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APPLICATIONS

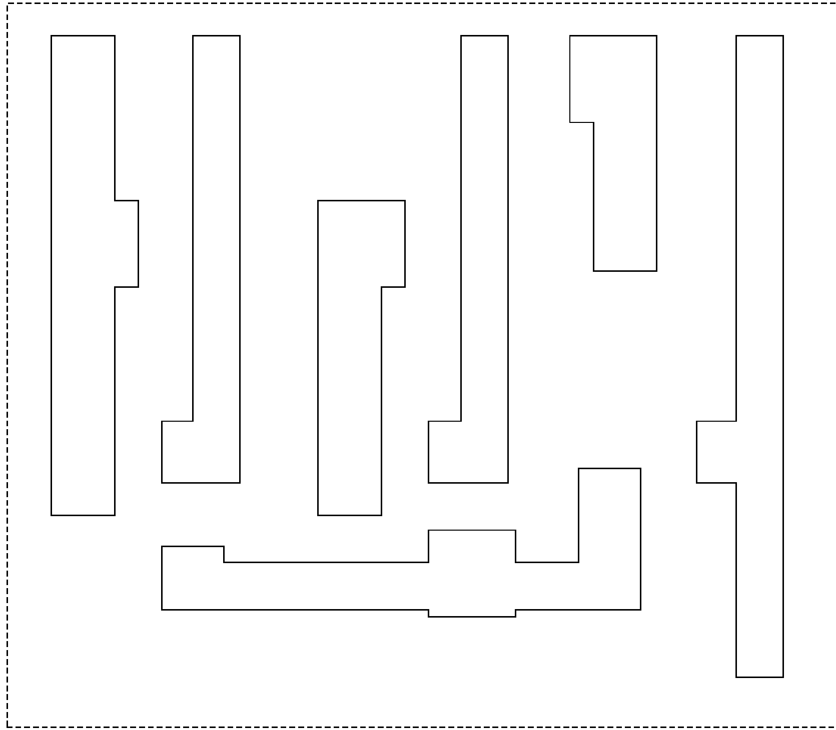
Influence of Shape PEC on resist profile

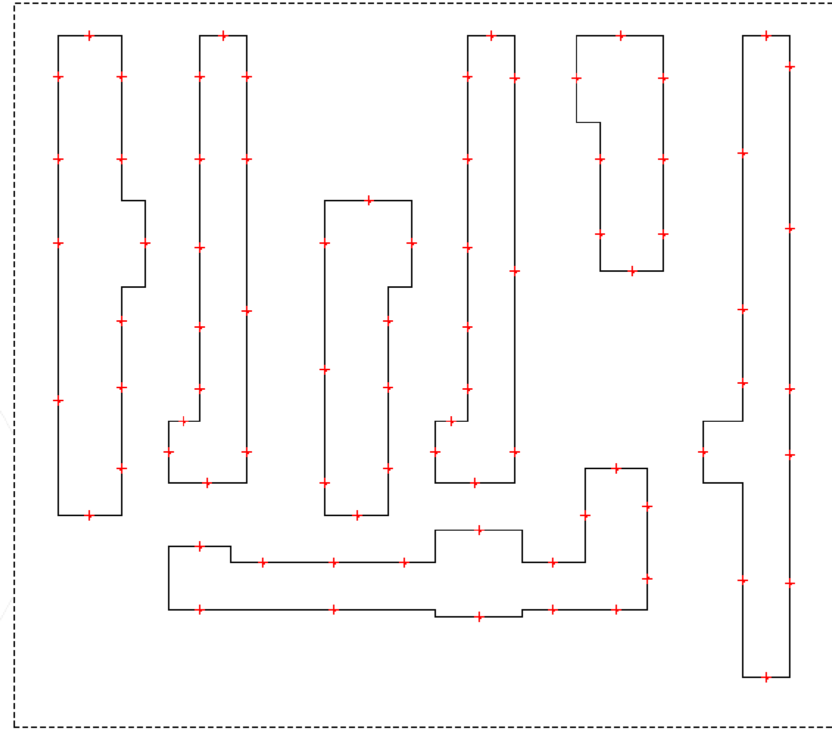
Precursor

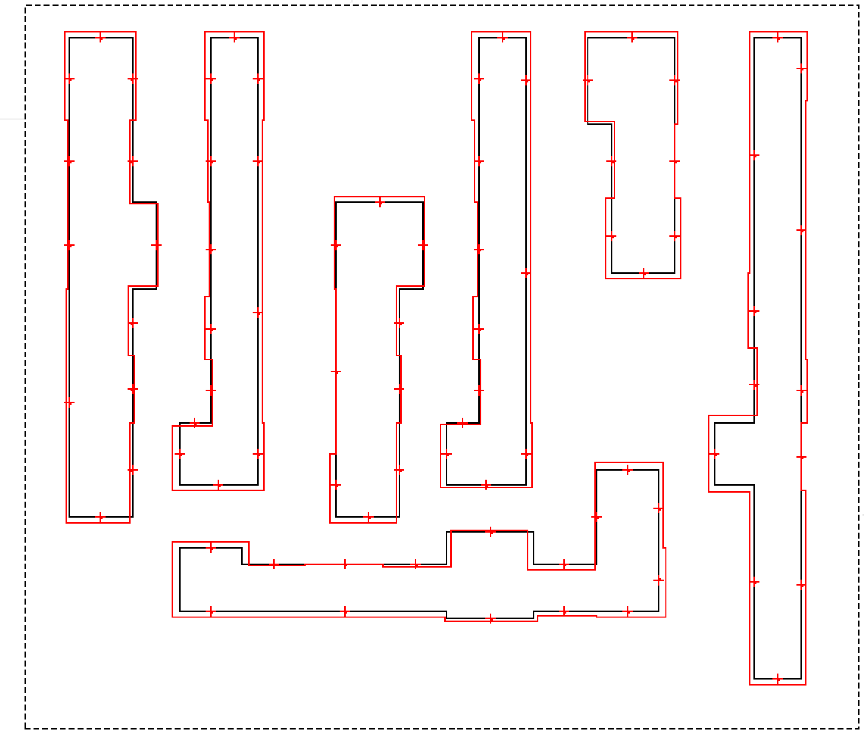
- Proximity effect correction (**PEC**) modulates the exposure dose considering the electron scattering effect of the E-Beam from the substrate (**long-range correction**)
- **Shape PEC** performs **short and mid-range** PEC by modifying pattern edges
- The model-based **Overdose/Undersize** (ODUS) Shape PEC allows over exposure to enhance pattern edges

This application note uses **LAB** to model the resist profile of a E-beam exposure, and to demonstrate the functionality of ODUS.

Shape PEC Principle







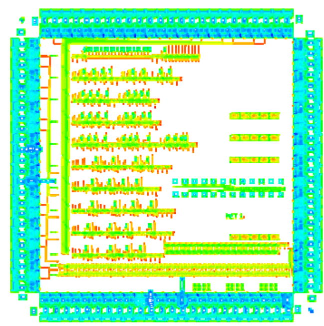
Shape PEC goal:
Move edges locally to compensate for short- and mid-range energy loss and obtain a uniform dose at all layout edges.

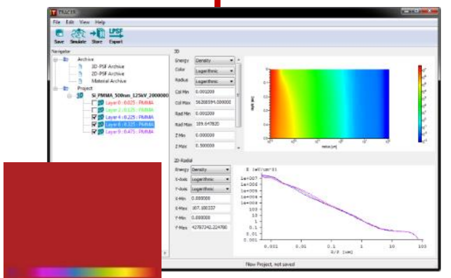
In a DRC step all edge segments are analyzed for the CD and distance to adjacent shapes.
A set of representative evaluation points (+) is defined.

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

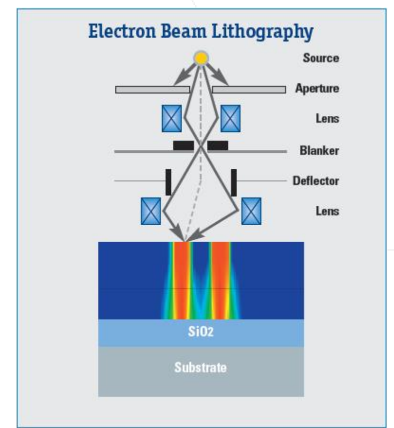
LAB 3D Simulation

Layout

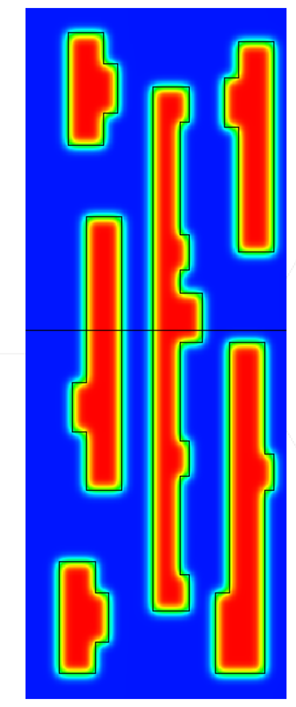




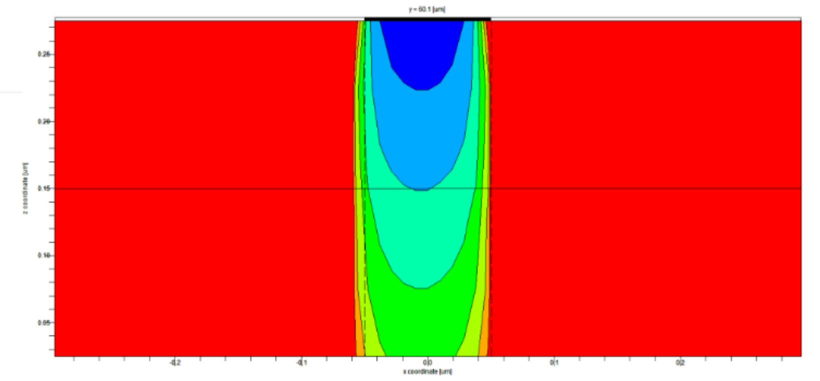
3D PSF

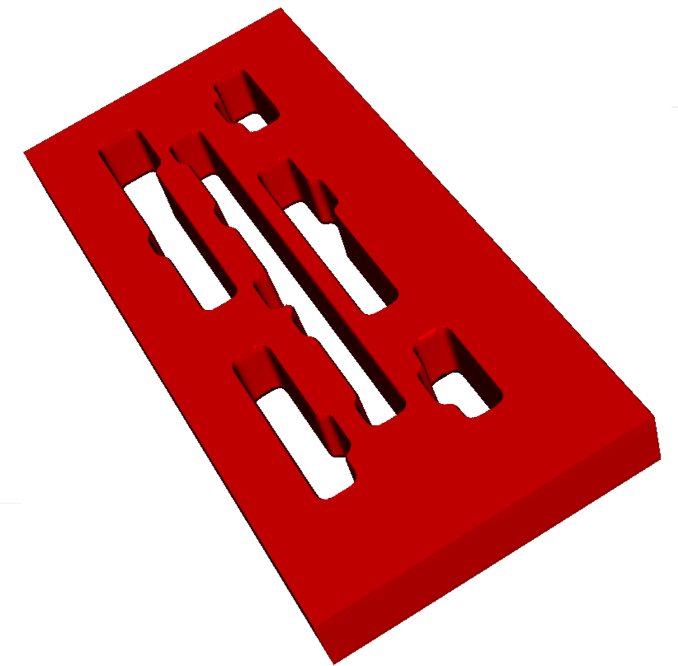


E-Beam Exposure



3D Bulk Energy

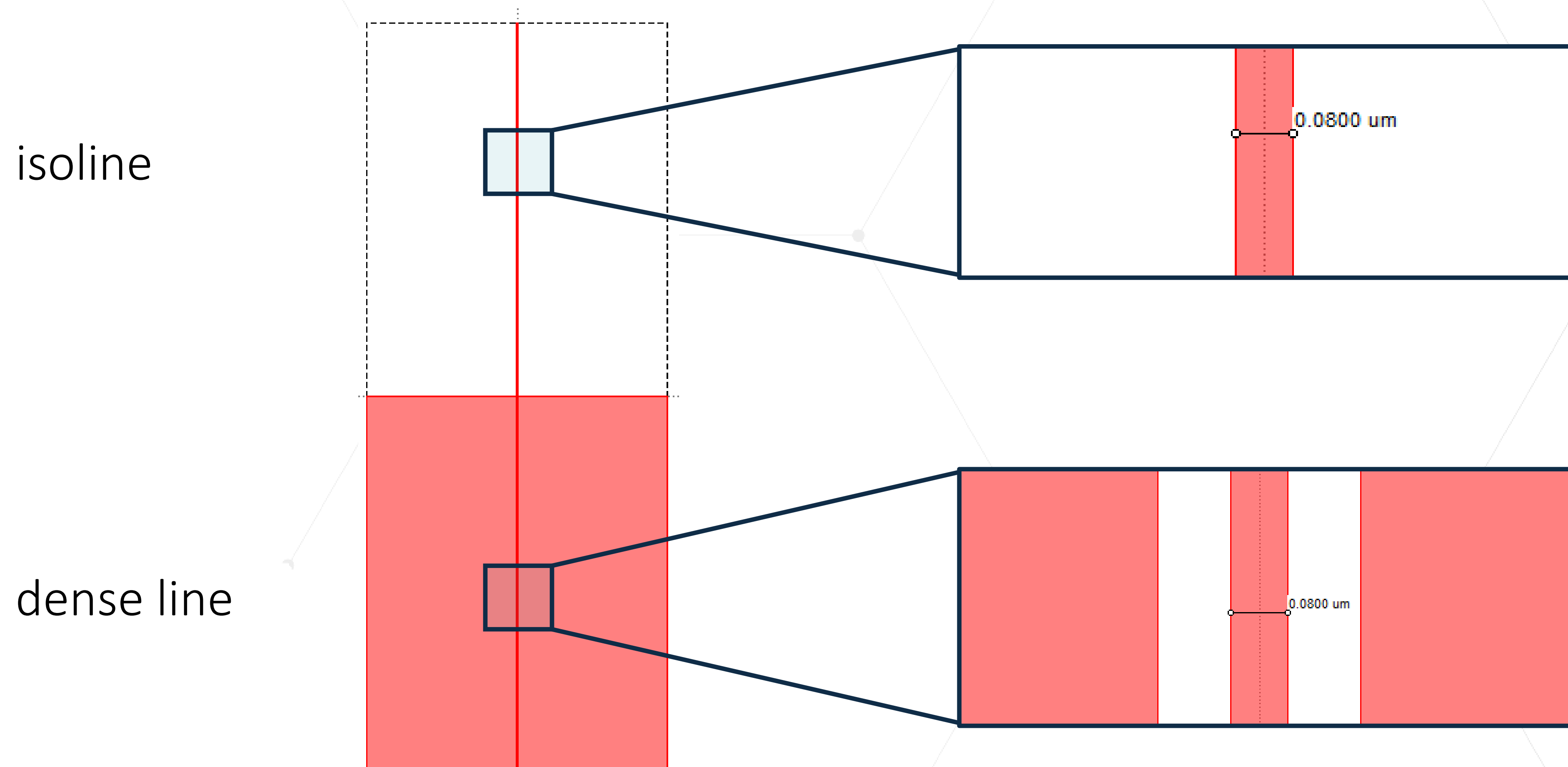




3D Resist Development

Pattern of study

- Simulation are run on a GaAs substrate with 200 nm PMMA 950K
- Dose PEC and Shape PEC - ODUS (overdose factor = 2) are used for pattern correction



Contrast Comparison

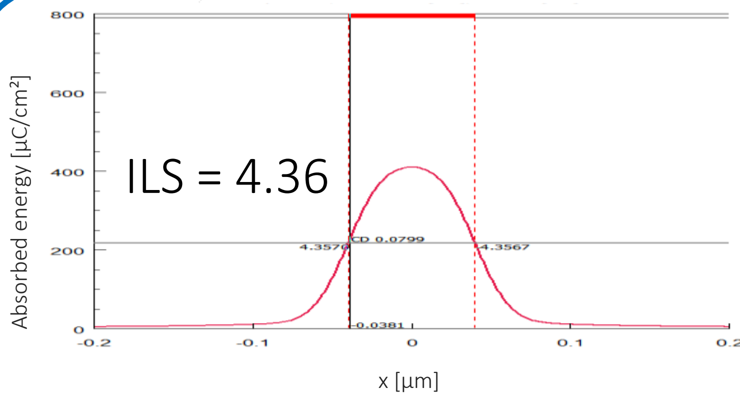
- The intensity across the line shows:
  - the enhancement of image contrast using ODUS (based on the Image Log Slope - ILS)
  - the dependence of image contrast on pattern density (Dense line has lower image contrast)

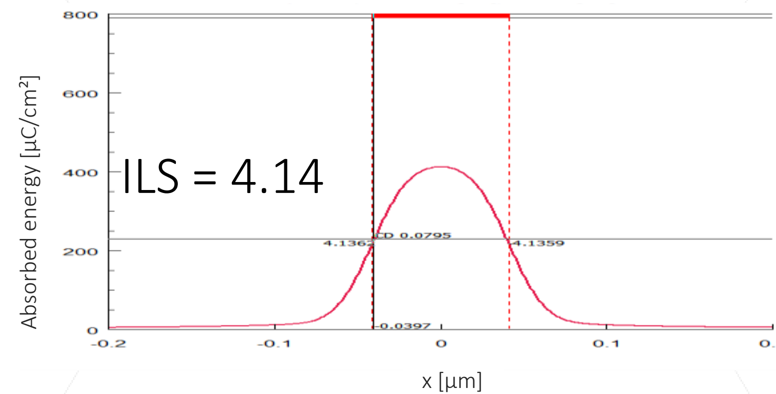
Dose PEC

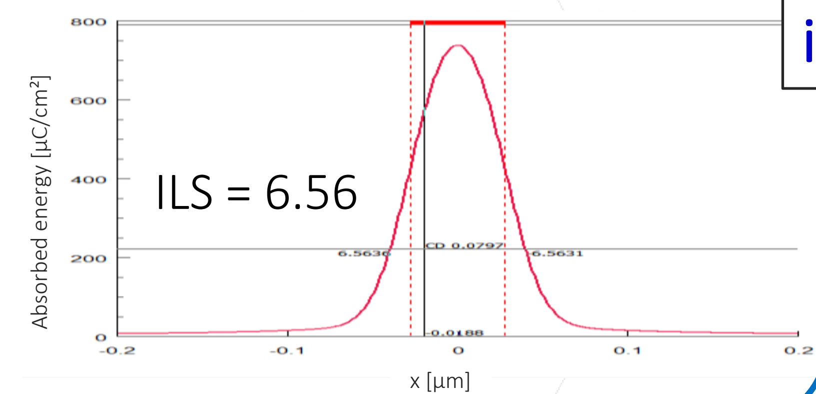
Shape PEC

ODUS

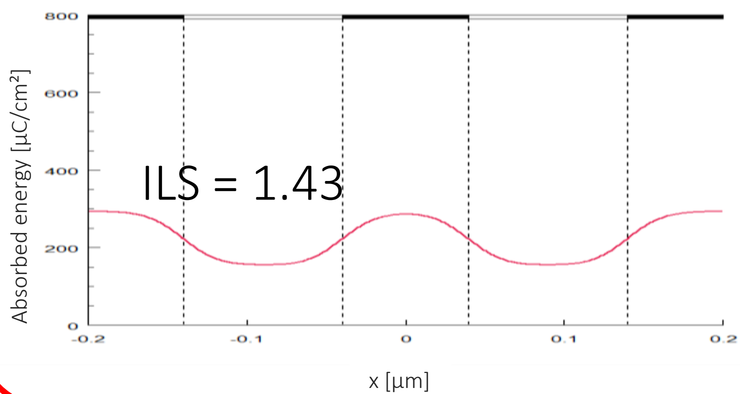
isoline

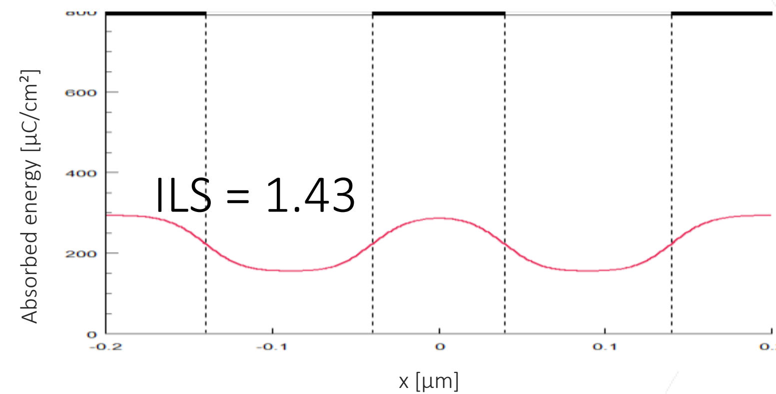


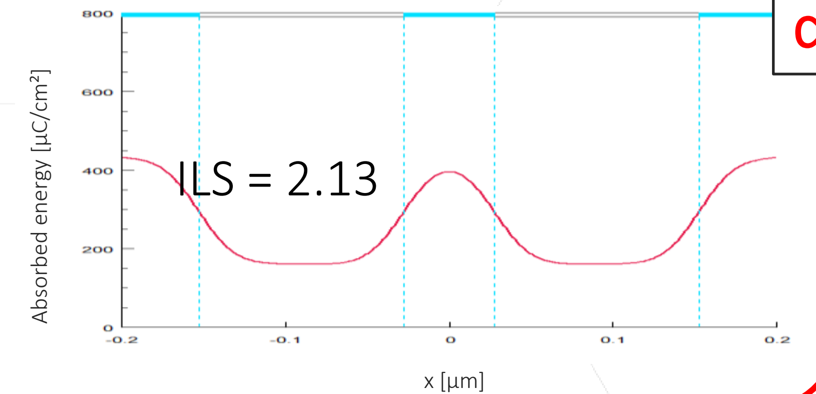




dense line

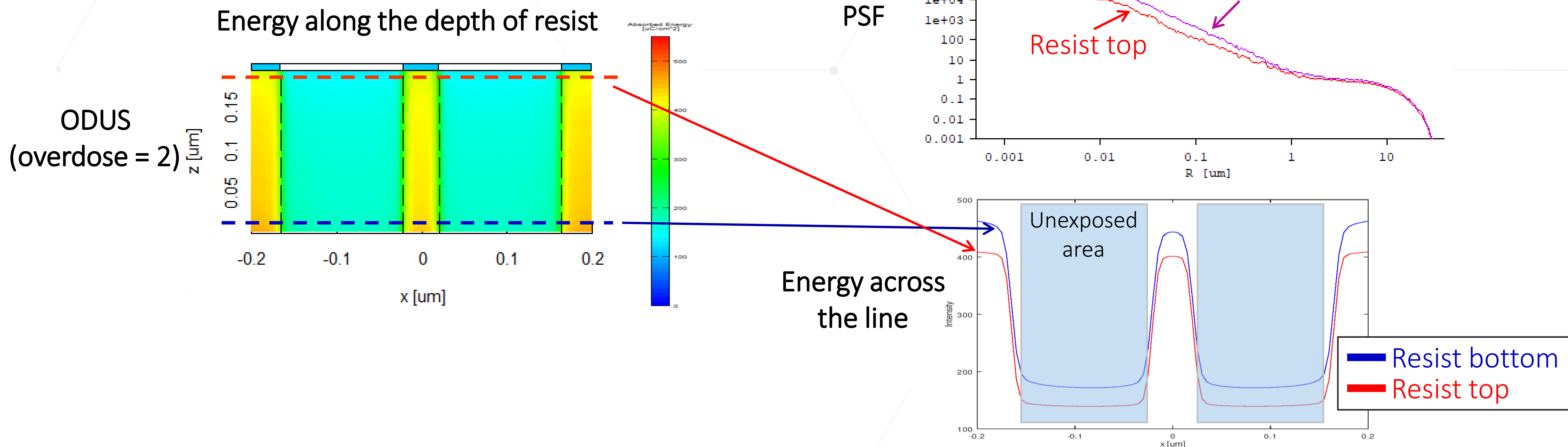






Bulk Energy

- Simulation considers 100 keV electron beam exposure
- The PSF varies with E-Beam scattering into the resist
- The energy in the unexposed area at the resist bottom is **15%** higher than that at the resist top



Resist Development

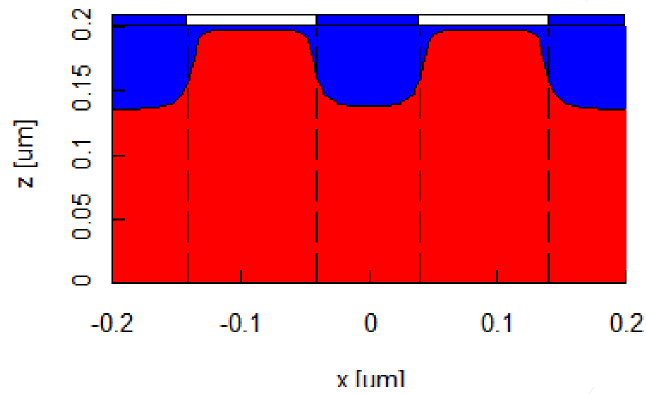
- Resist (red area) development front is modeled over time
- Developer flows both in depth and lateral direction
- ODUS leads the developer leaking into the resist faster due to over-dosed exposed area

20 s development

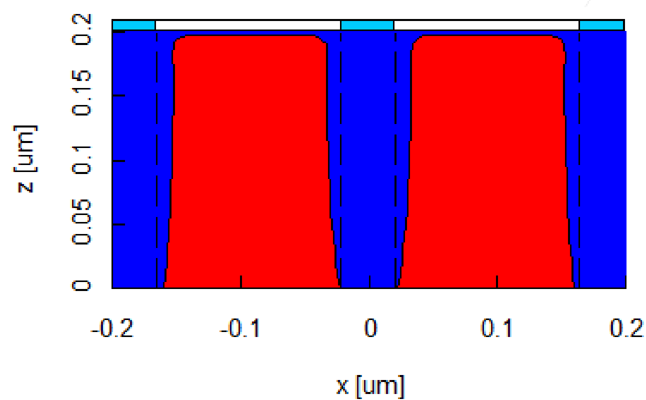
Energy in resist

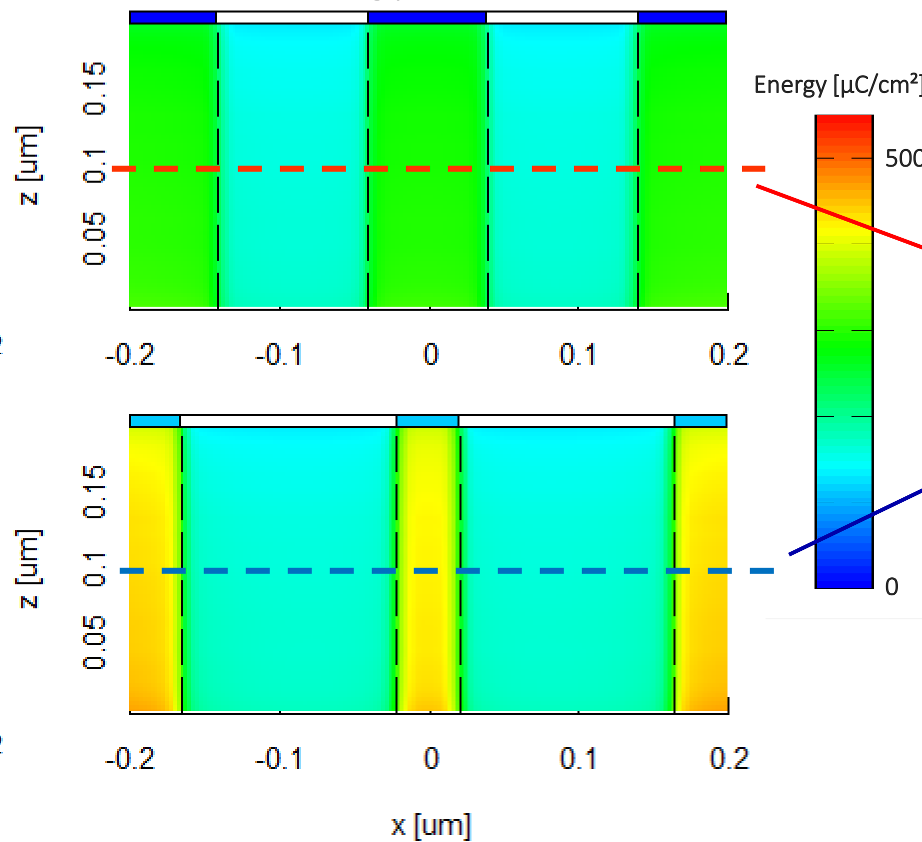
Energy across the lines

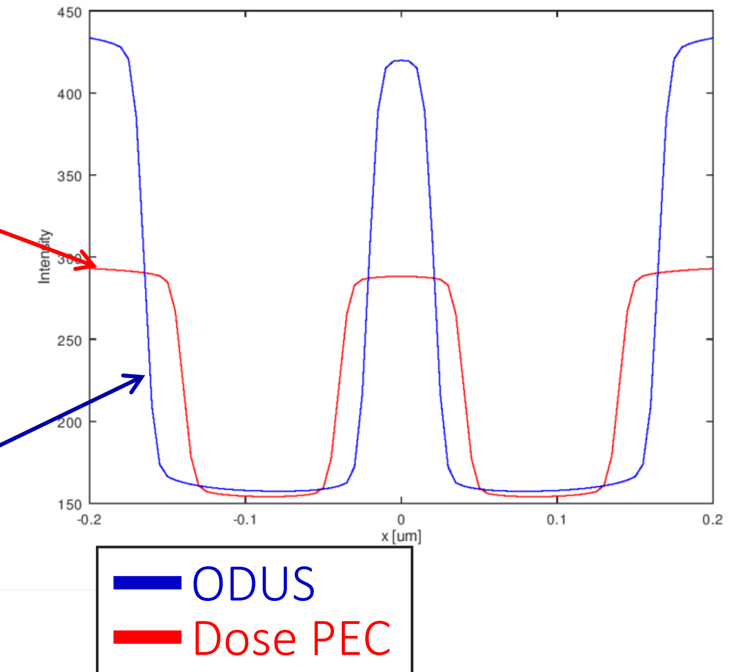
Dose PEC



ODUS (overdose = 2)







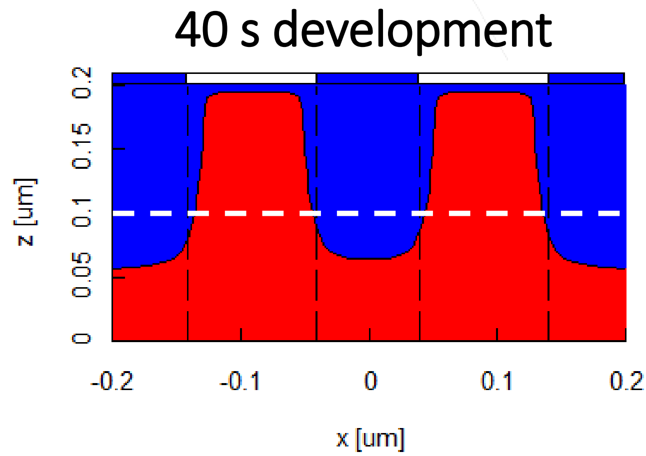
Resist Development

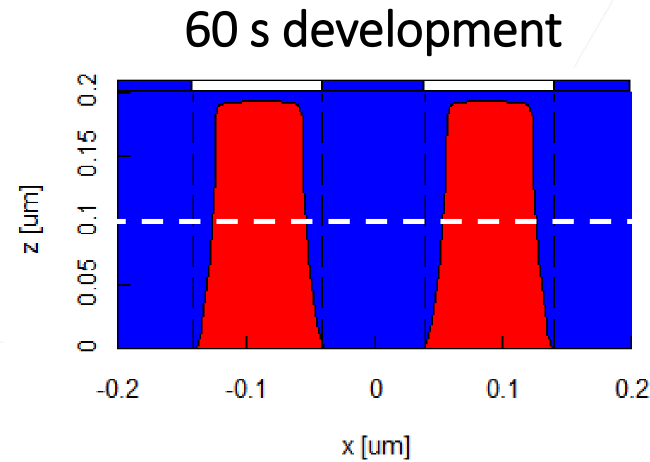
- After reaching the bottom, the developer flows laterally faster at the bottom than at the top, resulting in resist sidewall enhancement

40 s development

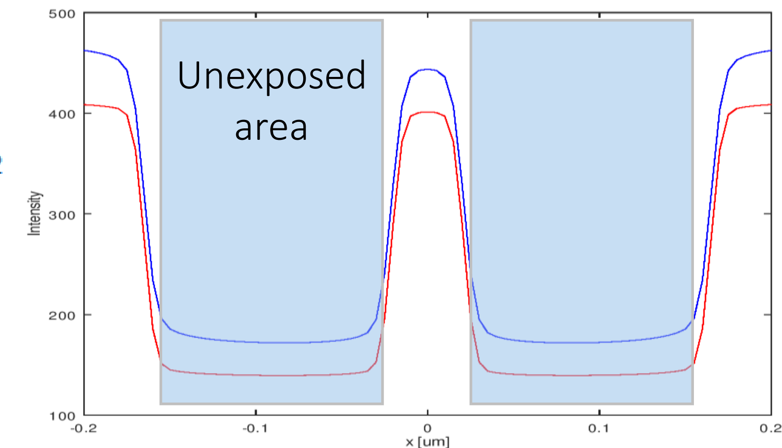
60 s development

Dose PEC

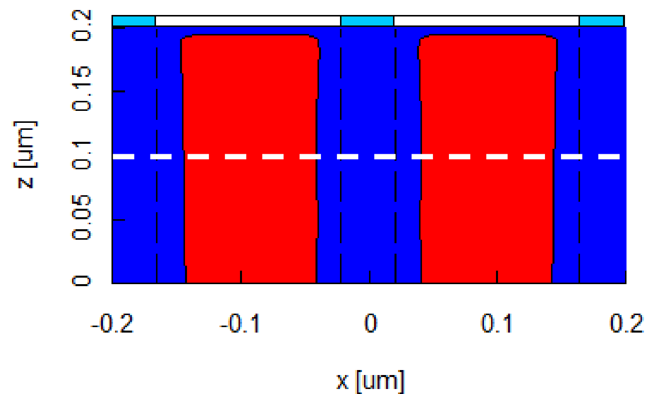


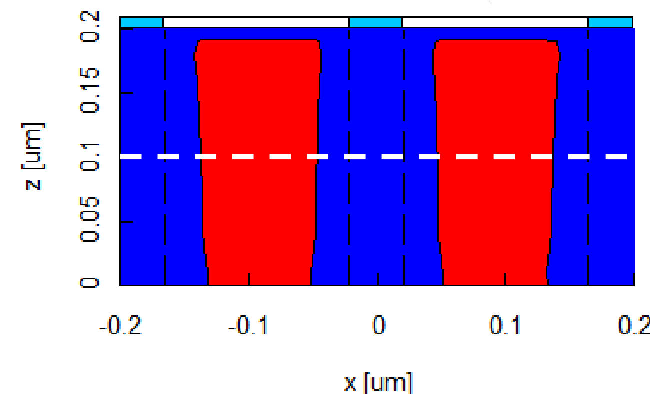


Energy across the line



ODUS (overdose = 2)



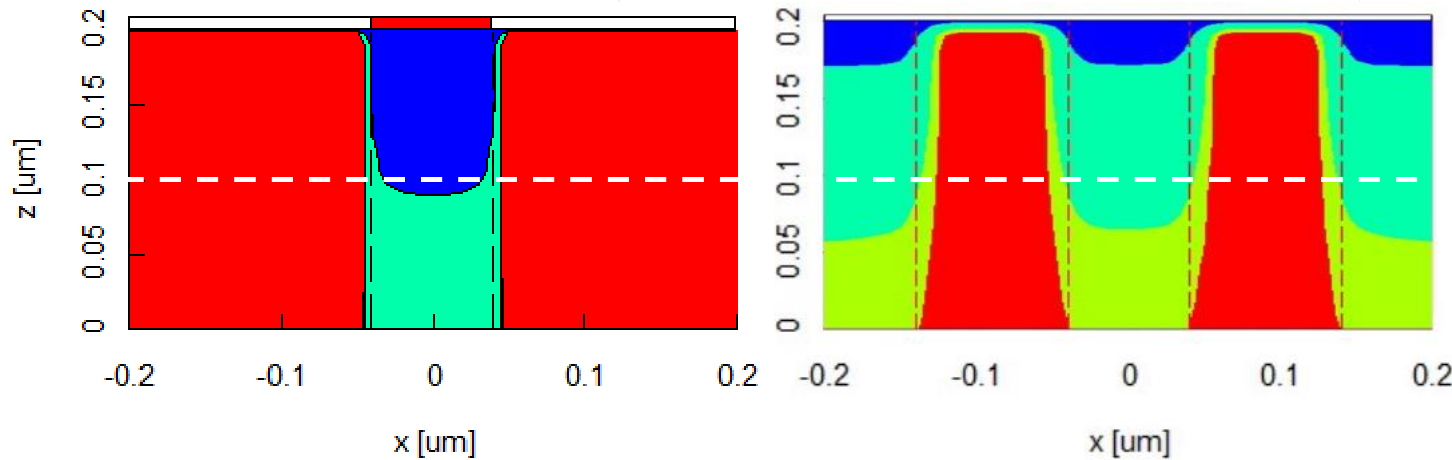


ODUS shows better sidewall enhancement

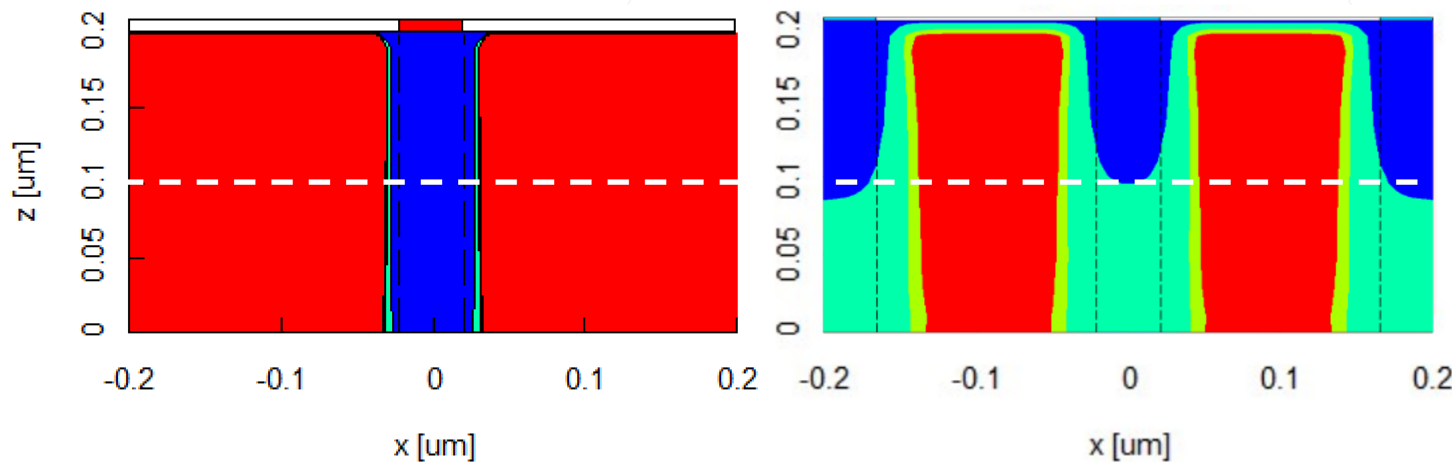
Pattern Density

- What affects the resist development? ➜ **pattern density**
- Developer front is faster for isoline patterns than for dense lines
- The lateral development rate is slower and background energy is lower in isolines
- Resist sidewall enhancement with ODUS is evident for dense lines

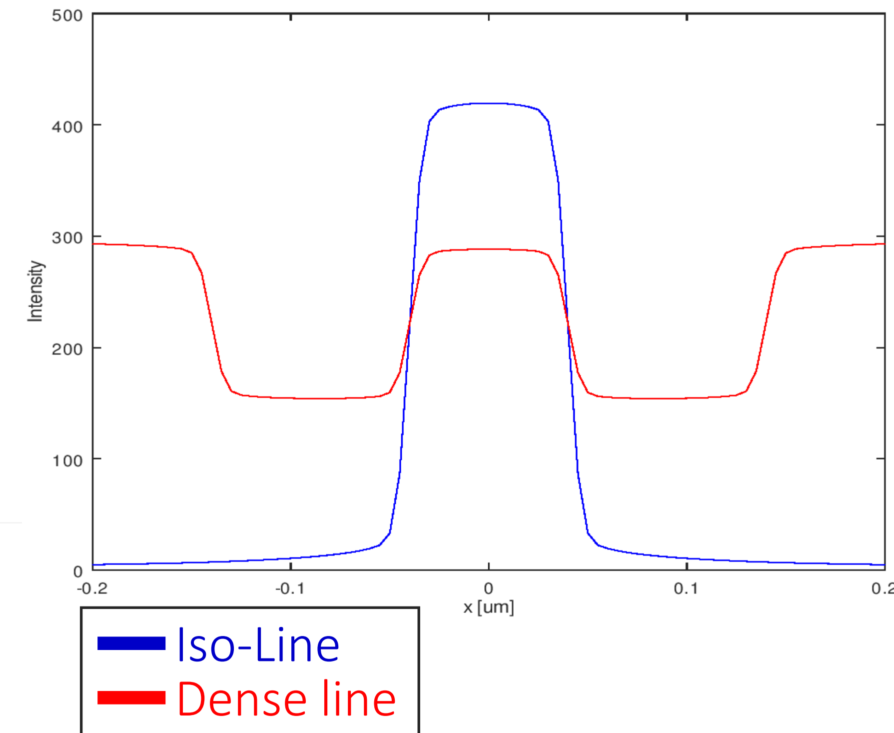
Dose PEC



ODUS
(overdose = 2)

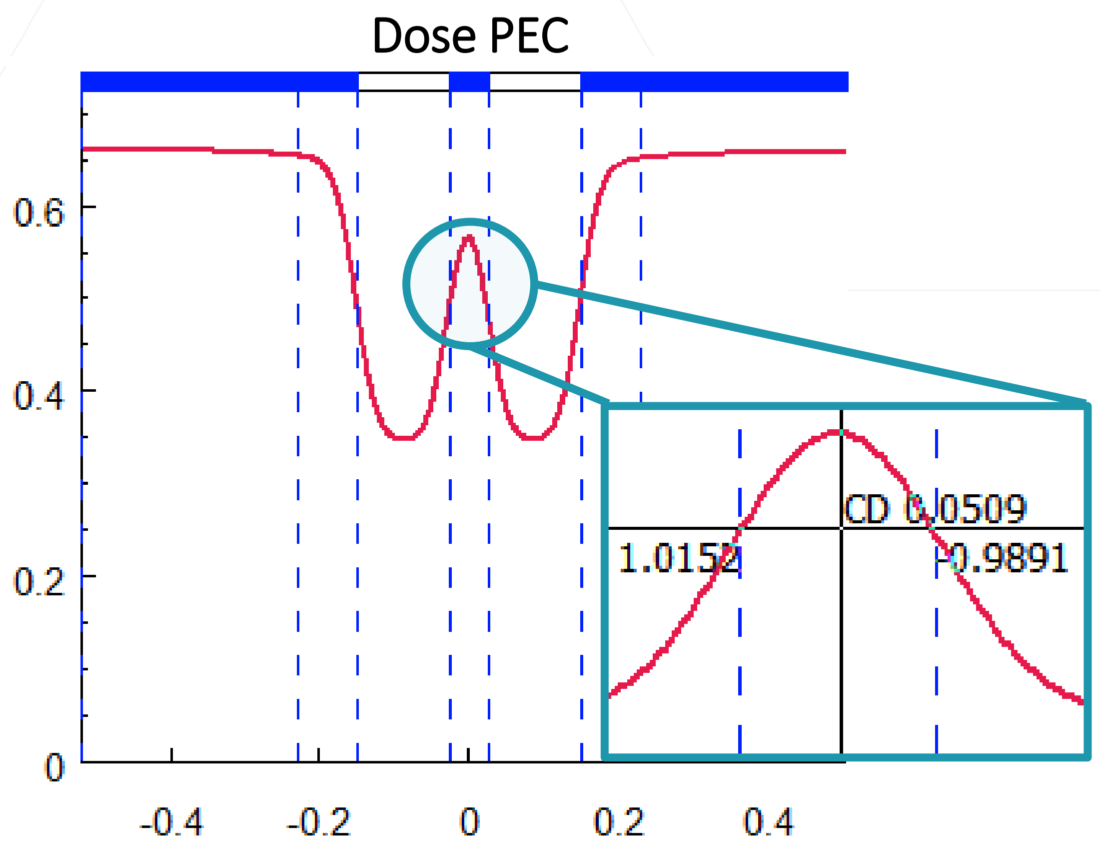


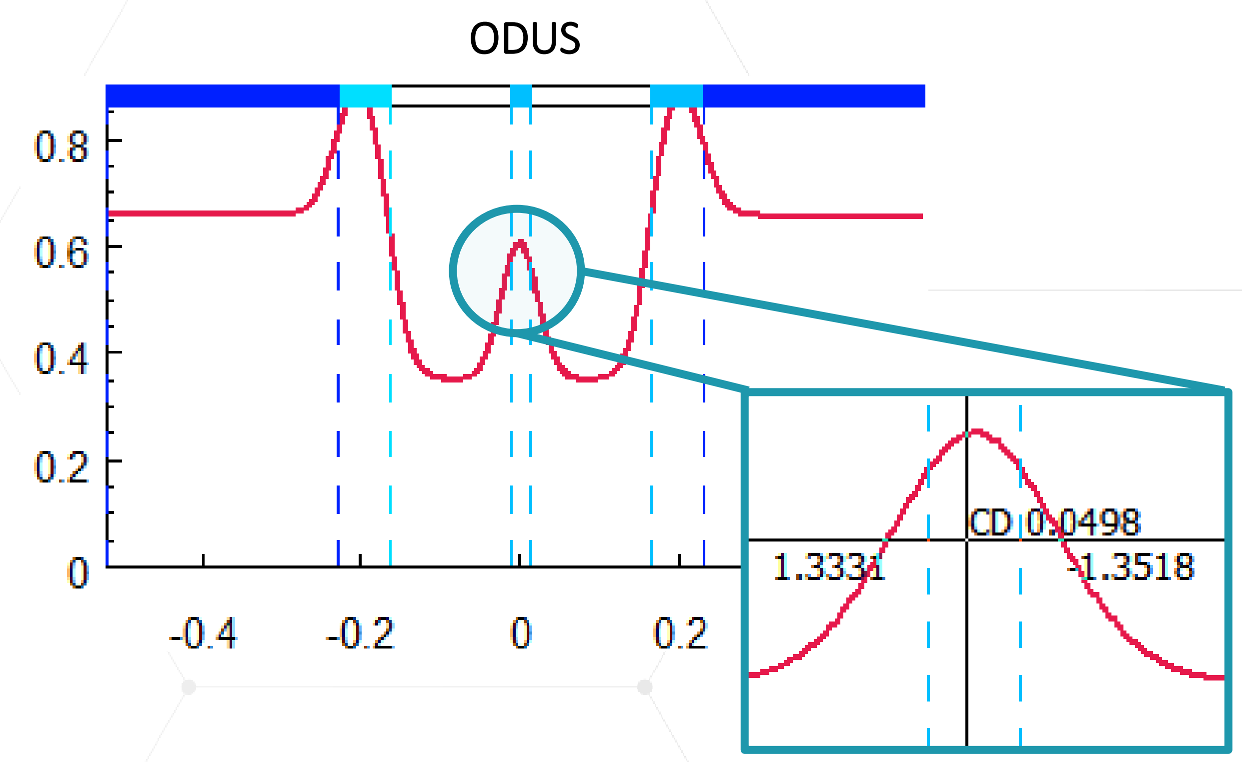
Time [s]
< 10
10-40
40-60
> 60



Side wall enhancement

- Side wall is measurable via the ILS
  - Higher slope ➡ higher wall definition





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Resist Thickness

- What affects the resist development? ➡ **resist thickness**
- Unexposed are of the thick resist has larger energy difference from bottom to top

Dose PEC

ODUS
(overdose = 2)

100 nm

-0.2 -0.1 0 0.1 0.2
x [um]

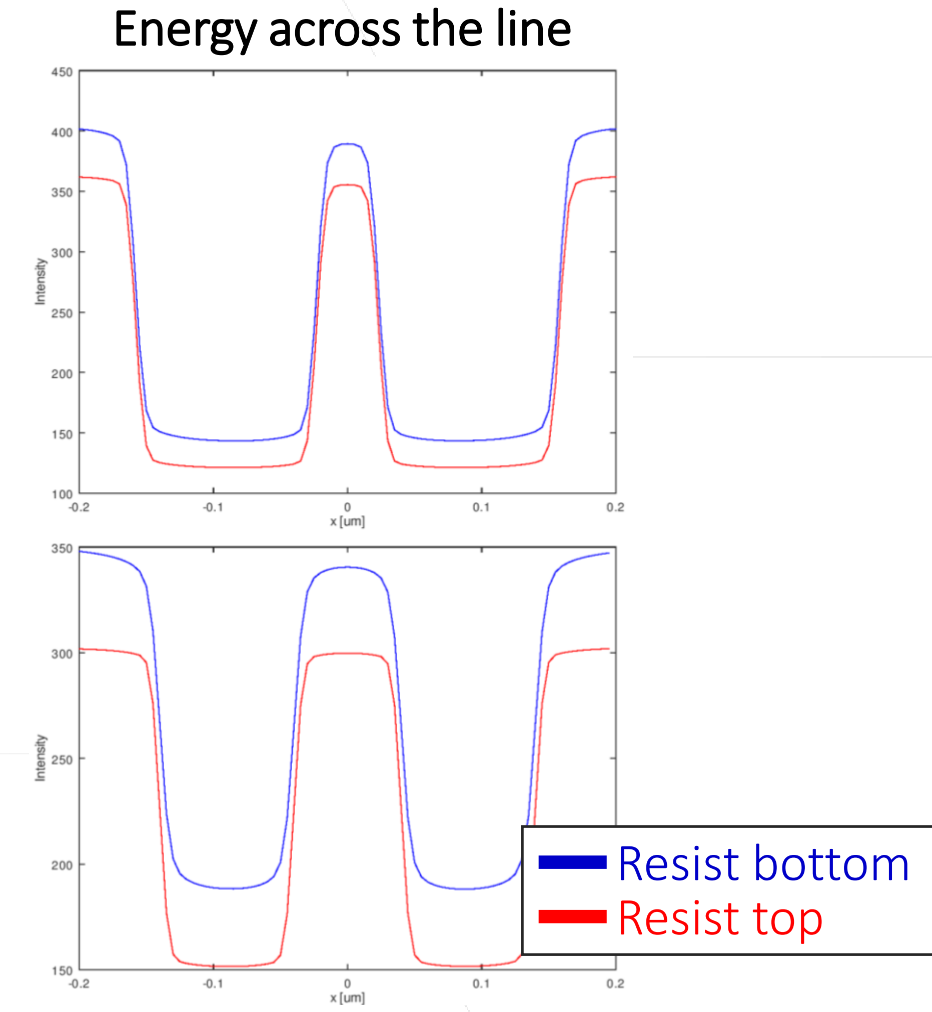
-0.2 -0.1 0 0.1 0.2
x [um]

Time [s]
< 20
20-40
40-60
> 60

300 nm

z [um]
0 0.1 0.2 0.3
-0.2 -0.1 0 0.1 0.2
x [um]

z [um]
0 0.1 0.2 0.3
-0.2 -0.1 0 0.1 0.2
x [um]



Substrate

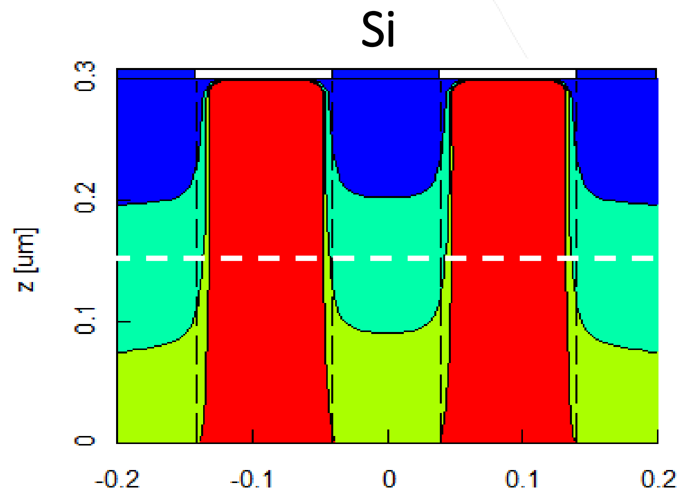
- What affects the resist development? ➔ **substrate material**
- Mid-range higher scattering implies larger energy at the unexposed area for GaAs substrate

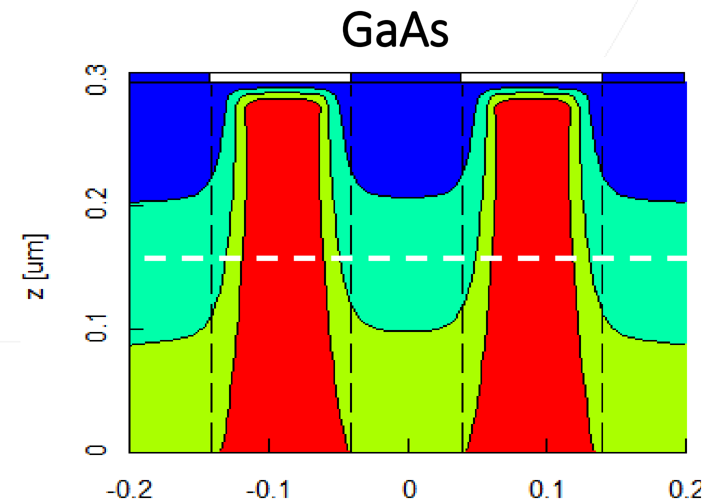
Si

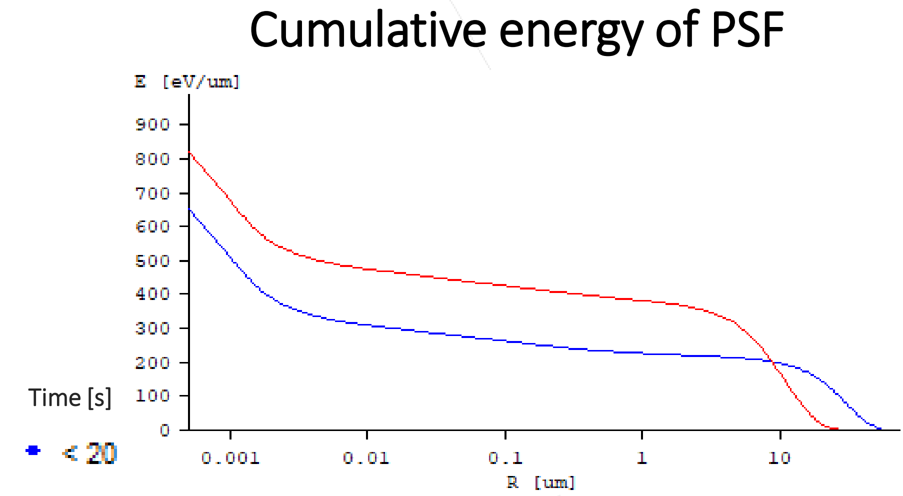
GaAs

Cumulative energy of PSF

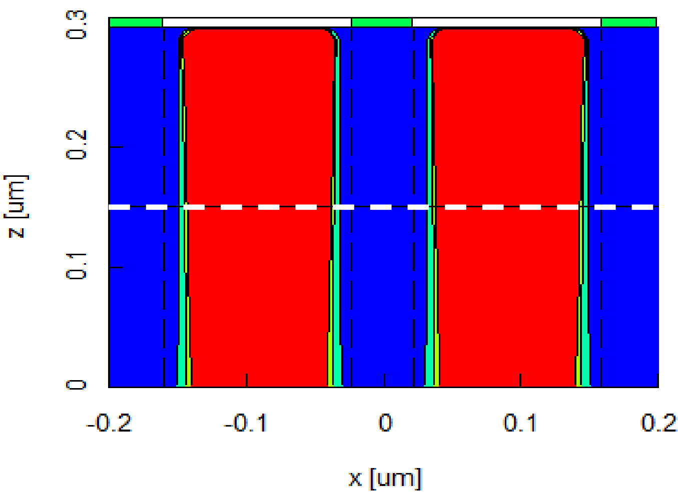
Dose PEC

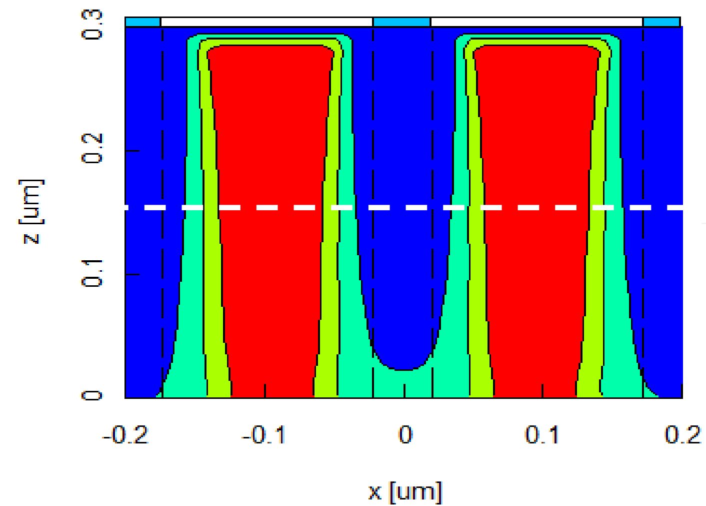


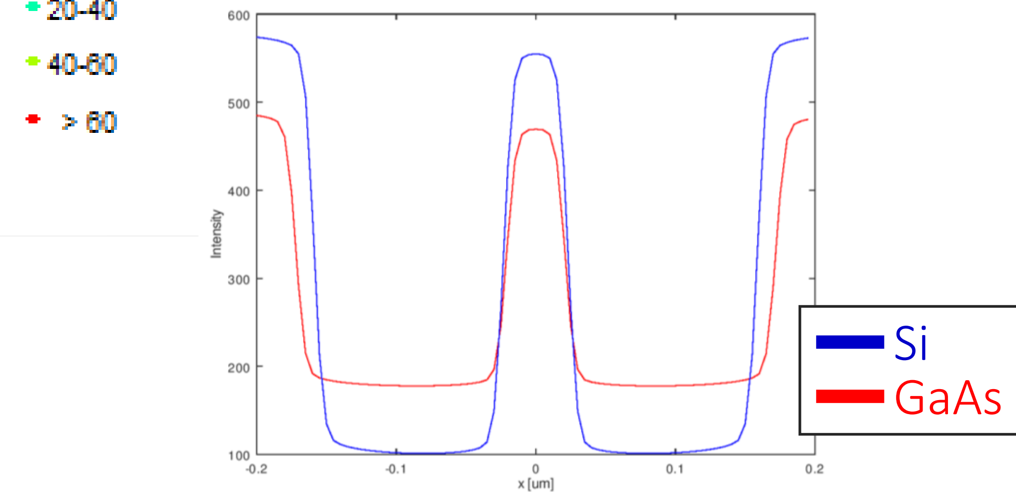




ODUS (overdose = 2)

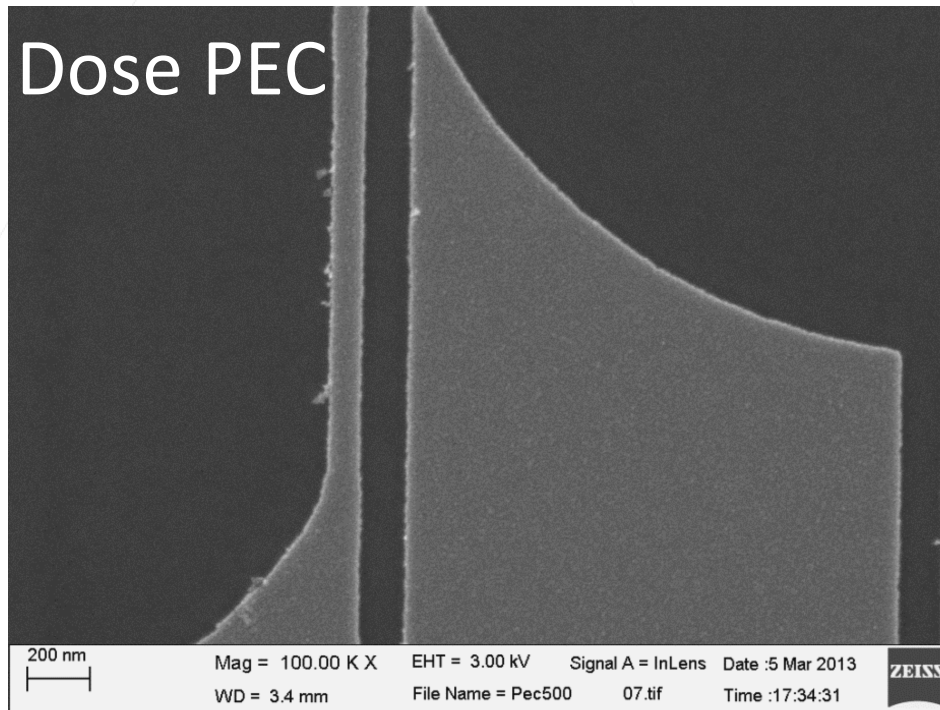


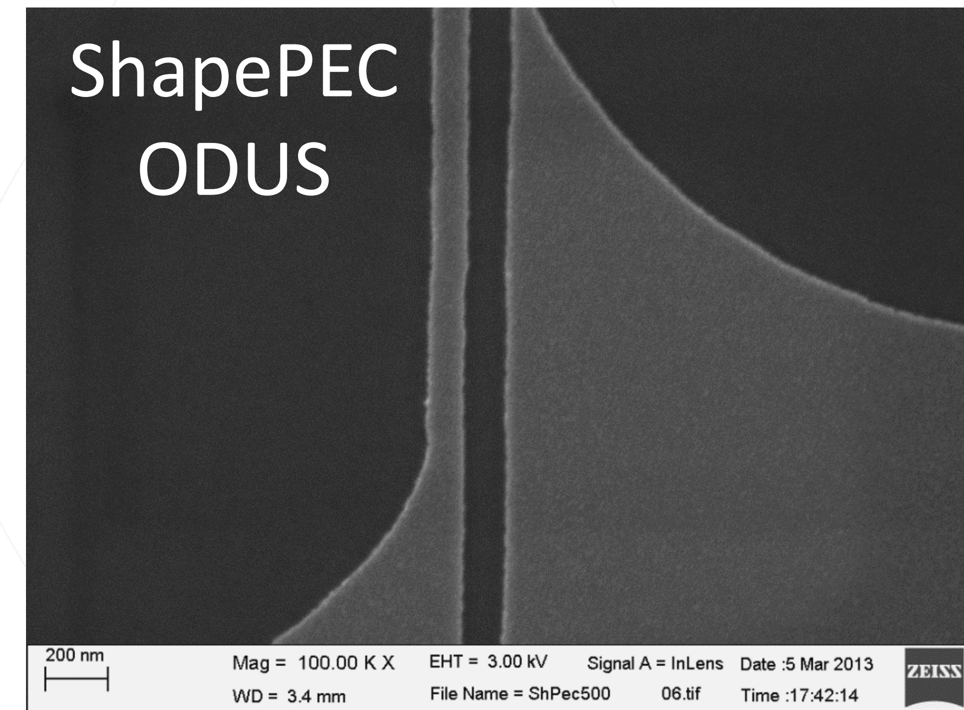




Application: Single Layer Lift-Off

Shape PEC - ODUS improves metal edge (liftoff) after EBL on single layer resist

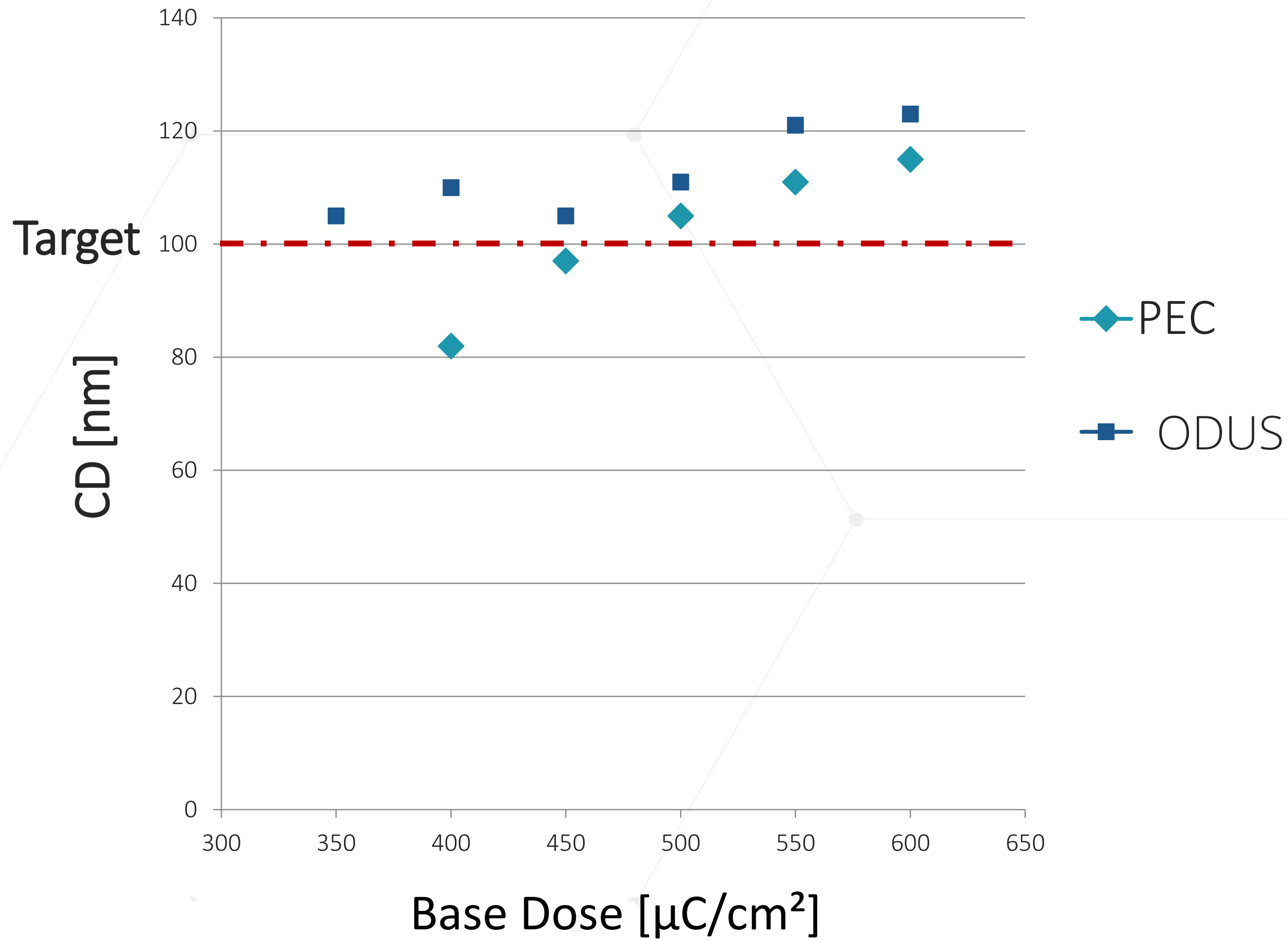




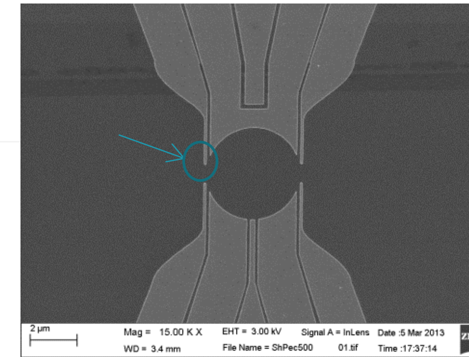
Why is Shape PEC - ODUS better?

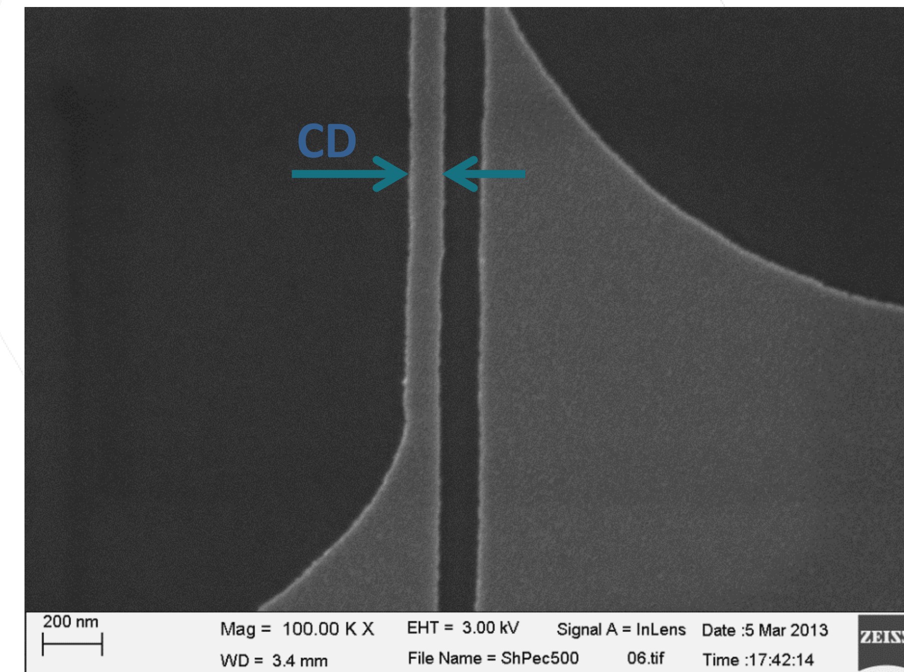
Presented at BEAMeeting Freiburg 2013:
Diana Mahalu – Compare Shape PEC and Dose PEC

Measured CD Sensitivity



CD design 100nm



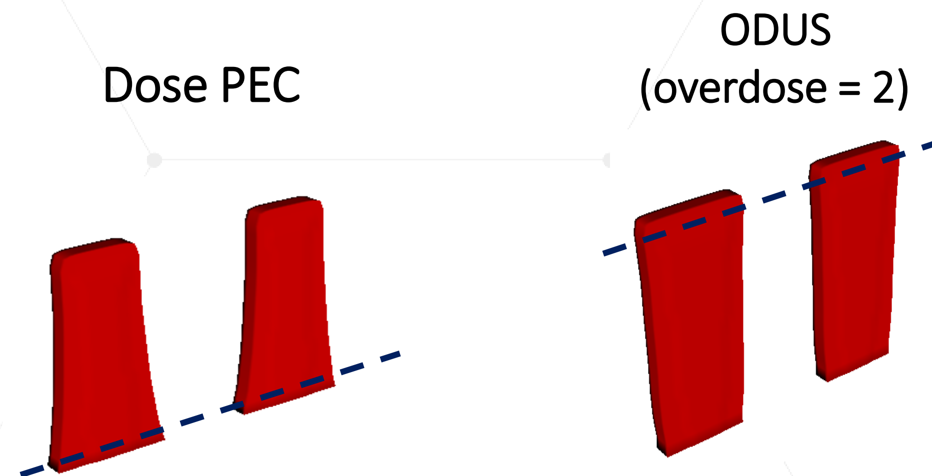


Larger lift-off process window when using ODUS (resist edge-slope)

Simulated CD Sensitivity

- The enhanced **image contrast** by ODUS results in enhanced **CD sensitivity**
- The CD of the metal line (after lift-off) is calculated with PEC and ODUS with 5% exposure dose

  - **Negative resist** (ODUS = 2) ➡ CD change determined at the **resist top**
  - **Positive resist** (PEC) ➡ CD change determined at the **resist bottom**



	Resist position	CD change [nm]
Dose PEC	Bottom	16
ODUS (overdose = 2)	Top	6

Application for Shape PEC - ODUS

Photonic Device Patterning Optimization

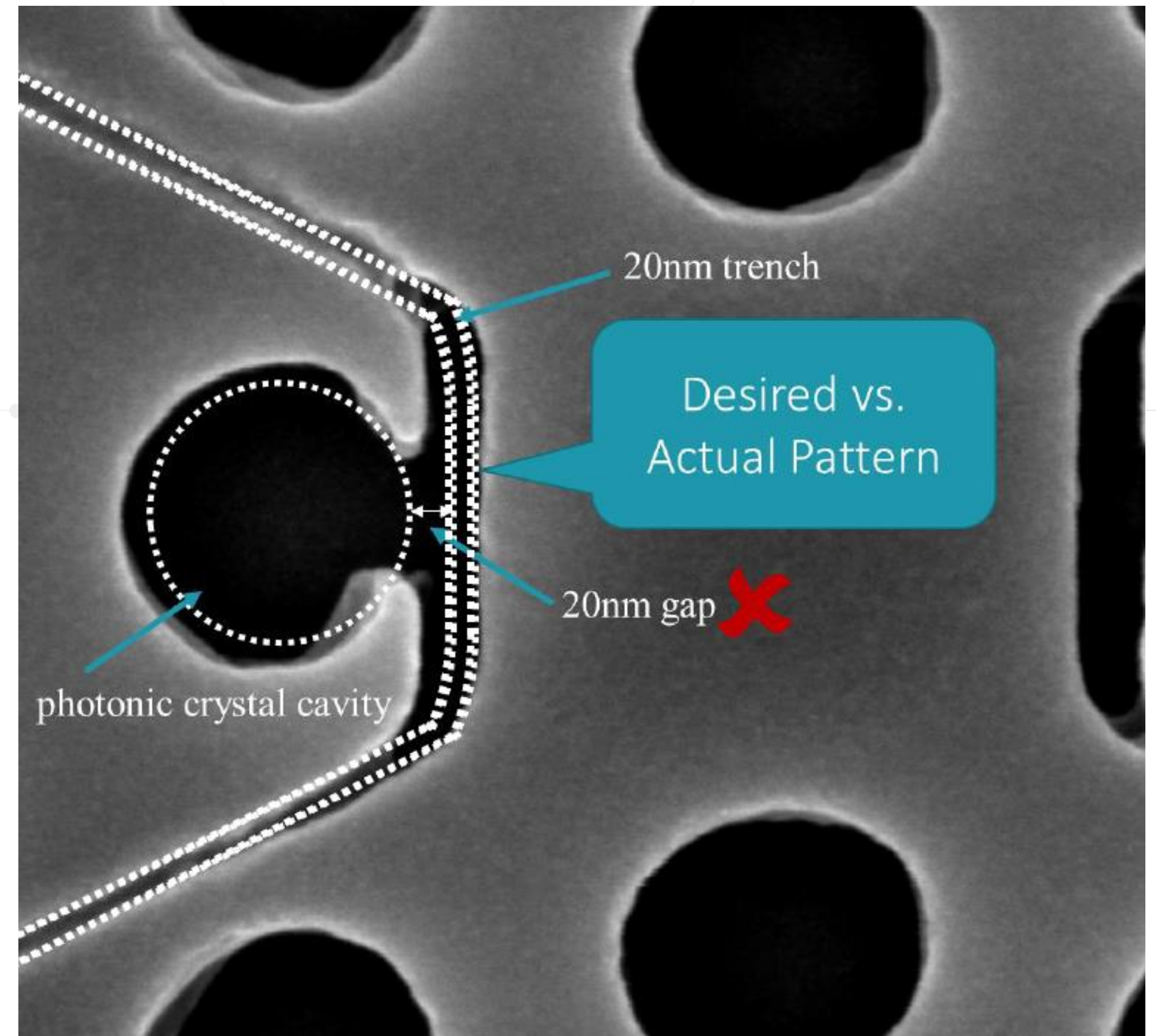
Improving Process Window via Contrast Enhancement

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

JEOL 8100 at 100 kV + 500 nm ZEP520A

- Challenges
  - Thick resist with etch requirements
  - 20 nm gap between photonic crystal cavity and trench
  - PEC insufficient to resolve gap

Presented at BEAMeeting EIPBN 2019



Challenges of the layout

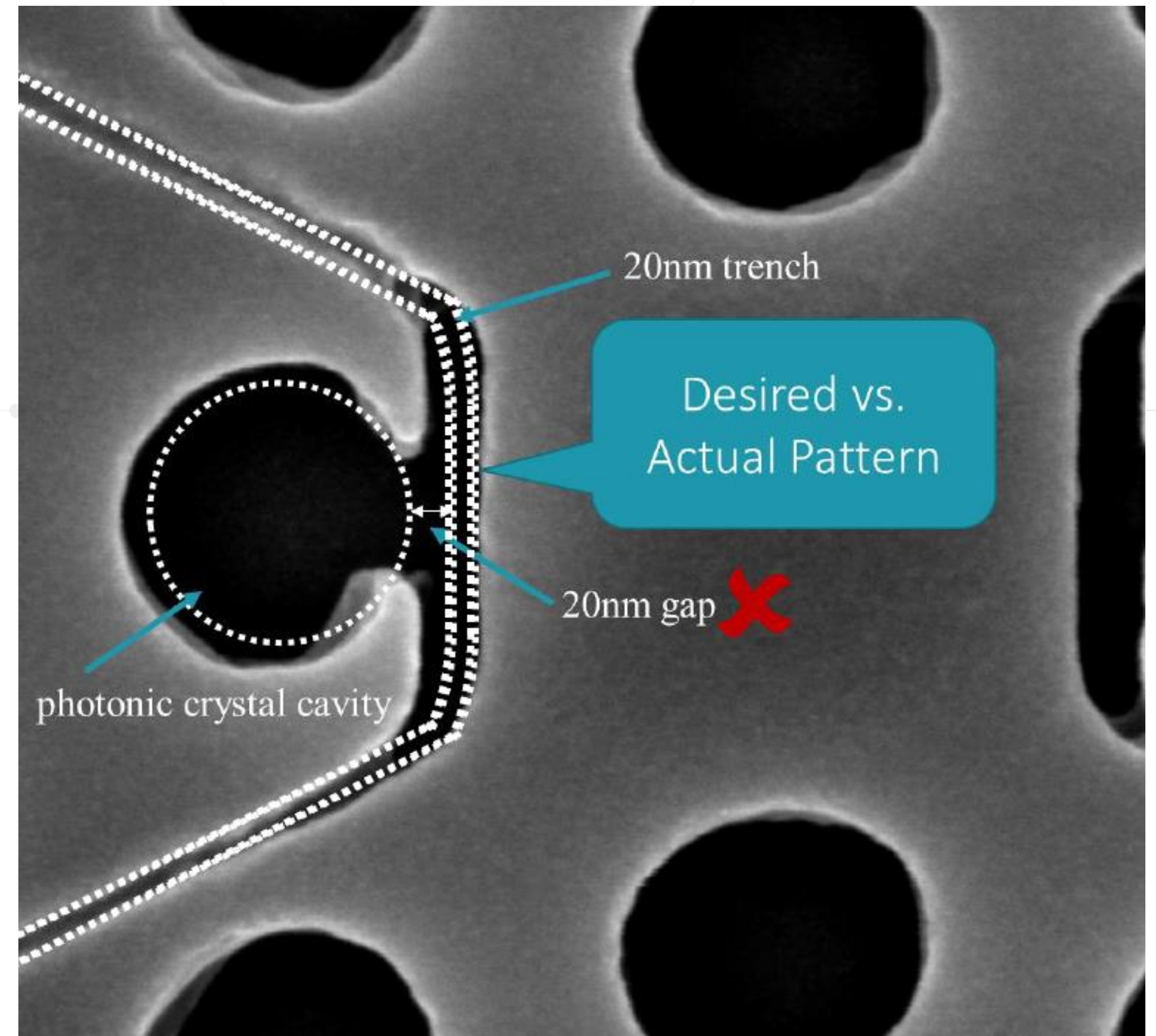
Presented at BEAMeeting EIPBN 2019

Critical Design Elements

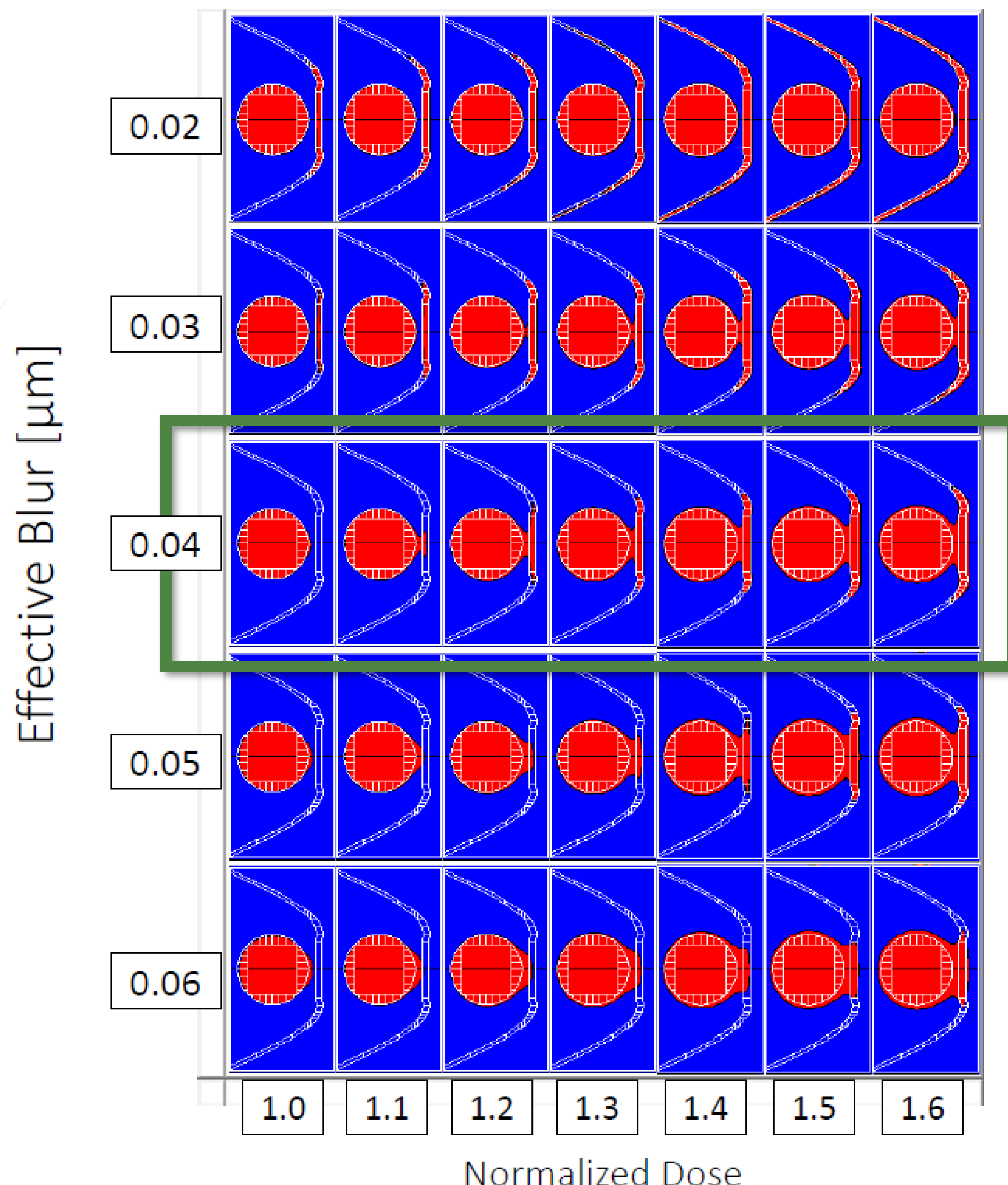
- Trench: 20 nm wide
- Gap: 20 nm wide
- Photonic crystal cavity: 200 nm (diameter)

Experiment with larger features

- Trench: 30 and 50 nm wide
- Gaps: 50 nm
- PEC for long range
- Simulations to match exposure latitude



Determination of Effective Blur by Simulation

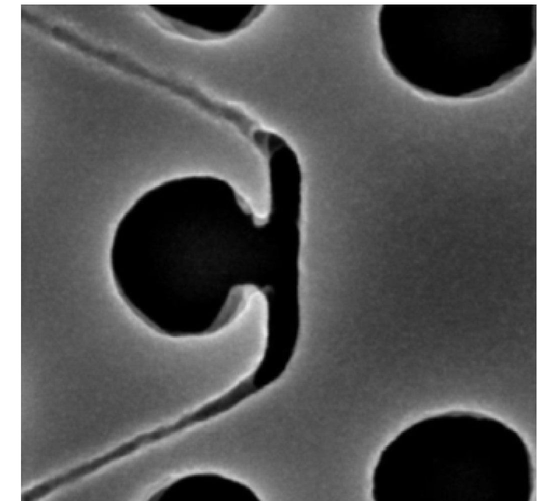


Threshold analysis

- 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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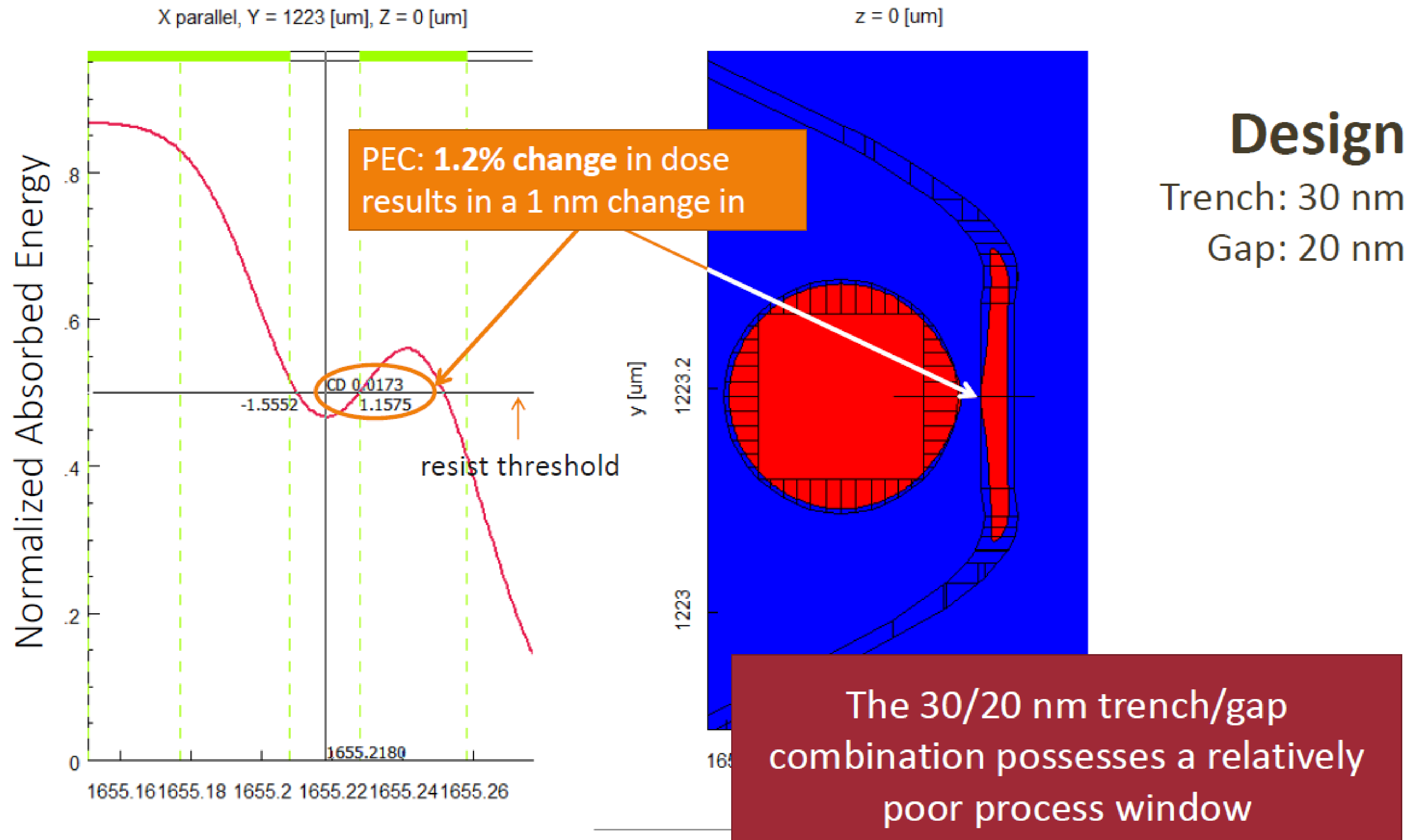
Dose PEC – Poor Process Window



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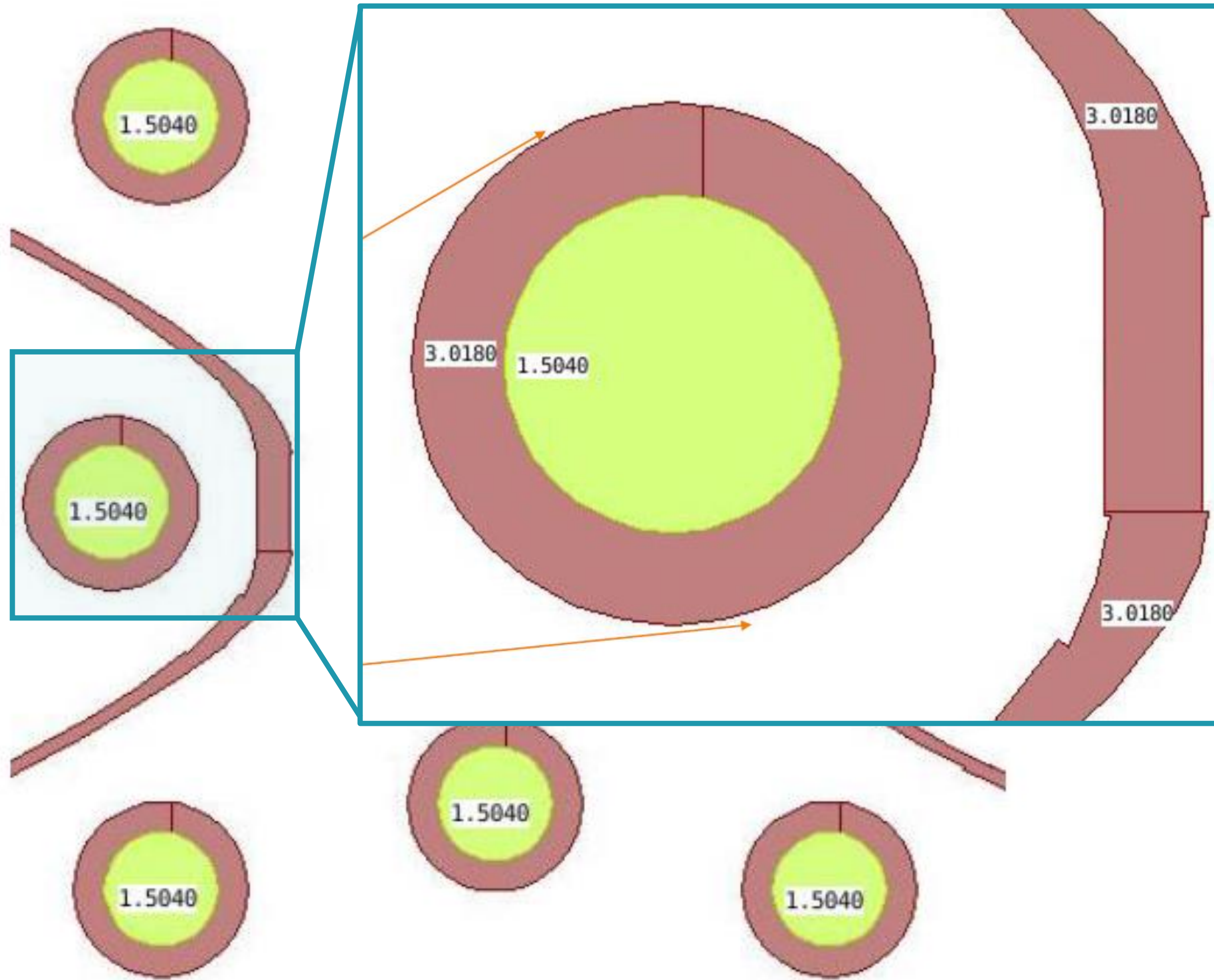
Shape PEC with overdose 2



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

Absorbed Energy [uC/cm^2]

CD 0.0174
-3.4723
2.9556
1655.2167

1655.18 1655.2 1655.22 1655.24 1655.26 1655.28

z = 0 [um]

y [um]

x [um]

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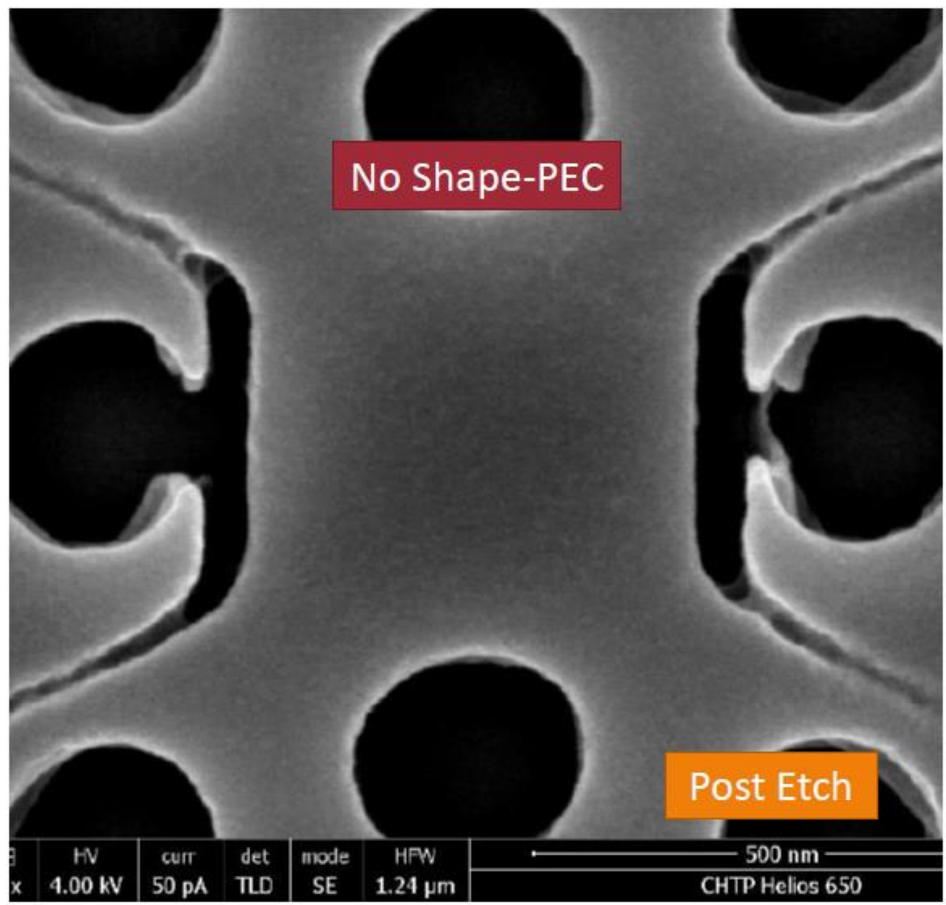
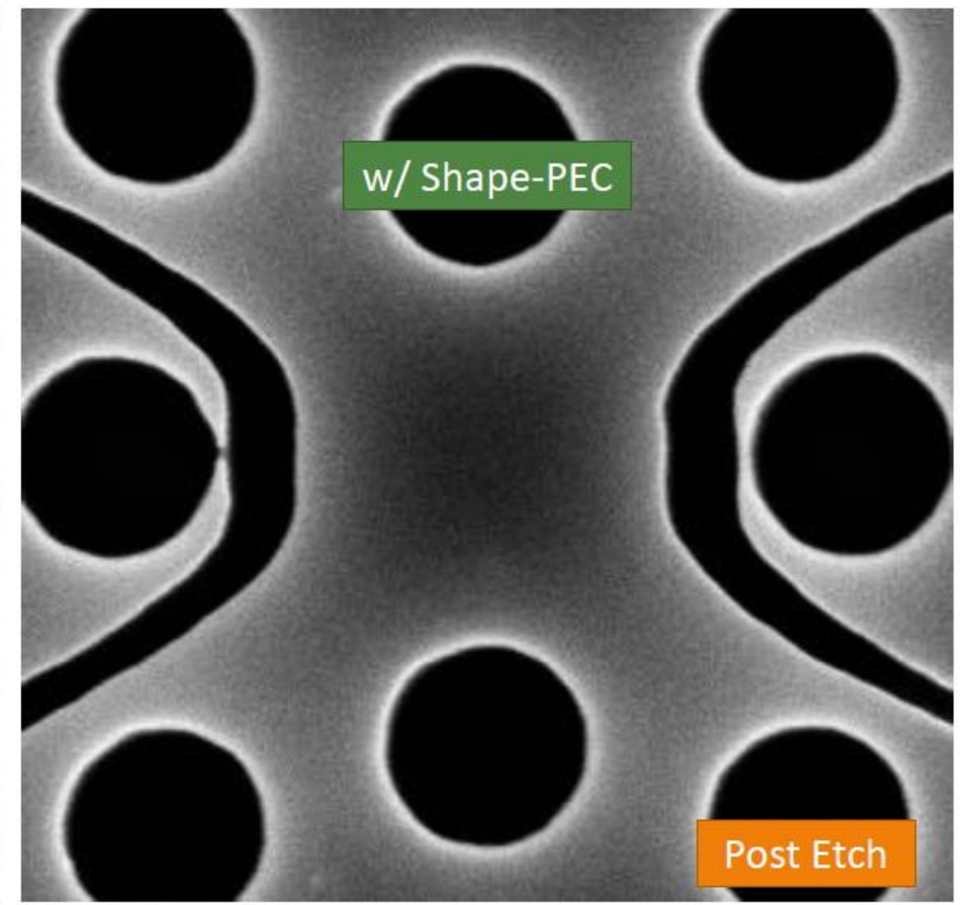
Final Photonic Device

Shape-PEC Applied





Gap: 20 nm
Trench: 30 nm

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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
+49-(0)89-3309197-61
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
+81 (0)45-532-6933
apsales@genisys-gmbh.com