GenISys
Advancing the Standard

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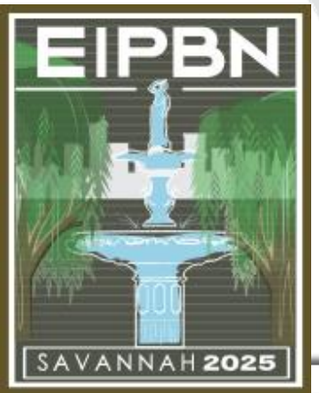
May 27th, 2025

A simulation guided approach to ebeam patterning

GenISys BEAMeeting
EIPBN 2025, Savannah

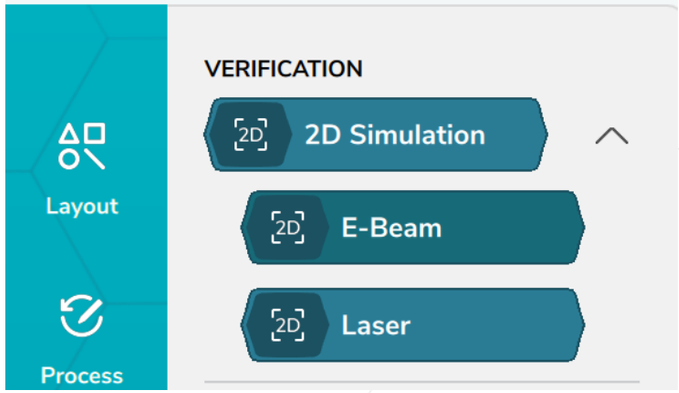


OUTLINE

- Why ebeam simulation matters
- Short range effects
- The role of blur in pattern fidelity
- Shape PEC and Over Dose Under Size
- Case studies and results
- Key takeaways

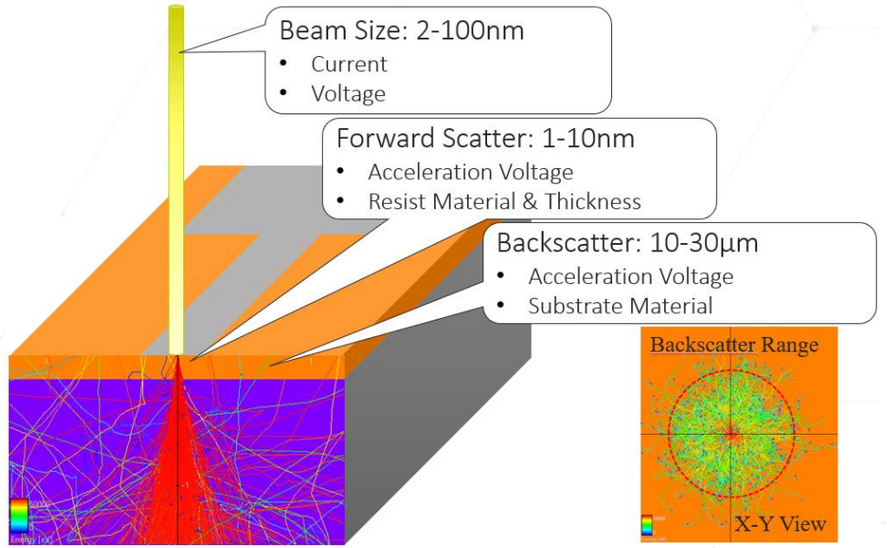
Why ebeam simulation matters

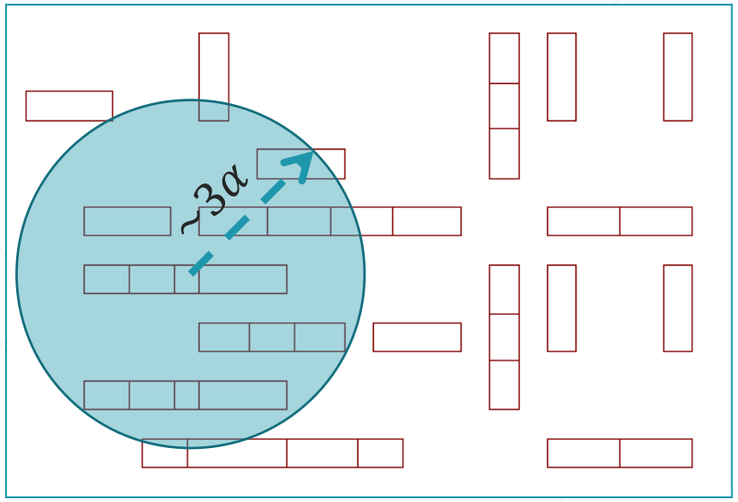
- Increasing pattern complexity with smaller CDs and higher feature densities
- When CDs are <100 nm and density exceeds 50%, short-range effects dominate
- Traditional 2D Proximity Effect Correction (PEC) is often insufficient as it only corrects for long range effects coming from the backscattering
- Short-range interactions distort edges, corners, and critical dimensions
- Trial-and-error approaches are time-consuming and inefficient
- E-beam simulation offers accurate energy deposition modeling and reliable lithography prediction



Short range effects

- Caused by electron forward scattering within the resist material
- Lead to localized energy deposition, typically within a few 10s on nm
- Results in pattern distortion at the feature level, especially in high density areas (lens arrays, dense metasurface pattern, small gaps)
- Can lead to CD error, corner rounding, or shape deformation
- To correct for these issues, advanced correction strategies like Shape PEC (dose + edge edjustment) are highly recommended
- But before fixing the issue, it is important to “see” the issue which can be done using ebeam simulation





Total Effective Blur

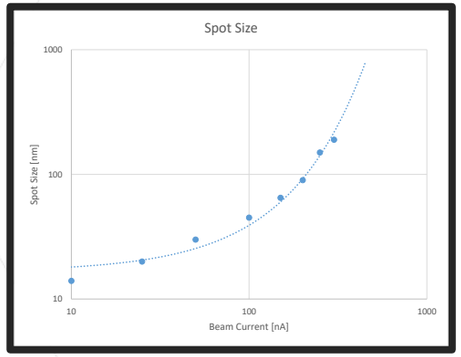
$Spot_{eff} = Spot_{Beam}$ ← depends on current, 2-100nm

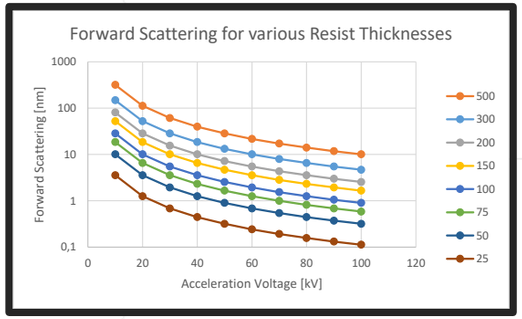
⊗ Jitter ← noise dominated

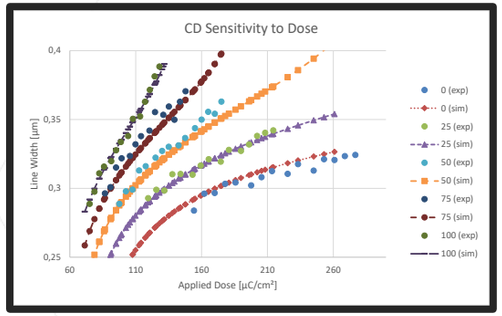
⊗ Forward Scattering ← 1-10nm

⊗ Back Scattering ← reduced EL for dense

⊗ Resist Effects ← diffusion, lateral development, …



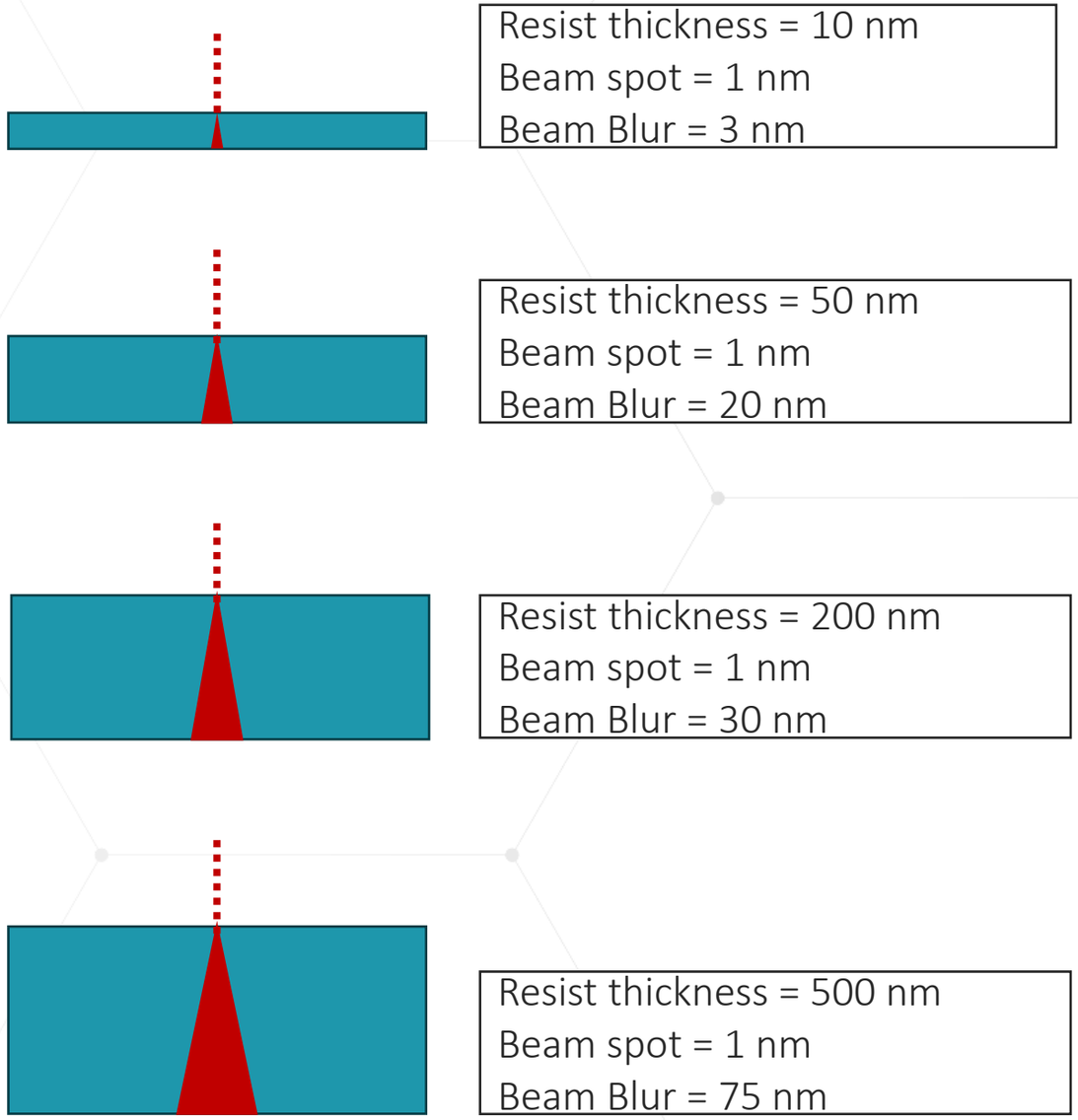




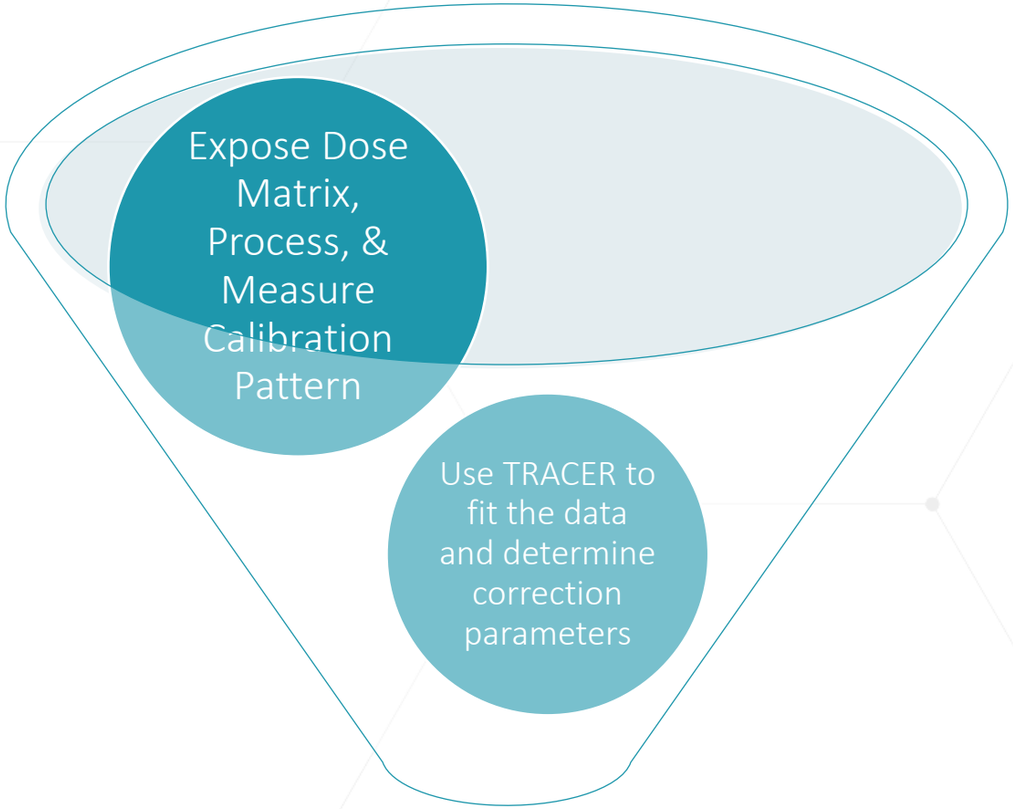
Development, Scattering and Beam Jitter typically dominate over native Beam Size

The role of blur in pattern fidelity

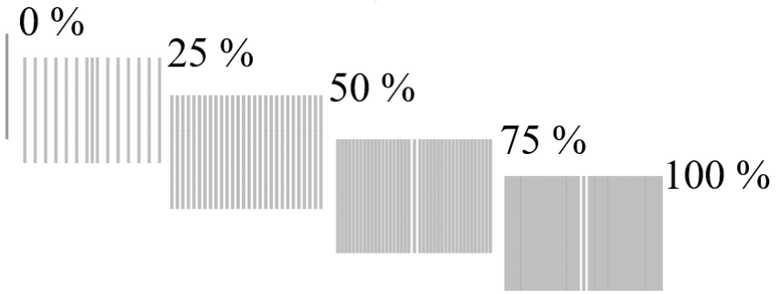
- Caused by electron forward scattering within the resist material
- Lead to localized energy deposition, typically within a few 10s on nm
- Results in pattern distortion at the feature level, especially in high density areas (lens arrays, dense metasurface pattern, small gaps)
- Can lead to CD error, corner rounding, or shape deformation
- To correct for these issues, advanced correction strategies like Shape PEC (dose + edge adjustment) are highly recommended
- But before fixing the issue, it is important to “see” the issue which can be done using ebeam simulation

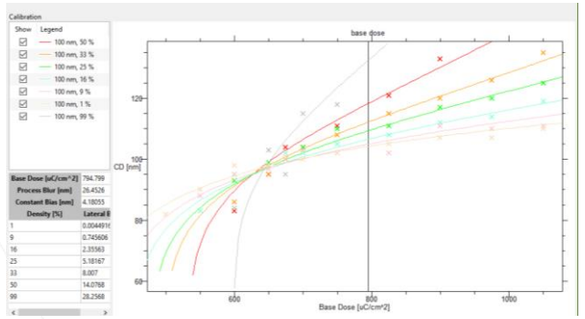


How to find blur: Process Calibration

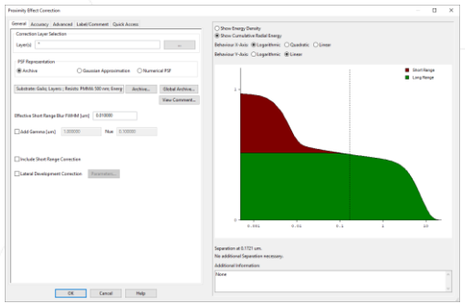


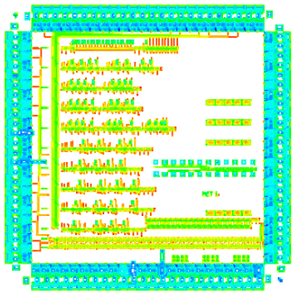
Apply correction parameters using BEAMER's PEC module



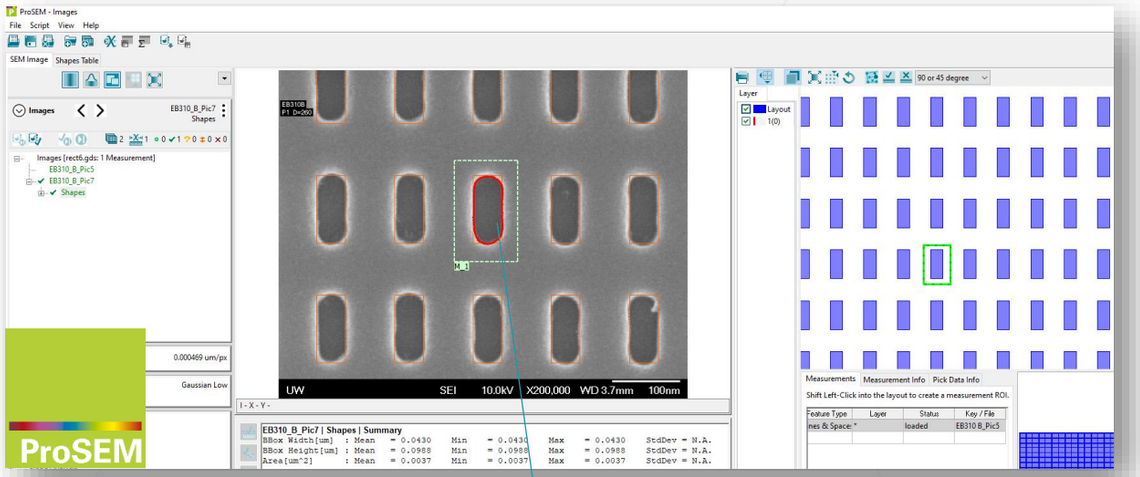


- Base Dose
- Effective Process Blur
- Constant and density-dependent bias
- UC/OC Mix Factor

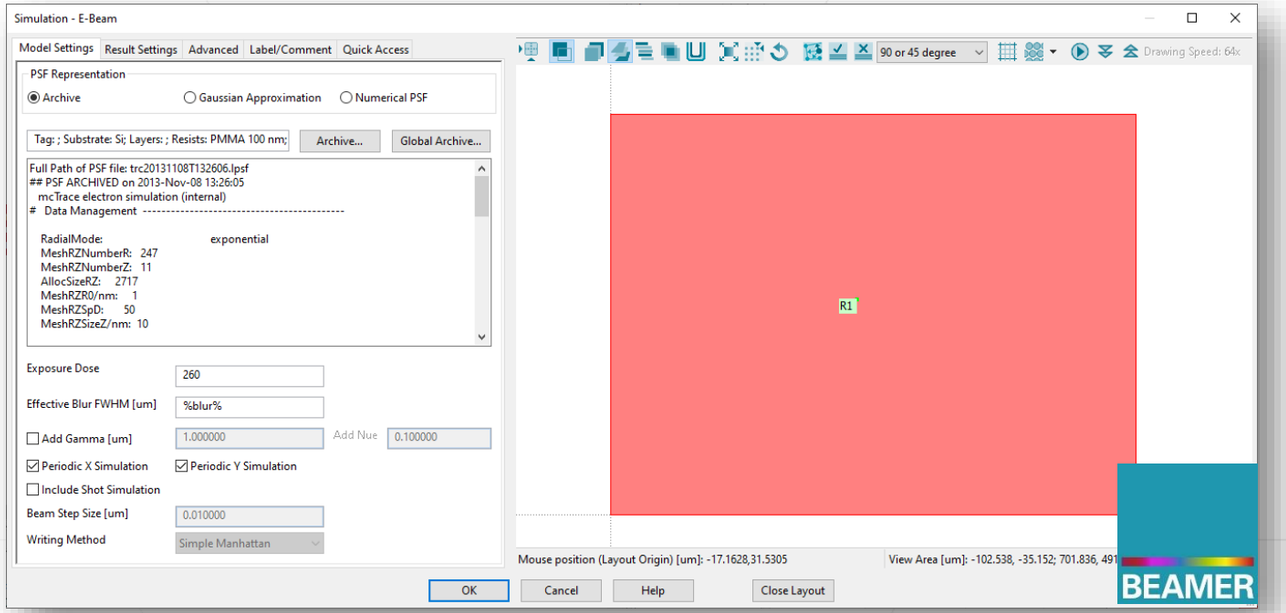




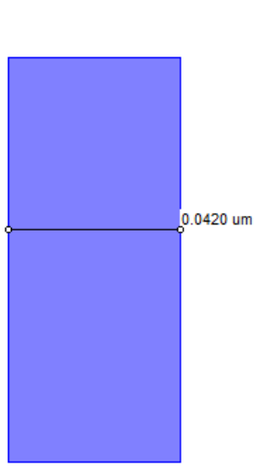
How to find blur: Using simulation + ProSEM

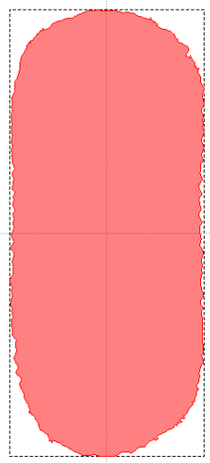


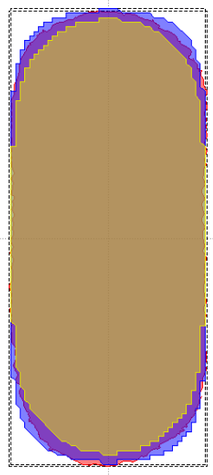
- Shape detection

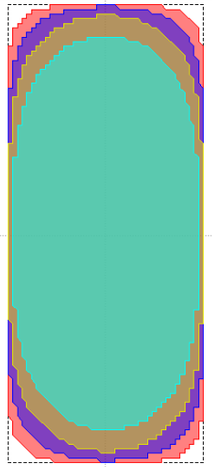


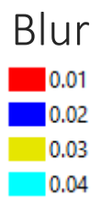
- Ebeam simulation







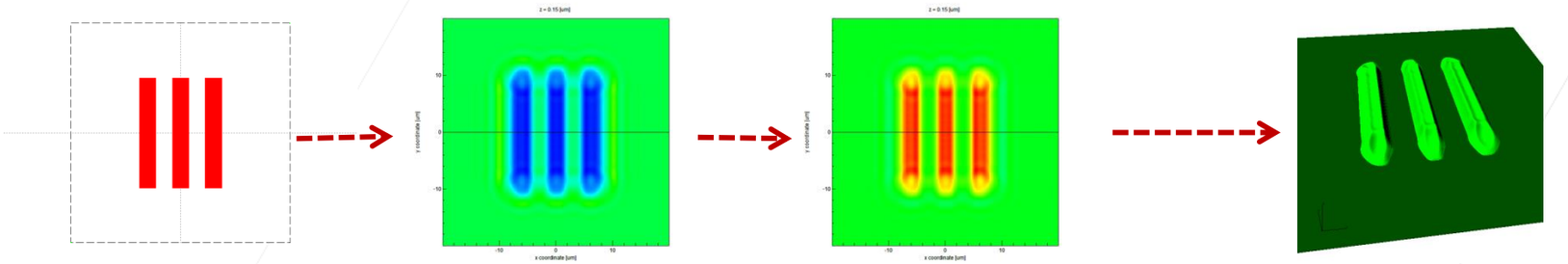




Blur is in between 20 and 30 nm

LAB Verification

- LAB is capable of modeling energy conversion from e-beam to energy distribution in resist, resulting in chemical change of resist and finally resist development.
- 3D-PSF is used for simulation, taking into account the depth dependence of PSF within the resist
- The resist development properties are modeled by Mack 4. Mack4 model is used to enhance the resist profile variation caused by image slope at the exposure edge. The model parameters are taken from a calibrated PMMA 950K e-beam resist.

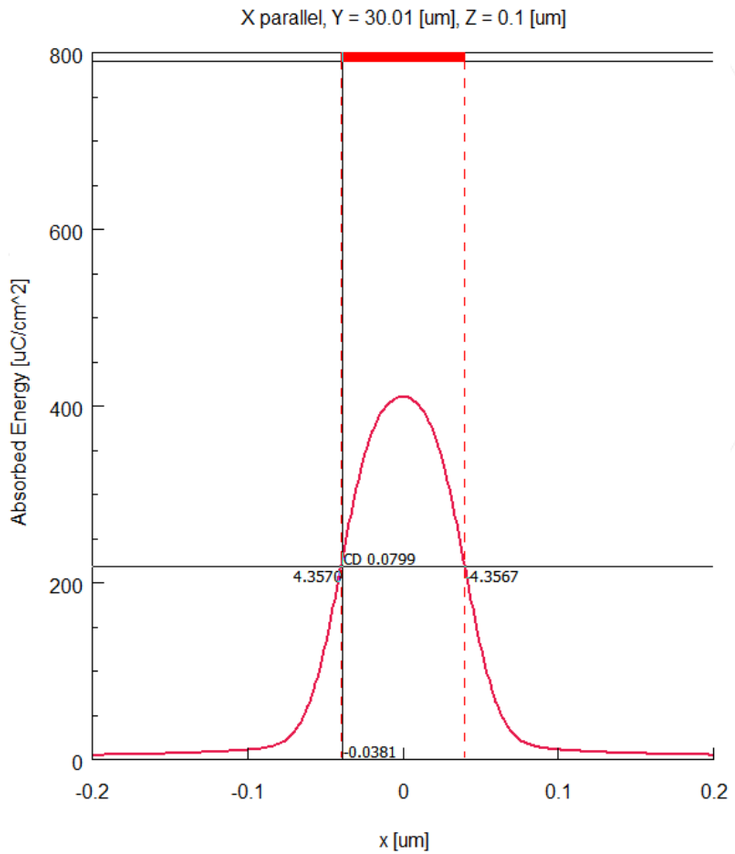


LAB

Intensity Comparison

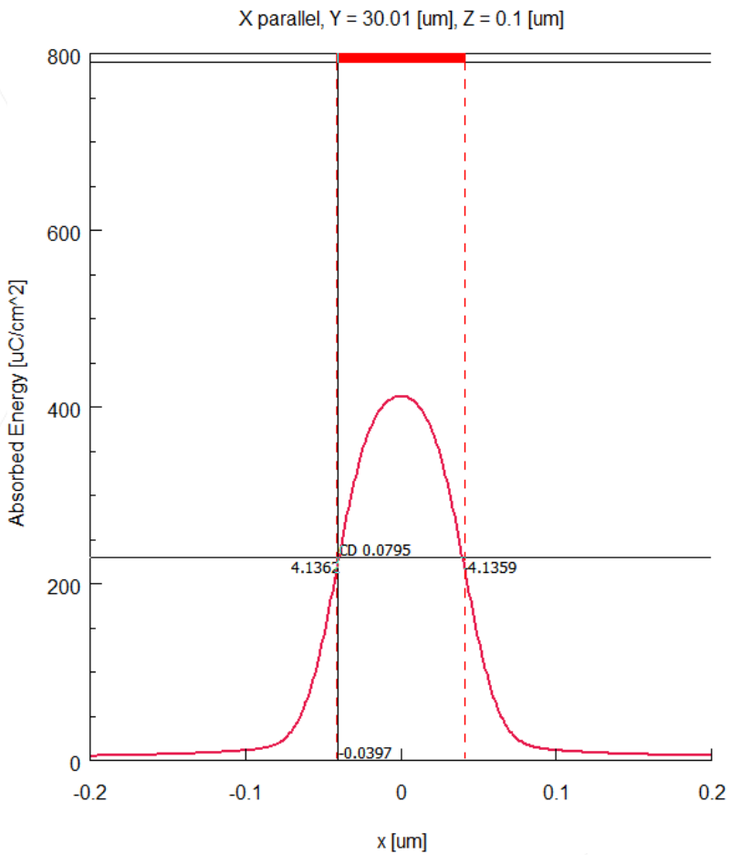
- The 1D intensity comparison across isoline (R1) is shown. The usage of overdose enhances the image log slope (ILS) at the expected edge.

PEC



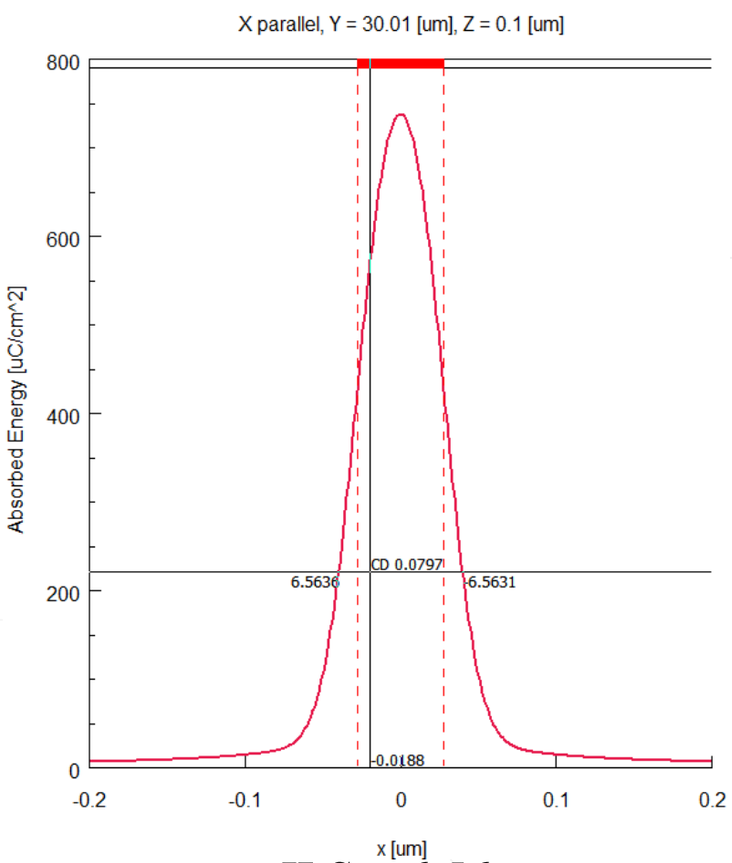
ILS = 4.36

Shape PEC



ILS = 4.14

Shape PEC (overdose = 2)

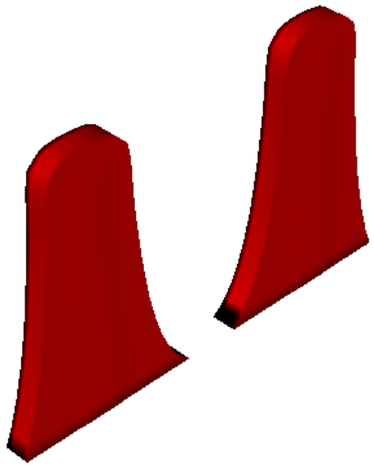


ILS = 6.56

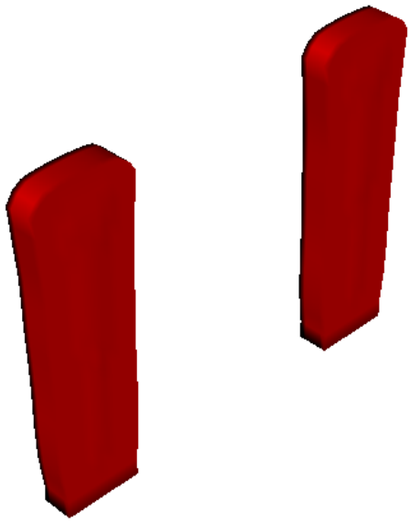
Resist Profile

- Simulation has shown the negative resist profile for ODUS shape PEC, which has advantage for clean clearing of lift-off, especially at the dense area.

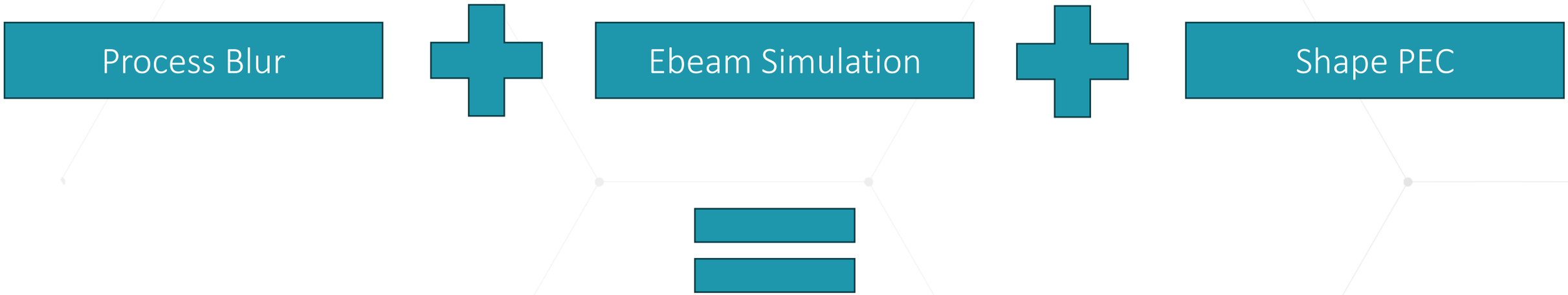
PEC



Shape PEC
(overdose = 2)



Secret recipe when you are operating in SR



Near perfect lithography
Less iterations/trial and error
Save time
Sharper corners, improved resolution

Case Study I:
Resolving small gap and trench in PhC

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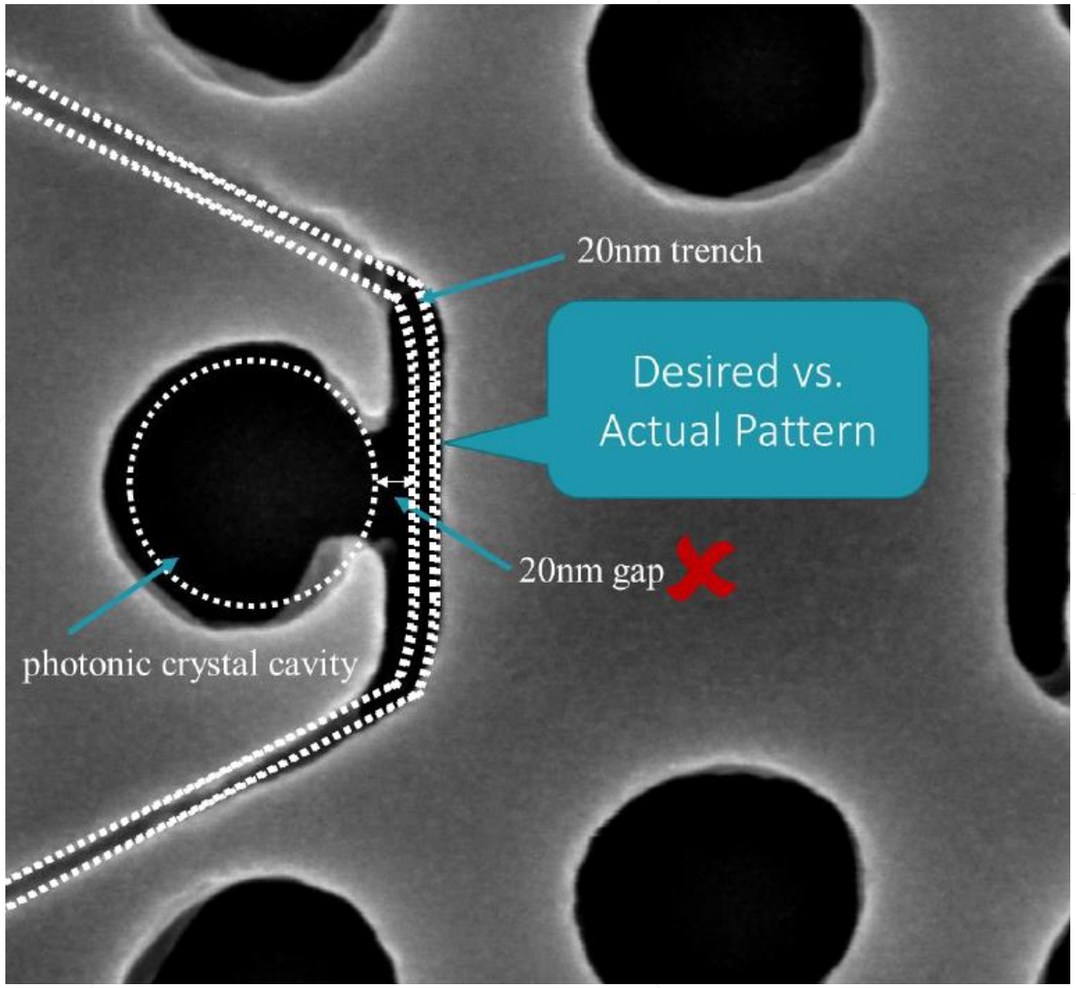
Critical Design Elements:
- **Trench:** 20 nm wide
- **Gap:** 20 nm wide
- **Photonic crystal cavity:** 200 nm (diameter)
- Resolving this **trench** and **gap** combination has proven to be elusive when using PEC.

Experiment
- An exposure was done on structures with 50 nm gaps with 30 and 50 nm wide trenches. Pattern was PEC'ed using only long range correction.
- Simulations were performed to match exposure latitude and observed phenomenon.



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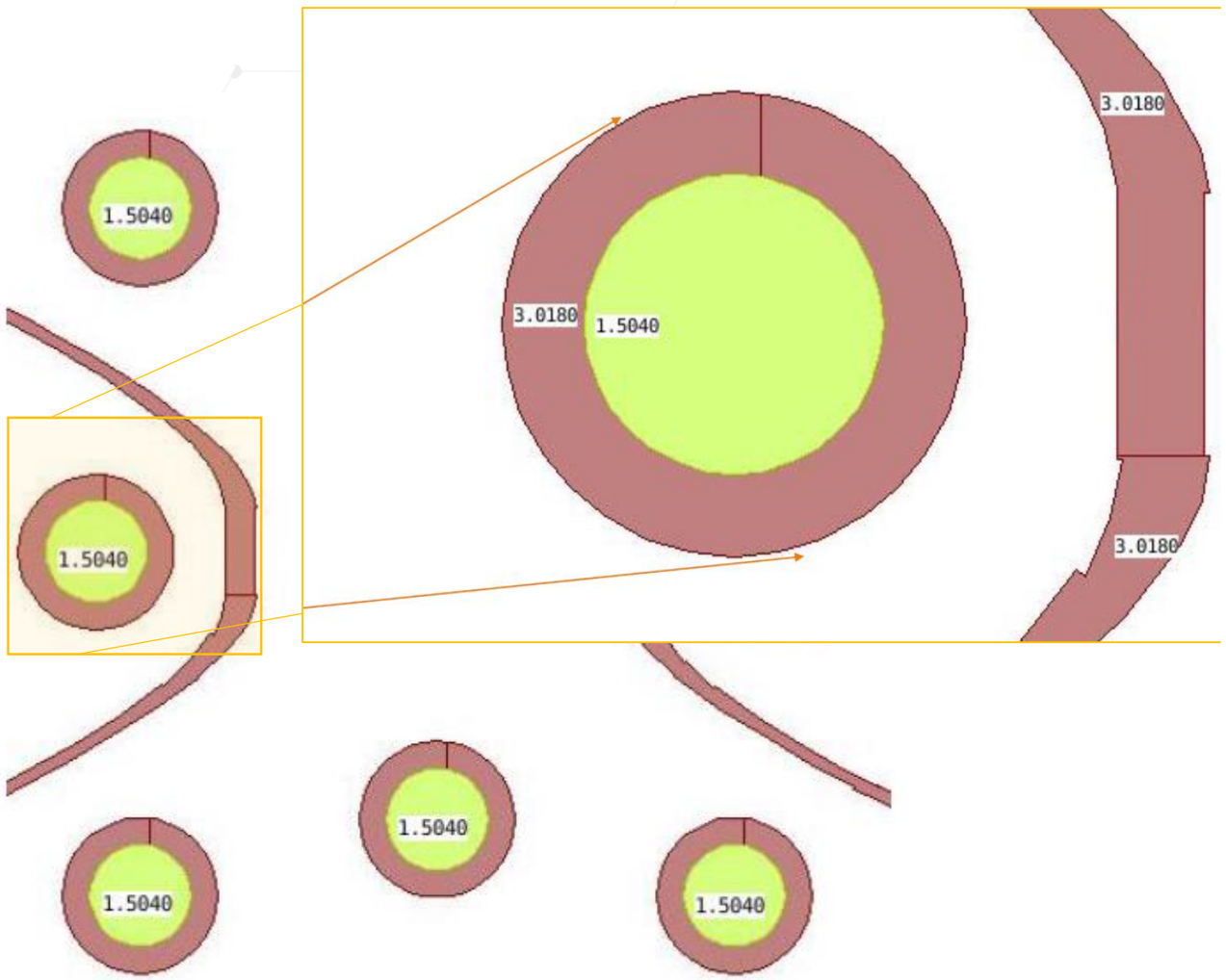
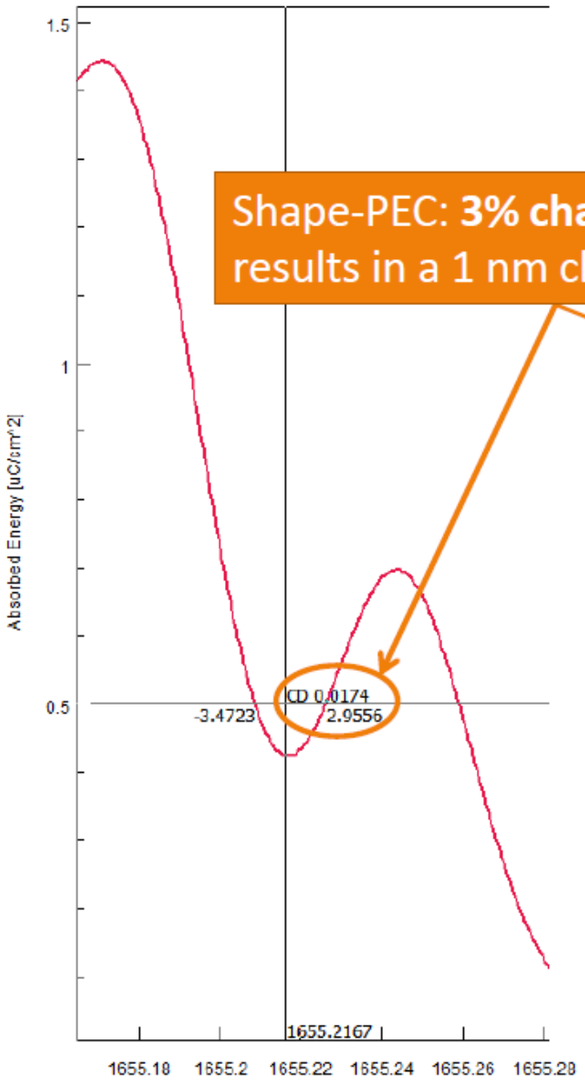
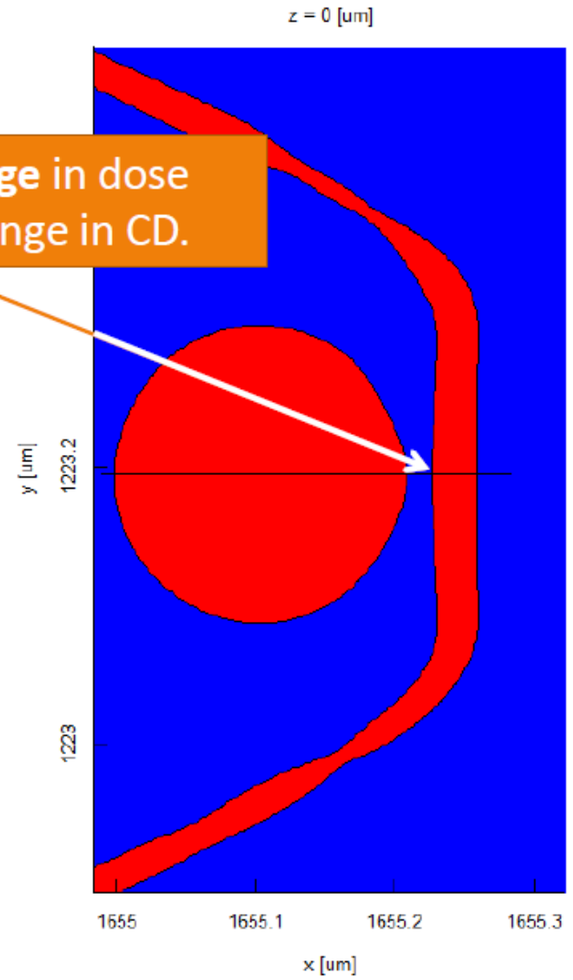
Case Study I: Resolving small gap and trench in PhC





Shape-PEC: **3% change** in dose results in a 1 nm change in CD.



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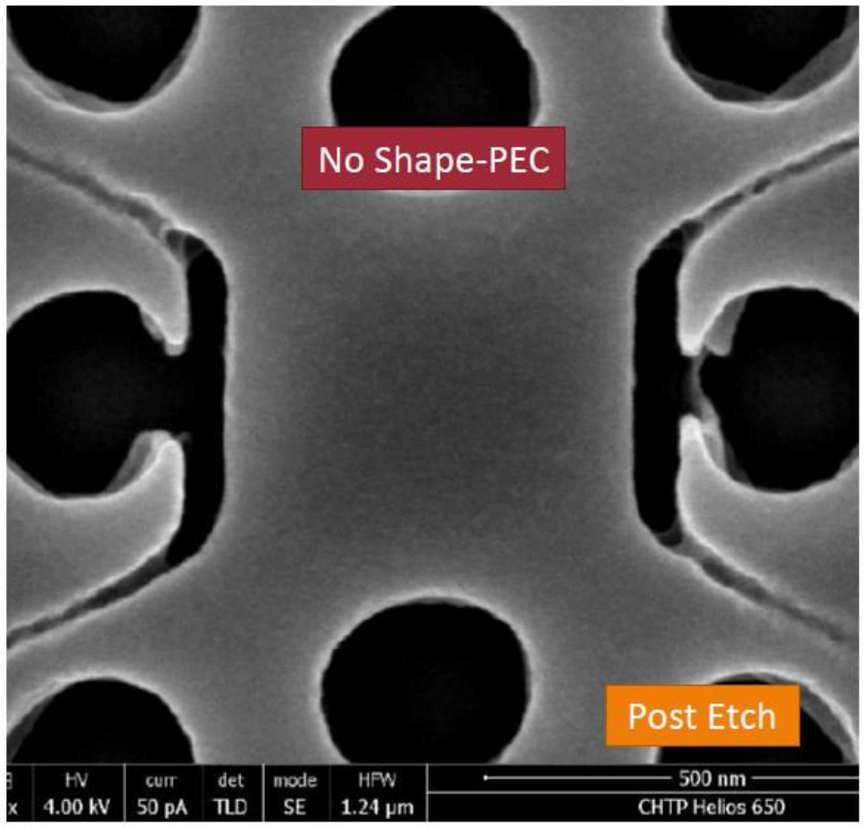
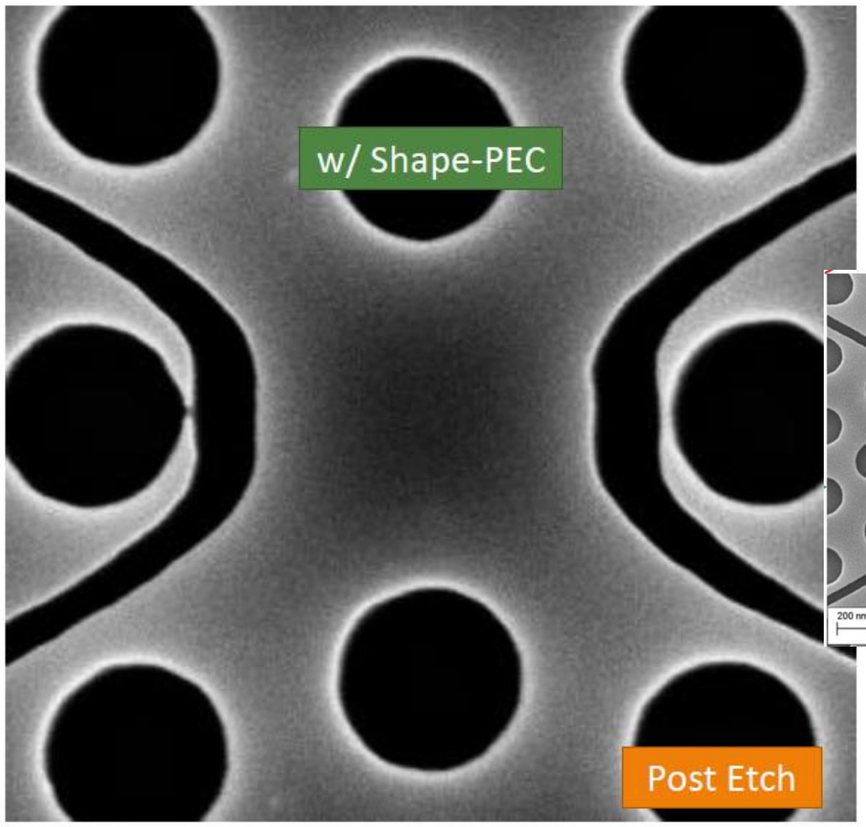
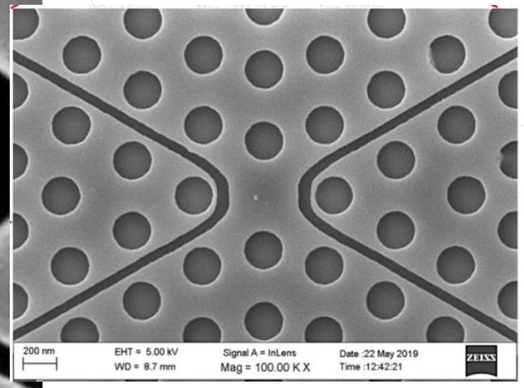
Case Study I: Resolving small gap and trench in PhC

Shape-PEC Applied





Gap: 20nm
Trench: 30nm



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Case Study II:
Patterning a mesh of 30 nm lines

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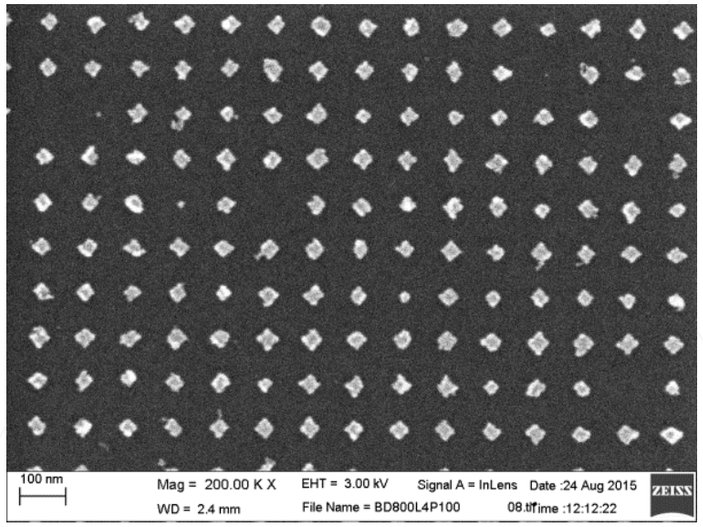
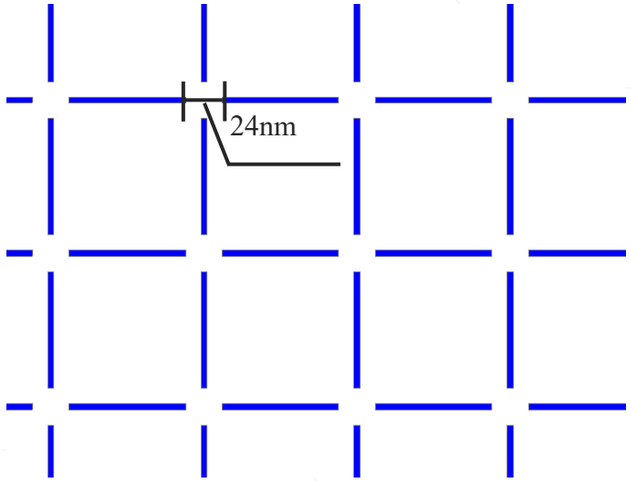
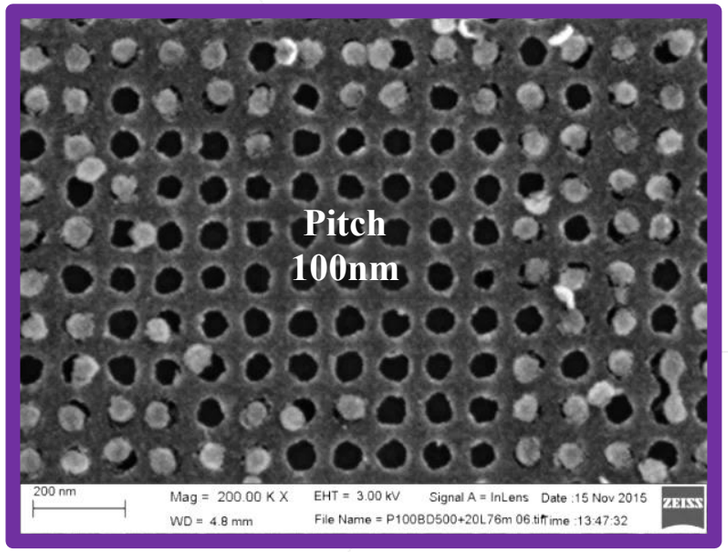


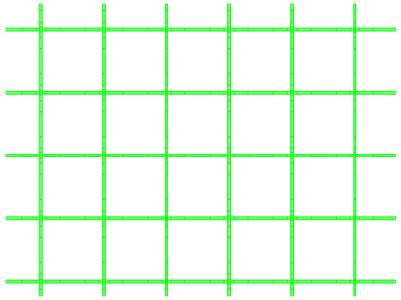
Design correction

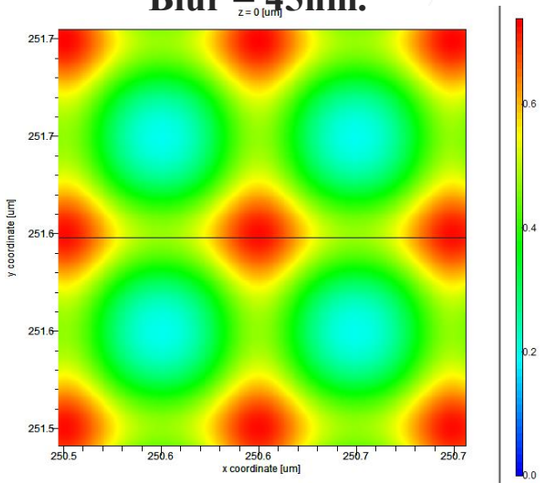




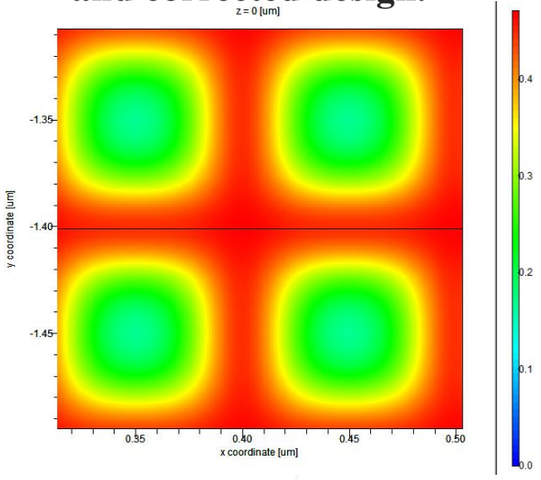
Lithography Results after design correction

Most similar simulation. Blur = 45nm.





Simulation with Blur = 45nm and corrected design.

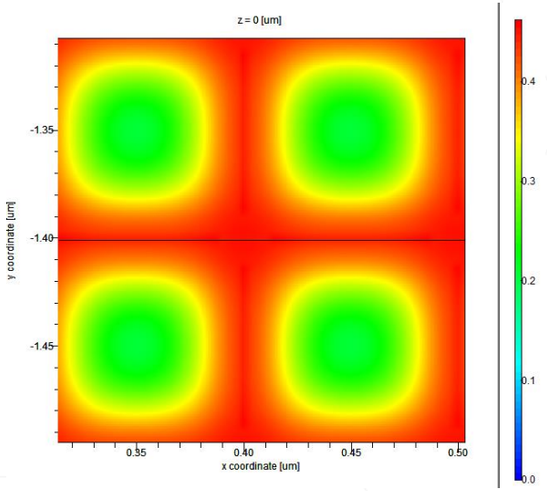


Presented at BEAMeeting Israel 2020

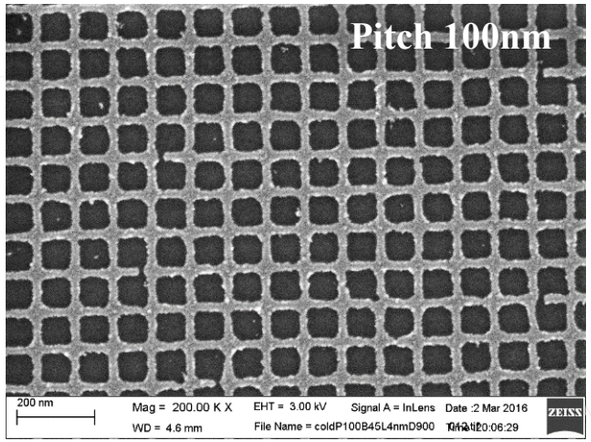
Case Study II: Patterning a mesh of 30 nm lines

- Further improvement using cold development
- The base dose requirement goes up
- The blur values go down
- Simulation and experimental verification shown on right

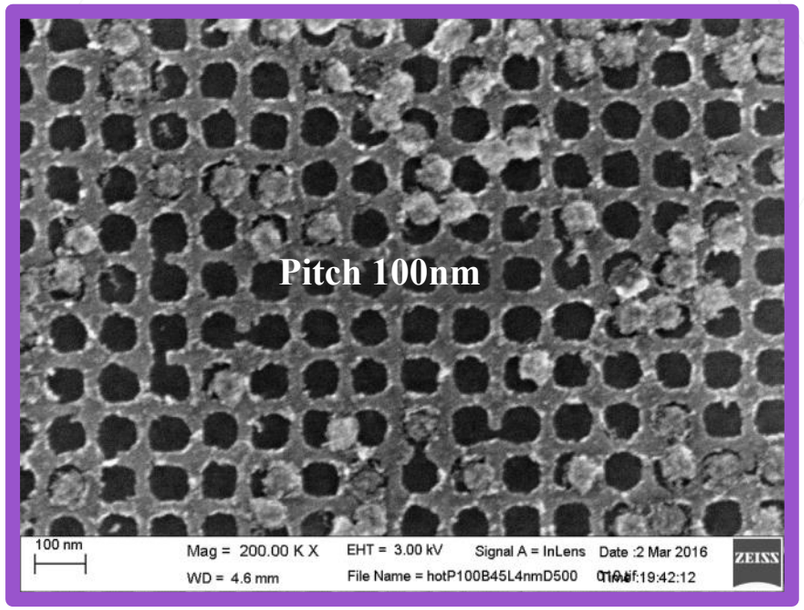
Simulation
Line 4nm, Hole 24nm, Blur 45nm.



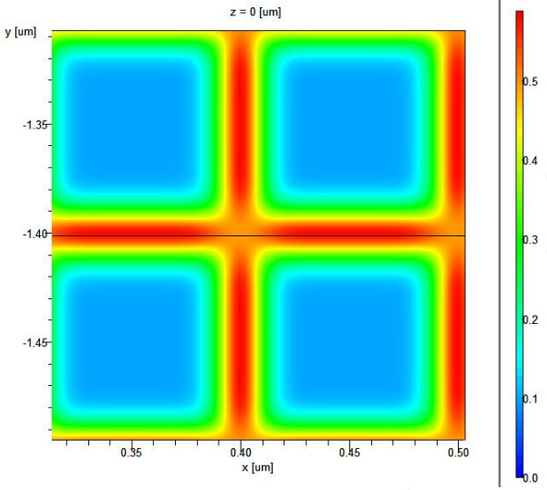
Cold developer
BD 80% higher



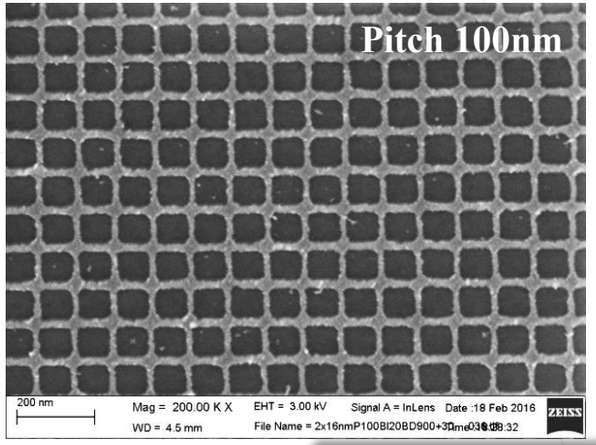
Room Temperature Developing



Simulation
Line 2nm, Hole 16nm, Blur 20nm



Cold developer + optimization
BD 135% higher



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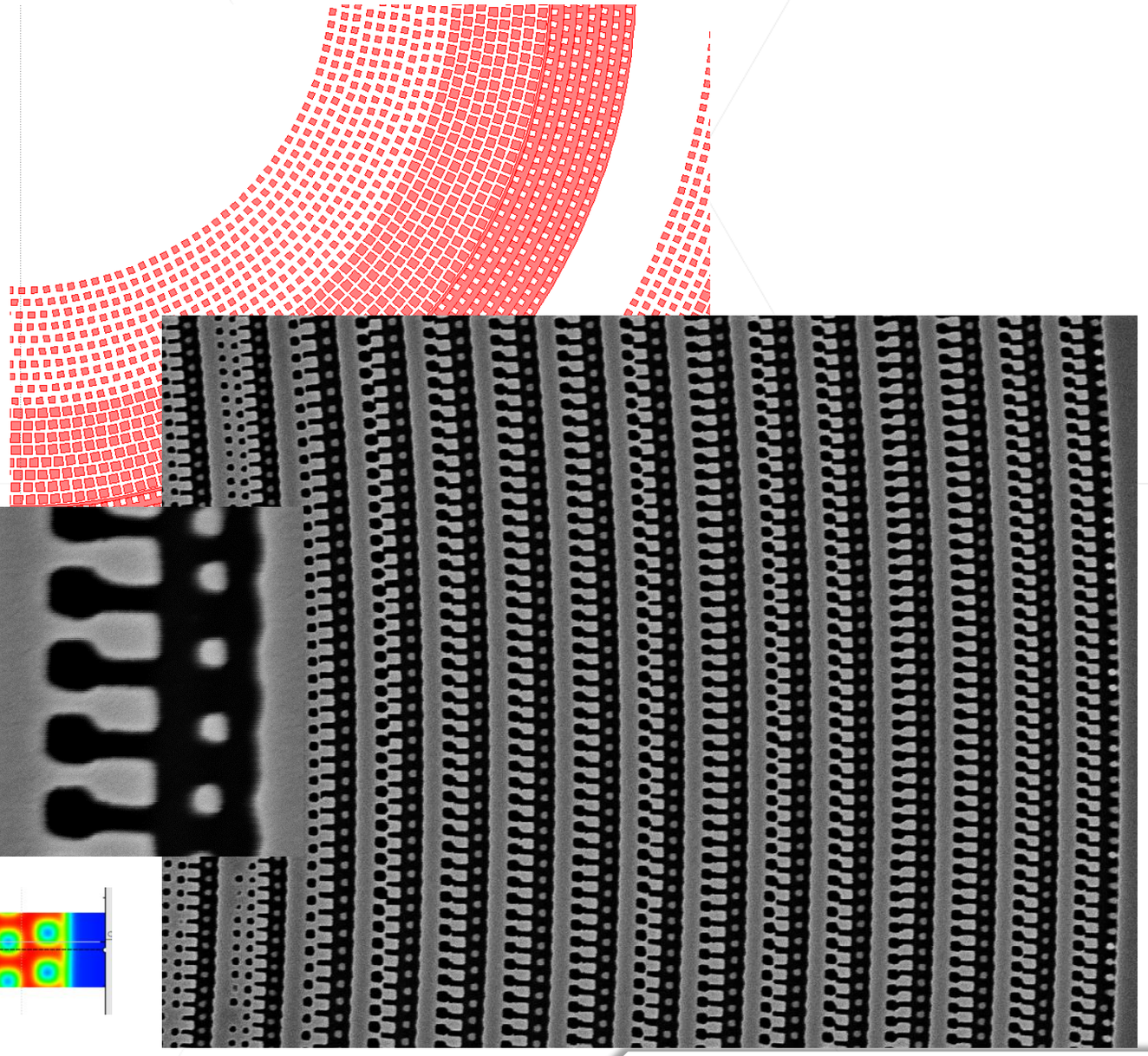
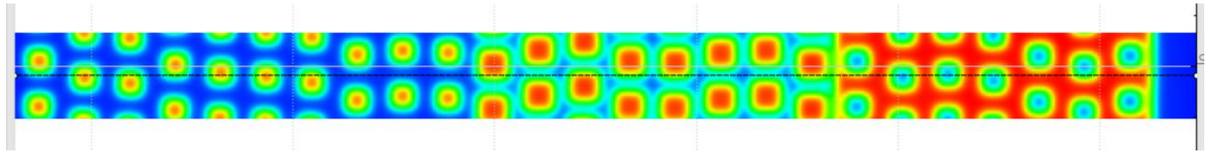
Case Study III:
Flat Lenses with subwavelength holes and posts

Case Study III: Flat Lenses with subwavelength holes and posts

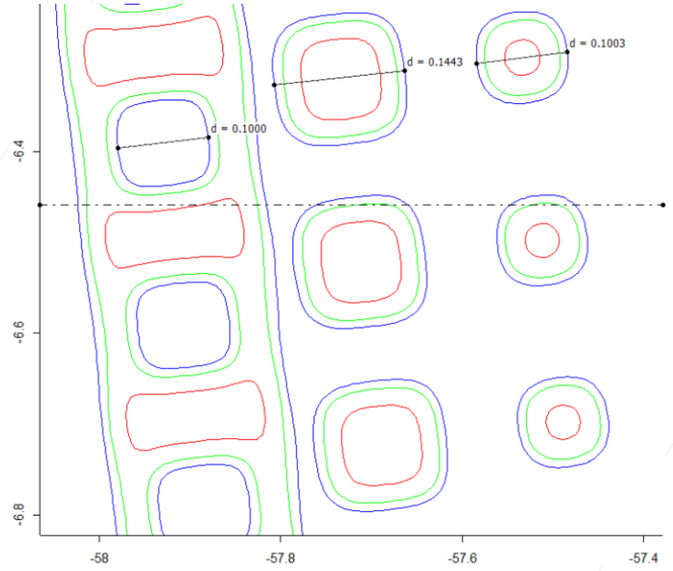
- Algorithmically created sub-wavelength holes and posts to adjust the refractive index of the glass substrate
- Design grid of 1 nm, Size 135 um^2
- Shape count ~ 230,000
- Resist thickness of 670 nm to withstand the etch process
- Original lithography results were far from perfect
- The challenge was patterning structures with both – positive and negative tone structures
- Using standard PEC with short range would provide some improvement, but increasing the contrast by an Overdose-Undersize method does far better in resolving the features and overcome the blur. Using short range could increase the shape count whereas ODUS would not.

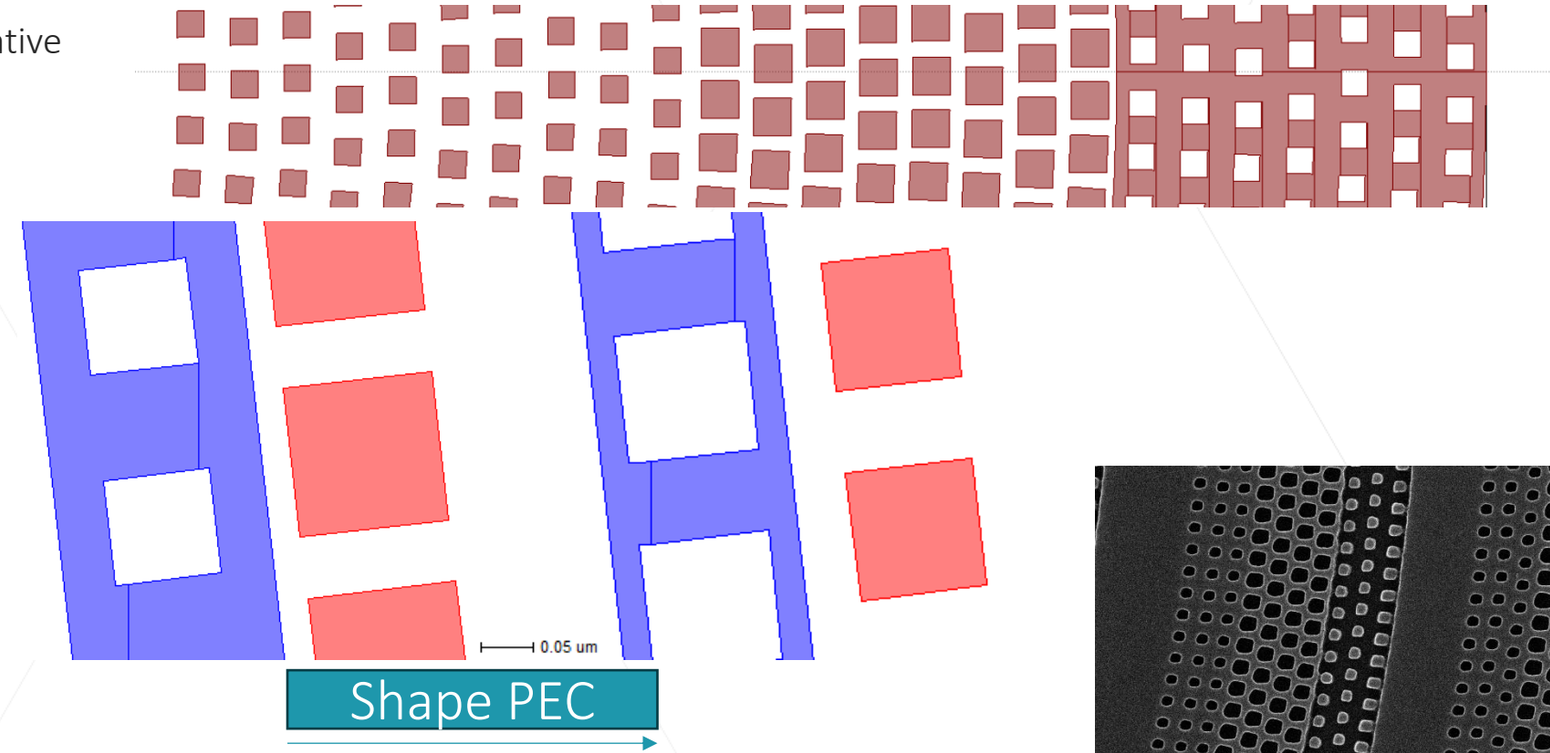


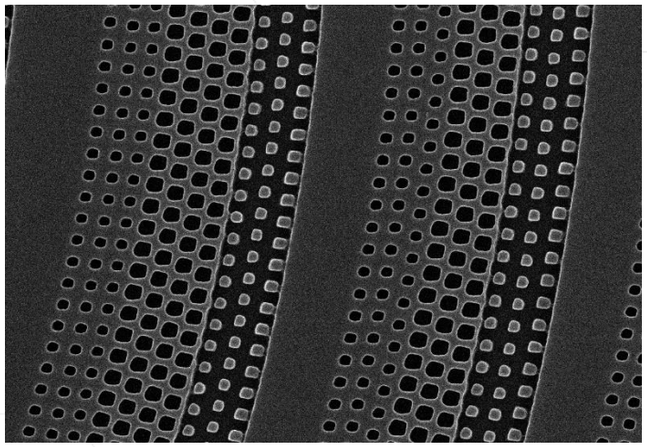


Case Study III: Flat Lenses with subwavelength holes and posts

- We did some Shape PEC tests with conservative movements of the edges
- This result was presented at EIPBN 2023





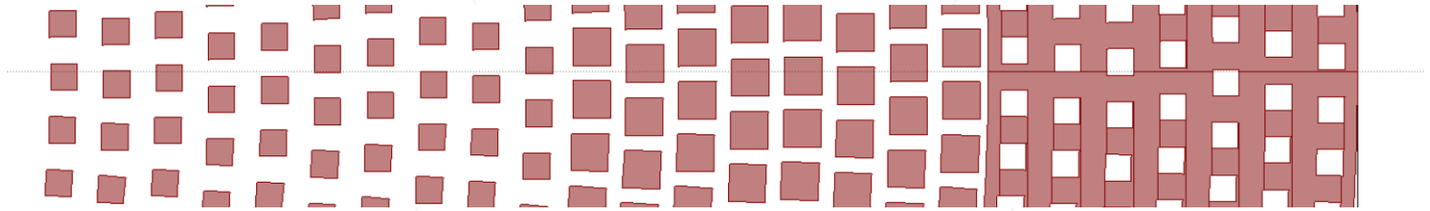


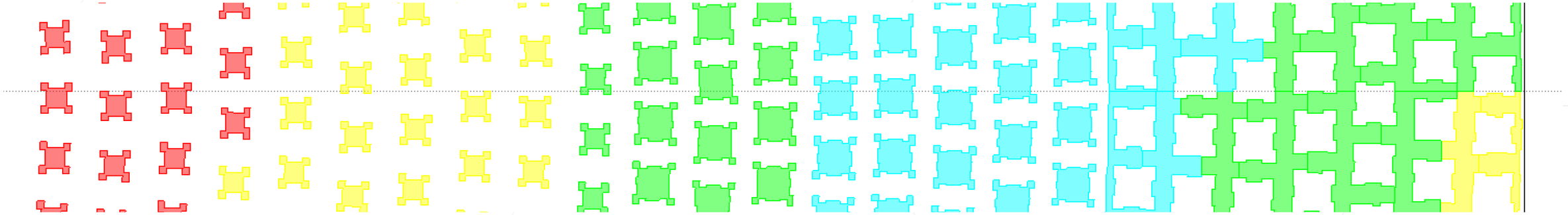
Presented at EIPBN 2023

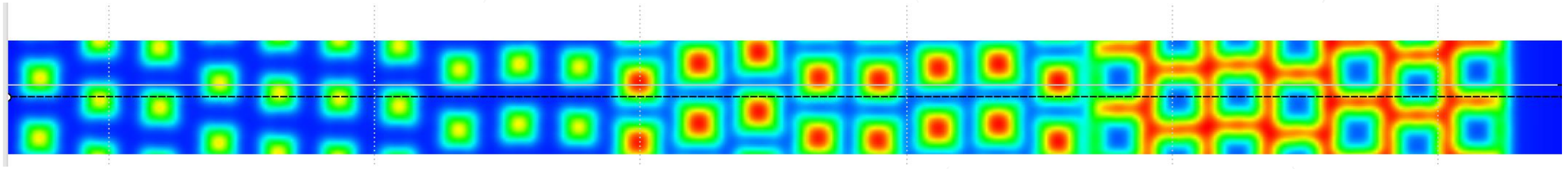
MIT.nano

Case Study III: Flat Lenses with subwavelength holes and posts

- Finding the blur values and then using ODUS, we can make the structure do a lot more dramatic edge movements
- Shape PEC not only moves edges but also corrects for long range dose corrections
- This is set up from the Advanced Settings in Shape PEC



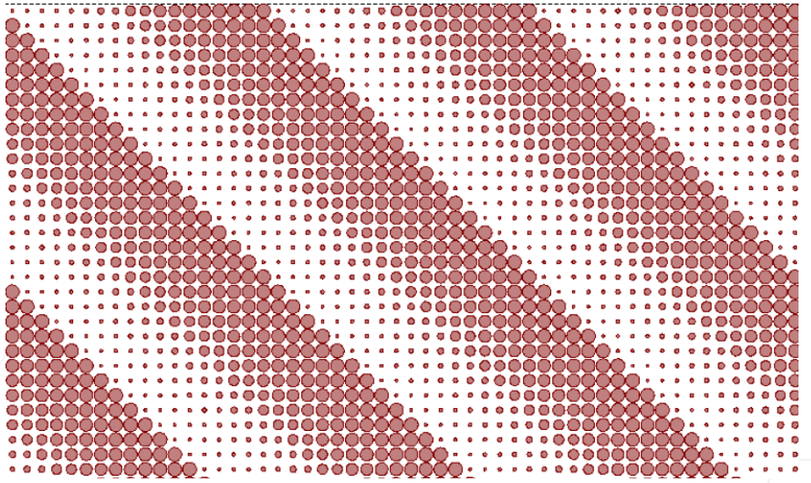


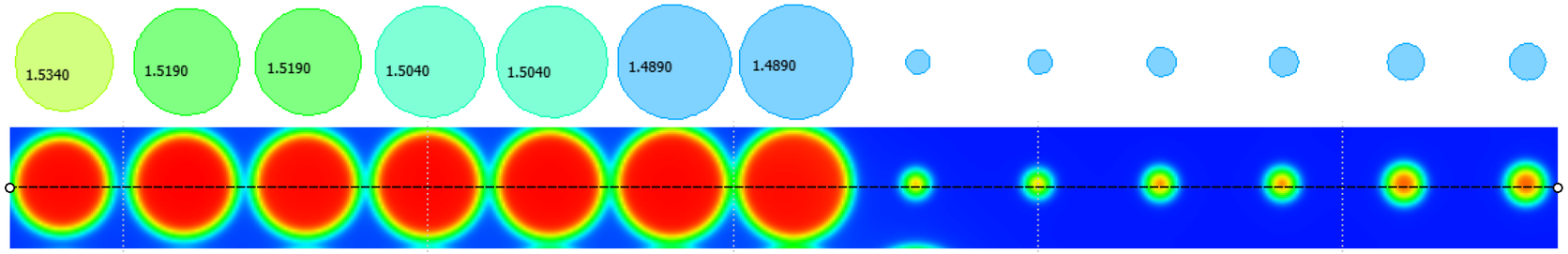


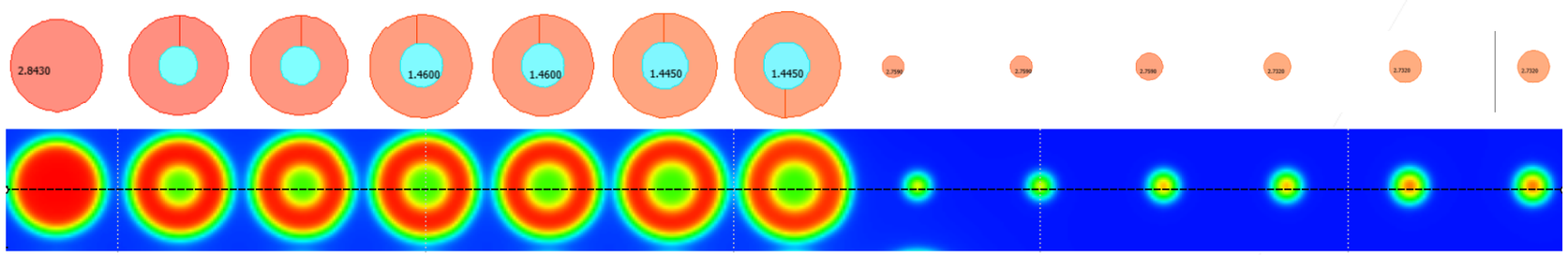
Case Study IV:
Metalens: Circles with varying shapes

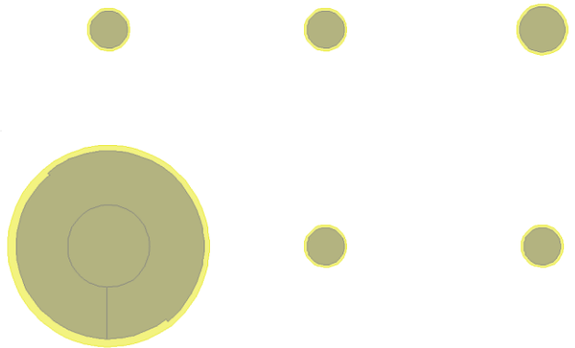
Case Study IV: Metalens, circles with varying shapes

- Metalenses are a hot research topic leading to structures that look like this
- In this example pattern, we have 400 nm to 80 nm diameter circles
- Smallest gap to resolve is about 25 nm
- This is again a typical “cannot be fixed by dose” problem
- Shape PEC with a 2x OD factor and the right blur values, you can start to resolve the gaps



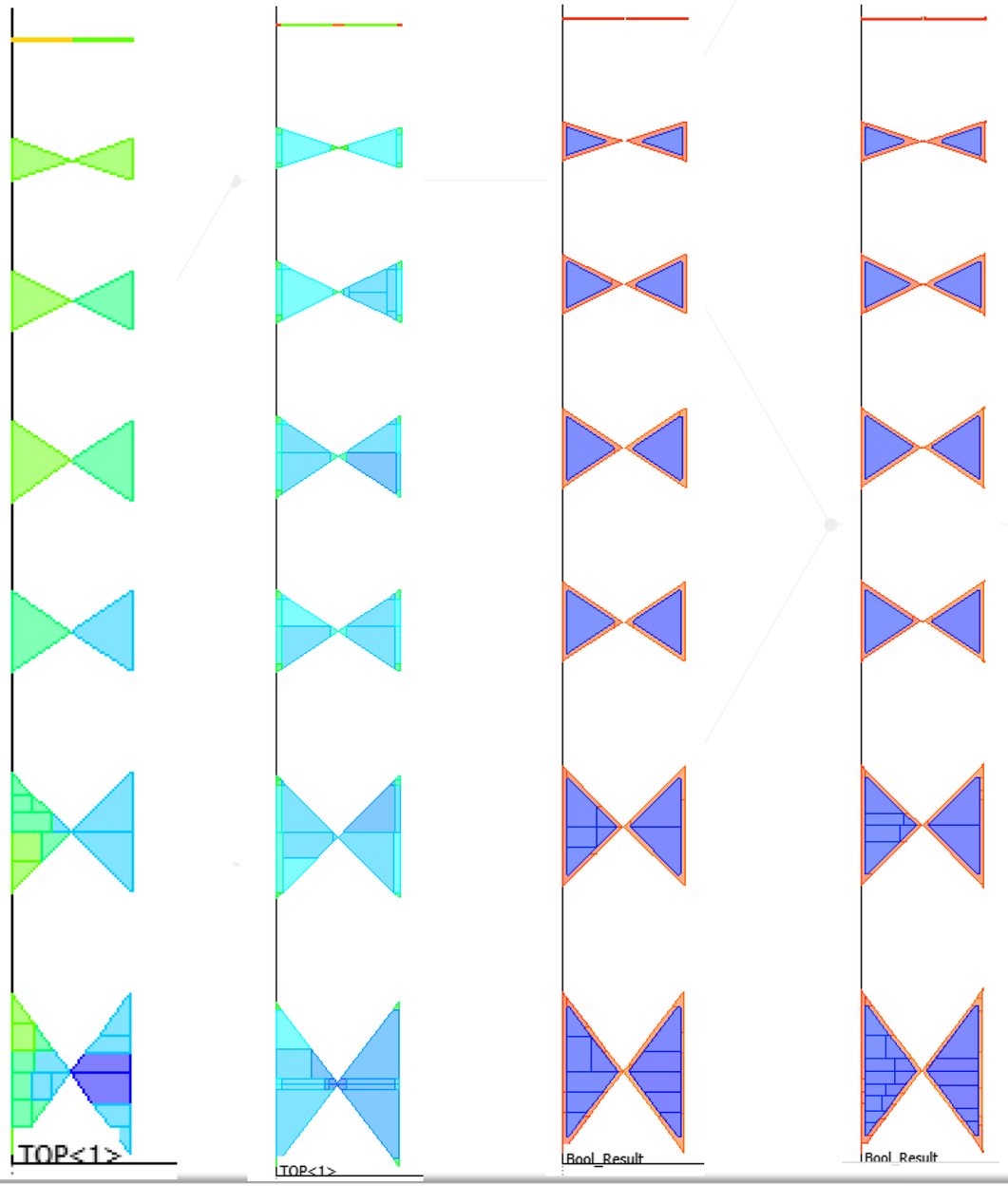






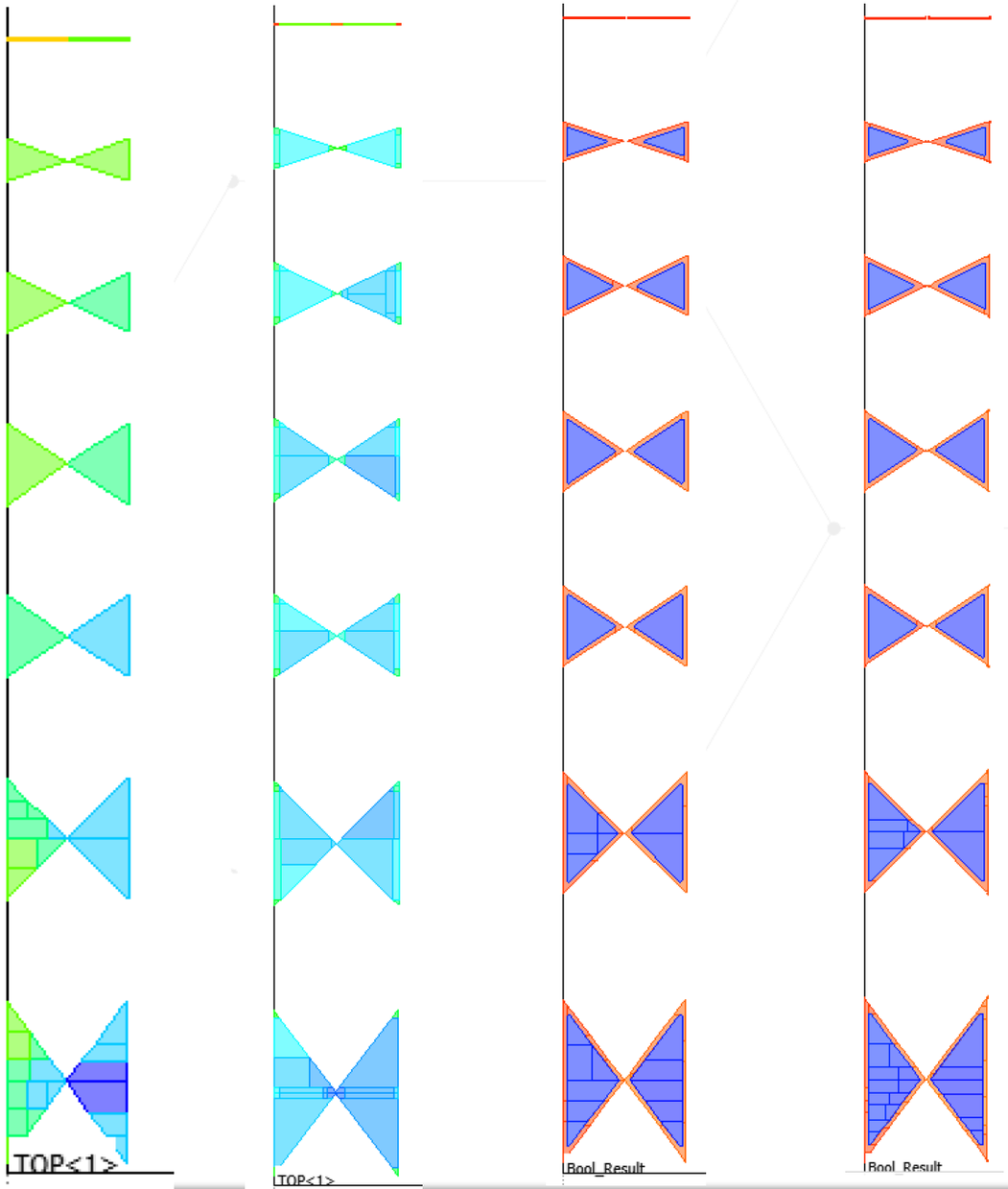
Case Study V:
Bow tie structures with small gaps

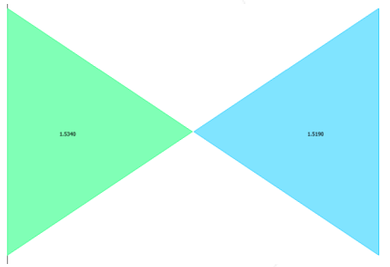
Case Study V: Bow tie structures with small gaps



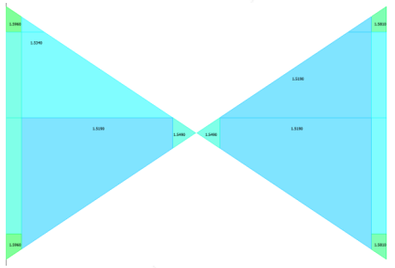
- These are bow tie shapes with gaps as small as 15 nm
- Traditional PEC only does dose allocations
- With short range PEC and a smaller MSF, we can improve the corners slightly my adding more dose there
- ODUS can me made a lot more granular for structures like these allowing finer edge movements
- The edge movements should be a multiple of the isodose grid
- If the resist is thin and the blur is small, with a smaller shot pitch, the corners can be made even sharper

Case Study V: Bow tie structures with small gaps

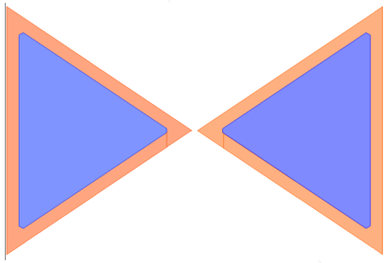




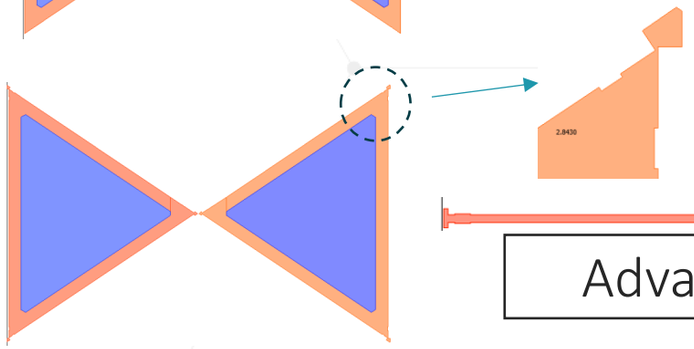
2d Long Range PEC



2d PEC (LR + SR)

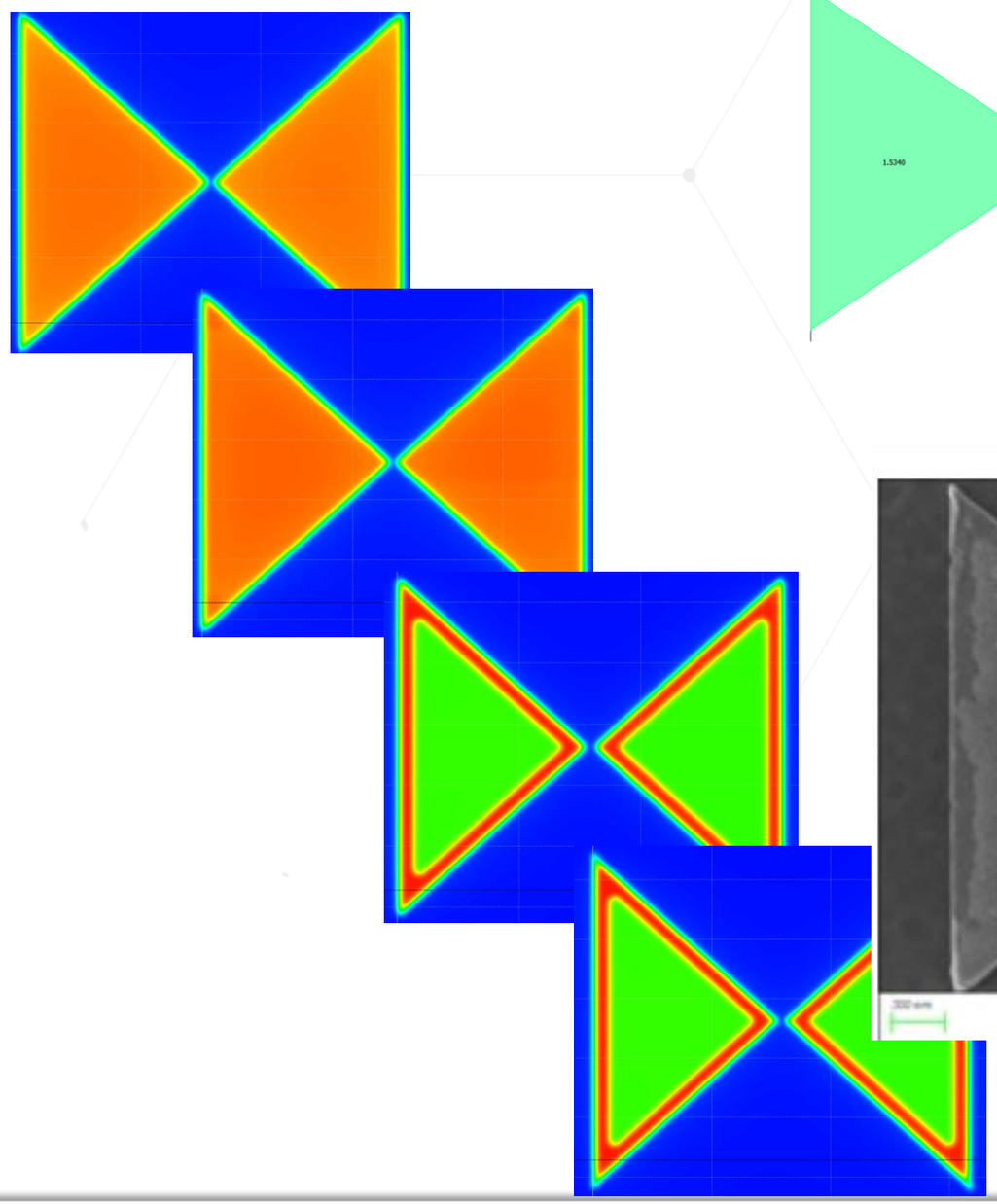


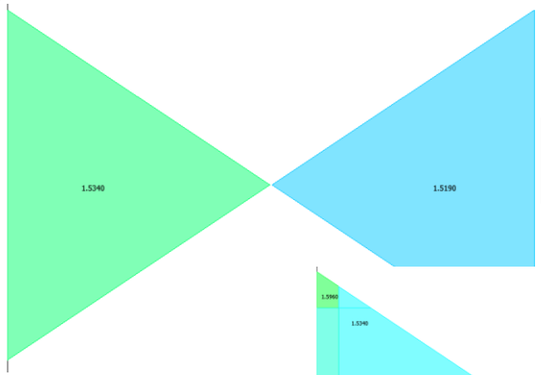
Shape PEC (OD=2x)



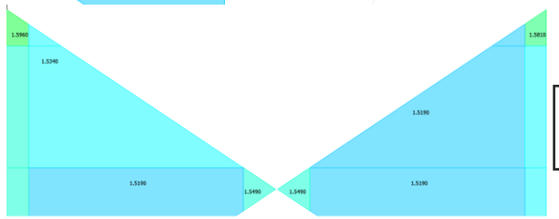
Advanced Shape PEC

Case Study V: Bow tie structures with small gaps

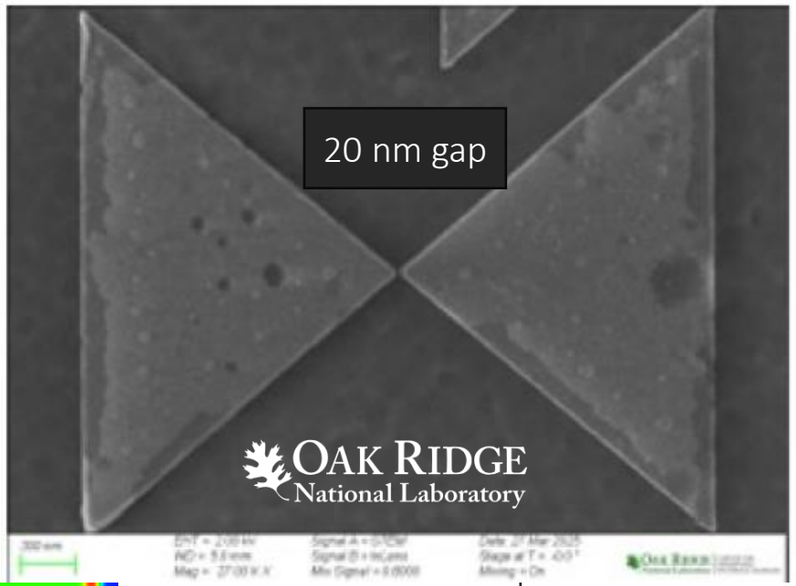


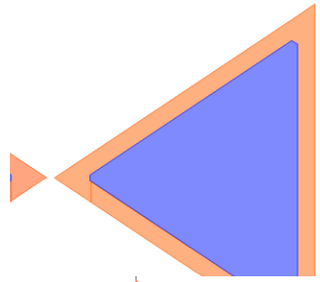


2d Long Range PEC

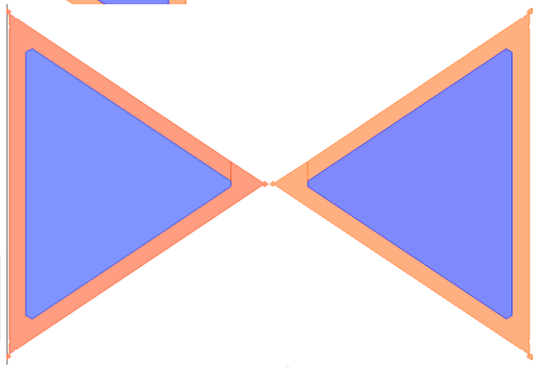


2d PEC (LR + SR)





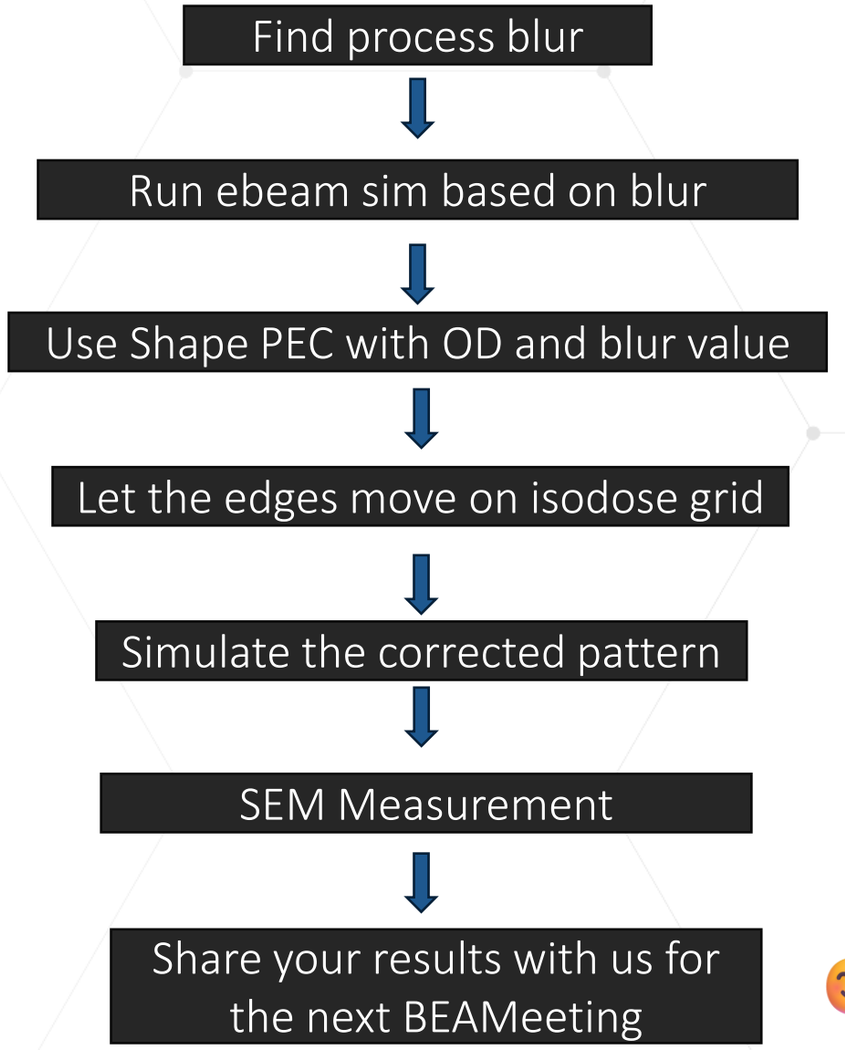
Shape PEC (OD=2x)



Advanced Shape PEC

Conclusion: Why does Shape PEC work

- Short range effects must be simulated to ensure pattern fidelity in dense, curved or angled structures
- Undersizing the edges compensates for forward scattering
- Overdosing and under sizing makes sure that the image log slope increases
- This means that now we are operating much below the FWHM of the gaussian beam
- The added dose optimization ensures long range effects are also corrected
- Simulation + Geometric correction closes the loop
- We highly encourage using the extremely powerful ebeam simulation module



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