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Advancing the Standard

Feb 24th, 2021
Satoshi Shimizu

Laser Lithography

レーザー露光装置による3Dグレイスケール及び2Dマスク露光用データ補正とシミュレーションの紹介

GenISys株式会社　清水 諭

About GenISys

GenISys offers software solutions for optimization of micro and nano fabrication processes

Company:

- Founded in 2005
- Headquartered in Munich, Germany
  - Expert team for lithography software development
- Subsidiaries in USA-California, **Japan-Yokohama**
- Global Technical Support
- Fast, Flexible, Responsive

Products

Electron and Laser Beam Direct Write Software

- Market leader for Gaussian beam direct write systems
- Installed at most major nano-fabrication centers worldwide
- Has become a MUST for advanced e-beam lithography

Monte Carlo simulation software

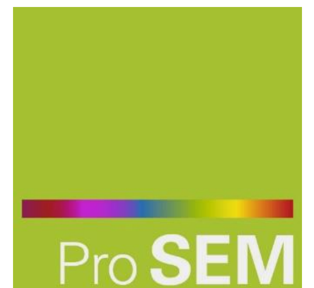
- MC- Simulation of electron distribution for e-beam lithography modeling and correction
- Process Calibration, PSF visualization, extraction and management

3D lithography simulation & OPC software

- Proximity Lithography (mask aligner) & Projection Lithography (stepper / scanner)
- Electron Beam Lithography
- Laser Beam Lithography (Heidelberg Instruments laser systems)

SEM Image Analysis & Metrology

- Metrology software for SEM



Installed Base

> 500 commercial licenses in World Wide

- > 230 BEAMER (83 EU, 80 APAC, 70 US/CA)
- 140 TRACER
- 65 LAB
- 30 ProSEM

- **Major nanofabrication center worldwide**
  - Universities, Research Center
- **Industrial R&D and special production**
  - Advanced FPD manufacturer

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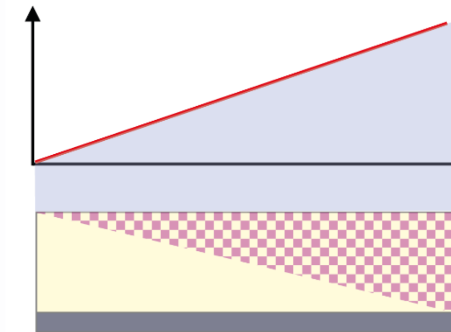
Agenda

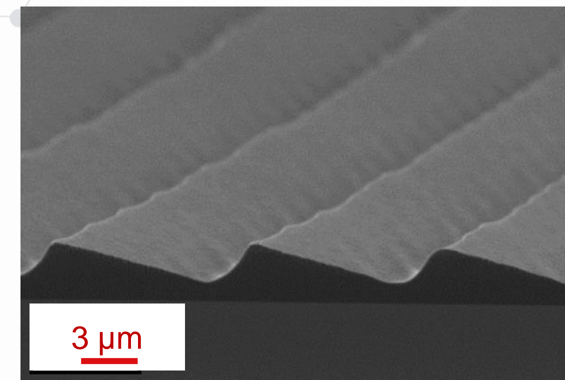
- バイナリ露光における近接効果と、現像による形状への影響
- Rule OPC と Model OPC 補正のご紹介
- グレイスケール露光における補正
- LAB によるシミュレーション
- まとめ

Greyscale vs. Binary

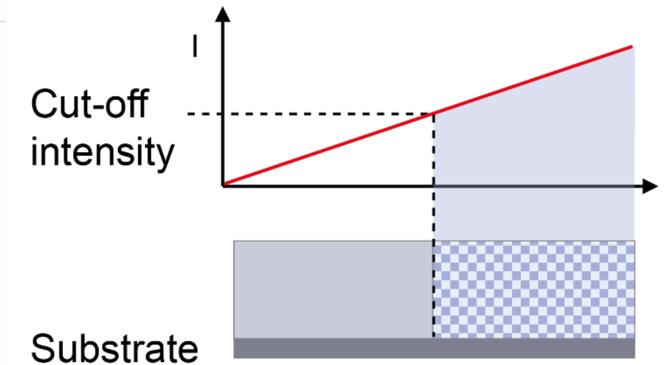
- Standard binary laser lithography sounds rather „simple“ (compared to greyscale)
  - Increase the intensity above dose to clear of the resist
  - Resist will be cleared in exposed area, remain on unexposed area (for positive resist)

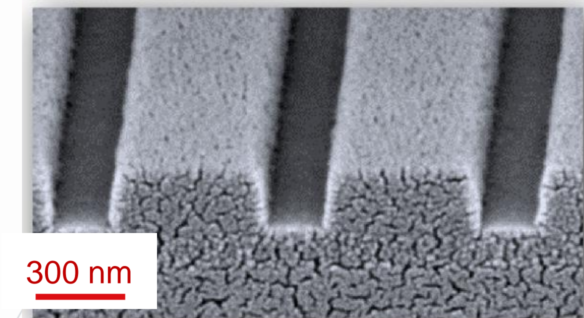
Grayscale Lithography





'Standard' Binary Lithography





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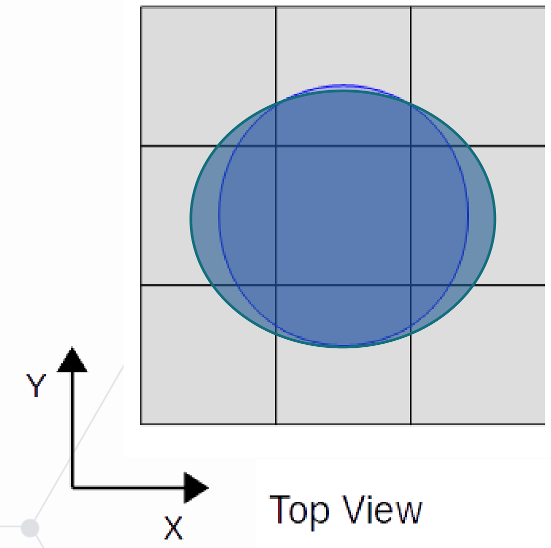
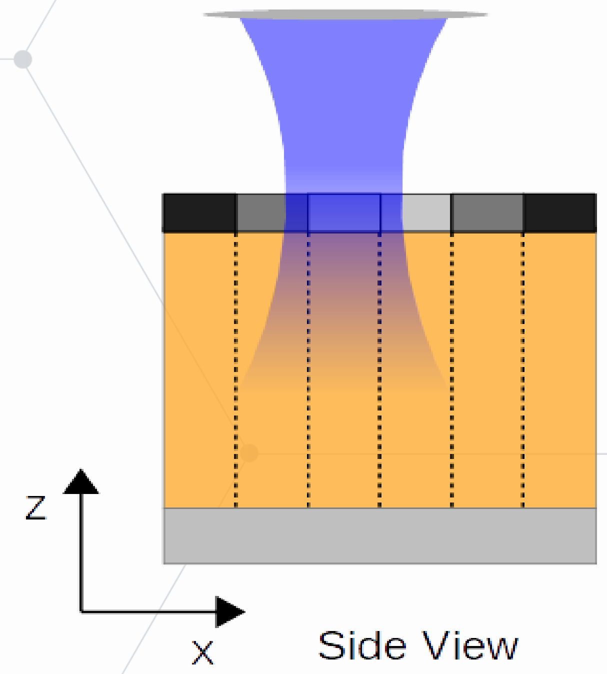
Proximity & Process Efects

- Unfortunately nothing is binary in lithography
  - Beam has a „blur“ (shape) 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

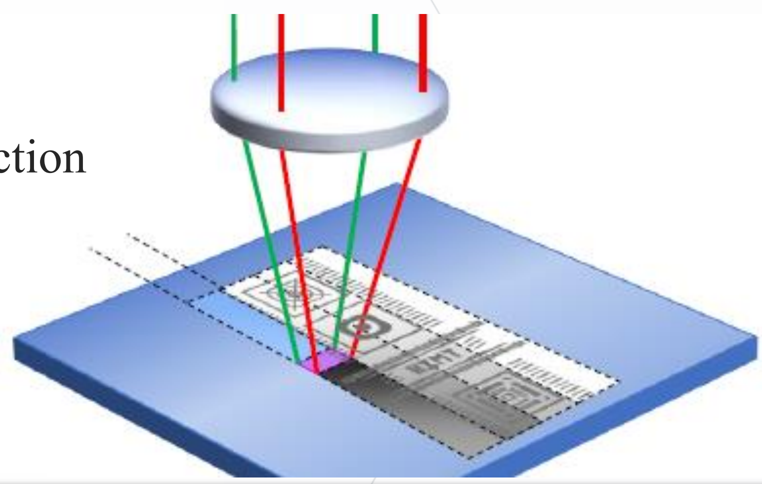


- …larger than the pixel size x-y may be different (not to scale!)



- …not constant along z-axis

- …Scan direction dependency



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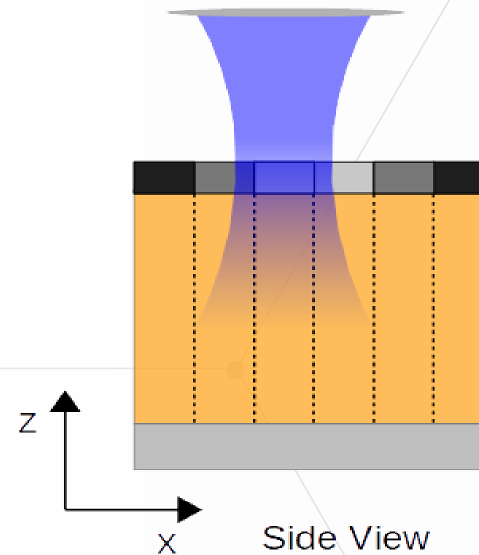
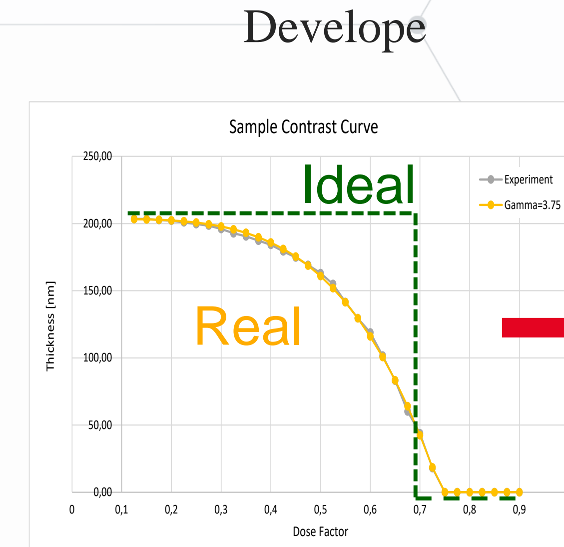
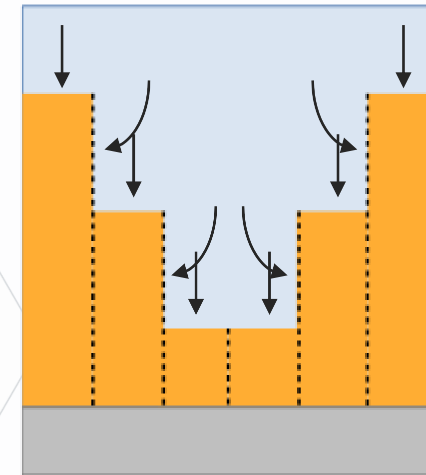
Proximity & Process Efects

- Unfortunately nothing is binary in lithography
  - 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)



Develope





- Developer front moving to all direction – lateral development

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

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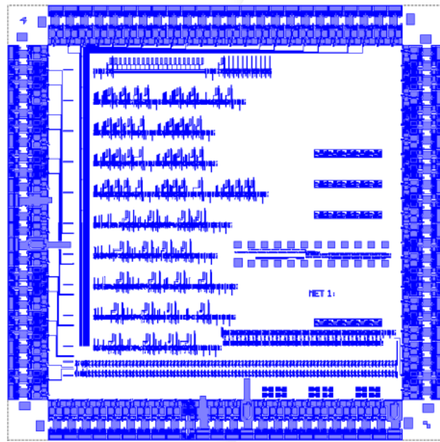
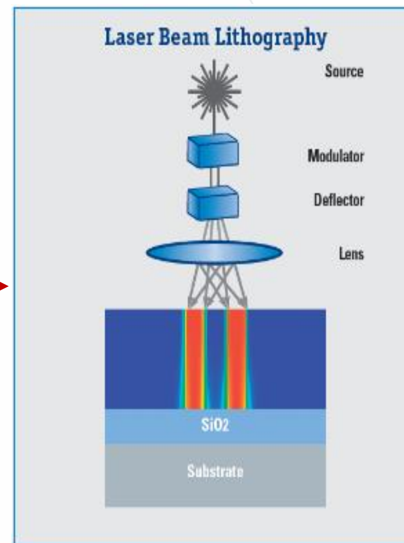
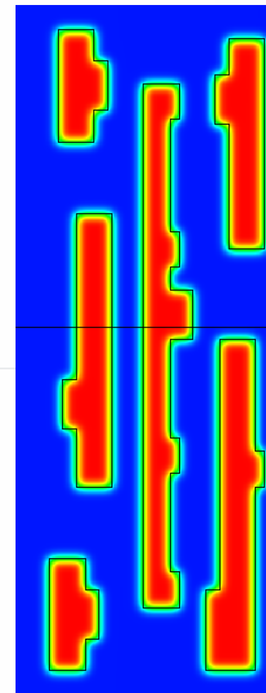
Analysis using 3D Laser Simulation

Layout

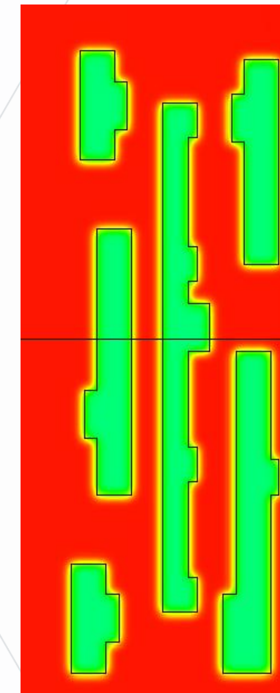




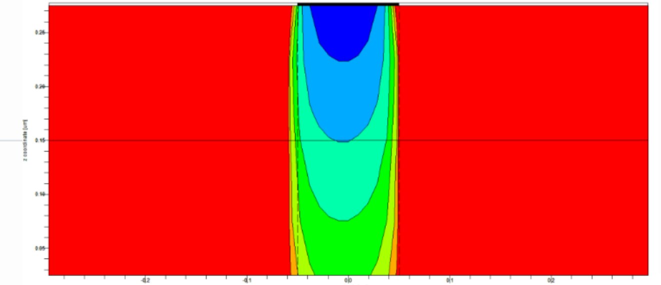
Laser Exposure

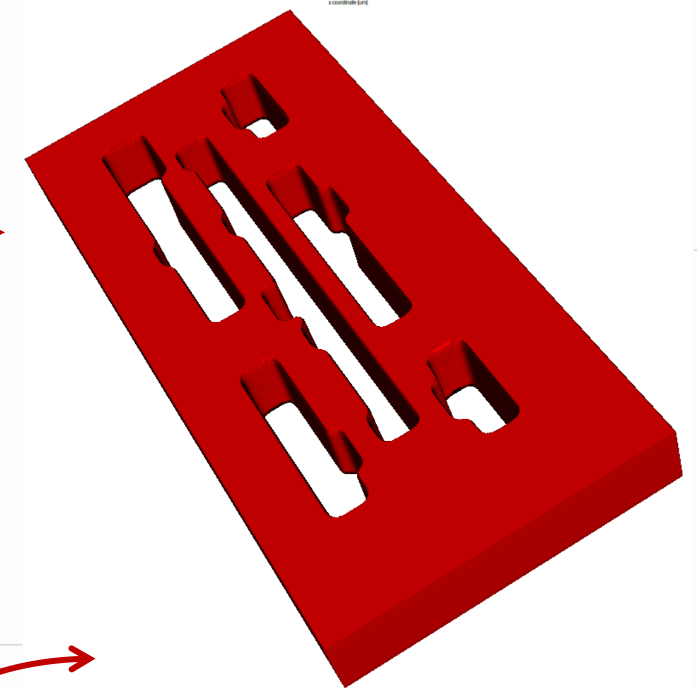


3D Bulk Intensity



3D Concentration





3D Resist

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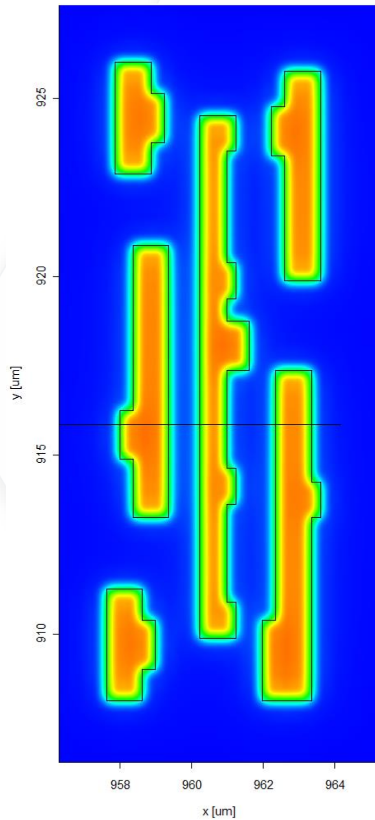
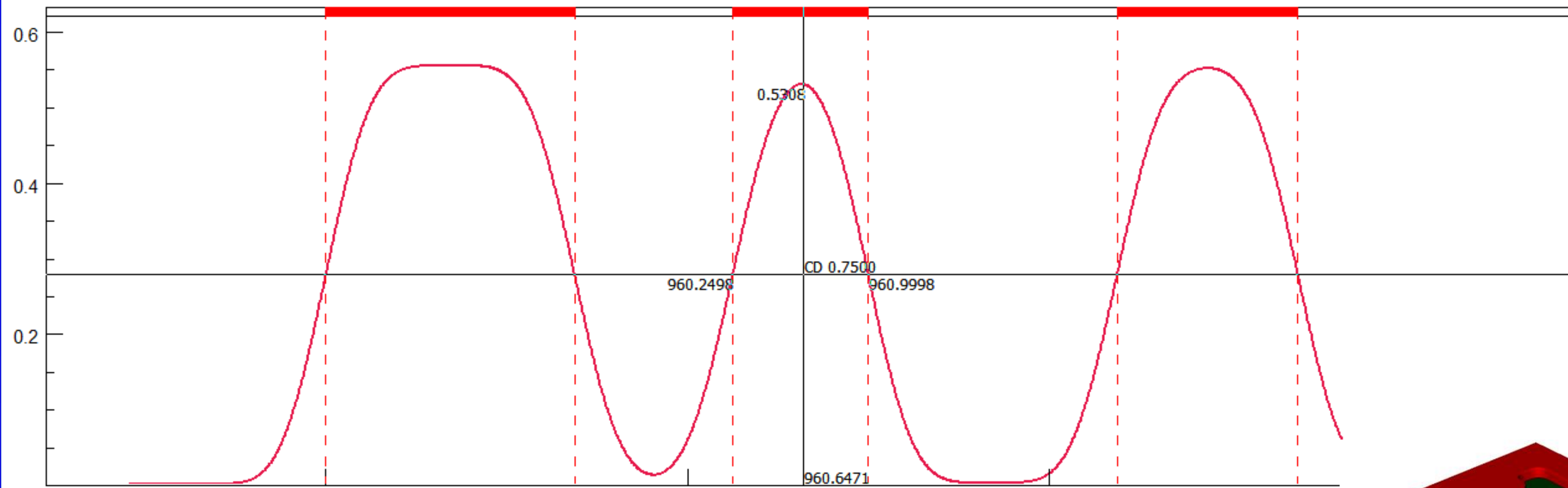
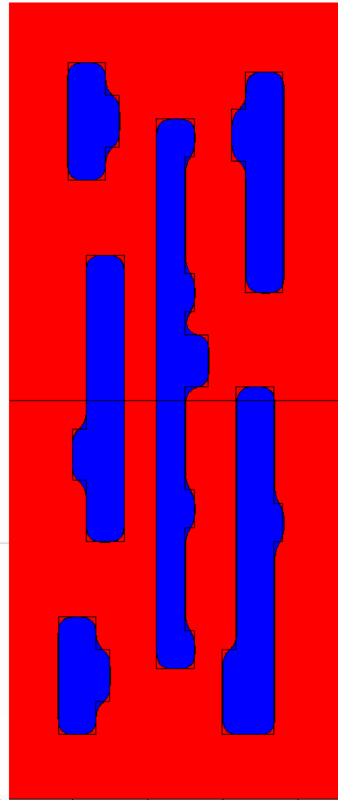
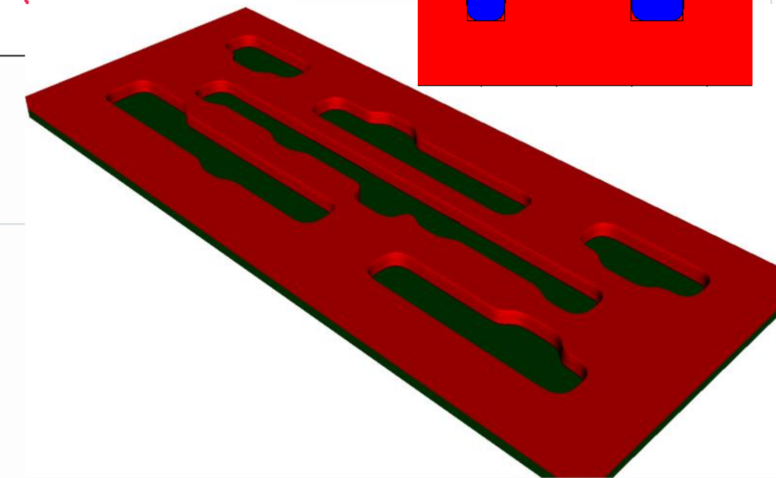
Optical Proximity Effects

- Small Beam Size (0.4 μm)









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Optical Proximity Effects

- Medium Beam Size (0.8µm)

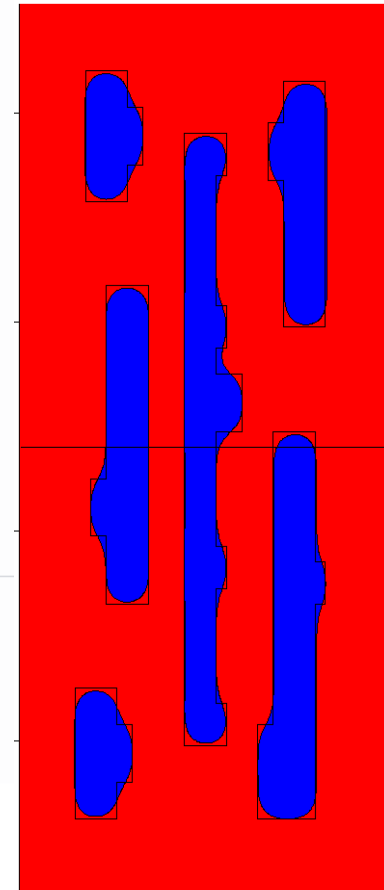
z = 0.25 [um]

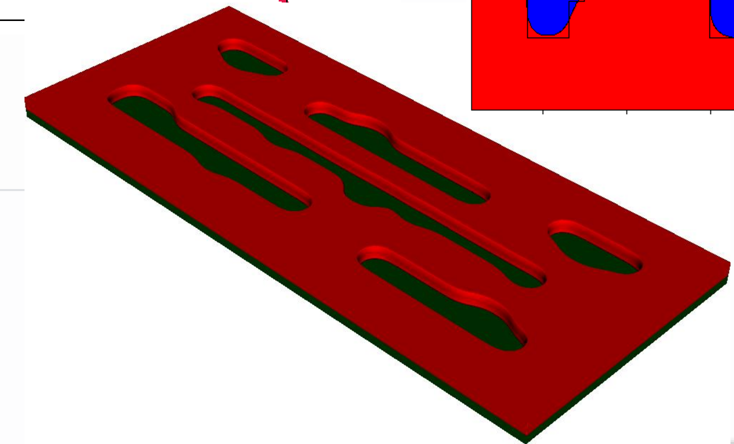
y [um]: 925, 920, 915, 910

x [um]: 958, 960, 962, 964

0.6
0.4
0.2
0

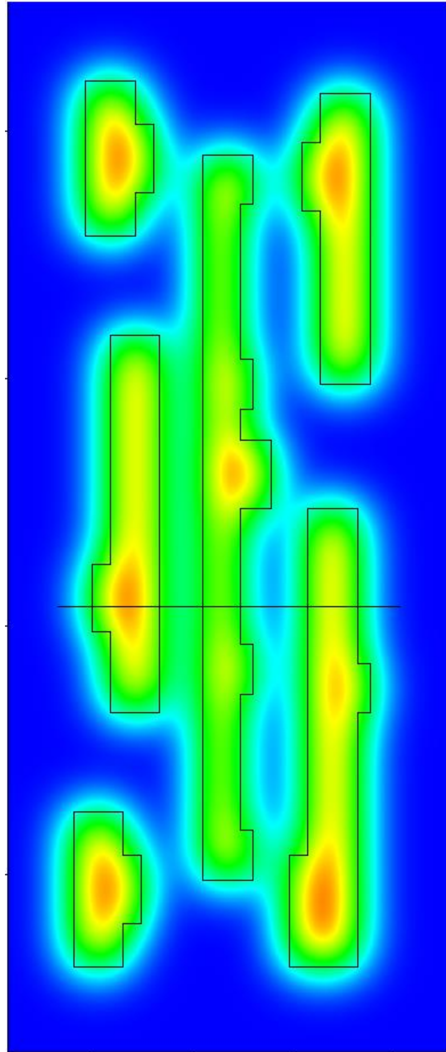
0.4116
CD 0.6912
960.2793
960.9705
960.5964

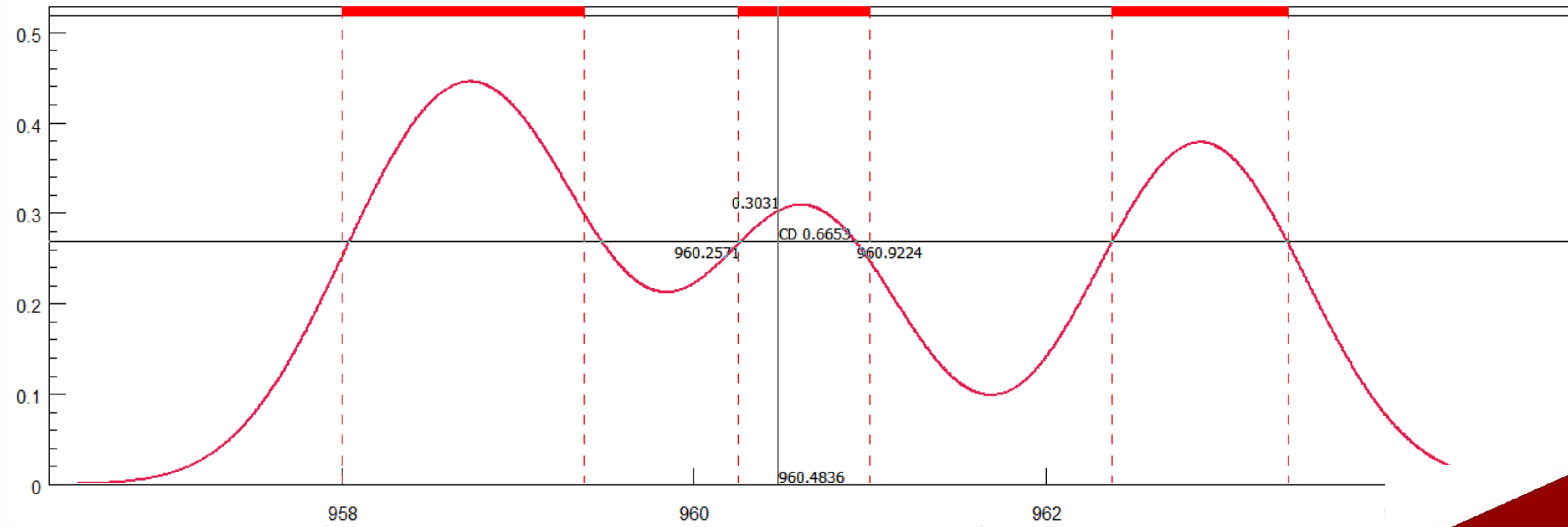


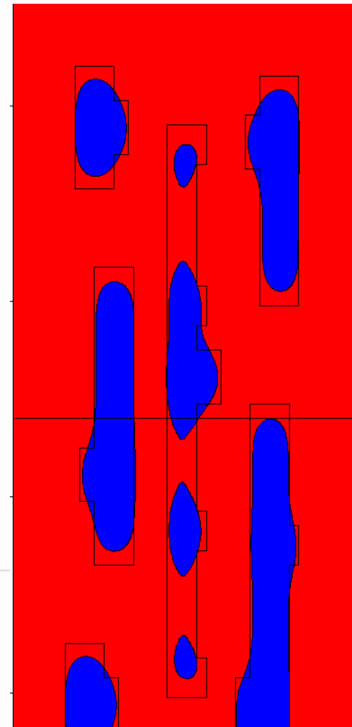


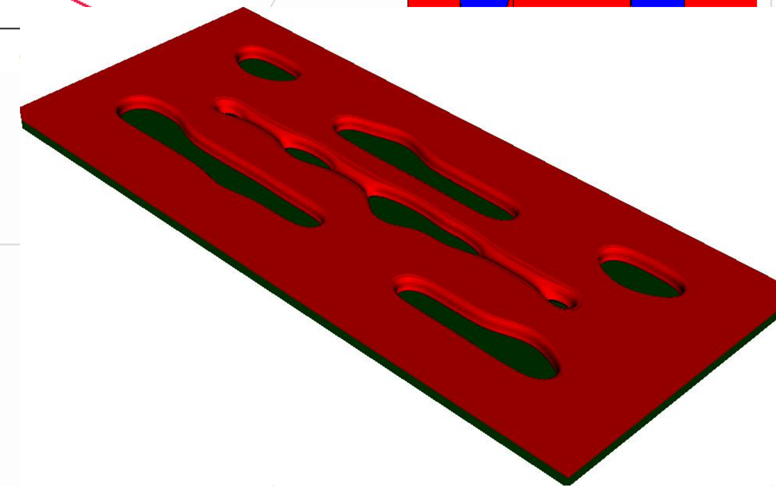
Optical Proximity Effects

- Large Beam Size (1.2µm)









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  - Rule OPC : 「線形補正」「コーナー補正」
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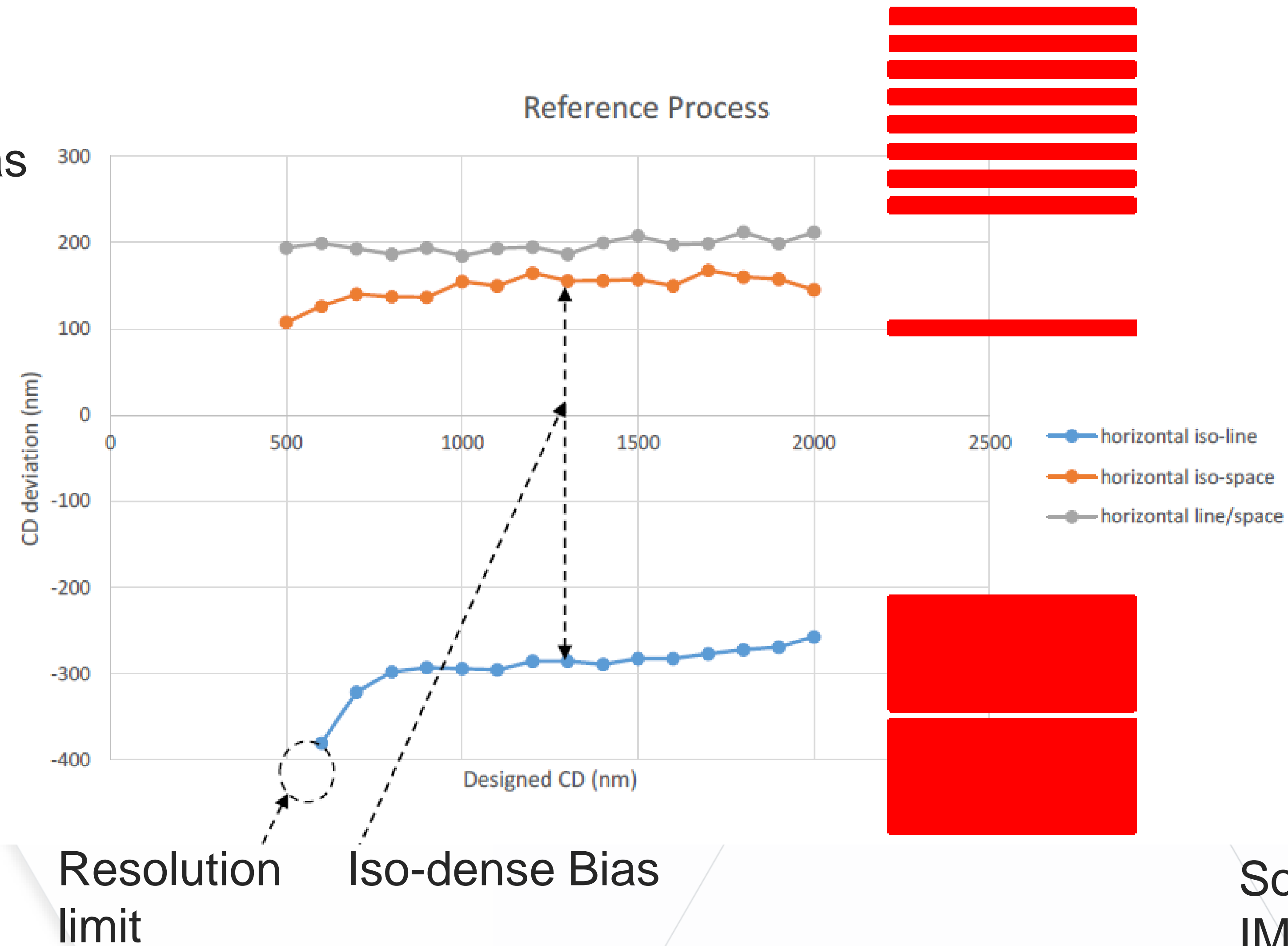
Laser Binary Exposure & Process Distorsion

CD variation

- Size → CD linearity
- Density → Iso-dense bias
- X-, Y- direction
- Angle dependent



Source:
IMS Chips Stuttgart

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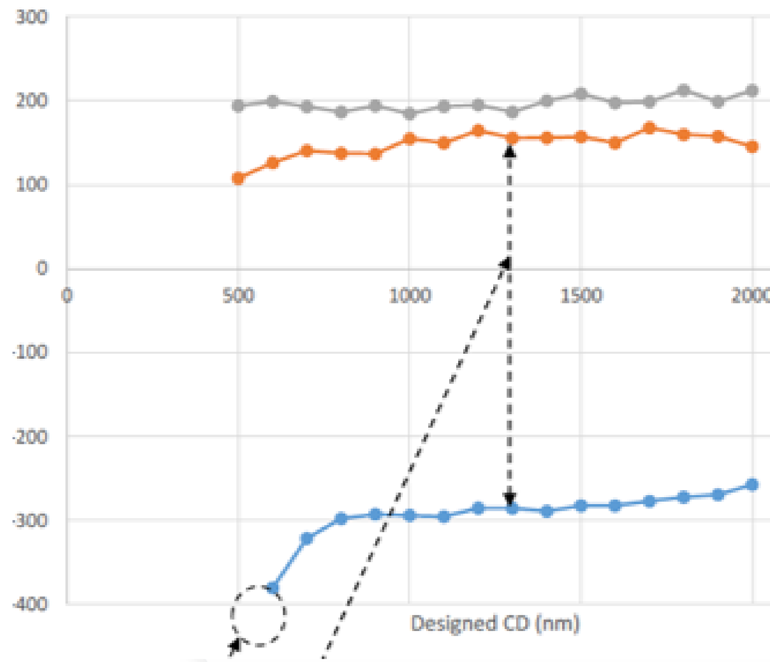
Rule Based OPC



Action

Bias
Bias
Serif
Hammerhead
Bar

Rule based Process Correction

General | Signal Definitions | Label/Comment

Hierarchical P

Edge Size [um] 0.050000 Min Segment Size [um] 0.1000

er Size [um] 0.150000

Dependence Param	Scenario	
CD	AnySegment	true

CD
Density
Space
Angle

Edit...

true

CD [um]	Bias [um]
2	0.000000
1	0.05
0.5	0.1
0.1	0.15

Bias

OK | Cancel | Help

LineEnd	true
AnySegment	true
Corner	true
AnySegment	true

LongSegment
Corner
Line/Space End
SmallFigure
InnerCorner
OuterCorner
LineEnd
SpaceEnd
SmallHole
SmallDot
AnySegment

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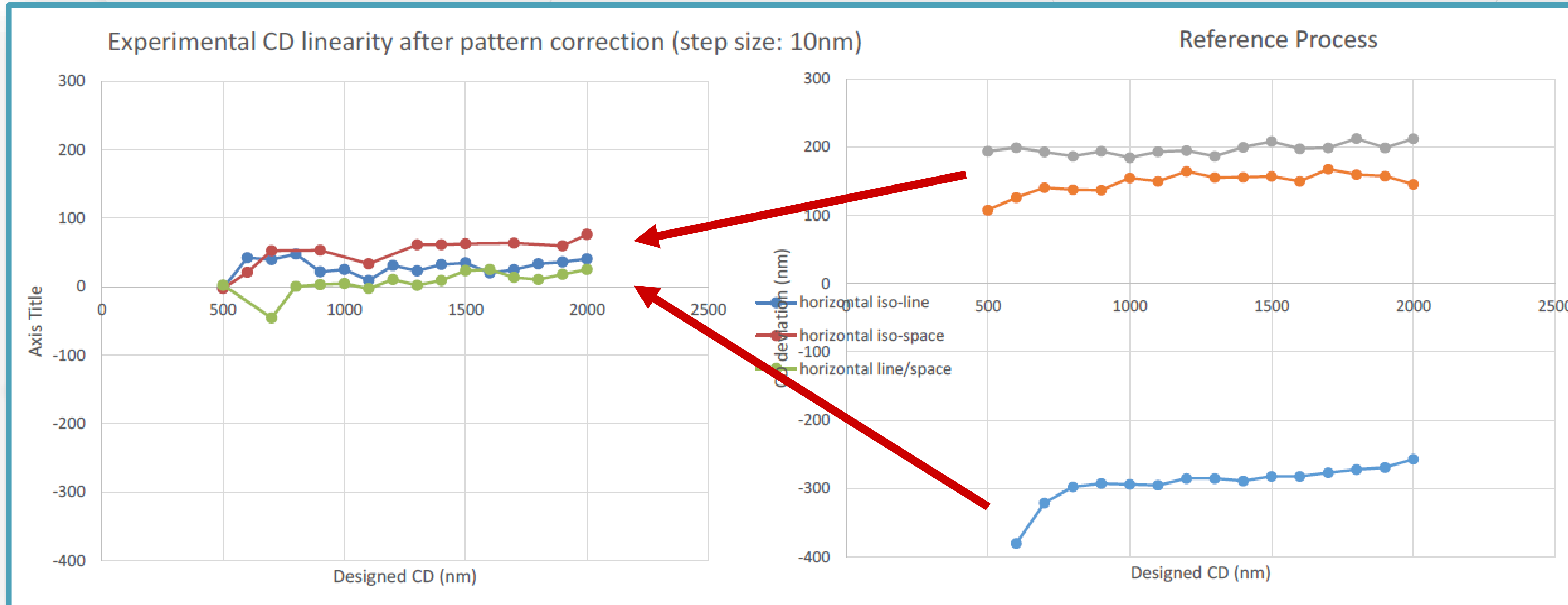
Application of Shape - OPC



After correction

- CD linearity is improved, esspecially for iso
- Iso-dense bias is largely corrected
- Resolution limit is improved to print 500nm

Source:
IMS Chips Stuttgart

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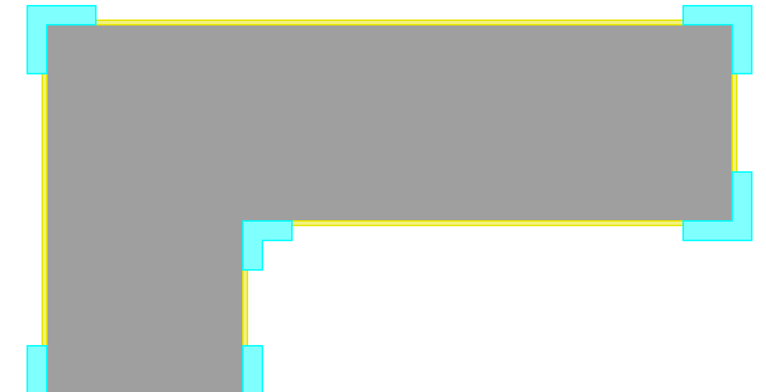
Rule-OPC process

Layout

Segmentation

LongSegment
Corner

Applying rules



1st section of parameters used to split layout to segments

Layer(s) * ... Hierarchical Processing ☐

Min Free Edge Size [um] 0.050000 Min Segment Size [um] 0.100000

Min Corner Size [um] 0.150000

Softframe [um] 0.000000

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

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

Insert
Delete
Up
Down

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Correction

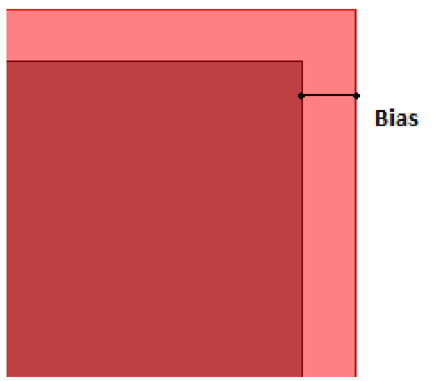
Action	Dependence Param	Scenario	Condition
Bias	CD	LongSegment	distIn/(distIn + distOut) < 0.25 and ((a
Bias	CD	Corner	distIn/(distIn + distOut) < 0.25 and ((a
Bias	CD	LongSegment	distIn/(distIn + distOut) >0.3 and ((ab
Serif	-	OuterCorner	true

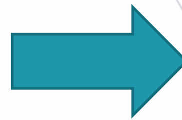
- Vertical lines iso
- Vertical lines with smaller distance to neighbor
- Serifs added for outer corners

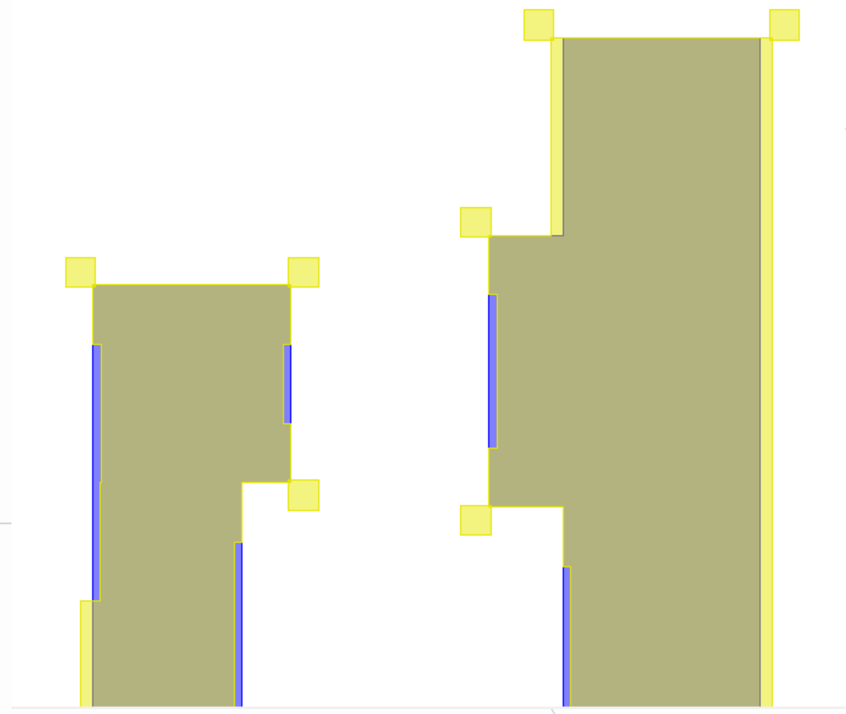
Condition: distIn/(distIn + distOut) < 0.25 and ((absangle

CD [um]	Bias [um]
0.250000	0.074351
0.350000	0.073052
0.500000	0.068322
0.575000	0.068919
0.650000	0.066311

Import... Insert Delete







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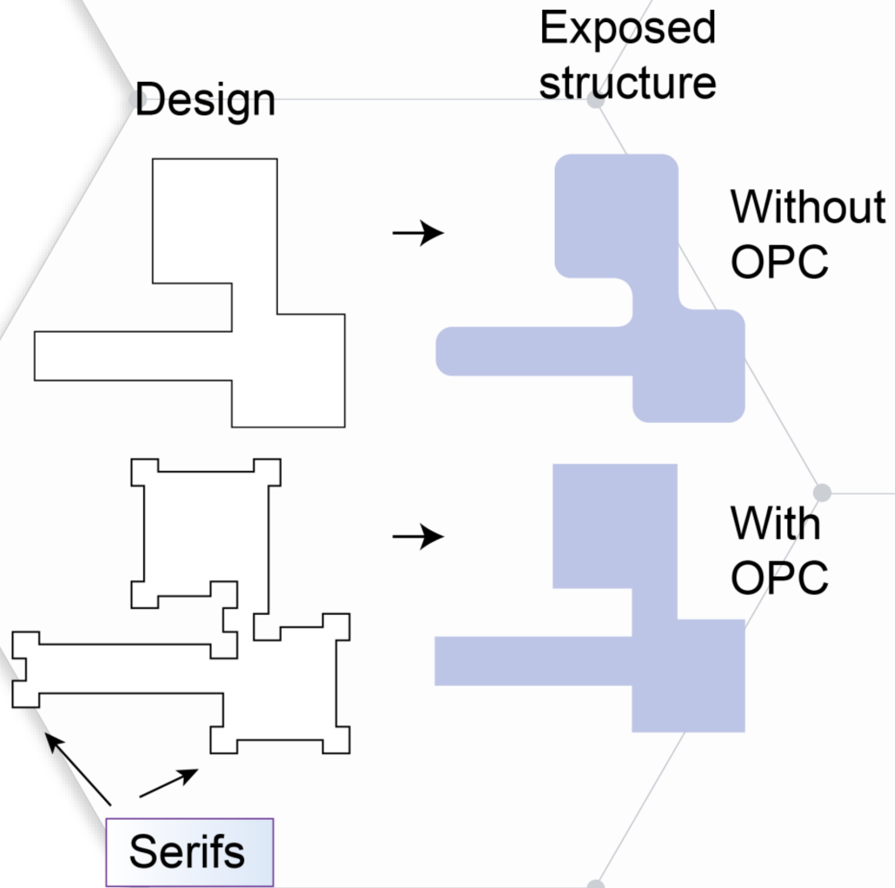
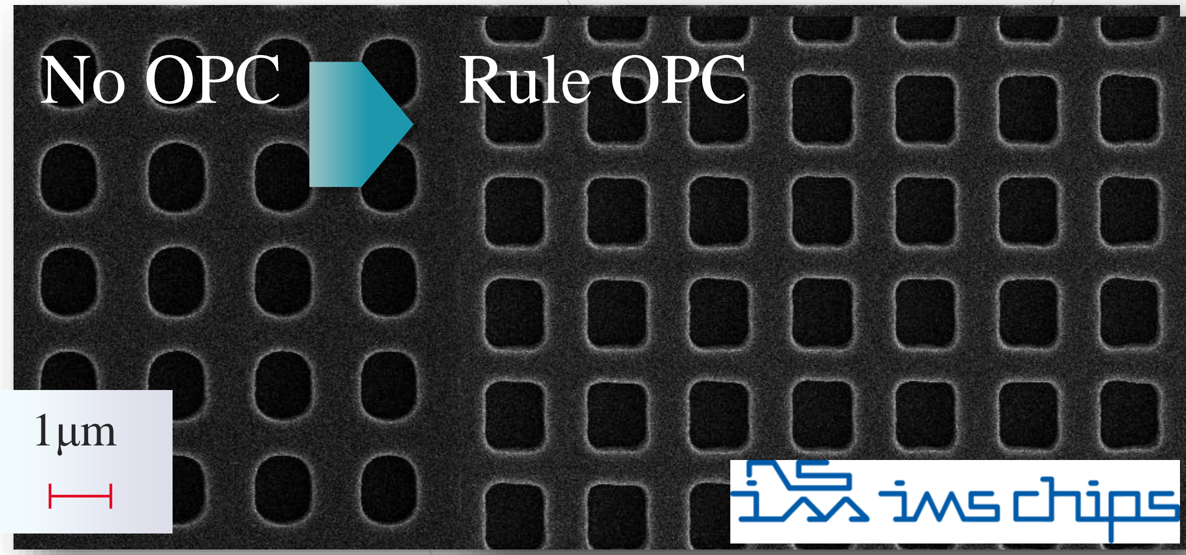
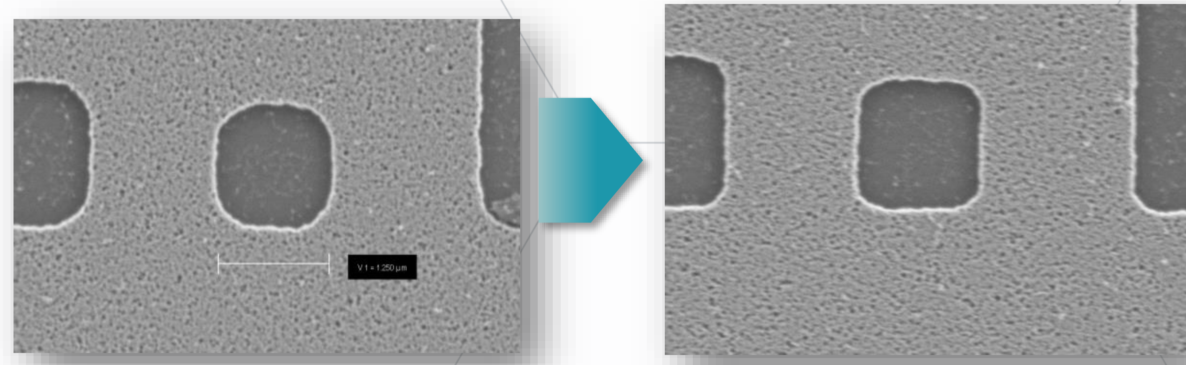
Corner Enhancement Example





0.9 µm Squares



1 µm Squares

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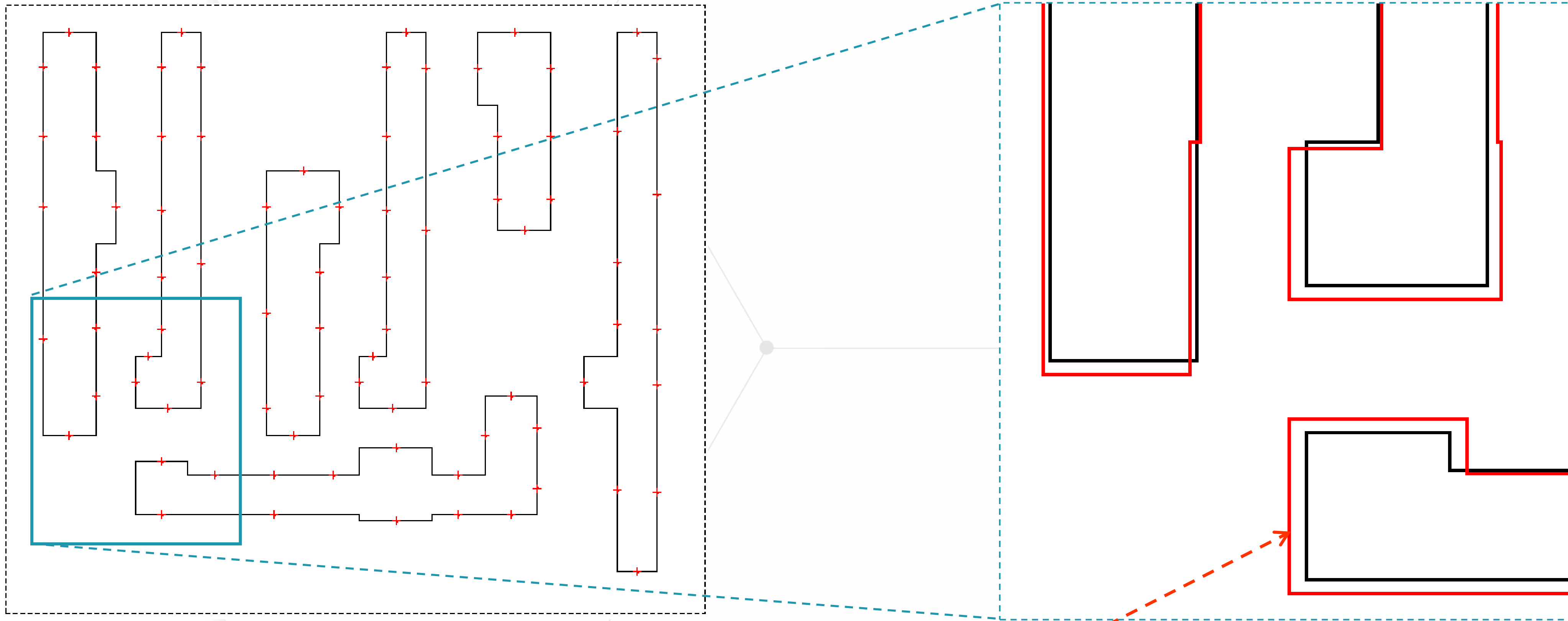
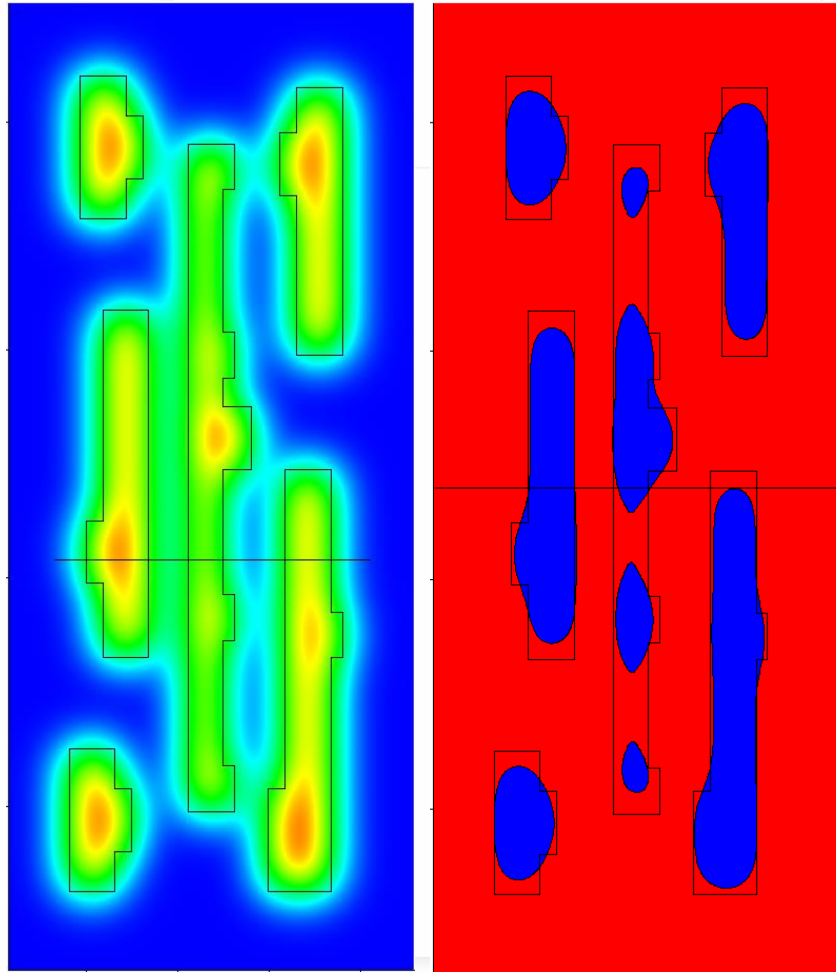
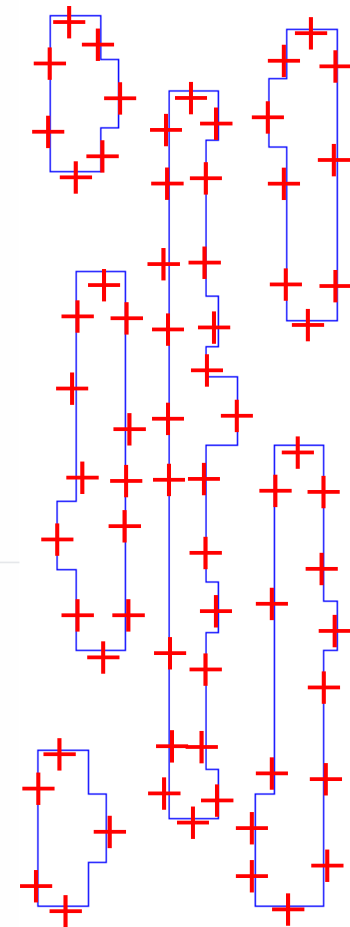
Self consistent edge equalization method

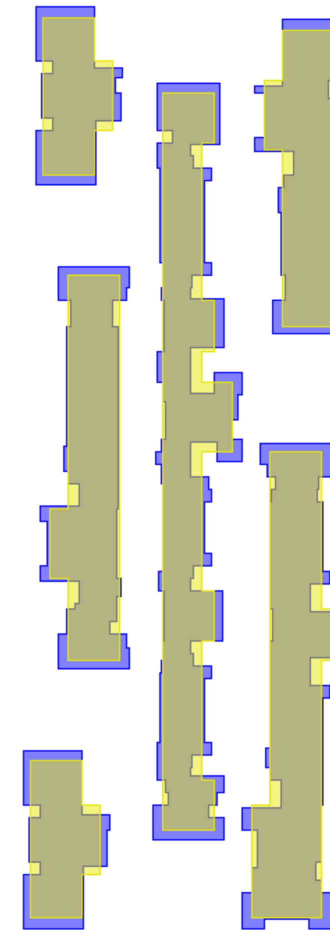


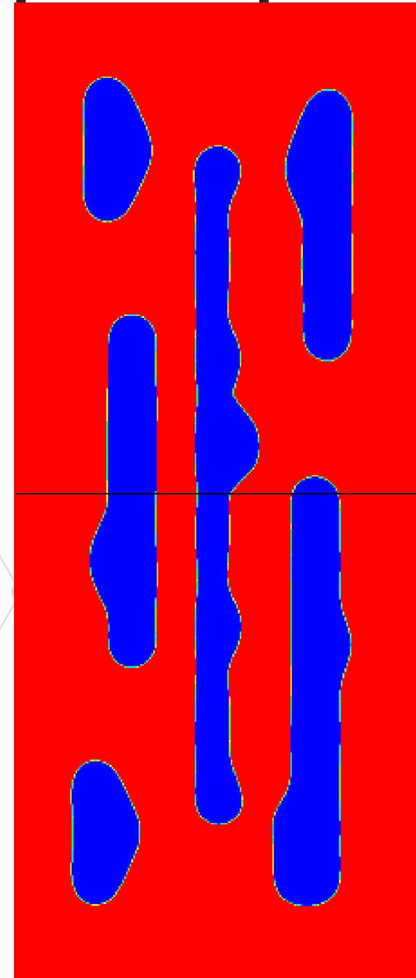
Each bias adds or subtracts exposed area : energy at the evaluation point is changed until a self consistent solution has been found.

Shape PEC / Model OPC principle









To solve:
Intensity at layout edges are not equal
- ➢ resist edge does not match layout edge
- ➢ Move edges locally to get equal intensity

In a DRC step all edge segments are analyzed for the CD and distance to adjacent shapes.
A set of representative evaluation points (+) is defined.

All segments with eval points are moved iteratively to adjust intensity at target layout edge to get equal

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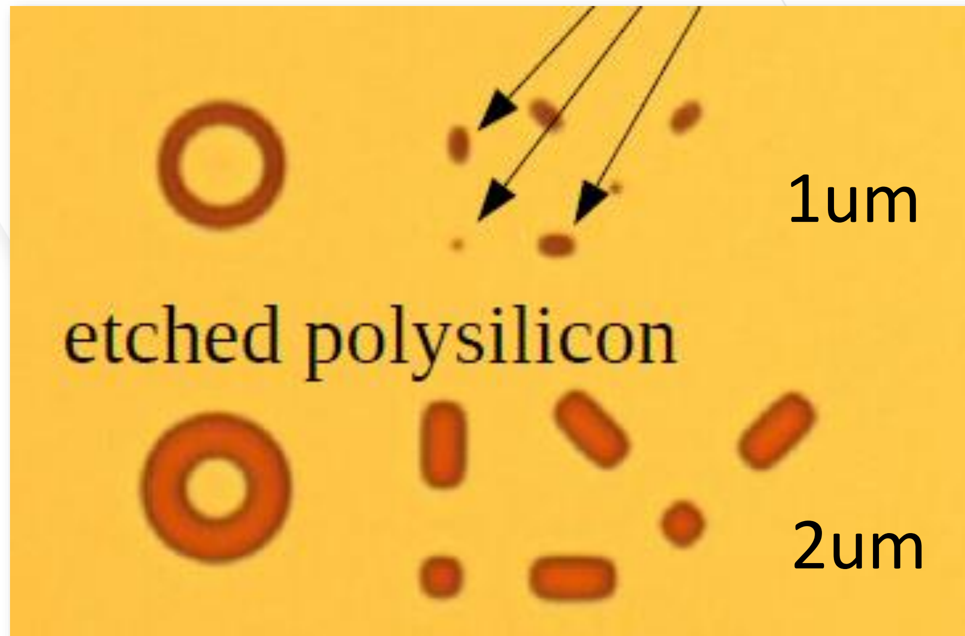
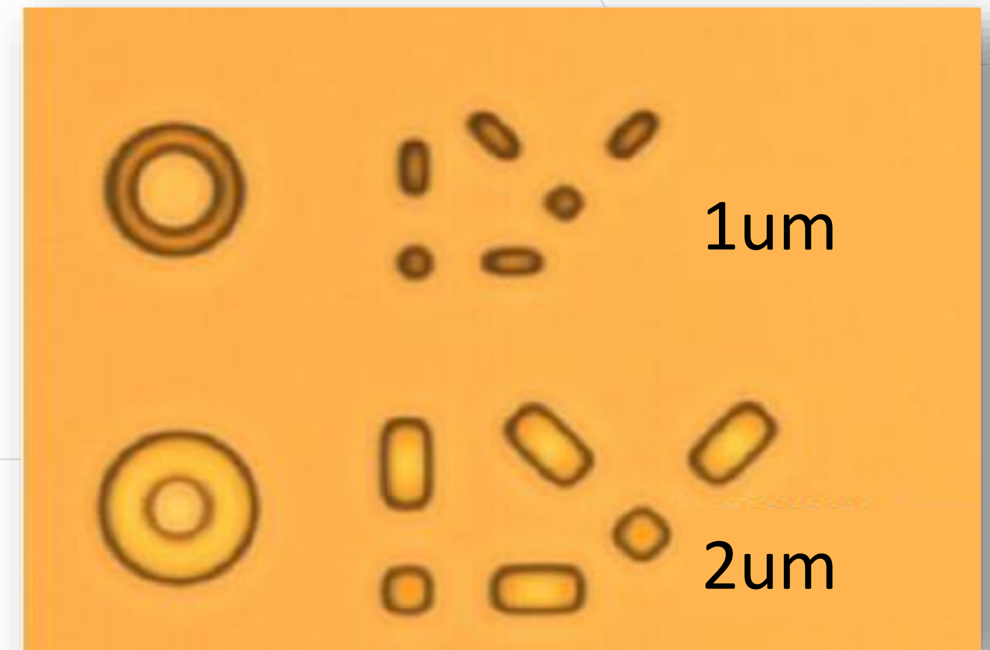
Model-based correction

- convolution kernel already corrects for major effects
  - CD-Linearity loss is an indicator for laser spot size
  - Flare is added as a constant background
  - Overdose accounts for out-of-*isofocal* process points (contrast enhancement)
- Other terms that could be easily added
  - Longer-range blur to account for process contributions
  - Elliptical spots to account for X-Y (scan/stepping) differences

Exposure on DWL sy
MPG in Munich - Ge





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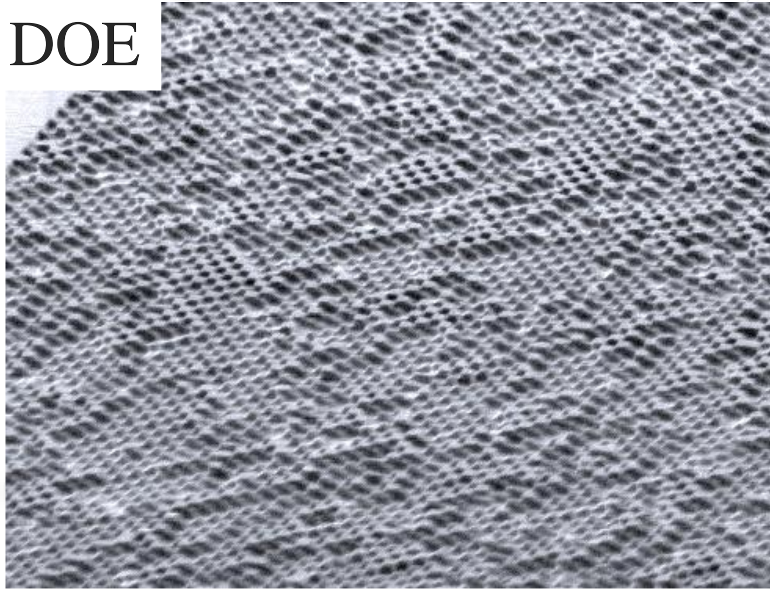
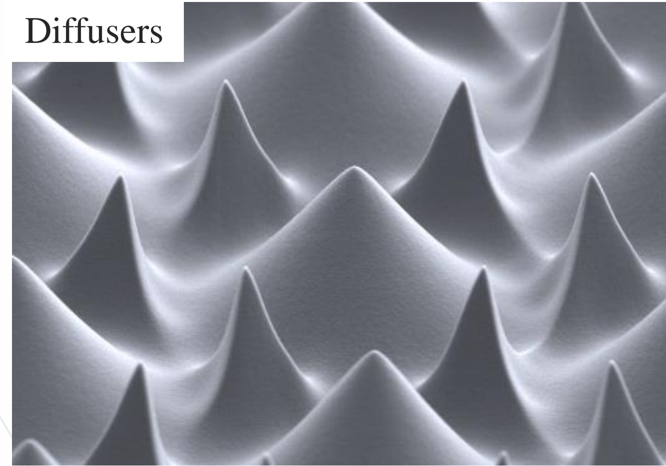
Laser Gray Scale Application

- Large variaty of application need 3D

DOE

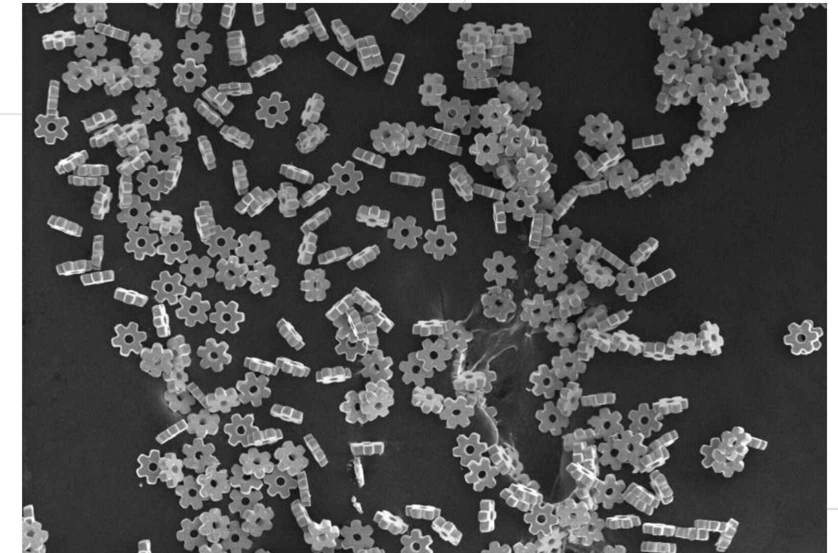


Diffusers



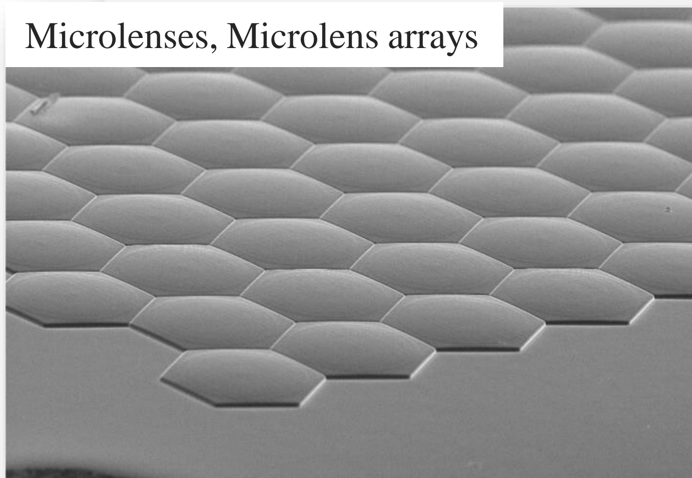
Courtesy of IGI

MEMS, MOEMS

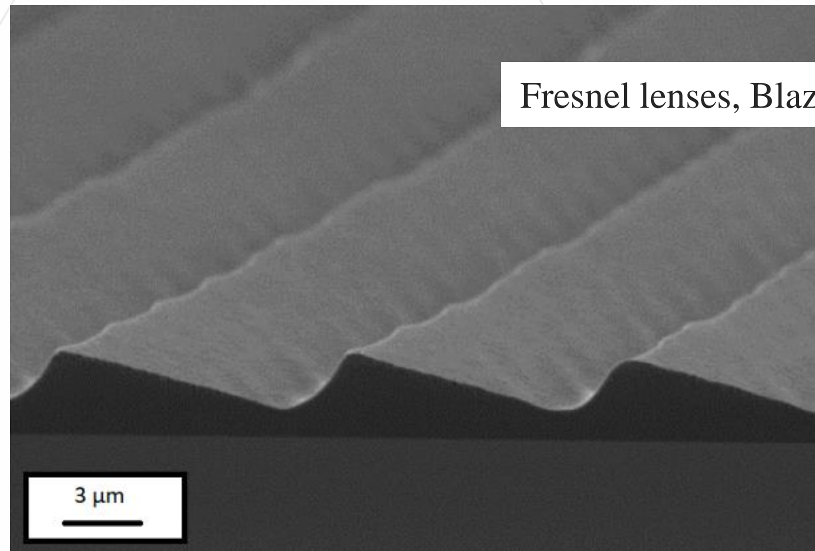


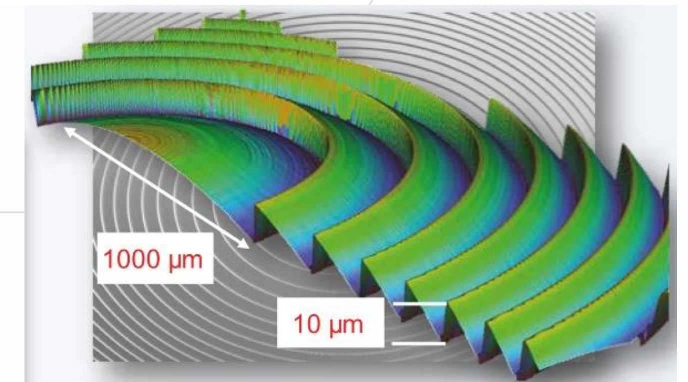
Courtesy of Kuraray

Microlenses, Microlens arrays



Fresnel lenses, Blazed gratings





Courtesy of IMS

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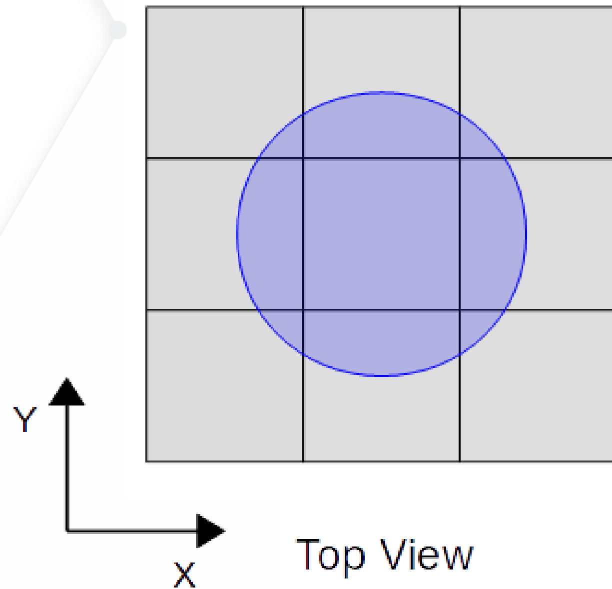
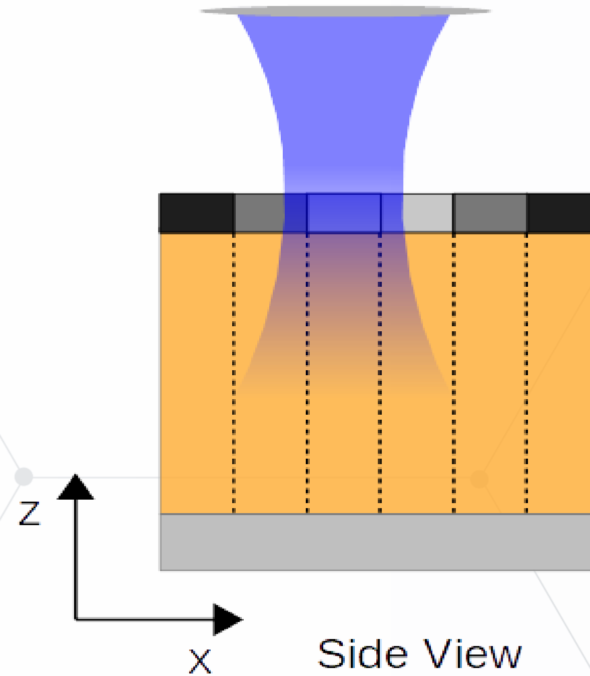
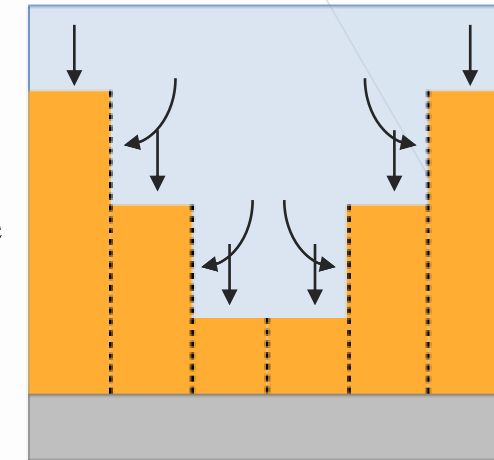
Proximity & Process Efefcts

- The beam intensity is





Develope



- …larger than the pixel size (not to scale)
- …not constant along z-axis
- Developer front moving to all direction – lateral development

Output topography strongly depends on target geometry and both tool and process parameters

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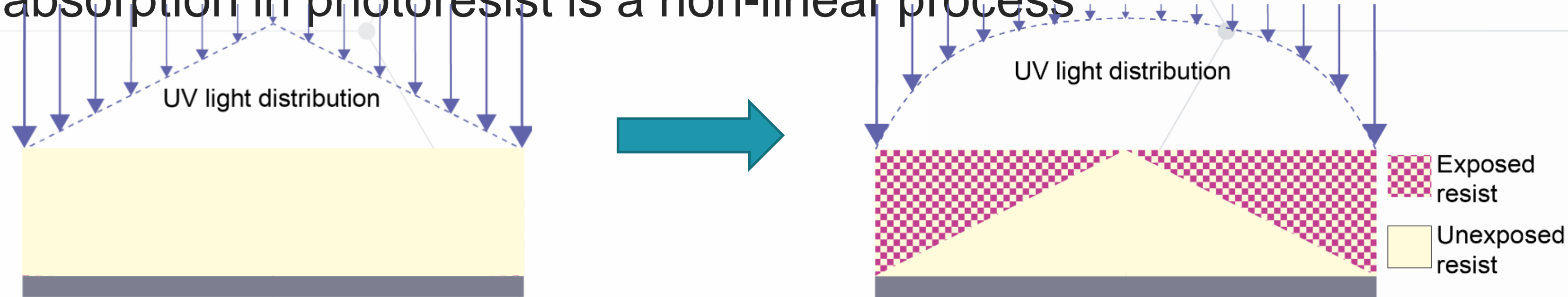
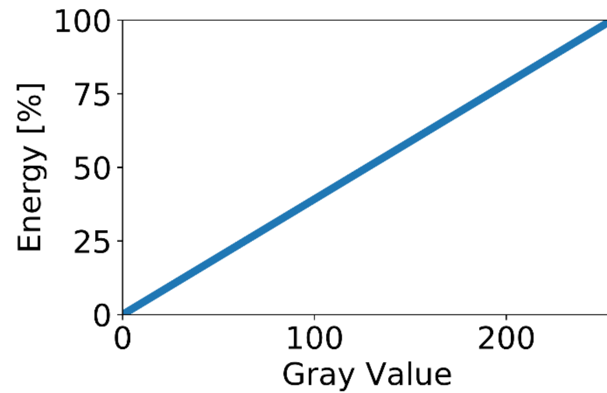
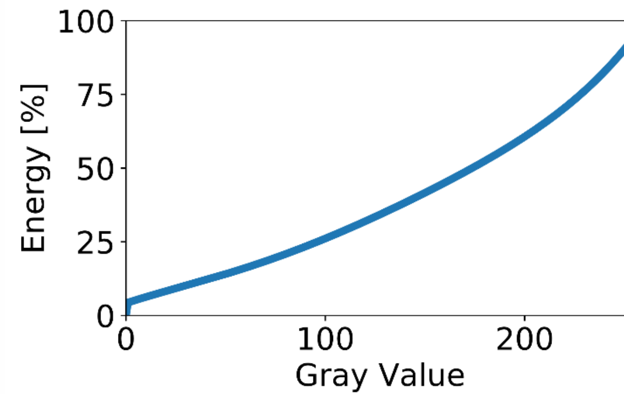
Gray Scale Exposure

- Light absorption in photoresist is a non-linear process



- Modify *how* energy is distributed into gray levels





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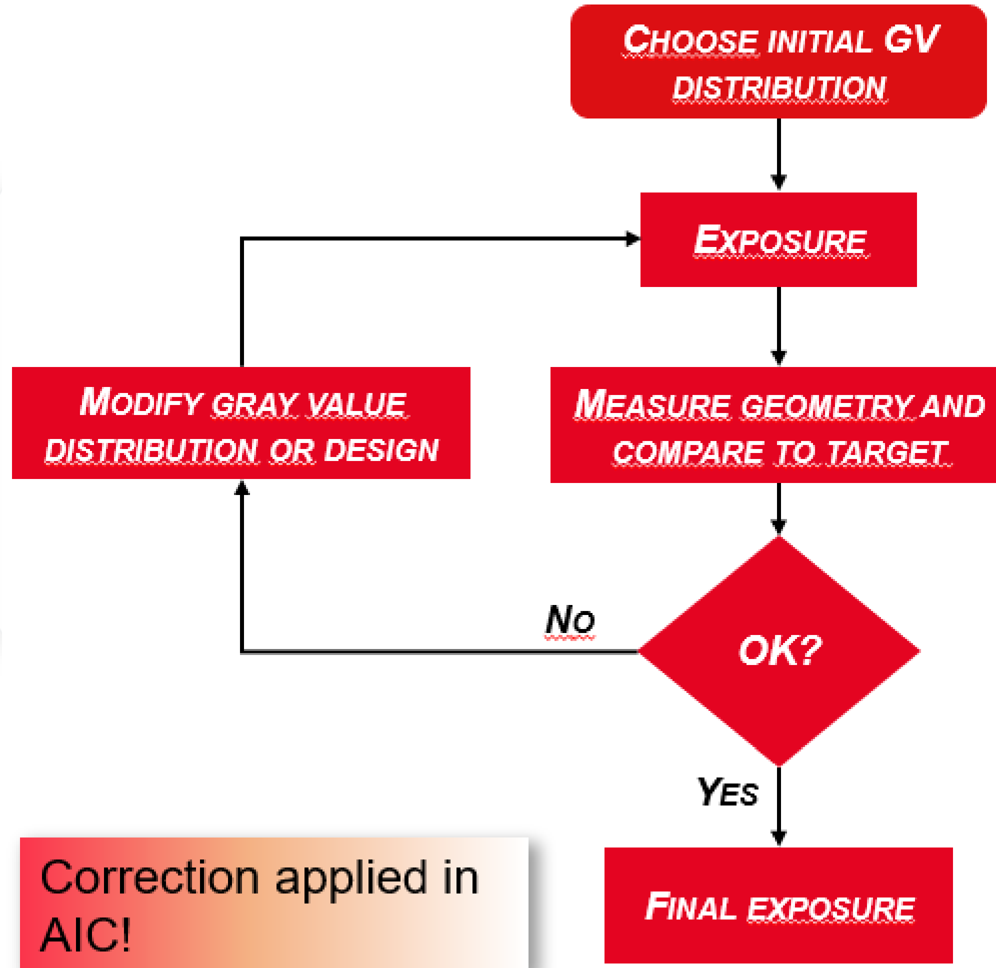
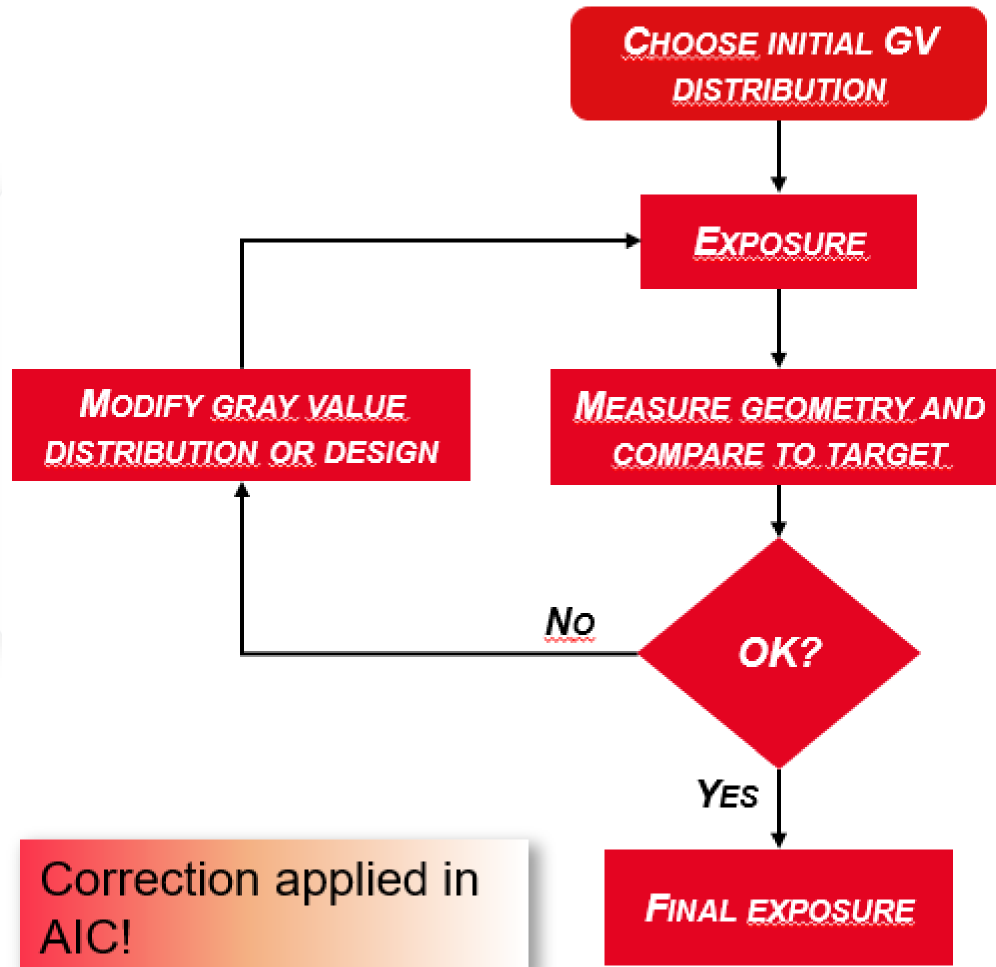
Laser Grey-Tone Correction

Experimental / iterative approach



Laser Grey-Tone Correction

Experimental / iterative approach



WORKS QUITE WELL, BUT…

- … can be very time consuming

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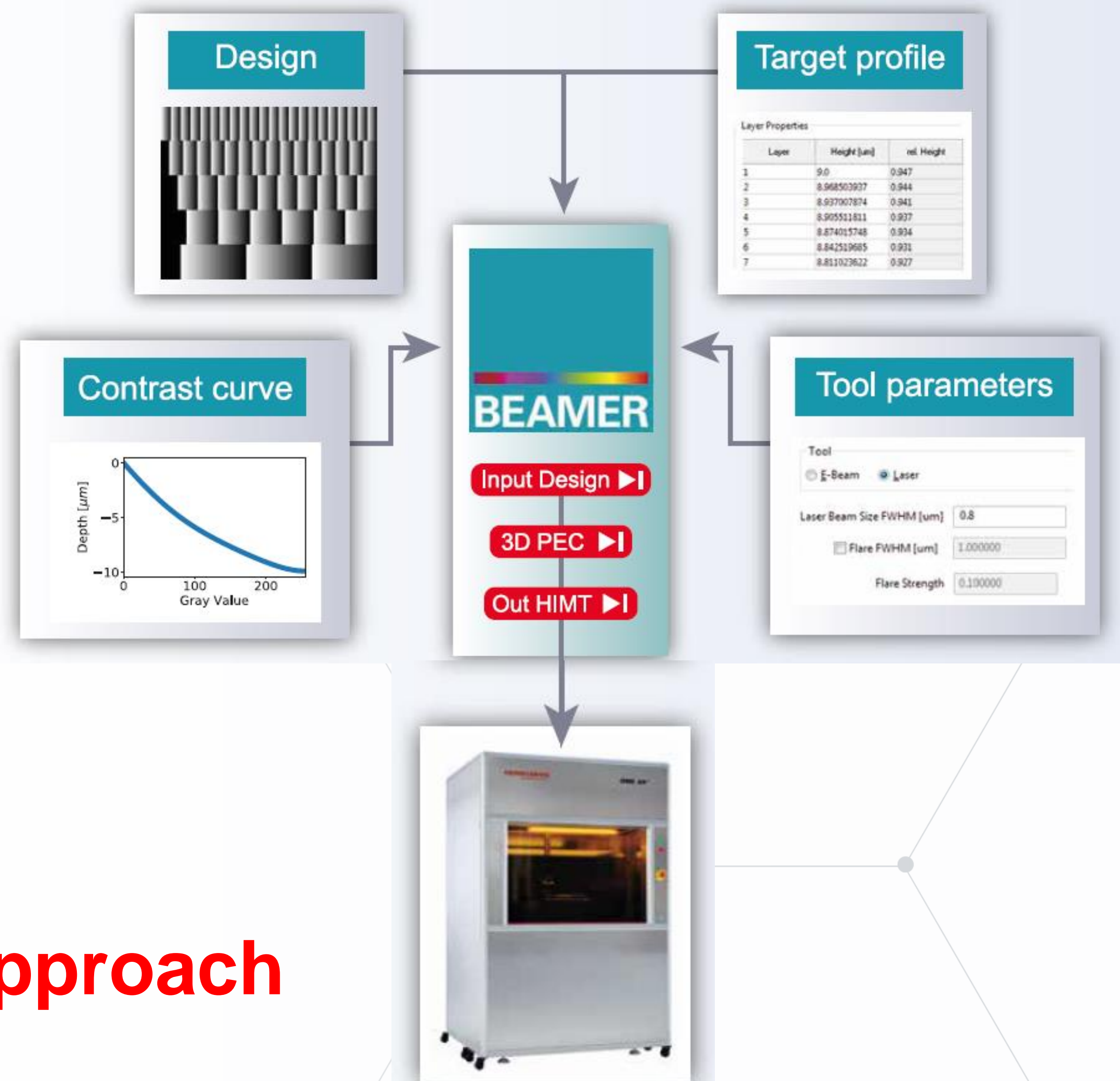
Laser Grey-Tone Correction

BEAMER offers a streamlined workflow to prepare exposure data for generating 3D resist profiles:

-Import PNG or GDS with target resist heights

-Import resist contrast curve

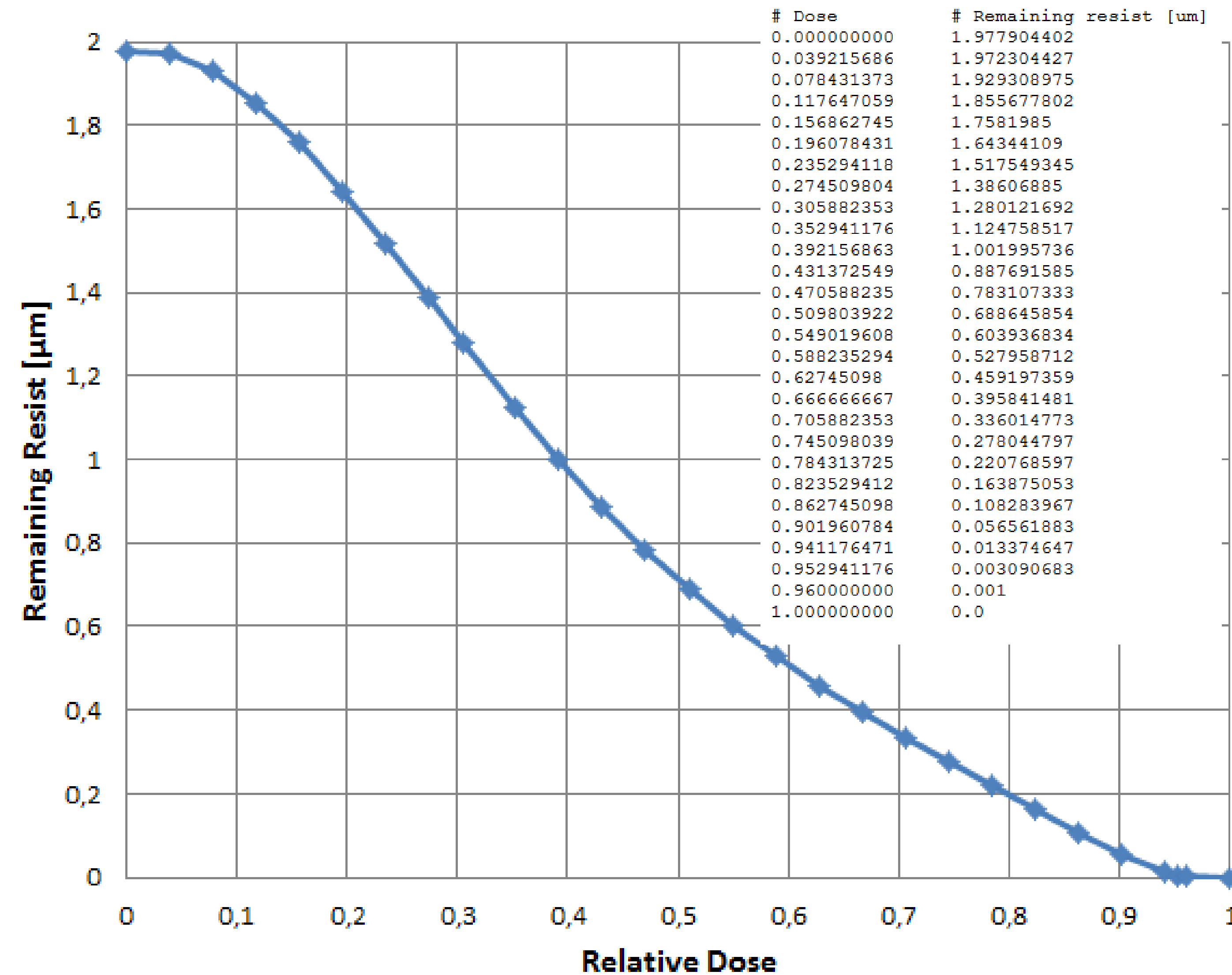
-Output: Corrected data in native Heidelberg Instruments machine-readable format. No further data preparation required for exposure



Model Based Approach

Laser Example Process

- Wafer stack
  - Substrate: 4" glass plate (soda lime)
  - Resist: 2.2µm of AZ1512HS
- Exposure
  - DWL66+ Write Mode II and optical aut
  - 1% (filter) of 230mW (405nm diode las
- Development
  - Developed with AZ726MIF 3min. @21
- Measurement
  - confocal microscope (Nanofocus)



# Dose	# Remaining resist [um]
0.000000000	1.977904402
0.039215686	1.972304427
0.078431373	1.929308975
0.117647059	1.855677802
0.156862745	1.7581985
0.196078431	1.64344109
0.235294118	1.517549345
0.274509804	1.38606885
0.305882353	1.280121692
0.352941176	1.124758517
0.392156863	1.001995736
0.431372549	0.887691585
0.470588235	0.783107333
0.509803922	0.688645854
0.549019608	0.603936834
0.588235294	0.527958712
0.62745098	0.459197359
0.666666667	0.395841481
0.705882353	0.336014773
0.745098039	0.278044797
0.784313725	0.220768597
0.823529412	0.163875053
0.862745098	0.108283967
0.901960784	0.056561883
0.941176471	0.013374647
0.952941176	0.003090683
0.960000000	0.001
1.000000000	0.0

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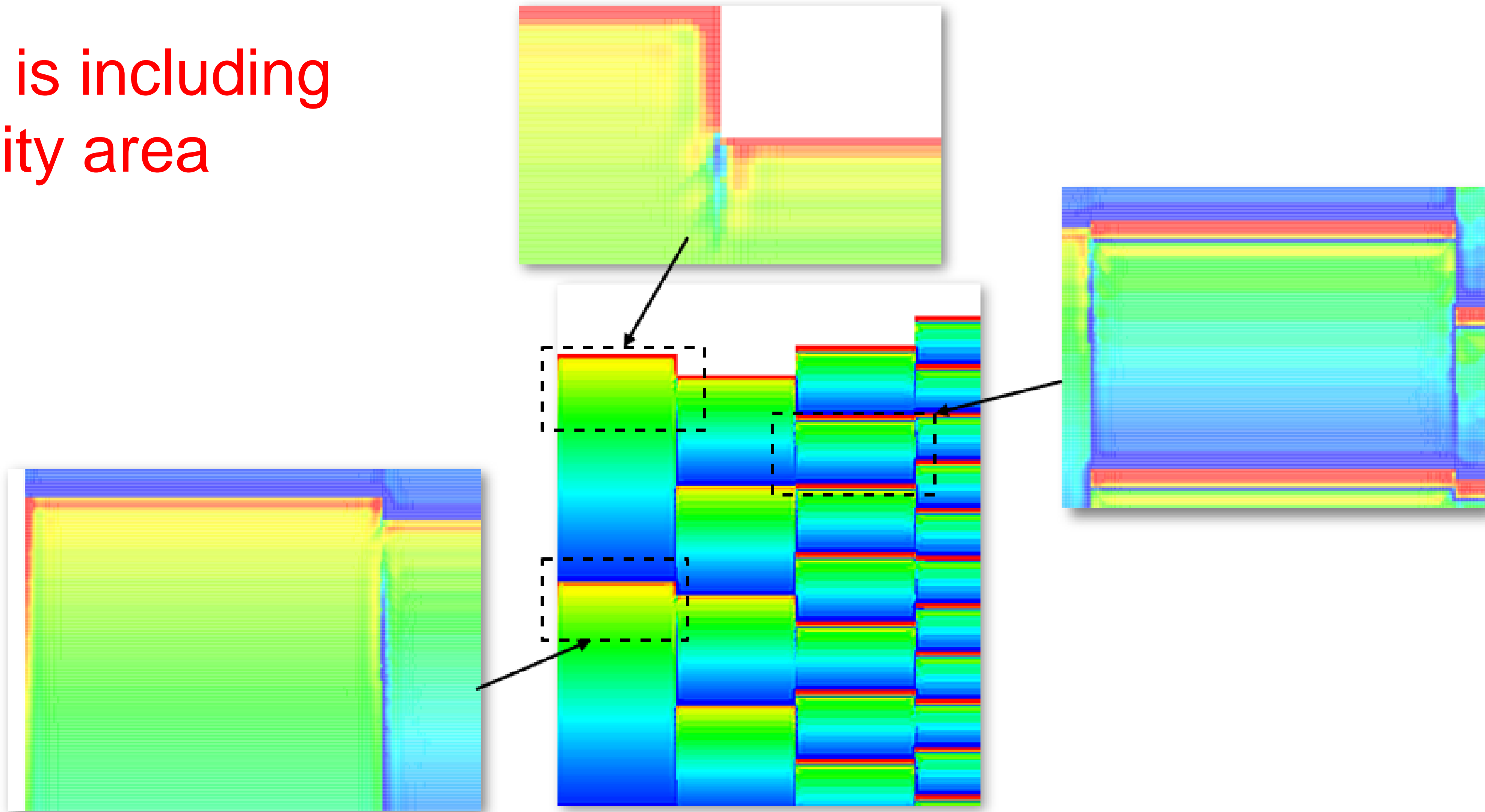
Exposure data after correction

Correction is including the proximity area



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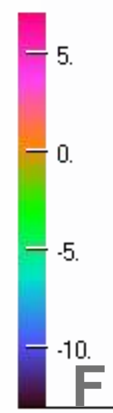
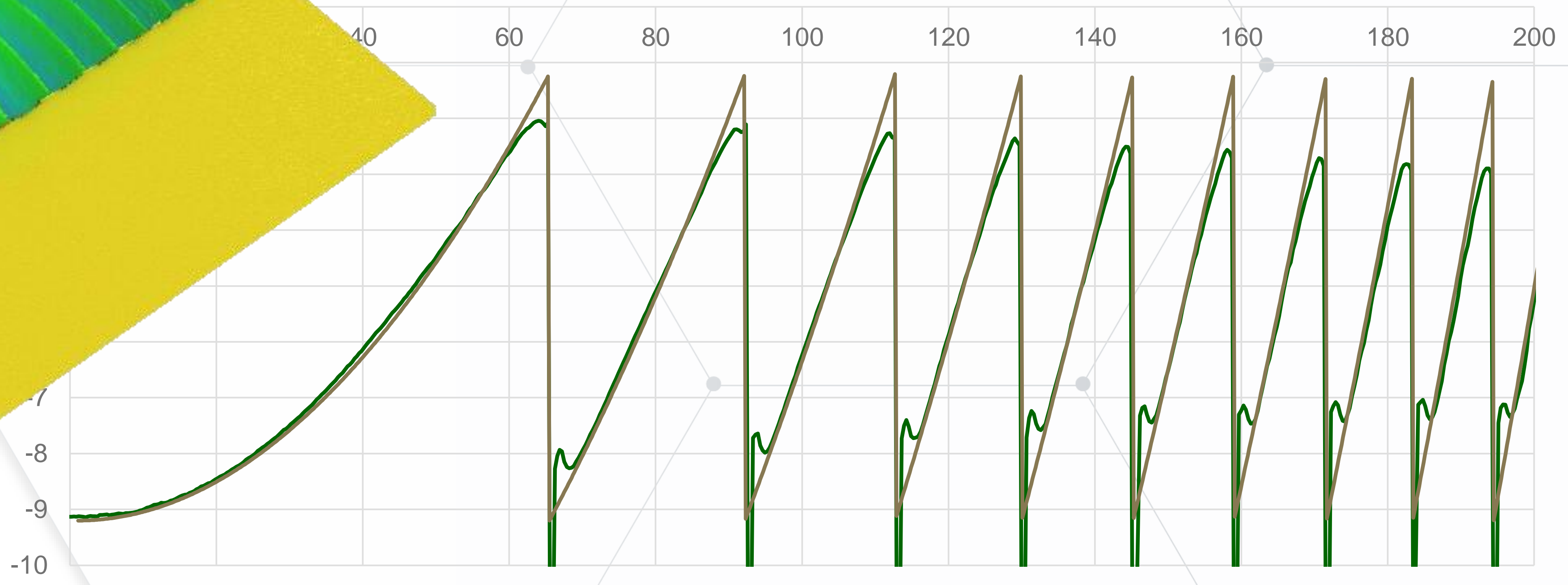
Fresnel Lens





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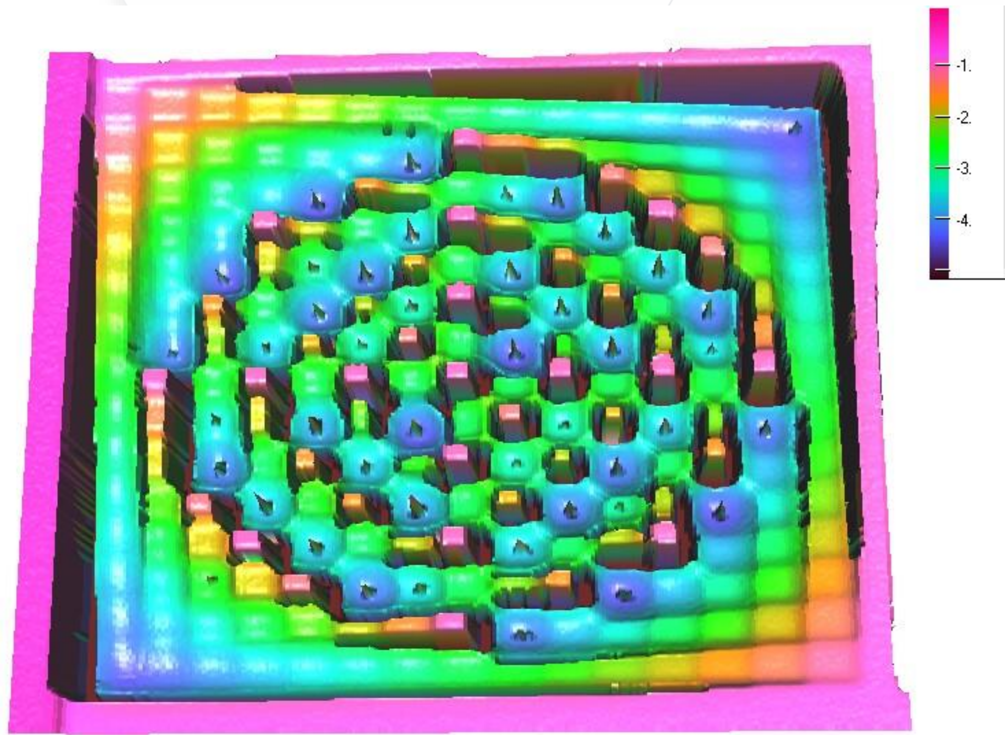
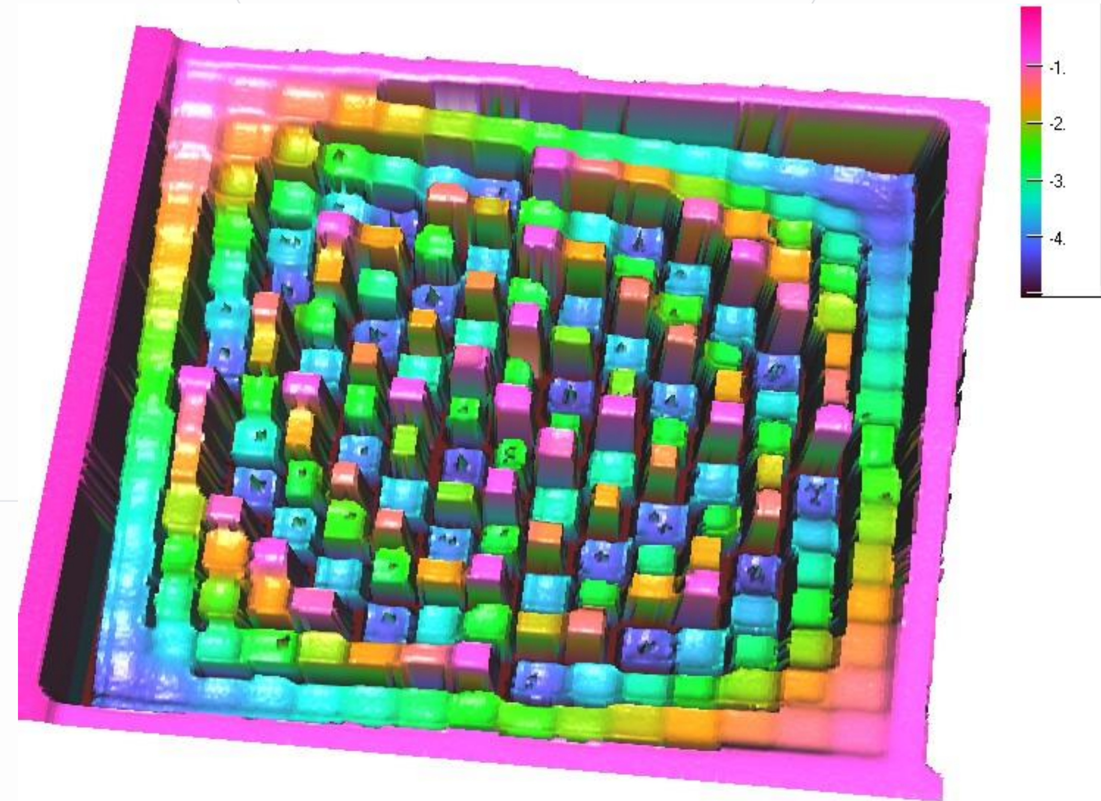
DOE – 3.2 µm Squares/Pixels



HIMT conventional



with BEAMER

BEAMER is significantly better for the DOE.

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Agenda

- バイナリ露光における近接効果と、現像による形状への影響
- Rule OPC と Model OPC 補正のご紹介
- グレイスケール露光における補正
- LAB によるシミュレーション
  - 3Dシミュレーション
  - 2D OPCシミュレーション
- まとめ

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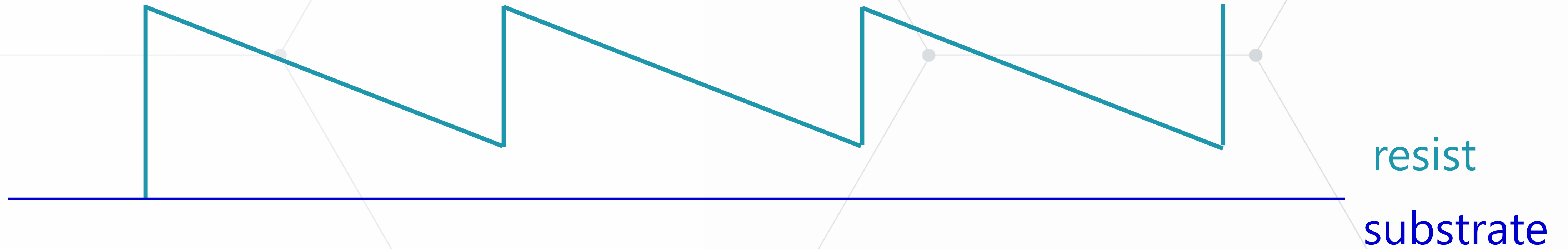
3D-PEC : Design Example



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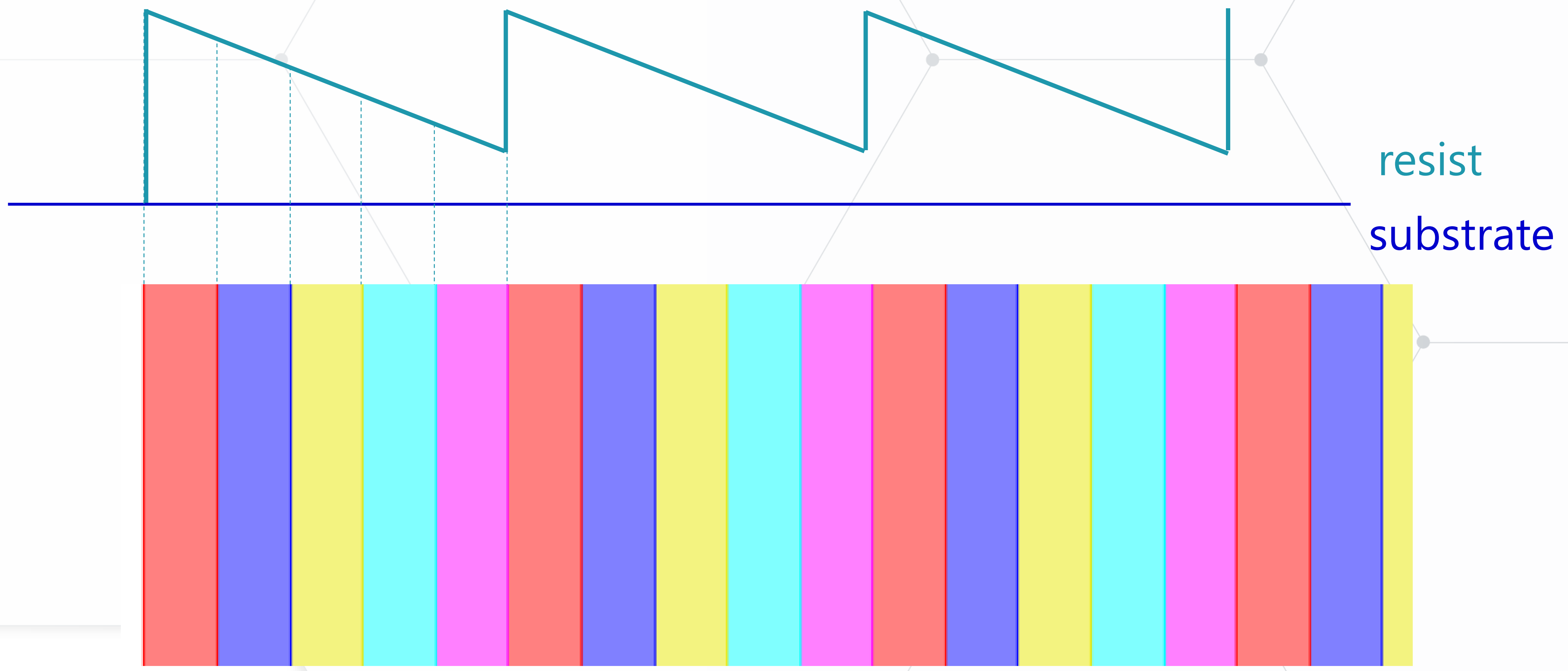
3D-PEC : Design Example



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LAB Simulation

LAB

File Edit View Help

Cut Copy Paste Up Save Variables Run Run To Cancel Pause Resume Reset Material Database Flow Setup Results Detach

Modules Variables Flow Libraries Examples

BG_simulation_Lab.lftxt

Layout & Data Handling
Import | Import 3D | Edit
Export | Export 3D

Simulation
Proximity | Projection | Laser
E-Beam 3D | Resist | Etching
Metrology | Model-OPC | Rule-OPC

Layout Operation
Extract | Transform | Grid
Heal | NOT | Bias
Size | OR | AND
XOR | P-XOR | MINUS
Filter | Mapping
Merge | FDA

Control
Split | Loop | Script
Calibration | Optimizer | Comment

In LEDB
Laser
Resist

Module Info | Log Info | Error/Warnings

Import C:¥Users¥shimizu¥Desktop¥Use Files¥Laser Lithography¥2017-05-18--internal--Heidelberg_Example-Flow¥Flow for LAB¥BG_steps_3DPEC_90deg.ldb
File type: LEDB file
Layerset: *

Exposure
Laser exposure

View Area [um]: -39.314, -9.644; 41.607, 11.708

GenISys
Advancing the Standard

LAB Simulation

LAB

File Edit View Help

Cut Copy Paste Up Save Variables Run Run To Cancel Pause Resume Reset Material Database Flow Setup Results Detach

Modules | Variables | Flow Libraries | Examples

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Split | Loop | Script
Calibration | Optimizer | Comment

BG_simulation_Lab.lftxt

In LEDB
Laser
Resist

Module Info | Log Info | Error/Warnings

Import C:¥Users¥shimizu¥Desktop¥Use Files¥Laser Lithography¥2017-05-18--internal--Heidelberg
File type: LEDB file
Layerset: *

Exposure
Laser exposure

View Area [um]: -39.314, -9.644; 41.607, 11.708

GenISys
Advancing the Standard

LAB Simulation

LAB

File Edit View Help

Cut Copy Paste Up Save Variables Run Run To Cancel Pause Resume Reset Material Database Flow Setup Results Detach

Modules Variables Flow Libraries Examples

Layout & Data Handling
Import Import 3D Edit
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Simulation
Proximity Projection Laser
E-Beam 3D Resist Etching
Metrology Model-OPC Rule-OPC

Layout Operation
Extract Transform Grid
Heal NOT Bias
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Filter Mapping
Merge FDA

Control
Split Loop Script
Calibration Optimizer Comment

BG_simulation_Lab.lftxt

In LEDB
Laser
Resist

R2

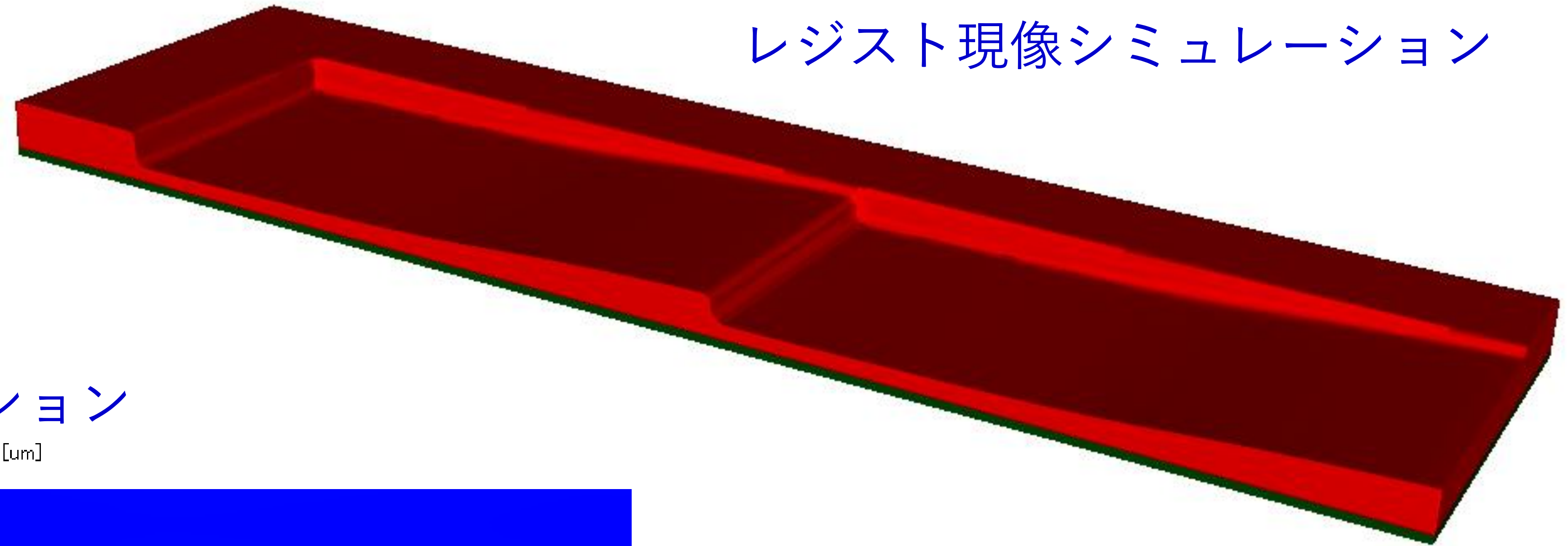
Module Info Log Info Error/Warnings

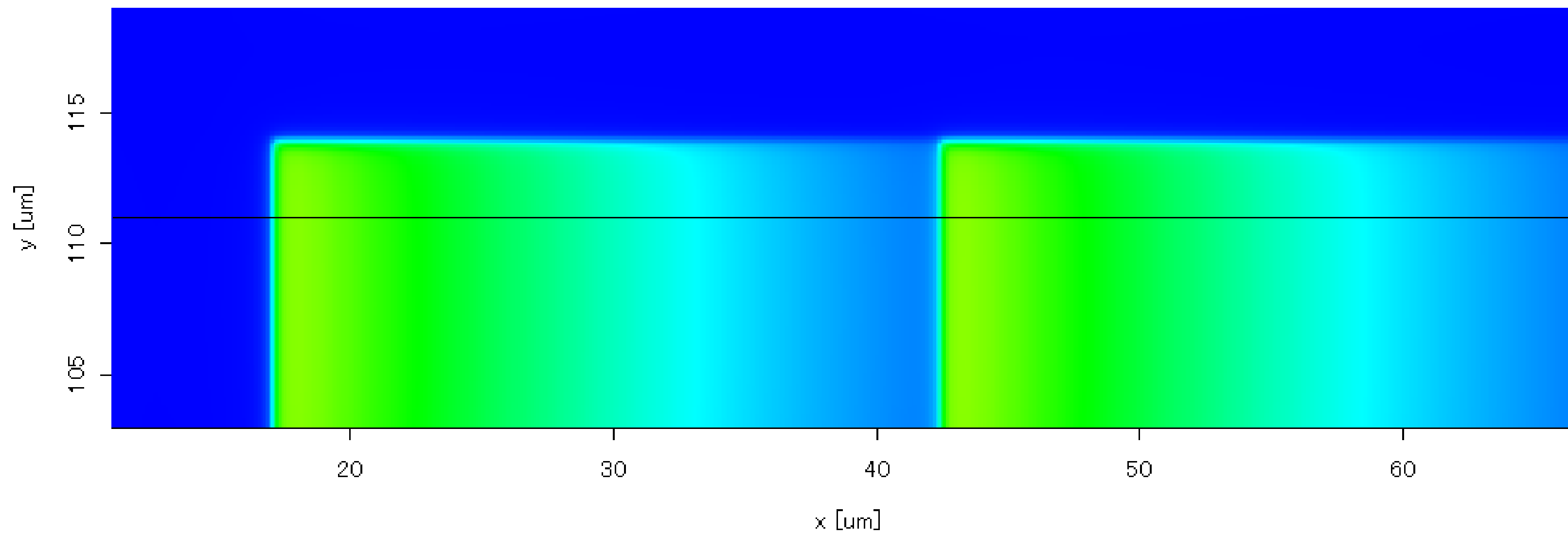
Import C:¥Users¥shimizu¥Desktop¥Use Files¥Laser Lithography¥2017-05-18--internal--Heidelberg_Example-Flow¥Flow for LAB¥BG_steps_3DPEC_90deg.ldb
File type: LEDB file
Layerset: *

Exposure
Laser exposure

View Area [um]: -39.314, -9.644; 41.607, 11.708

LAB Simulation





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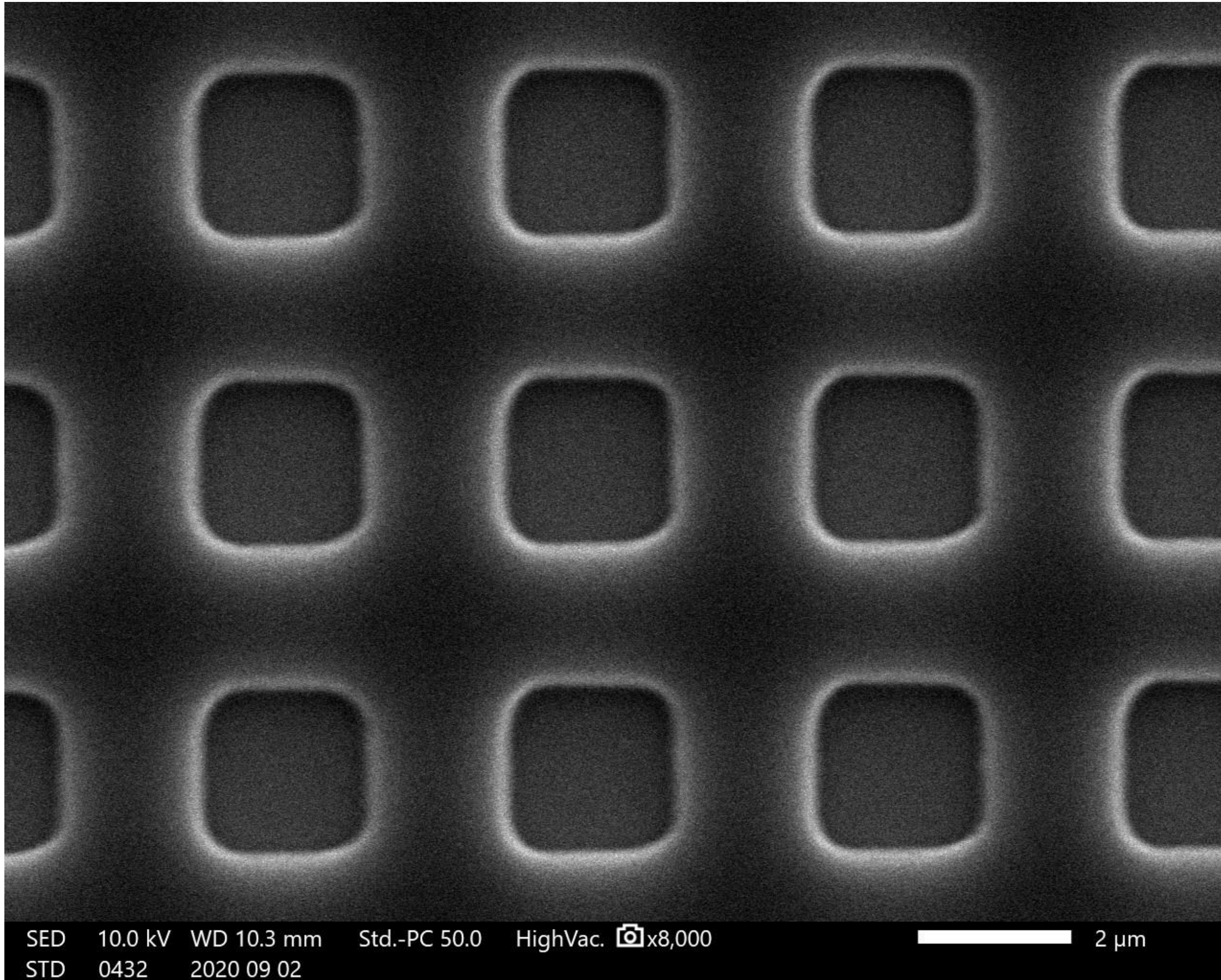
2um Square Dots

without correction



Corner Rounding = **0.65 um** (av.)

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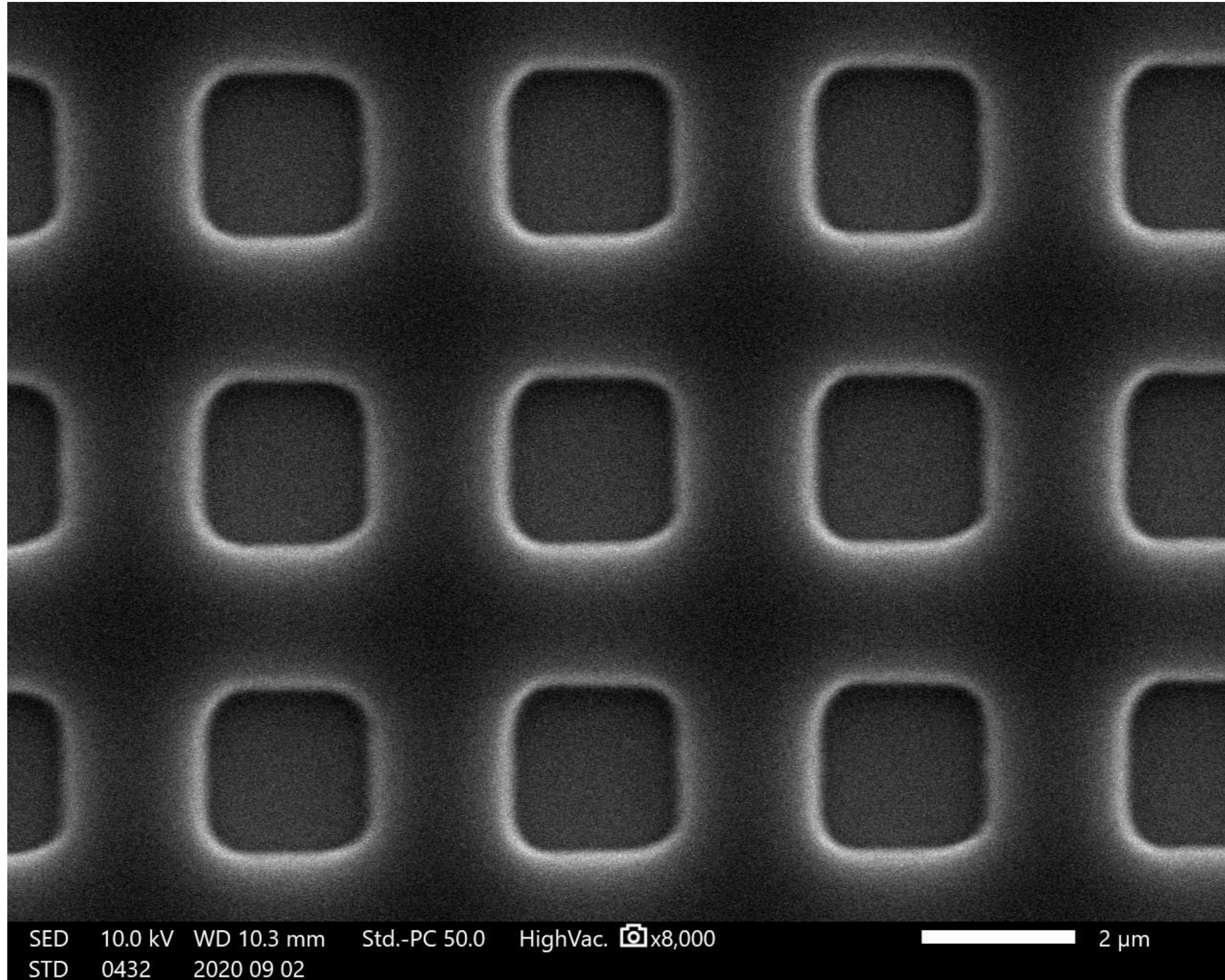
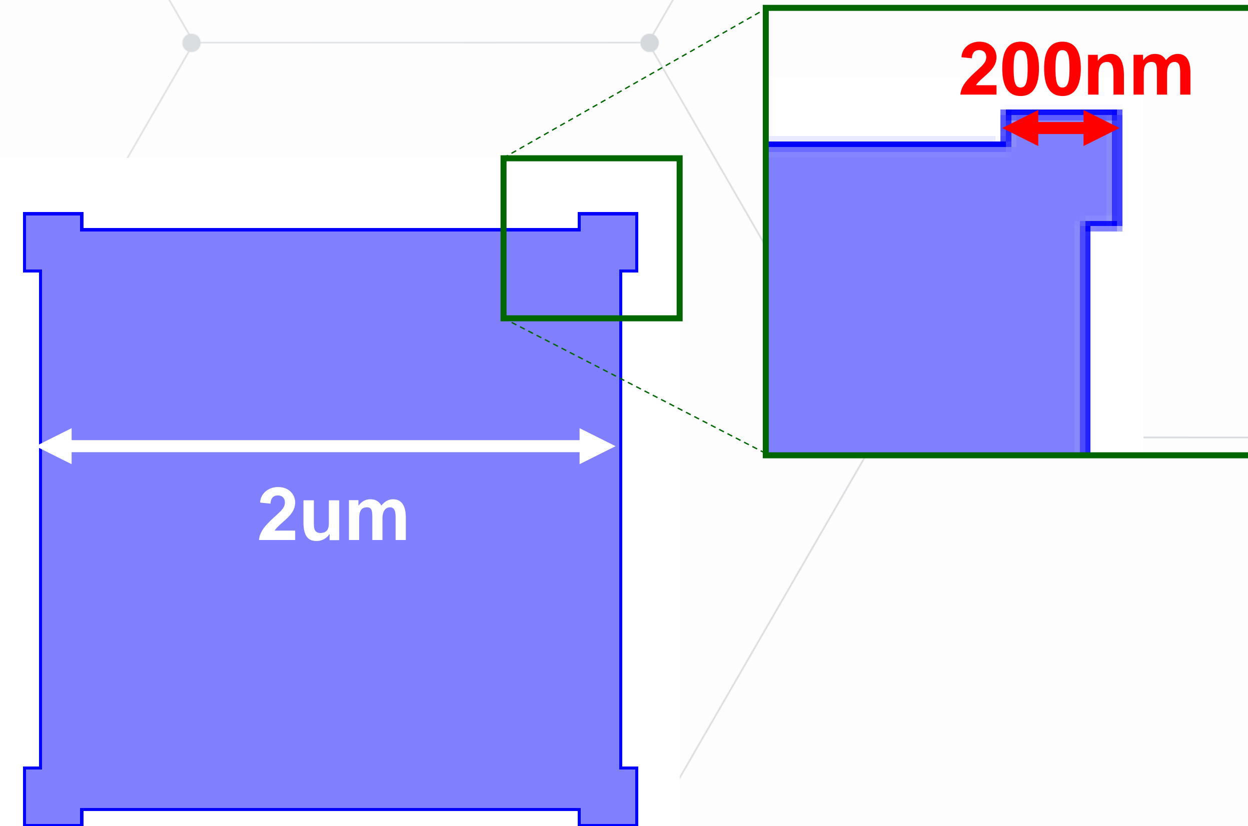
2um Square Dots

without correction



Corner Rounding = 0.65 um (av.)

200nm Serif with 70% overlap

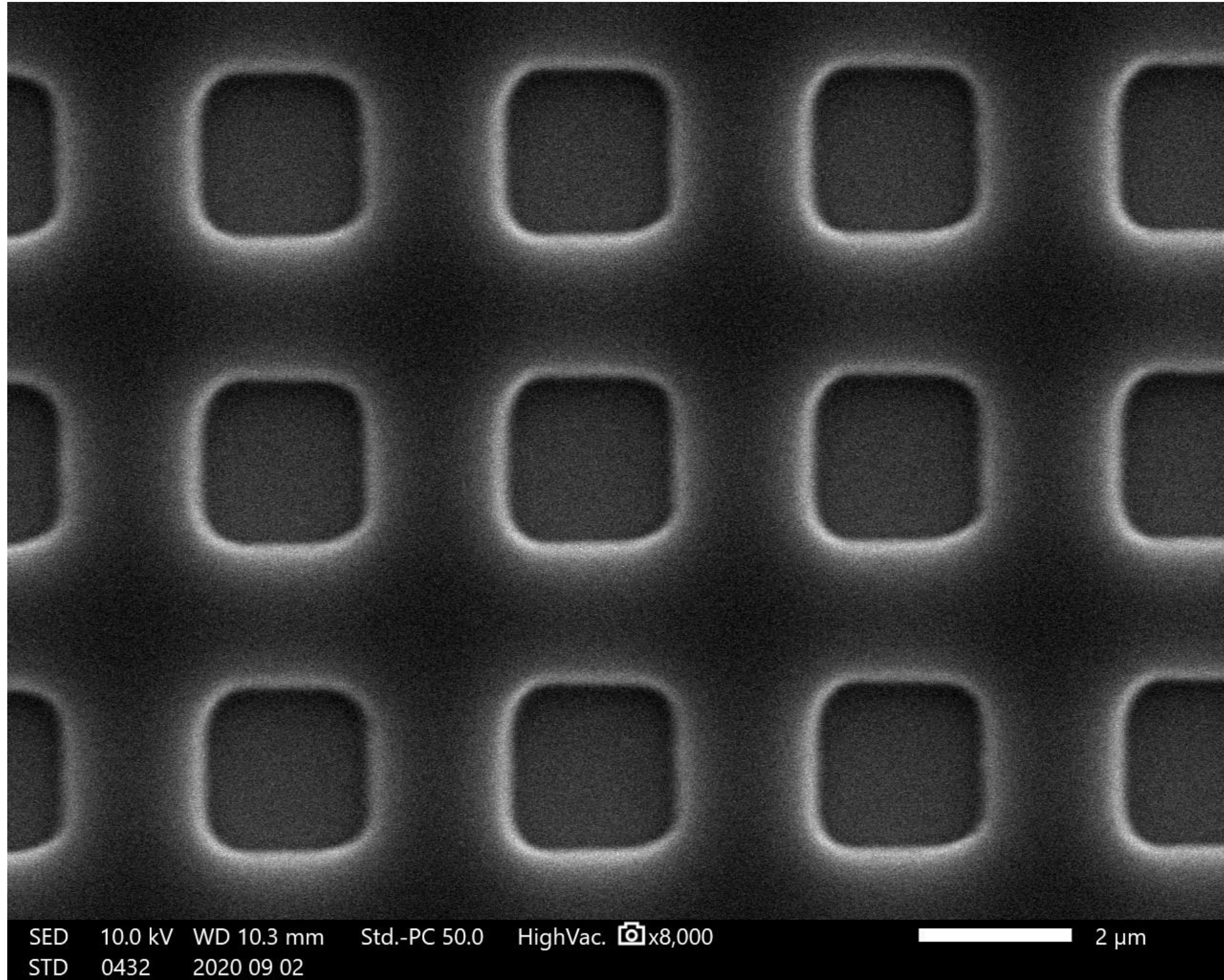


Rule-OPC

GenISys
Advancing the Standard

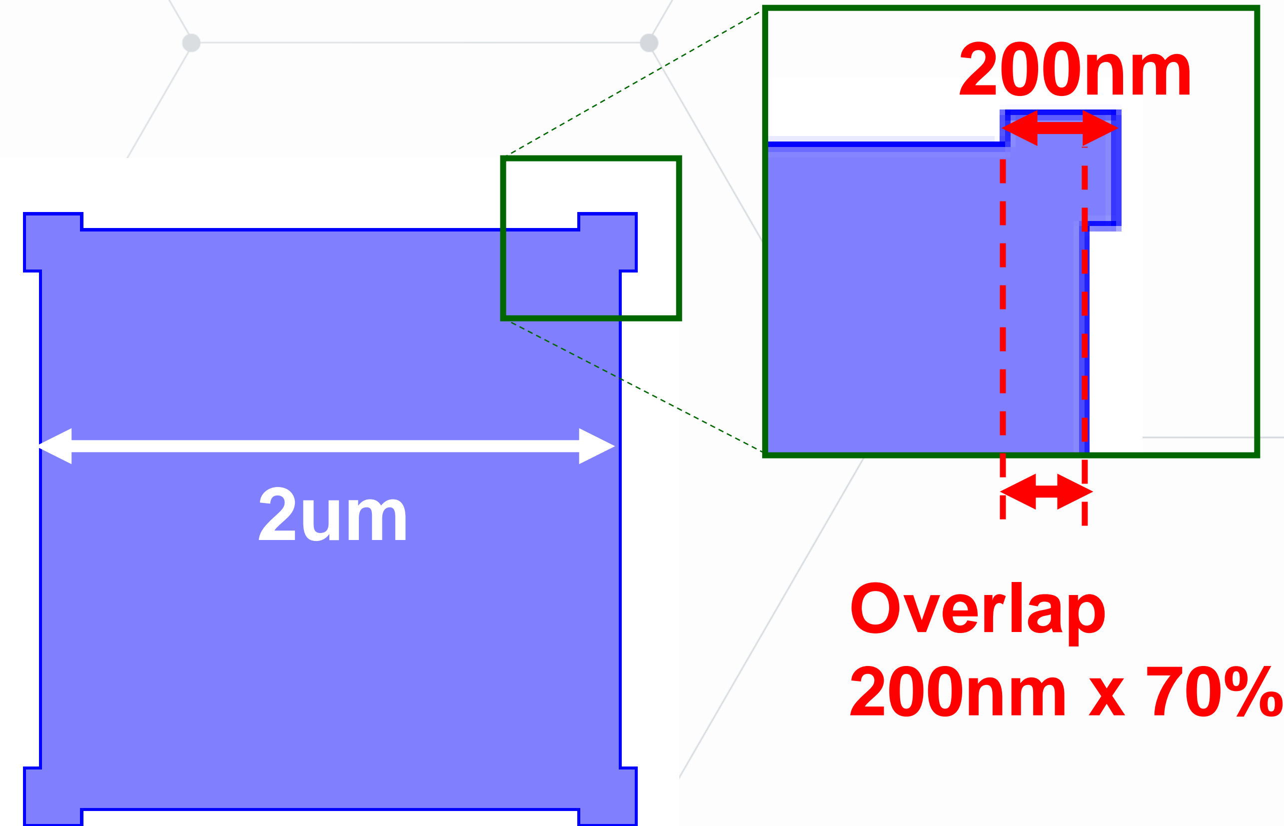
2um Square Dots

without correction



Corner Rounding = **0.65 um** (av.)

200nm Serif with 70% overlap

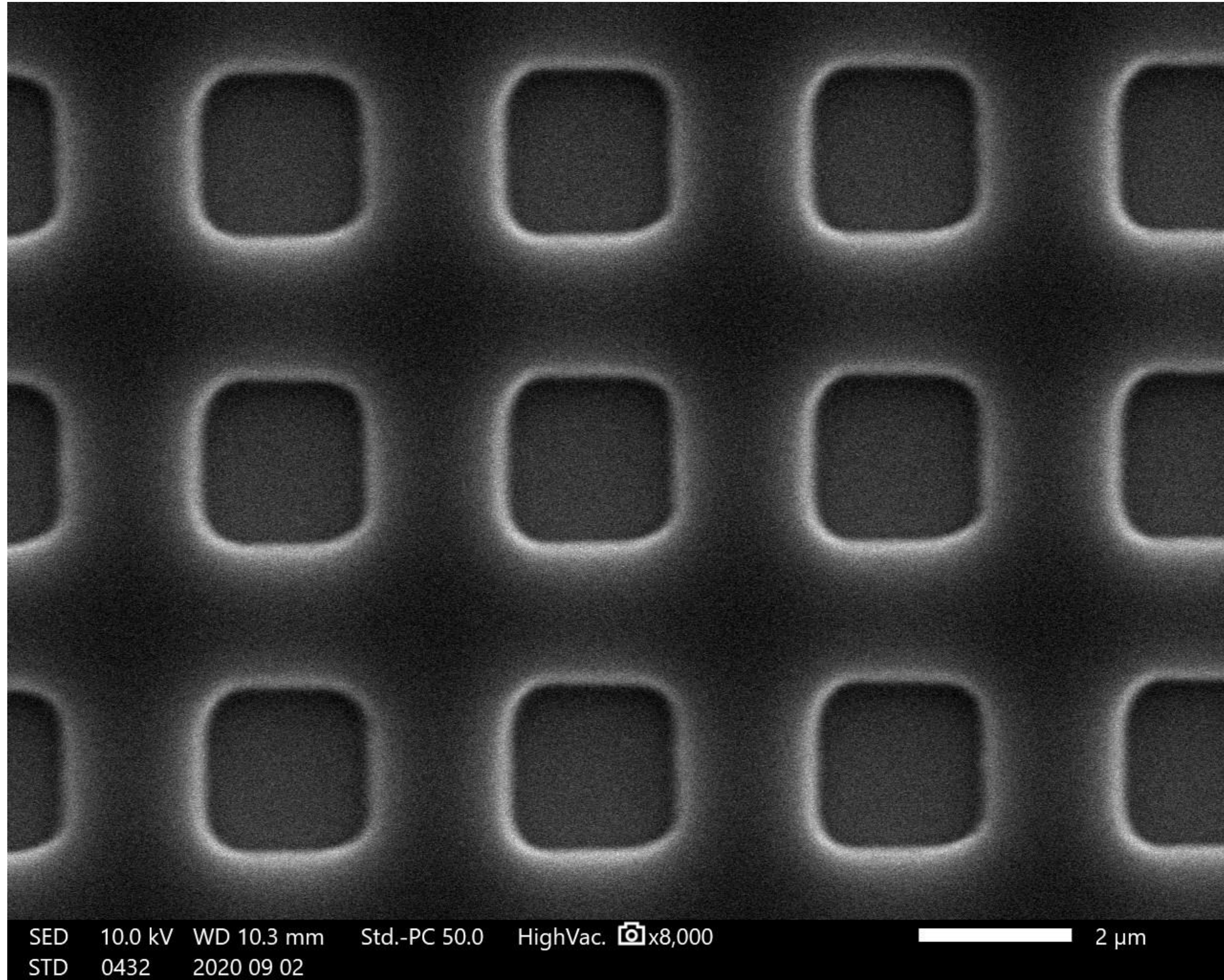


Rule-OPC

GenISys
Advancing the Standard

2um Square Dots

without correction



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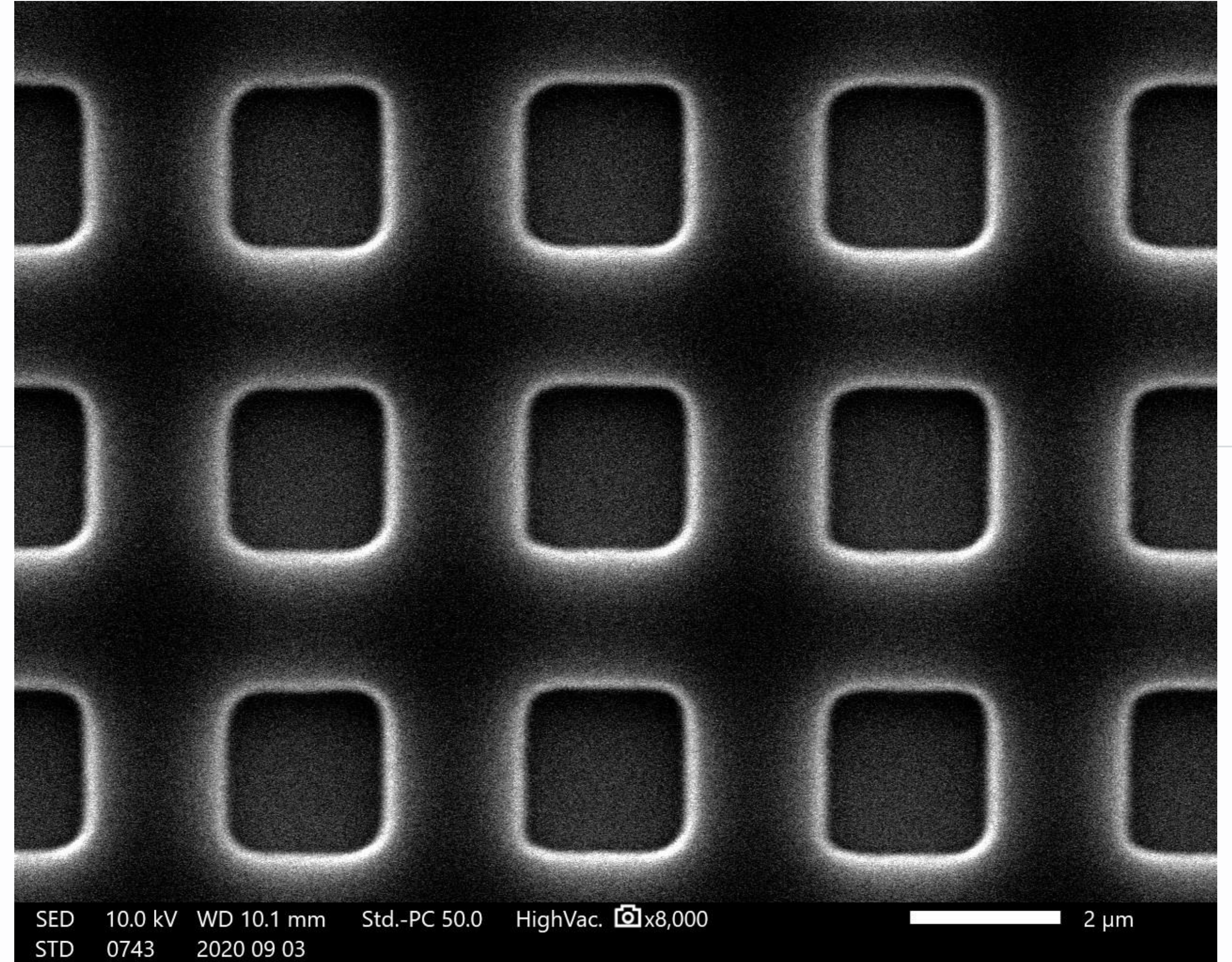

Corner Rounding = **0.65 um** (av.)

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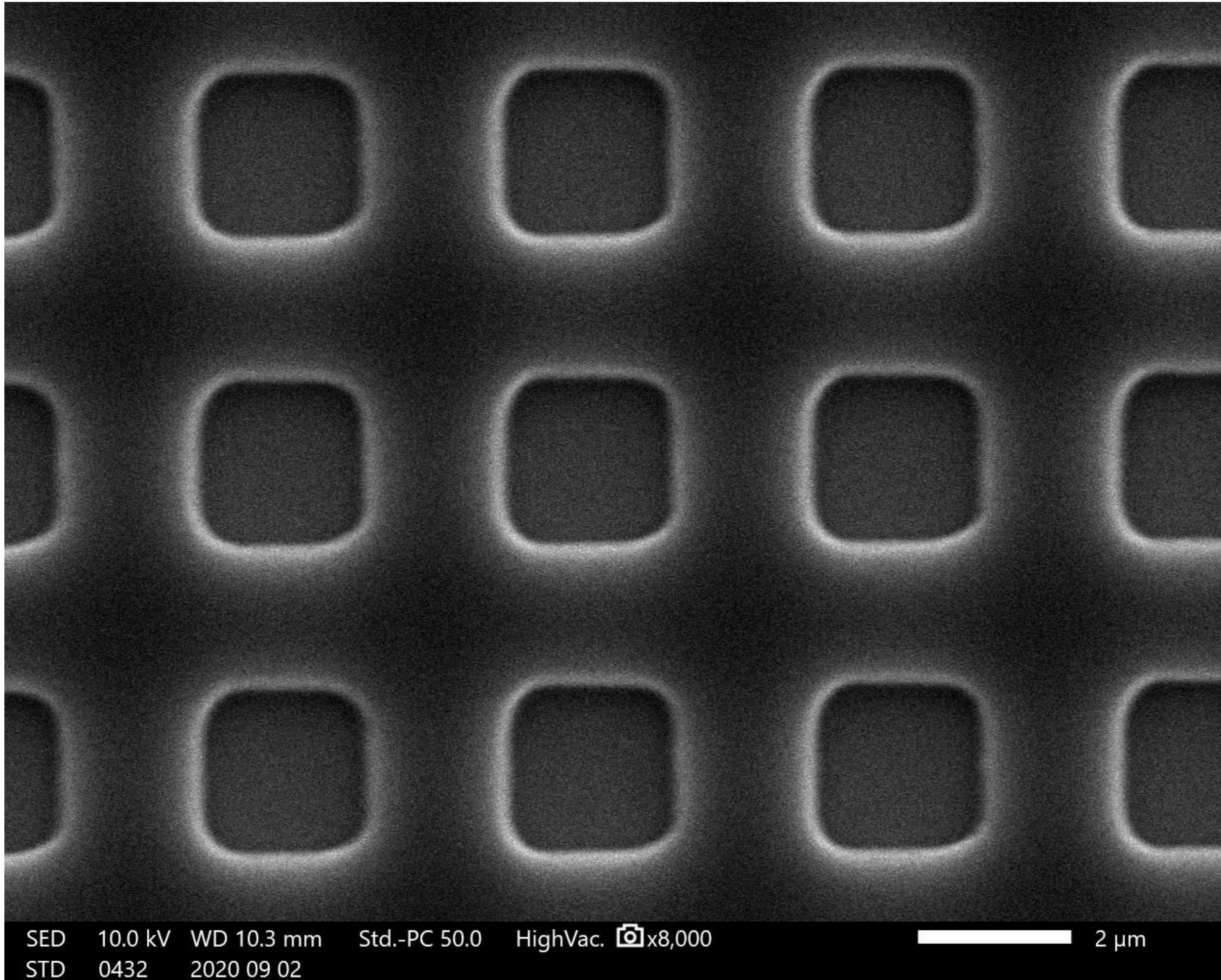
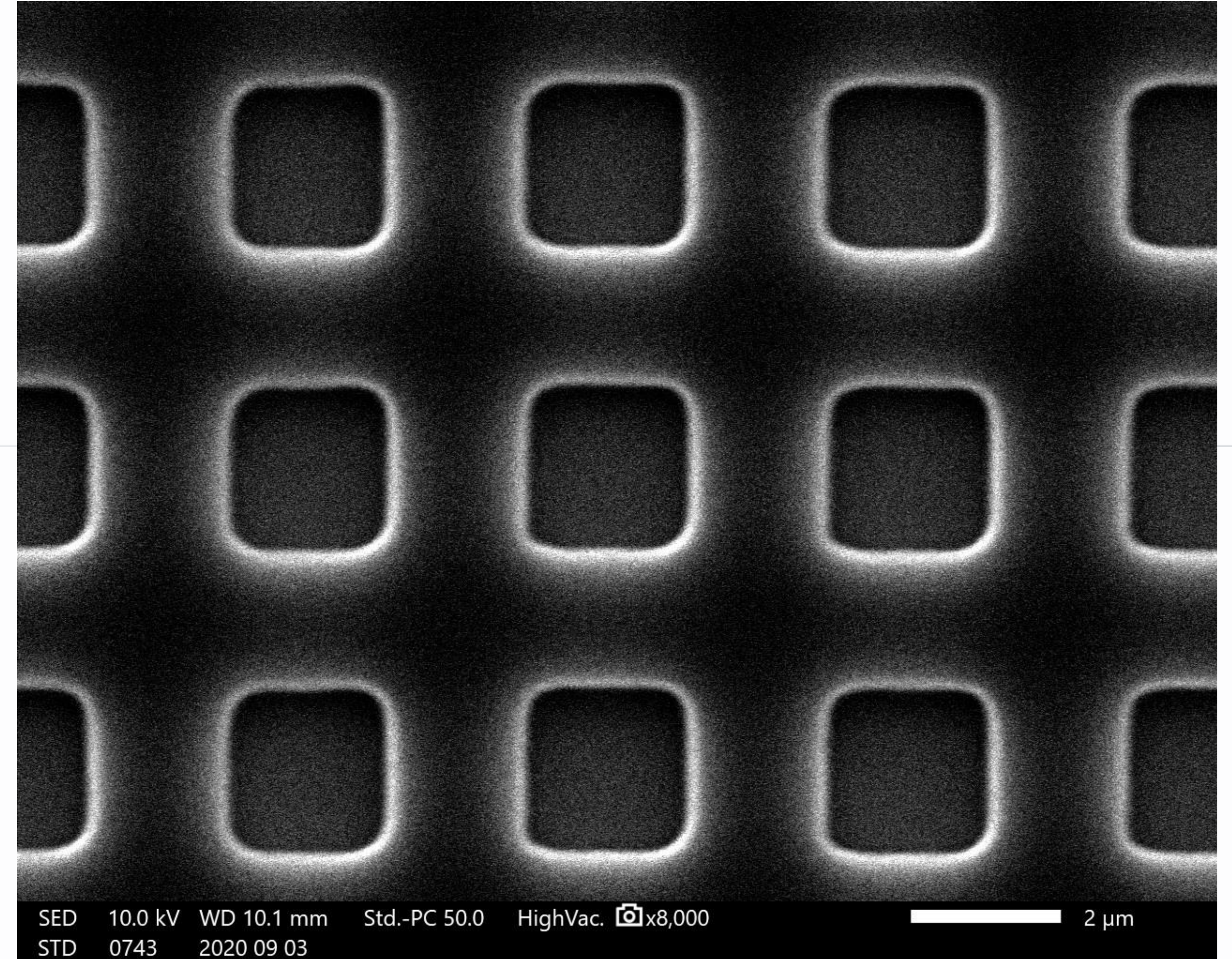
2um Square Dots

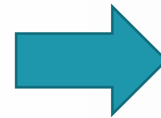
without correction



200nm Serif with 70% overlap



Corner Rounding = **0.65 um** (av.)



Corner Rounding = **0.56 um** (av.)

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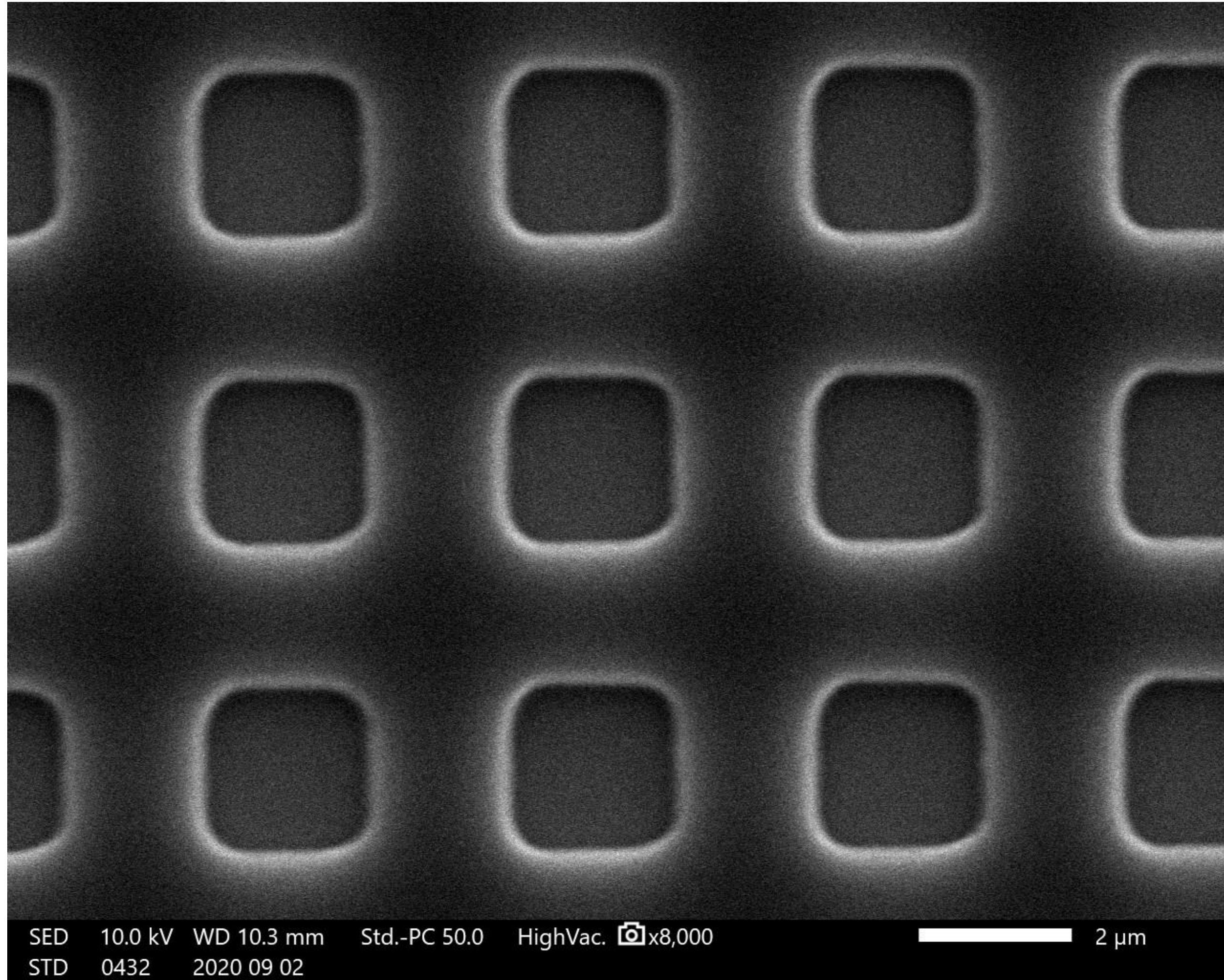
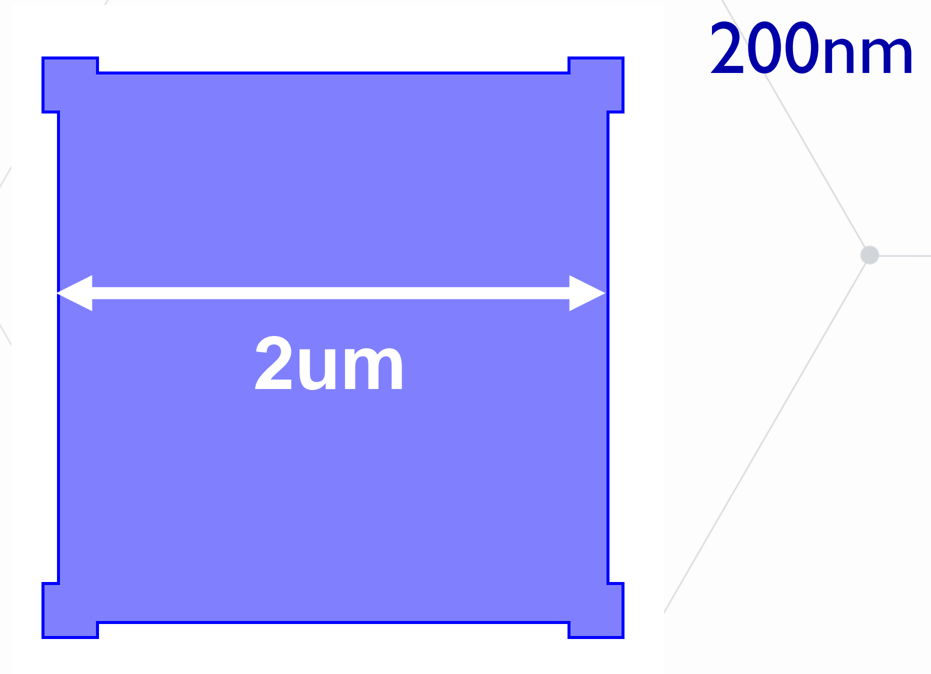
2um Square Dots

without correction



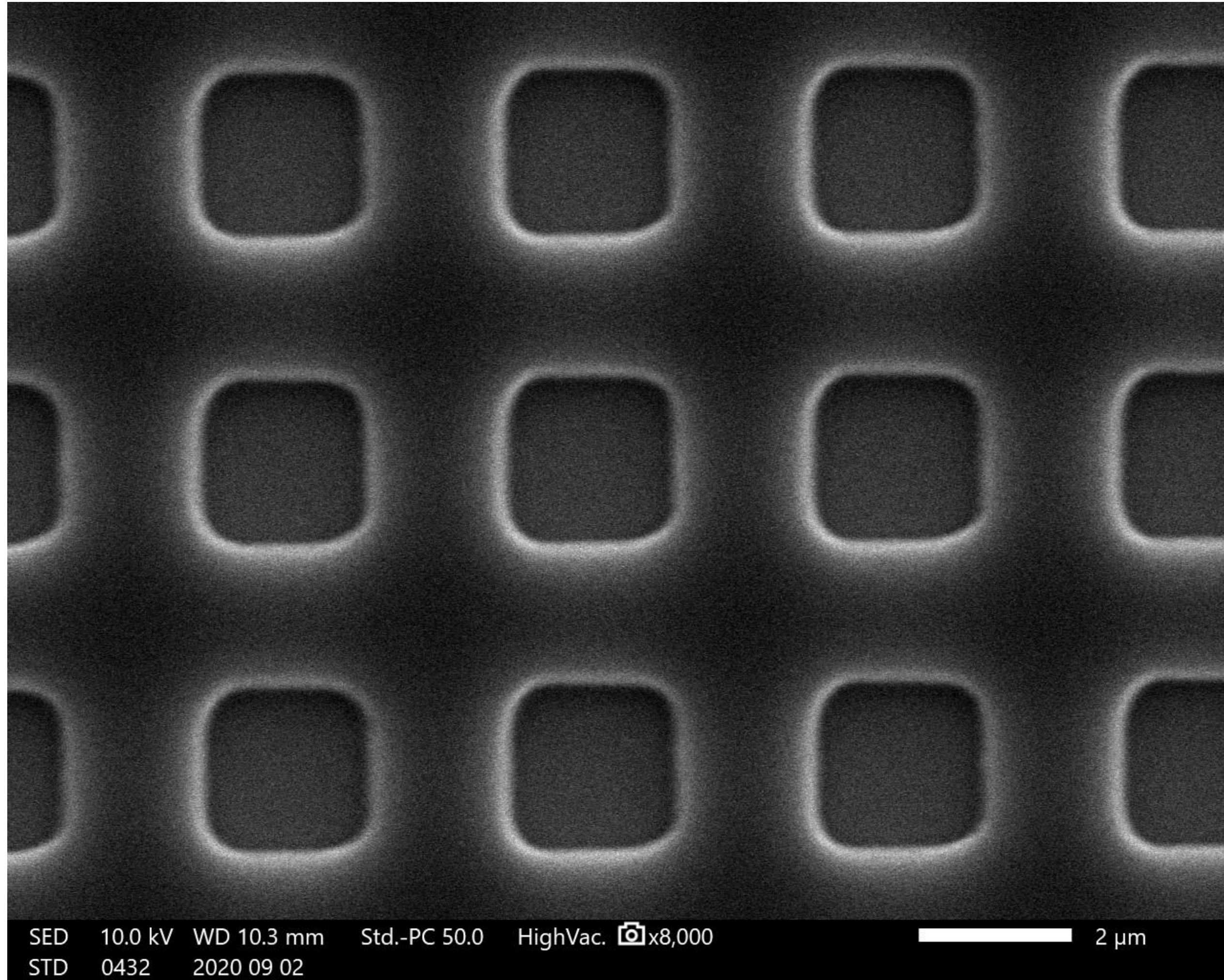


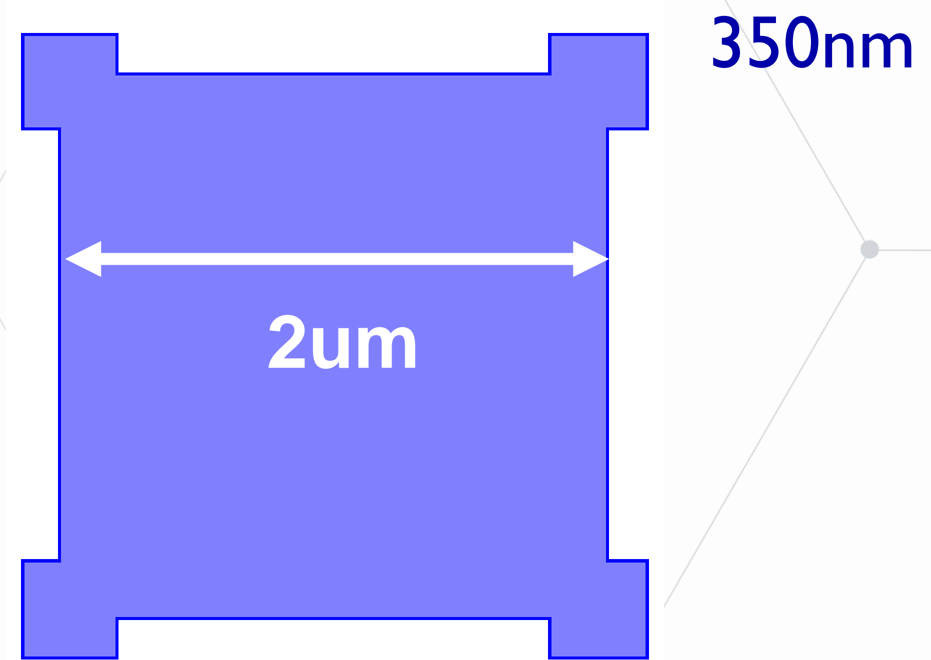
200nm

Rule-OPC

2um Square Dots

without correction





350nm

Rule-OPC

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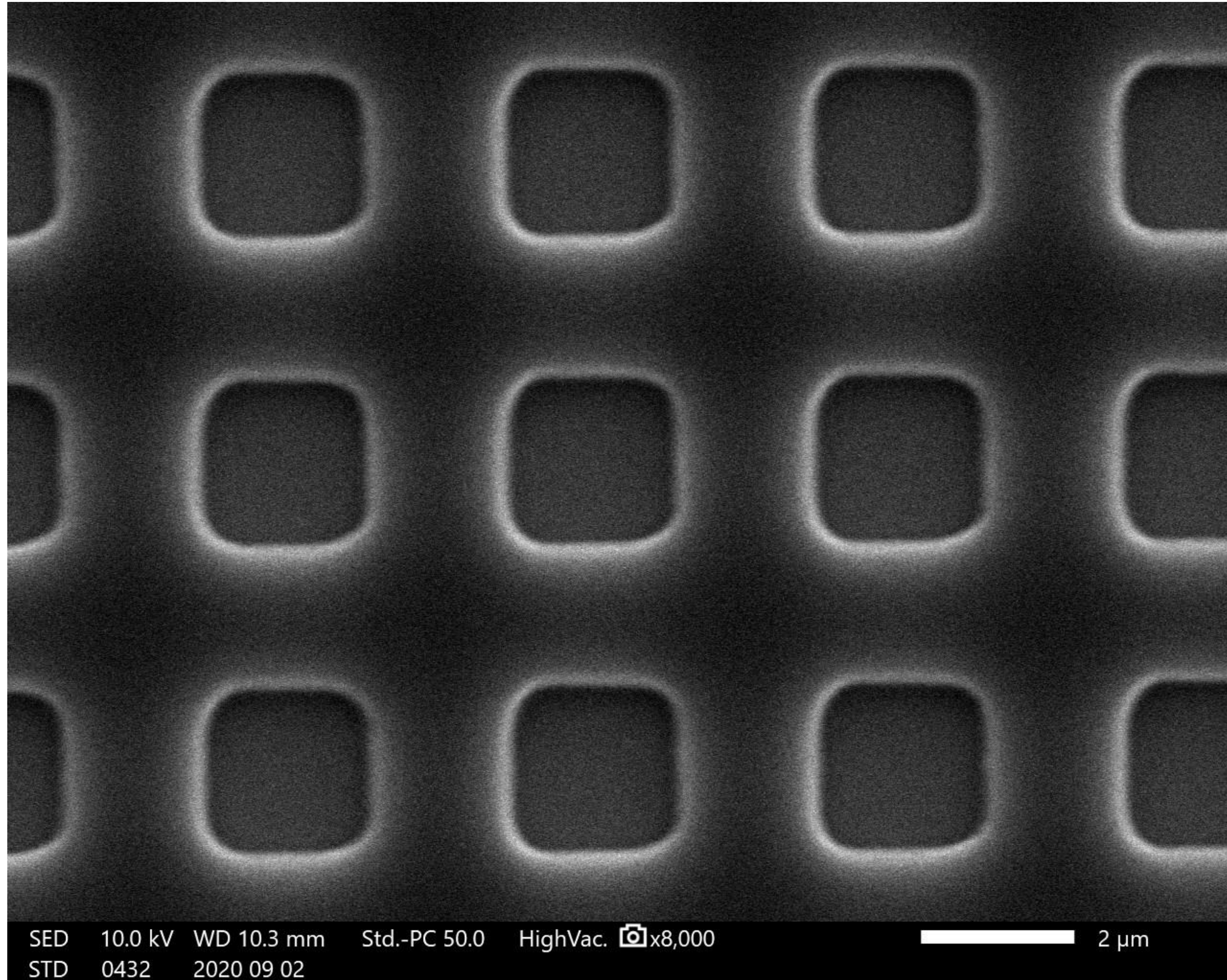
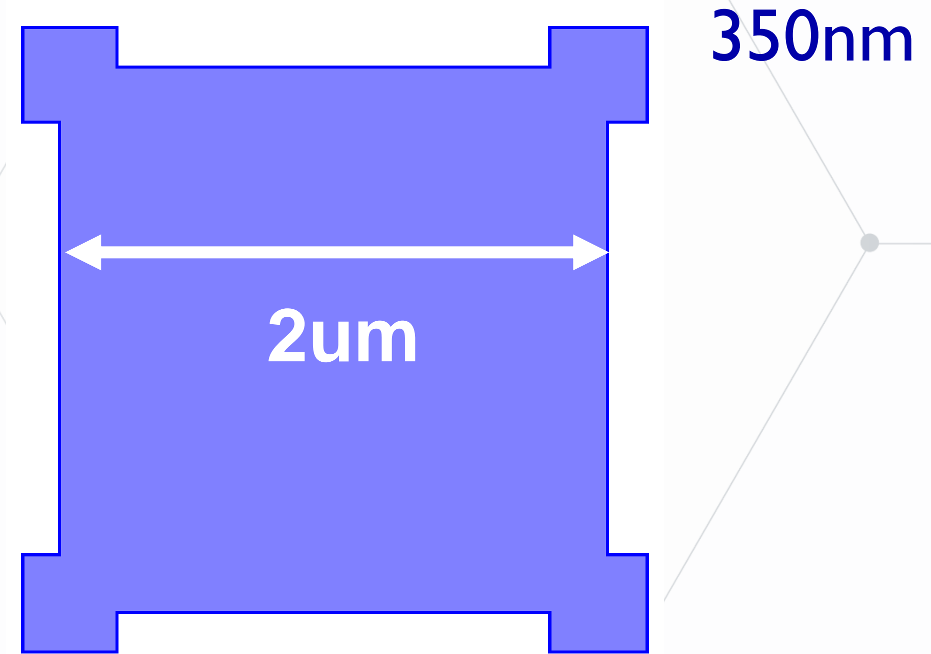
2um Square Dots

without correction



Aim is to see serif size & overlap influences by experiment

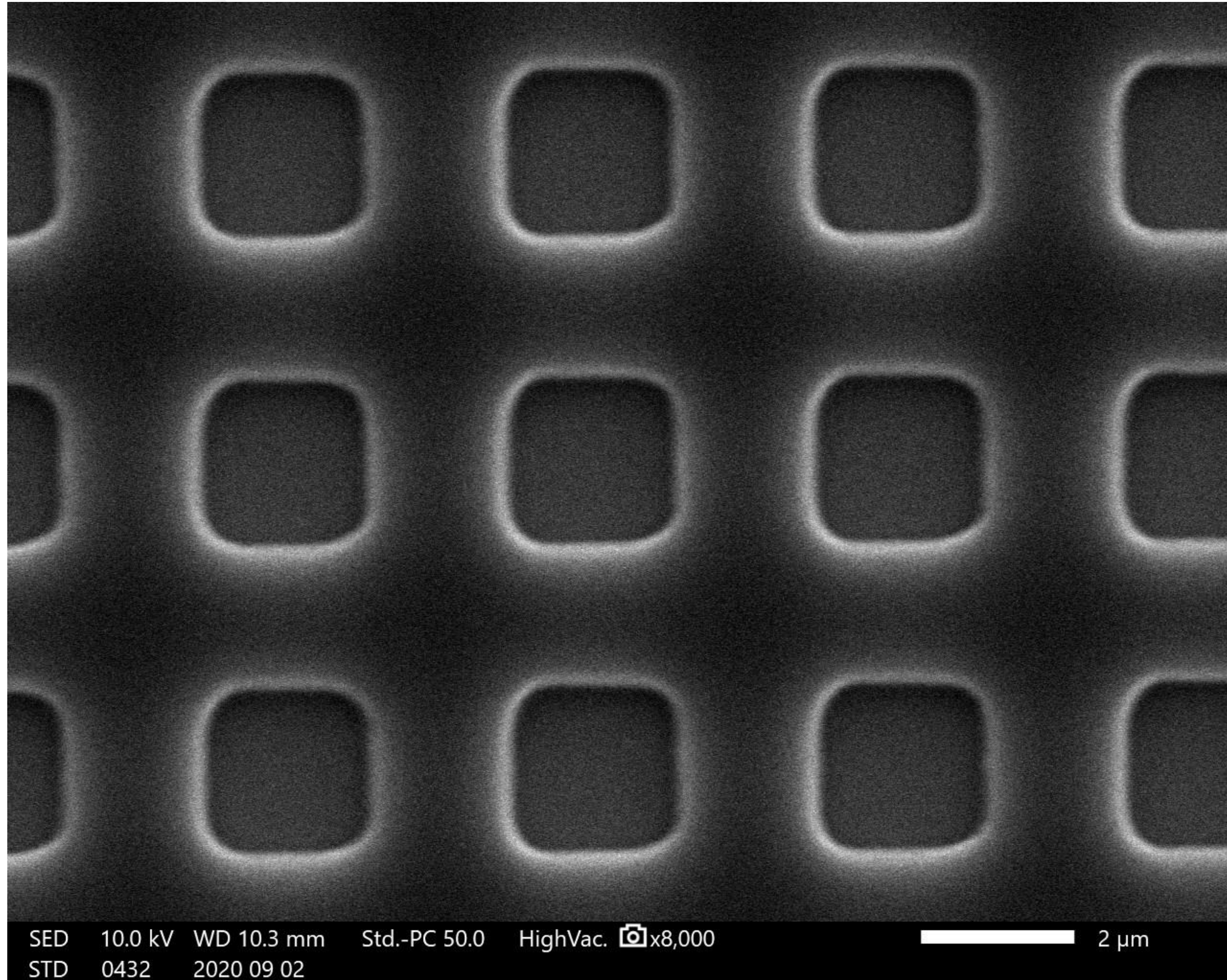
350nm



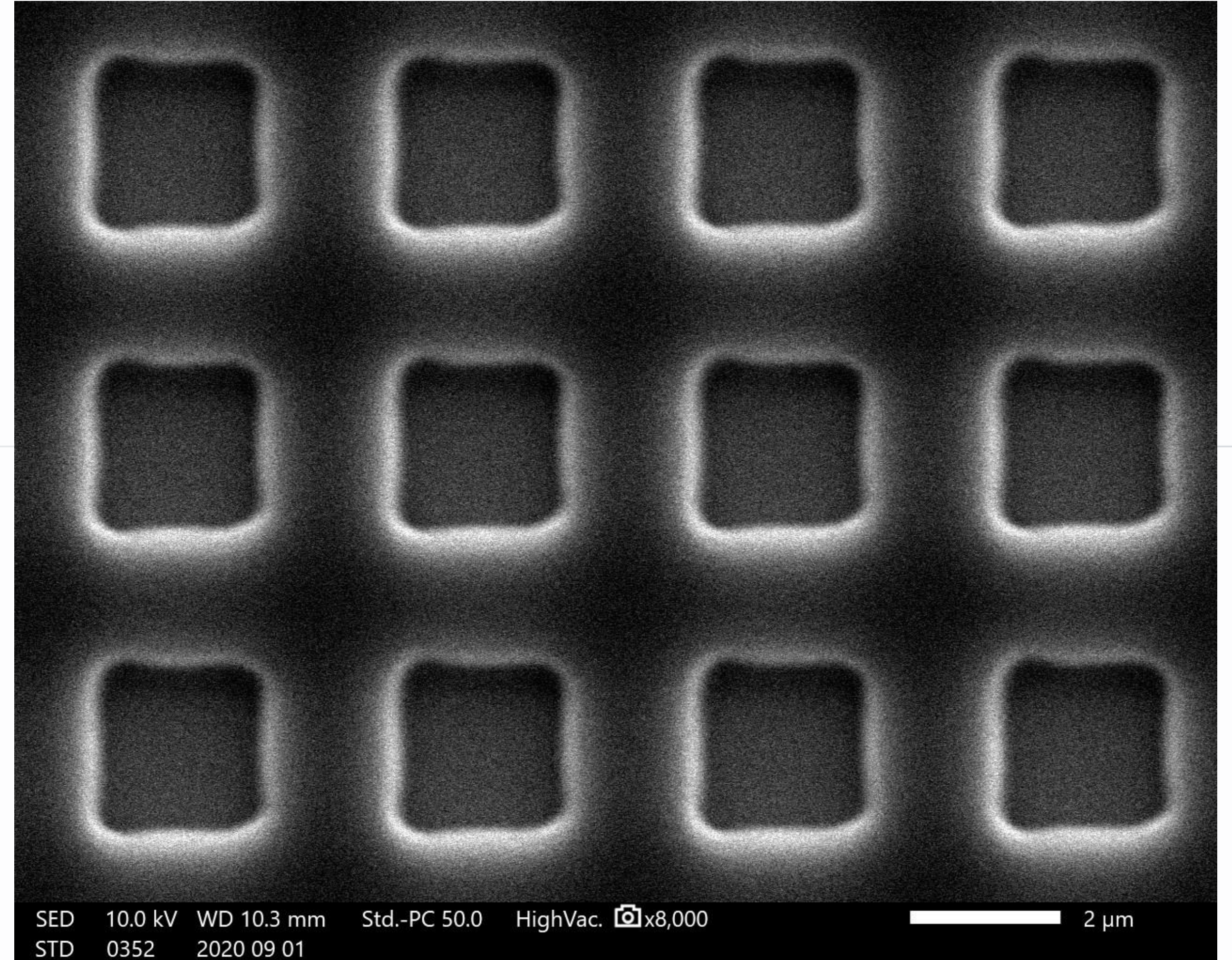
Rule-OPC

2um Square Dots

without correction



350nm Serif with 60% overlap



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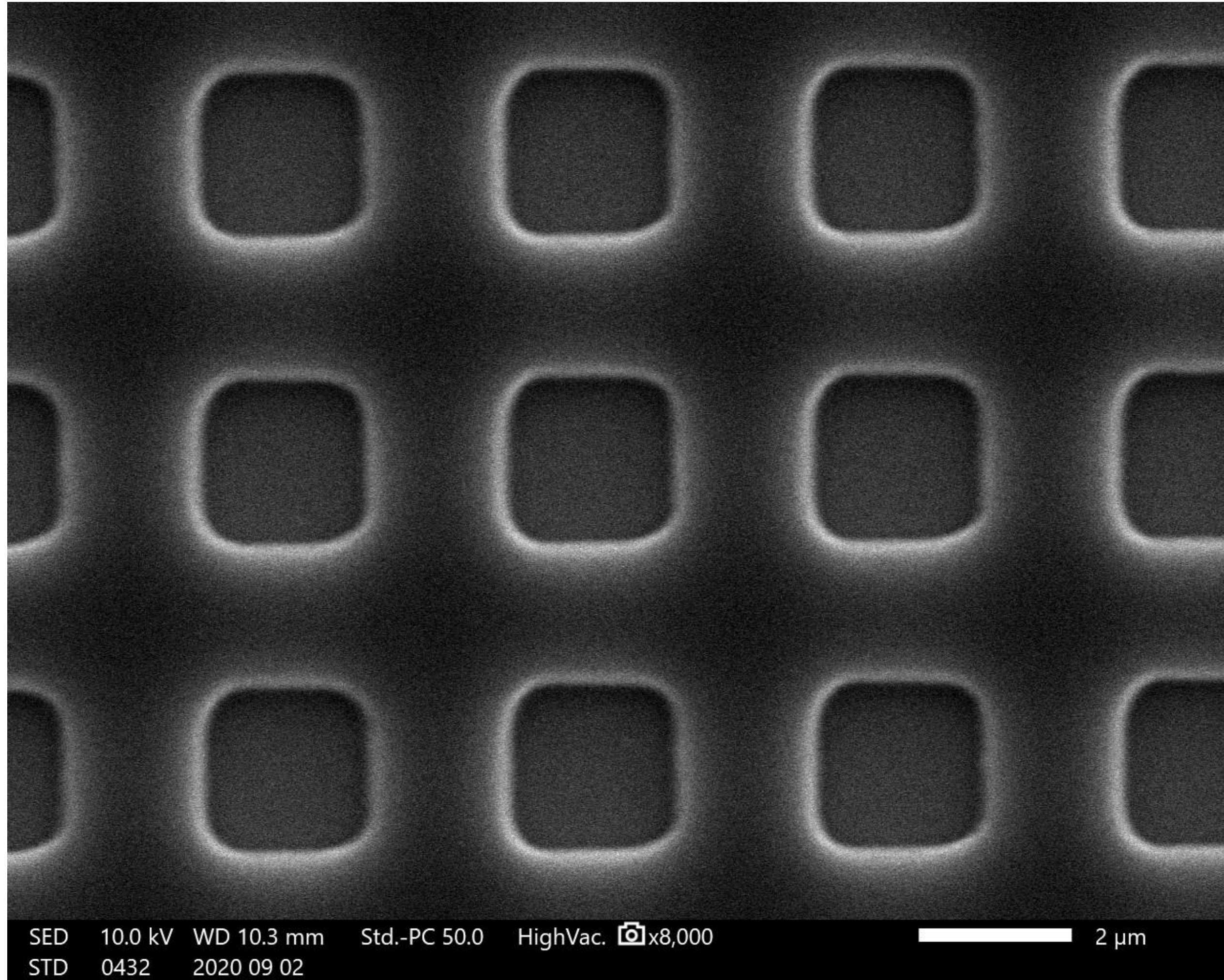
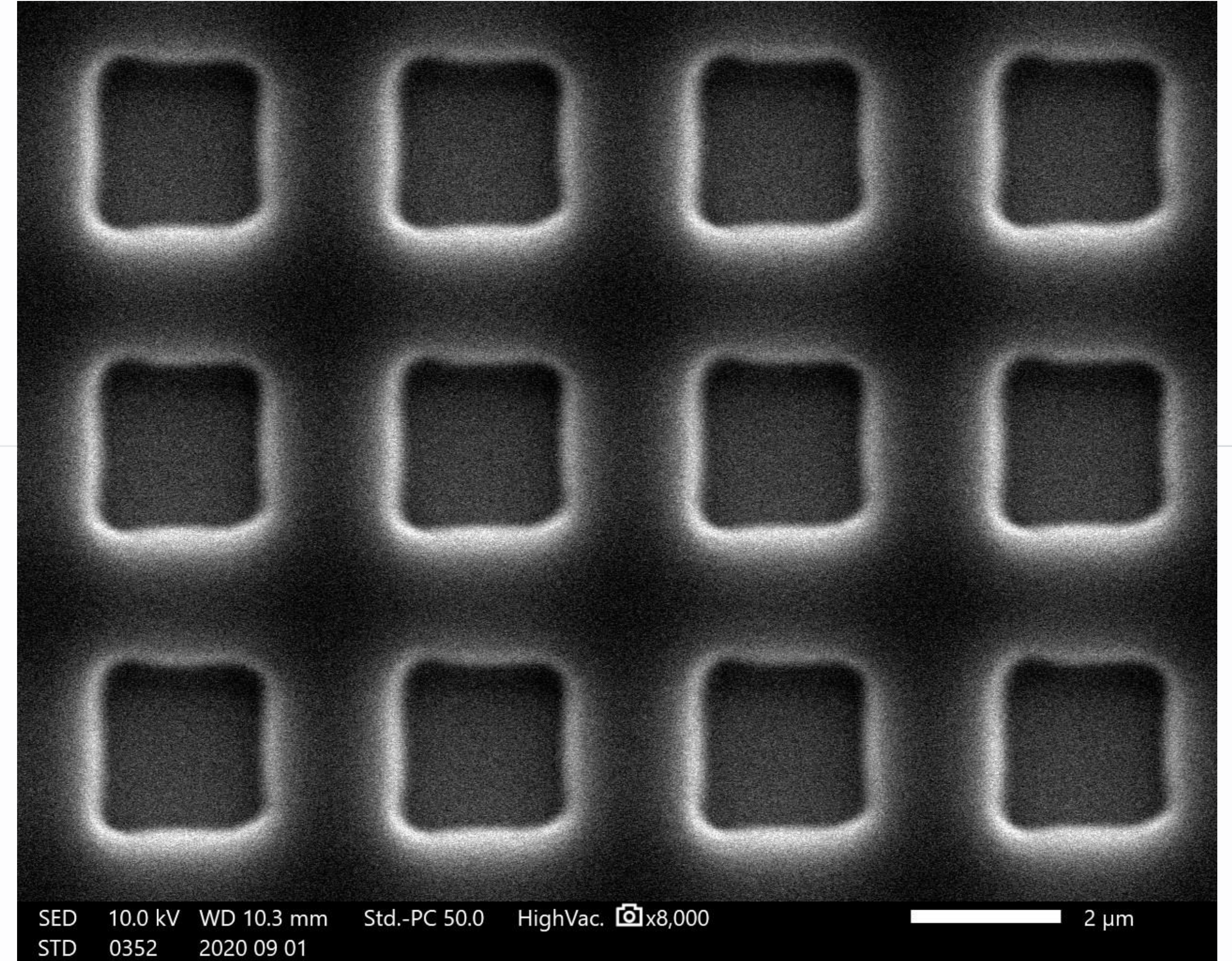
2um Square Dots

without correction



350nm Serif with 60% overlap

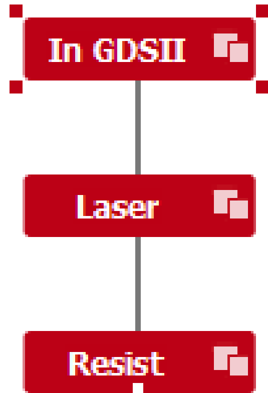


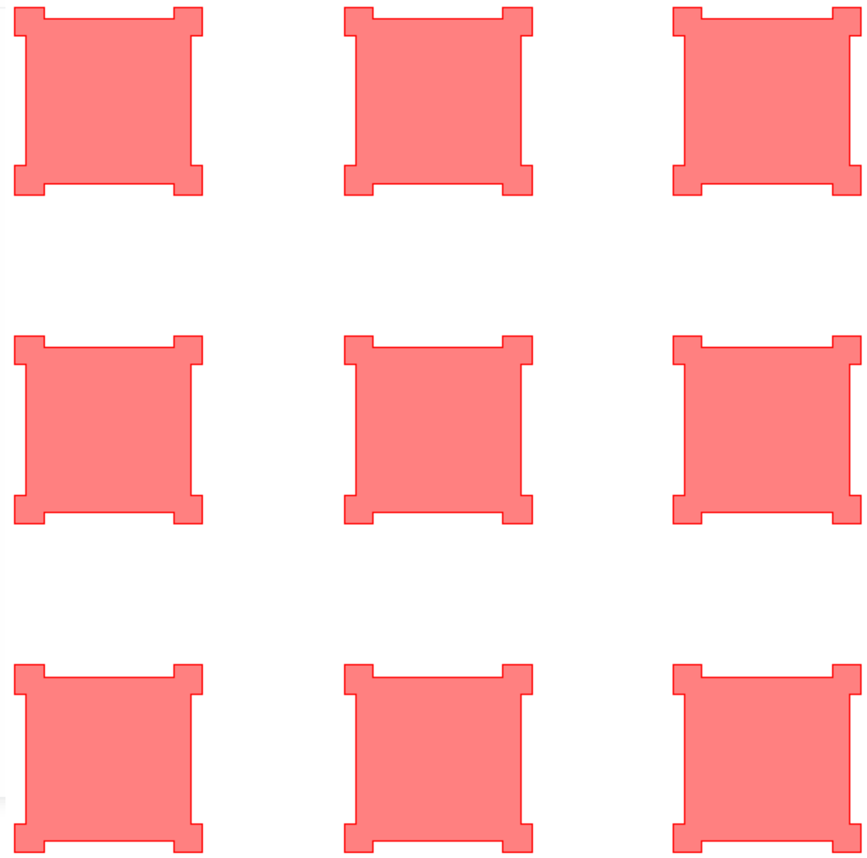
Overshooting correction

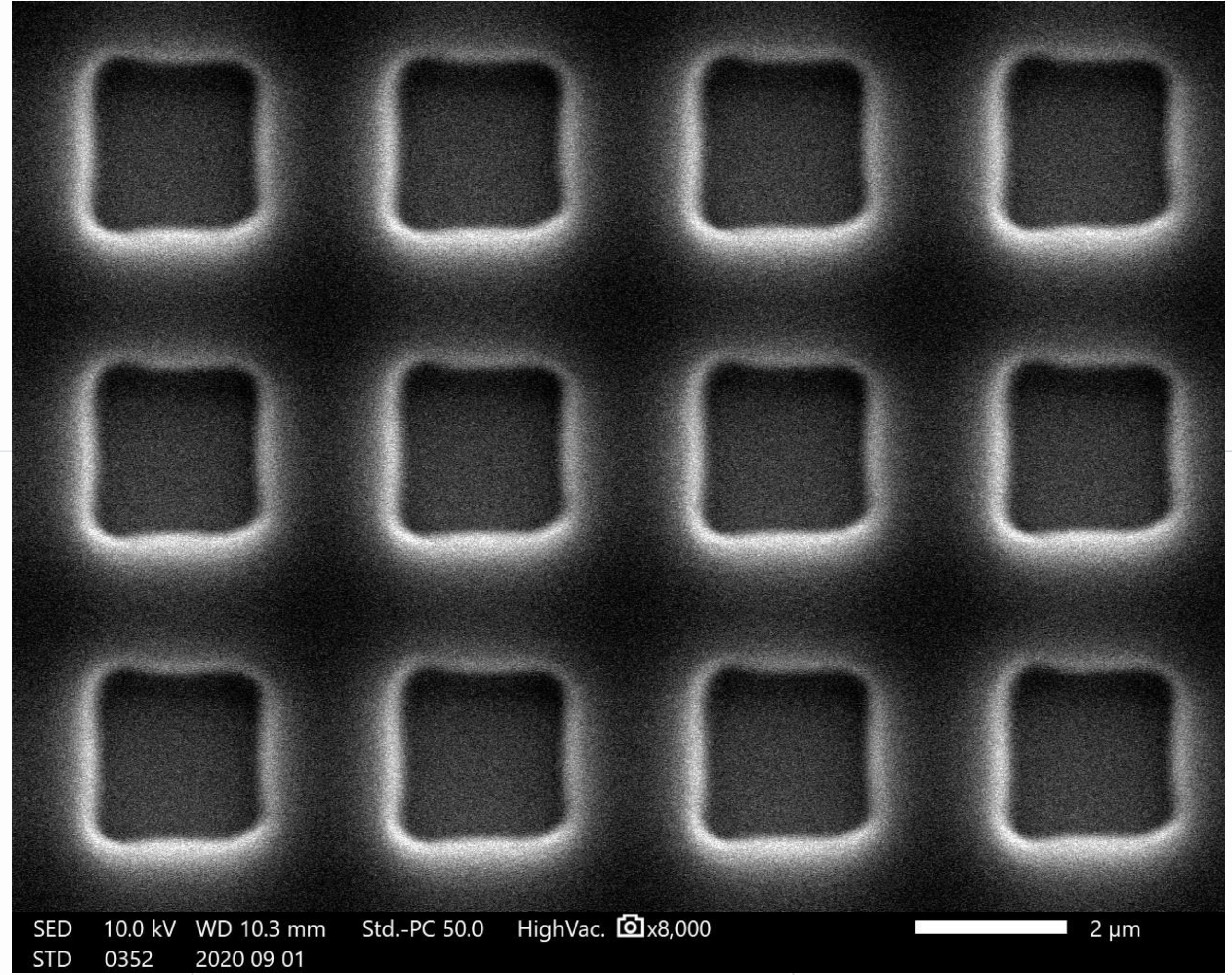
LAB Simulation : 2um Square Dots

Pattern with Corner Serifs

350nm Serif with 60% overlap







Overshooting correction

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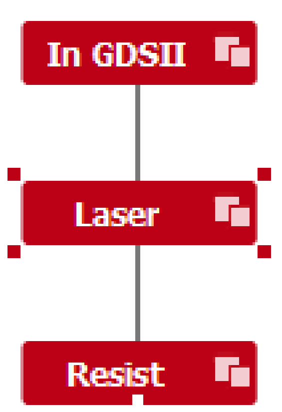
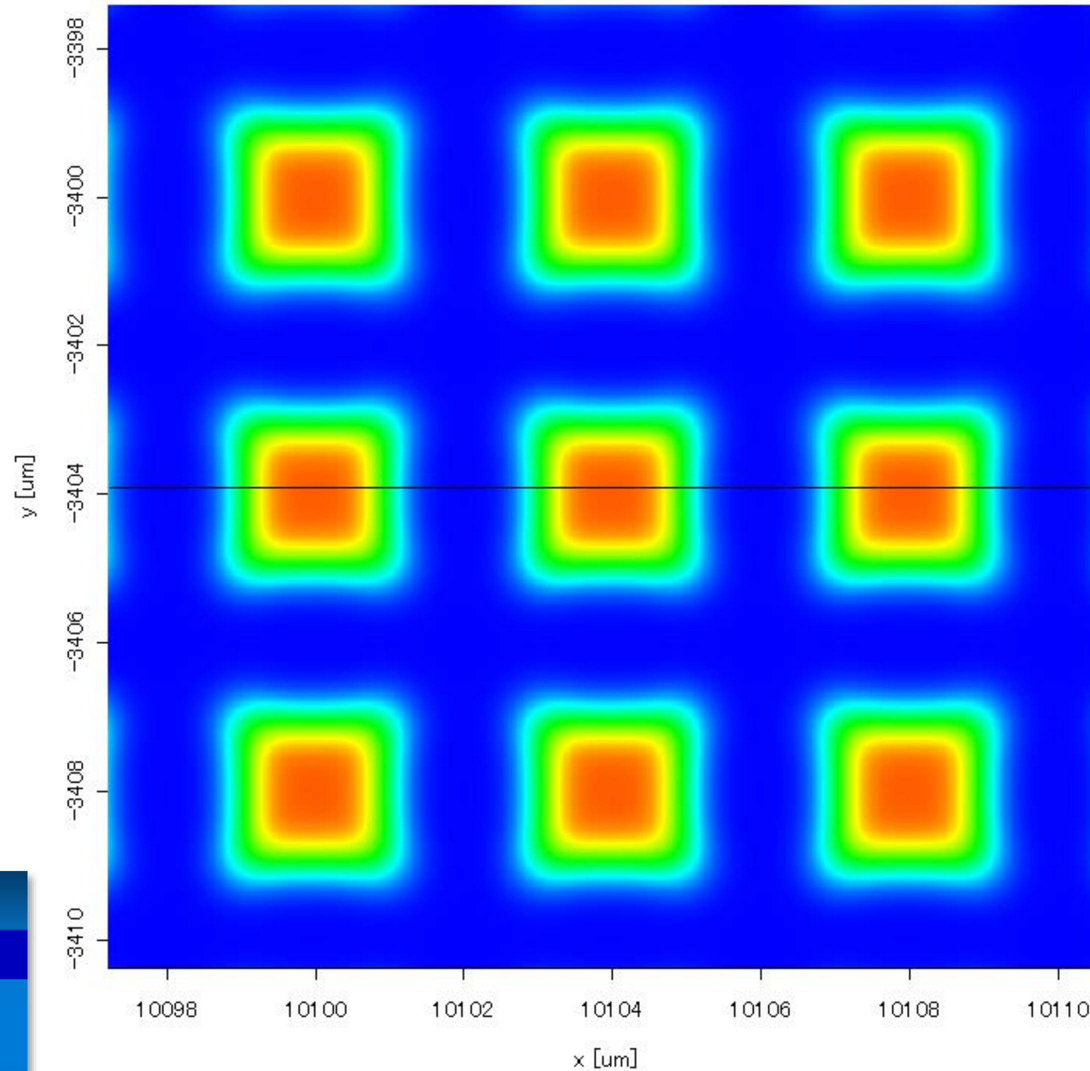
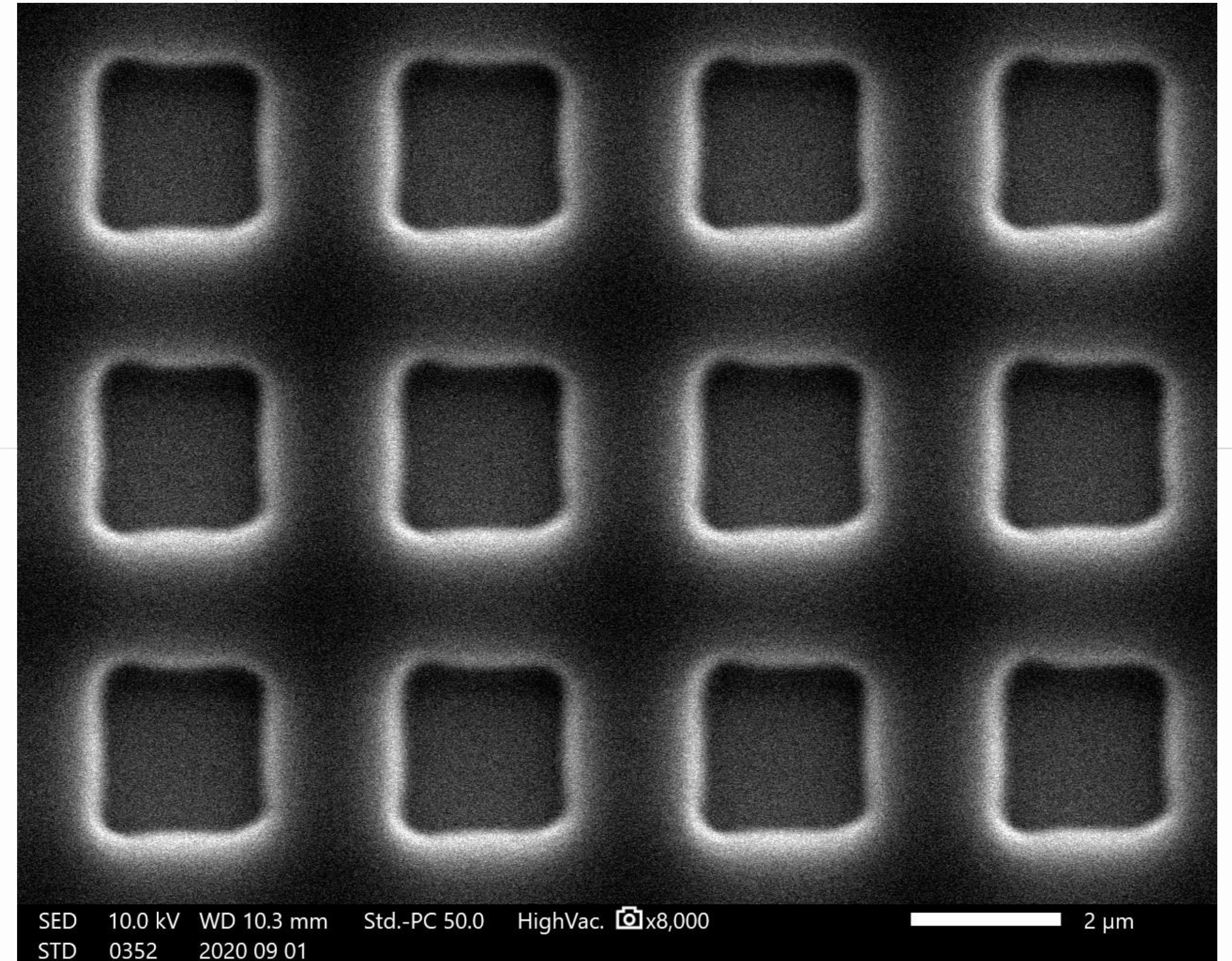
LAB Simulation : 2um Square Dots

Absorbed Energy (405nm)

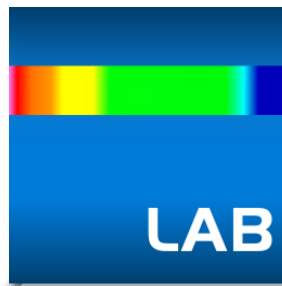




350nm Serif with 60% overlap



Overshooting correction



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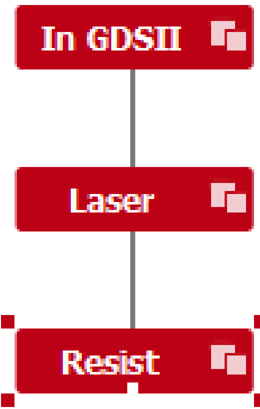
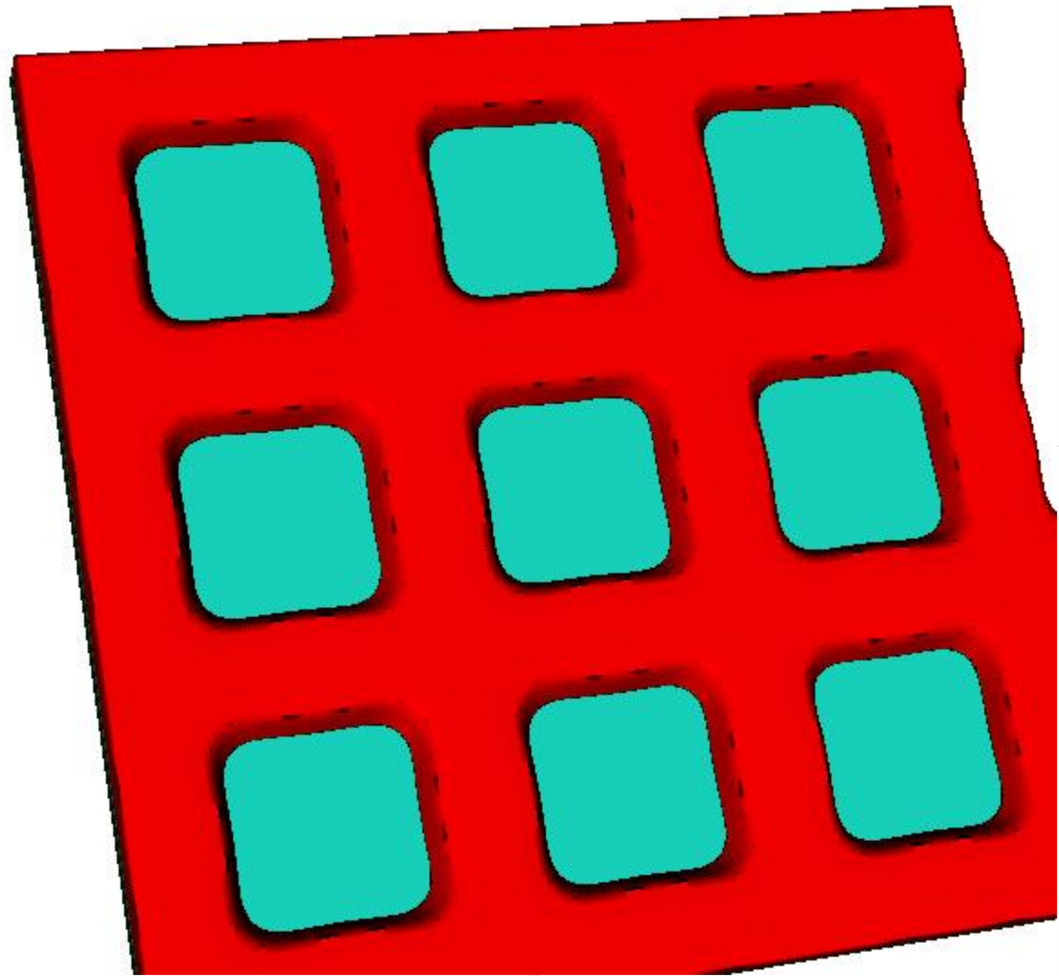
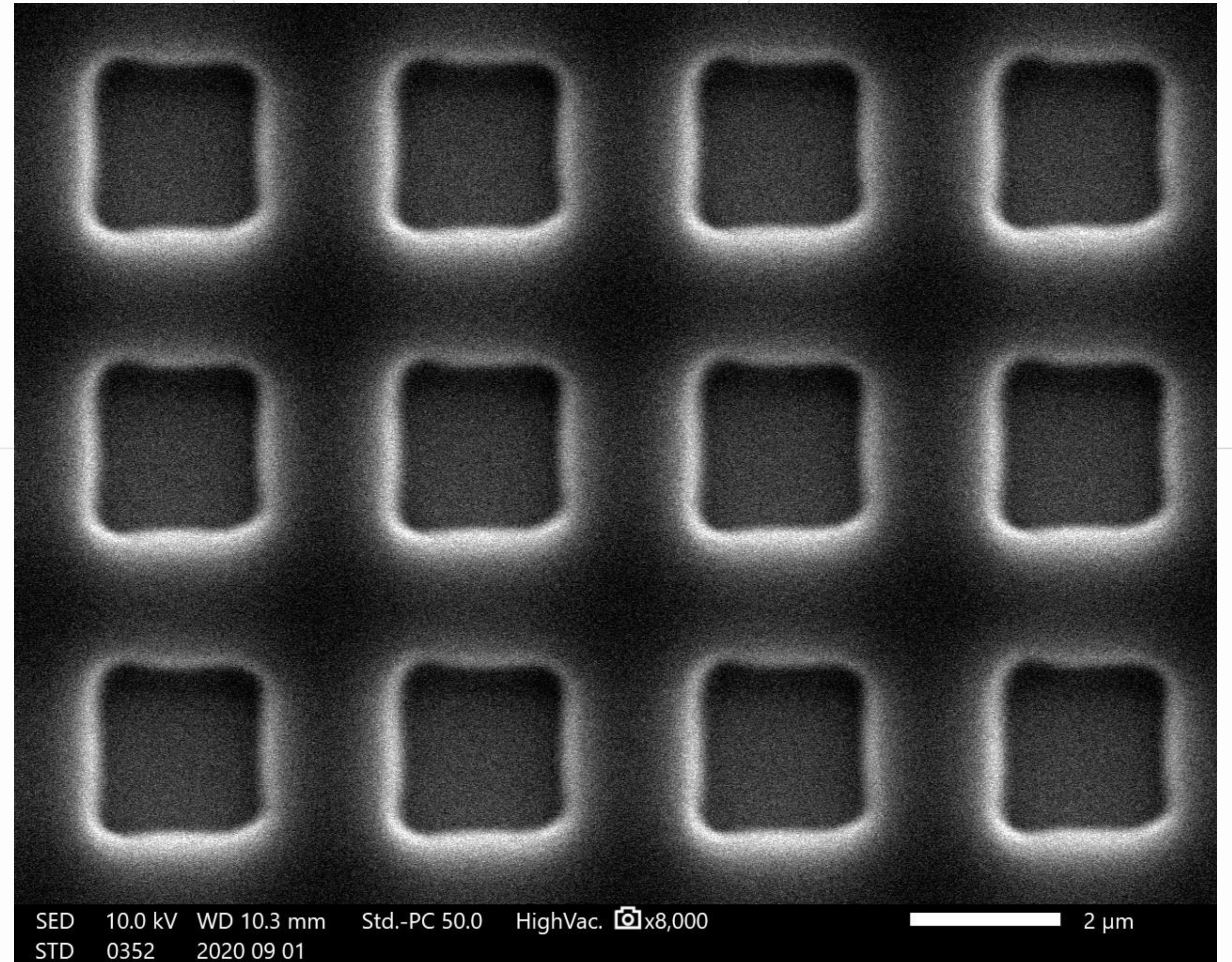
LAB Simulation : 2um Square Dots

350nm Serif with 60% overlap

3D Resist View







Overshooting correction

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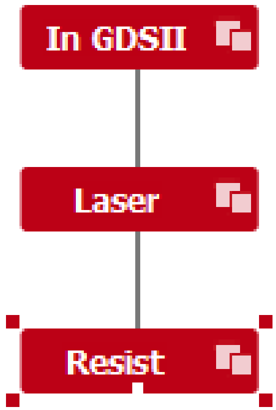
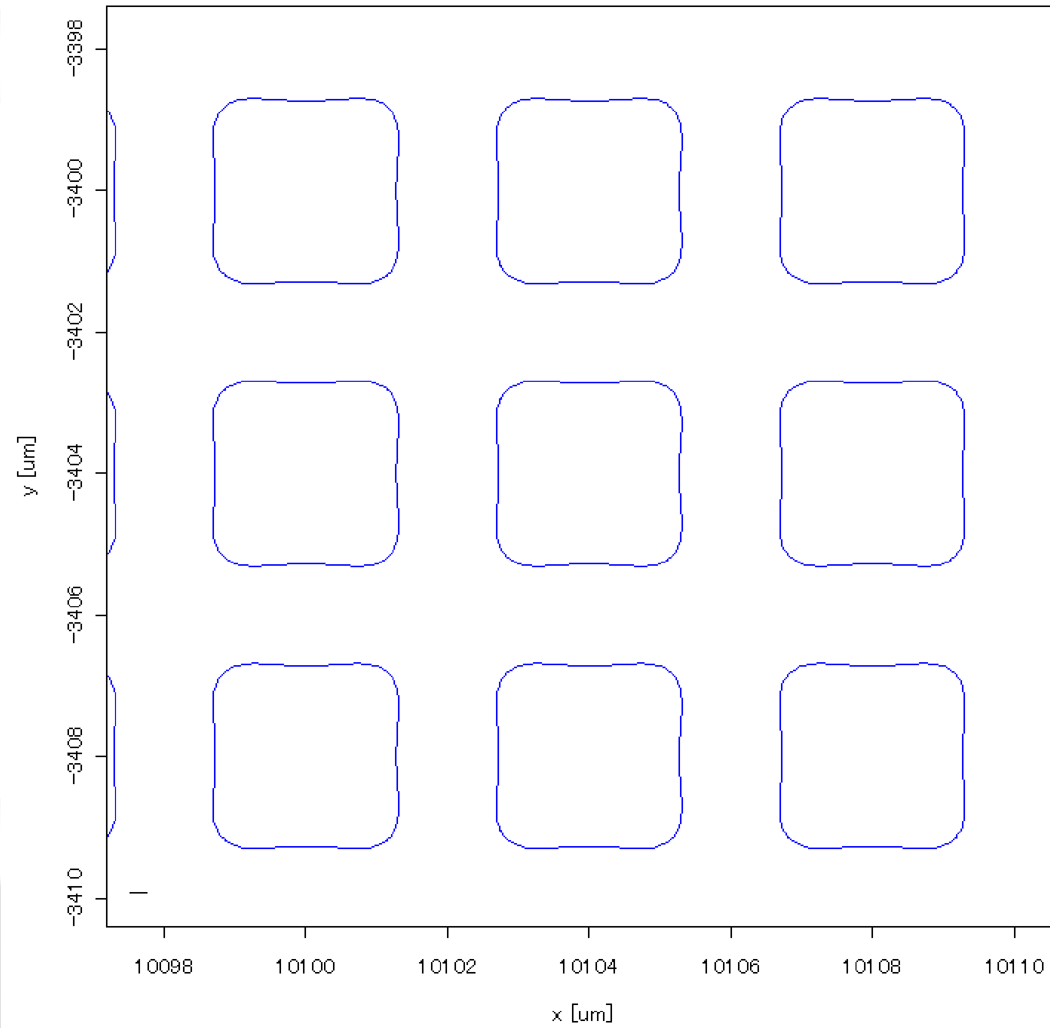
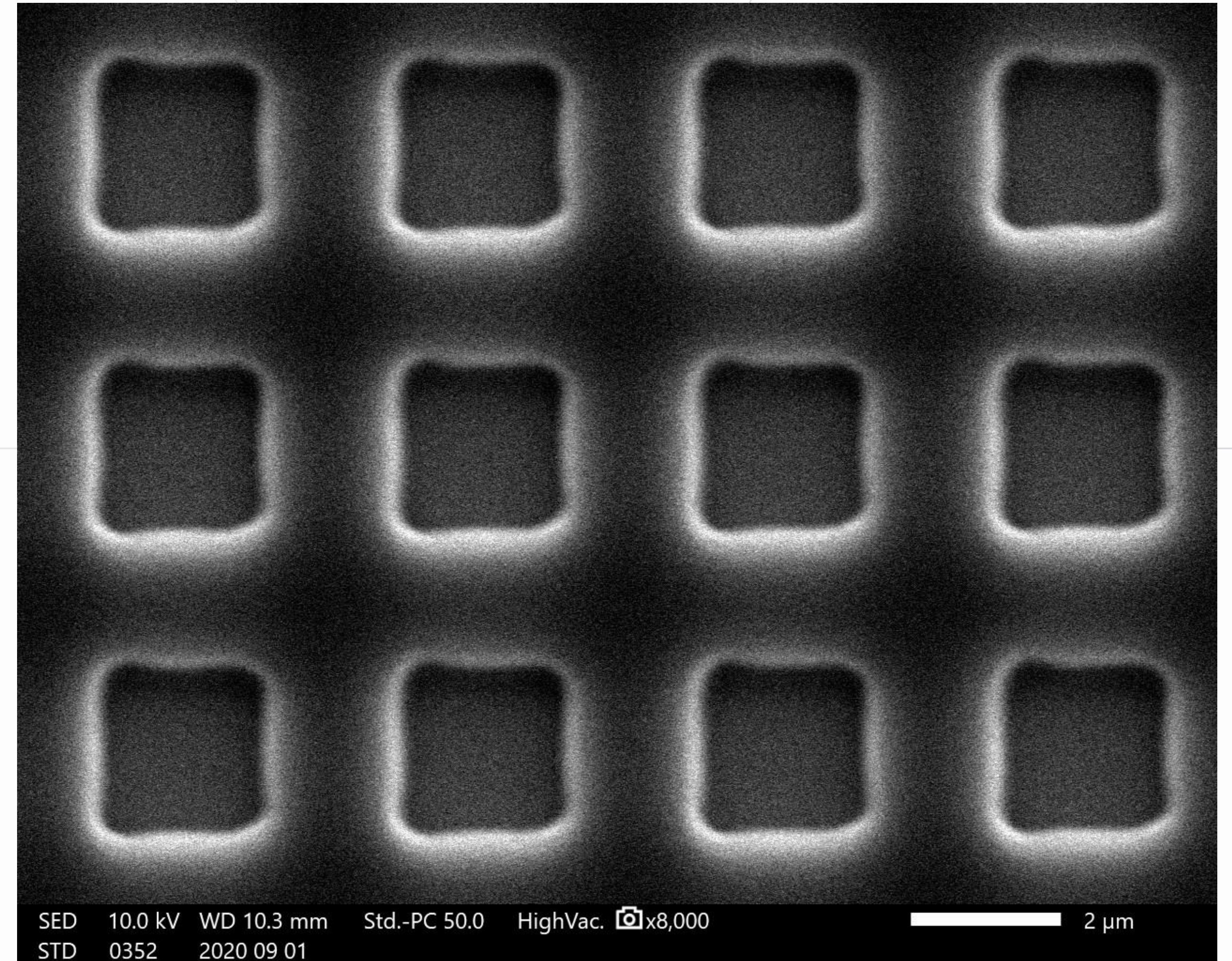
LAB Simulation : 2um Square Dots

350nm Serif with 60% overlap

Resist Contour

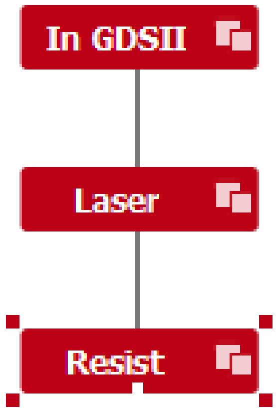




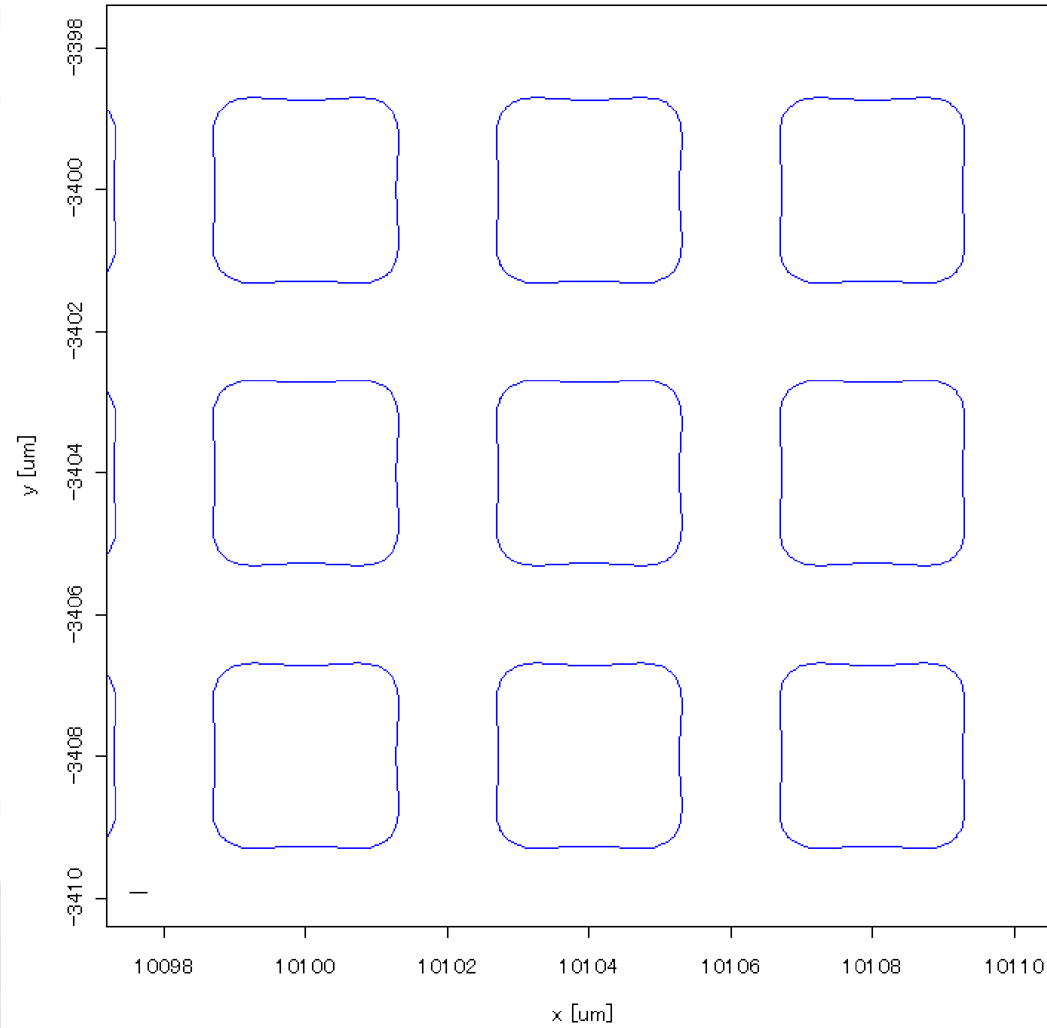


Overshooting correction

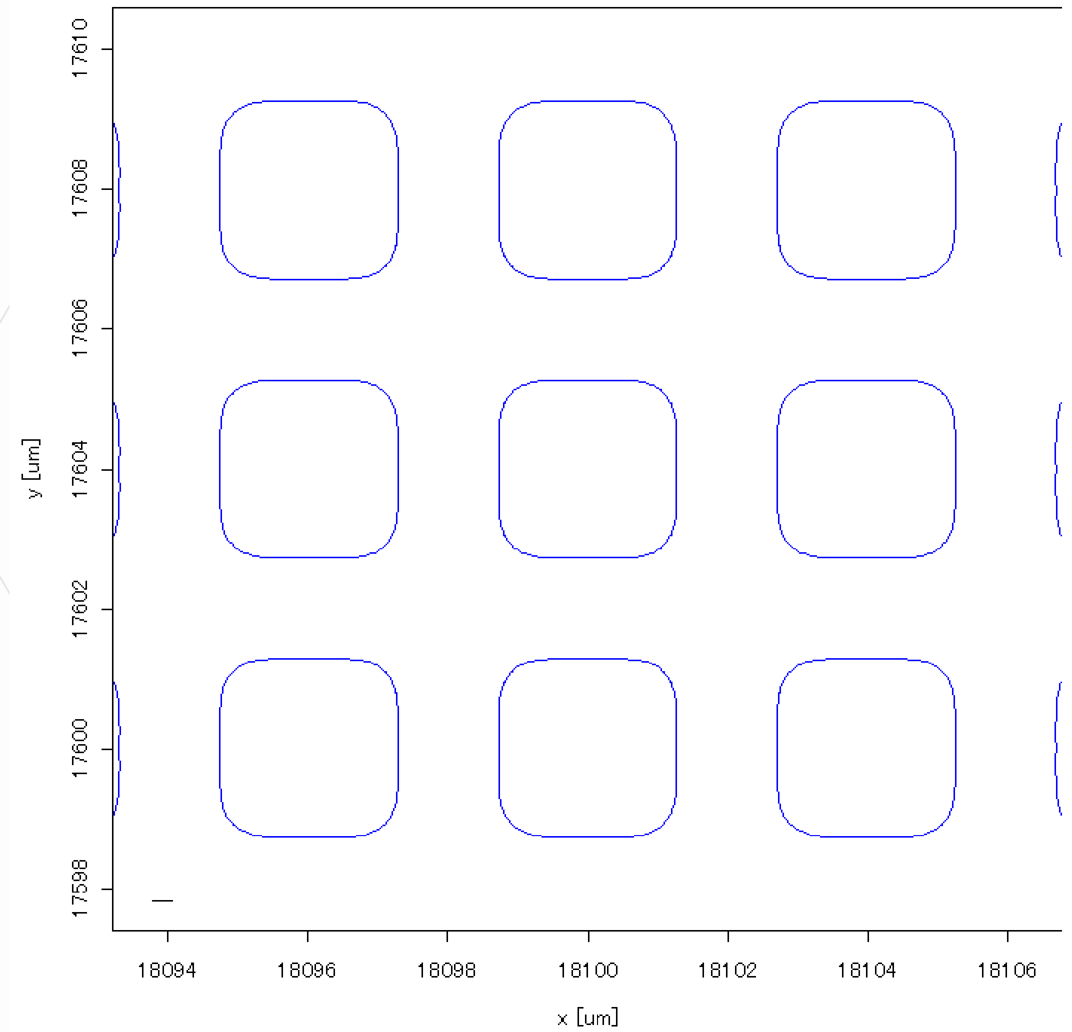
LAB Simulation : 2um Square Dots



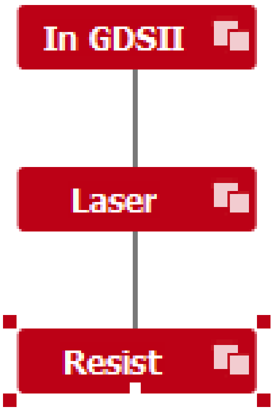
350nm Serif with 60% overlap



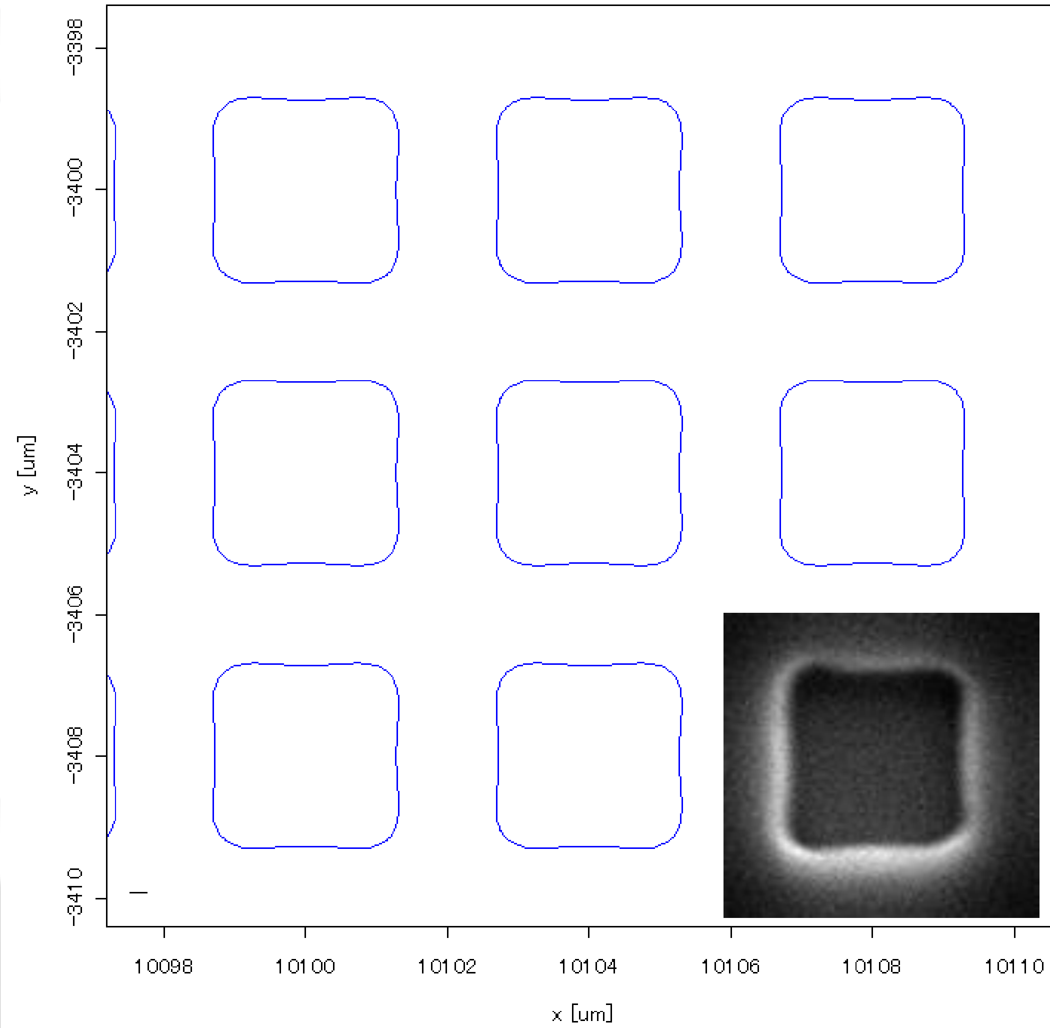
200nm Serif with 70% overlap



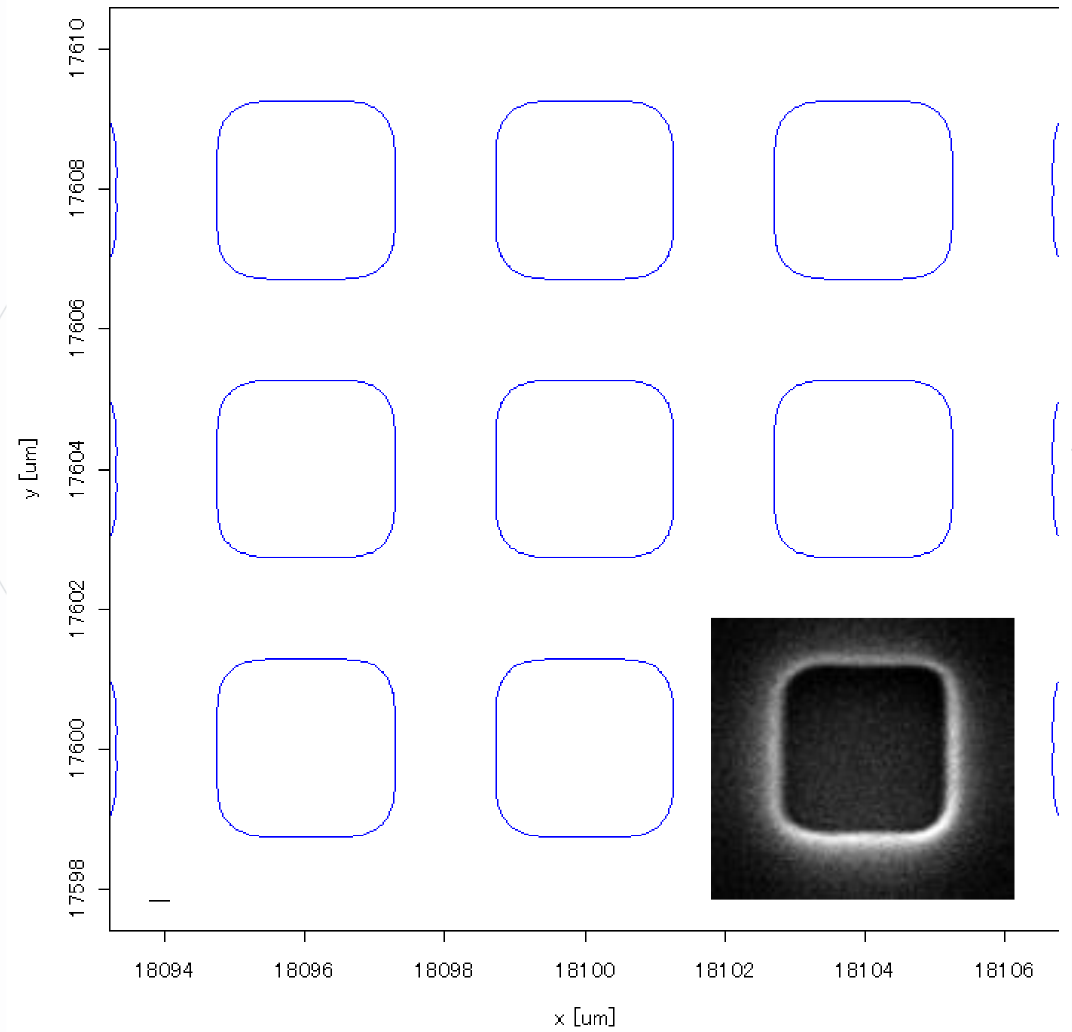
LAB Simulation : 2um Square Dots



350nm Serif with 60% overlap



200nm Serif with 70% overlap



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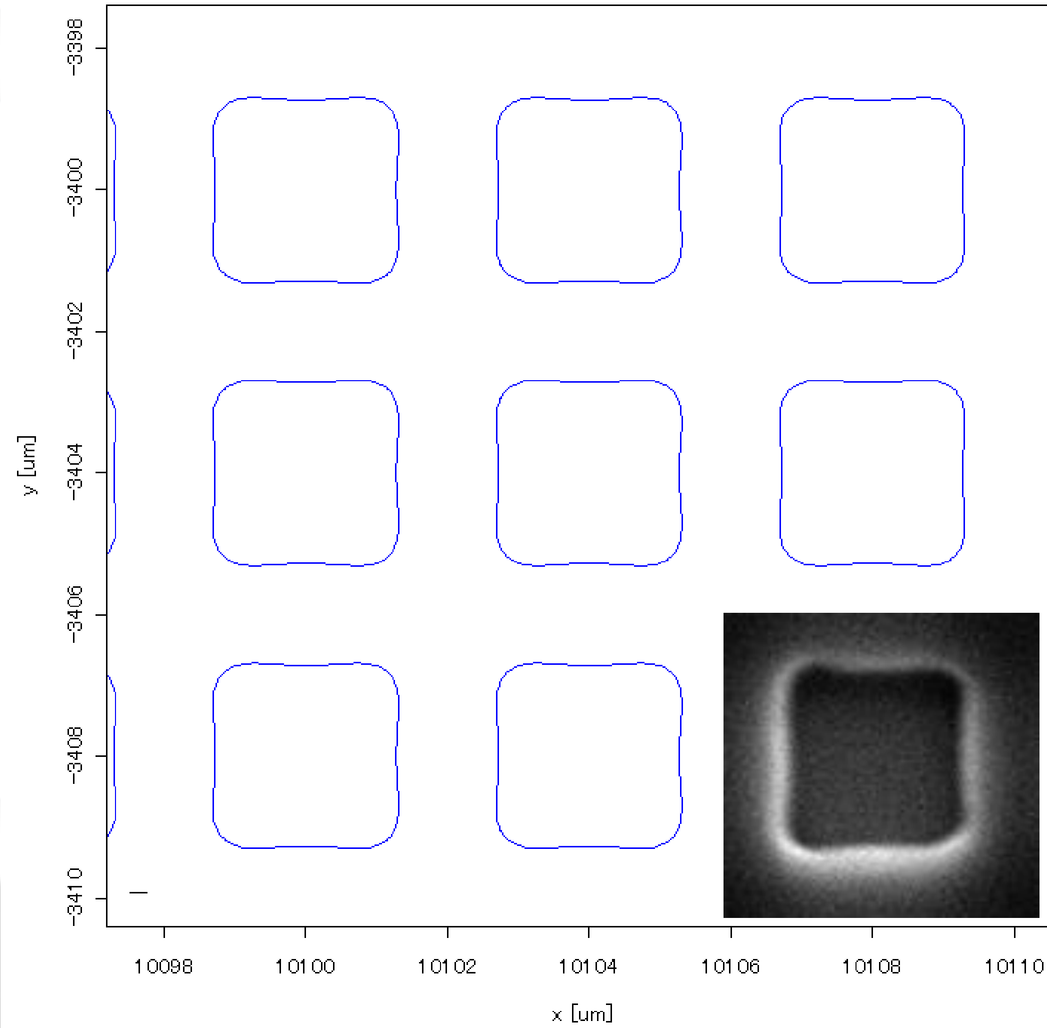
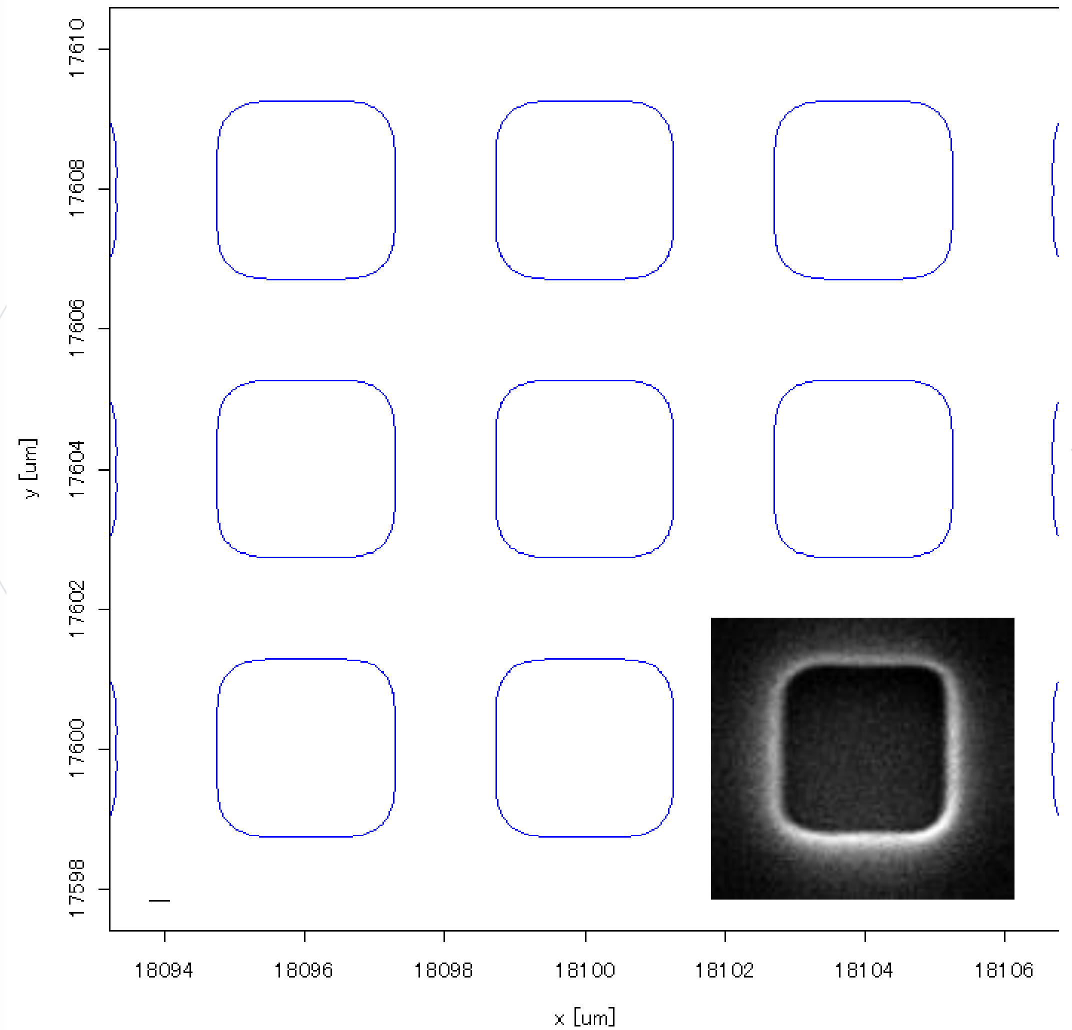
LAB Simulation : 2um Square Dots

In GDSII
Laser
Resist

350nm Serif with 60% overlap



200nm Serif with 70% overlap



LAB

Simulation is able to predict proper serif size in advance

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Agenda

- バイナリ露光における近接効果と、現像による形状への影響
- Rule OPC と Model OPC 補正のご紹介
- グレイスケール露光における補正
- LAB によるシミュレーション
- まとめ

Summary

- レーザー描画において、レーザー光による近接効果や現像の影響（横方向現像等）は仕上がり形状に影響を与えるため、補正が必要となる。
- サイズ形状補正を行うRule-OPCや、物理露光モデルをベースとした Model-OPCといった自動補正ツールを用いて、形状の線形性やコーナー補正が可能。
- グレイスケール露光では、CADを読み込み後、BEAMERによる自動計算アルゴリズムにより設計値に対する適切な露光量が簡便に求められる。応用例：マイクロレンズ、フレネルレンズ、DOE
- LAB によるレジスト計算を用いて、２Dや３D形状の事前予測が可能。結果を見ながら露光パラメータの選択範囲を実験前に絞り込むことが出来る。

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Thank You!

support@genisys-gmbh.com

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