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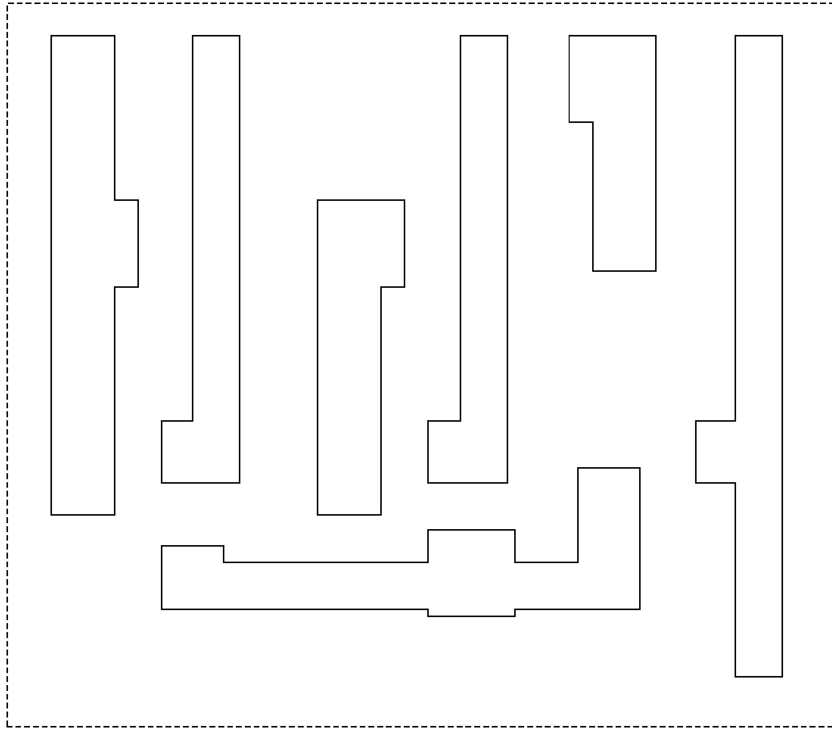
# APPLICATIONS

## Influence of Shape PEC on resist profile

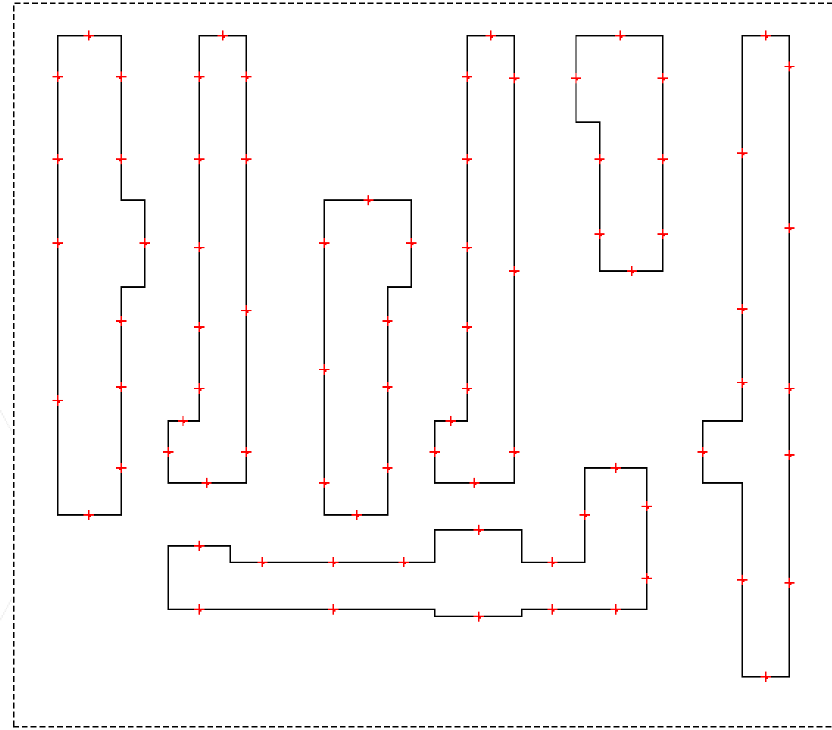
# Precursor

- Proximity effect correction (PEC) modulates the exposure dose by taking into account the electron scattering effect of the E-Beam from the substrate (long-range correction).
- Shape PEC performs short and mid-range PEC by modifying pattern edges.
- The model-based undersize/overdose (ODUS) Shape PEC allows over exposure to give an enhanced intensity image slope at the pattern edge.
- This application note is focused on using LAB to model the resist profile of E-beam exposure, and to demonstrate the functionality of ODUS. Two customer examples are included as ODUS applications.

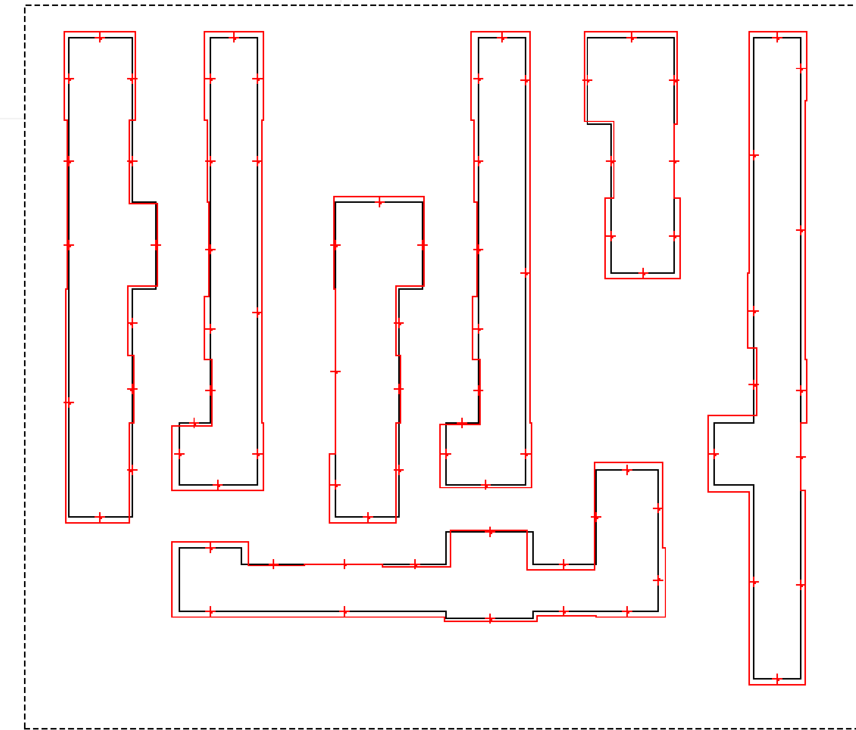
# Shape PEC Principle



Shape PEC goal:
Move edges locally to compensate for short- and mid-range energy loss and obtain a uniform dose at all layout edges.



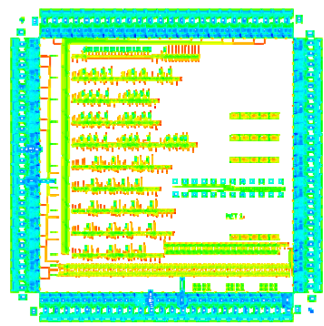
In a DRC step all edge segments are analyzed for the CD and distance to adjacent shapes.
A set of representative evaluation points (+) is defined.

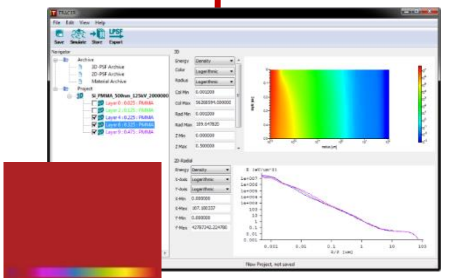


Shifts for all PEC segments (eval. points) are **iteratively** adjusted.

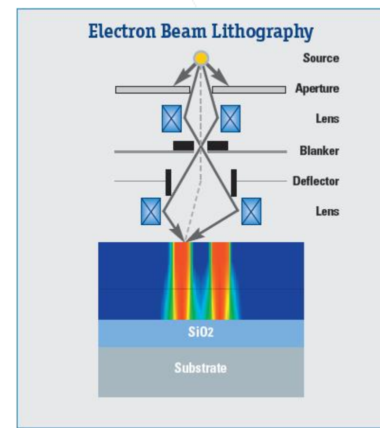
# LAB 3D Simulation

Layout

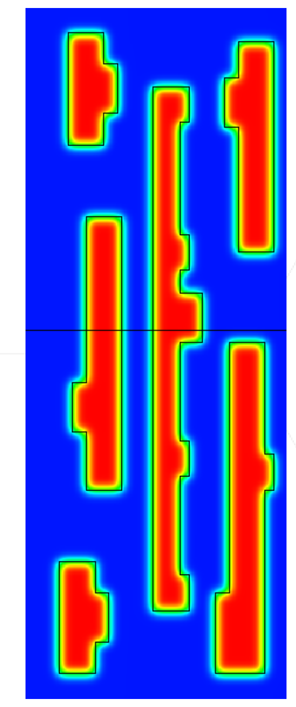




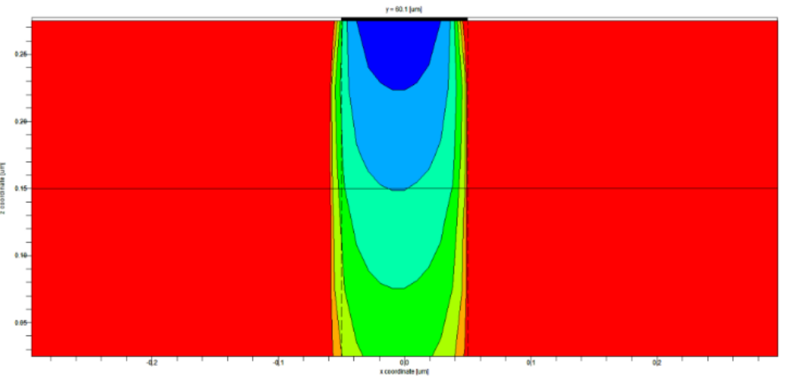

3D PSF

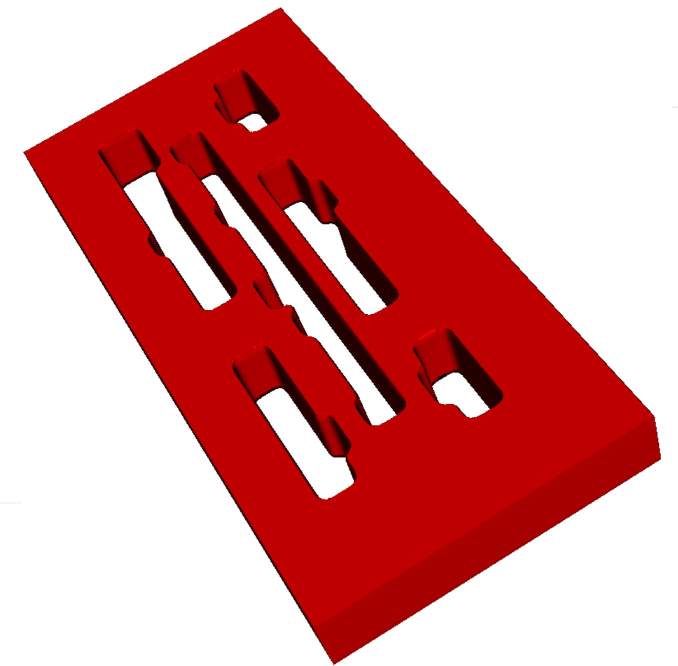



E-Beam
Exposure



3D
Bulk Energy

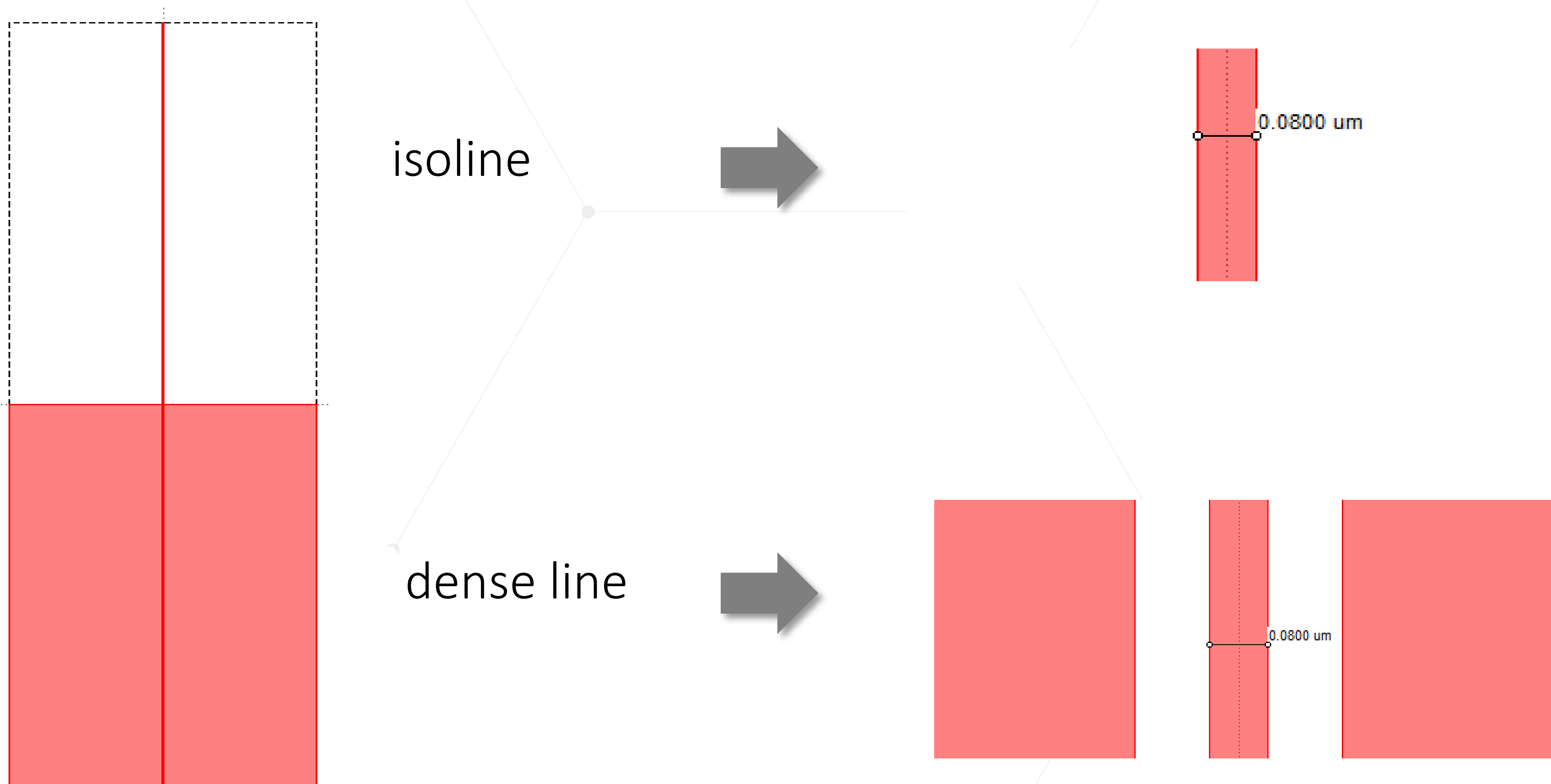




3D Resist
Development

# Analyzed Pattern

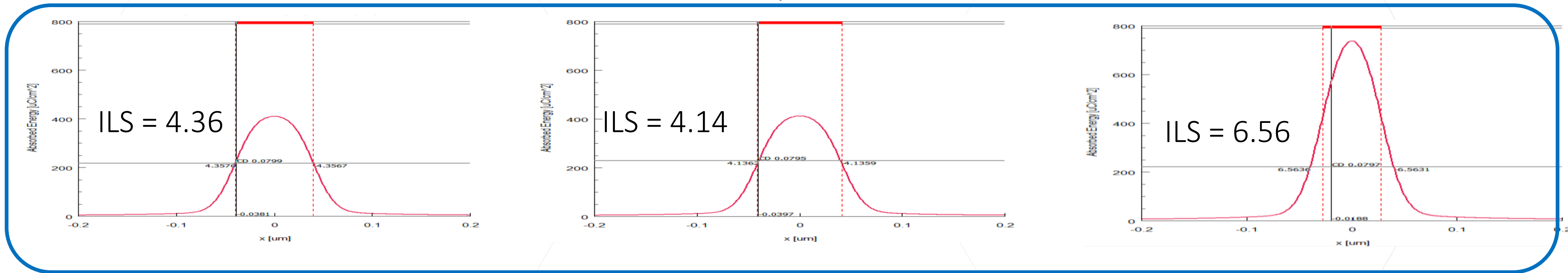
- The analyzed pattern is shown below.
- Simulation is carried out for 200 nm PMMA 950K on GaAs substrates.
- Dose PEC, shape PEC, ODUS (overdose factor = 2) are used for pattern correction.



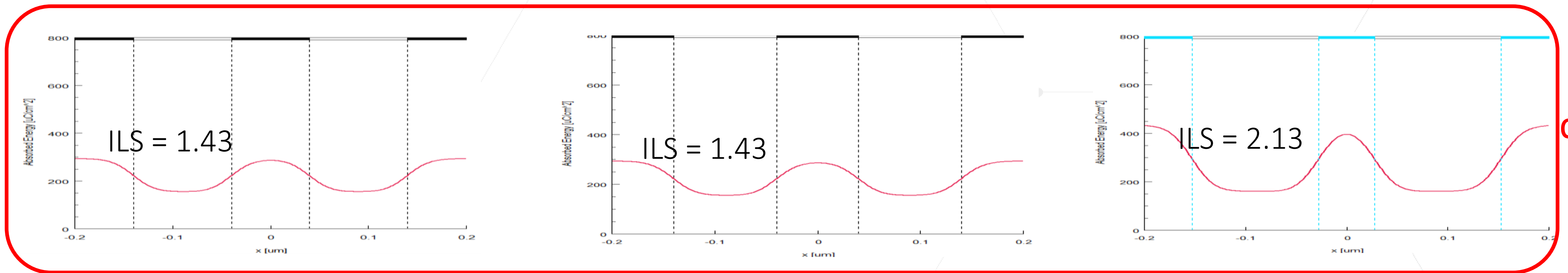
# Contrast Comparison

- Simulation is carried out for 100keV electron beam exposure on 200 nm PMMA 950K on a GaAs substrate.
- The intensity cross the line shows
- the enhancement of image contrast (represented by ILS) by ODUS
- the dependence of image contrast on pattern density. Dense line has a smaller image contrast.

Dose PEC | Shape PEC | ODUS



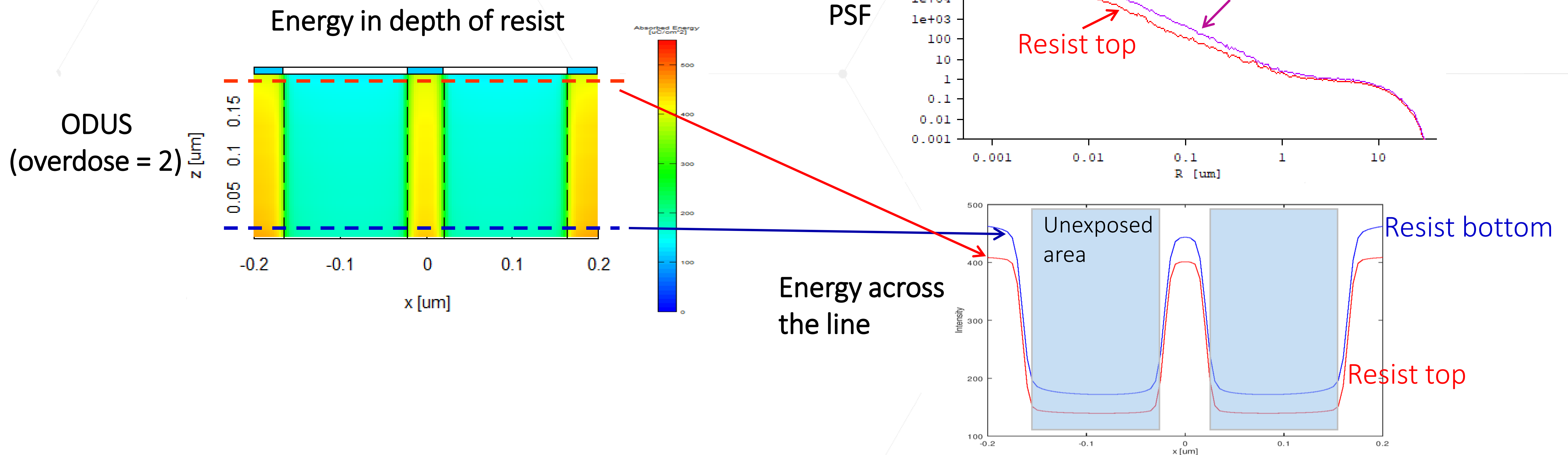

isoline




dense line

# Bulk Energy

- Simulation is carried out for 100keV electron beam exposure on 200 nm PMMA on a GaAs substrate
- The PSF varies with E-Beam scattering into the resist.
- The energy for unexposed area at the bottom is 20% more than that at the resist top.



# Resist Development

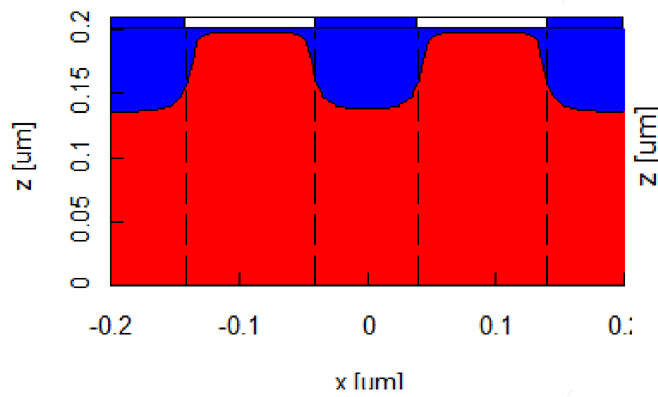
- Resist (red area) development front is modeled over time.
- Developer is moving both in depth and side direction.
- The ODUS has the developer moving faster down into the resist due to over-dose in the exposed area

20 seconds development

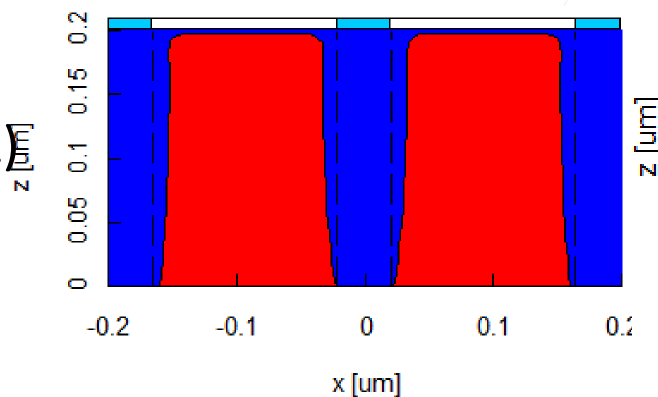
Energy in resist

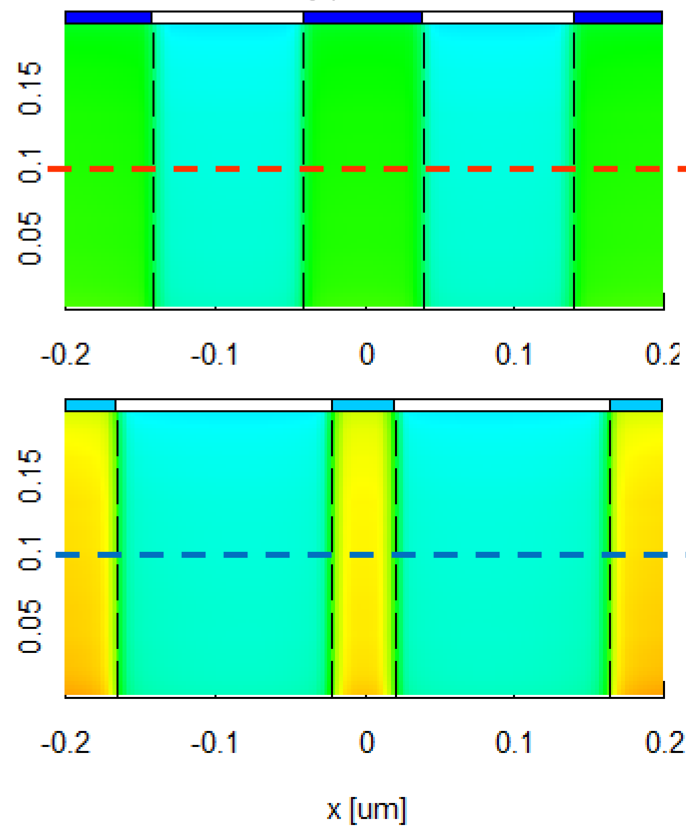
Energy across the line

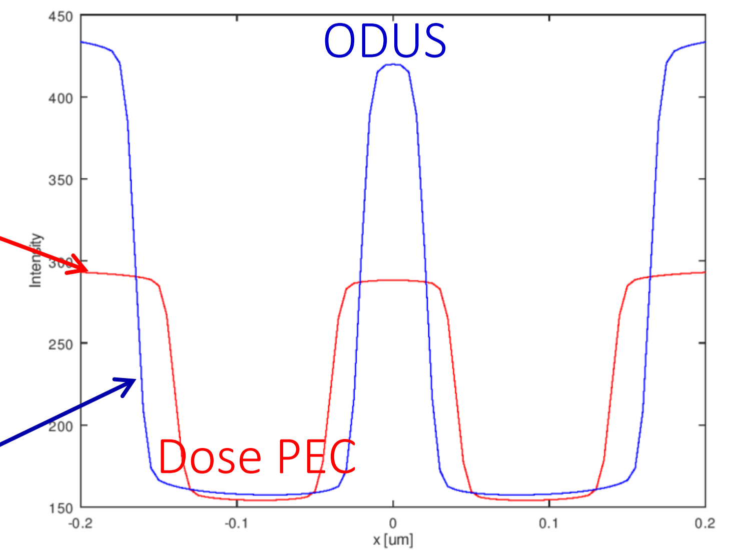
Dose PEC




ODUS
(overdose = 2)



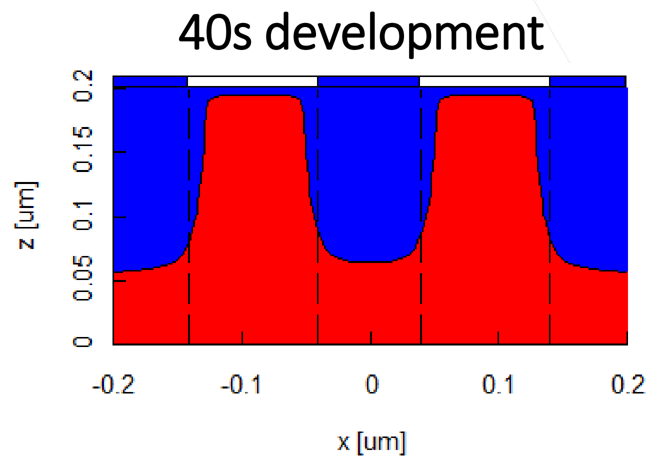
# Resist Development

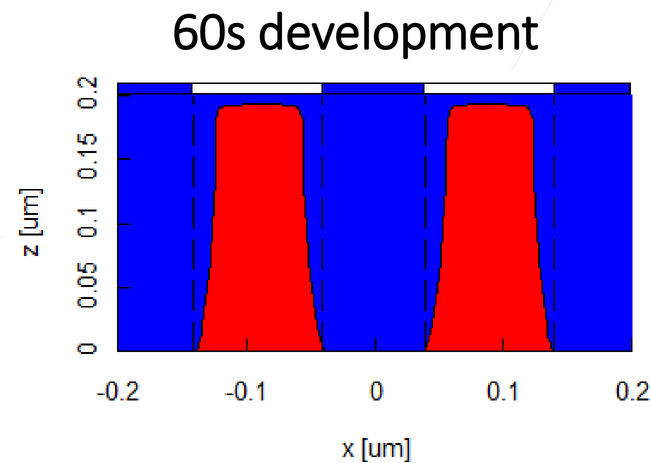
- Resist (red area) development front is modeled over time.
- Developer is moving both in depth and side direction.
- After reaching the bottom, the developer is moving to the side at the bottom faster than at the top, resulting in resist sidewall enhancement. ODUS shows better sidewall enhancement.

40s development

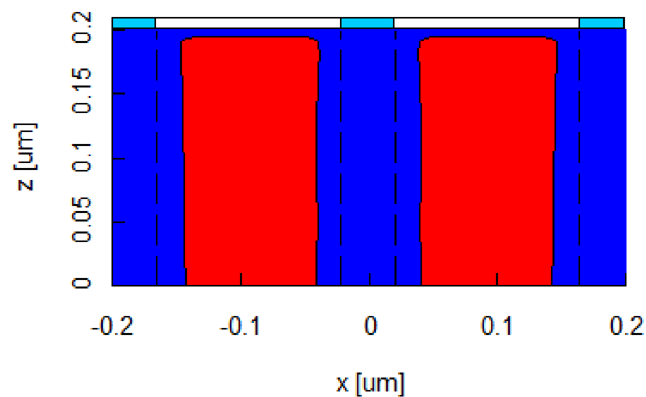
60s development

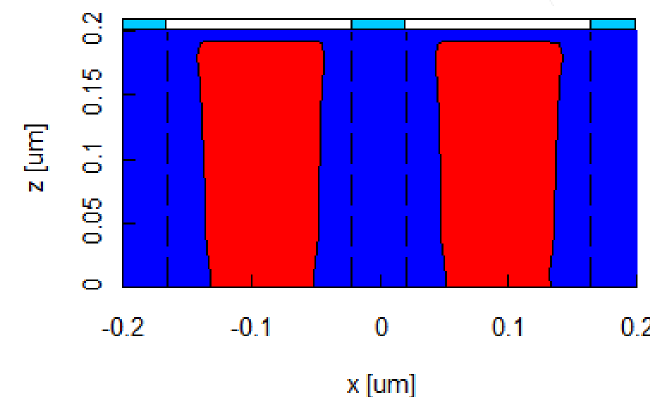
Dose PEC



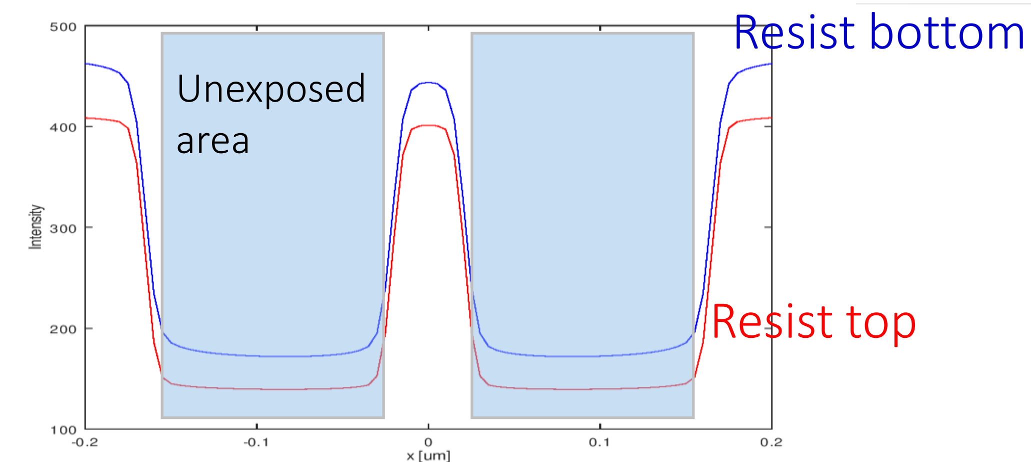




ODUS
(overdose = 2)



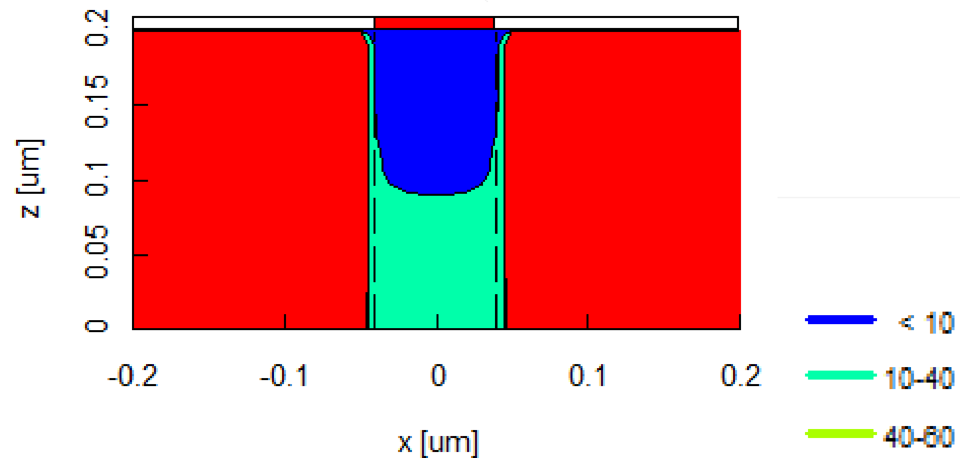

Energy across the line



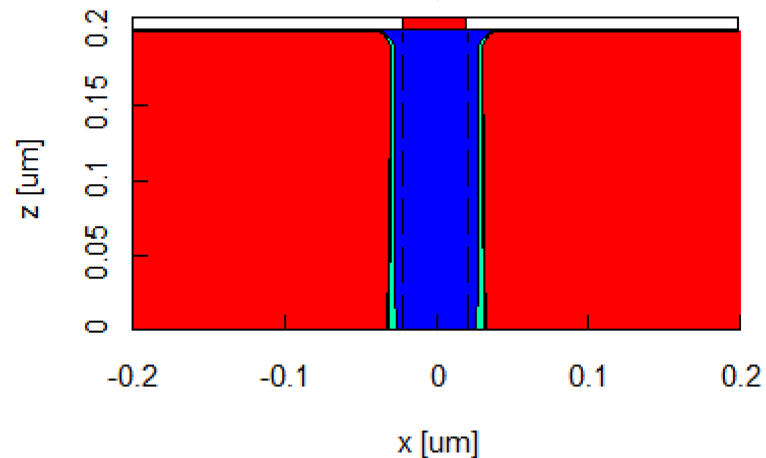
# Pattern Density

- What affects the resist development: pattern density
- Developer front for isoline patterns is moving faster in comparison to dense lines.
- The lateral development rate is less for isolines with less background energy in unexposed area.
- Resist sidewall enhancement with ODUS is more apparent for dense lines.

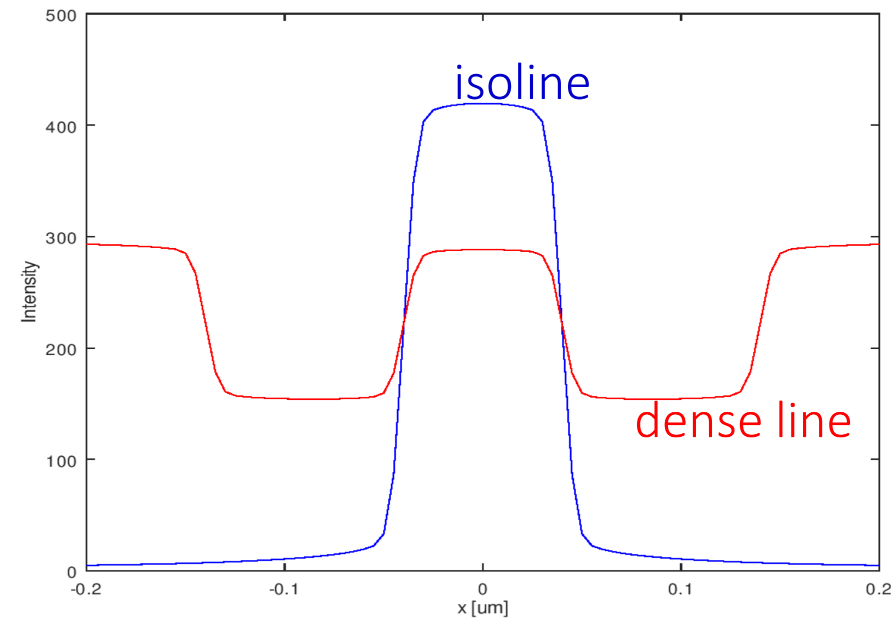
Dose PEC




ODUS (overdose = 2)




Energy across the line

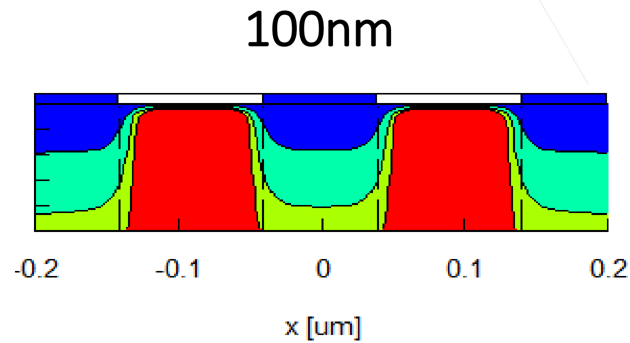


# Resist Thickness

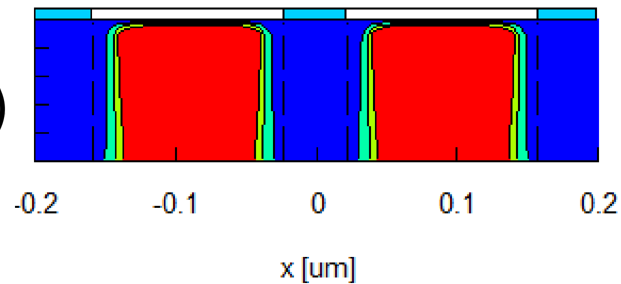
- What affects the resist development: resist thickness
- At the unexposed area, the energy difference between bottom and top is more for thicker resist.
- The ODUS enhancement on resist profile is more apparent for thicker resist.

100nm

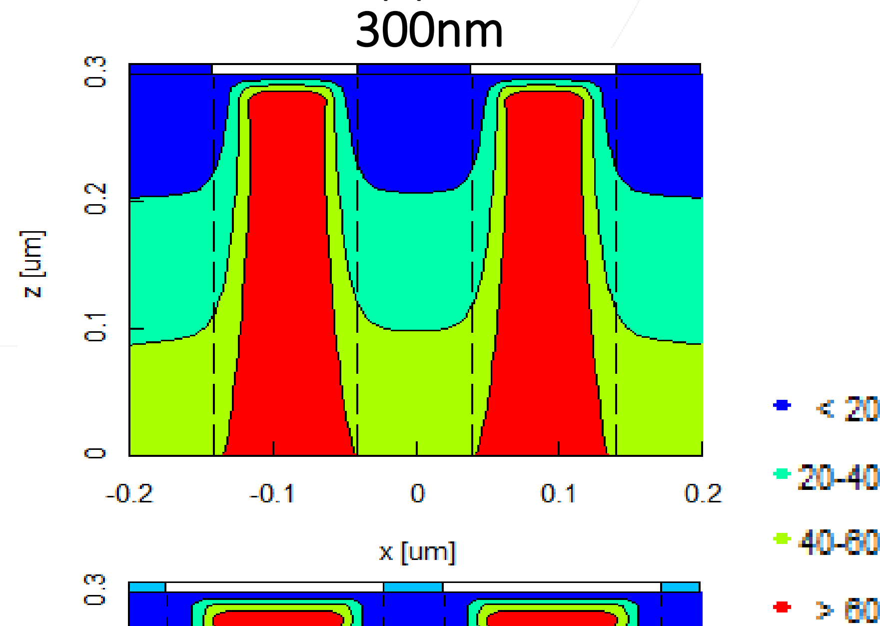
Dose PEC

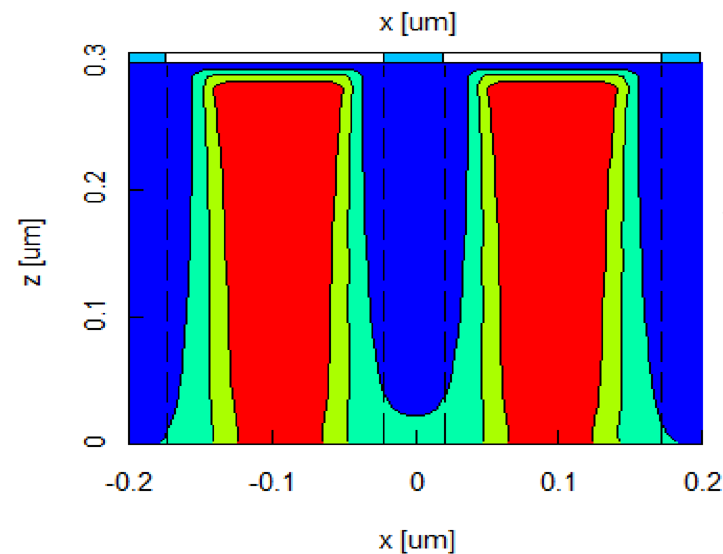



ODUS
(overdose = 2)

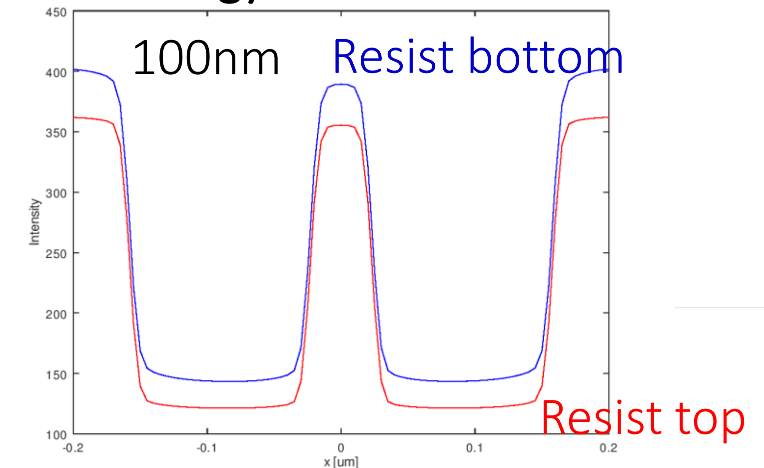


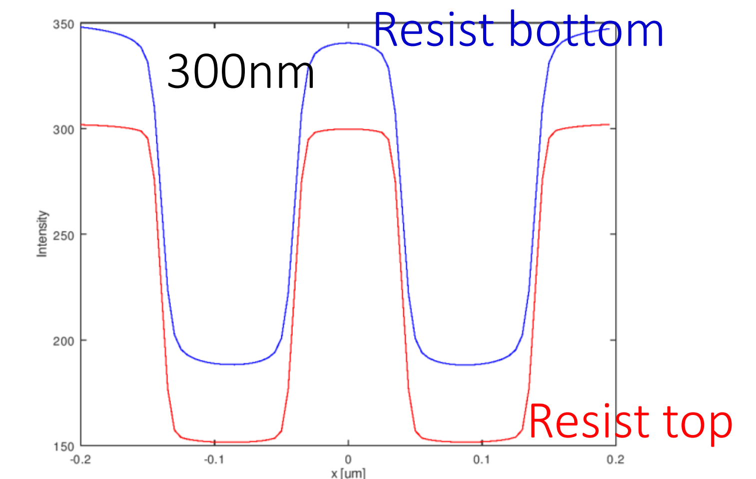

300nm




Energy across the line



# Substrate

- What affects the resist development: substrate material
- More scattering at the mid-range implies more energy at the unexposed area for GaAs substrates.
- The resist profile enhancement by ODUS is more apparent for GaAs substrate.

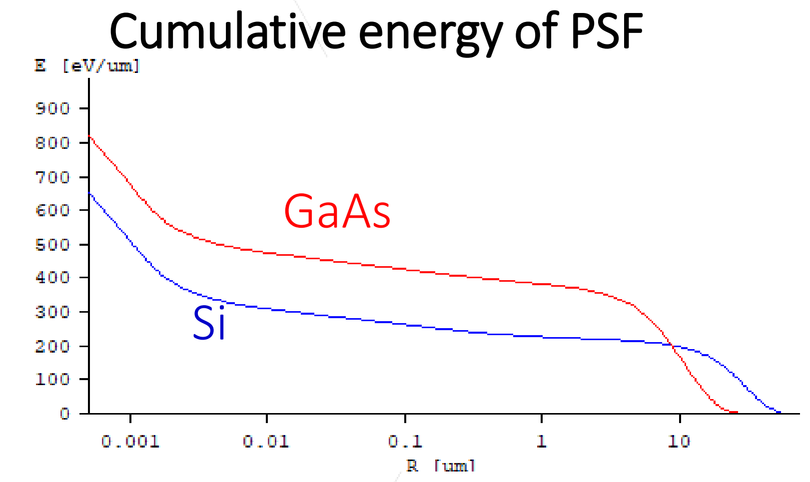
Si | GaAs

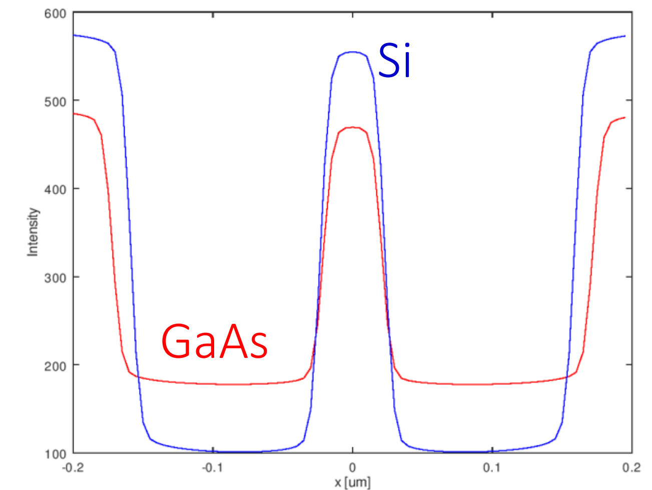
Dose PEC

ODUS (overdose = 2)

< 20
20-40
40-60
> 60

Cumulative energy of PSF

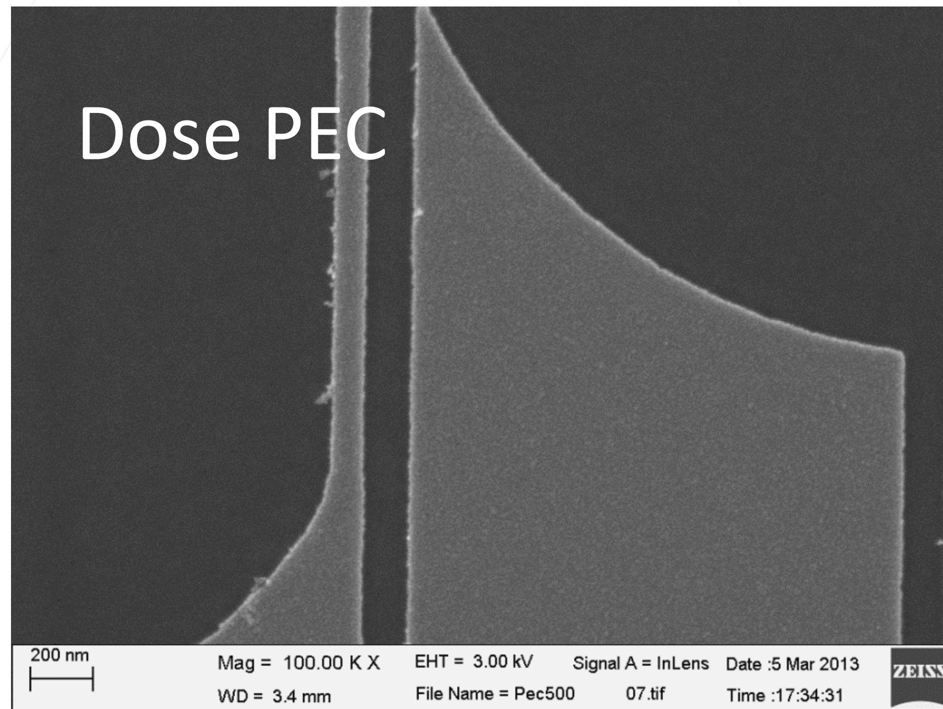


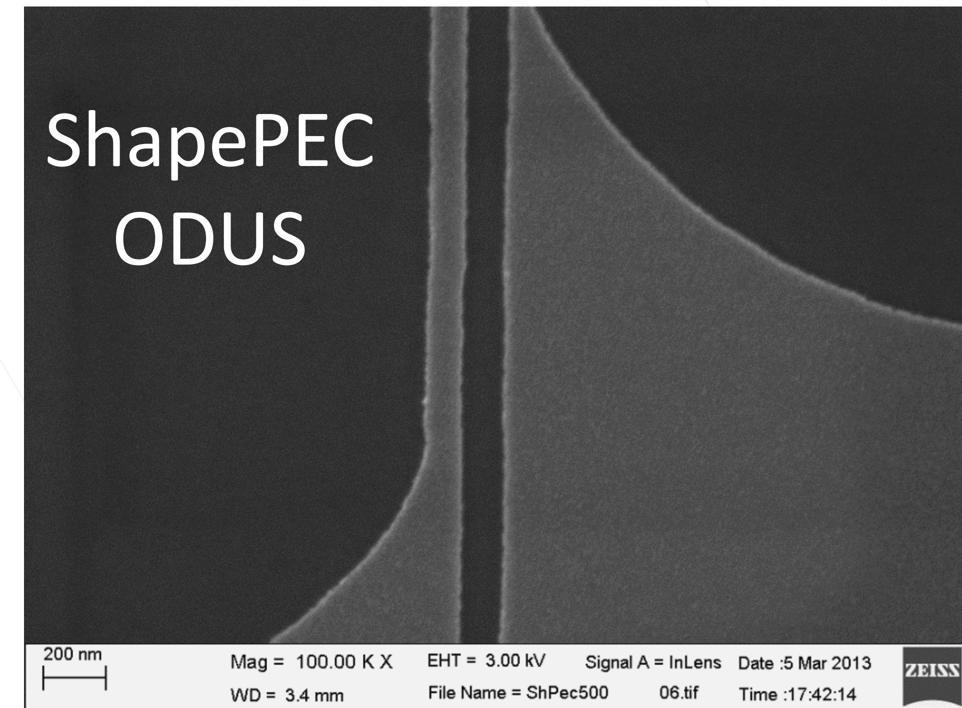



# Application: Single Layer Lift-Off

Application: ODUS shape PEC shows Better metal edge (liftoff) after EBL on single layer resist.

Why is ODUS ShapePEC better?




Presented at BEAMeeting Freiburg 2013:
Diana Mahalu – Compare Shape PEC and Dose PEC

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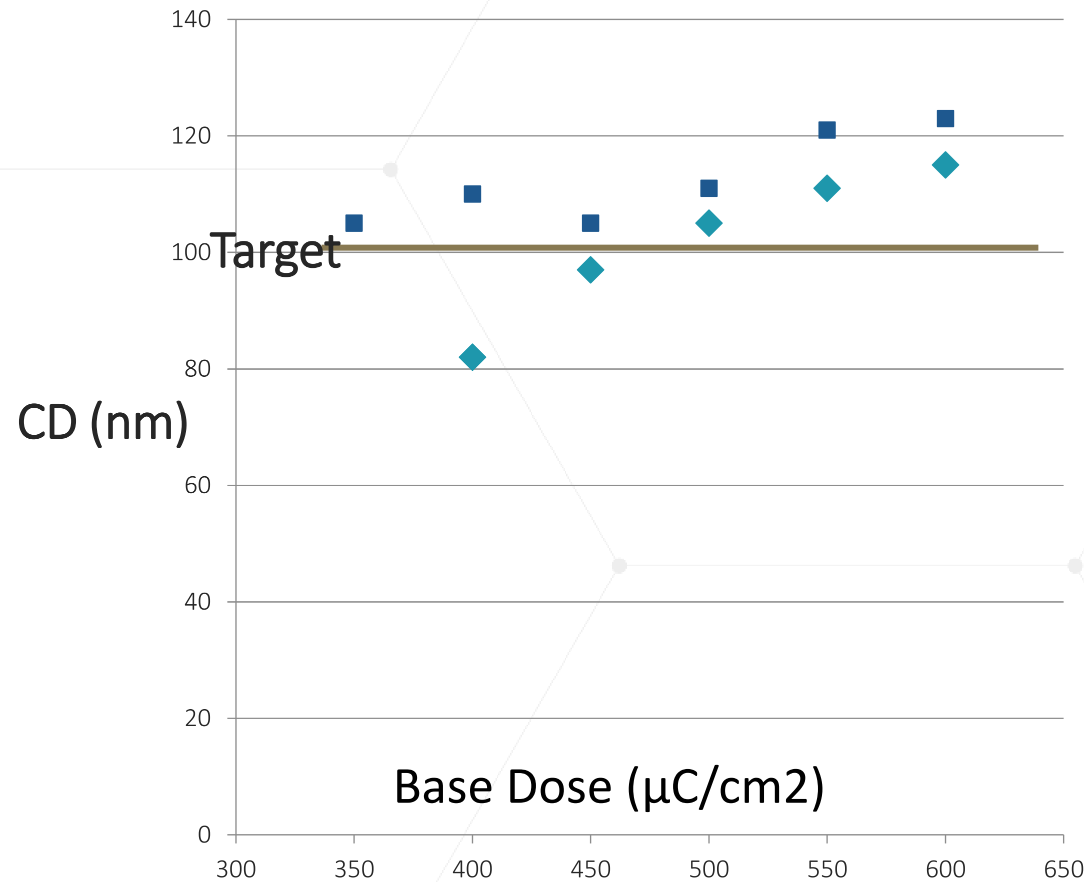
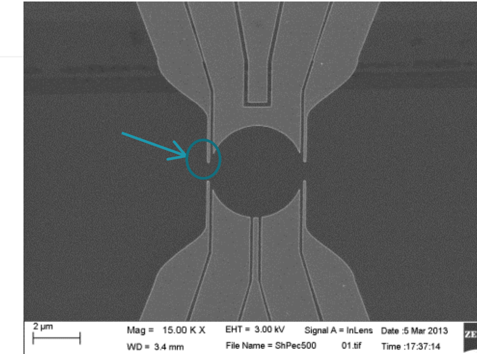
# Measured CD Sensitivity

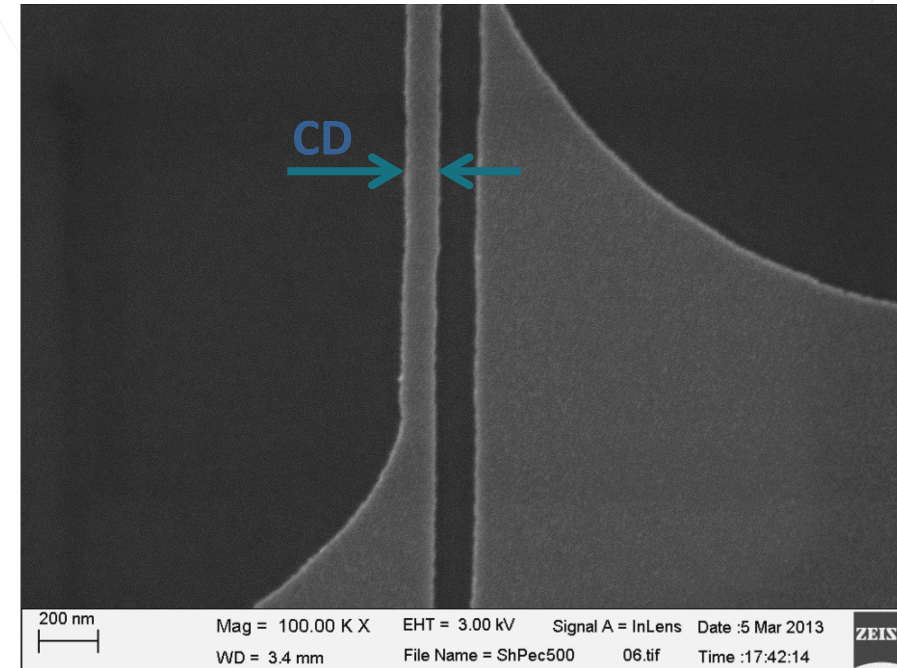



PEC

ODUS

CD design
100nm






Bigger lift-off process window
when using ODUS
(resist edge-slope)

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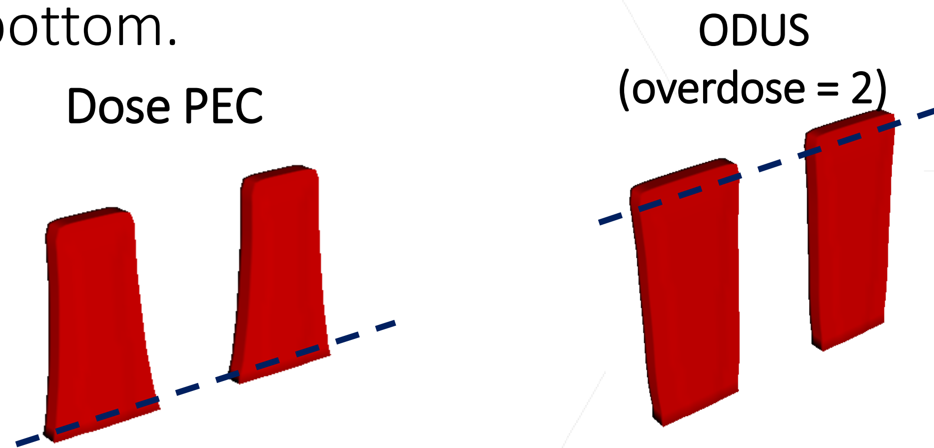
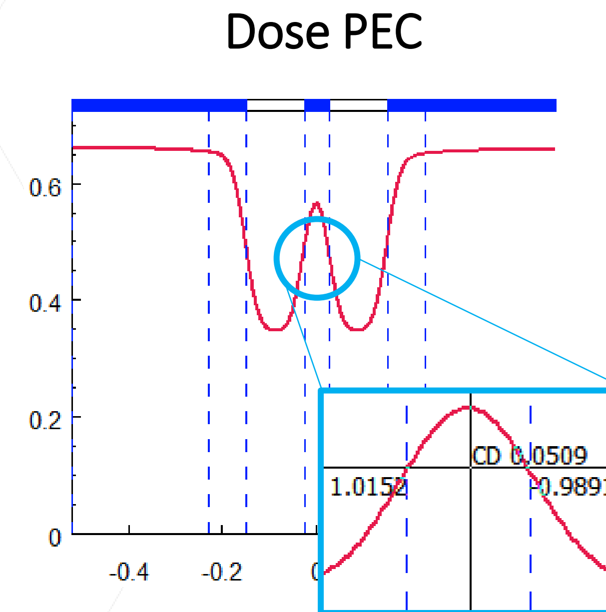
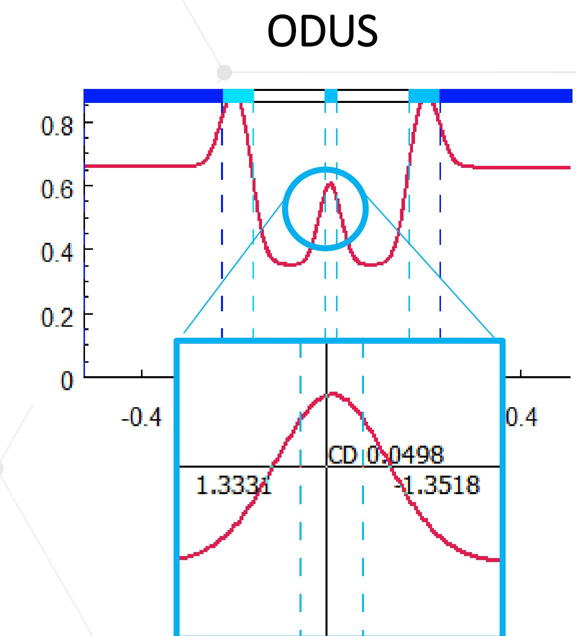
# Simulated CD Sensitivity

- In theory, the enhanced image contrast by ODUS results in enhanced CD sensitivity.
- The CD change of the metal line (after lift-off) is calculated for PEC and ODUS with 5% exposure dose change.
- With negative resist profile for ODUS(overdose = 2), the CD change at the resist top is responsible for patterns from lift-off technique. The CD change for positive resist profile (PEC) is determined at the resist bottom.




| | Position | Simulated CD change |
|---|---|---|
| Dose PEC | Resist bottom | 16 nm |
| ODUS (overdose = 2) | Resist Top | 6 nm |



# Photonic Device Patterning Optimization

Improving Process Window via Contrast Enhancement

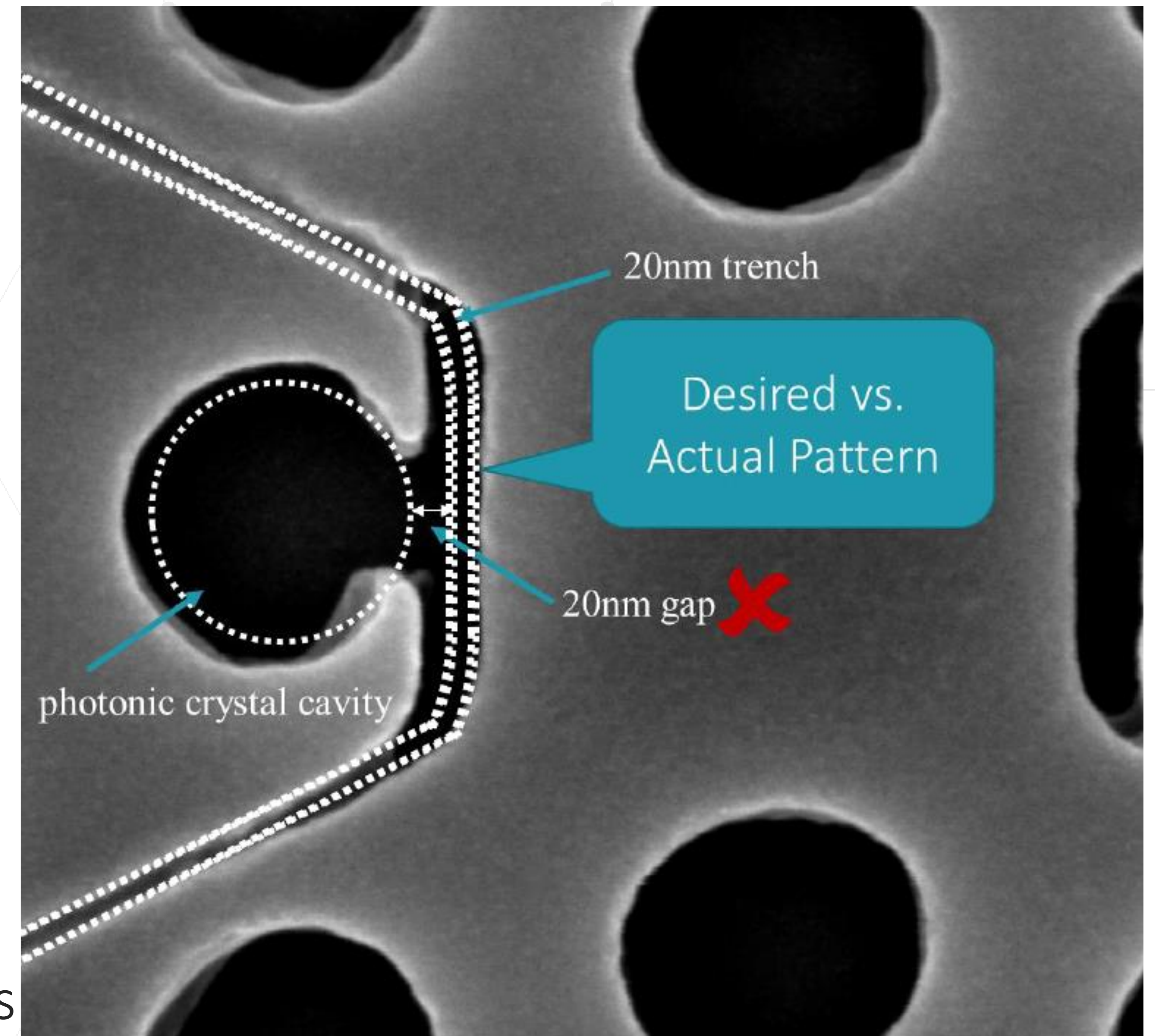
Kashif Masud Awan and Gerald Lopez
University of British Columbia and University of Pennsylvania

Presented at BEAMeeting EIPBN 2019

JEOL 8100 at 100kV + 500nm ZEP520A

- Challenges
- Attempting to resolve a 20 nm gap between a photonic crystal cavity and trench (NEMS + Photonic circuit)
- PEC initially did not yield any intuitive results.

- Limitations:
- Cannot reduce resist thickness due to etch requirements
- Anything near 20 nm does not resolve



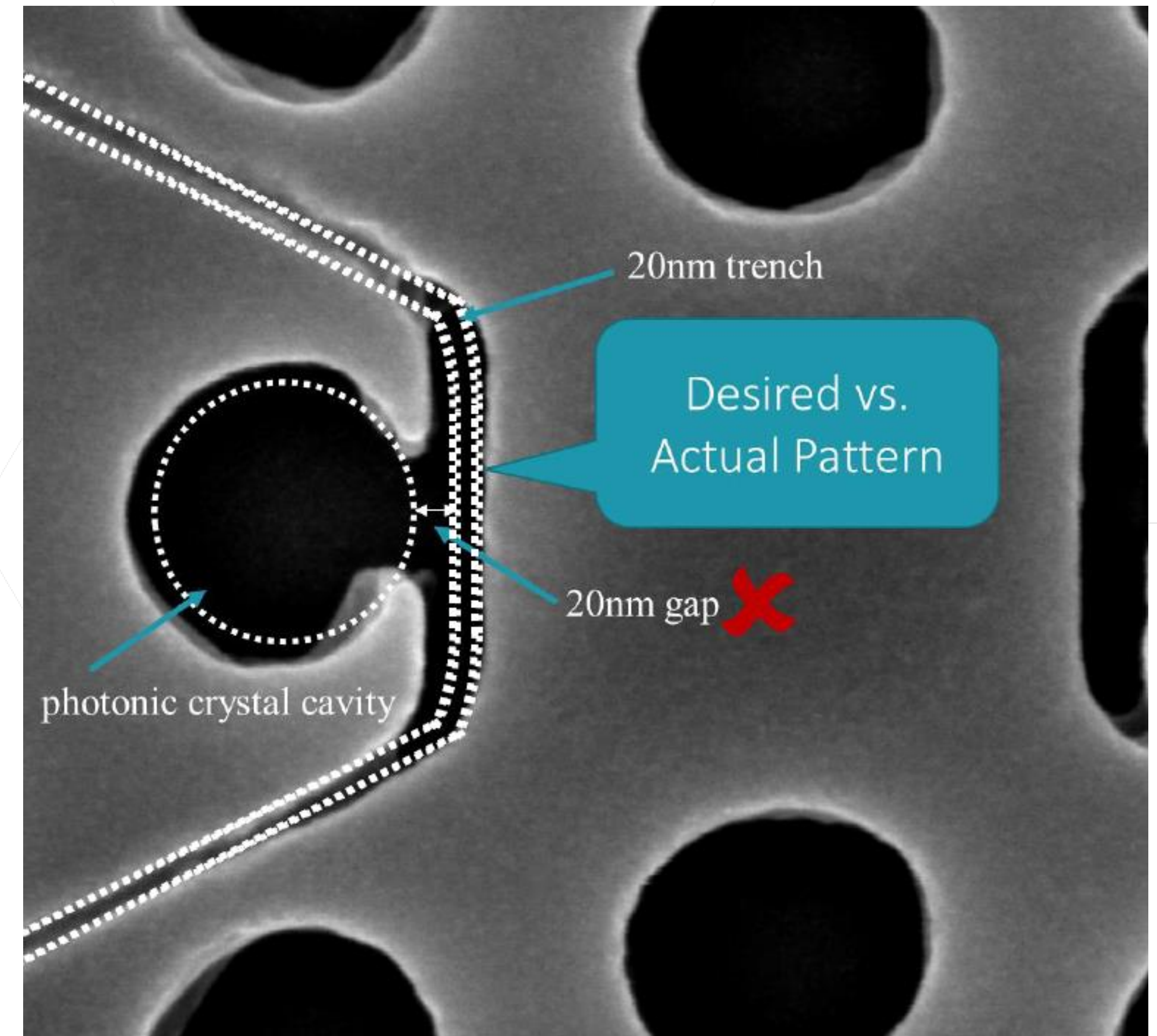
# Application Example for ODUS

## 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

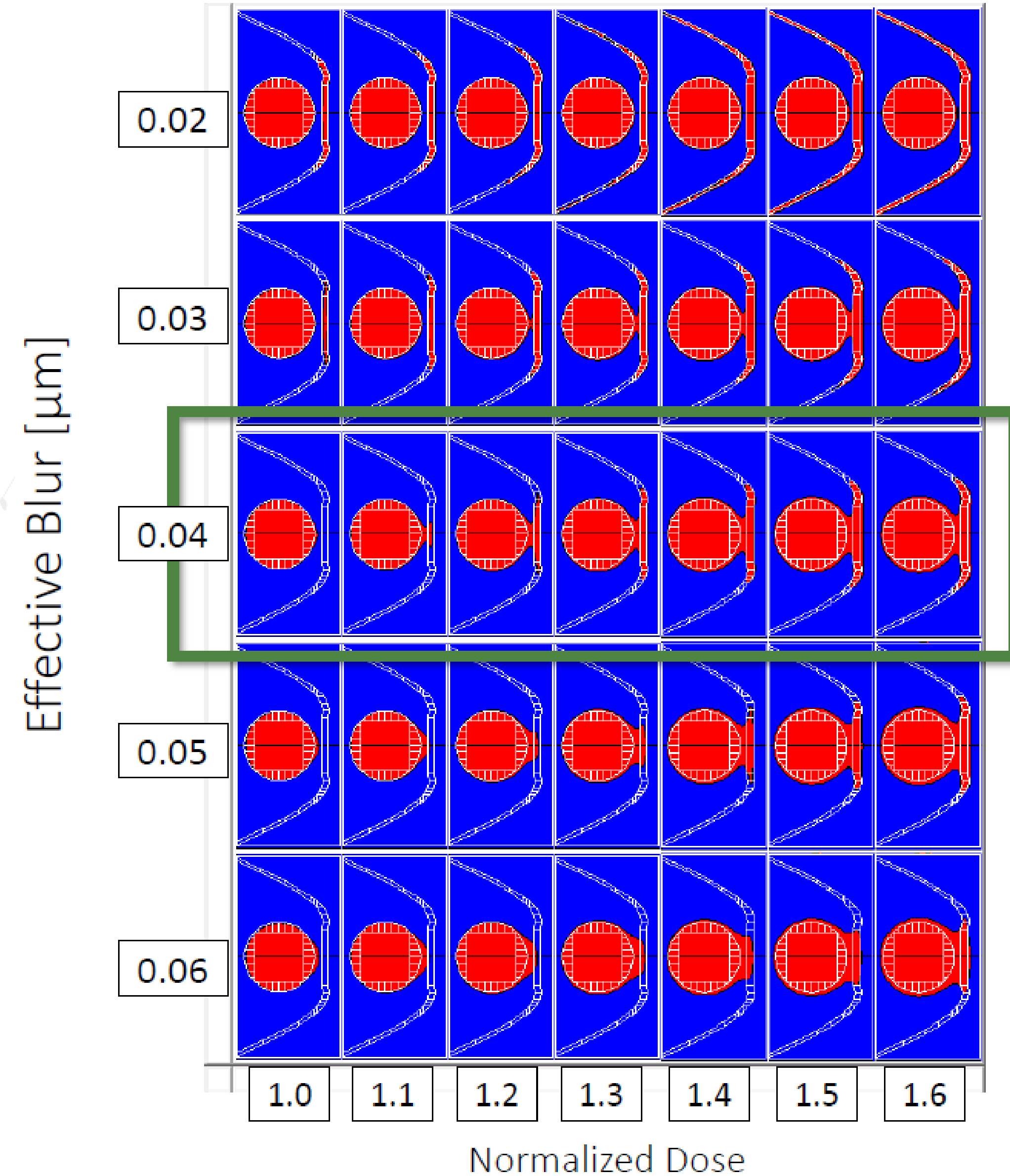
- An exposure was done on structures with 50 nm gaps with 30 and 50 nm wide trenches. Pattern was PEC'ed using only long range correction.
- Simulations were performed to match exposure latitude and observed phenomenon.




Presented at BEAMeeting EIPBN 2019 by University of British Columbia

# Determination of Effective Blur by Simulation

## Simulation: 20 nm Trench

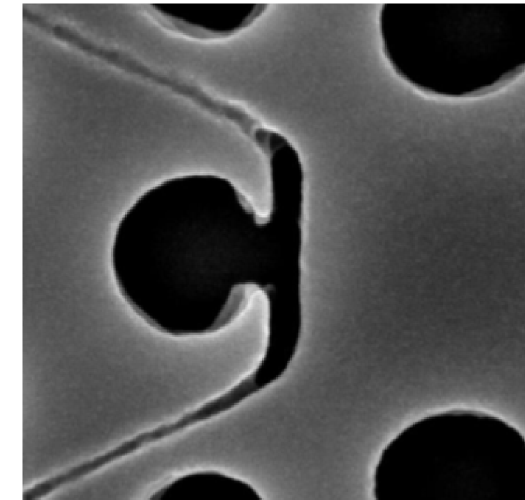



### Threshold analysis

- Pattern was corrected with only long range correction.
- The absorbed energy at 50% is shown.
- This is the threshold of the resist or the constant energy that is tied to the resist development to where the resist edge will land.

### Key Observation

Large $blurs_{eff}$ (i.e., 50 and 60 nm) do not closely describe the observed phenomenon.



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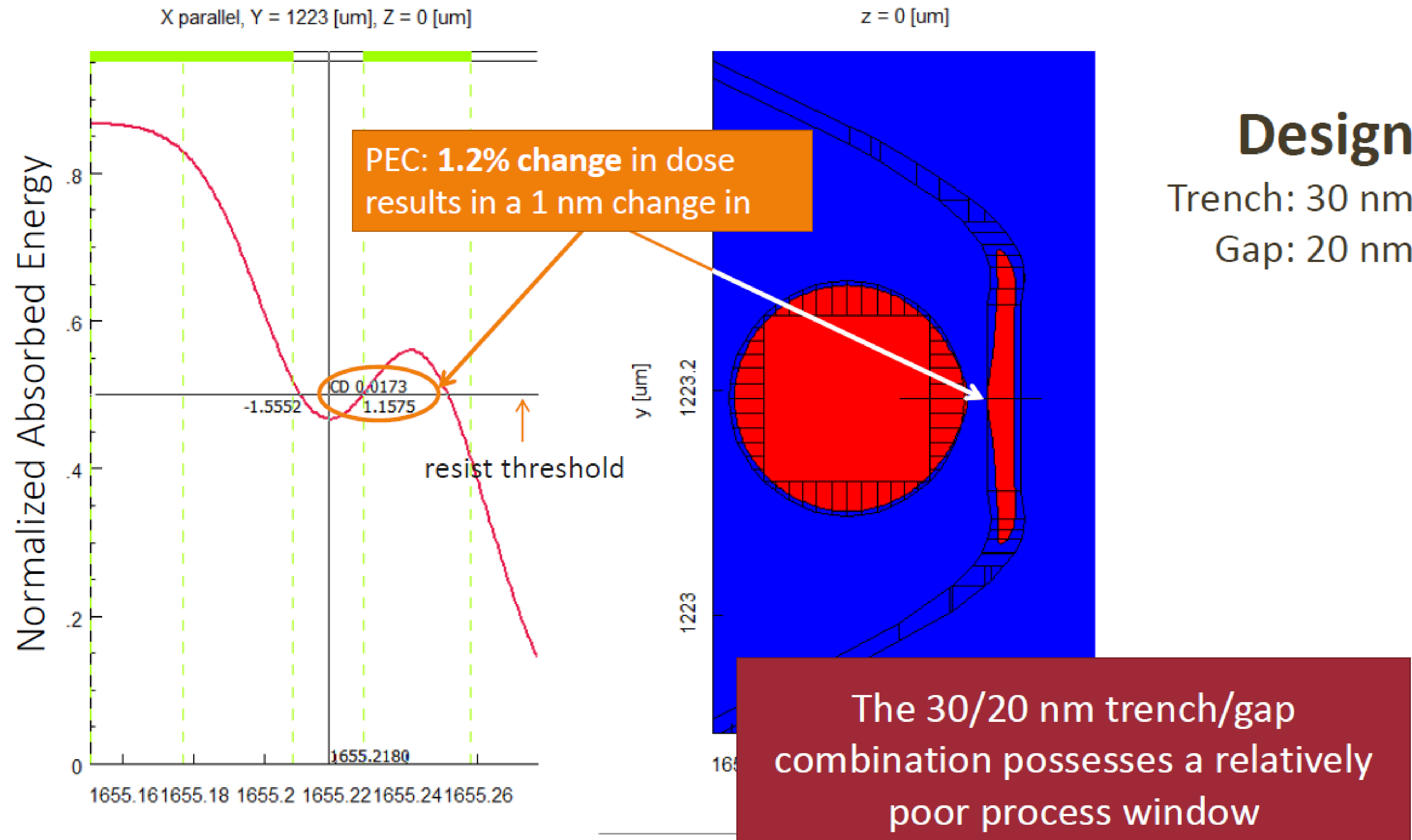
# Dose PEC – Poor Process Window




## Design

Trench: 30 nm

Gap: 20 nm

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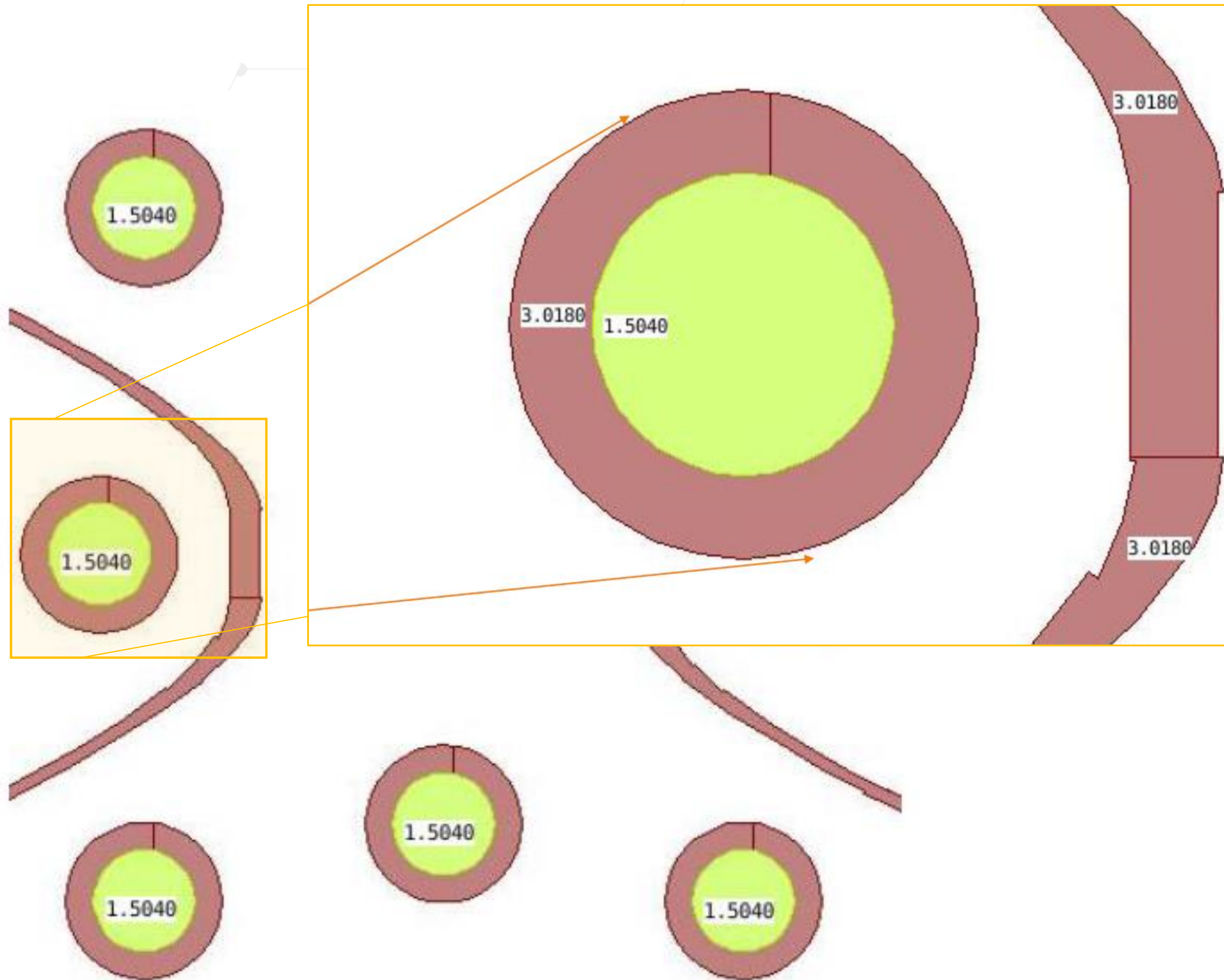
# ShapePEC with OD 2.0




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

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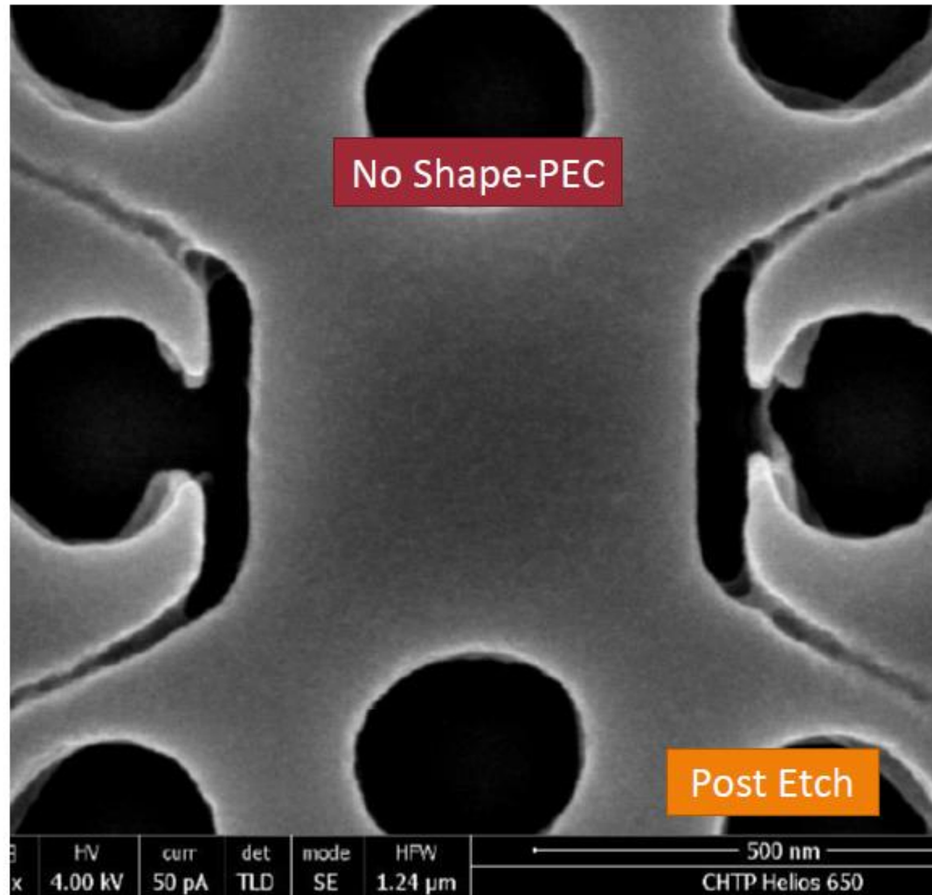
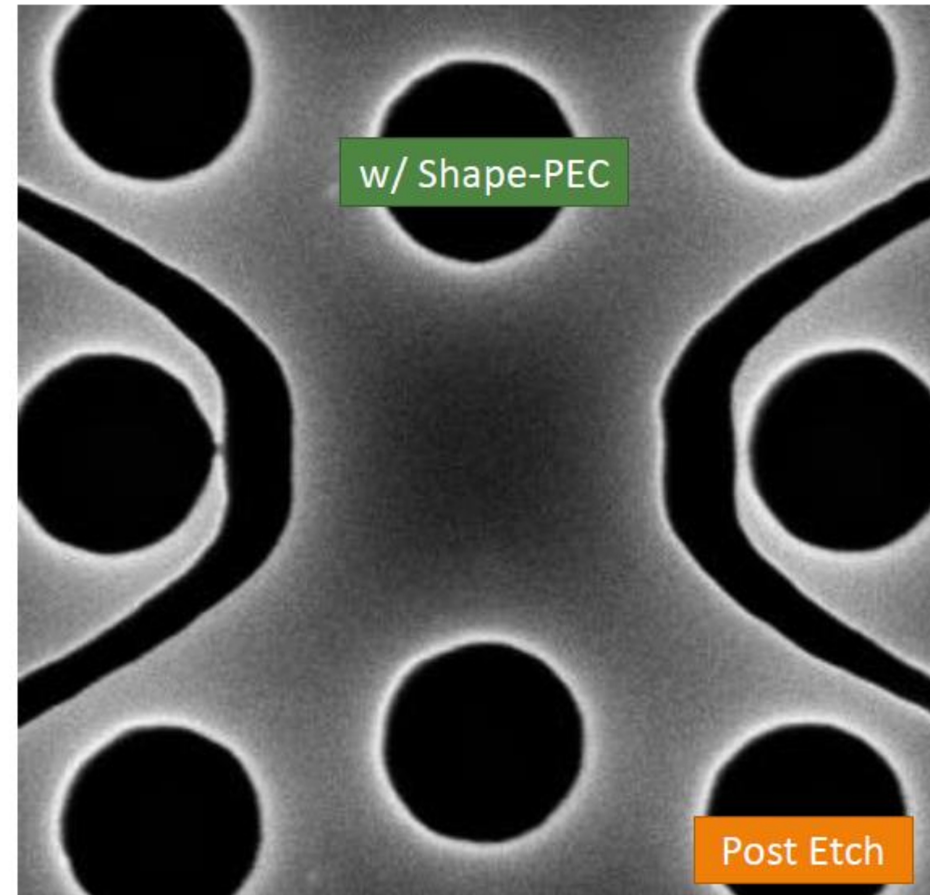
# Application Example for ODUS

## Shape-PEC Applied




University of British Columbia

Gap: 20 nm
Trench: 30 nm

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# Thank You!

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