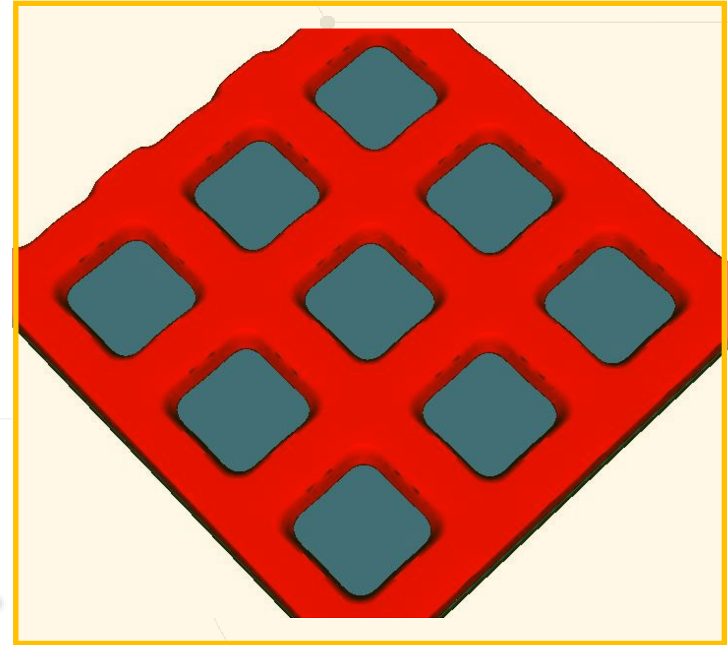
With optimal parameters, an exposure is further improved via design optimisation

Corners Rounding

- *LAB* has an internal *Optimizer* within the *Rule-OPC* module





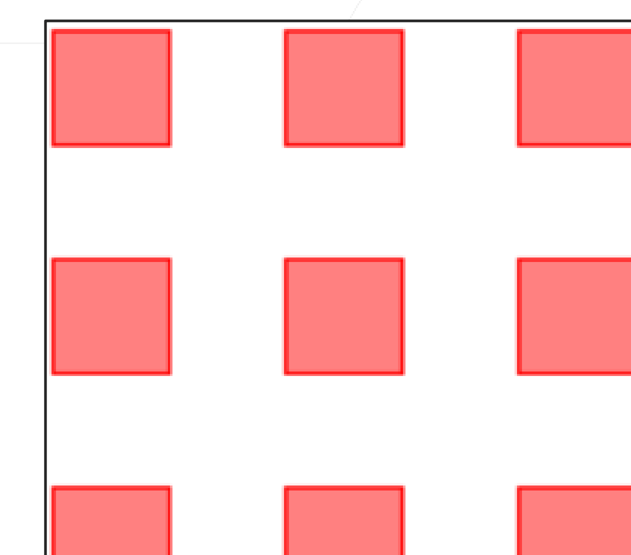


Rule-OPC module allows **manual adjustment** to optimize segments in the layout

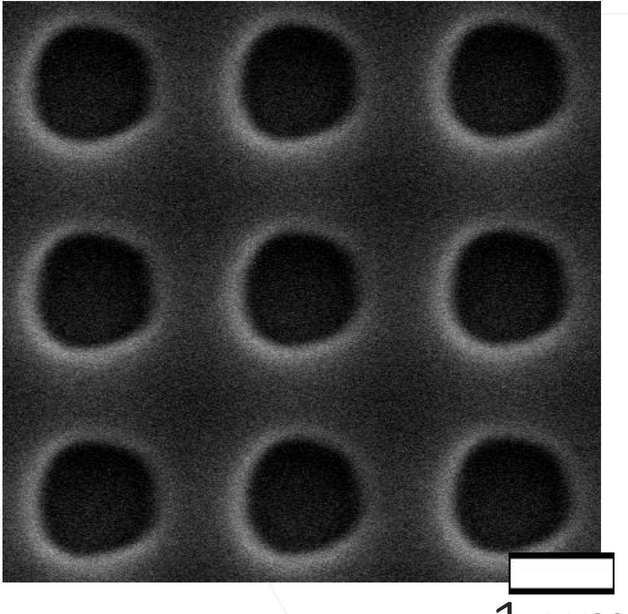
Layout correction

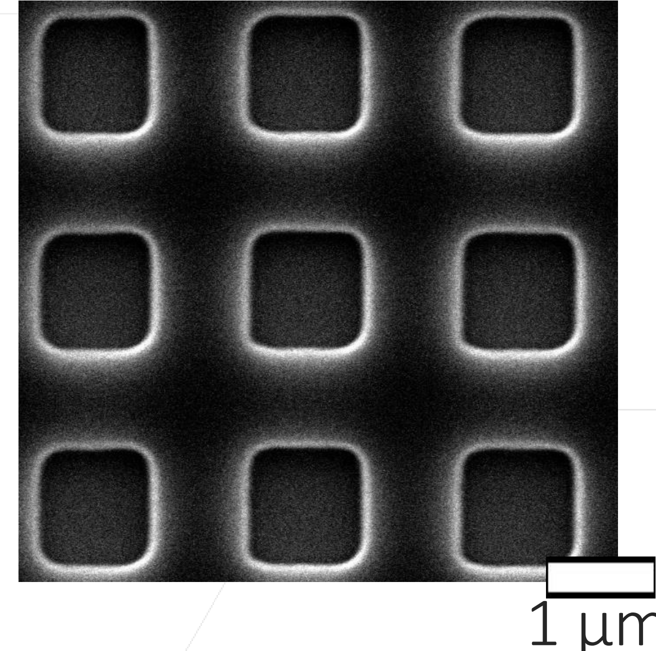
squares_matrix
Laser
Rule-OPC
Laser (1)
Resist

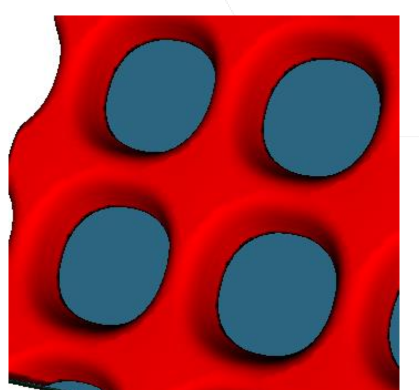
Layout

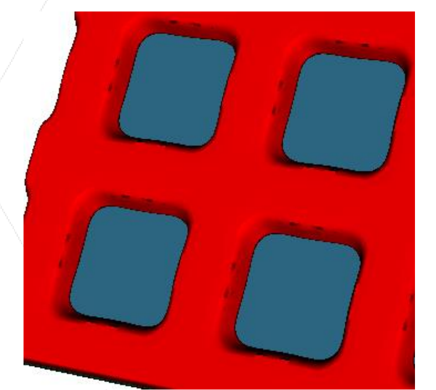


1st exposure







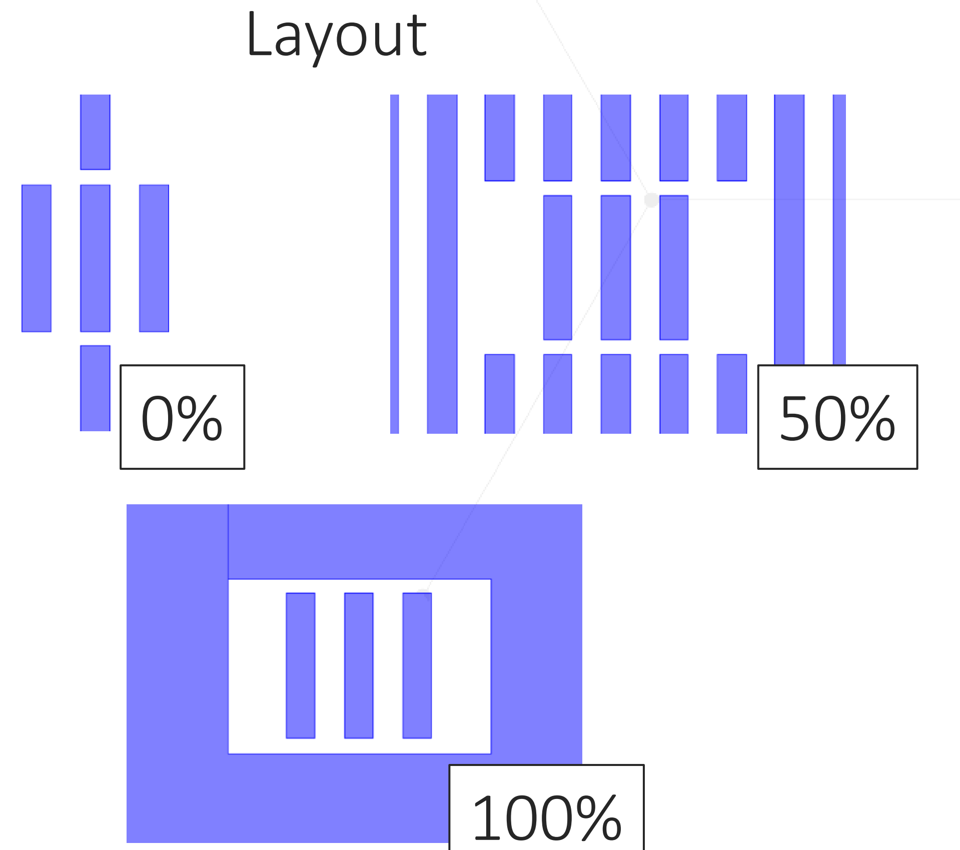


Outline

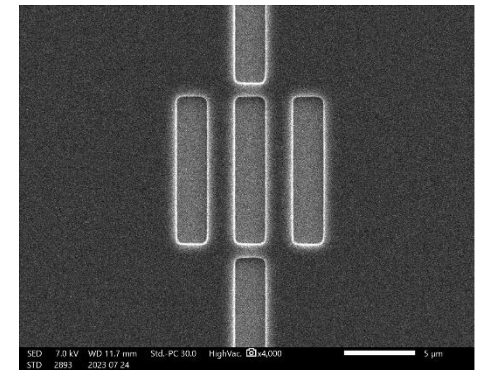
- Laser Lithography
- Exposure and Development Simulation
- Application Cases
  - 2D
    - Matrix of Squares
    - Gratings
  - 3D
    - Diffractive Optical Elements (DOEs)

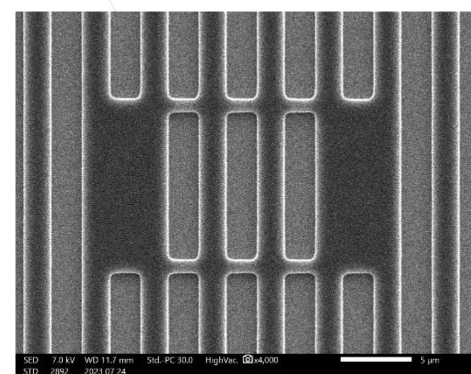
Boosting pattern fidelity: Gratings

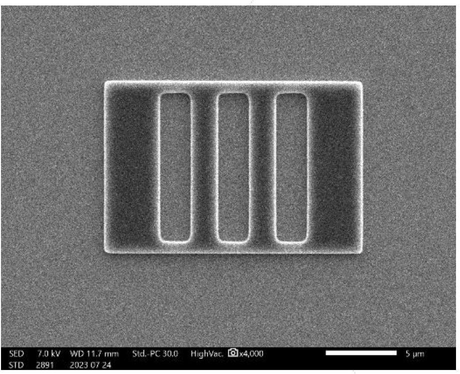
- Layout: Gratings at 0, 50 and 100% density
- Substrate: 500 nm of AZ1500 on SiO_2
- Tool resolution: 600 nm



SEM image

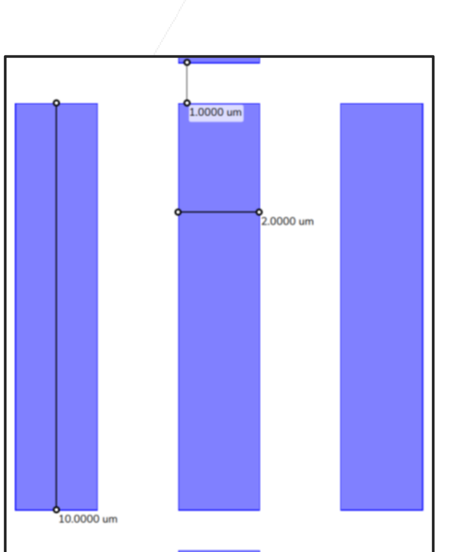


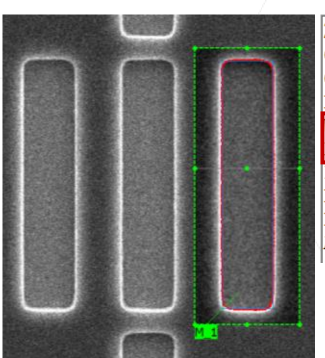




The results in numbers

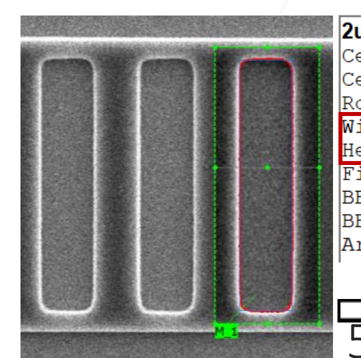
- **ProSEM** to process *ALL* the SEM images

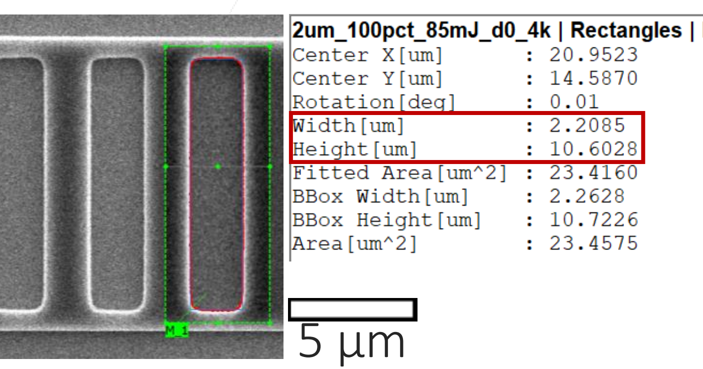




2um_iso_vert_85mJ_d0_4k | Rectangles | M_1	
Center X[um]	: 20.8305
Center Y[um]	: 14.3581
Rotation[deg]	: 0.04
Width[um]	: 2.1627
Height[um]	: 10.4948
Fitted Area[um^2]	: 22.6969
BBox Width[um]	: 2.2200
BBox Height[um]	: 10.6120
Area[um^2]	: 22.7312

2um_50pct_85mJ_d0_4k | Rectangles | M_1	
Center X[um]	: 20.4917
Center Y[um]	: 13.6963
Rotation[deg]	: -0.01
Width[um]	: 2.1623
Height[um]	: 10.5057
Fitted Area[um^2]	: 22.7163
BBox Width[um]	: 2.2240
BBox Height[um]	: 10.6024
Area[um^2]	: 22.7342

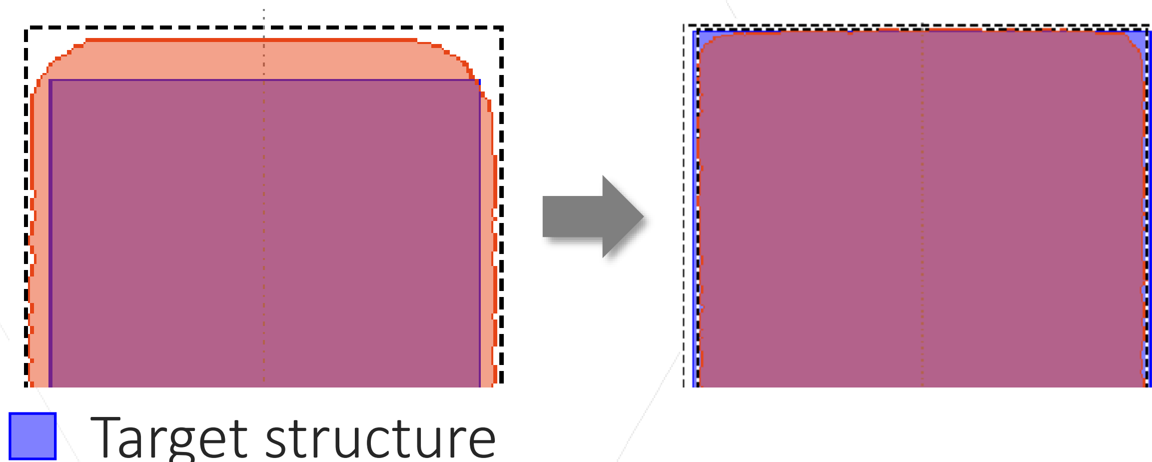




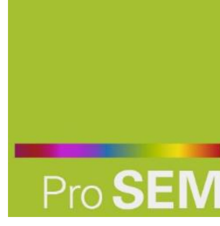
2um_100pct_85mJ_d0_4k | Rectangles | M_1	
Center X[um]	: 20.9523
Center Y[um]	: 14.5870
Rotation[deg]	: 0.01
Width[um]	: 2.2085
Height[um]	: 10.6028
Fitted Area[um^2]	: 23.4160
BBox Width[um]	: 2.2628
BBox Height[um]	: 10.7226
Area[um^2]	: 23.4575

What can be fixed?

- Width
- Height
- Corners



Target structure
Contour structure



Process threshold

- Using *Laser* simulation in **BEAMER** to find the *Resist Energy Threshold*

Gaussian beam

Layout
Threshold Loop
Laser
End Loop

Loop to obtain the *Threshold*

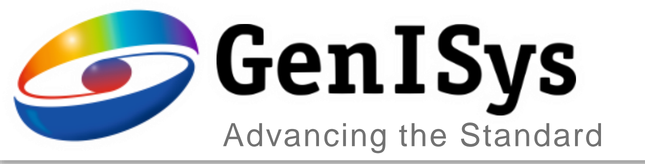
Simulation - Laser

Model Settings
Result Settings
Advanced
Comment

Results Data Type
Image | Contour
Threshold
%threshold%

ProSEM Contour
Threshold simulation
Target layout

BEAMER



Simulating the exposure

- *LAB* can simulate the experiment with the first exposure

Layout
Laser wo/correction
Rule-OPC
Laser w/correction
Resist

Intensity [mJ/cm^2]

x [um]
y [um]

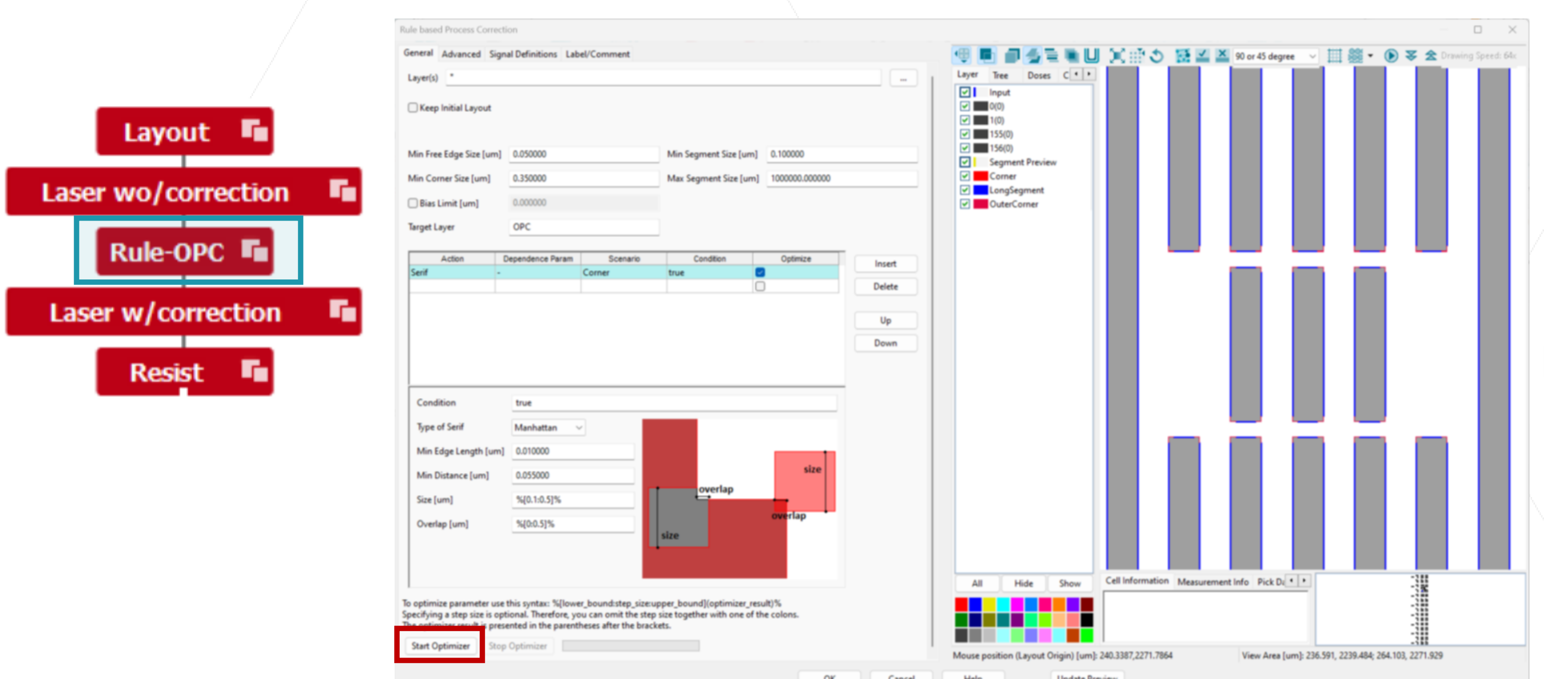
Simulation

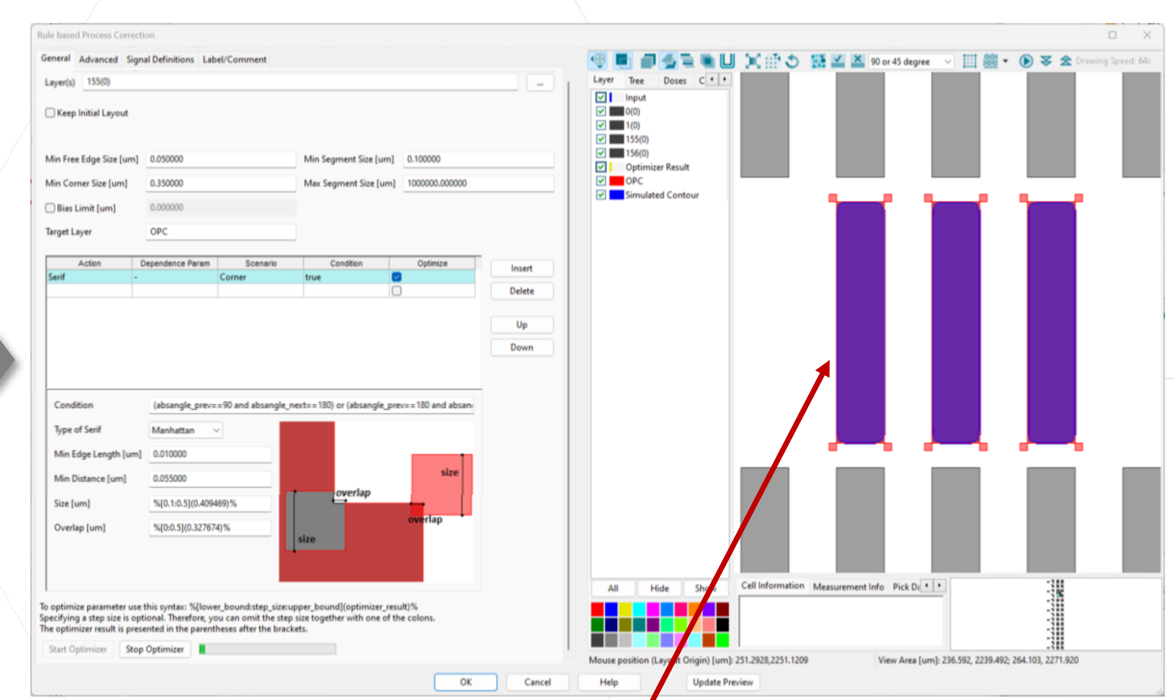
1st exposure result

LAB

Optimizing Rule-OPC

- *Serifs* and *Bias* actions to improve pattern fidelity:

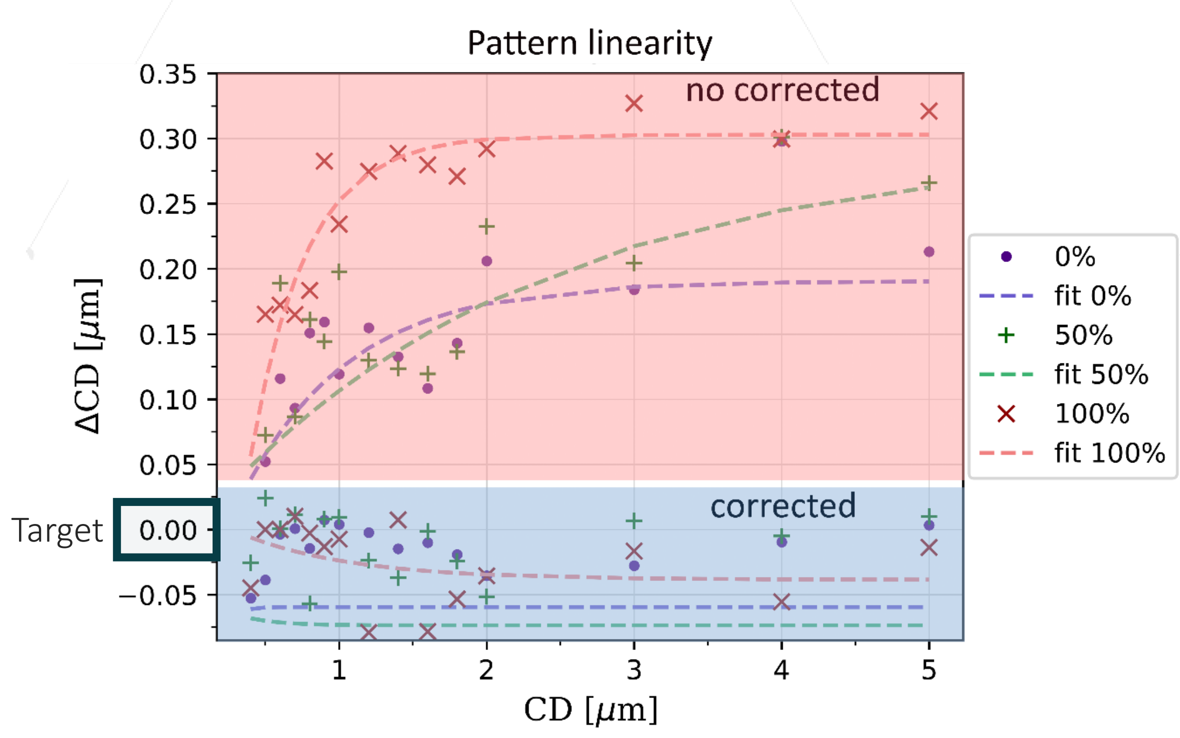


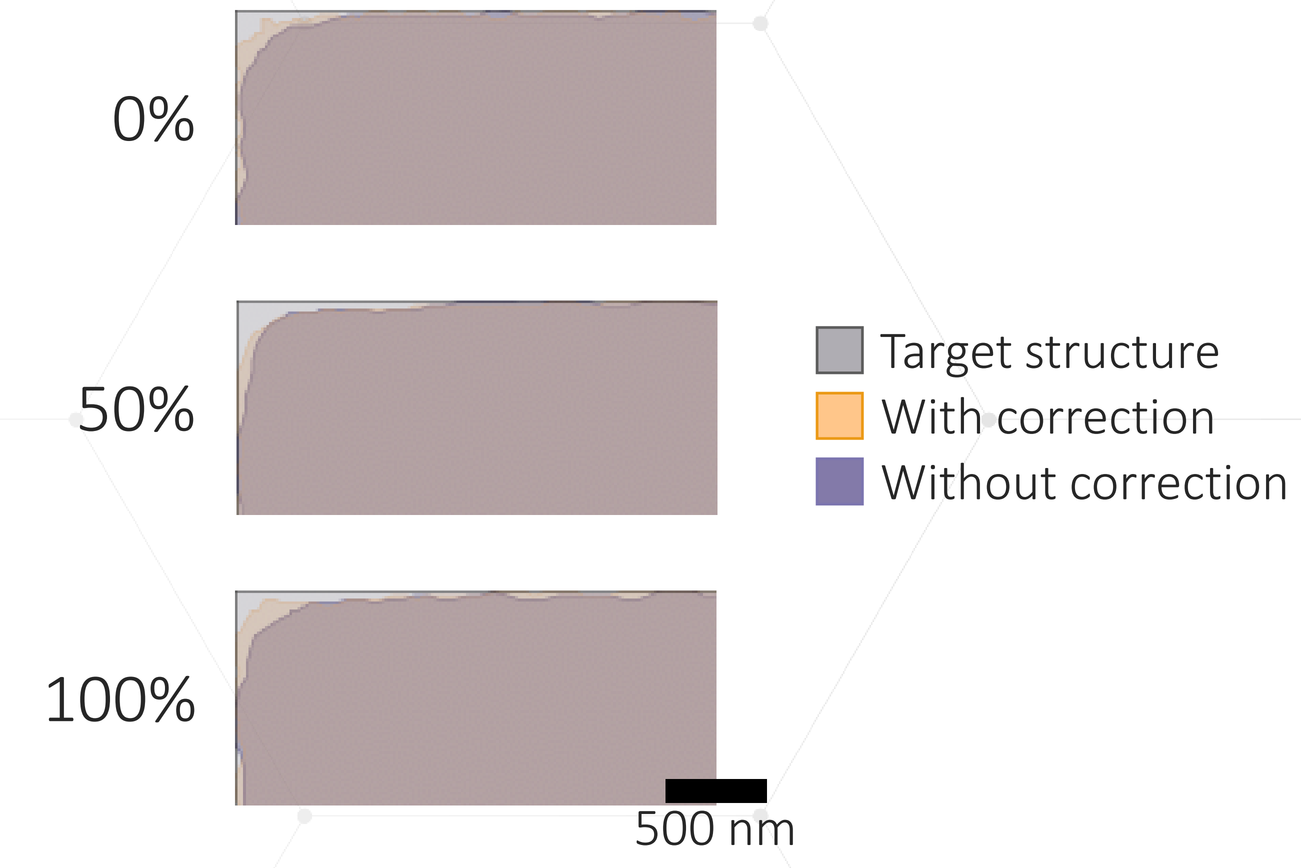


Immediate visual feedback

Gratings - The results

- After correction, the CD and corner rounding are closer to the target design





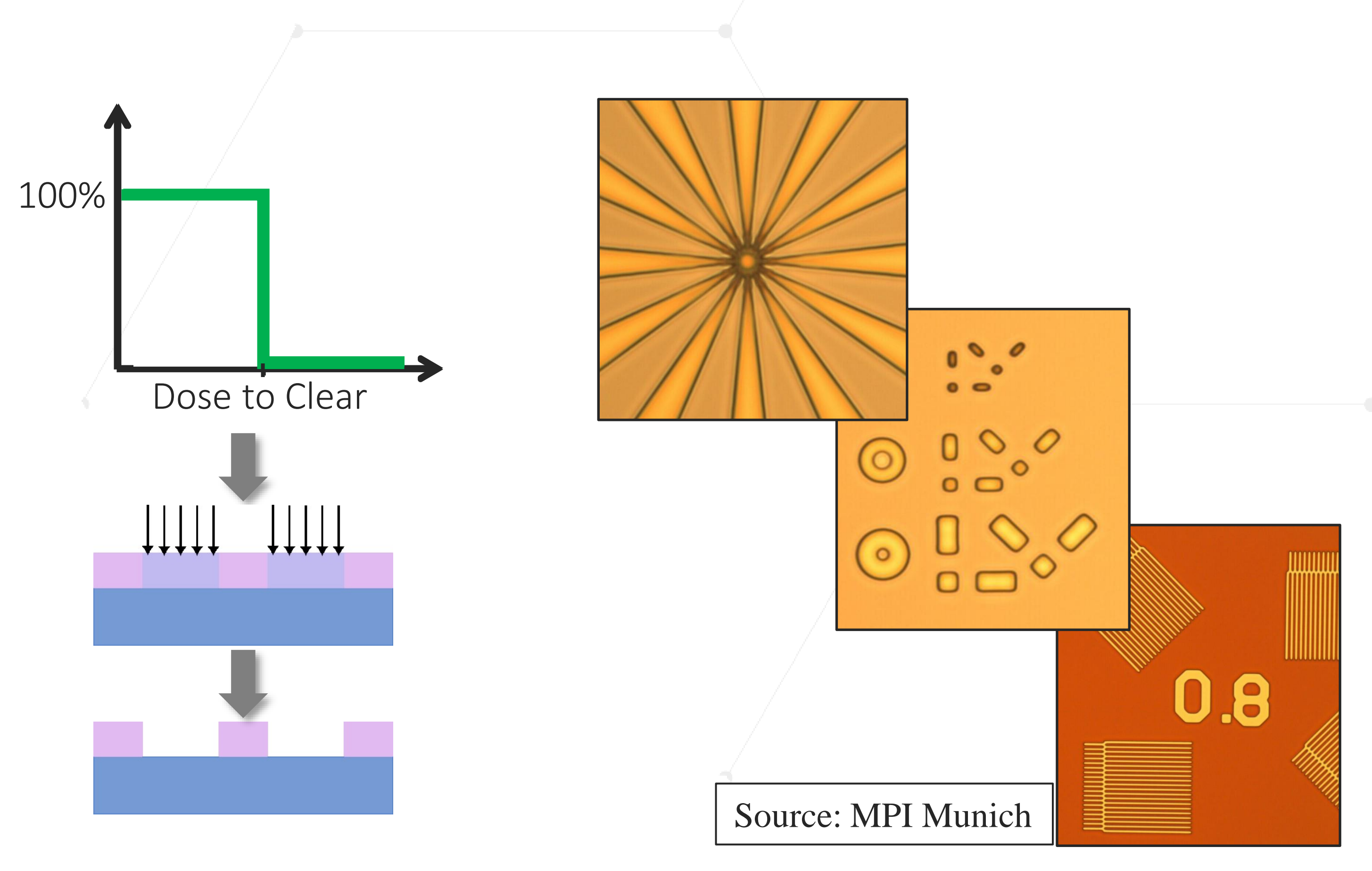
Curvature	0% [nm]	50% [nm]	100% [nm]
Without Correction	505.36	404.28	555.89
With Correction	277.95	328.48	252.68

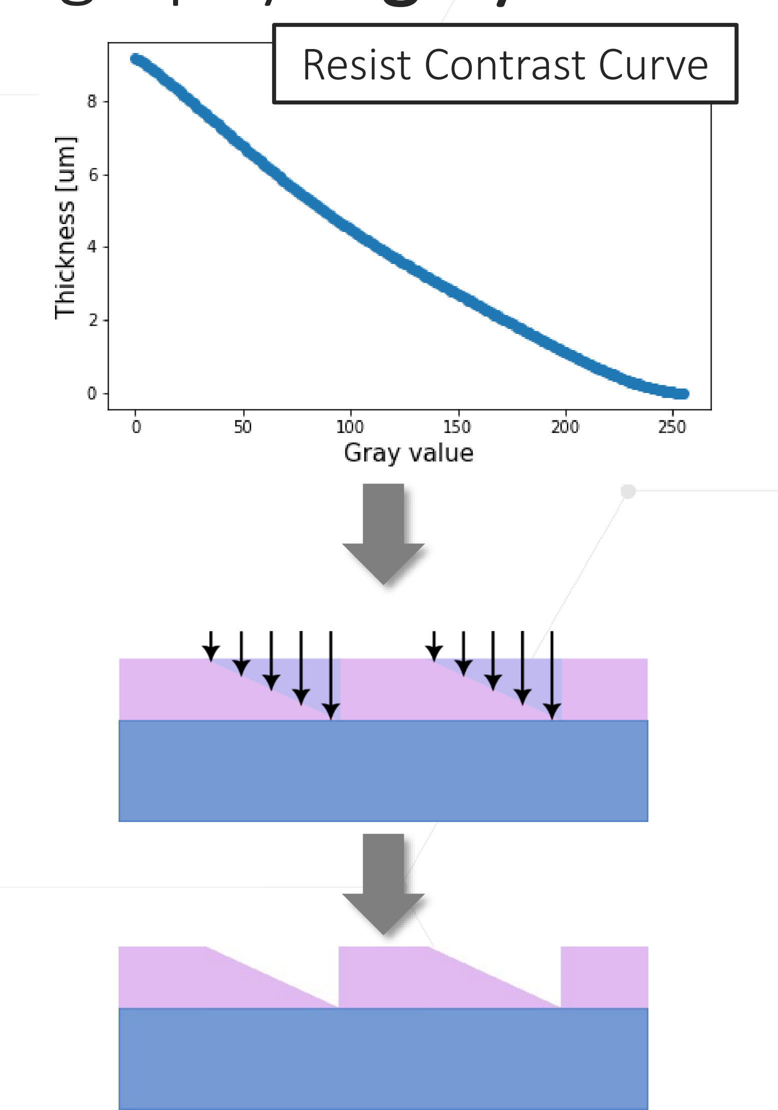
Outline

- Laser Lithography
- Exposure and Development Simulation
- Application Cases
  - 2D
    - Matrix of Squares
    - Gratings
  - 3D
    - Diffractive Optical Elements (DOEs)

3D lithography

- Traditional 2D lithography is **Binary**
- 3D lithography is **grayscale** based

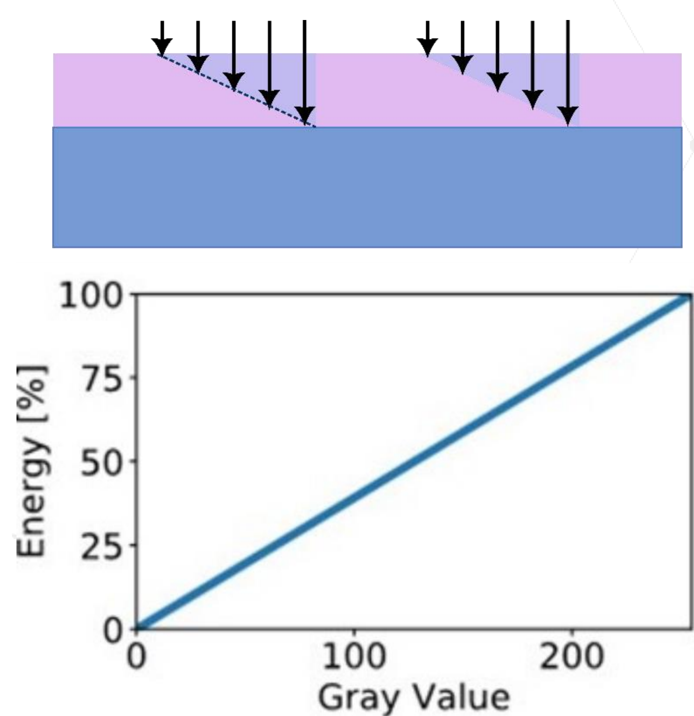




Real energy profile for 3D

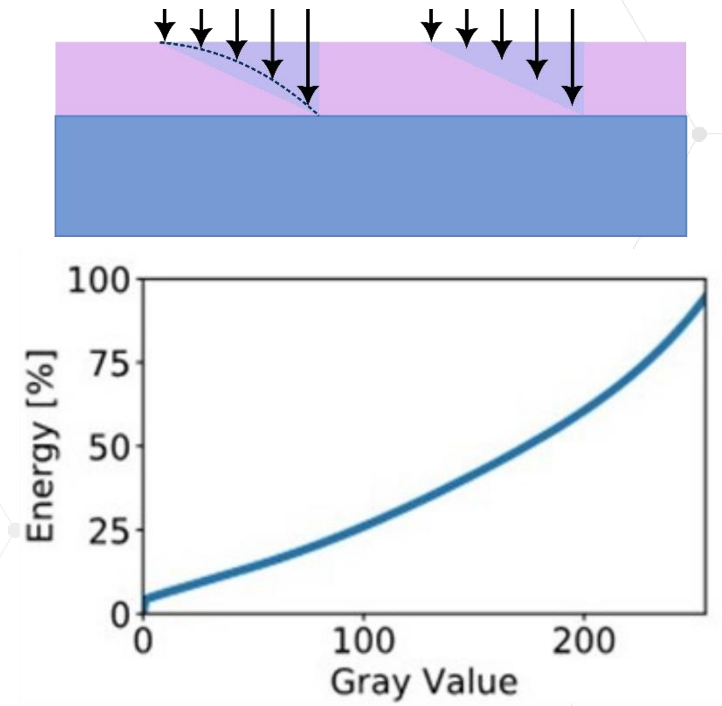
- Ideally

Energy is linear with the gray value

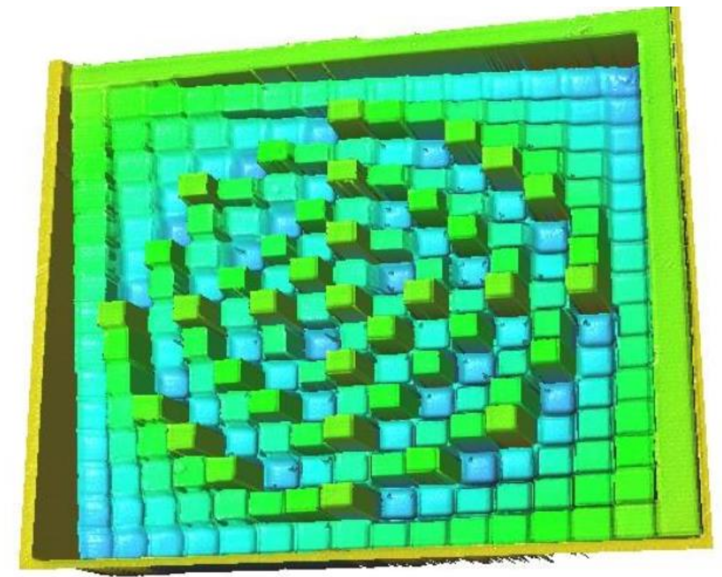


- Reality

Energy is non-linear with the gray value and depends on the resist

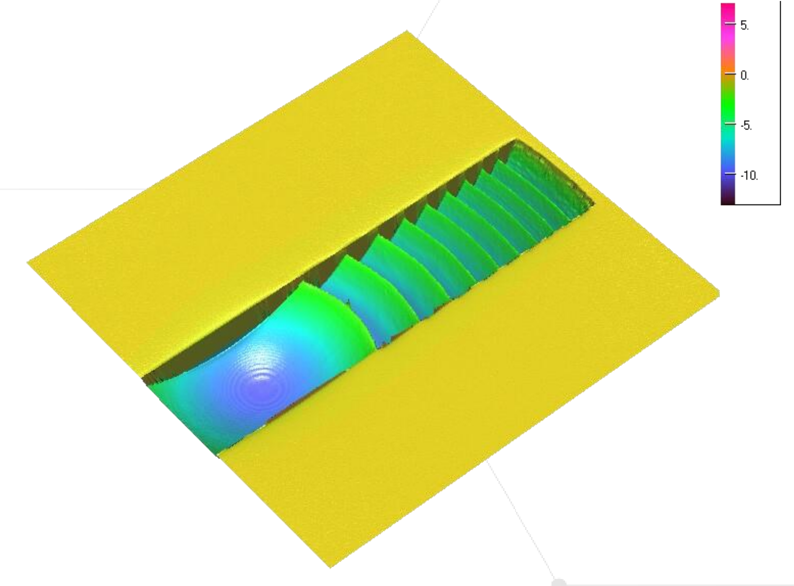


3D lithography examples

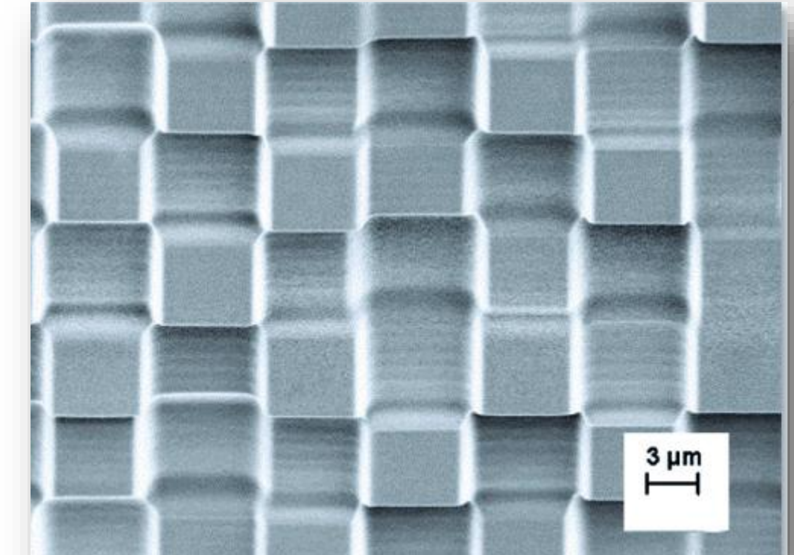


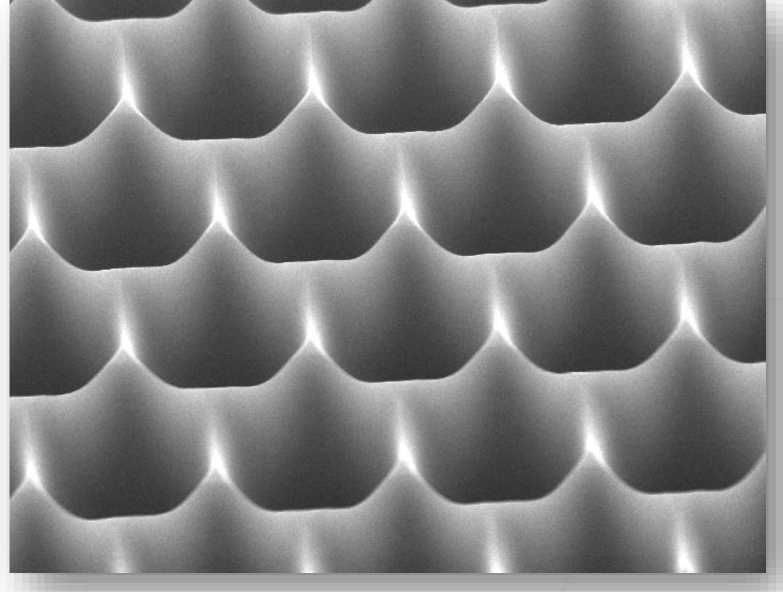
DOEs

Convex lenses



Fresnel lenses





Source: Heidelberg Instruments

Outline

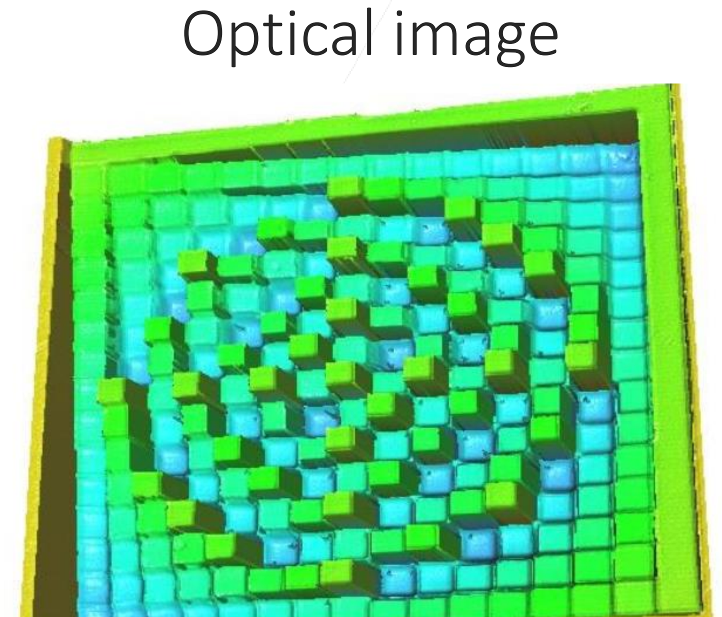
- Laser Lithography
- Exposure and Development Simulation
- Application Cases
  - 2D
    - Matrix of Squares
    - Gratings
  - 3D
    - Diffractive Optical Elements (DOEs)

3D lithography

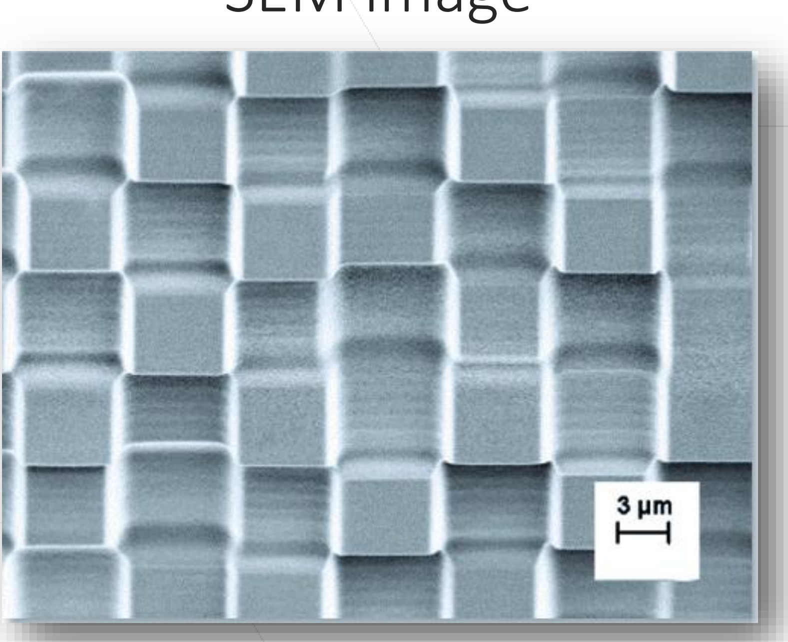
- Layout: Diffractive Optical Element (DOE)
- Substrate: 6 µm of AZ4562 on SiO_2
- Extra information: 3.2 µm pixel size and exposed height from 1- 5 µm

png image

Optical image



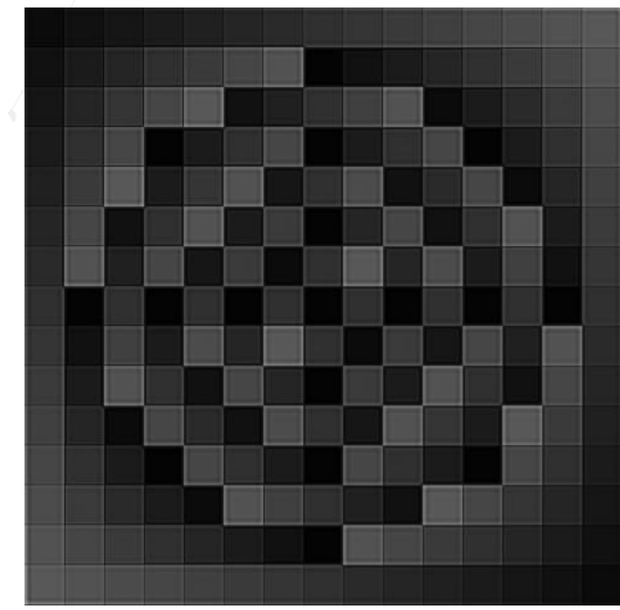
SEM image

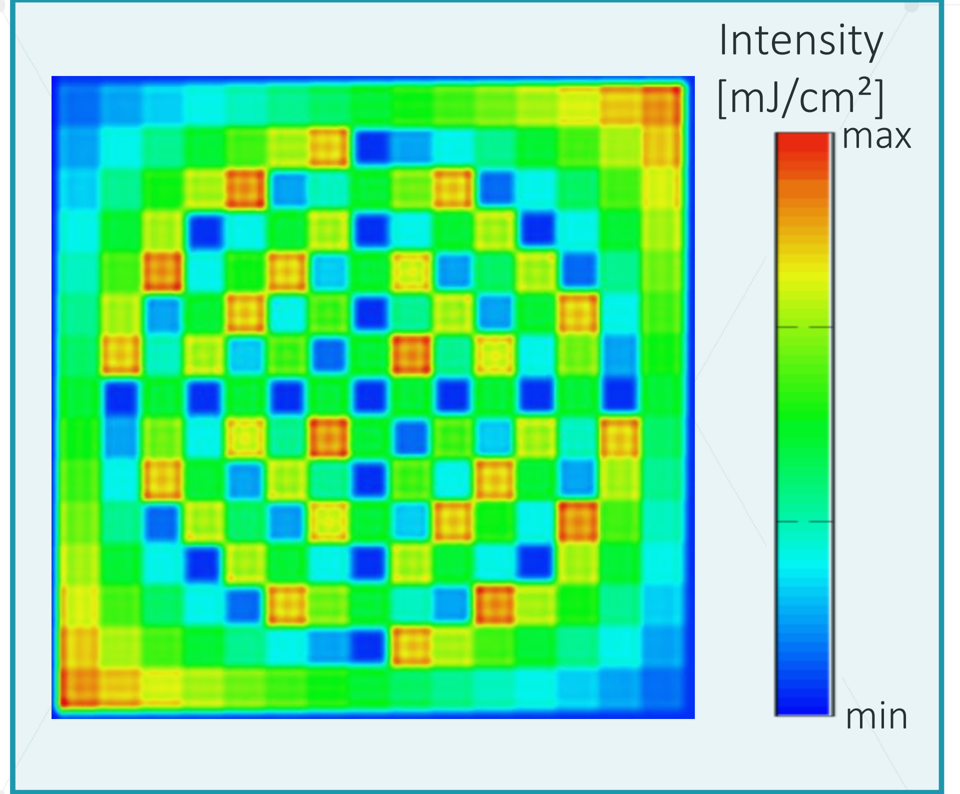


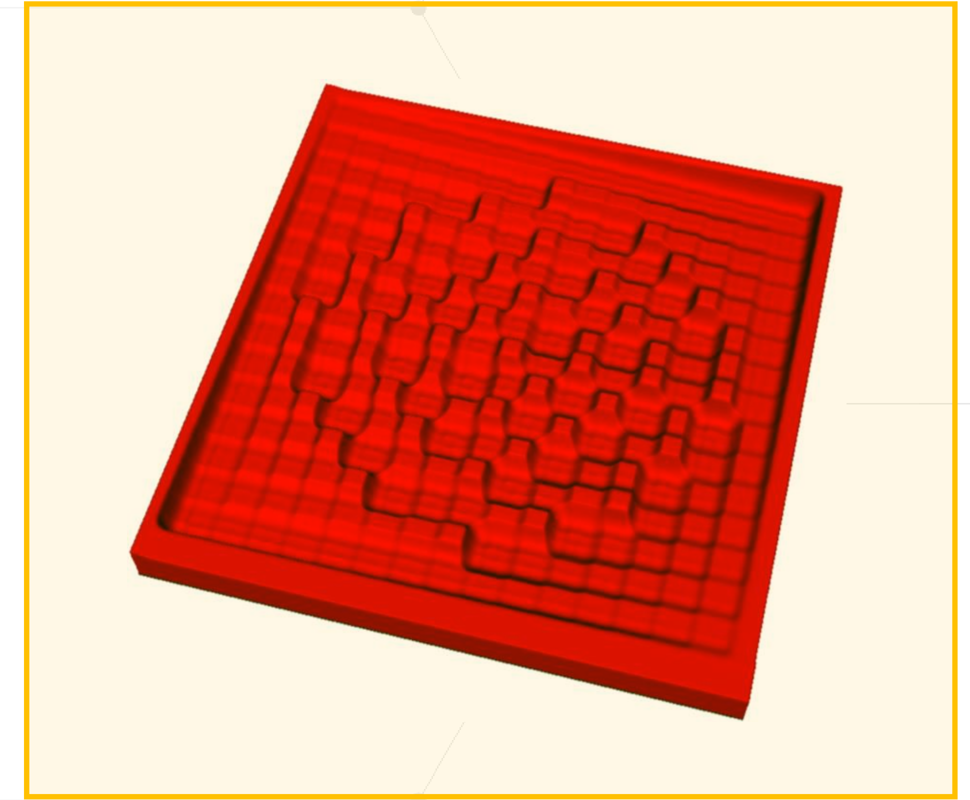
Source: Heidelberg Instruments

Simulating the DOE

png image







Summary

- *LAB* offers *Laser exposure simulation* to support 2D and 3D exposure of patterns
- The optimal exposure conditions are retrieved using a *Process Window* simulation
- 2D-pattern fidelity is boosted via *Rule-OPC* optimisation using
  - *Serifs* to improve corner rounding
  - *Bias* to control shape widening
- *LAB* predicts *Resist* contours allowing to do process-corrections without many experimental iterations

Thank You!

support@genisys-gmbh.com

Headquarters
GenISys GmbH
Eschenstr. 66
D-82024 Taufkirchen (Munich)
GERMANY
✆ +49-(0)89-3309197-60
Fax +49-(0)89-3309197-61
✉ info@genisys-gmbh.com

USA Office
GenISys Inc.
P.O. Box 410956
San Francisco, CA
94141-0956
USA
✆ +1 (408) 353-3951
✉ usa@genisys-gmbh.com

Japan / Asia Pacific Office
GenISys K.K.
German Industry Park
1-18-2 Hakusan Midori-ku
Yokohama 226-0006
JAPAN
✆ +81 (0)45-530-3306
Fax +81 (0)45-532-6933
✉ apsales@genisys-gmbh.com