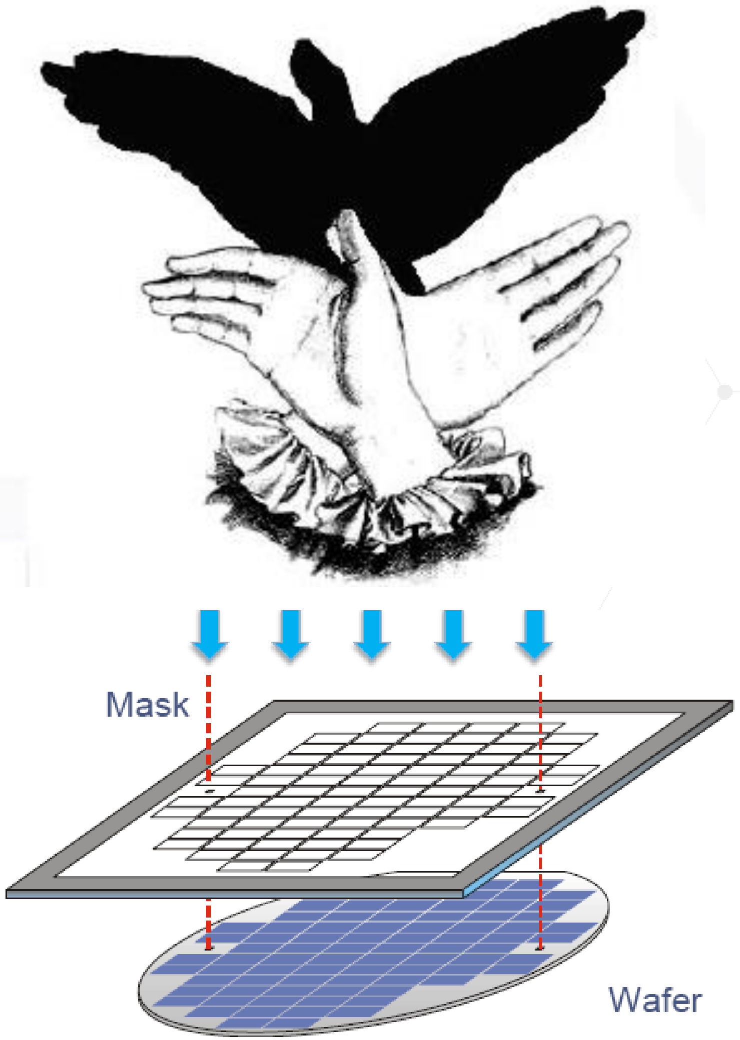
APPLICATIONS

LAB simulation methods and Optical Proximity Correction in Lithography

LAB

Proximity Lithography

Proximity Lithography = Shadow Printing



Mask Aligner

Source: Süss Microtech

Flat Panel Display Proximity Printer:

Source: Hitachi High Tech

Lithography Elements

Source

- Broadband wavelength emission
- Collimation and Tilt angles
- Shape

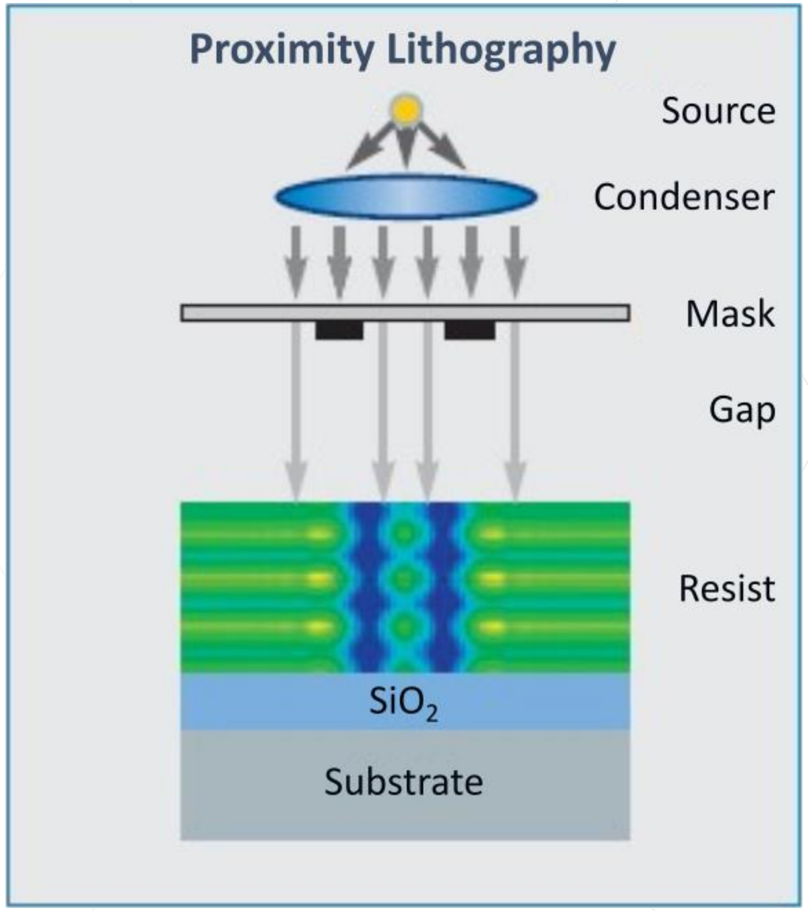
Mask

- Feature sizes
- Diffraction effects
- Type:
  - Transmission, Greyscale, Phase

Proximity gap

Resist and stack

- Material optical properties
- Thicknesses
- Reflections



The Lithography Challenges: Resolution

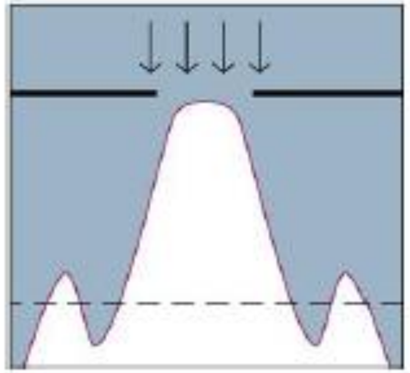
- Theoretical Resolution Limit

$$HP = \frac{3}{2} \cdot \sqrt{\lambda \cdot \left(\text{exp. gap} + \frac{\text{resist thickness}}{2} \right)}$$

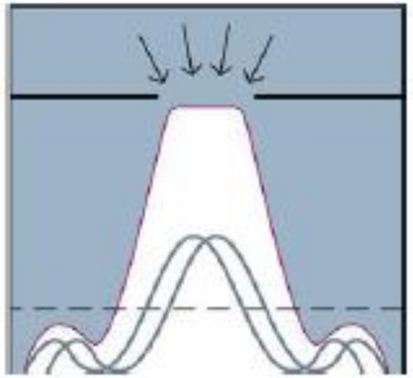
HP is the minimum resolved dimension in a grating mask

Parallel Light

Diffuse Light



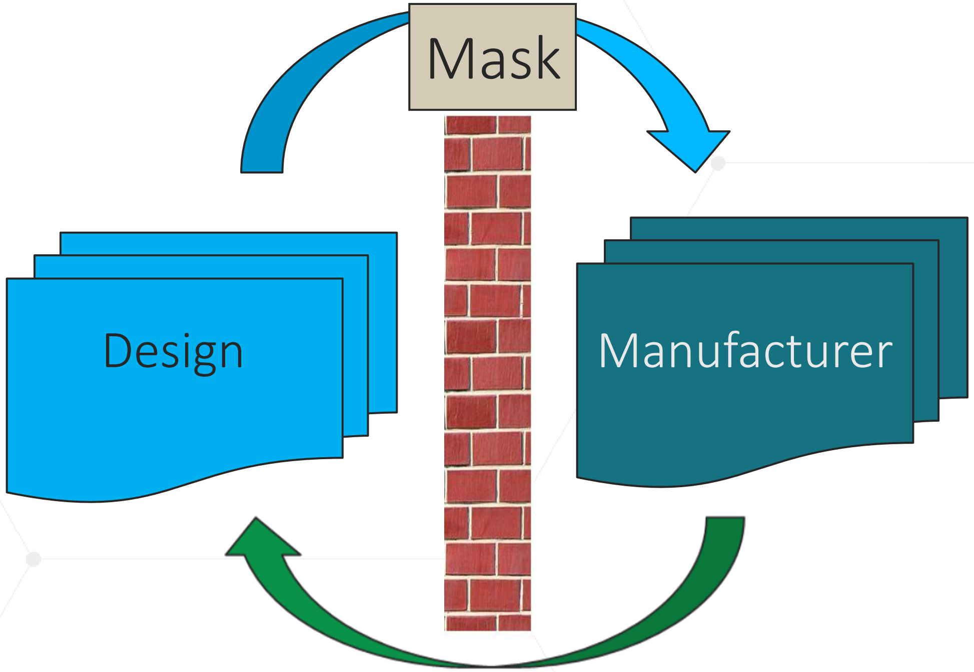
Parallel Light



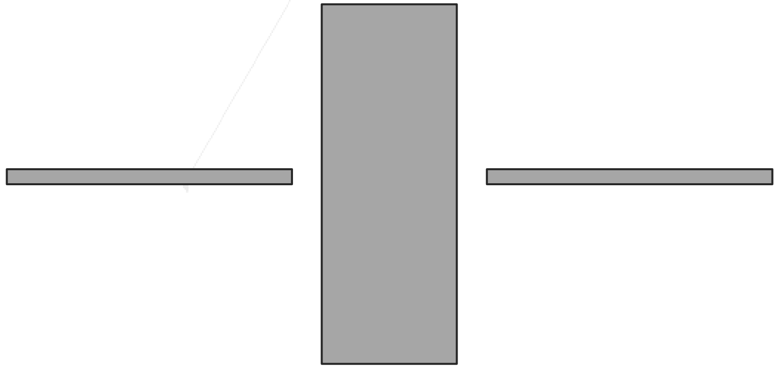
Apodization

The Lithography Challenges: Optimisation

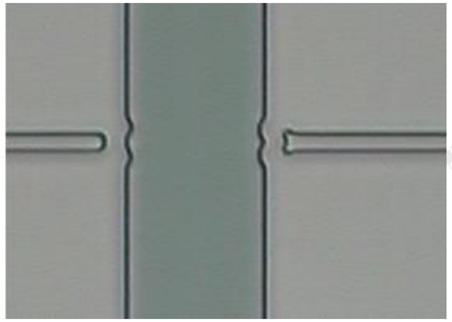
Iterative process of design and manufacturing



The Desired Pattern



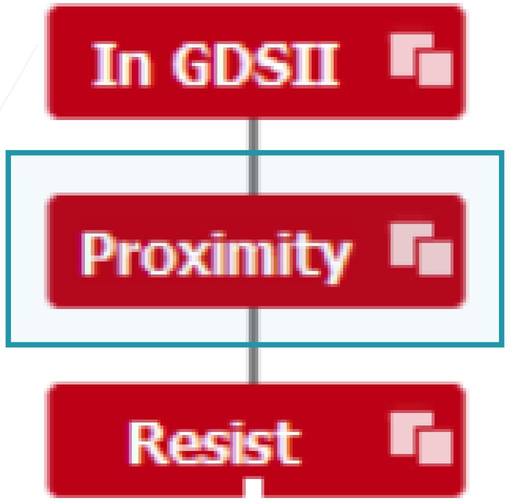
The Result

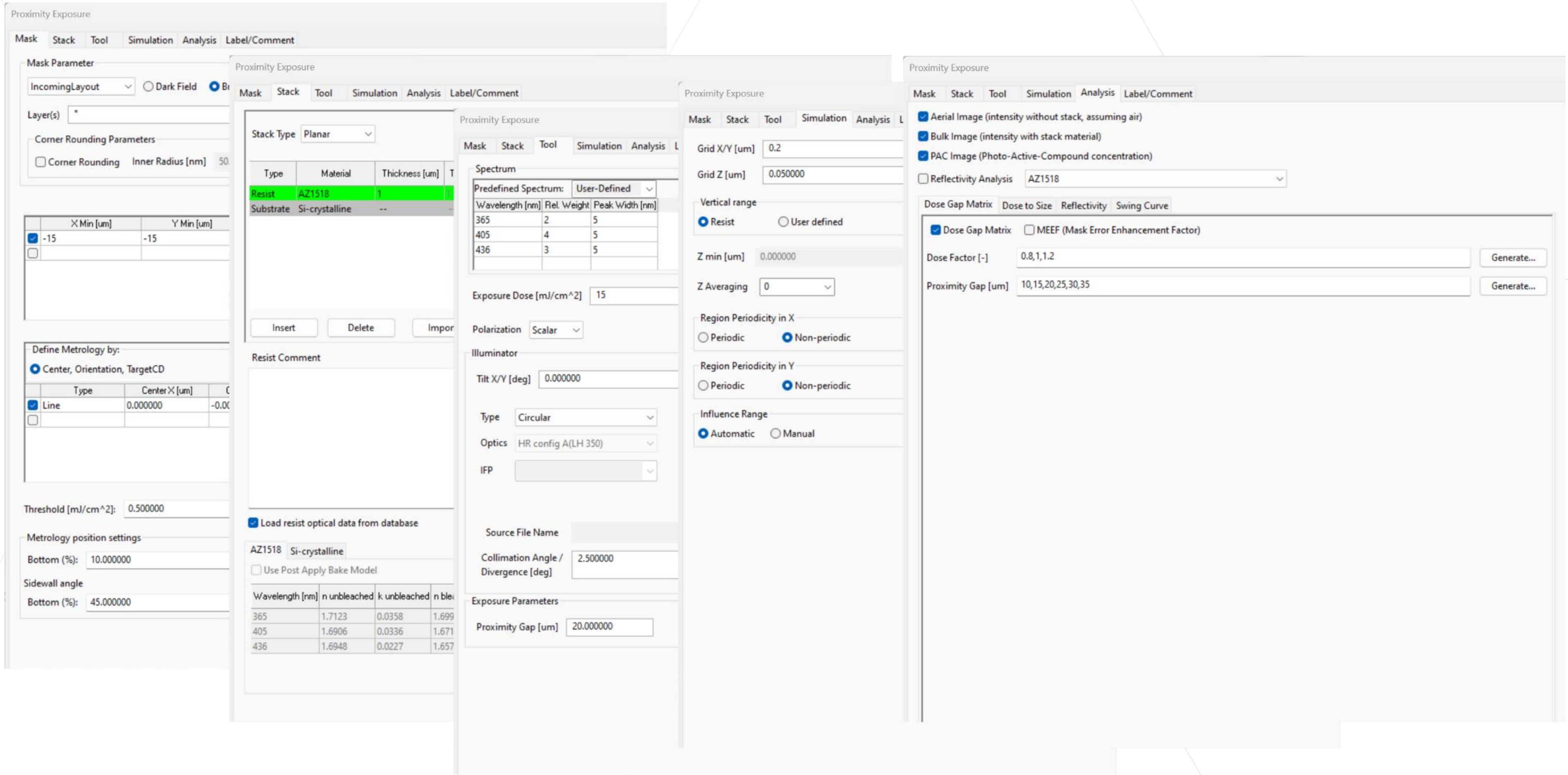


Time consuming and expensive

Simulation Settings

- **LAB** provides many settings to emulate multiple experimental conditions giving the tools to optimise an exposure process


In GDSII
Proximity
Resist



Mask Parameter
IncomingLayout ○ Dark Field ● Br
Layer(s) *
Corner Rounding Parameters
☐ Corner Rounding Inner Radius [nm] 50.

	X Min [um]	Y Min [um]
☑	-15	-15
☐		

Define Metrology by:
● Center, Orientation, TargetCD

	Type	Center X [um]	C
☑	Line	0.000000	-0.0C
☐			

Threshold [mJ/cm^2]: 0.500000
Metrology position settings
Bottom (%): 10.000000
Sidewall angle
Bottom (%): 45.000000

Stack Type Planar

Type	Material	Thickness [um]	T
Resist	AZ1518	1	
Substrate	Si-crystalline	--	

Resist Comment
☑ Load resist optical data from database
AZ1518 Si-crystalline
☐ Use Post Apply Bake Model

Wavelength [nm]	n unbleached	k unbleached	n blea
365	1.7123	0.0358	1.699
405	1.6906	0.0336	1.671
436	1.6948	0.0227	1.657

Spectrum
Predefined Spectrum: User-Defined

Wavelength [nm]	Rel. Weight	Peak Width [nm]
365	2	5
405	4	5
436	3	5

Exposure Dose [mJ/cm^2] 15
Polarization Scalar
Illuminator
Tilt X/Y [deg] 0.000000
Type Circular
Optics HR config A(LH 350)
IFP
Source File Name
Collimation Angle / Divergence [deg] 2.500000
Exposure Parameters
Proximity Gap [um] 20.000000

Grid X/Y [um] 0.2
Grid Z [um] 0.050000
Vertical range
● Resist ○ User defined
Z min [um] 0.000000
Z Averaging 0
Region Periodicity in X
○ Periodic ● Non-periodic
Region Periodicity in Y
○ Periodic ● Non-periodic
Influence Range
● Automatic ○ Manual

☑ Aerial Image (intensity without stack, assuming air)
☑ Bulk Image (intensity with stack material)
☑ PAC Image (Photo-Active-Compound concentration)
☐ Reflectivity Analysis AZ1518

☑ Dose Gap Matrix ☐ MEEF (Mask Error Enhancement Factor)
Dose Factor [-] 0.8,1,1.2
Proximity Gap [um] 10,15,20,25,30,35

LAB

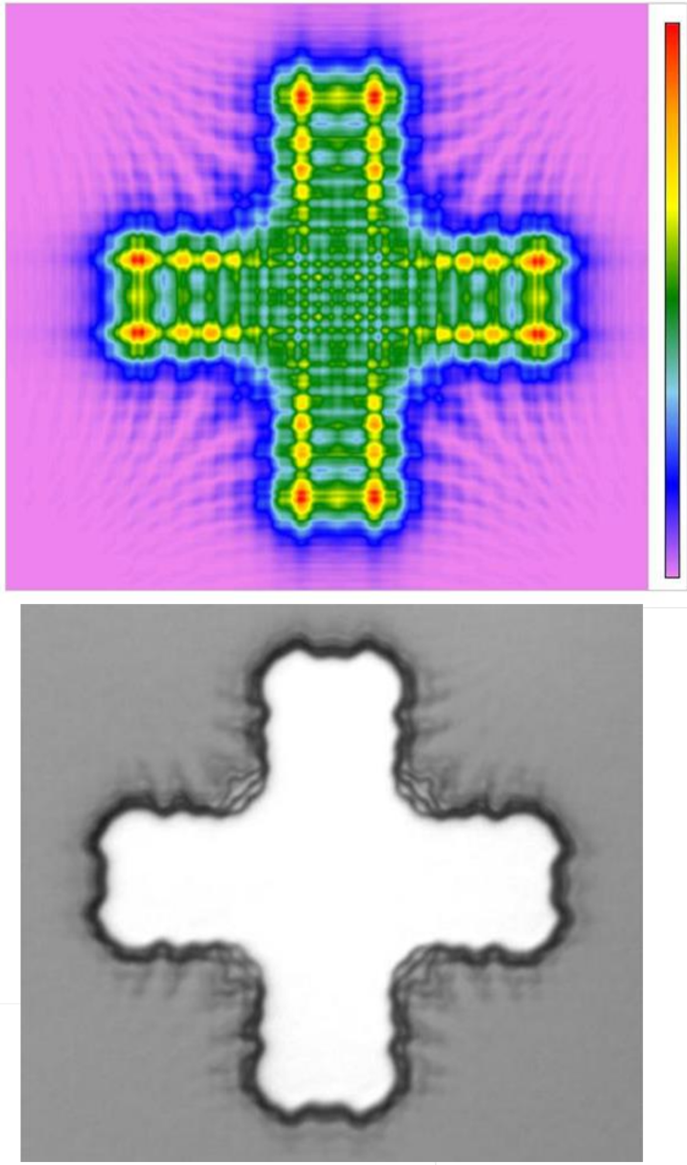
Benefits

Simulation is:

- Saving Time and Material
  - No need to produce masks, print wafers or inspect → no materials wasted
- Saving engineering resources

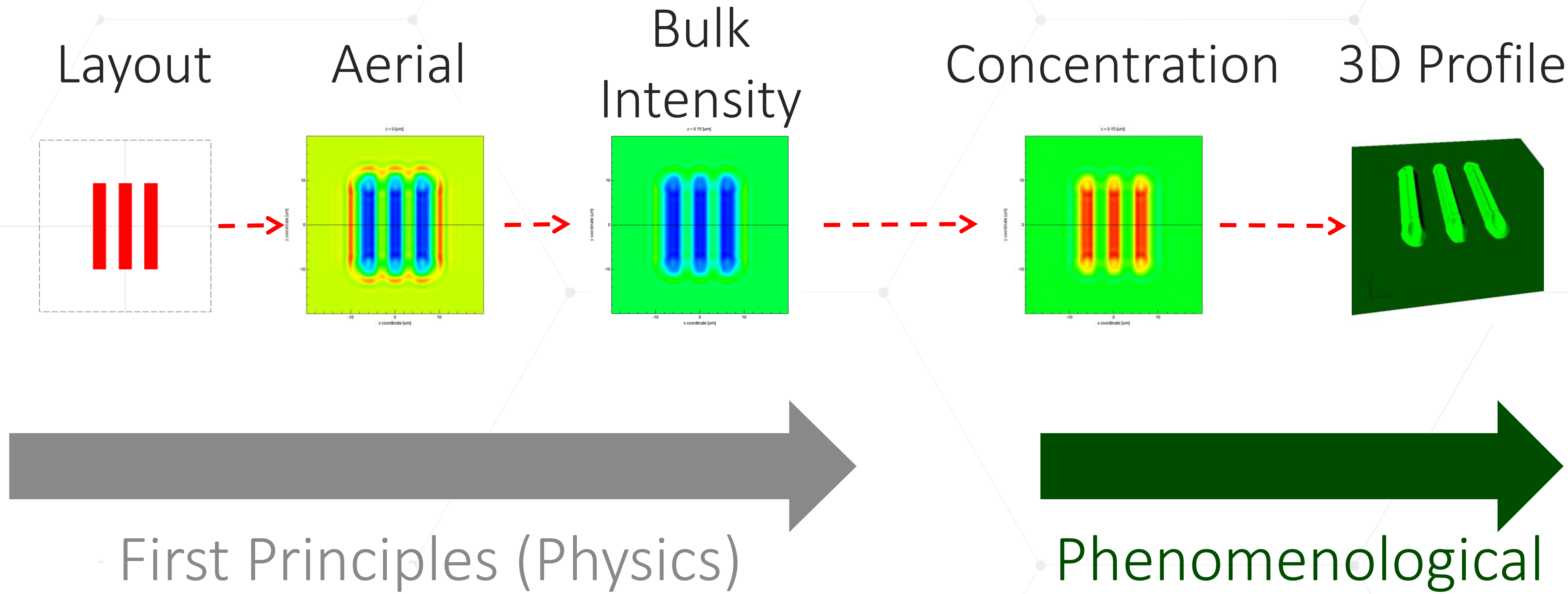
Simulation supports:

- Designer
  - Development of design rules
  - Layout verification → hot-spot detection
  - Layout optimisation → Optical Proximity Corrections
- Process engineer
- Equipment, mask and material supplier



Cross of 10 m line width at 30µm proximity gap

Simulation Flow



Layout

Aerial

Bulk Intensity

Concentration

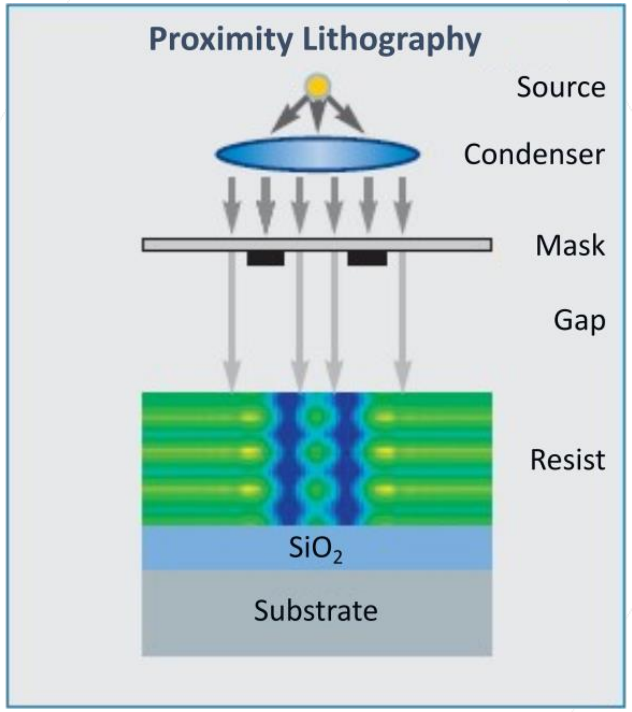
3D Profile

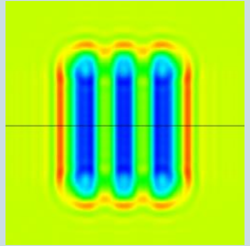
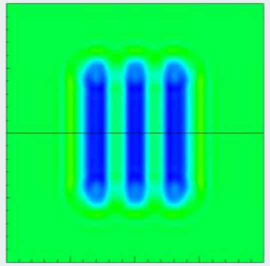
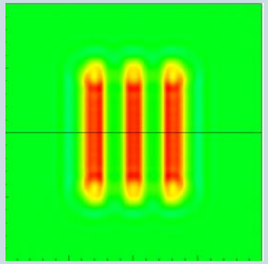
First Principles (Physics)

Phenomenological

Simulations optimise trhoughput

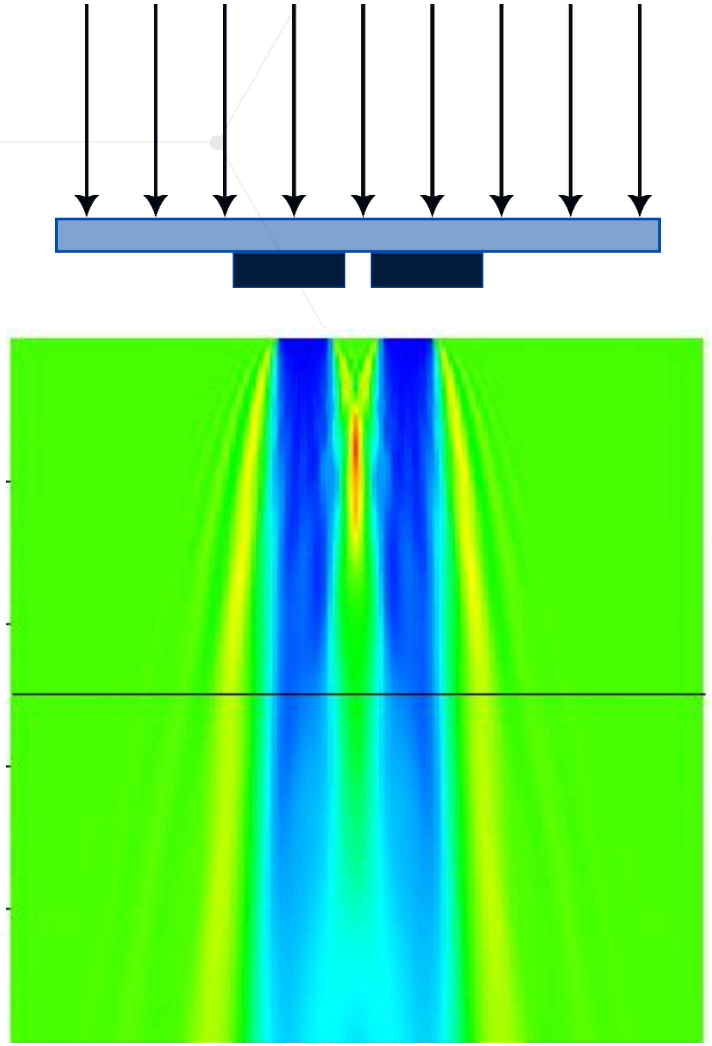
LAB simulation images



Description	Proximity
Aerial image Image of the layout in air in the gap	
Bulk image Intensity in the resist	
Concentration view Intensity image multiplied by the rate constant of the exposure reaction	

Proximity Image Formation

- Calculation of the **Aerial image** at arbitrary gaps is based on **Kirchhoff Scalar Diffraction** theory
  - „thin mask“ ➡ Non-vectorial (polarization) effects
  - Rayleigh-Sommerfeld integral is solved (no need of considering light near optical axis)
  - Image calculation at arbitrary distances from mask



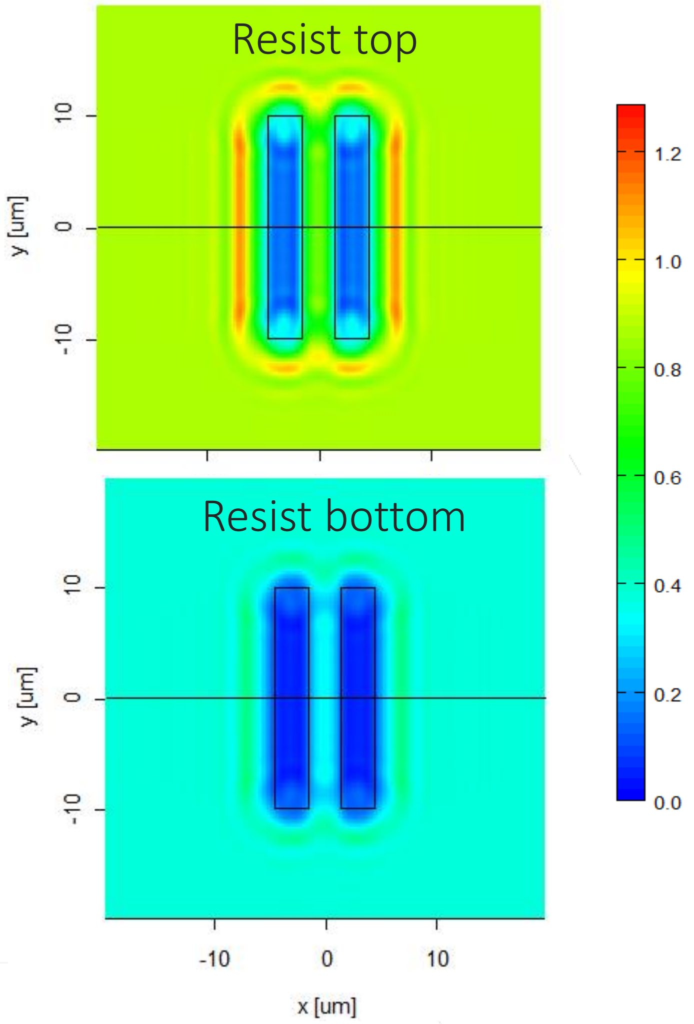
Models have been proven in IC manufacturing for over 20 years

Intensity Image Modelling

- The calculation of **Image intensity** (aerial image / bulk image) is based on solid physics (optics) and mathematics.

- Accuracy of algorithms are proven by benchmarks with rigorous experiments.

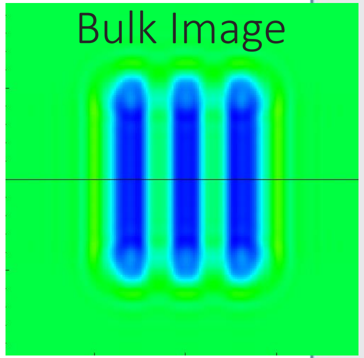
- Optimisation of processes using intensity images reduce waste of materials and time.

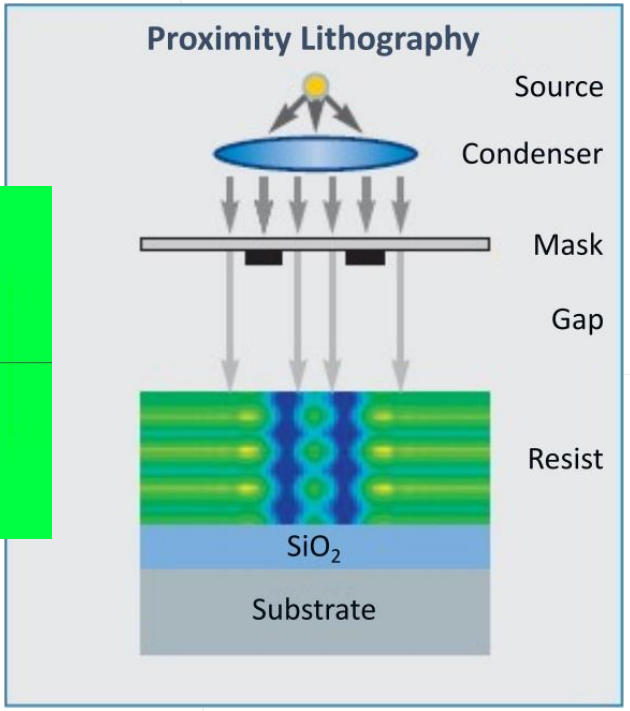


Bad intensity image will result in bad exposed resist on wafer!
Optimum intensity image is the best base for good resist results!

Bulk Image Calculation

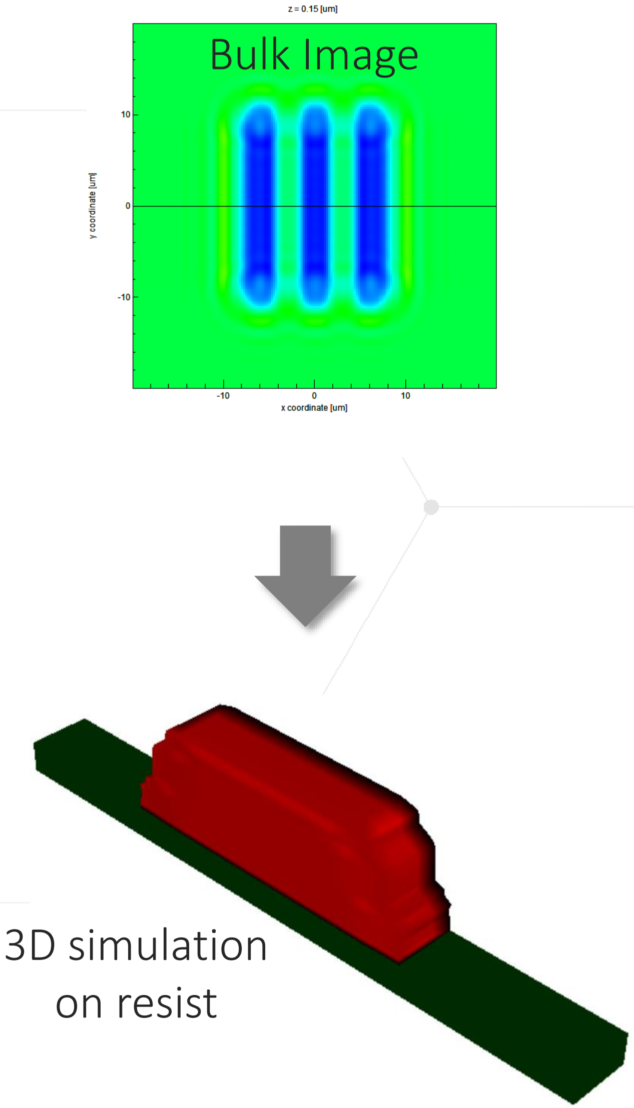
- **Transfer Matrix Model** (thin-film algorithm) considers:
  - Propagation and absorption of light in a stack of homogeneous layers of different material
  - **n(λ)** and **k(λ)**
  - Reflection at material interface
  - Change of propagation angle at material interface
- **Bleaching**:
  - Change of **n** and **k** during the exposure
    - Optical properties **n** and **k** of non-exposed and exposed resist are needed
  - Exposure is modelled in multiple steps





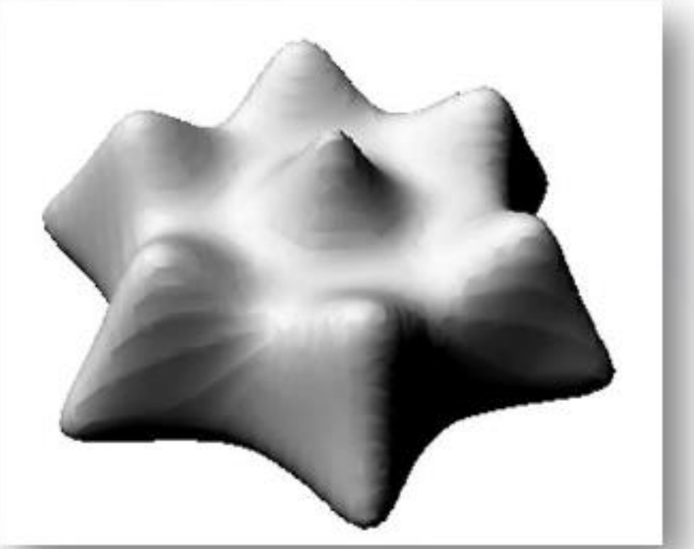
3D Resist Modelling

- Typical resist modelling is based on:
  - Dill model: Converts **Bulk image** into Photo-Active-Compound (PAC) concentration
  - Mack-4 model: Calculates the **dissolution rate** from the PAC concentration
- **3D resist development model** is based on development-rate parameter
- The **3D development front** is modeled as function of development time

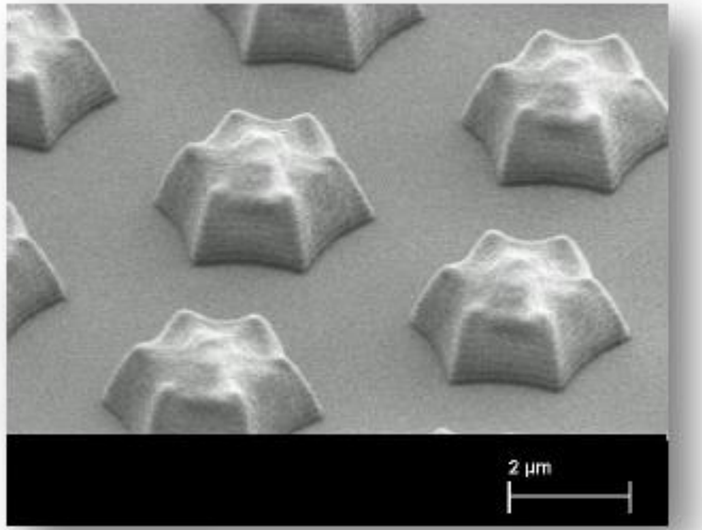


3D Resist Modelling - Example

- Resist-model parameter requires fitting experimental data:
    - Contrast Curve
    - Development Rate Monitoring
    - Resist profile



Simulation 3D Resist Structure
(Layout Lab, GenISys)

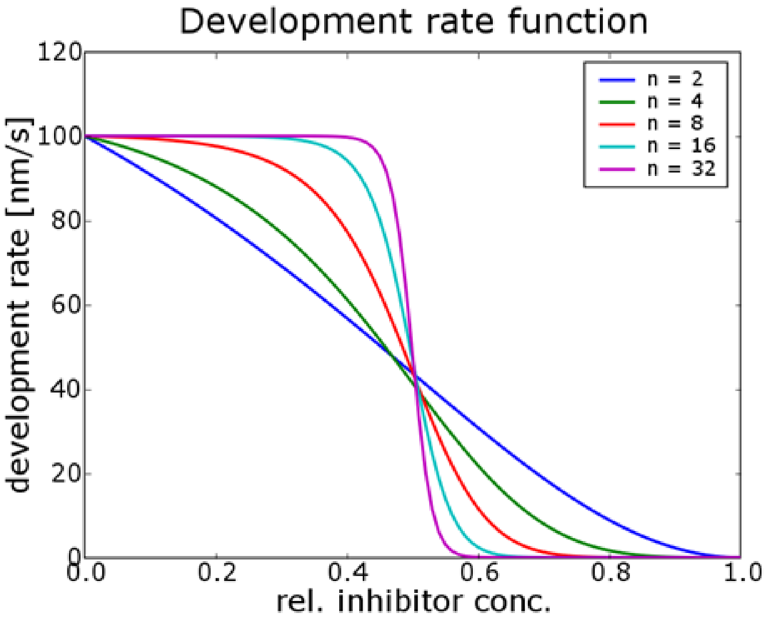


Printed Resist Structure

Layout **LAB** offers the Calibration module for fitting parameters to experimental data

Mack Development Model

Some Typical Mack Development Rate Parameters



3D resist simulation vs experiment after resist parameter calibration

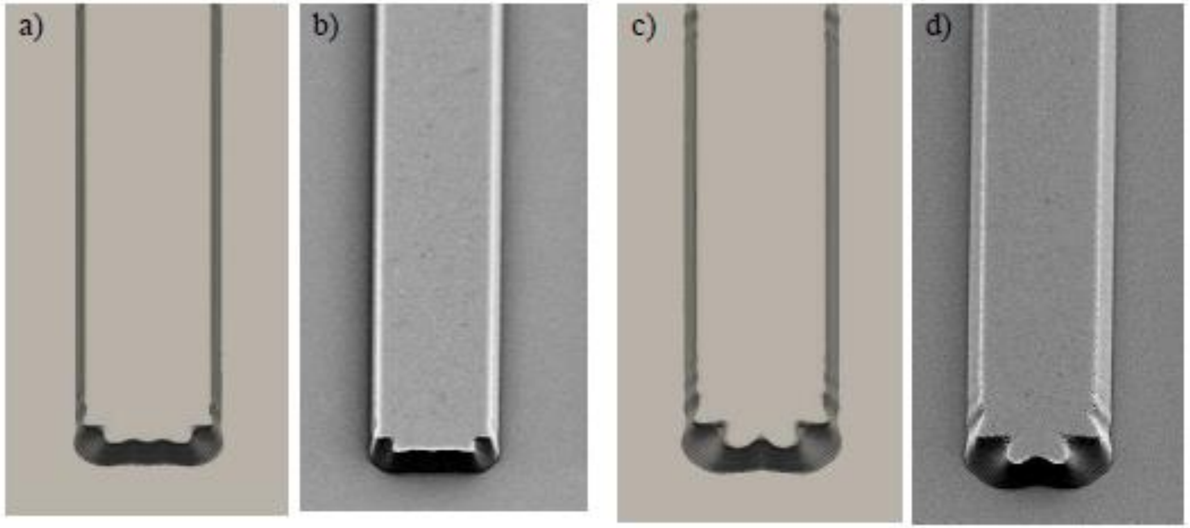


Figure 4: Comparison of simulated ((a) and (c)) and experimentally observed ((b) and (d)) photoresist profiles.

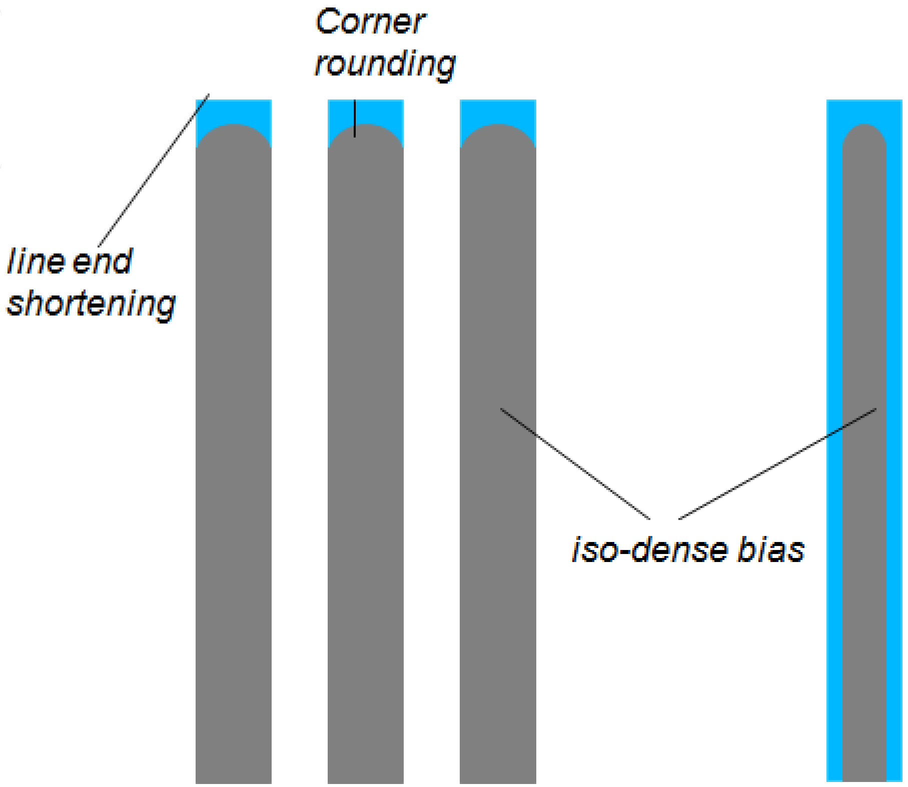
Lithography Simulation

from A. Erdmann: Lithography Lecture

Fraunhofer IISB

Pattern Fidelity Issues

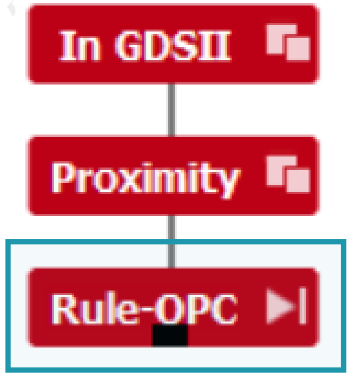
- Common artifacts seen after exposure and development of features are:
    - Corner rounding
    - Length shortening
    - Critical dimension shrinking/widening



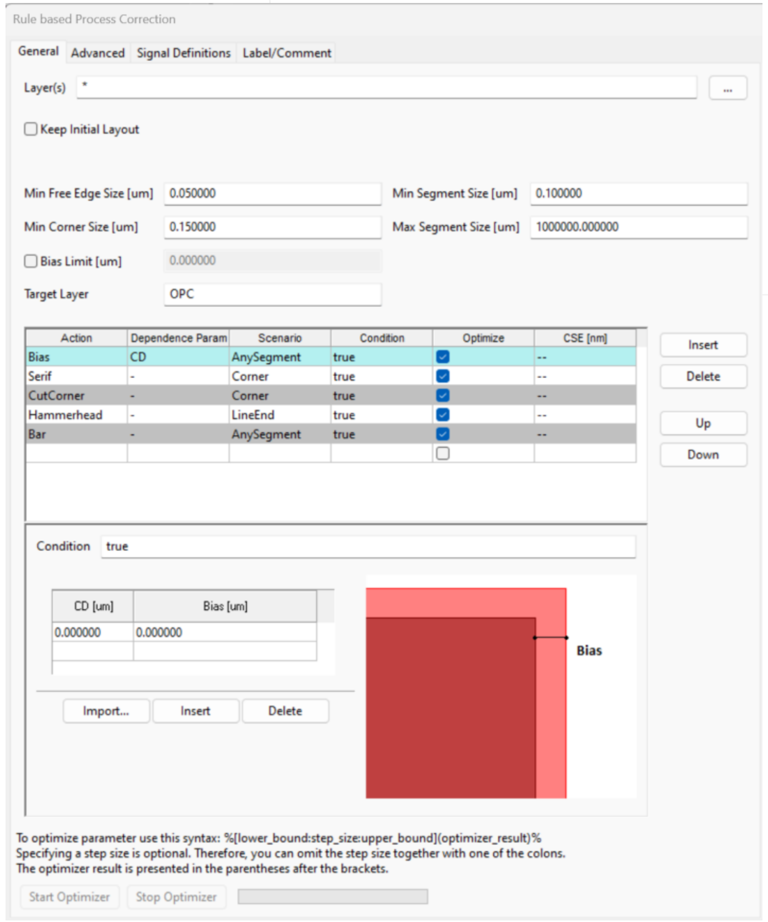
Optical Proximity Correction

OPC Strategy

- Typical OPC methods in high-end lithography



In GDSII
Proximity
Rule-OPC



Layer(s) *

☐ Keep Initial Layout

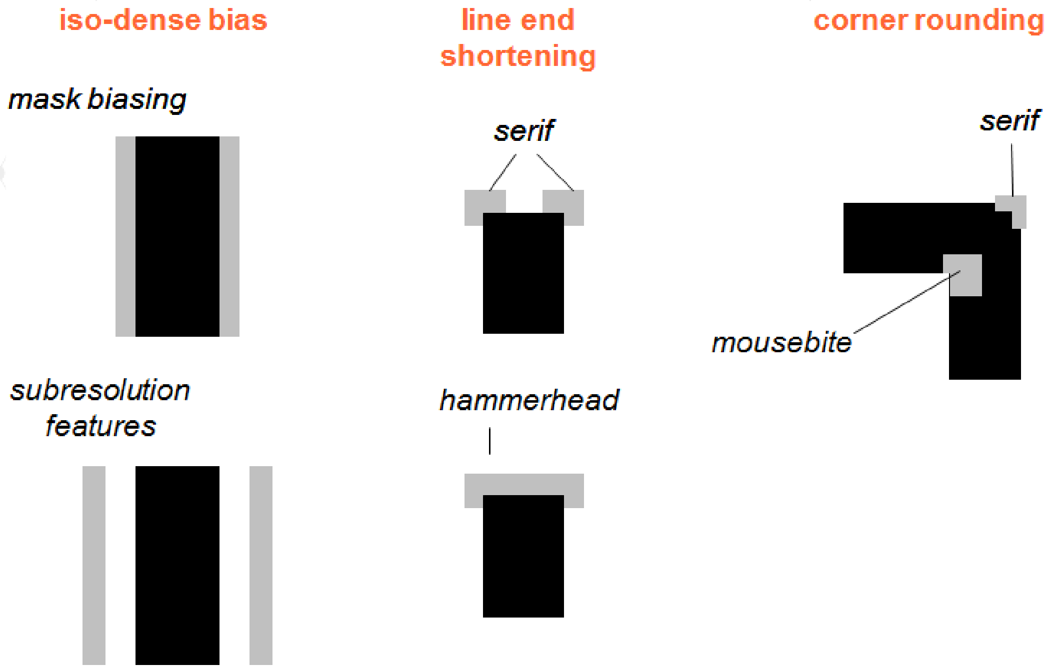
Min Free Edge Size [um] 0.050000
Min Segment Size [um] 0.100000
Min Corner Size [um] 0.150000
Max Segment Size [um] 1000000.000000
☐ Bias Limit [um] 0.000000
Target Layer OPC

Action	Dependence Param	Scenario	Condition	Optimize	CSE [nm]
Bias	CD	AnySegment	true	☑	--
Serif	-	Corner	true	☑	--
CutCorner	-	Corner	true	☑	--
Hammerhead	-	LineEnd	true	☑	--
Bar	-	AnySegment	true	☑	--
				☐	

Condition true

CD [um]	Bias [um]
0.000000	0.000000

To optimize parameter use this syntax: %[lower_bound:step_size:upper_bound](optimizer_result)%
Specifying a step size is optional. Therefore, you can omit the step size together with one of the colons.
The optimizer result is presented in the parentheses after the brackets.



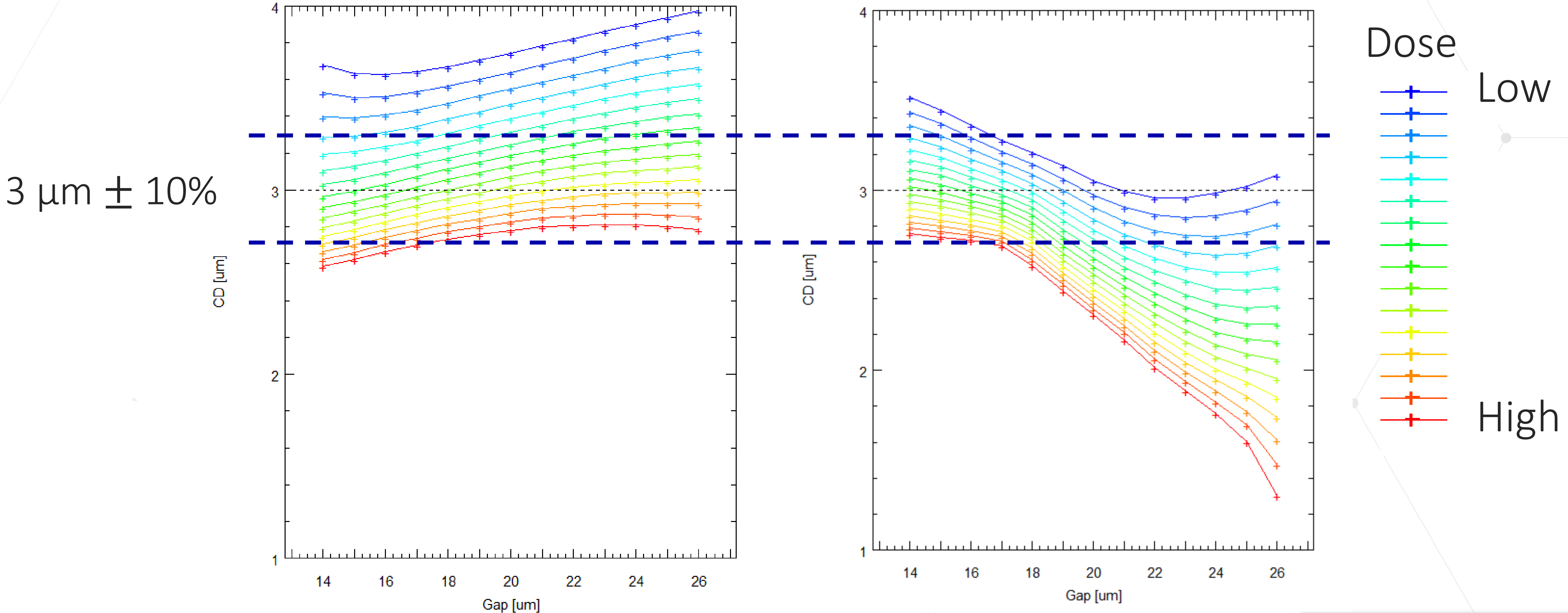
Biasing Example

- A simple example: patterning of 3 µm iso- and dense lines

Process window analysis

3 µm iso-line on mask

3 µm dense lines on mask

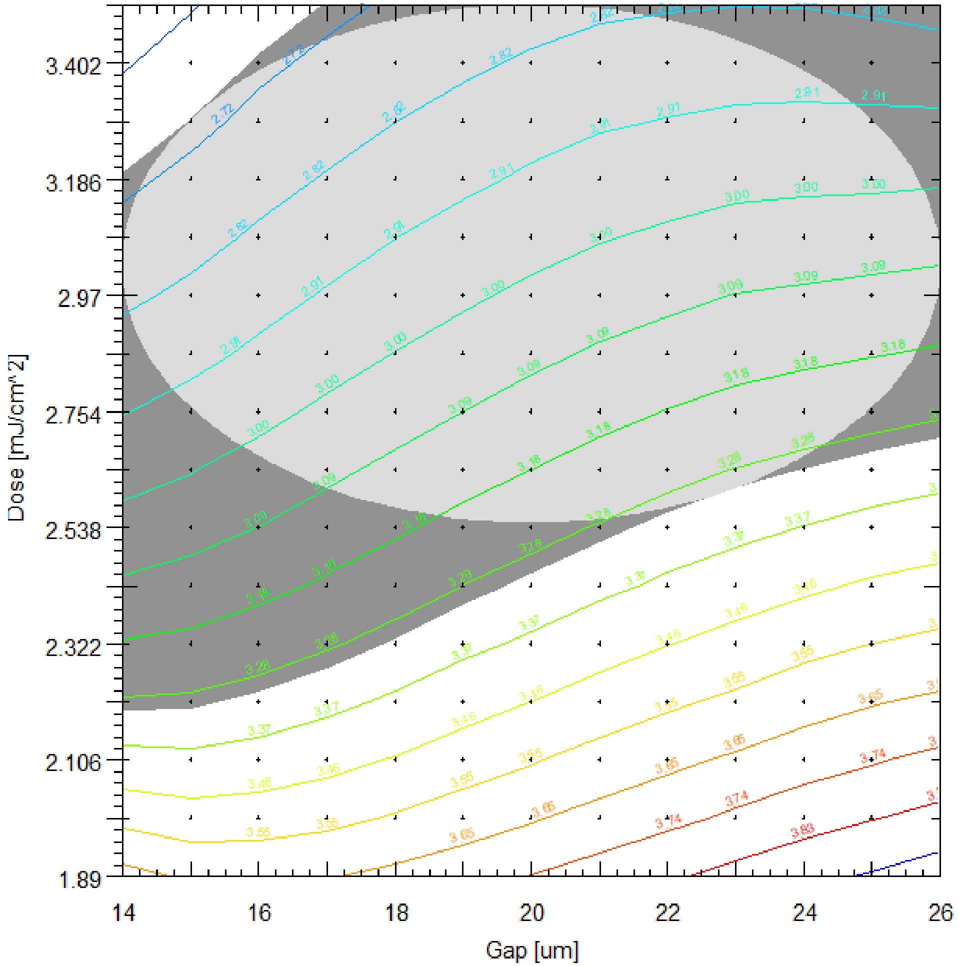


Biasing Example

Process window analysis

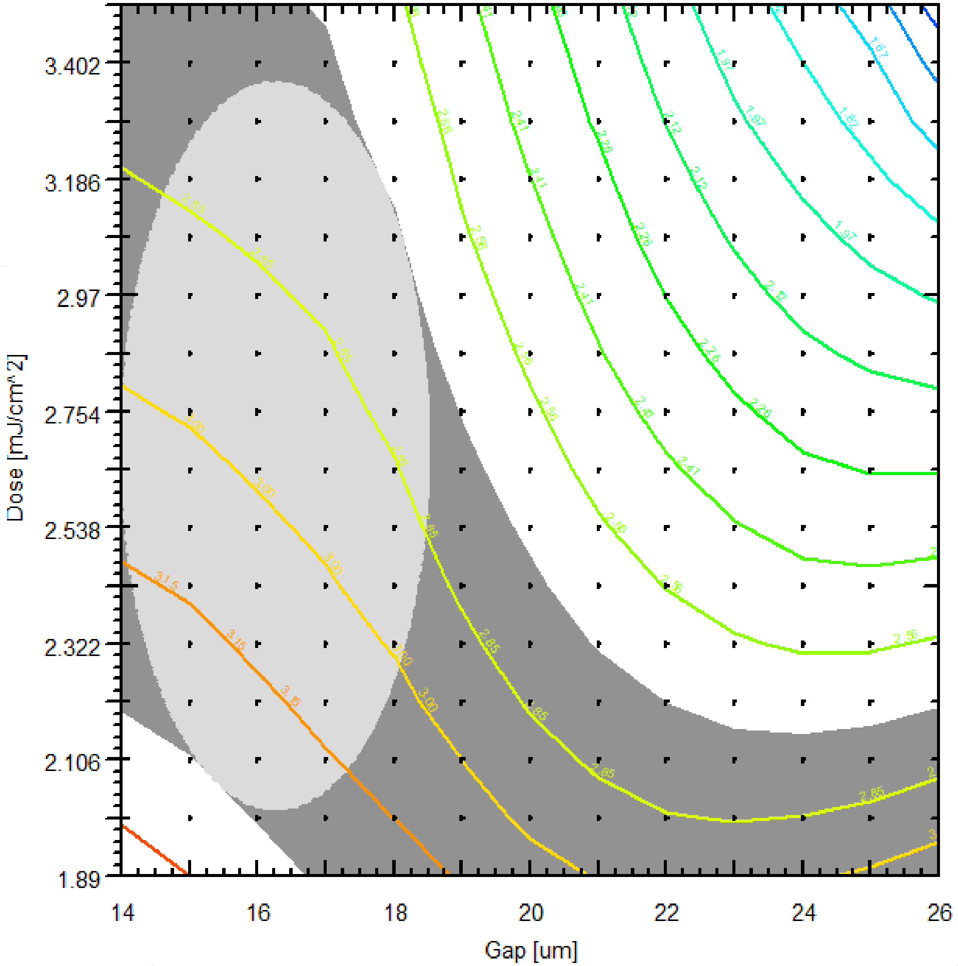
3 µm iso-line on mask

Process Window:
Exposure Latitude 0.960 (Best Dose 3.030)
Gap Range 12.000 (Best Gap 20.000)



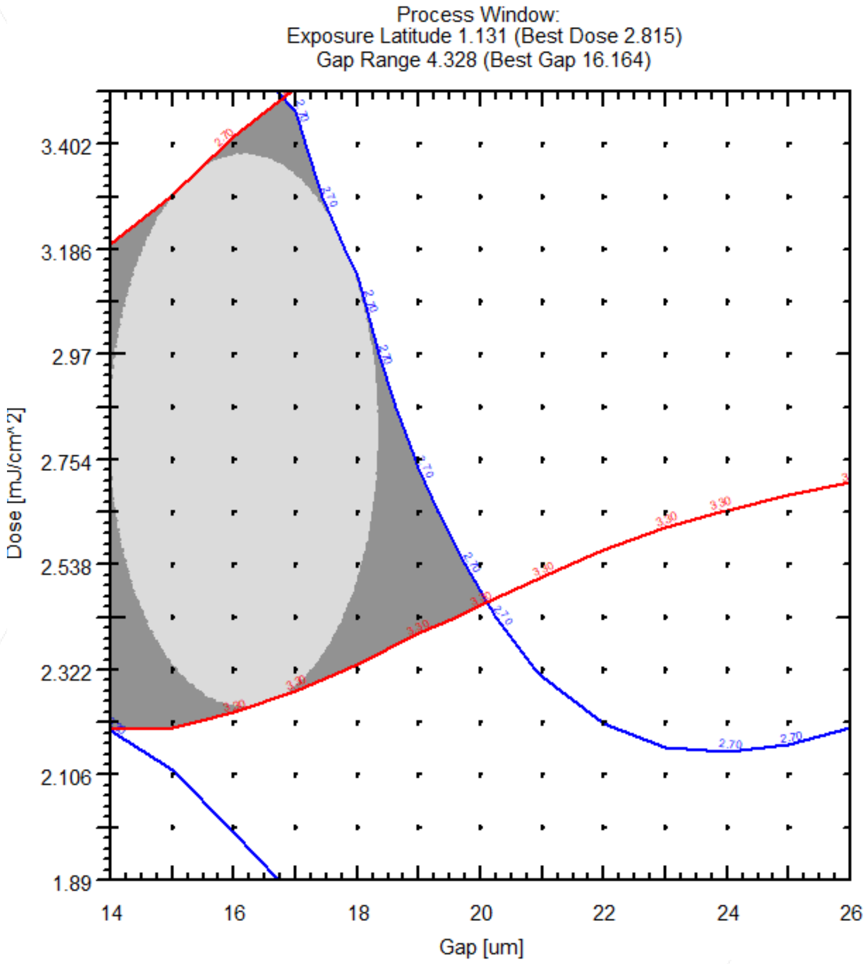
3 µm dense lines on mask

Process Window:
Exposure Latitude 1.354 (Best Dose 2.690)
Gap Range 4.519 (Best Gap 16.260)



Biasing Example

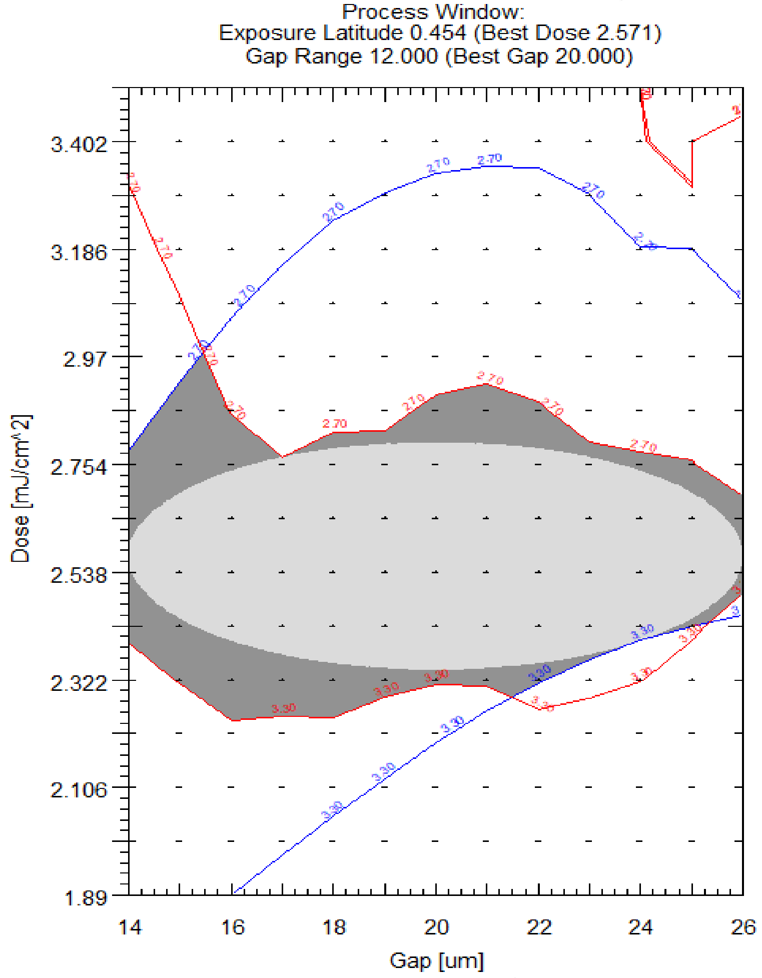
- Overlap of the process window shows:
  - Impossible to print both iso-line and dense lines at Gap larger than 20 µm



Biasing Example

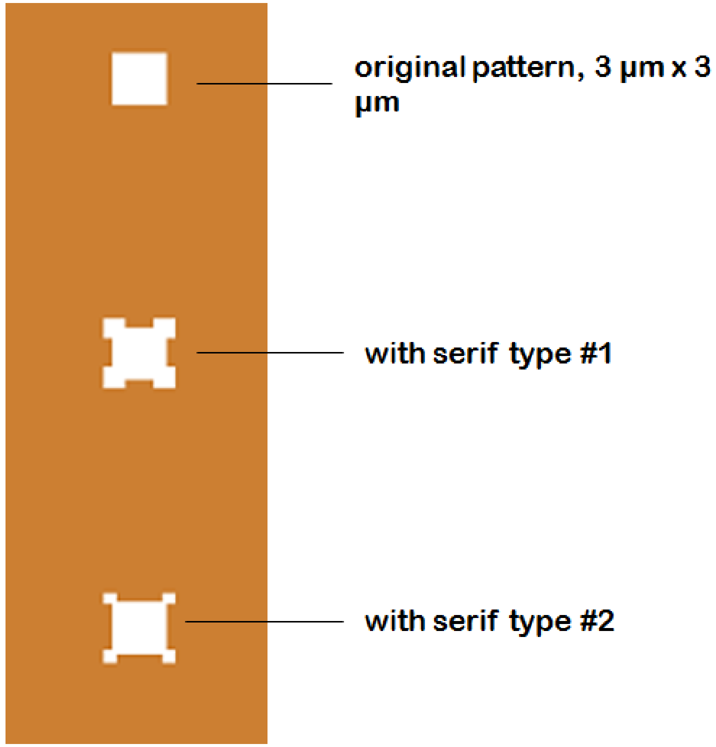
- Biasing of pattern improves the printability of both iso-line and dense lines at gap 20 µm

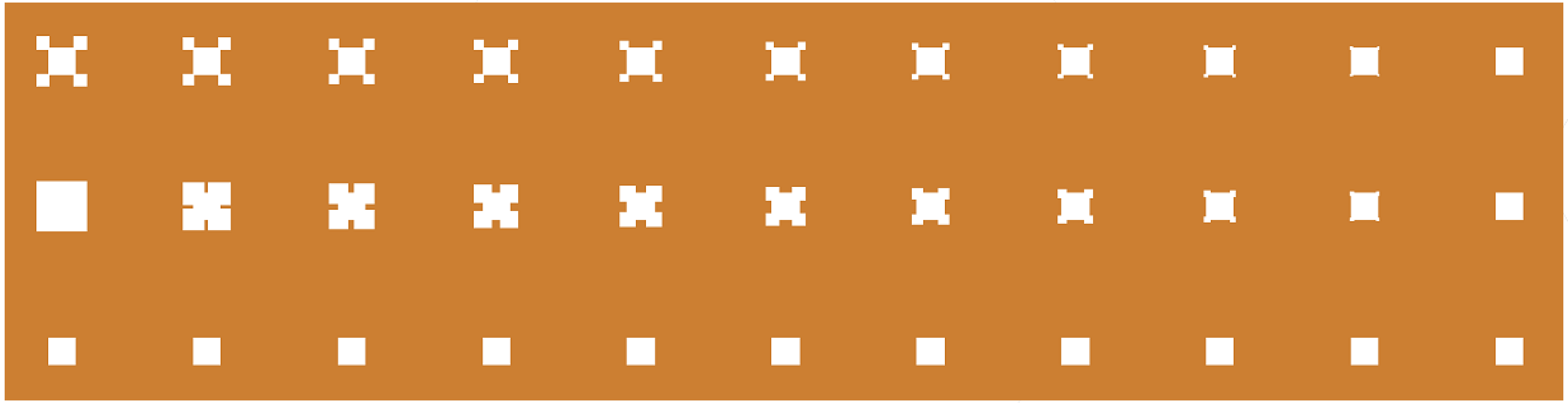
Process window when the linewidth are biased (linewidth for iso line is 2.6 µm and linewidth for dense lines is 4 µm)



OPC in Holes and Dots

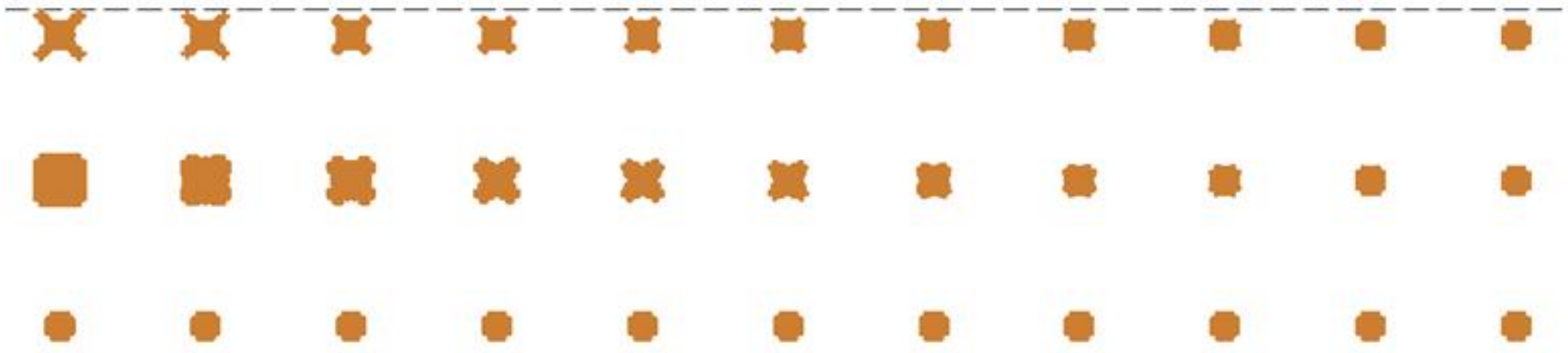
- Mask layout

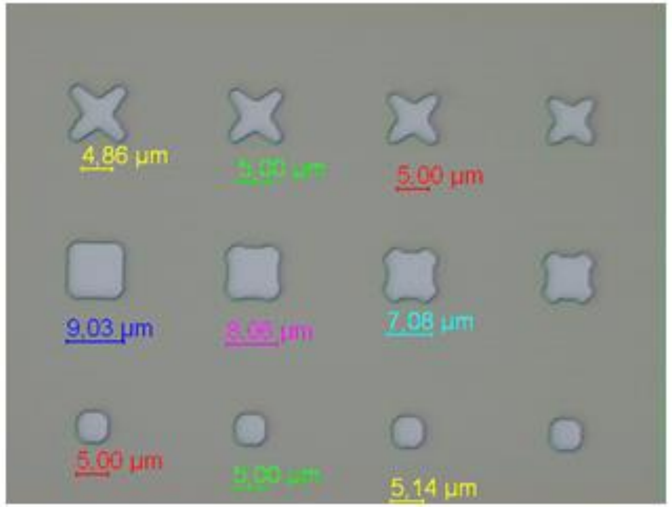


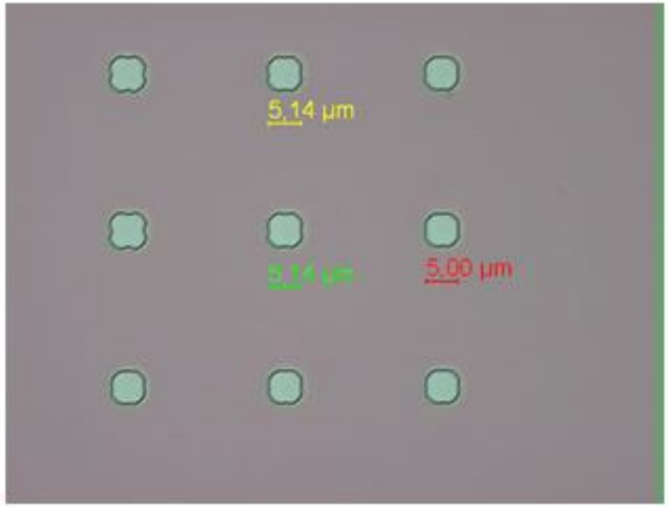


Simulation vs Experiment

- Comparison simulation to experiment - dots

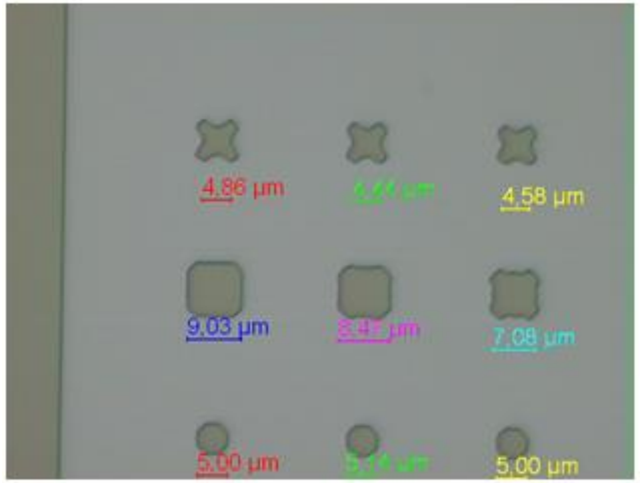


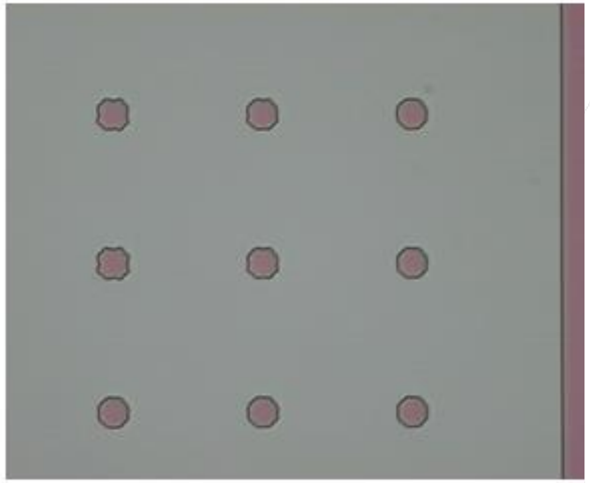




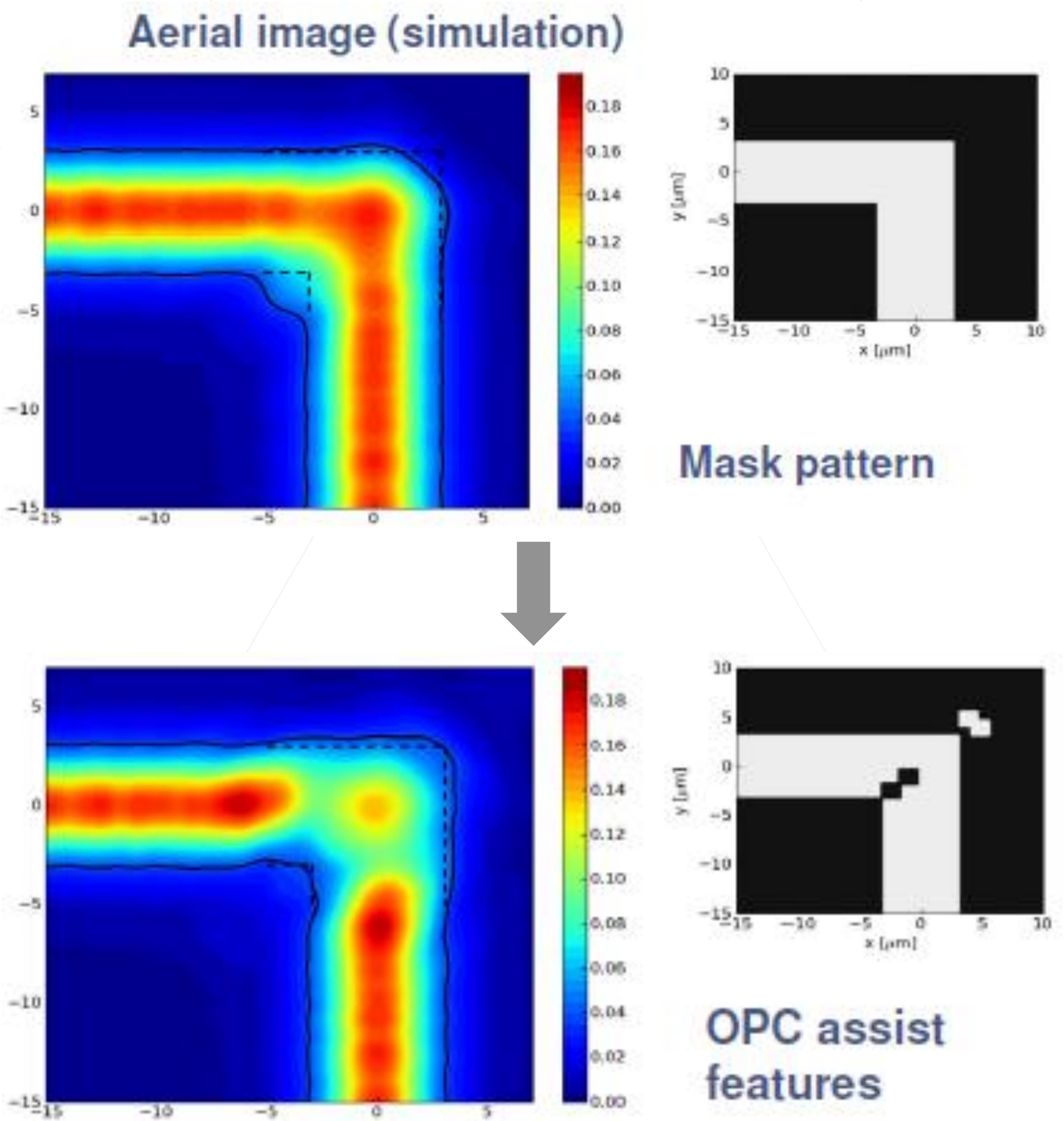
Simulation vs Experiment

- Comparison simulation to experiment - holes





OPC Assist Features

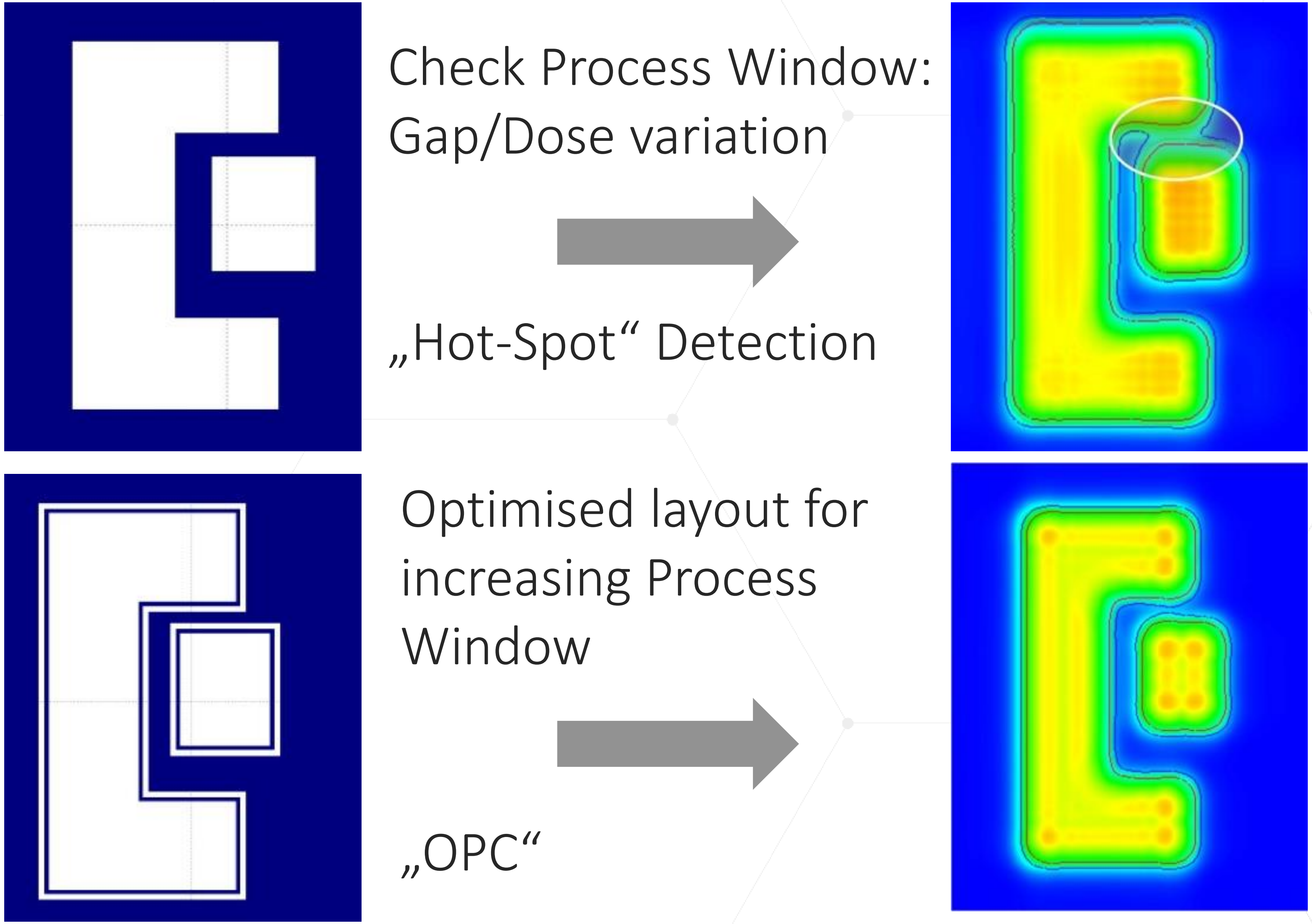

Aerial image (simulation)

Mask pattern

OPC assist features

Fraunhofer
IISB

Sub-resolution Features



Check Process Window:
Gap/Dose variation

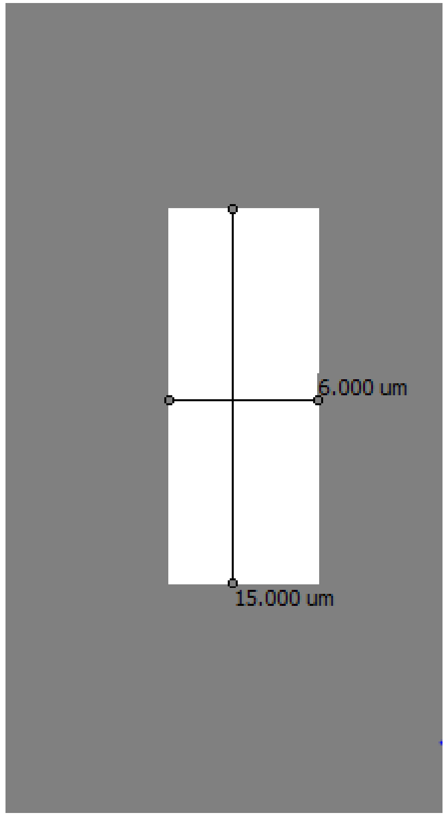
„Hot-Spot“ Detection

Optimised layout for increasing Process Window

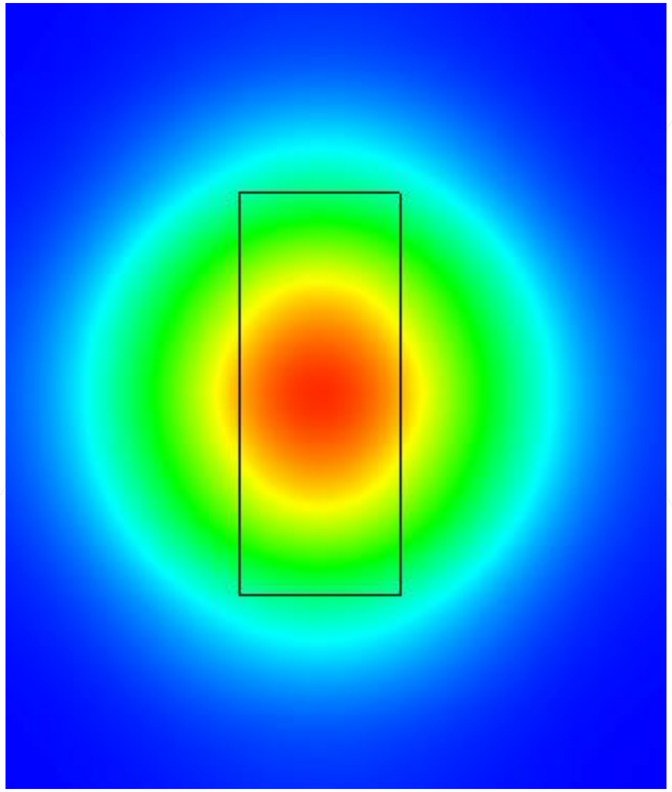
„OPC“

Example feature without OPC

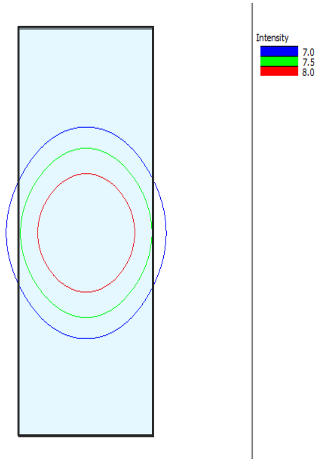
Mask Layout at
150 µm gap



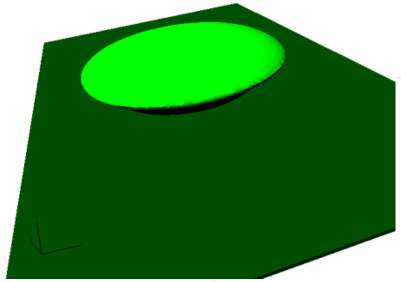
Simulation result without OPC



Intensity Image



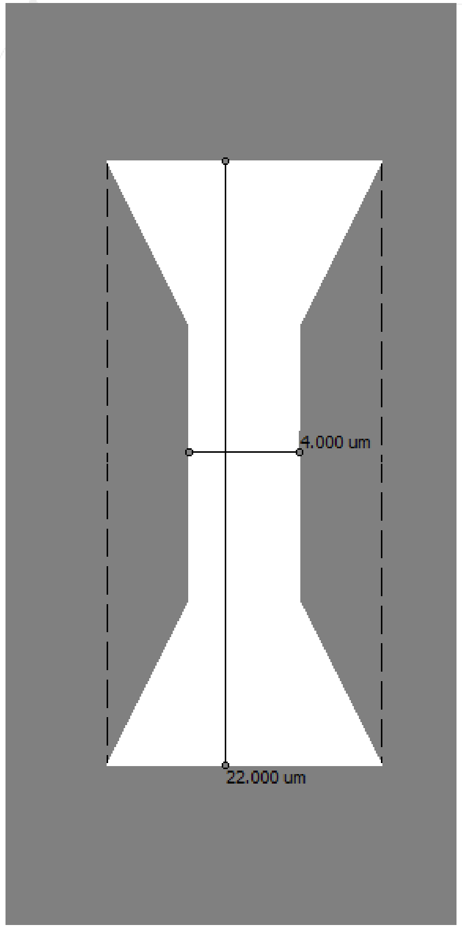
Threshold ± 10%
Dose variation



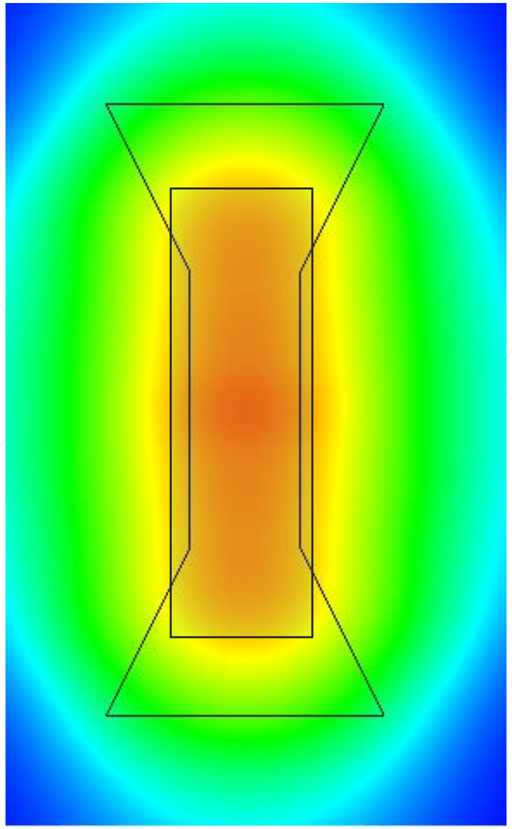
3D profile for
negative resist

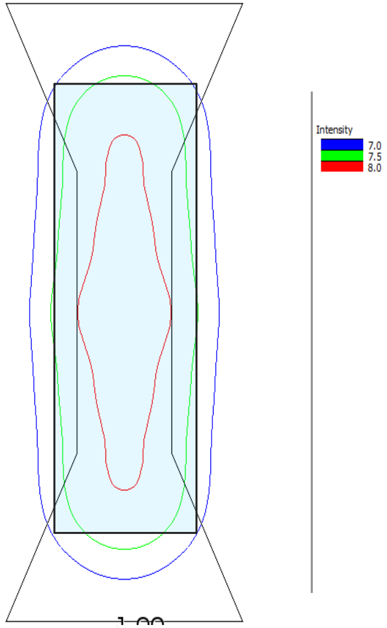
Example feature with OPC

Mask Layout using OPC

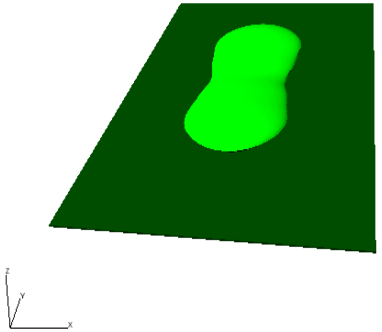


Simulation result with OPC





Threshold ± 10%
Dose variation



3D profile for
negative resist

Thank You!

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