Laser

Simulation, Calibration & Correction

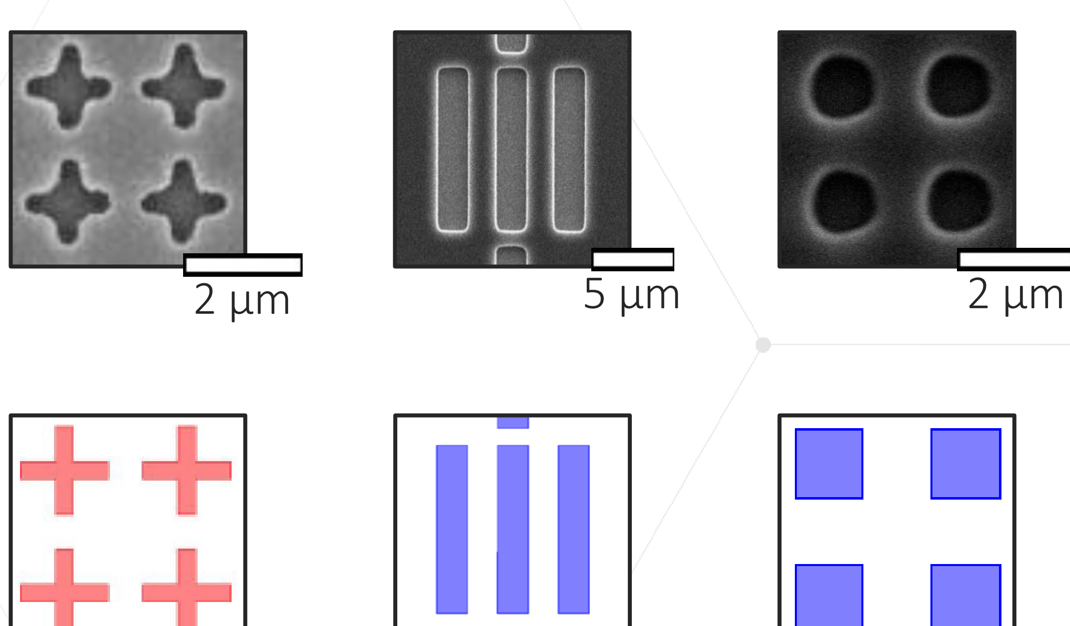
OUTLINE

- Laser Proximity and Process Effects
- Calibration for MLA 150
- Rule Based OPC and results
- Summary

Why is pattern fidelity important?

The ultimate shape of a structure affects the optical, electrical or fluidic performance of devices

- Medical devices (tissue engineering)
- Biofluidic devices
- MEMS
- Thermal sensors
- Microfluidics

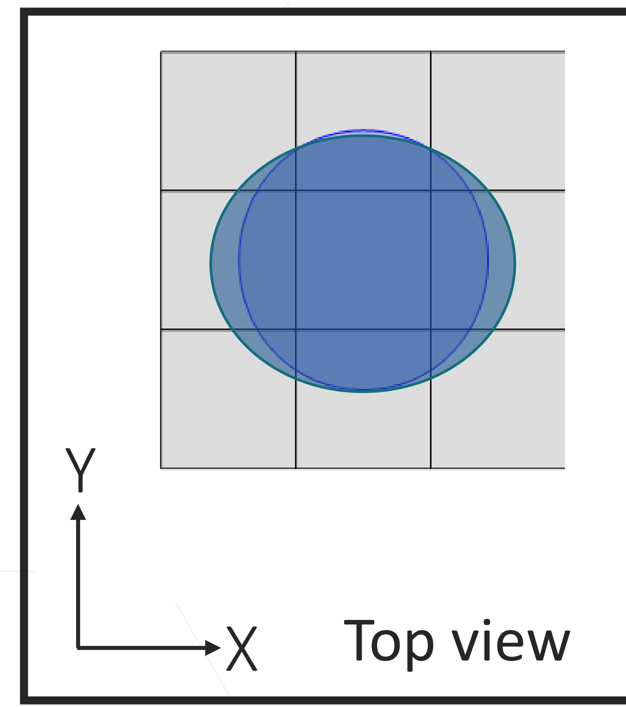


What are the determining factors and how to easily improve?

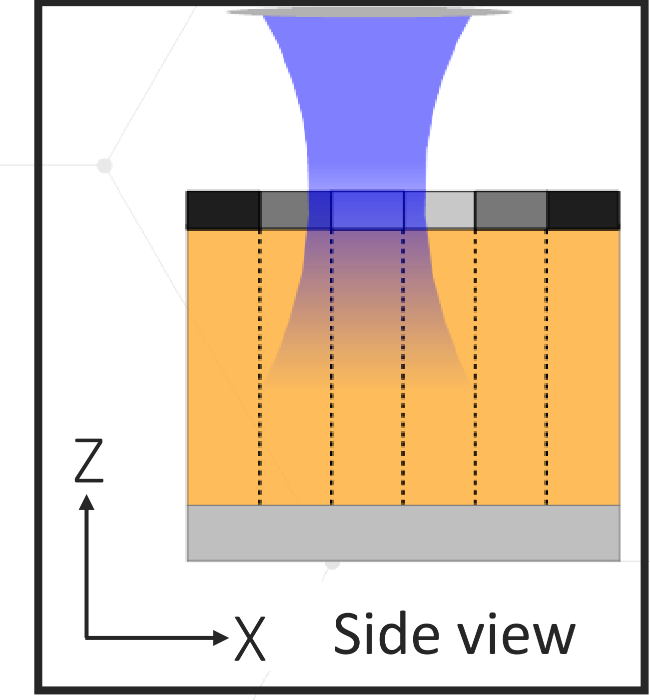
Proximity & Process Effects

Optical Proximity Effects

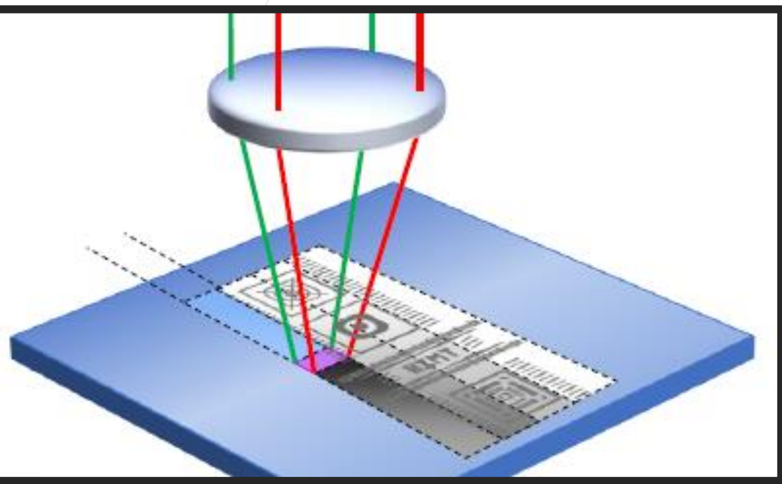
- Beam has a „blur“ which spreads the intensity radially, not necessaraly radial-symetric
- Exposure is on a pixel grid, typicall much smaller than the beam
- x/y dependency by scan / step
- Beam is focused to one plane, depth of focus is NA dependent (write head)
- Resist is not fully transparent, mostly bleaching, leading to depth dependent intensity



Beam size is larger than pixel size & it‘s direction dependent



Not constant along z-axis

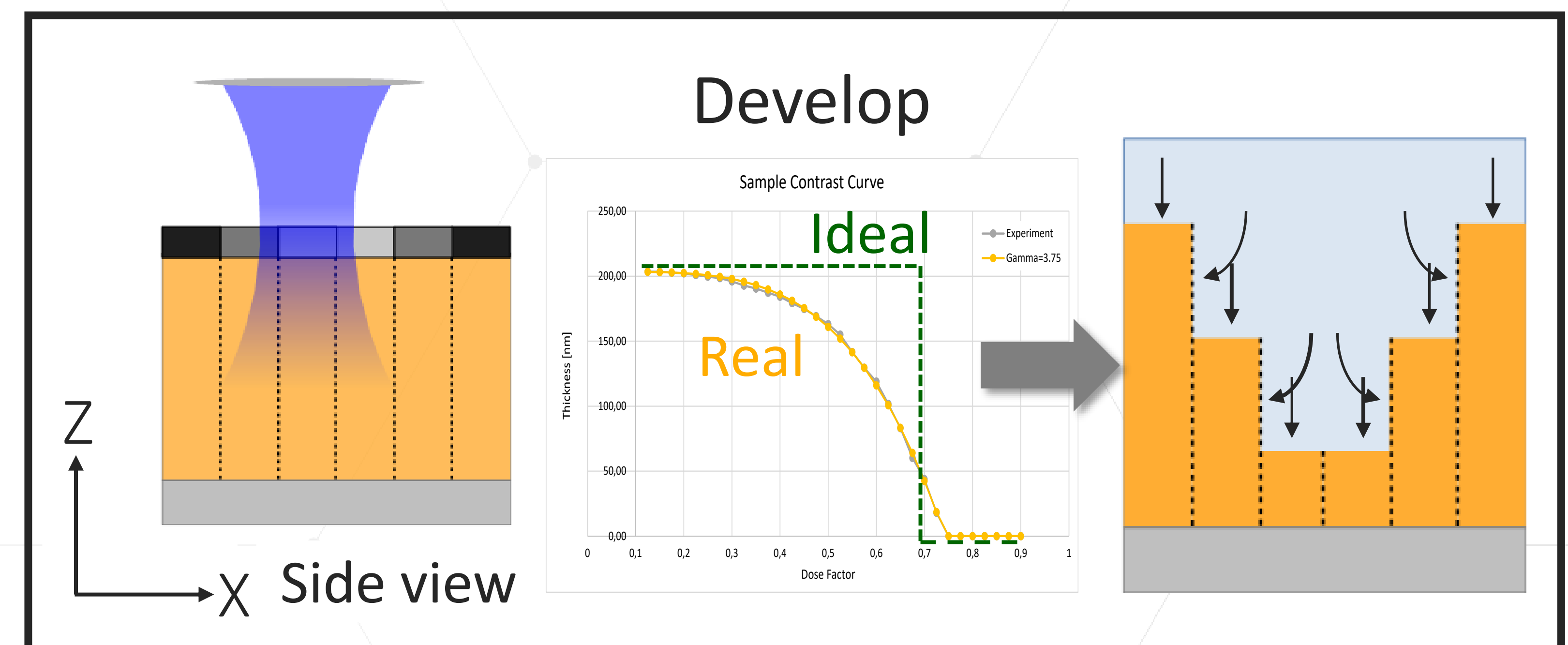


Scan direction dependency

Proximity & Process Effects

Process Effects

- Resist is not „digital“, most laser resists are quite low contrast
- Dissolution rate depends on local intensity (3D!)
  - Lateral development
  - Depth dependent development time
- Resist development loading effects
  - Macro-loading (very large area)
  - Micro-loading (very small area)



Exposure result:
Dimension (CD), feature fidelity (e.g. corner rounding), profile (sidewall angle) depends on tool and process parameters

Analysis using 3D Laser Simulation

Laser Beam Lithography
Source
Modulator
Deflector
Lens
SiO2
Substrate

Layout

Laser Exposure

3D Bulk Intensity

3D Concentration

3D Resist

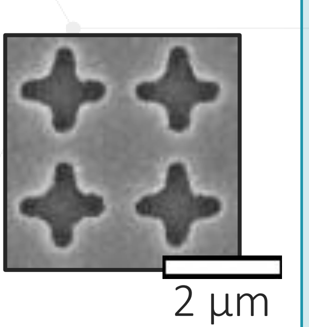
LAB

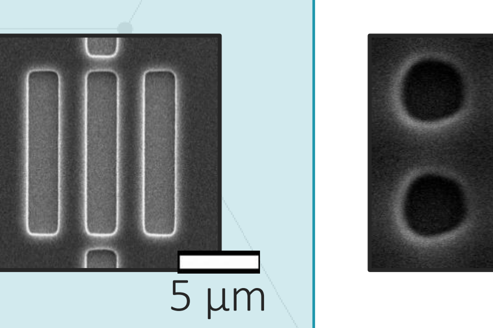
BEAMER improves Laser Lithography

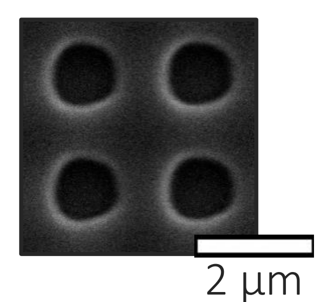
BEAMER provides the tools to to correct for major proximity and process effects

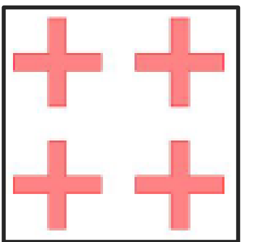
Laser direct write systems (also MLA) can use **BEAMER** to prepare data for exposures

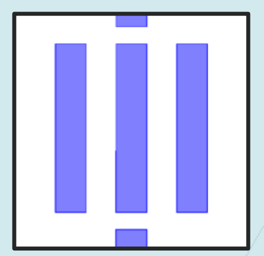
How?

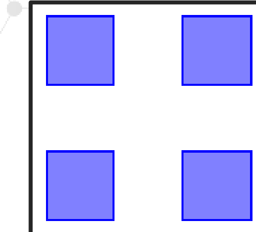


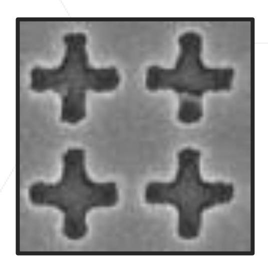


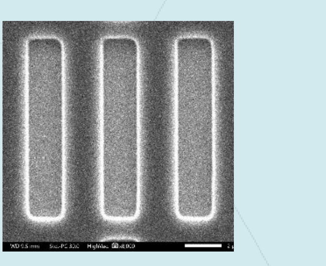


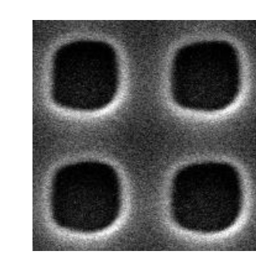












Rule-OPC calibration and correction

Expose and process calibration

3.0um iso

3.0um 1-1

3.4um 1-1

2.2um iso

2.4um iso

2.6um iso

Measure results with CD-SEM

Create correction rules

Action	Dependence Param	Scenario	Condition
Bias	CD	AnySegment	true
Serif	-	Corner	true

Min Free Edge Size [um] 0.03
Min Segment Size [um] 0.01
Min Corner Size [um] 0.150000
Max Segment Size [um] 1000000.000000
Bias Limit [um] 0.000000

Run Rule-OPC on desired design

OUTLINE

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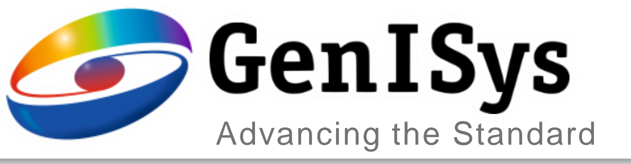
Maskless Aligner 150

- The tool

Writing performance	Write Mode I
Minimum feature size [µm]	0.6
Minimum Lines and Spaces size [µm]	0.8
Global 2nd layer alignament [nm]	500
Local 2nd layer alignament [nm]	250
Backside alignment [nm]	1000
Exposure time 405 nm laser for 4“ wafer [min]	35
Max. write speed 405 nm laser [mm²/min]	285



The experiment

- The layout

CD →

Density →

Gratings at 0, 50, and 100% density

Lengths 100 µm / 10 µm

CD → 0.4 – 1 µm in steps of 0.1 µm

→ 1.2 – 2 µm in steps of 0.2 µm

→ 3 – 5 µm in steps of 1 µm

- The process

We thank Dr. Srimongkon for her support during the experiments

Substrate	Type Material Size Provided by	Mask Glass 2.5 inches HIKK (Clean surface)
Photoresist	Name Type Thickness Spin coating Baking	AZ1500 Positive 500 nm N/A 30 min @ 95 °C
Development	Developer Dillution Time	AZ 400K 1:4 1 min

Exposure Results

- The layout

Gratings at 0, 50, and 100% density

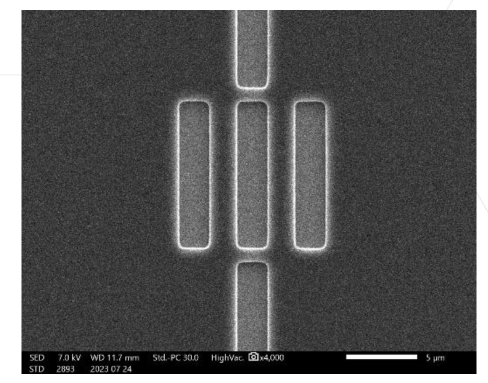
Lengths 100 µm / 10 µm

CD → 0.4 – 1 µm in steps of 0.1 µm
→ 1.2 – 2 µm in steps of 0.2 µm
→ 3 – 5 µm in steps of 1 µm

CD →

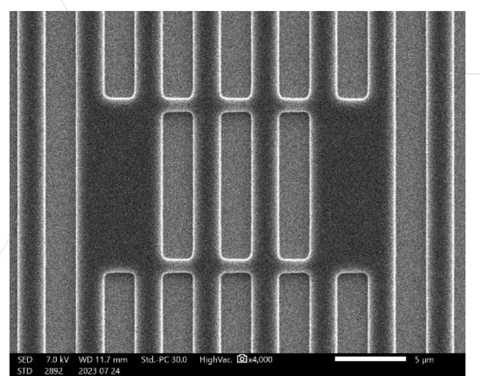
Density →

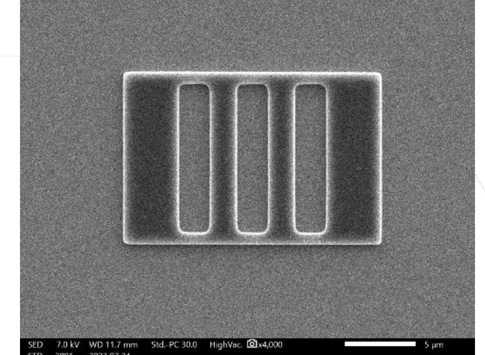
- SEMs of 2 µm gratings @85 mJ/cm²



0%

50%

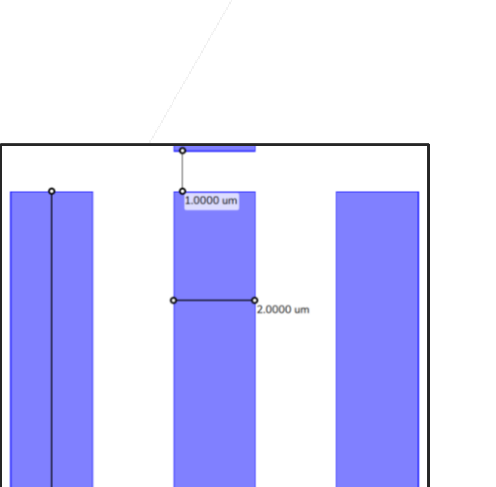


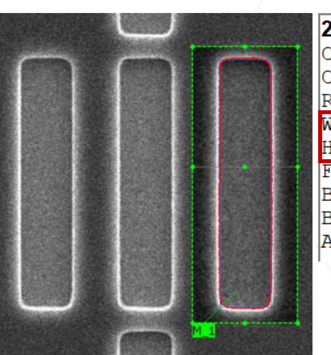


100%

The results in numbers

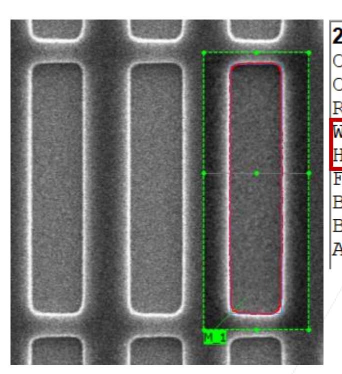
- **ProSEM** to process *ALL* the SEM images





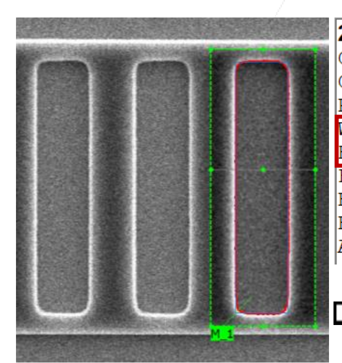
2um_iso_vert_85mJ_d0_4k | Rectangles | M_1

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



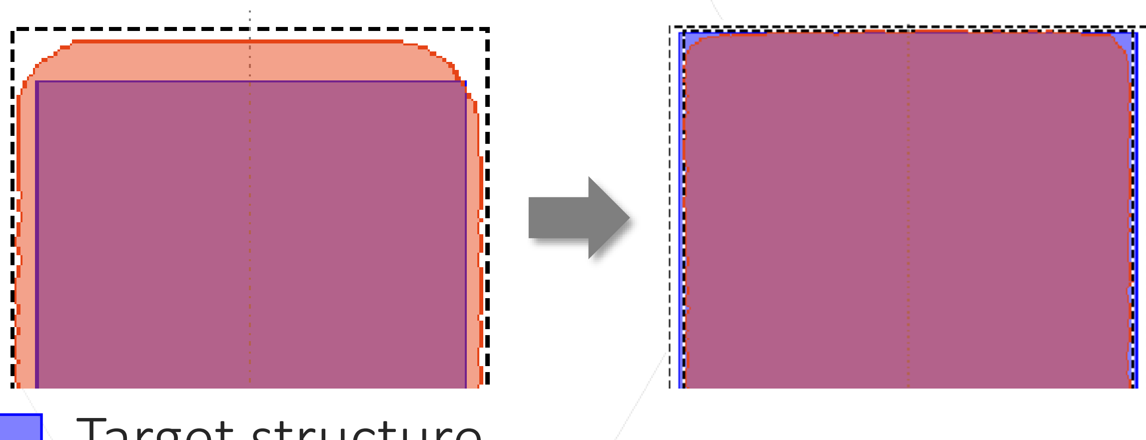
2um_100pct_85mJ_d0_4k | Rectangles | M_1

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

5 µm

What can be corrected?

- Width
- Height
- Corners



Target structure

Contour structure

The strategy

1. Emulate experimental beam conditions
2. Obtain *Serifs* to improve corners
3. Analyse the *Bias* to improve width and height

Process threshold

- Using *Laser* simulation to find the *Resist 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

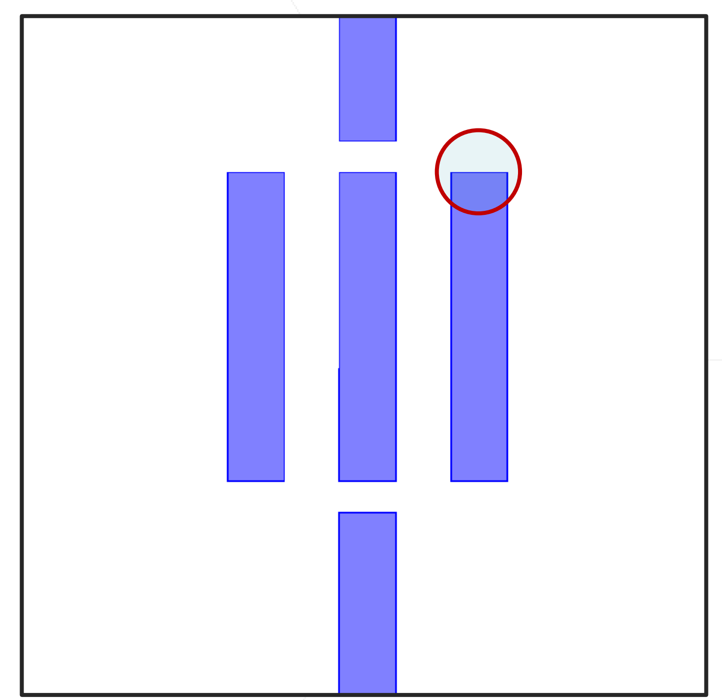
BEAMER

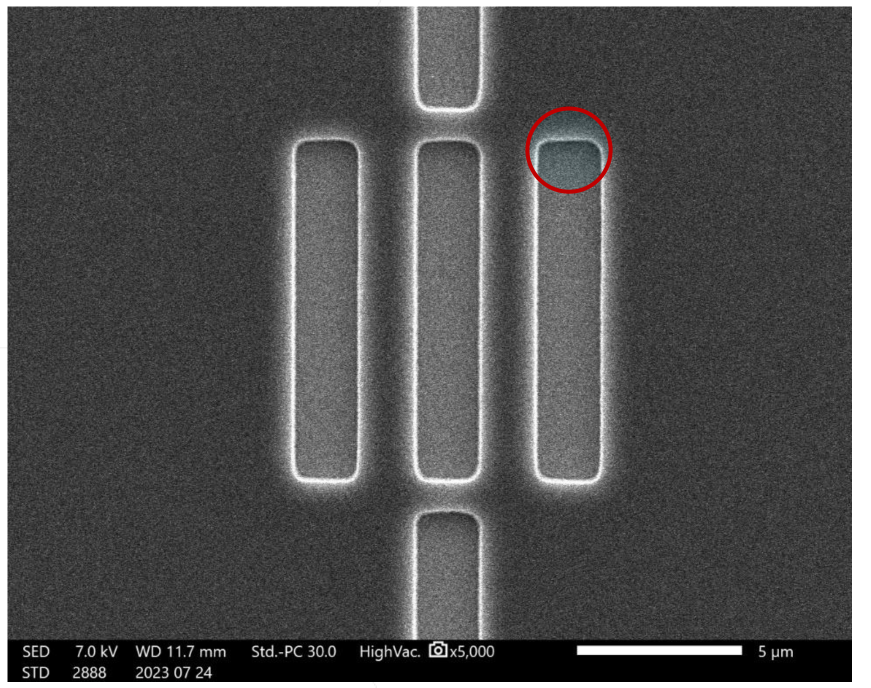
The strategy

1. Emulate experimental beam conditions
2. Obtain *Serifs* to improve corners
3. Analyse the *Bias* to improve width and height

Localised corrections

- When only minor or localised corrections are required



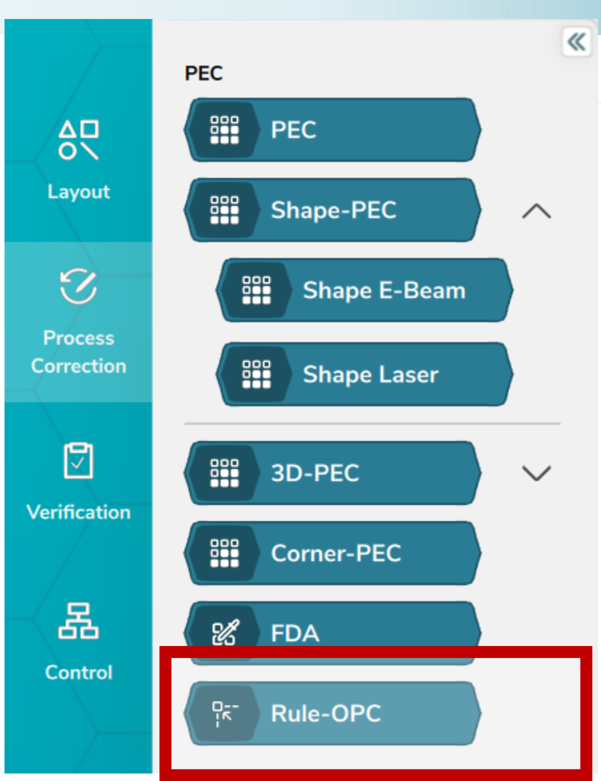


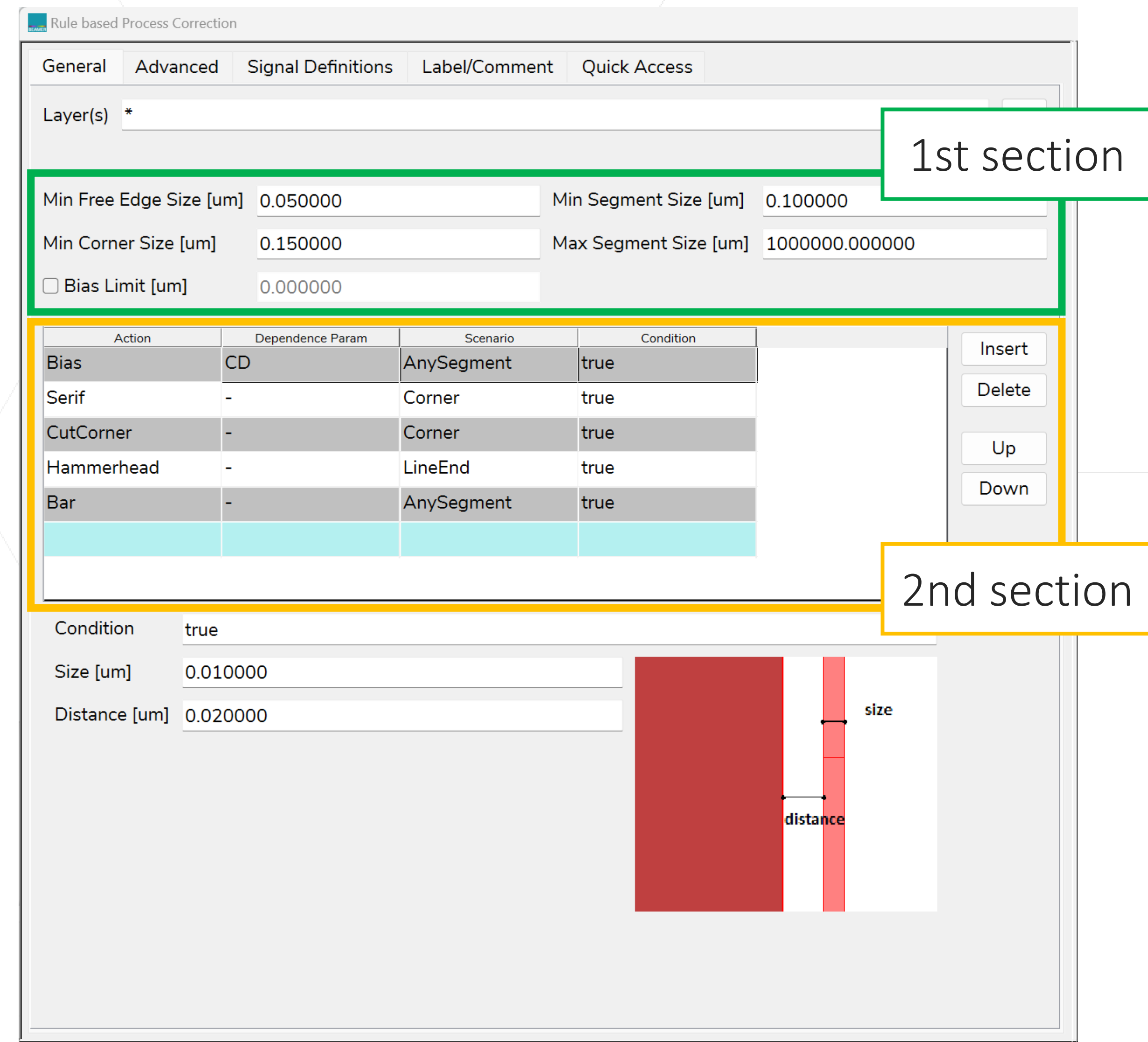
Optical Proximity Correction
(Rule-OPC)

2D lithography corrections

- Rule-OPC

  Adjustment of Rules according to measurements feedback (SEM images)





Rule-OPC process

Layout

Segmentation

LongSegment
OuterCorner

Applying rules

1st section of parameters used to split layout to segments

Min Free Edge Size [um]	0.050000	Min Segment Size [um]	0.100000
Min Corner Size [um]	0.350000	Max Segment Size [um]	1000000.000000
Bias Limit [um]	0.000000		

2nd section of parameters – table of rules determines changes for each

Action	Dependence Param	Scenario	Condition
Bias	CD	AnySegment	true
Serif	-	Corner	true
Bar	-	AnySegment	true

Insert
Delete
Up
Down

Serifs rules

- Using loops allow us to quickly examine several conditions

Size [µm]

0.3 | 0.7 | 1

Overlap [%]

0 | 0.5 | 1

Layout

Size

Overlap

Rule-OPC

End Loop (1)

End Loop

Type of Serif	Manhattan
Min Edge Length [um]	0.010000
Min Distance [um]	0.055000
Size [um]	%size%
Overlap [um]	%size%*%over%

size
overlap
overlap
size

Rule-OPC structure
Simulation

The strategy

1. Emulate experimental beam conditions

2. Obtain *Serifs* to improve corners

3. Analyse the *Bias* to improve width and height

Getting the bias

- Using **ProSEM** to get the height and width of the inner gratings

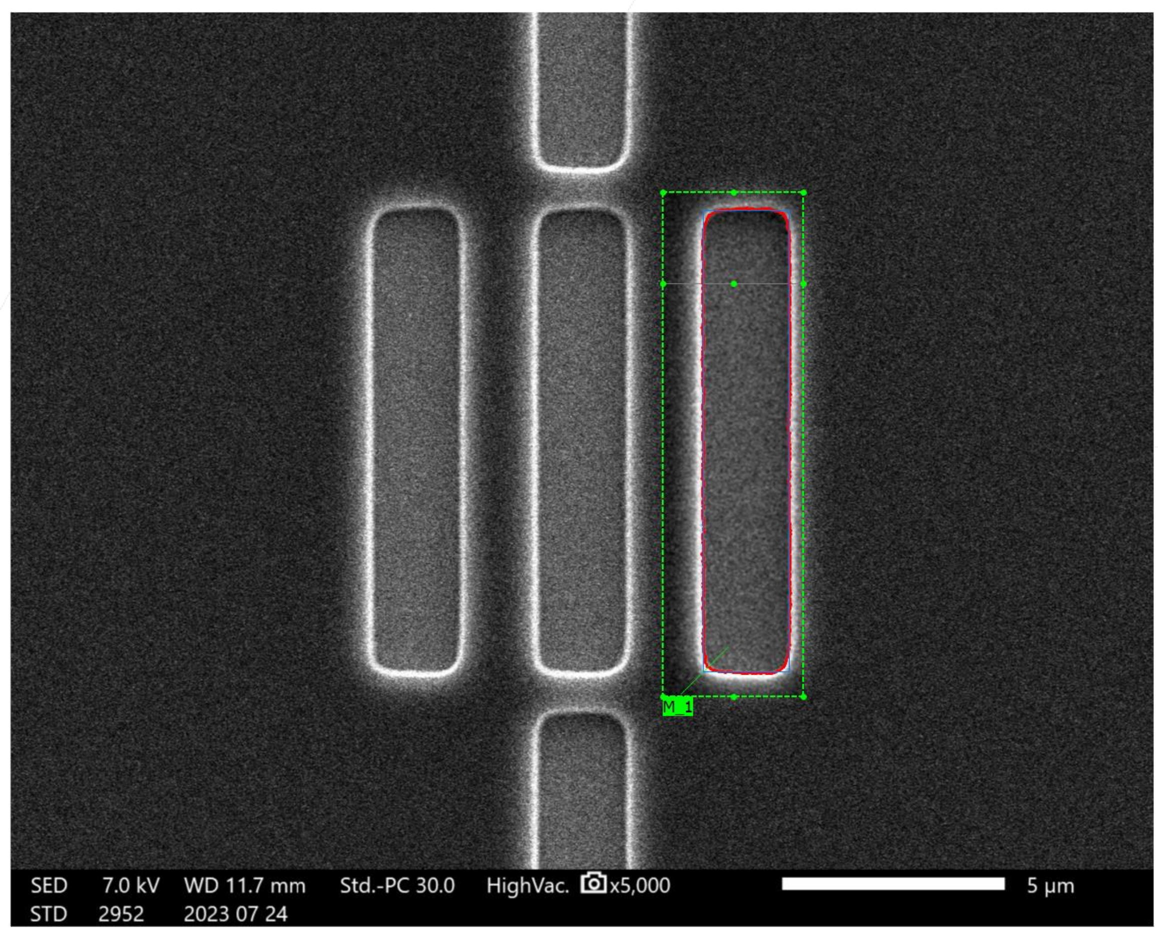
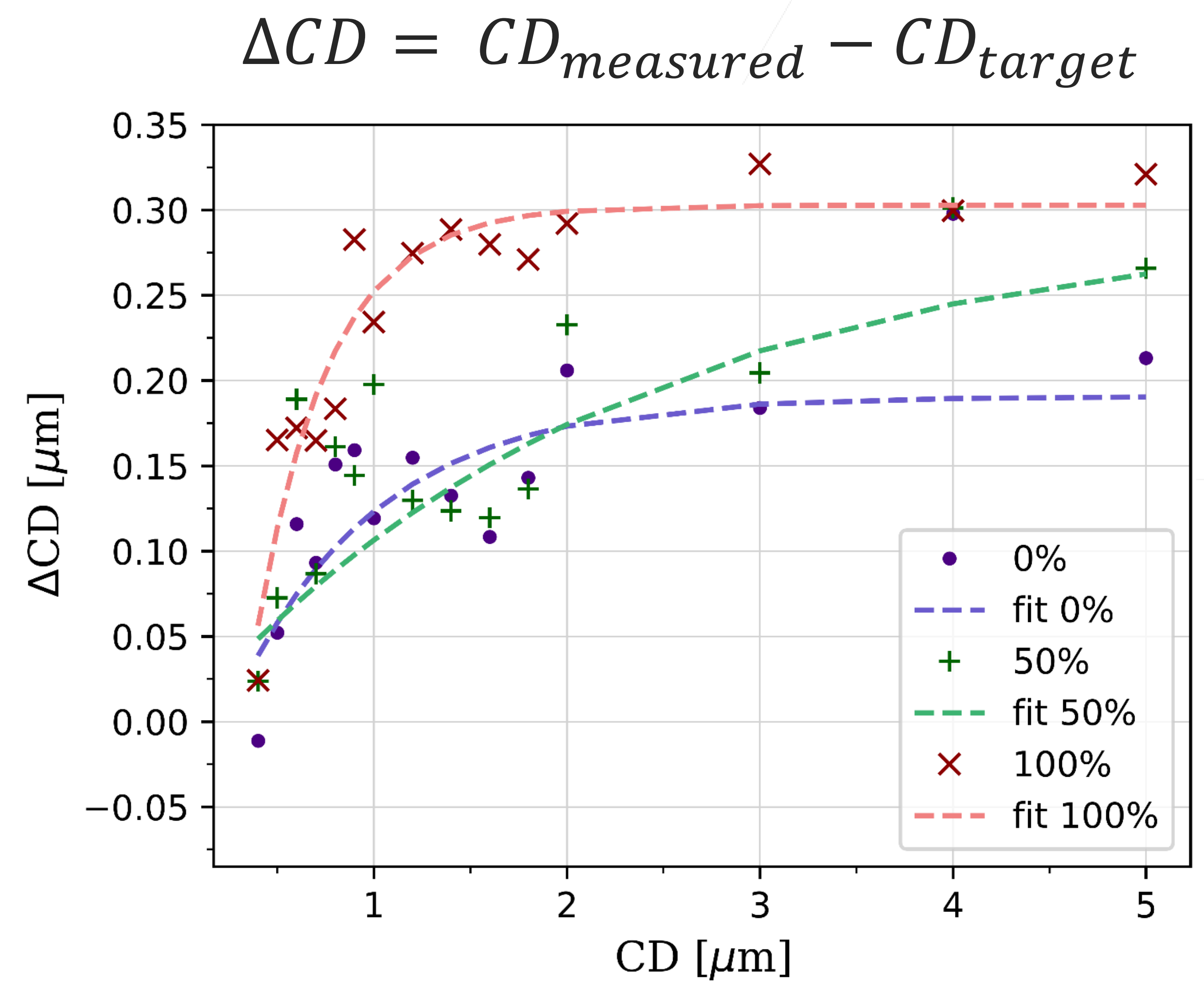


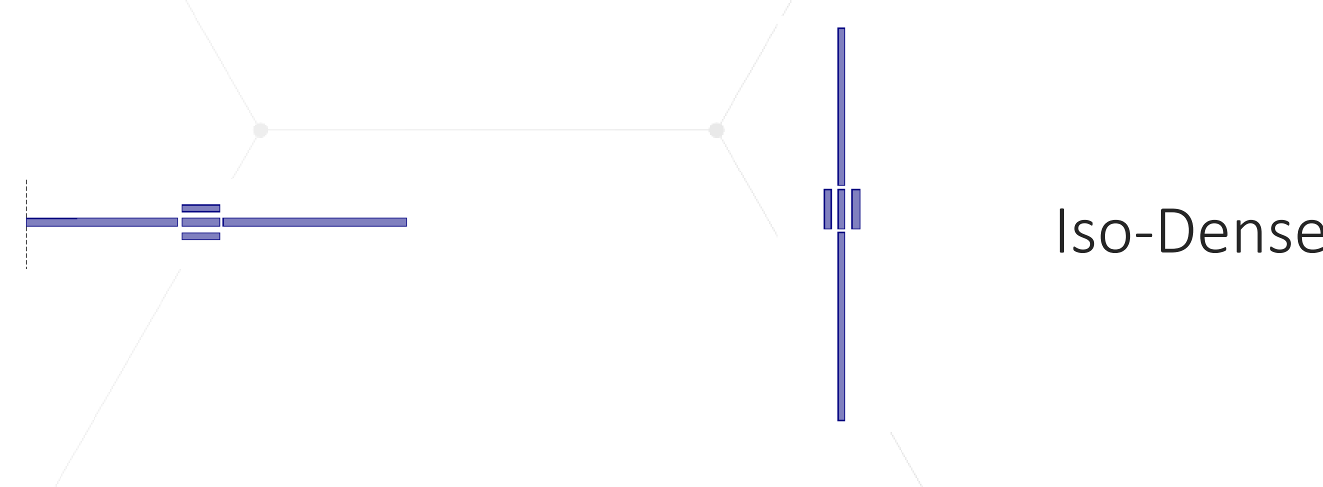
Image	Group ID	Measurement ID	Validation	Center X[um]	Center Y[um]	Rotation[deg]	Width[um]	Height[um]	Fitted Area[um^2]	Fit Error Mean[um]
1.6um_100pct_85mJ_d0_5k	Rectangles	M_1	Validated	16.4469	11.3185	-0.02	1.8084	10.4027	18.8121	0.0153
1.6um_100pct_90mJ_d0_5k	Rectangles	M_1	Validated	16.7099	11.1834	-0.02	1.8799	10.5294	19.7941	0.0146
1.6um_50pct_85mJ_d0_5k	Rectangles	M_1	Validated	16.1315	10.8724	0.01	1.6835	10.3311	17.3927	0.0145
1.6um_50pct_90mJ_d0_5k	Rectangles	M_1	Validated	16.1013	11.4737	0.02	1.7196	10.3741	17.8388	0.0187
1.6um_iso_vert_85mJ_d0_5k	Rectangles	M_1	Validated	16.6224	10.9765	0.04	1.6747	10.3339	17.3064	0.0136
1.6um_iso_vert_90mJ_d0_5k	Rectangles	M_1	Validated	16.8243	11.2963	-0.01	1.7083	10.4092	17.7815	0.0169
1.8um_100pct_85mJ_d0_5k	Rectangles	M_1	Validated	16.8402	11.2105	-0.06	1.9970	10.4053	20.7800	0.0156
1.8um_100pct_90mJ_d0_5k	Rectangles	M_1	Validated	16.4565	11.0266	-0.04	2.0710	10.5061	21.7578	0.0165
1.8um_50pct_85mJ_d0_5k	Rectangles	M_1	Validated	16.6447	11.0873	-0.07	1.9091	10.3210	19.7039	0.0151
1.8um_50pct_90mJ_d0_5k	Rectangles	M_1	Validated	16.4950	10.9646	-0.03	1.9363	10.3796	20.0976	0.0193
1.8um_iso_hor_85mJ_d0_5k	Rectangles	M_1	Validated	12.8937	15.0530	89.91	1.8849	10.2291	19.2805	0.0155
1.8um_iso_hor_90mJ_d0_5k	Rectangles	M_1	Validated	12.6883	15.2405	89.95	1.9448	10.2920	20.0160	0.0182
1.8um_iso_vert_85mJ_d0_5k	Rectangles	M_1	Validated	17.1521	11.3481	-0.16	1.9125	10.3093	19.7168	0.0141
1.8um_iso_vert_90mJ_d0_5k	Rectangles	M_1	Validated	16.5857	10.9592	0.02	1.9430	10.4000	20.2073	0.0177

$$\Delta CD = CD_{measured} - CD_{target}$$

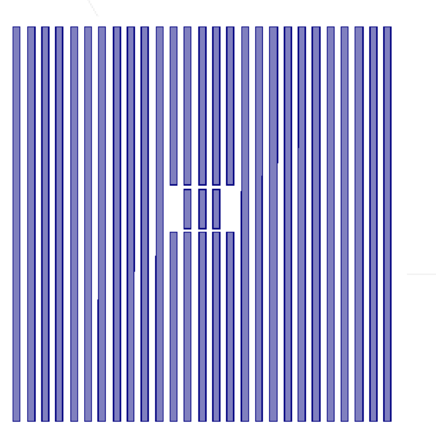
Linearity and process signatures

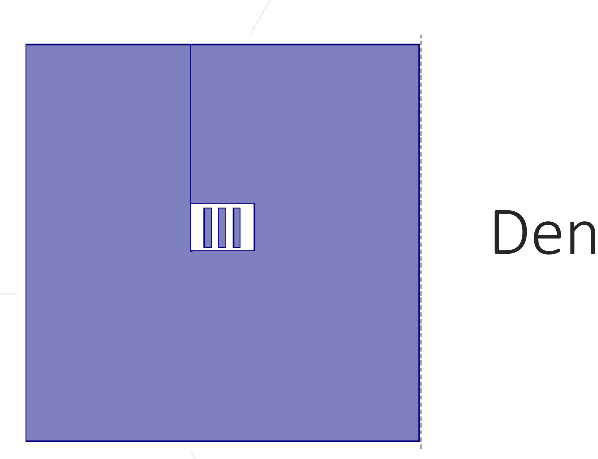
$$\Delta CD = CD_{measured} - CD_{target}$$

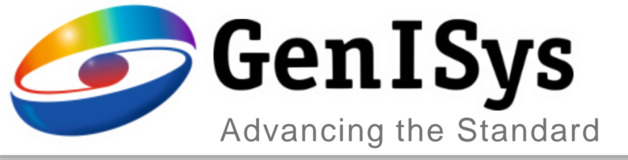




Different calibration scenarios are **exposed** and **measured**





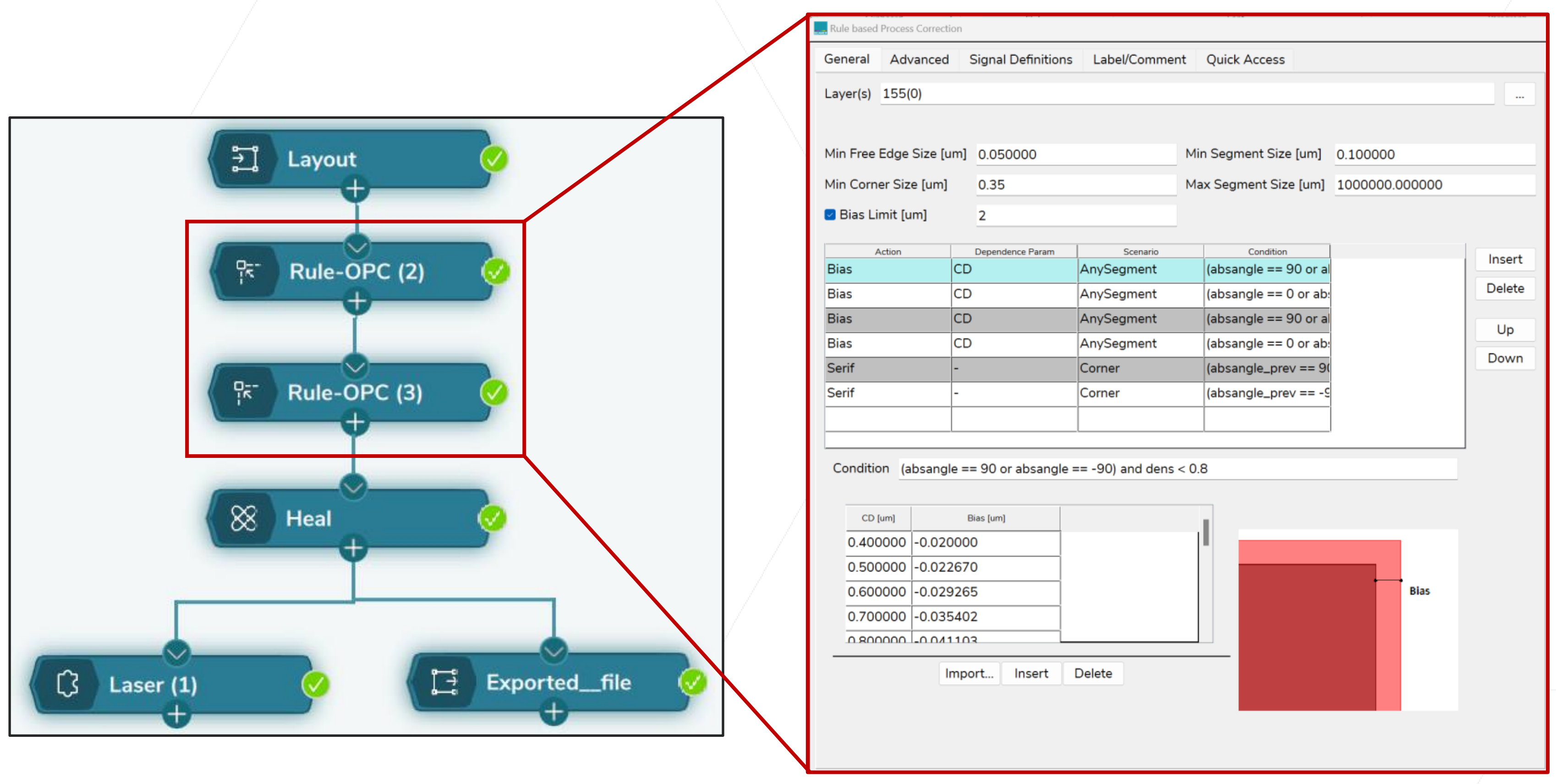


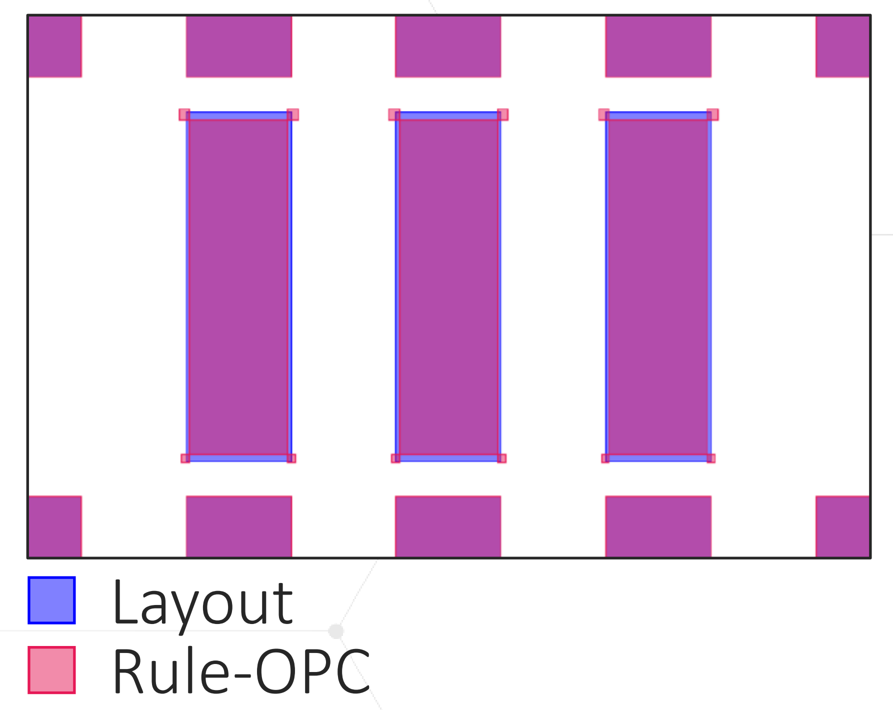
OUTLINE

- Laser Proximity and Process Effects
- Calibration for MLA 150
- Rule Based OPC and results
- Conclusion

The final flow

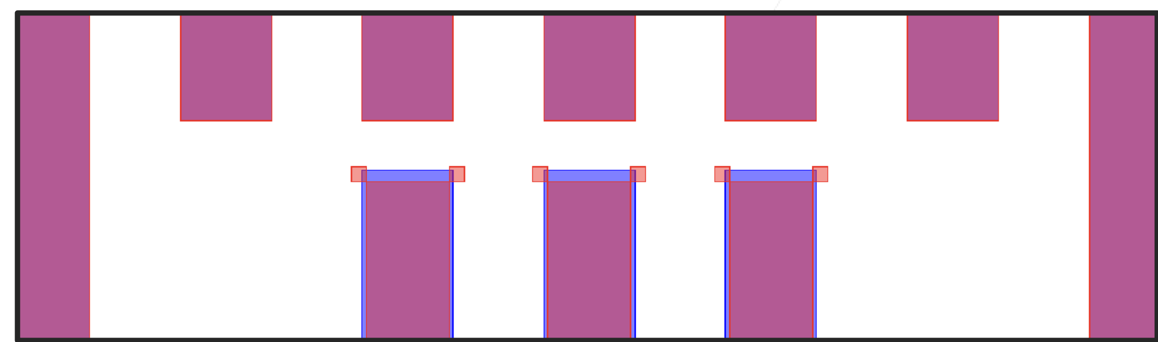
- *Serifs* and *Bias* rules are all included in a single ***Rule-OPC*** module (one for vertical and one for horizontal gratings)



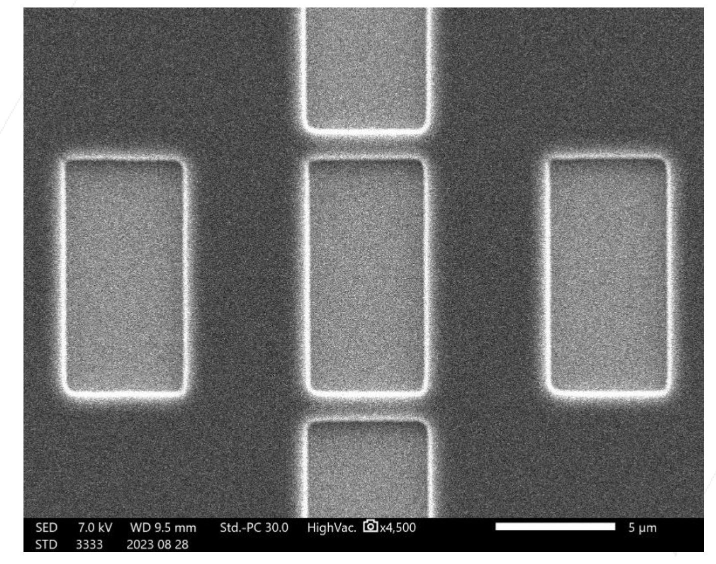


Ready for a second exposure!

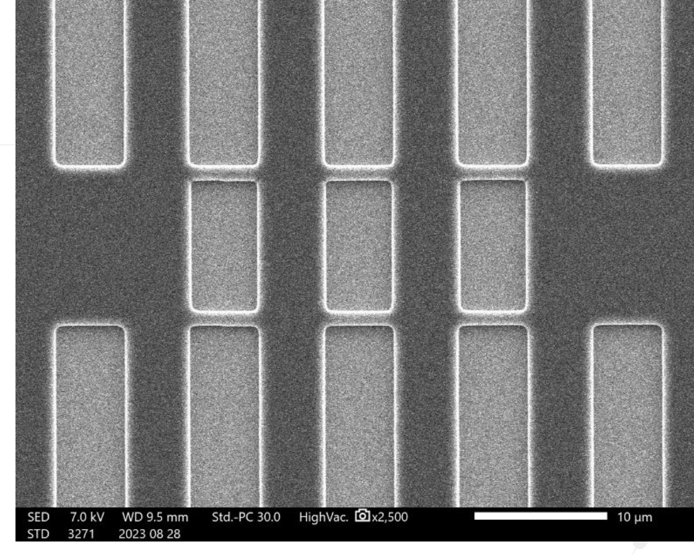
Experimental Results after correction



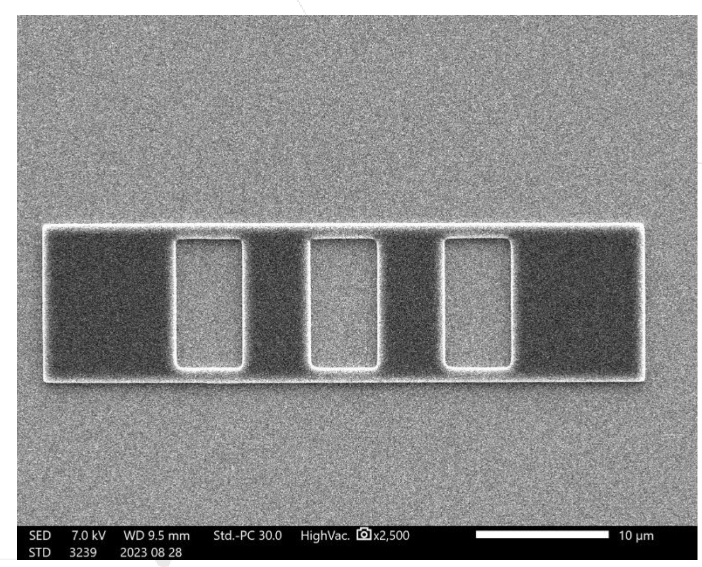
Gratings of 5 µm @85 mJ/cm² exposure



0%



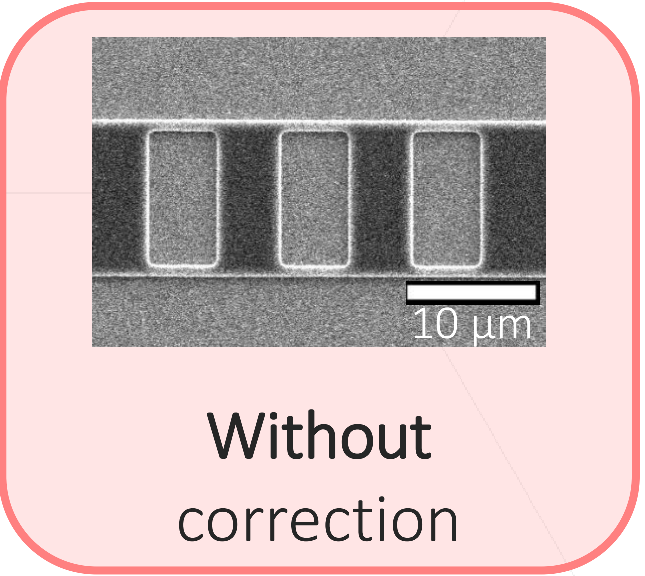
50%



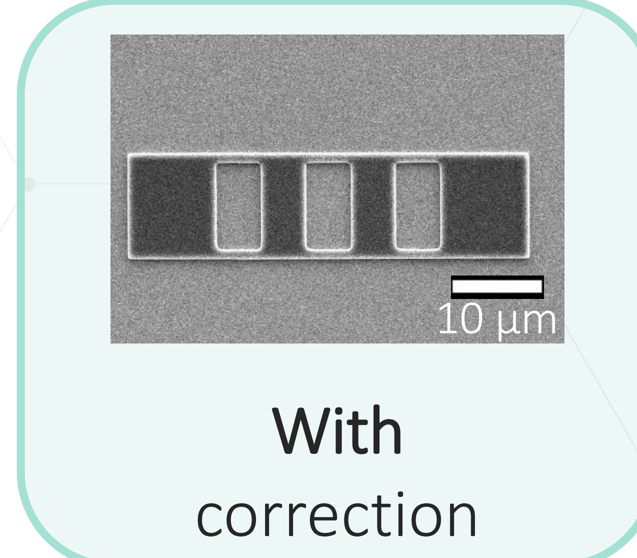
100%

Did we do better?

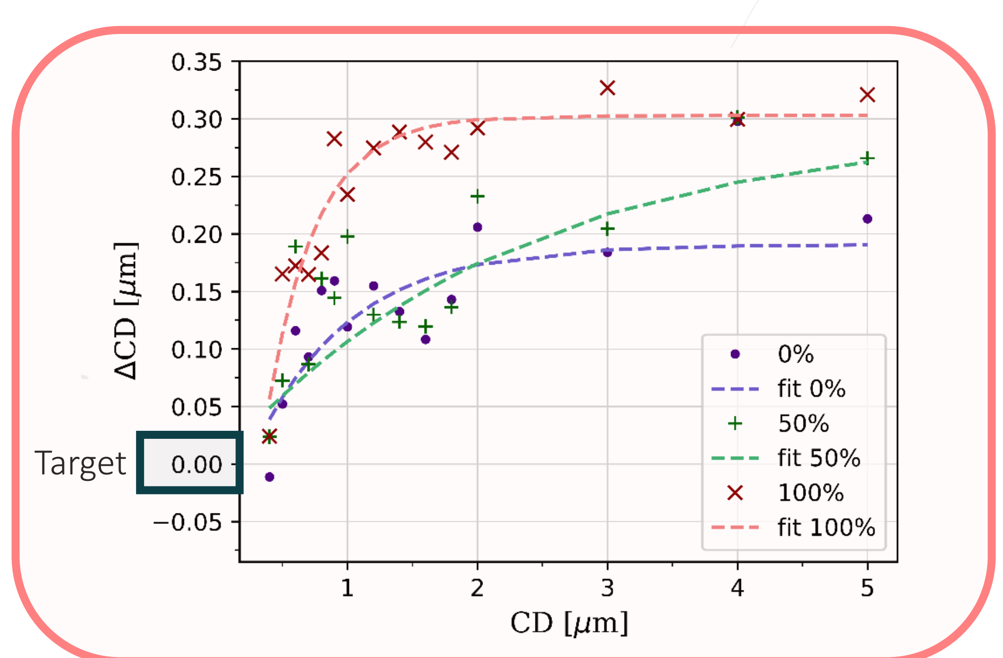
CD before and after corrections

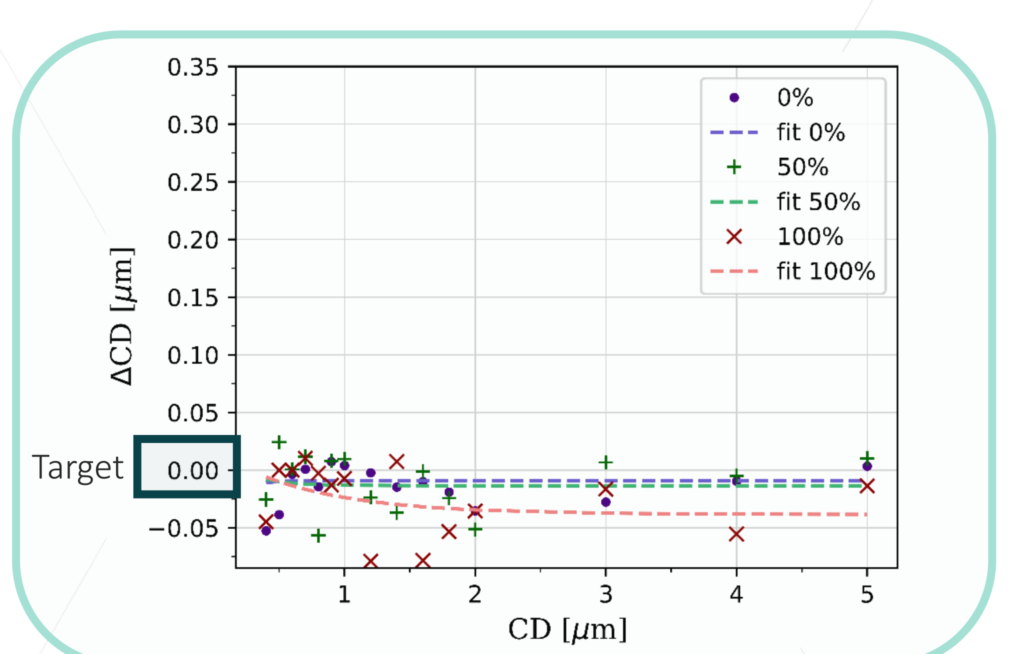


Without correction

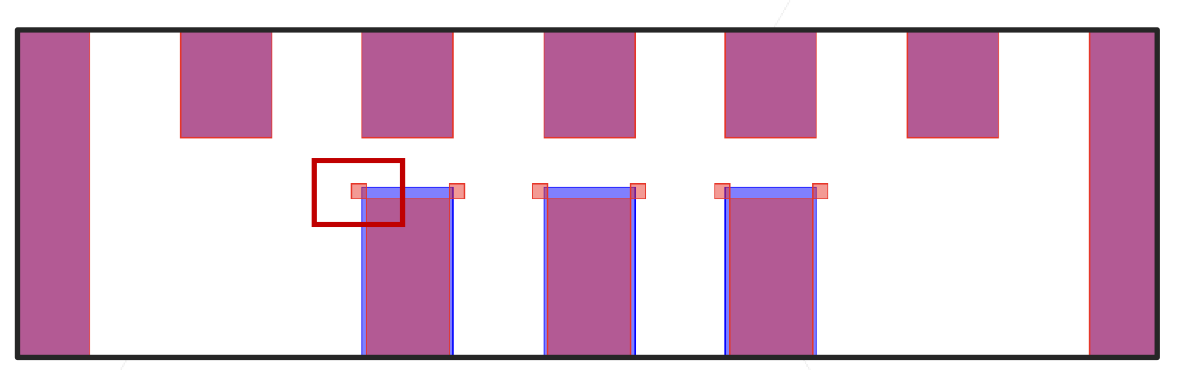


With correction



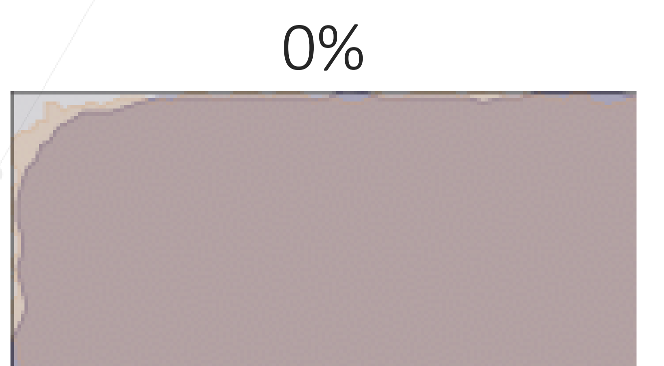


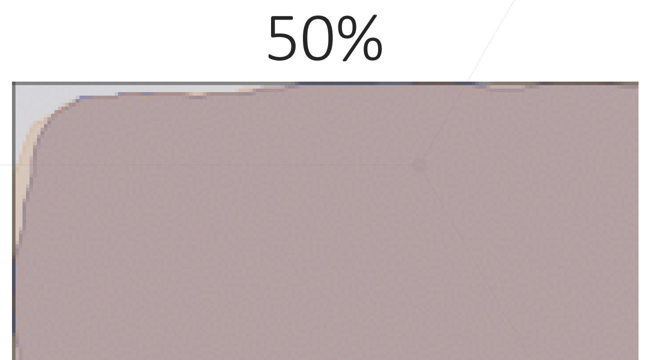
Serifs result

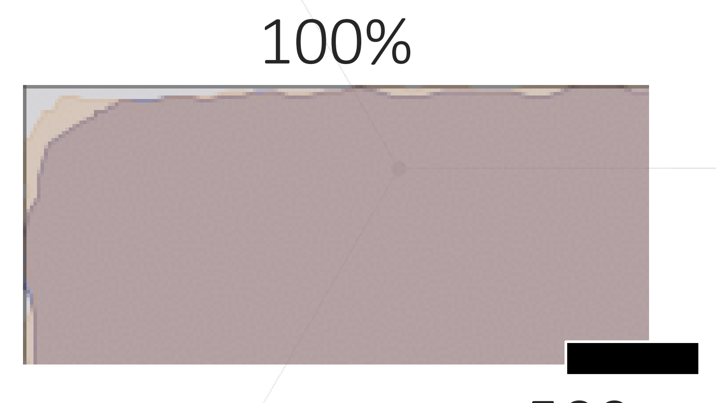


- Contours taken using **ProSEM**
- Corners overlap to compare roundness

0% | 50% | 100%







500 nm

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

Target structure
With correction
Without correction

Can we do things even faster?

An easier path

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

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

Intensity [mJ/cm^2]
0.6
0.4
0.2
0.0

y [um]
2260
2255
2250
2245

x [um]
240
245
250
255
260

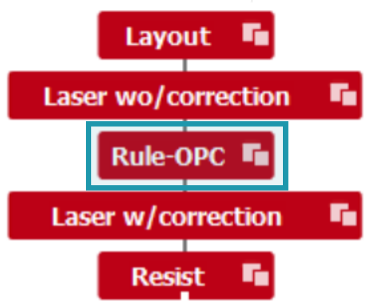
Simulation

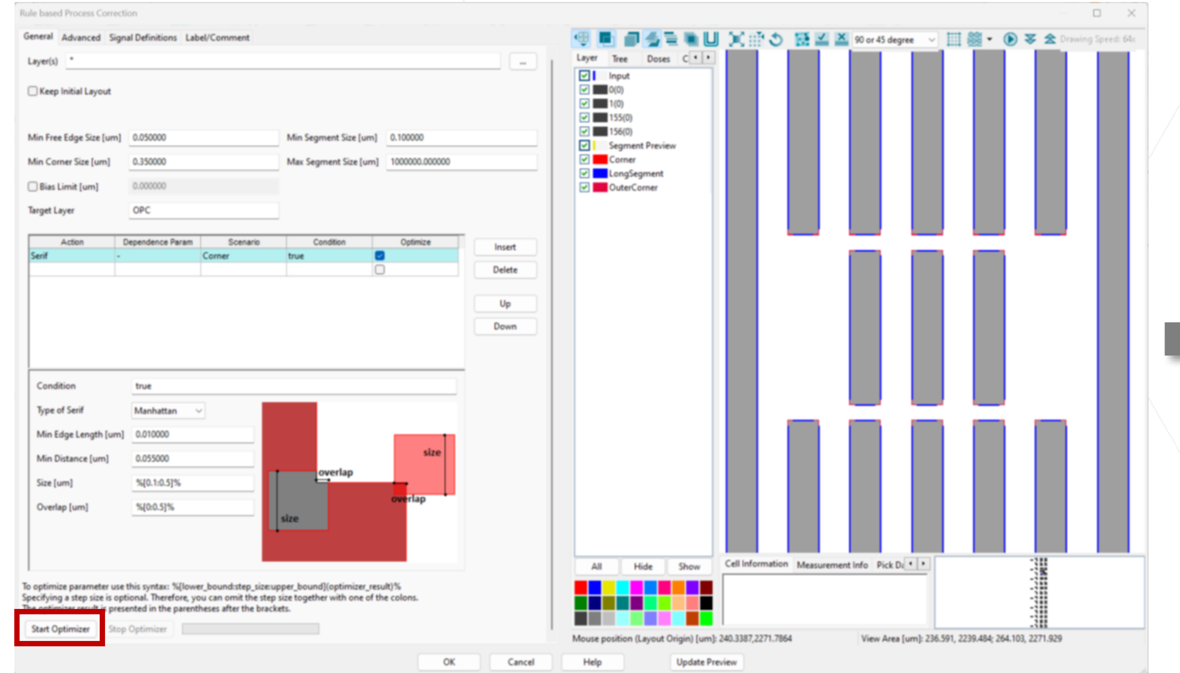
1st exposure result

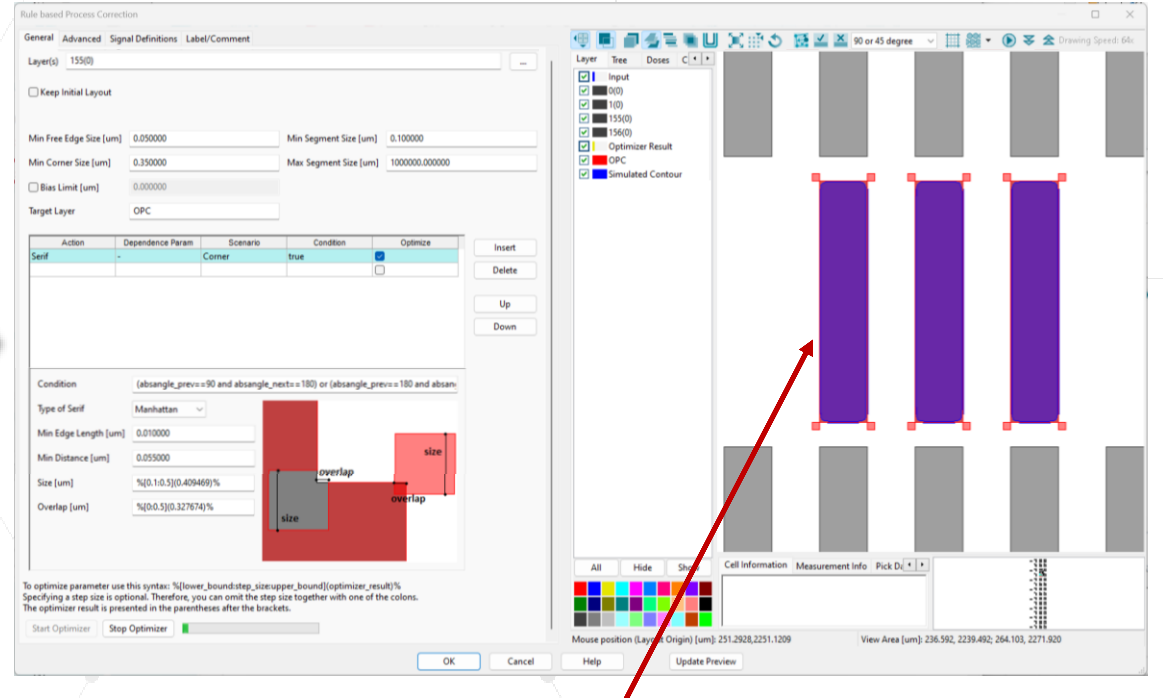
LAB

Optimising Rule-OPC

- *LAB* has an internal *Optimizer* within the *Rule-OPC* module that avoids external *Loops*

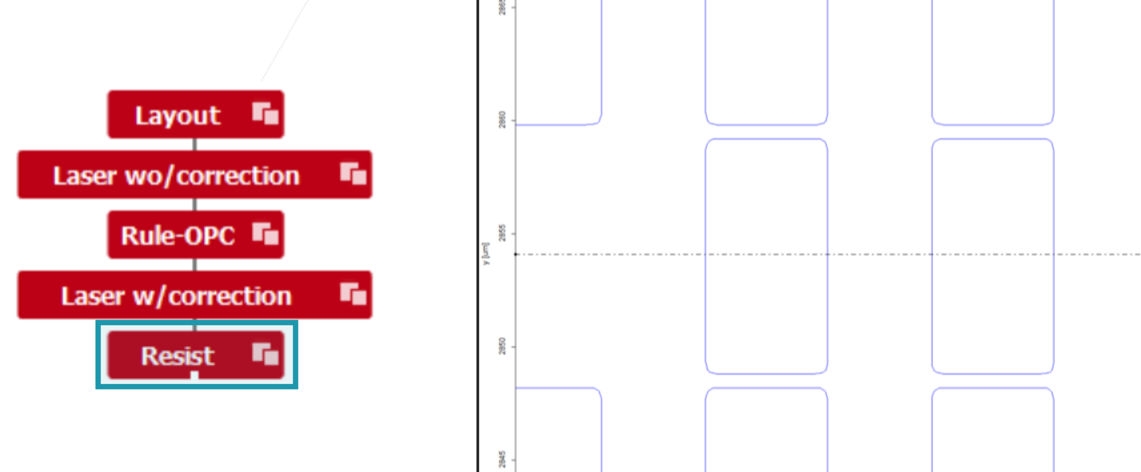






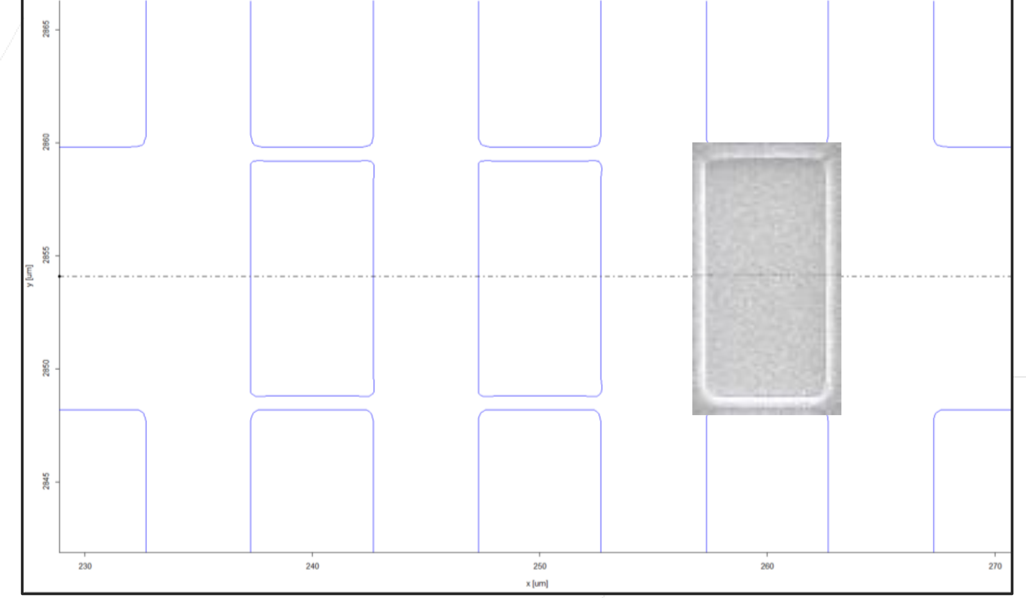
Immediate visual feedback

Modeling the experiment

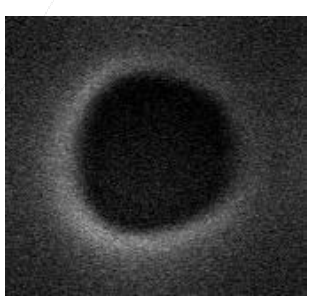


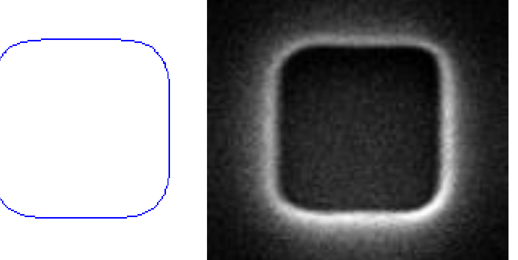
Without correction

With correction



Squares instead of rectangles





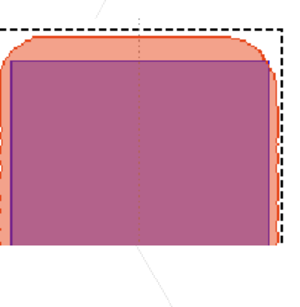
OUTLINE

- Laser Proximity and Process Effects
- Calibration for MLA 150
- Rule Based OPC and results
- Conclusion

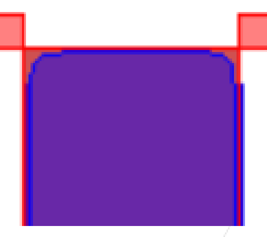
Conclusions

- BEAMER provides numerical means to improve layouts

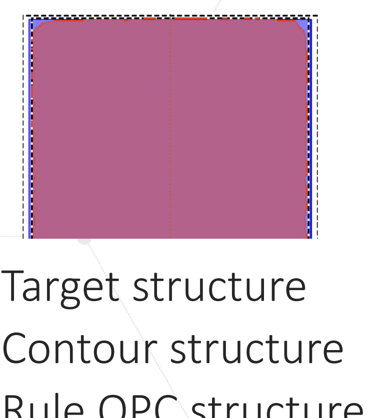
Rule OPC (among others)



- Rule-OPC allows selective modifications to a structure



- A team effort speeds up a process



Target structure
Contour structure
Rule OPC structure

Thank You!

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