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Advancing the Standard

GenISys Team
Dec 2nd, 2020

Proximity Effect in E-Beam Lithography

Overview and Agenda

Please note that this session will be recorded (may be discoverable in legal matters). By joining these webinar sessions, you automatically consent to such recordings. If you do not consent to being recorded, do not join the session.

BEAMER LAB TRACER ProSEM MASKER

Webinar Outline

Part	Subject	Date
1	Electron Scattering and Proximity Effect	07-Oct-2020, 6:00pm CEST, 12:00pm EDT, 9:00am PDT
2	Dose PEC Algorithm and Parameter	14-Oct-2020, 6:00pm CEST, 12:00pm EDT, 9:00am PDT
3	Optimization of Dose PEC Parameter	21-Oct-2020, 6:00pm CEST, 12:00pm EDT, 9:00am PDT
4	Process Effect, Calibration and Correction	28-Oct-2020, 5:00pm CET, 12:00pm EDT, 9:00am PDT
5	Shape PEC – "ODUS" Contrast Enhancement	04-Nov-2020, 6:00pm CET, 12:00pm EST, 9:00am PST
	Break	11-Nov-2020 -- No Session
6	3D Surface PEC for Grayscale Lithography	18-Nov-2020, 6:00pm CET, 12:00pm EST, 9:00am PST
	Thanksgiving Week	25-Nov-2020 -- No Session
➡ 7	3D T-Gate and Edge PEC for multilayer resist	02-Dec-2020, 6:00pm CET, 12:00pm EST, 9:00am PST

- The webinar series will explain one of the most important techniques in advanced e-beam lithography. Modern E-beam systems are able to form small spot sizes in nm range. In principle this enables to achieve feature sizes in nm-range. In practice this is limited by physics, chemistry and tool limitations…

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Doc Daugherty, Nezih Ünal

Dec 2nd, 2020

Proximity Effect in E-Beam Lithography

Part 7: 3D T-Gate and Edge PEC for multilayer resist

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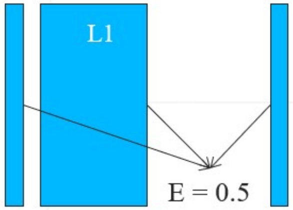
Outline

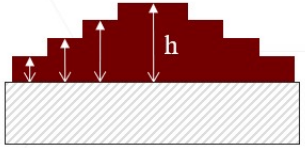
- Part 6 Summary: 3D Surface PEC for greyscale lithography
- T-Gate Introduction
- Multi-Layer Resist PEC
- Resist Profile with ODUS
- Application Example
- Summary
- Q&A

3D Grayscale - Summary

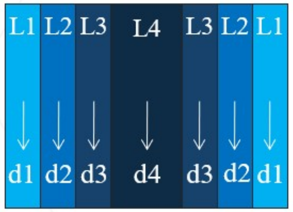
- Grayscale lithography requires
    - Adjust absorbed energy at all location
    - Consider contrast curve (development rate) for target
    - Consider proximity effect, also over z (resist thickness)
    - Consider 3D development front

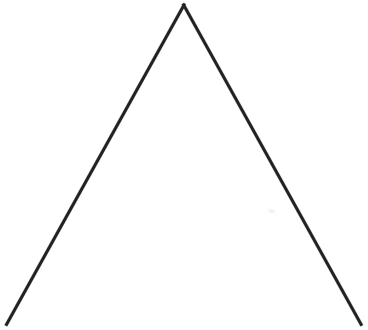
Corection Target



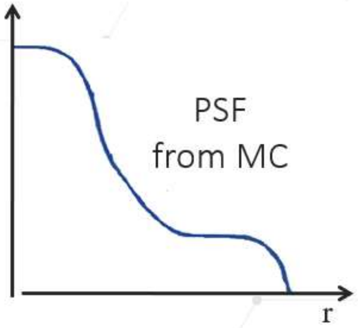


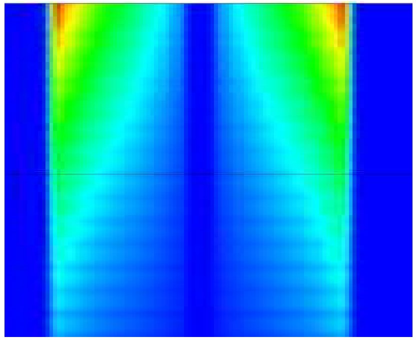
Corection Target



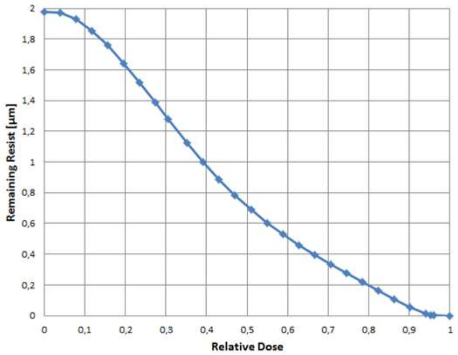


Target Shape

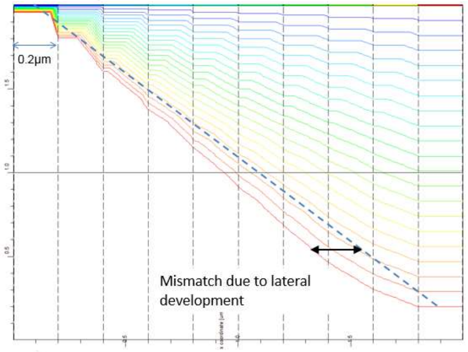




x – z Absorbed Energy



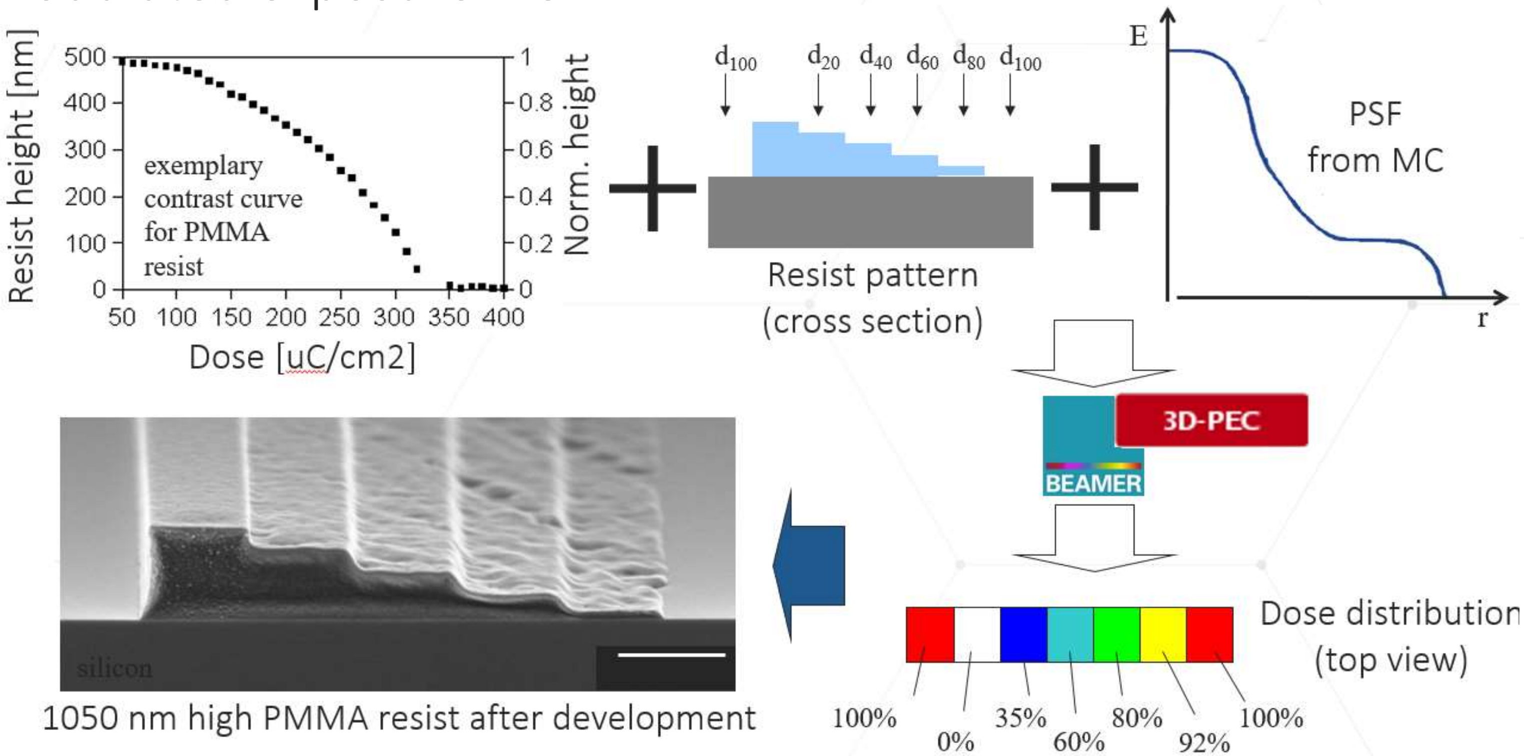
Contrast Curve



Lateral Development

E-Beam Grayscale Correction

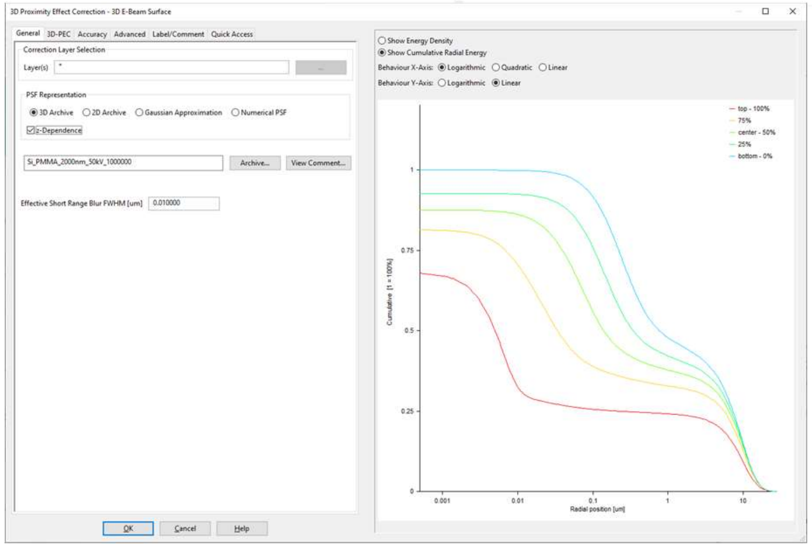
- Input: Target layout (png, stl, gds, …), resist contrast curve, MC-PSF
- Surface equalization algorithm considering the development front
- Creates dose modulated exposure file



1050 nm high PMMA resist after development

New Improvement: 3-D PSF

- So far, we have used a 2-D PSF for PEC
- But absorbed energy will vary with Z position within the resist layer, especially in thicker layers
- A new extension to 3D-PEC is the ability use a 3D-PSF



3D Proximity Effect Correction - 3D E-Beam Surface

General | 3D-PEC | Accuracy | Advanced | Label/Comment | Quick Access

Correction Layer Selection

Layer(s): *

PSF Representation

● 3D Archive ○ 2D Archive ○ Gaussian Approximation ○ Numerical PSF

☑ z-Dependence

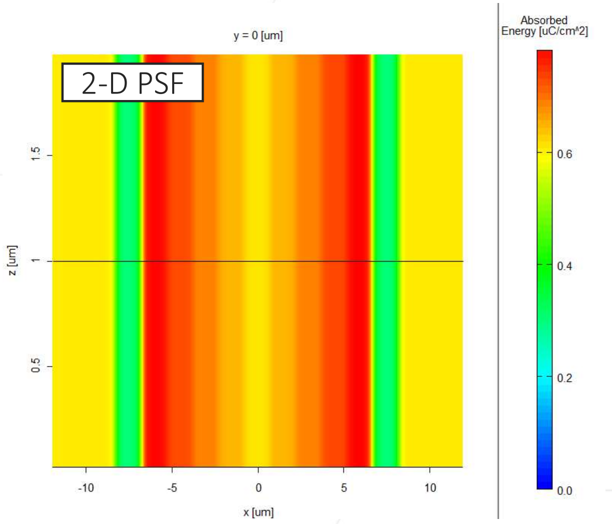
Si_PMMA_2000nm_50kV_1000000

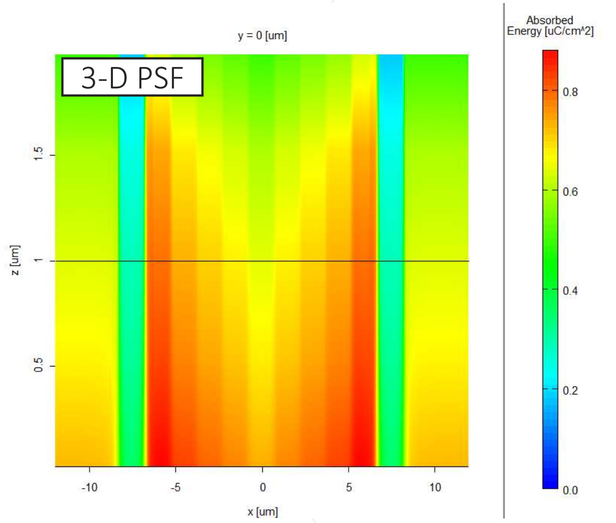
Effective Short Range Blur FWHM [um]: 0.010000

○ Show Energy Density
● Show Cumulative Radial Energy

Behaviour X-Axis: ● Logarithmic ○ Quadratic ○ Linear

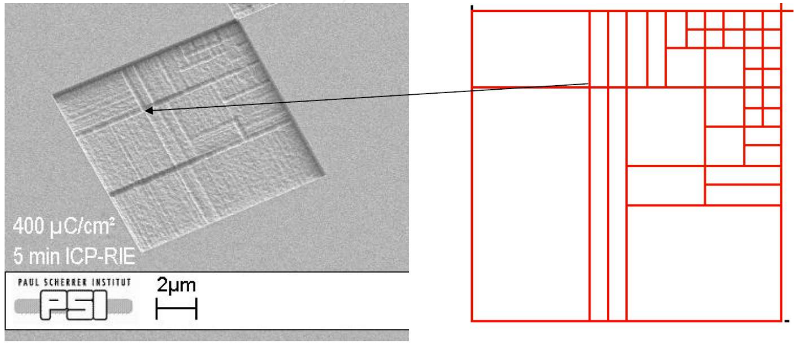
Behaviour Y-Axis: ○ Logarithmic ● Linear



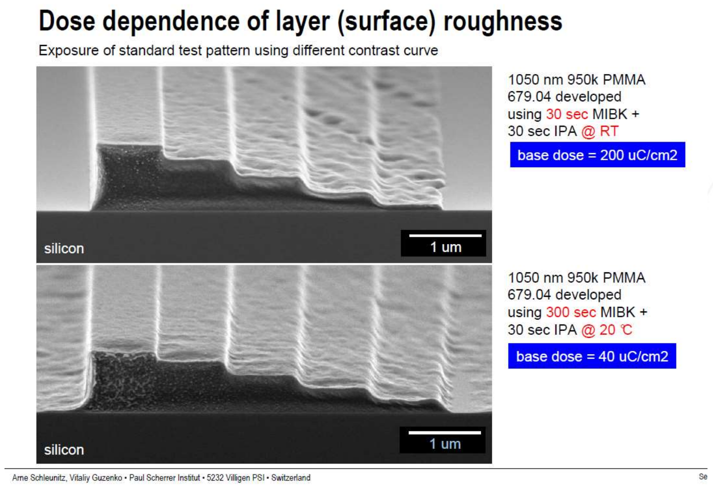


E-Beam Grayscale Exposure Issues

- Resist surfaces show roughness, holes, or bumps, often at regular spacing, indicating dosing issues at shape or sub-field borders may need:
  - Low contrast development
  - Amplified gain - allow small gaps between shots
  - Larger spots – blurs the dose
  - (dose selective) multi-pass



PSI Example, showing clear effects at fracture borders



Dose dependence of layer (surface) roughness

Exposure of standard test pattern using different contrast curve

1050 nm 950k PMMA
679.04 developed
using 30 sec MIBK +
30 sec IPA @ RT

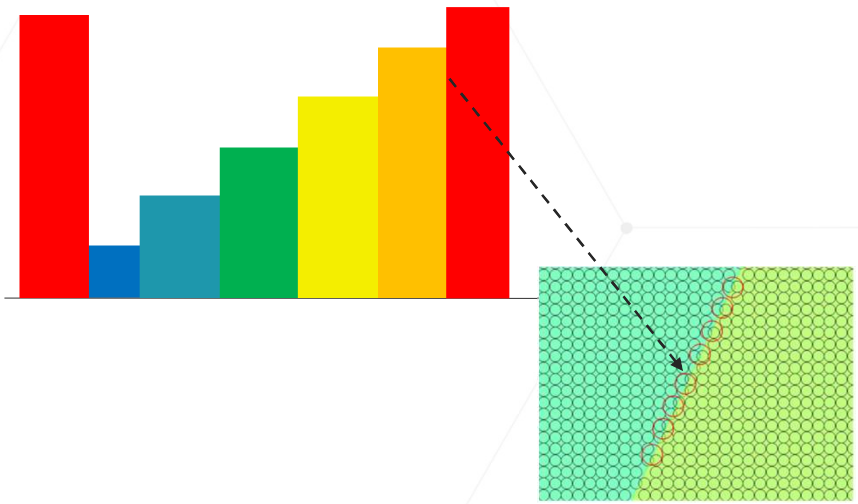
base dose = 200 uC/cm2

1050 nm 950k PMMA
679.04 developed
using 300 sec MIBK +
30 sec IPA @ 20 ℃

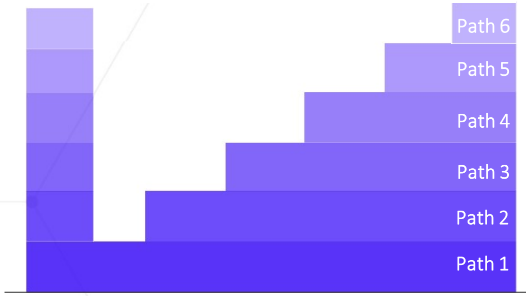
base dose = 40 uC/cm2

Arne Schleunitz, Vitaliy Guzenko • Paul Scherrer Institut • 5232 Villigen PSI • Switzerland

Desired Dose Profile



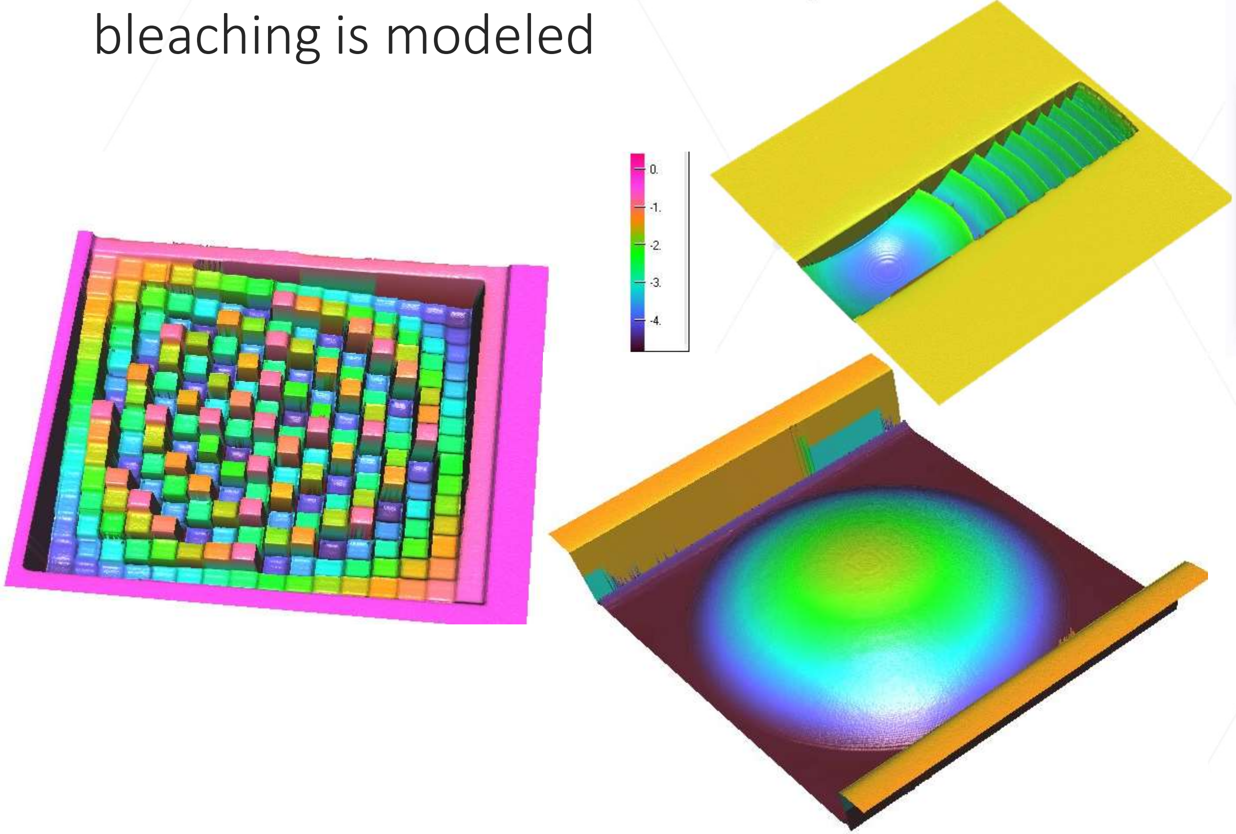
Overlap Mode Exposure Strategy

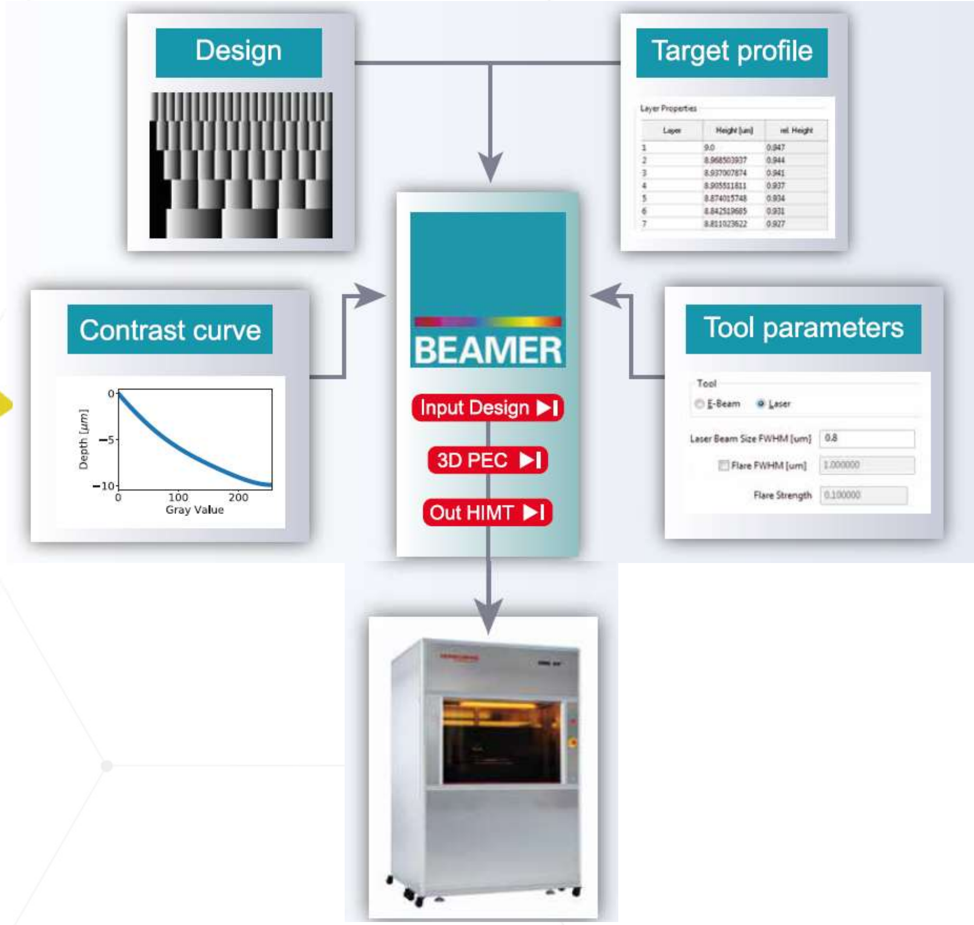


New in BEAMER v6.1

Laser Greyscale

- Optical laser model is used for intensity calculation
- Resist depth dependent absorption and bleaching is modeled





Layer Properties

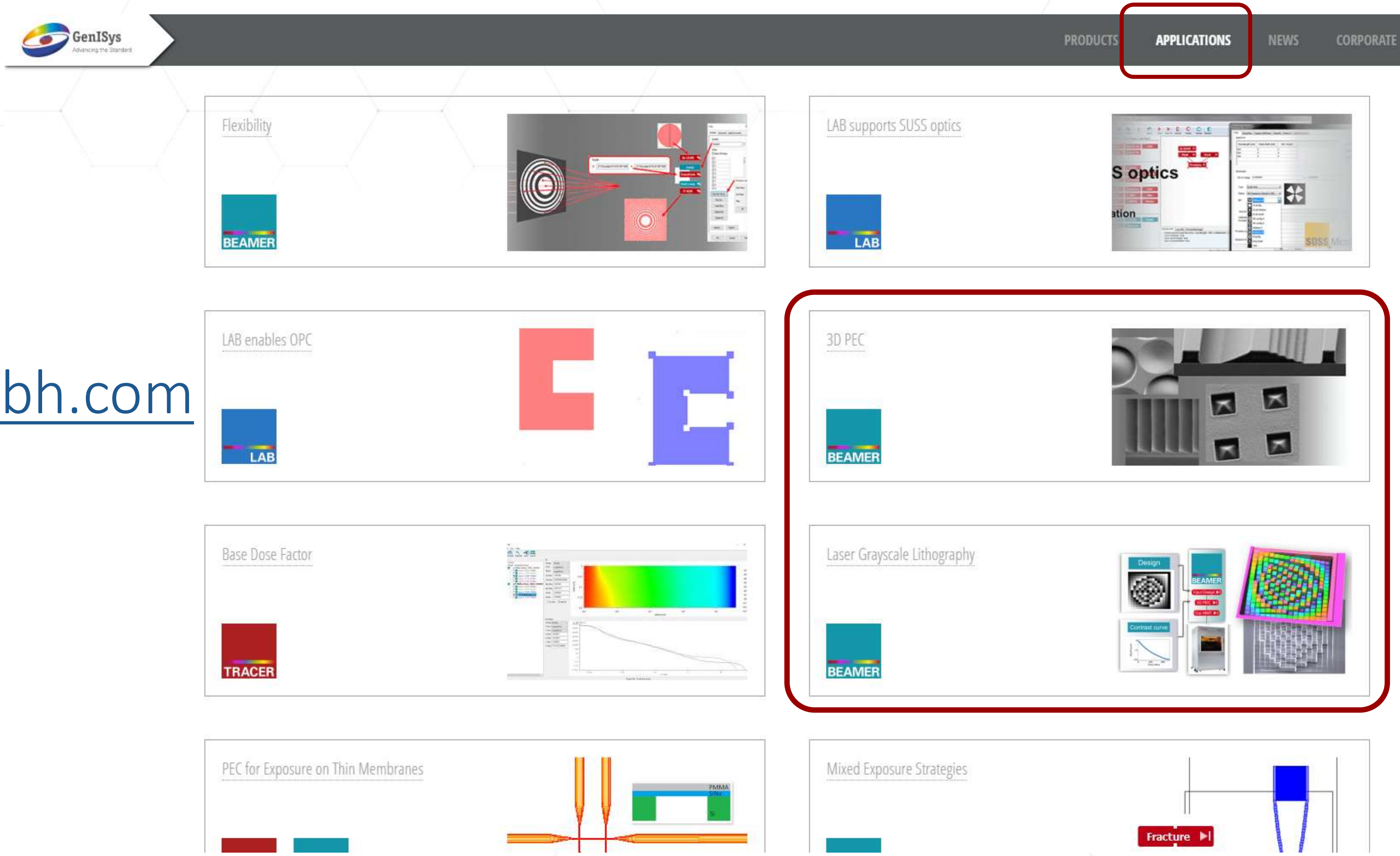
Layer	Height [um]	rel. Height
1	9.0	0.947
2	8.968503937	0.944
3	8.937007874	0.941
4	8.905511811	0.937
5	8.874015748	0.934
6	8.842519685	0.931
7	8.811023622	0.927

Tool
○ E-Beam ● Laser

Laser Beam Size FWHM [um]: 0.8
☐ Flare FWHM [um]: 1.000000
Flare Strength: 0.100000

For more information look here:

www.genisys-gmbh.com



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- Part 6 Summary: 3D Surface PEC for greyscale lithography
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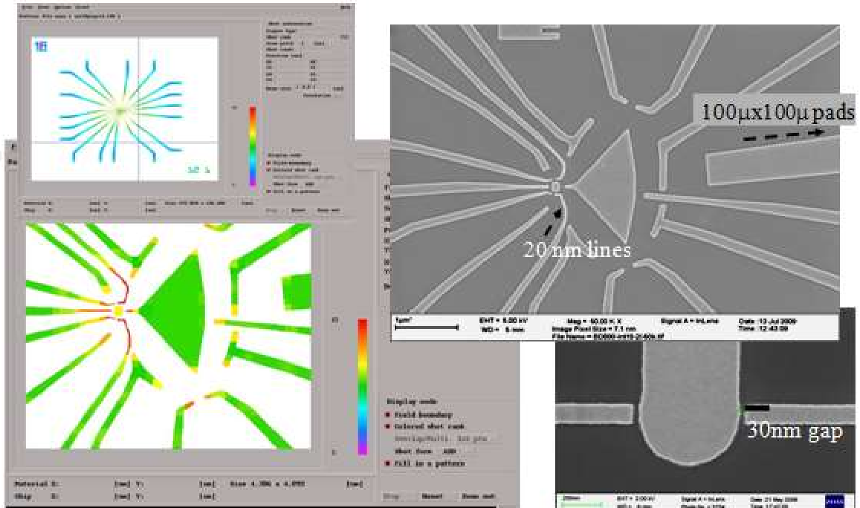
Single Layer 2D Lithography

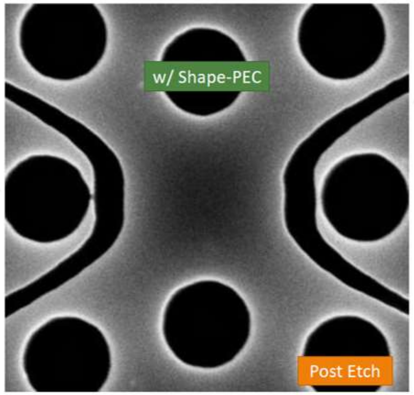
Dose PEC



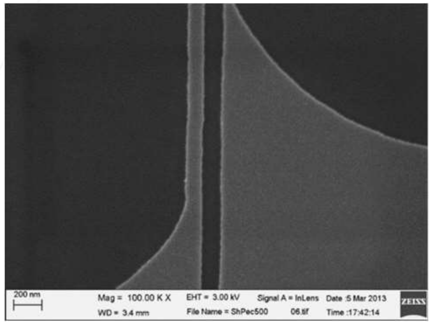
100kV Exposure on GaAs

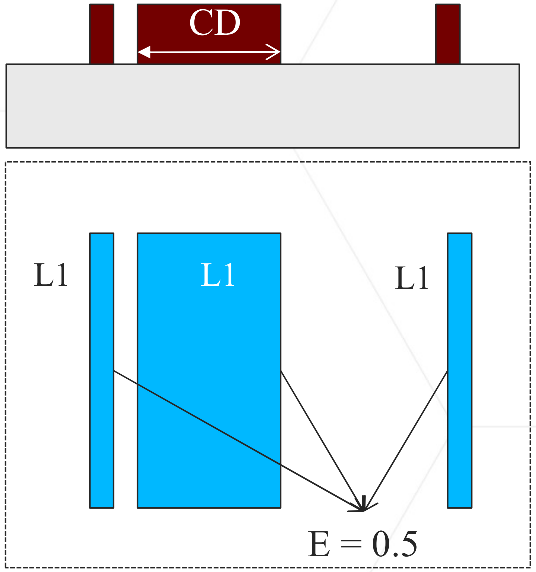
Source: Weizmann Institute

Shape PEC
ODUS



University of British Columbia



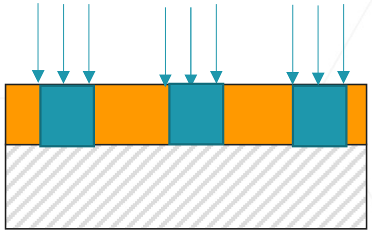


2D Correction Target:

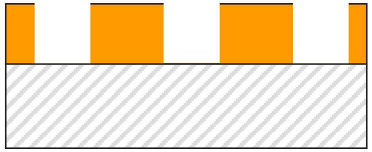
- Require absorbed energy at all feature edges to have same value (Dose to Clear)
- Consequence
  - Absorbed Energy inside features > Dose to Clear
  - Absorbed Energy outside features < Dose to Clear

Single Layer 2D Litho vs. 3D Litho

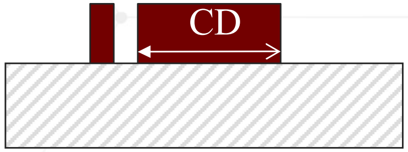
2D Litho



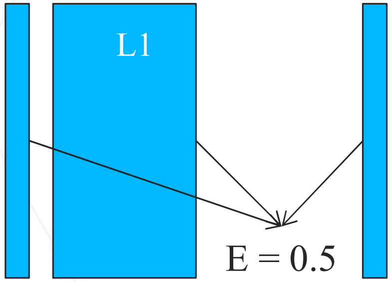
Exposure (binary)



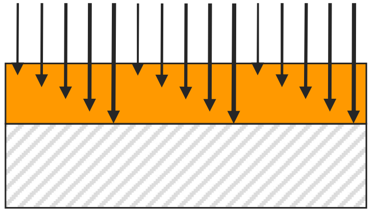
Development



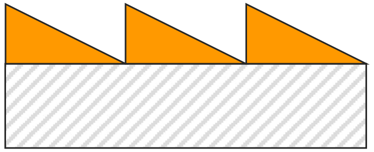
Correction Target



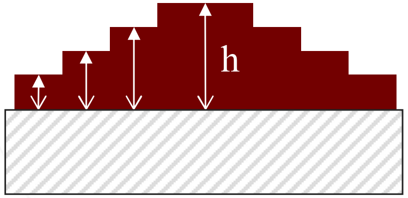
3D Litho



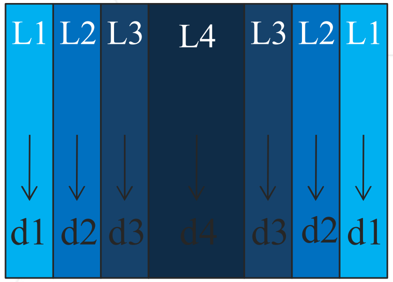
Exposure (Intensity Modulation)

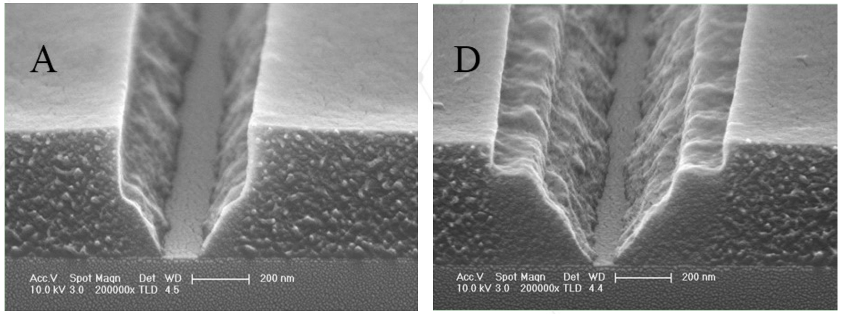


Development



Correction Target





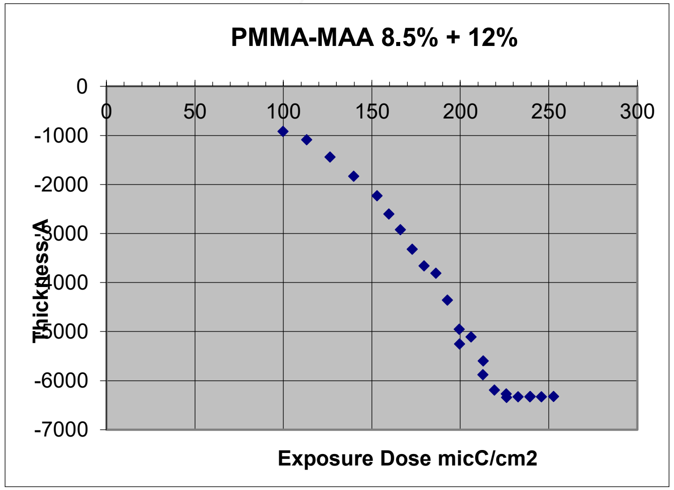
Multi Layer Resist Process

- Multiple (e.g. two) resist layer with different sensitivity are coated and exposed

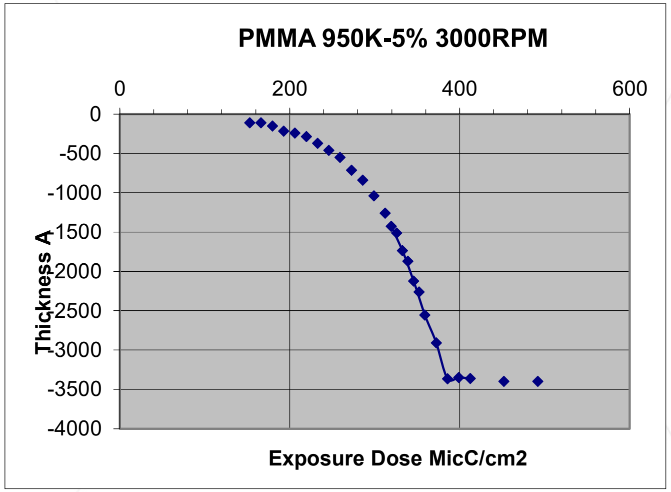

Resist 1 – PMMA
Resist 2 – MMA
Wafer


Resist 2 – MMA
Resist 1 – PMMA
Wafer

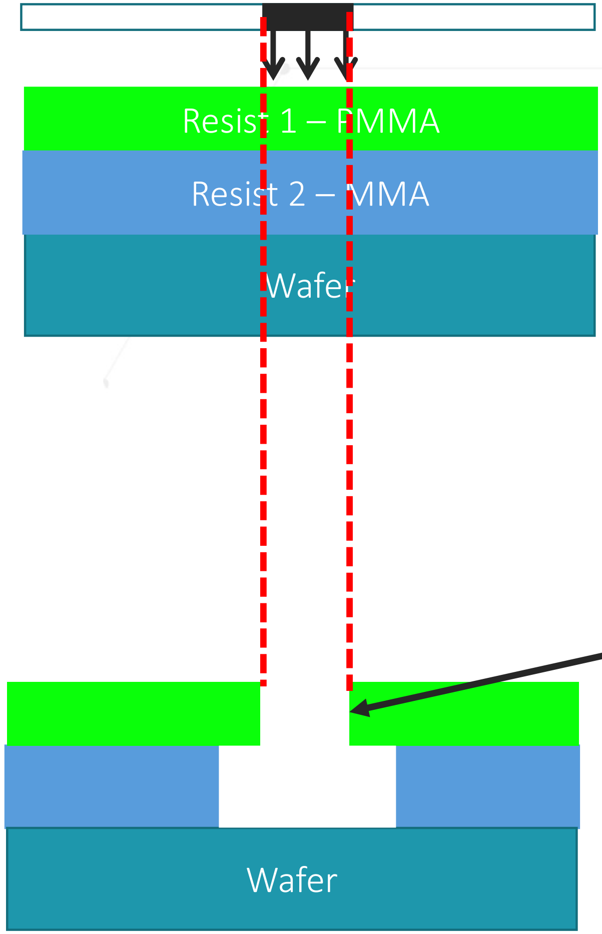
High Sensitivity



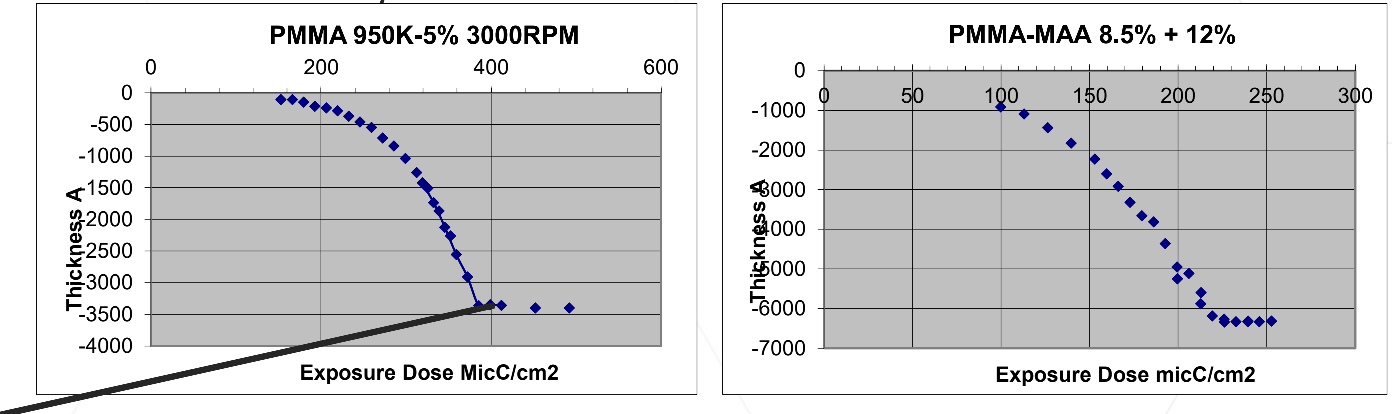
Low Sensitivity



Multi Layer Resist Process



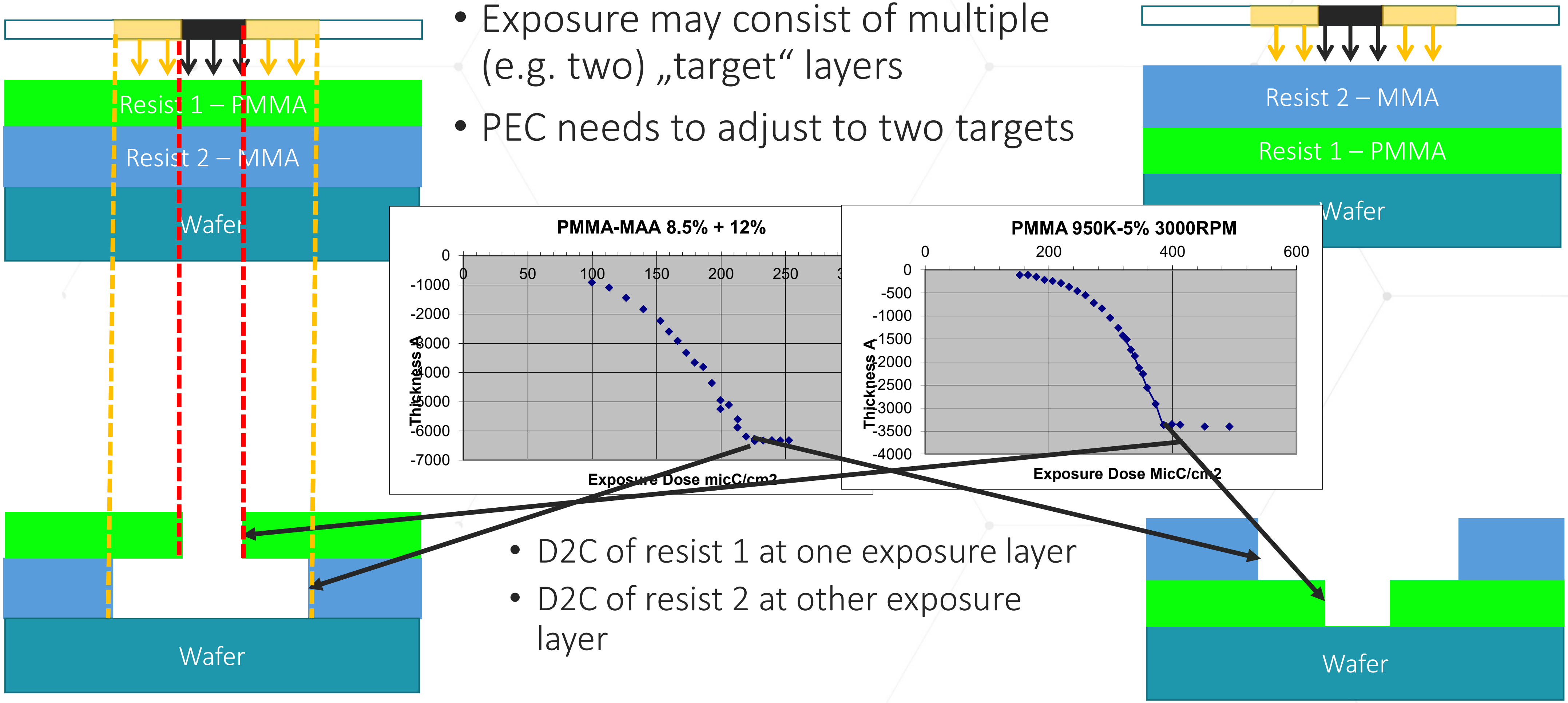
- Exposure may consist of multiple „target“ layers
- PEC adjusted to target of low sensitivity / high resolution layer



- The 2nd (high sensitivity / low resolution) layer is not controlled
  - Undercut is density dependent

Multi Layer Resist Process

- Exposure may consist of multiple (e.g. two) „target“ layers
- PEC needs to adjust to two targets



- D2C of resist 1 at one exposure layer
- D2C of resist 2 at other exposure layer

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- Multi-Layer Edge PEC
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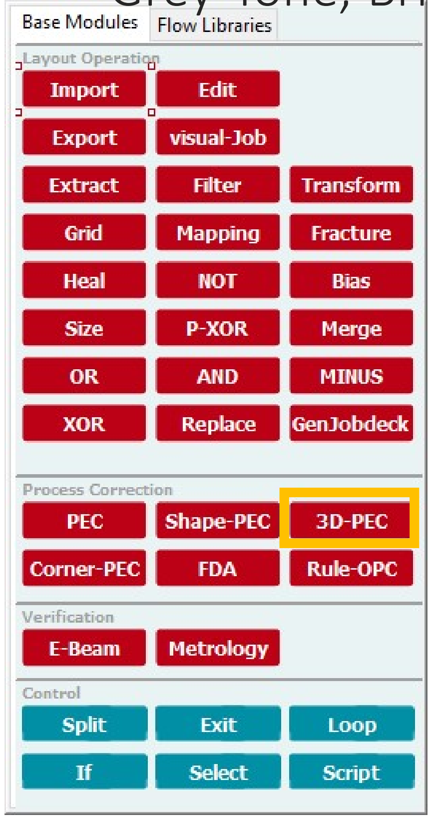
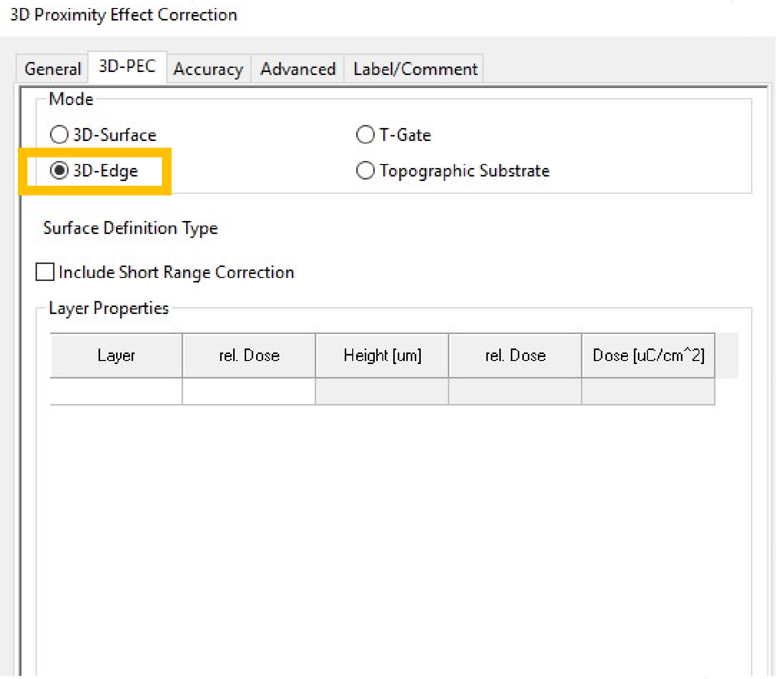
- GenISys was 1st to offer a correction for multi-layer resist processes
  - Paper at MNE 2009!
  - Grey-Tone, Bridges, T-Gate





3D Proximity Effect Correction

Mode

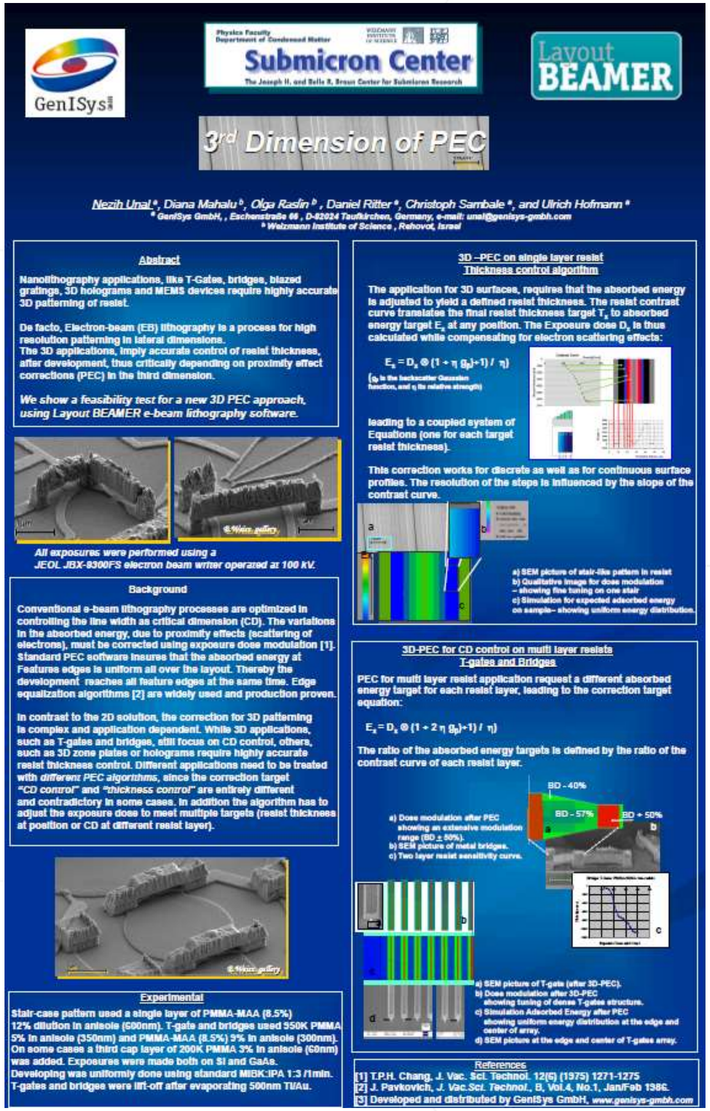
○ 3D-Surface
● 3D-Edge
○ T-Gate
○ Topographic Substrate

Surface Definition Type

☐ Include Short Range Correction

Layer Properties

Layer	rel. Dose	Height [um]	rel. Dose	Dose [uC/cm^2]



3rd Dimension of PEC

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Abstract

Nanolithography applications, like T-Gates, bridges, blazed gratings, 3D holograms and MEMS devices require highly accurate 3D patterning of resist.

De facto, Electron-beam (EB) lithography is a process for high resolution patterning in lateral dimensions.
The 3D applications, imply accurate control of resist thickness, after development, thus critically depending on proximity effect corrections (PEC) in the third dimension.

We show a feasibility test for a new 3D PEC approach, using Layout BEAMER e-beam lithography software.

All exposures were performed using a JEOL JBX-9300FS electron beam writer operated at 100 kV.

Background

Conventional e-beam lithography processes are optimized in controlling the line width as critical dimension (CD). The variations in the absorbed energy, due to proximity effects (scattering of electrons), must be corrected using exposure dose modulation [1]. Standard PEC software insures that the absorbed energy at Features edges is uniform all over the layout. Thereby the development reaches all feature edges at the same time. Edge equalization algorithms [2] are widely used and production proven.

In contrast to the 2D solution, the correction for 3D patterning is complex and application dependent. While 3D applications, such as T-gates and bridges, still focus on CD control, others, such as 3D zone plates or holograms require highly accurate resist thickness control. Different applications need to be treated with *different PEC algorithms*, since the correction target *"CD control"* and *"thickness control"* are entirely different and contradictory in some cases. In addition the algorithm has to adjust the exposure dose to meet multiple targets (resist thickness at position or CD at different resist layer).

Experimental

Stair-case pattern used a single layer of PMMA-MAA (8.5%) 12% dilution in anisole (600nm). T-gate and bridges used 950K PMMA 5% in anisole (350nm) and PMMA-MAA (8.5%) 9% in anisole (300nm). On some cases a third cap layer of 200K PMMA 3% in anisole (60nm) was added. Exposures were made both on Si and GaAs.
Developing was uniformly done using standard MIBK:IPA 1:3 /1min.
T-gates and bridges were lift-off after evaporating 500nm Ti/Au.

3D –PEC on single layer resist
Thickness control algorithm

The application for 3D surfaces, requires that the absorbed energy is adjusted to yield a defined resist thickness. The resist contrast curve translates the final resist thickness target T_x to absorbed energy target E_x at any position. The Exposure dose D_x is thus calculated while compensating for electron scattering effects:

$$E_x = D_x \otimes (1 + \eta\, g_b) + 1) / \eta)$$

(g_b is the backscatter Gaussian function, and η its relative strength)

leading to a coupled system of Equations (one for each target resist thickness).

This correction works for discrete as well as for continuous surface profiles. The resolution of the steps is influenced by the slope of the contrast curve.

a) SEM picture of stair-like pattern in resist
b) Qualitative image for dose modulation – showing fine tuning on one stair
c) Simulation for expected adsorbed energy on sample– showing uniform energy distribution.

3D-PEC for CD control on multi layer resists
T-gates and Bridges

PEC for multi layer resist application request a different absorbed energy target for each resist layer, leading to the correction target equation:

$$E_x = D_x \otimes (1 + 2\eta\, g_b) + 1) / \eta)$$

The ratio of the absorbed energy targets is defined by the ratio of the contrast curve of each resist layer.

a) Dose modulation after PEC showing an extensive modulation range (BD ± 50%).
b) SEM picture of metal bridges.
c) Two layer resist sensitivity curve.

a) SEM picture of T-gate (after 3D-PEC).
b) Dose modulation after 3D-PEC showing tuning of dense T-gates structure.
c) Simulation Adsorbed Energy after PEC showing uniform energy distribution at the edge and center of array.
d) SEM picture at the edge and center of T-gates array.

References
[1] T.P.H. Chang, J. Vac. Sci. Technol. 12(6) (1975) 1271-1275
[2] J. Pavkovich, *J. Vac.Sci. Technol.*, B, Vol.4, No.1, Jan/Feb 1986.
[3] Developed and distributed by GenISys GmbH, www.genisys-gmbh.com

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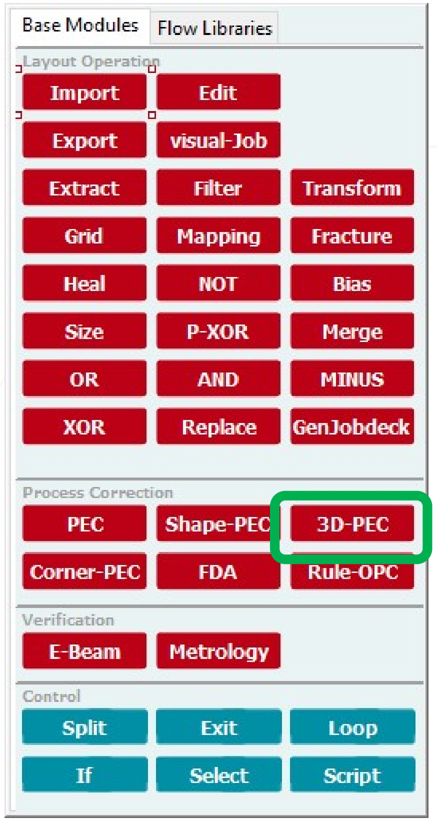
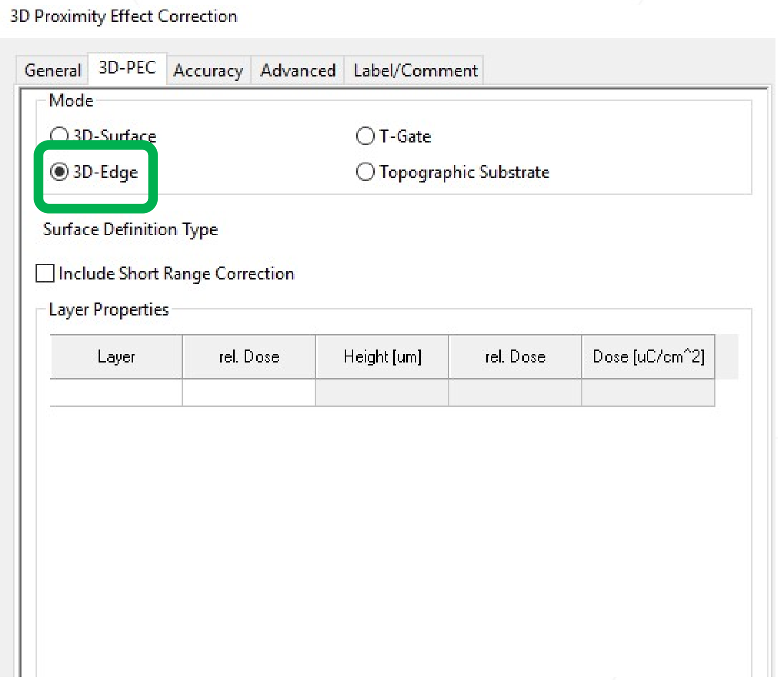
Edge PEC with multiple Target





3D Proximity Effect Correction

Mode
○ 3D-Surface
● 3D-Edge
○ T-Gate
○ Topographic Substrate

Surface Definition Type

☐ Include Short Range Correction

Layer Properties

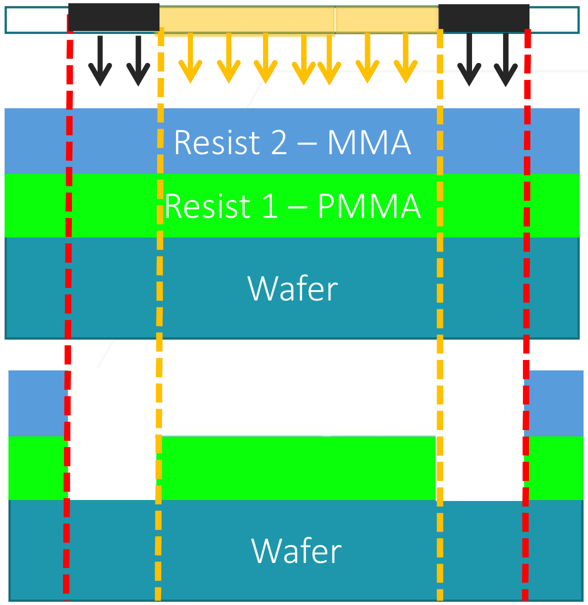
Layer	rel. Dose	Height [um]	rel. Dose	Dose [uC/cm^2]

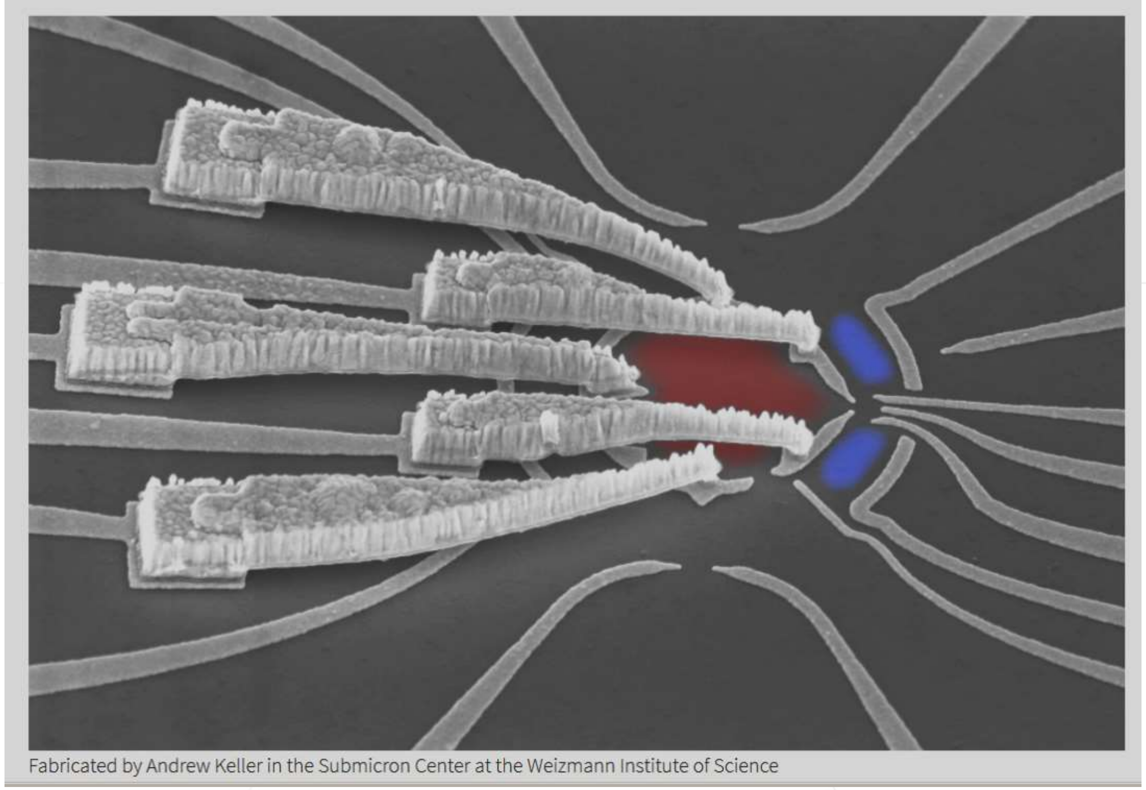
3D Edge PEC:

This mode is for multi layer resist with different sensitivity. The layer with highest dose is regarded as target layer. The PEC adjusts the exposure dose to adjust the edge of the highest dose layer to target! Useful for controlled undercut, bridges and simple T-Gate. The sensitivity ratio between resist layers defines target.

3D Edge PEC for Bridges

- The top is building a metal bridge after metalization
- The bottom layer creates the foots for interconnection



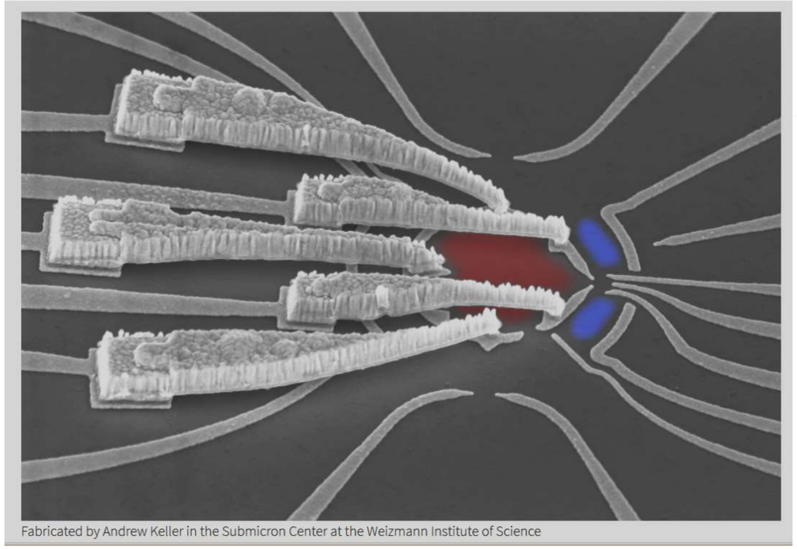


Fabricated by Andrew Keller in the Submicron Center at the Weizmann Institute of Science

A. J. Keller, L. Peeters, C. P. Moca, I. Weymann, D. Mahalu, V. Umansky, G. Zaránd & D. Goldhaber-Gordon,**"Universal Fermi liquid crossover and quantum criticality in a mesoscopic system,"** **Nature 526, 237–240 (2015)**.

3D Edge PEC for Bridges

- 3D Edge PEC is needed for
  - Compensating the electron proximity effect (using the PSF) to
    - Clear both layer at the foots
    - Clear ONLY top preserve the bottom layer at the bridge



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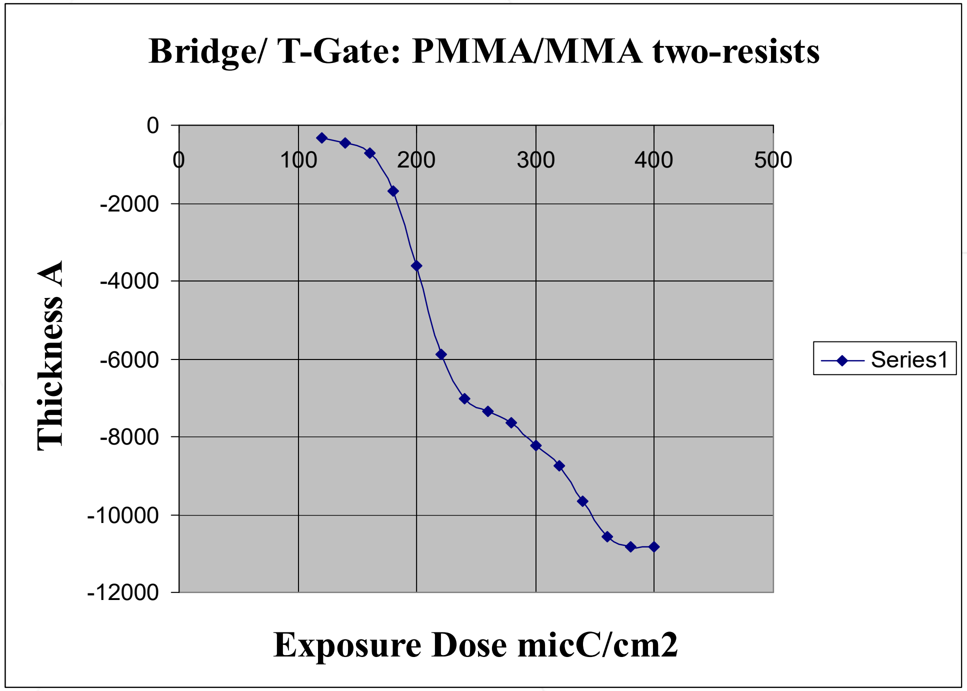
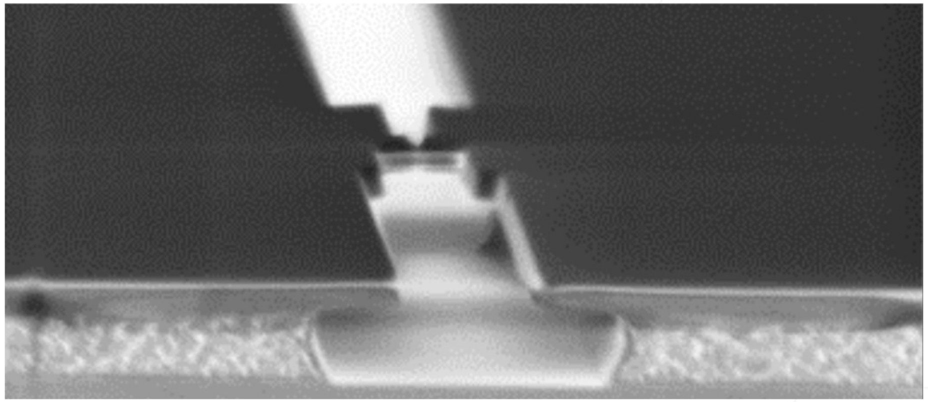
A. J. Keller, L. Peeters, C. P. Moca, I. Weymann, D. Mahalu, V. Umansky, G. Zaránd & D. Goldhaber-Gordon, "Universal Fermi liquid crossover and quantum criticality in a mesoscopic system," Nature 526, 237–240 (2015).



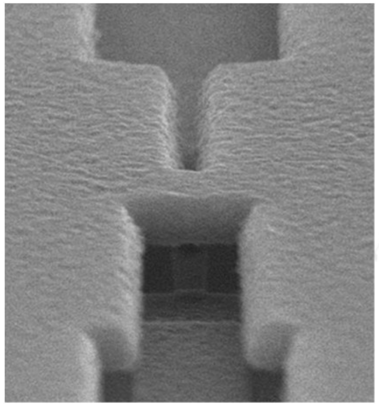
The ratio of the absorbed energy targets (for 3DEdge) is defined by the ratio of the contrast curve of each resist layer.

Application Case: Dolan Bridge

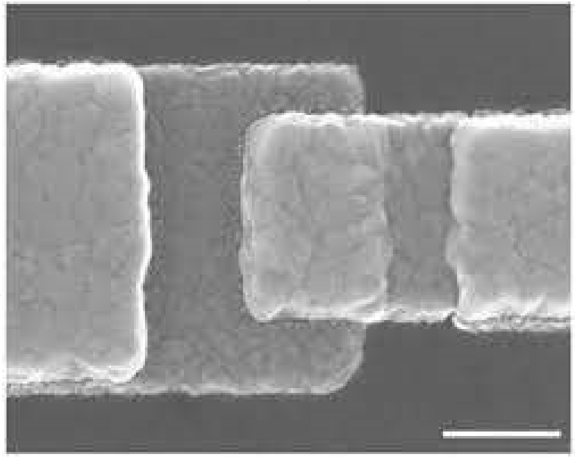
- Common task in Quantum technology is generating Josephson Junction
- This is done using multi-layer process
  - generating a „resist bridge“ (Dolan Bridge)
  - Forming the Josephson junction by shadow evaporation under an angle



After resist development

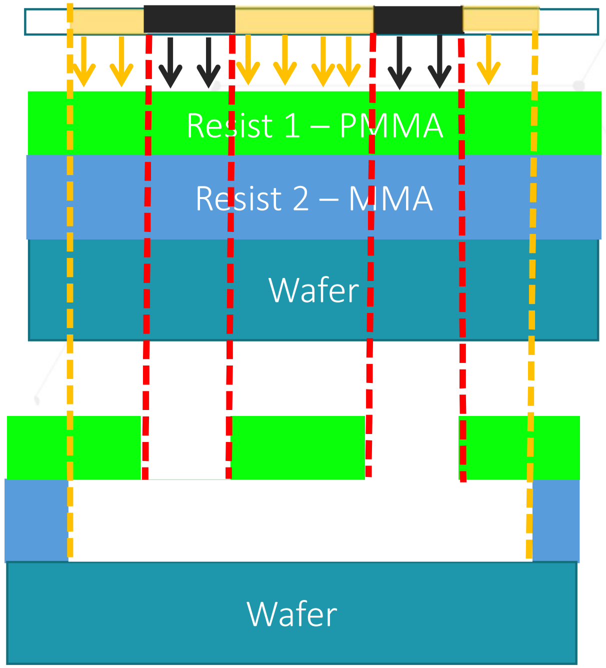


N Foroozani *et al* 2019 *Quantum Sci. Technol.* **4** 025012
In this work the Dolan bridge is generated using optical (stepper) lithography



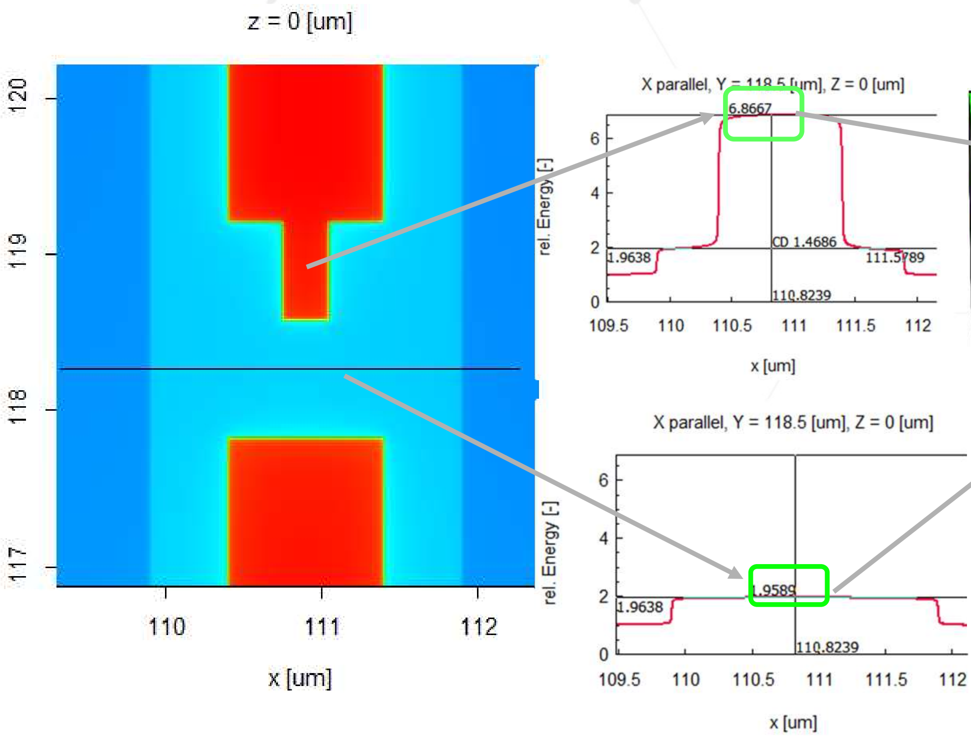
Yu-Lin Wu *et al* 2013 *Chinese Phys. B* **22** 060309

3D Edge PEC for Undercut-Control

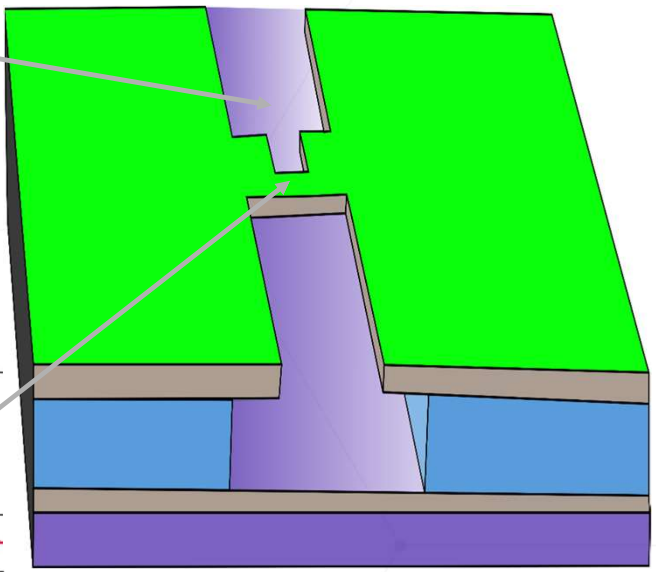


- The top layer is defining the feature dimension
- The bottom layer is defining the undercut
  - Optimized lift-off process
  - May also generate a „resist bridge“ (Dolan Bridge)

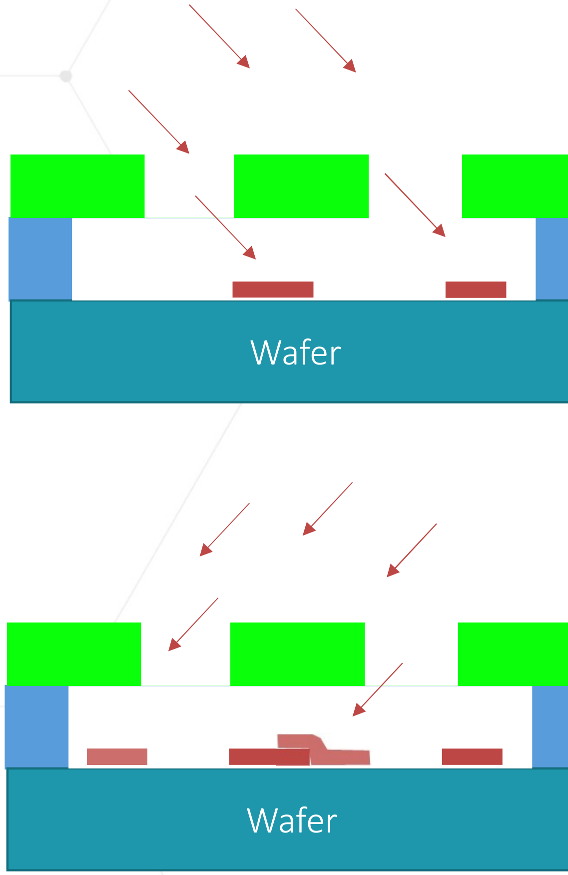
Application Case: Dolan Bridge



E-beam Simulation



After Development



Evaporation with 2 angle

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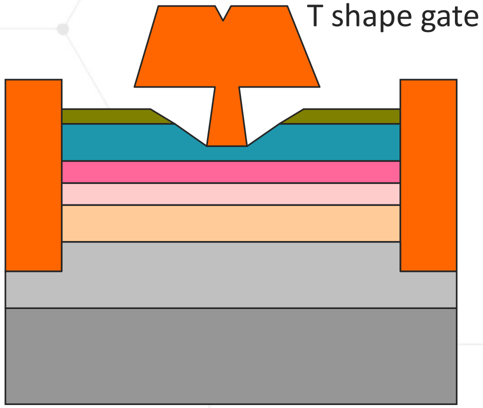
Outline

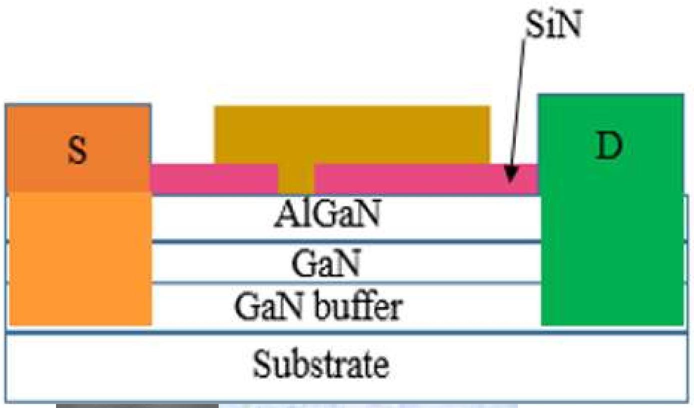
- Part 6 Summary: 3D Surface PEC for greyscale lithography
- T-Gate Introduction
- Multi-Layer Edge PEC
- T-Gate Correction
- Demo & Example
- Summary
- Q&A

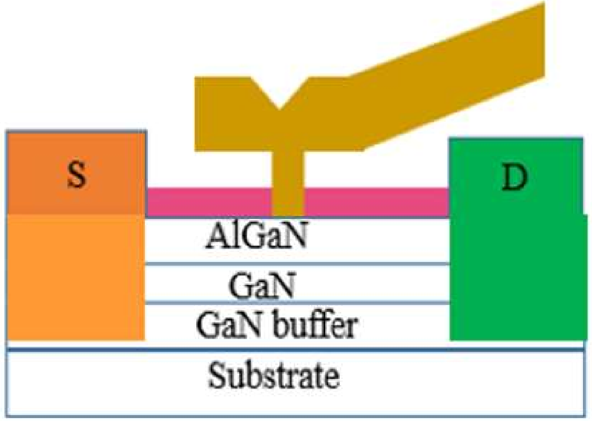
T-Gate Intro

- T-Gate is important application for e-beam
  - High speed / frequency
  - Most 3-5 sites are working on t-gates
  - Popular 3-5 are GaAs, AlGaN, InGaAs, InP (high density!)
  - Most critical is CD control of foot
  - Wing dimension less critical, but also important for device performance
  - Not standardized (like CMOS), many types (e.g. Asymmetric, stepped,...)

T shape gate:
big width head, short gate length





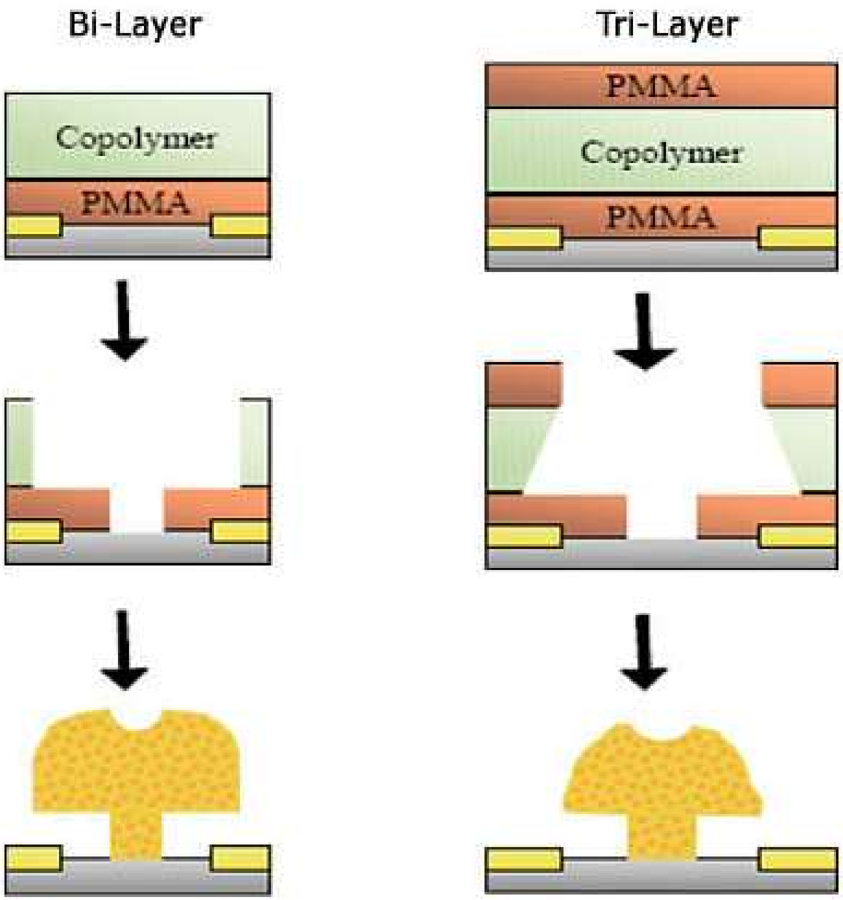


Head: increases the cross-sectional area of the gate, reducing gate resistance
Foot : reduces the gate capacitance

Device frequency increase!

T-Gate Process

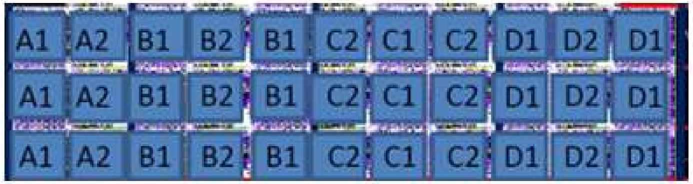
- Fabrication methods:
  - E-beam lithography
  - Optical (stepper) lithography
  - E-beam / optical lithography
- Multi Layer Process
  - Mostly based on Bi-Layer or Triple layer resist
    - PMMA / PMMA-MAA
    - PMMA / PMMA-MAA/PMMA
    - PMMA / Al / UVIII
    - PMMA / LOR / UVIII
    - ZEP / PMGI / ZEP
    - ZEP / LOR / UVIII
    - …..
  - One exposure / multi-exposure



Source: Microchem

„Traditional“ Optimization

- Run DOE varying foot and wing design size, dose modulation foot,...
  - Lot of experiments limited to one design and process



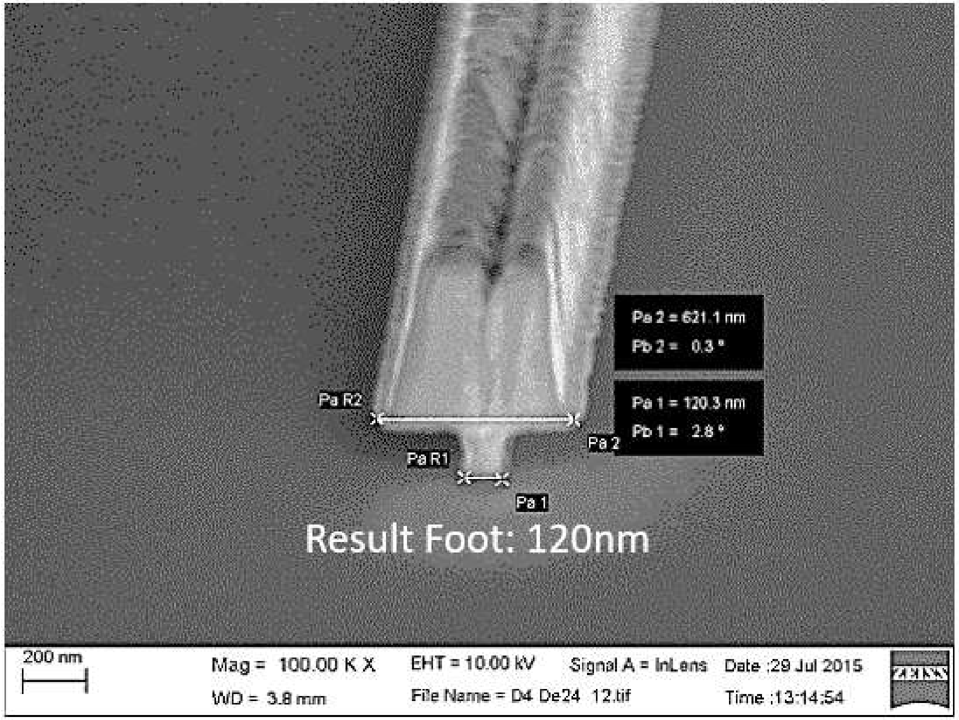
A1	A2	B1	B2	B1	C2	C1	C2	D1	D2	D1
A1	A2	B1	B2	B1	C2	C1	C2	D1	D2	D1
A1	A2	B1	B2	B1	C2	C1	C2	D1	D2	D1

Foot Design in nm: 18,24,30
Wings Total in nm: 456; 504; 552

BD arbitrary chosen at 800micC/cm2

Dose modulations FOOT:
BD+ 115%; BD+130%; BD+145%;BD+160%

Wings dose: BD-50%



Result Foot: 120nm

Designed CD foot = 24nm
Result for D4/ CD foot = 120nm

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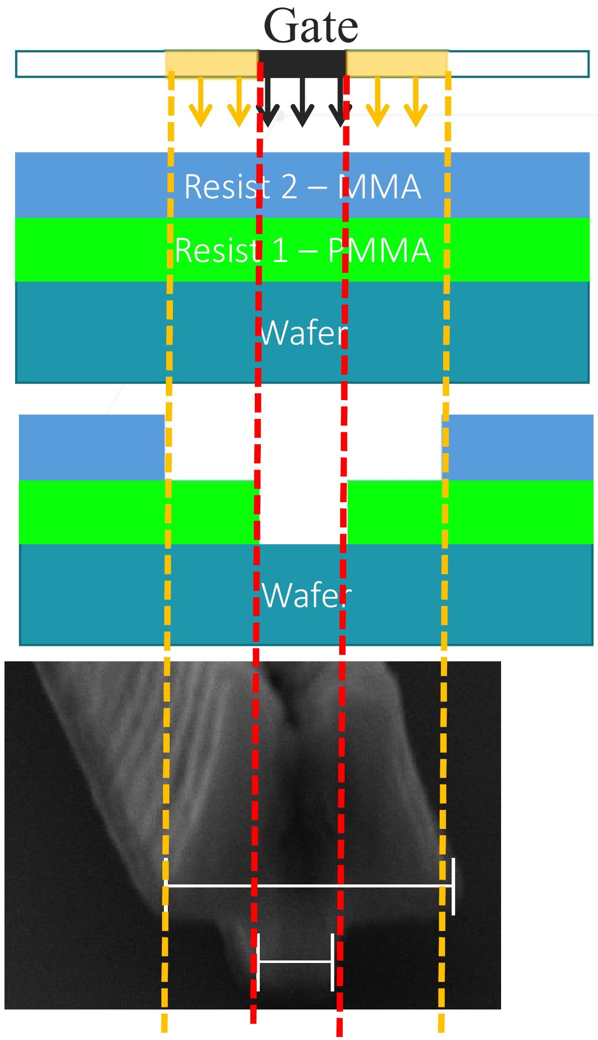
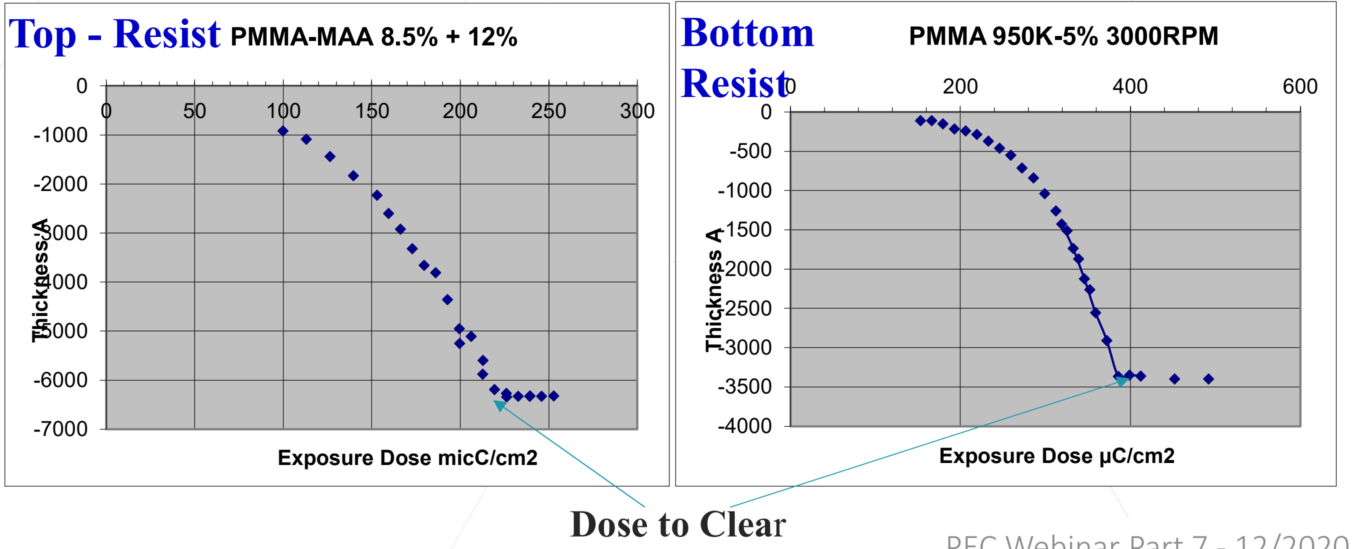
Multi Layer T-Gate Process



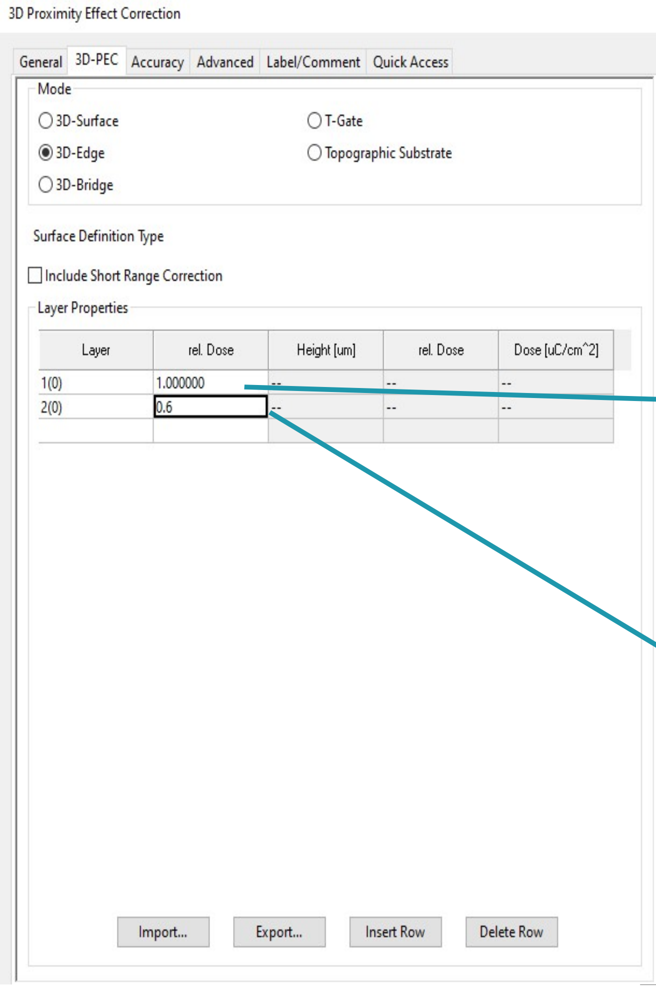
- Multiple (e.g. two) resist layer with different sensitivity are coated and exposed
- Gate is exposed at high dose to clear both layers, wing is exposed to clear only top layer, but not bottom layer
- Need to adjust not only one CD, but both CDs (where the gate is more critical CD)


Top - Resist PMMA-MAA 8.5% + 12%

Bottom Resist PMMA 950K-5% 3000RPM

Dose to Clear

T-Gate using 3D Edge PEC



3D Proximity Effect Correction

Mode

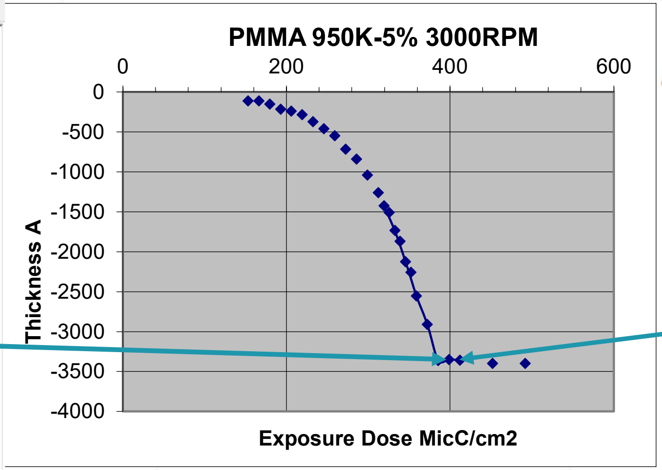
○ 3D-Surface
● 3D-Edge
○ 3D-Bridge
○ T-Gate
○ Topographic Substrate

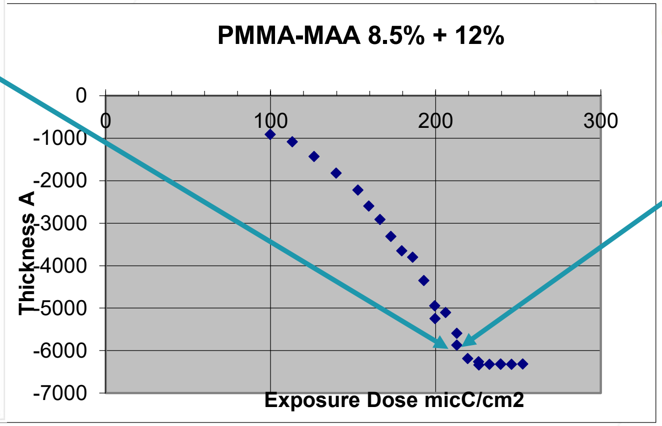
Surface Definition Type

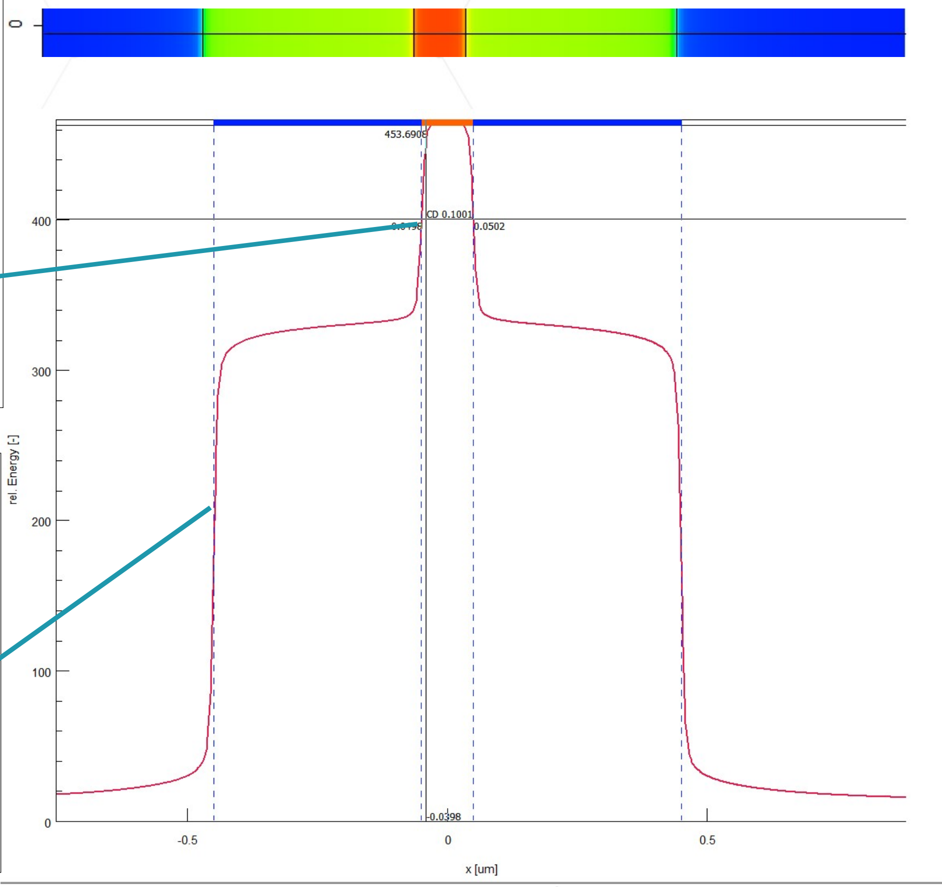
☐ Include Short Range Correction

Layer Properties

Layer	rel. Dose	Height [um]	rel. Dose	Dose [uC/cm^2]
1(0)	1.000000	--	--	--
2(0)	0.6	--	--	--

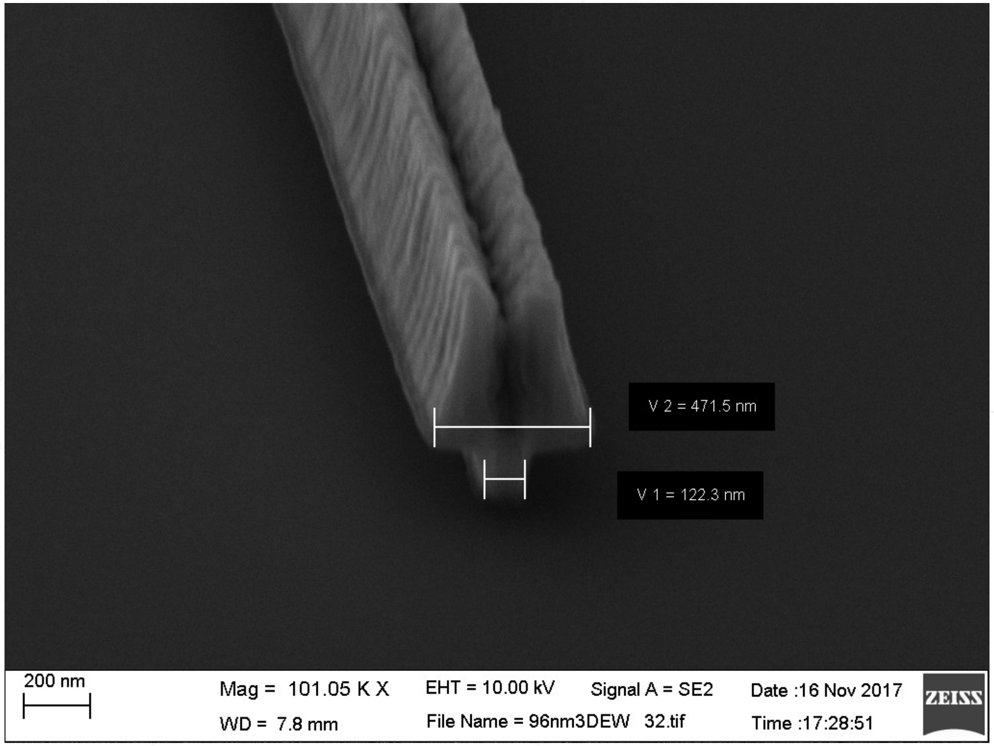






Gate is often oversized

- Design 84 nm results in >> 100nm
- Lower base dose gives residues
- Gate already too large when cleared!



Oversize > 30nm

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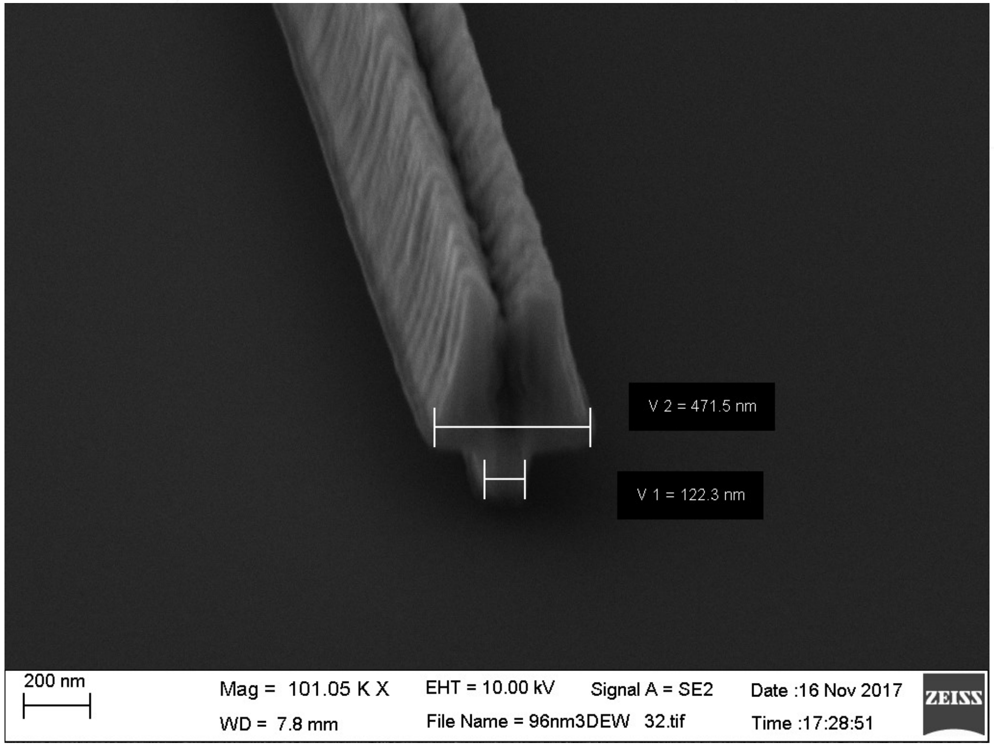
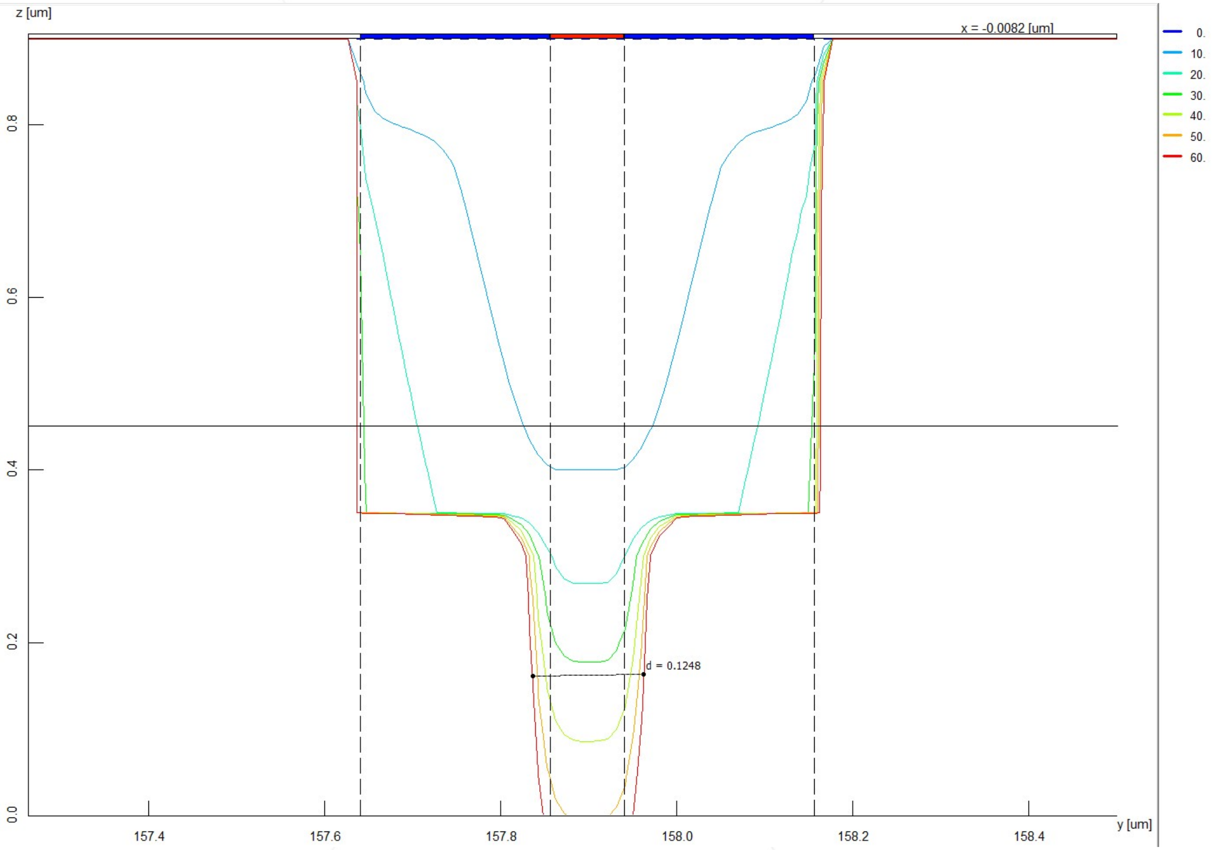
Root Cause of Oversize





Oversize > 30nm due to lateral development

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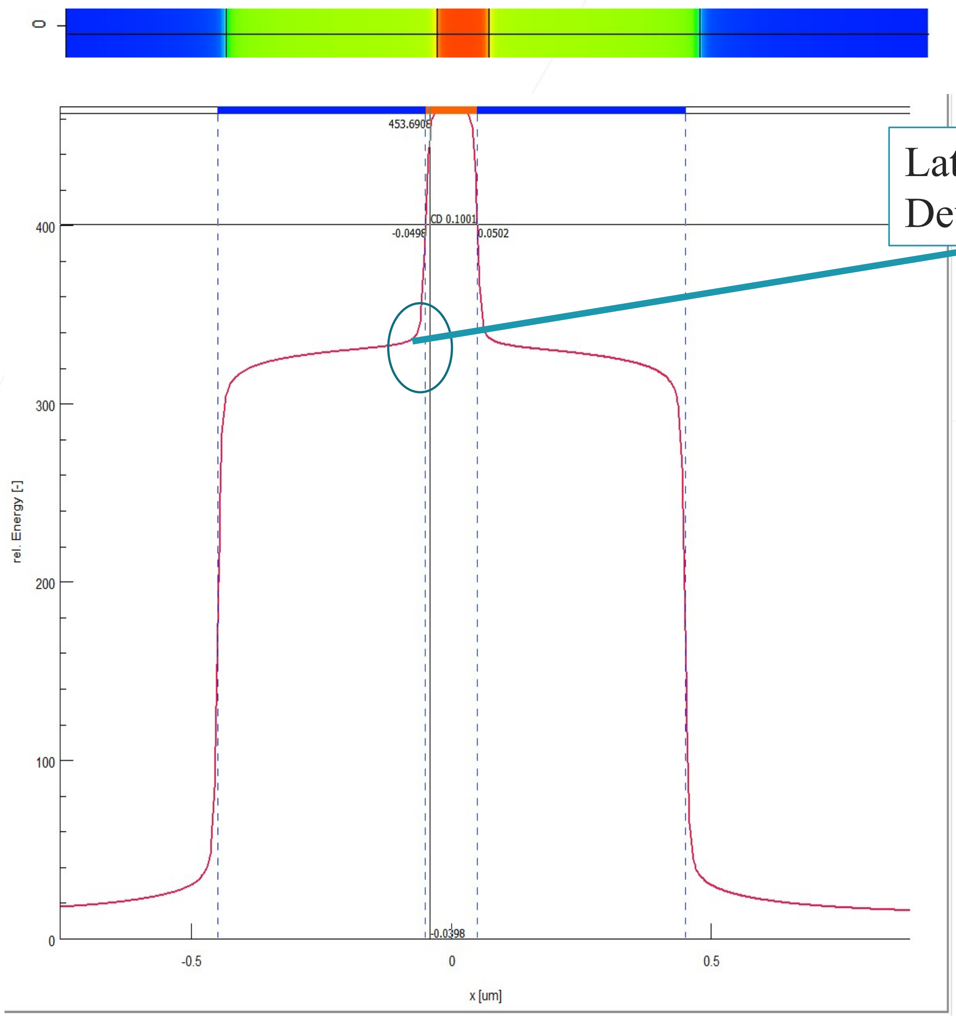
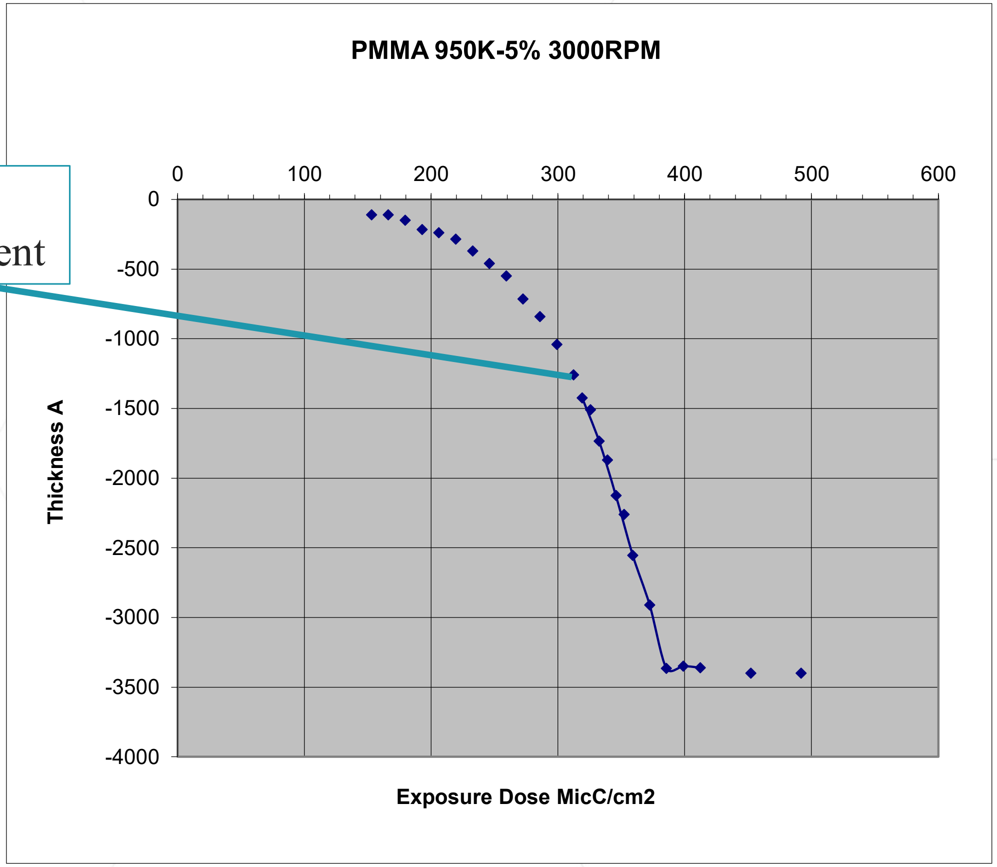
Root Cause of Oversize



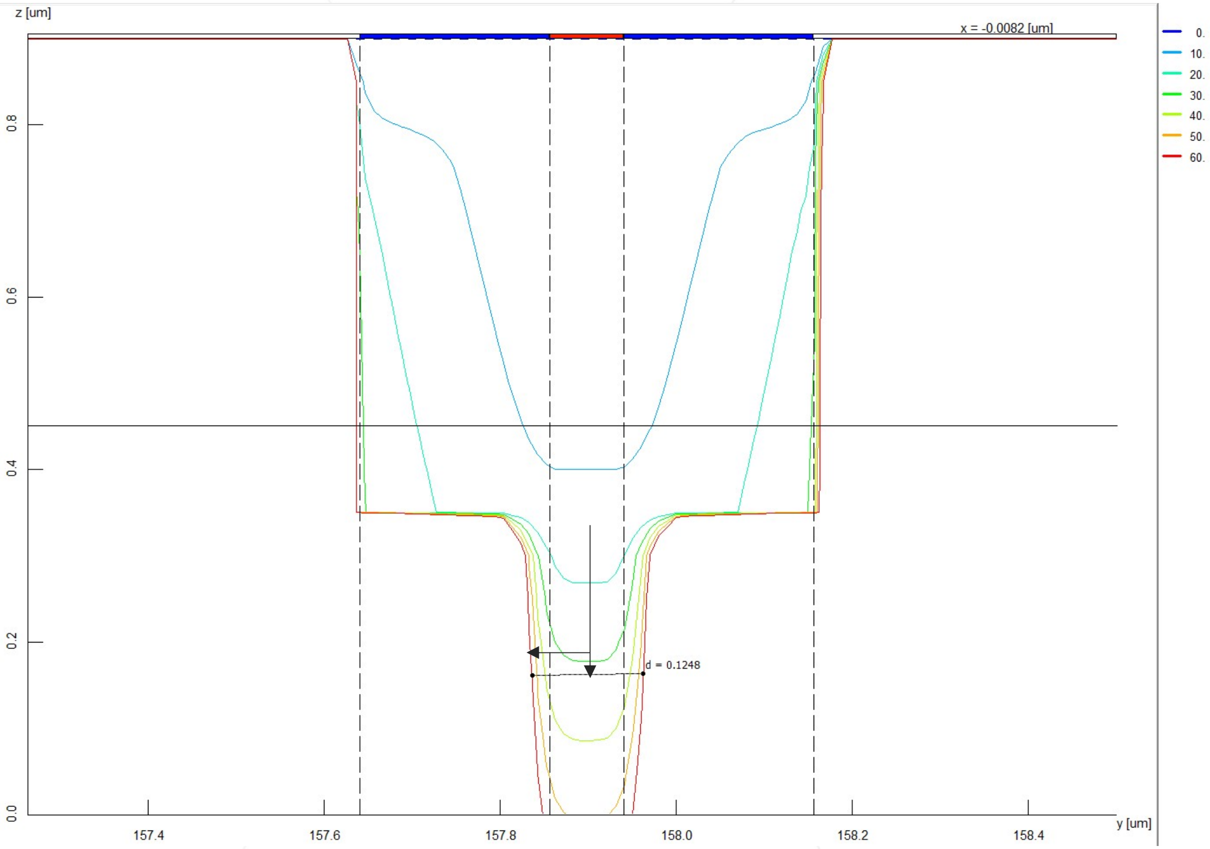
Lateral Development



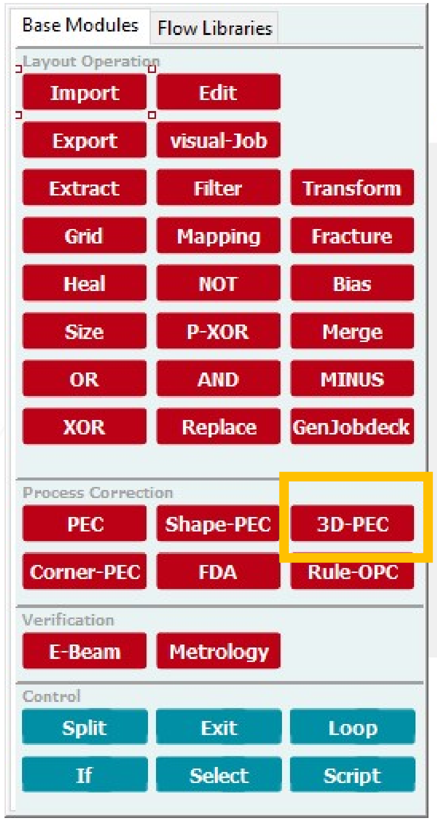
Lateral Bias

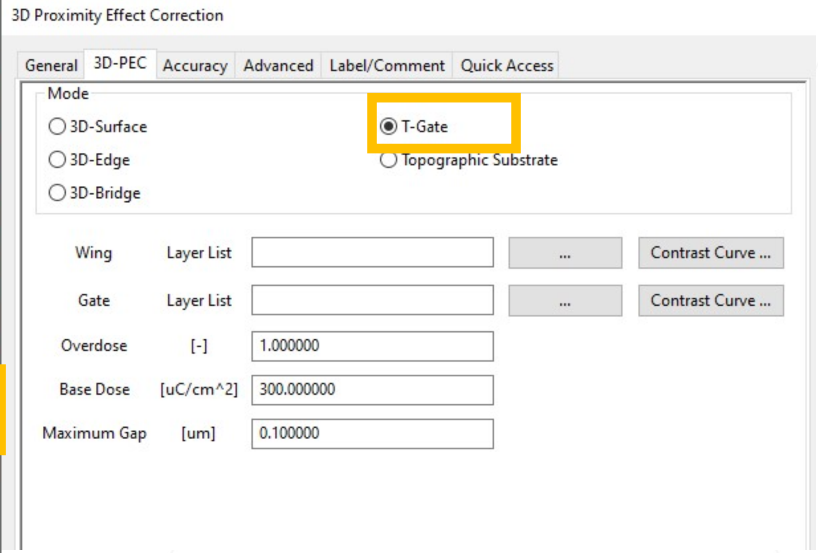
- Development front moves not only down, but also to the side
- The development to the side is dependent on background energy and blur
- The lateral development bias needs to be considered

➢ Dedicated T-Gate - PEC



T-Gate PEC with gate & wing layer





3D Proximity Effect Correction

Mode
○ 3D-Surface
● T-Gate
○ 3D-Edge
○ Topographic Substrate
○ 3D-Bridge

Wing Layer List
Gate Layer List
Overdose [-] 1.000000
Base Dose [uC/cm^2] 300.000000
Maximum Gap [um] 0.100000

3D T-Gate PEC:

This mode is optimized for double-layer T-Gate process. It considers the full resist contrast curves of both resists, models and corrects lateral development bias, and enables contrast enhancement by ODUS of gate.

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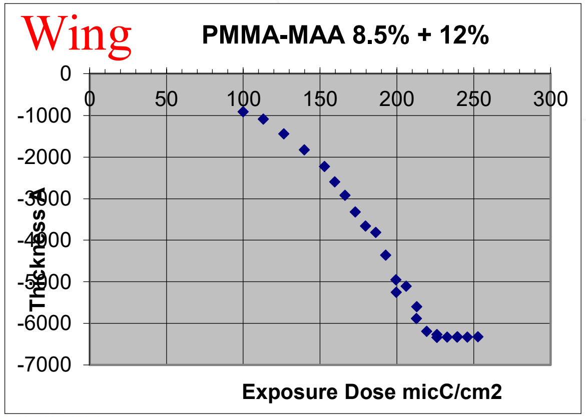
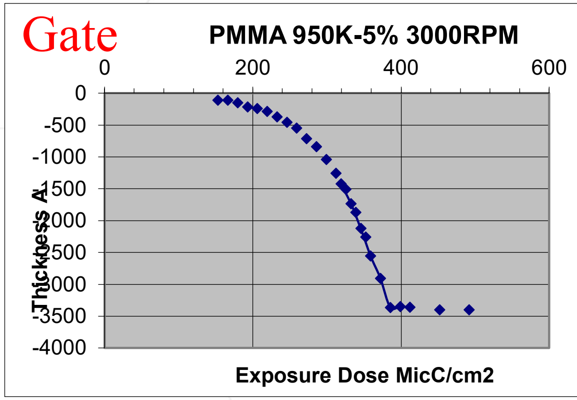
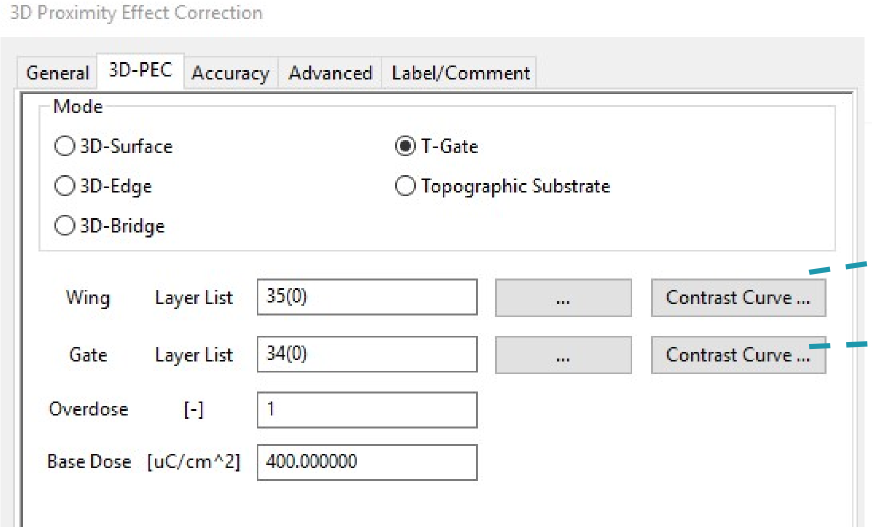
T-Gate PEC **with resist development**

The correct edge placement is assured in a complementary step by simulating the lateral development. For this purpose the T-Gate mode now requires contrast curves in order to enable the simulation.

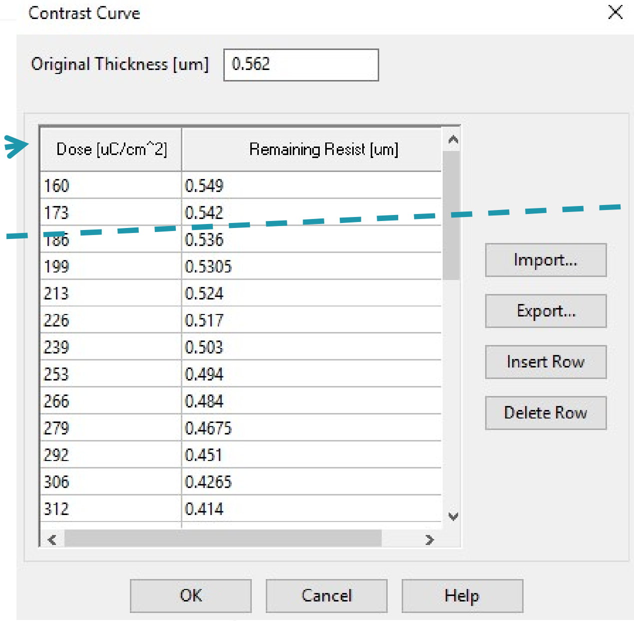






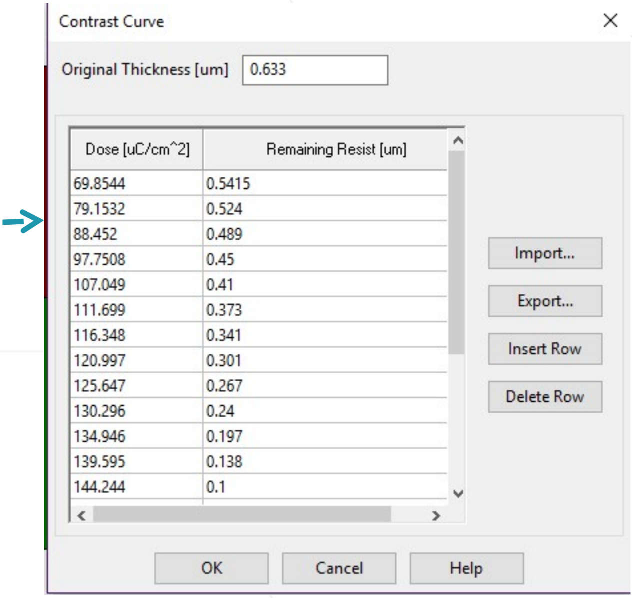
Mode
○ 3D-Surface ● T-Gate
○ 3D-Edge ○ Topographic Substrate
○ 3D-Bridge

Wing Layer List: 35(0)
Gate Layer List: 34(0)
Overdose [-]: 1
Base Dose [uC/cm^2]: 400.000000



Original Thickness [um]: 0.562

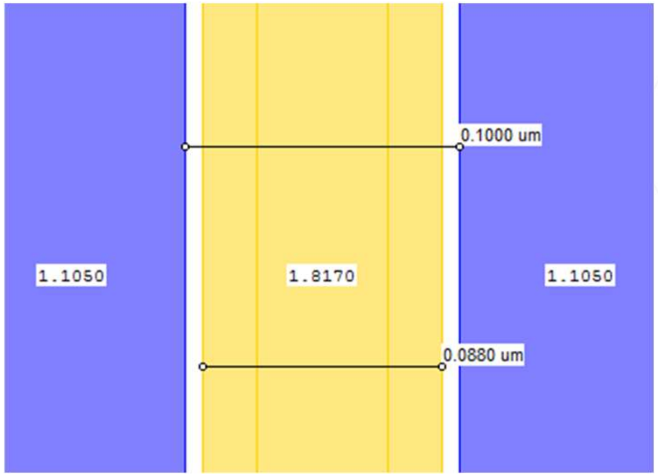
Dose [uC/cm^2]	Remaining Resist [um]
160	0.549
173	0.542
186	0.536
199	0.5305
213	0.524
226	0.517
239	0.503
253	0.494
266	0.484
279	0.4675
292	0.451
306	0.4265
312	0.414



Original Thickness [um]: 0.633

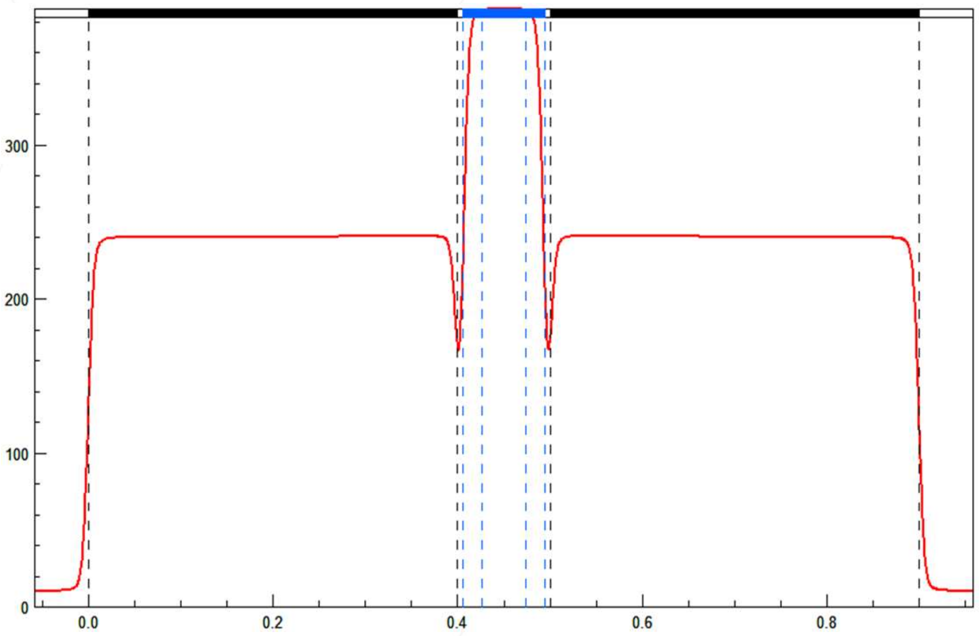
Dose [uC/cm^2]	Remaining Resist [um]
69.8544	0.5415
79.1532	0.524
88.452	0.489
97.7508	0.45
107.049	0.41
111.699	0.373
116.348	0.341
120.997	0.301
125.647	0.267
130.296	0.24
134.946	0.197
139.595	0.138
144.244	0.1

Compensation of lateral development



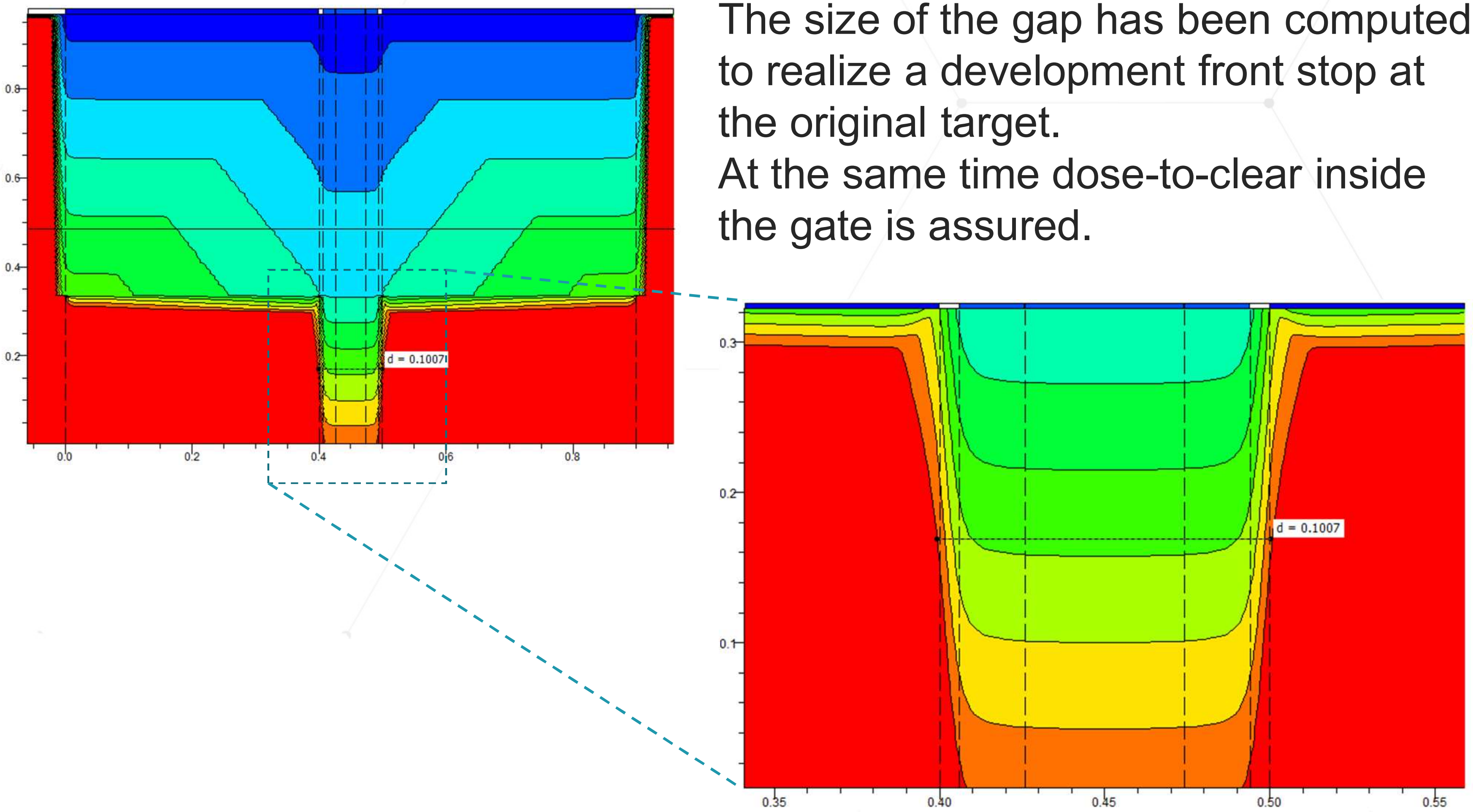
Bias applied to gate level in order to compensate for lateral development.

The introduced gap significantly reduces the dev. rate at the gate edge.



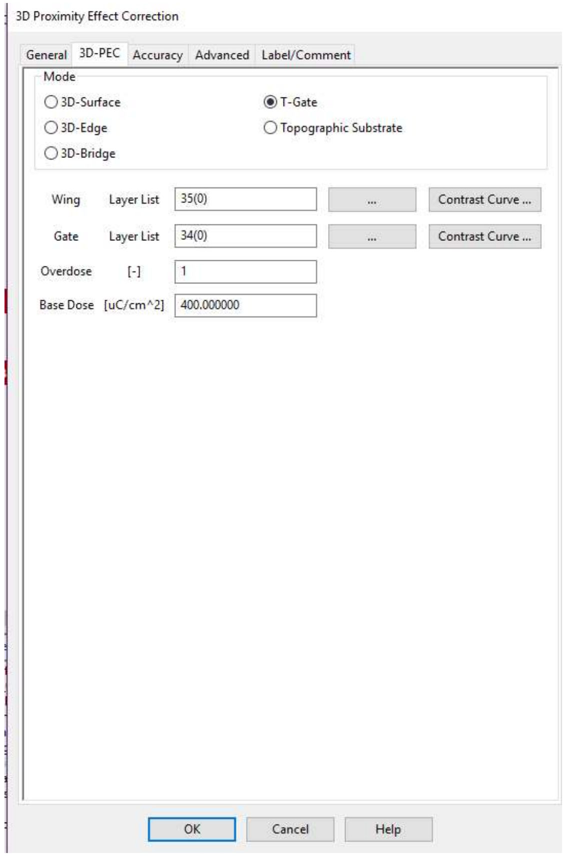
Simulation PEC incl. Lat. dev.

The size of the gap has been computed to realize a development front stop at the original target.
At the same time dose-to-clear inside the gate is assured.



T-Gate Correction

- Without Overdose, 36nm blur (from Tracer calibration!)



3D Proximity Effect Correction

Mode

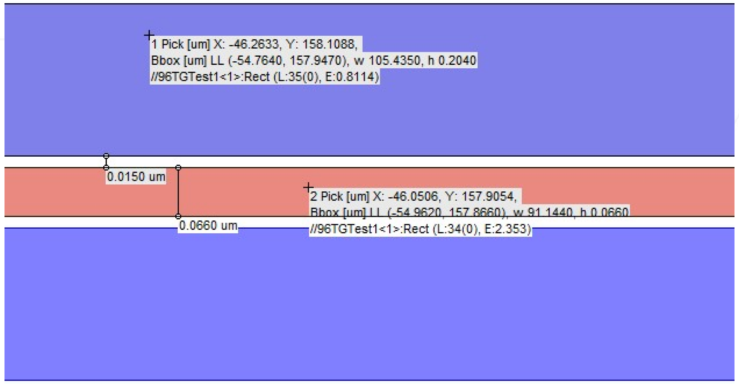
○ 3D-Surface
● T-Gate
○ 3D-Edge
○ Topographic Substrate
○ 3D-Bridge

Wing Layer List: 35(0)

Gate Layer List: 34(0)

Overdose [-]: 1

Base Dose [uC/cm^2]: 400.000000

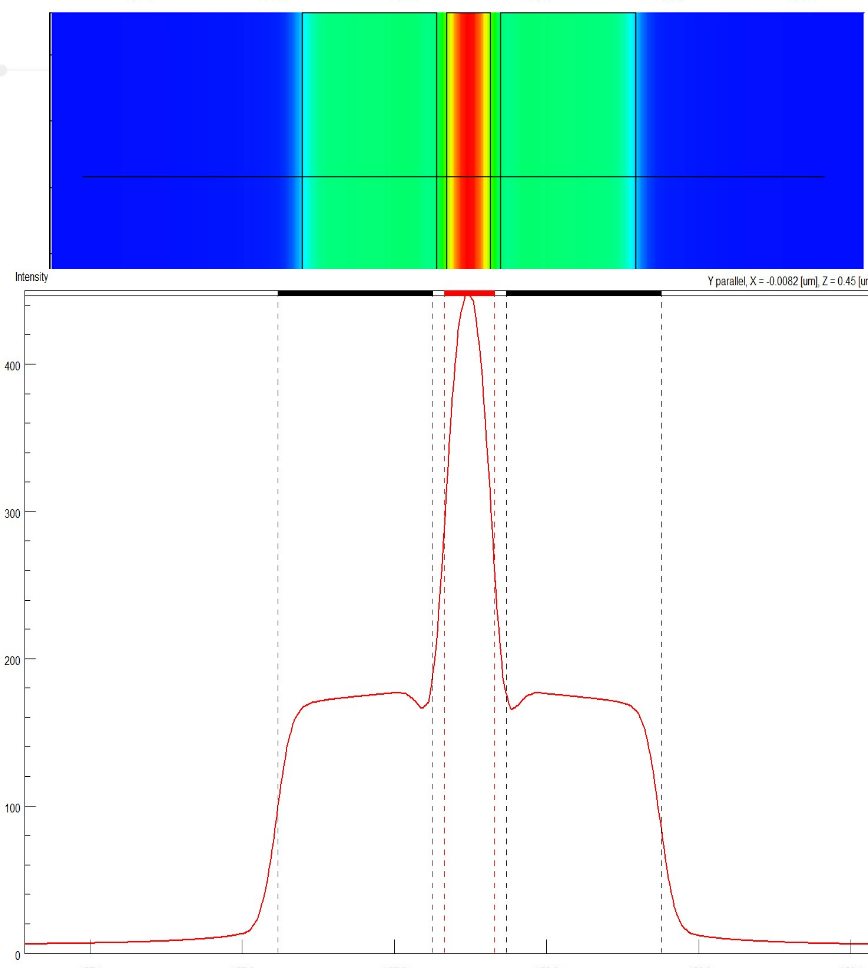


1 Pick [um] X: -46.2633, Y: 158.1088,
Bbox [um] LL (-54.7640, 157.9470), w 105.4350, h 0.2040
//96TGTest1<1>:Rect (L:35(0), E:0.8114)

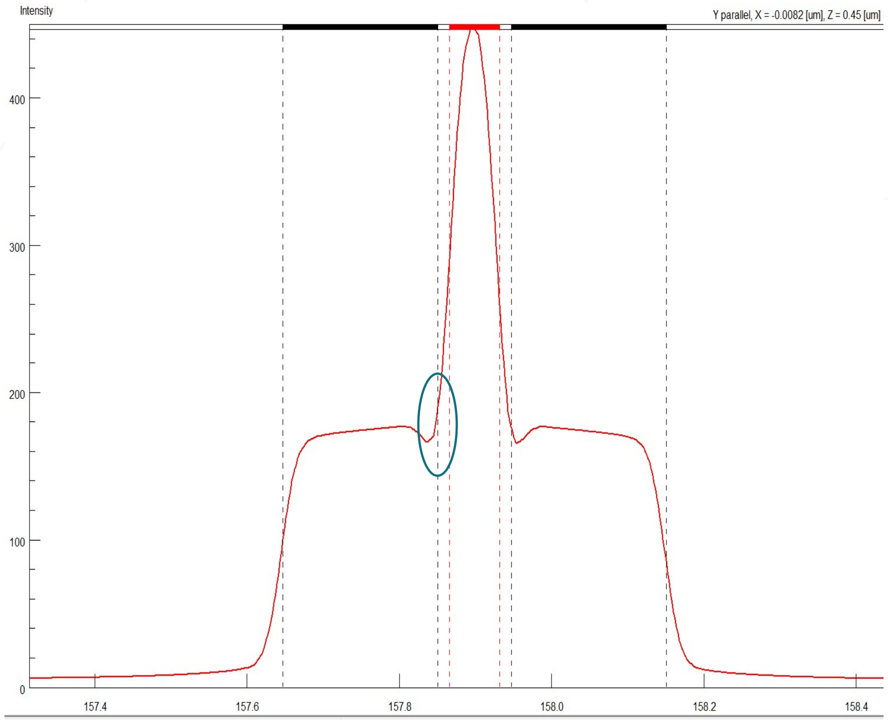
0.0150 um

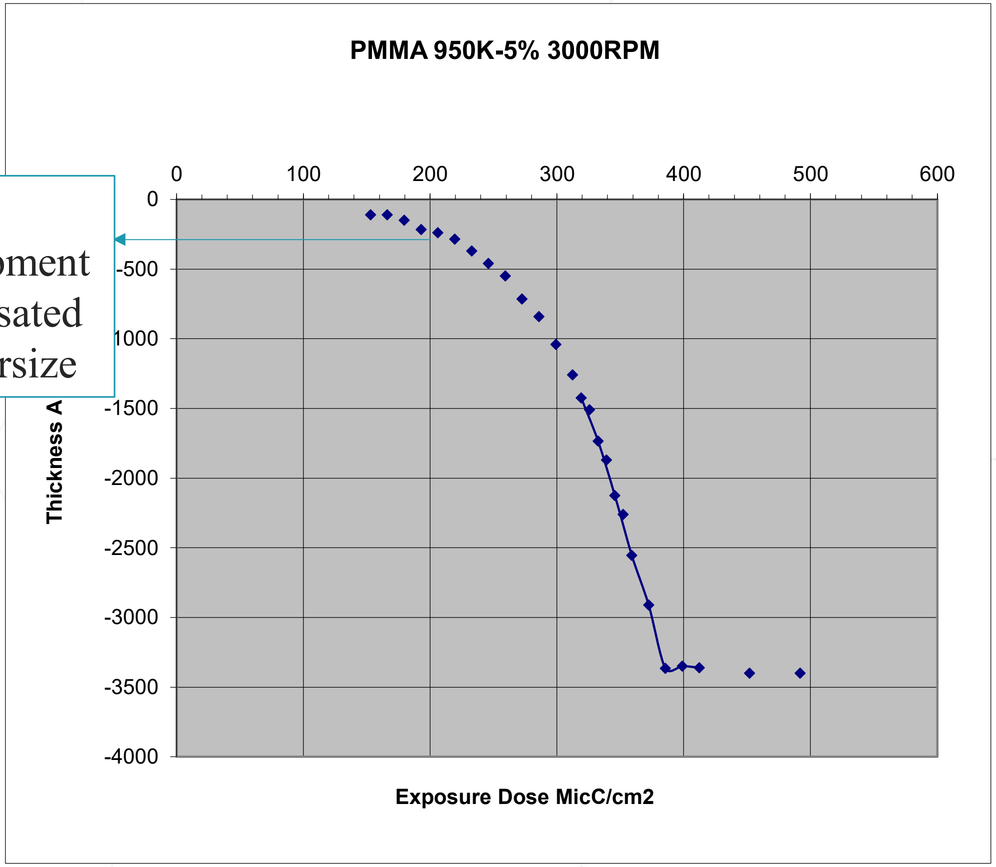
0.0660 um

2 Pick [um] X: -46.0506, Y: 157.9054,
Bbox [um] LL (-54.9620, 157.8660), w 91.1440, h 0.0660
//96TGTest1<1>:Rect (L:34(0), E:2.353)



T-Gate Correction

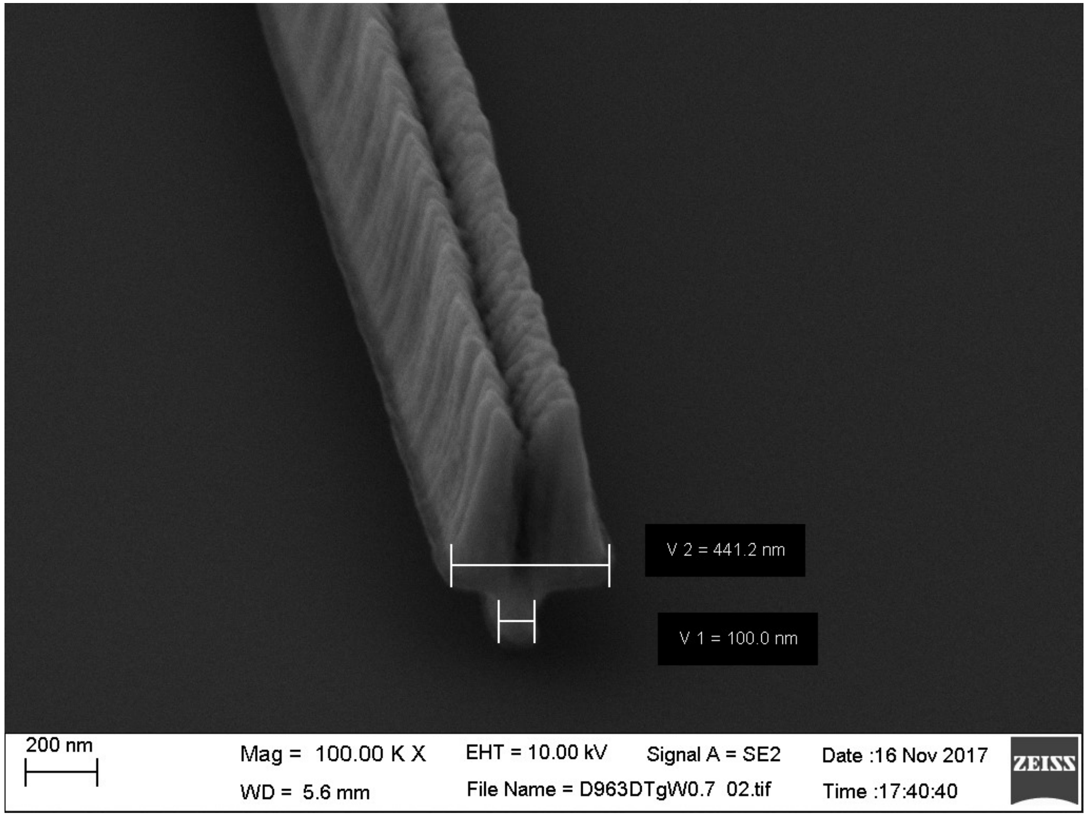


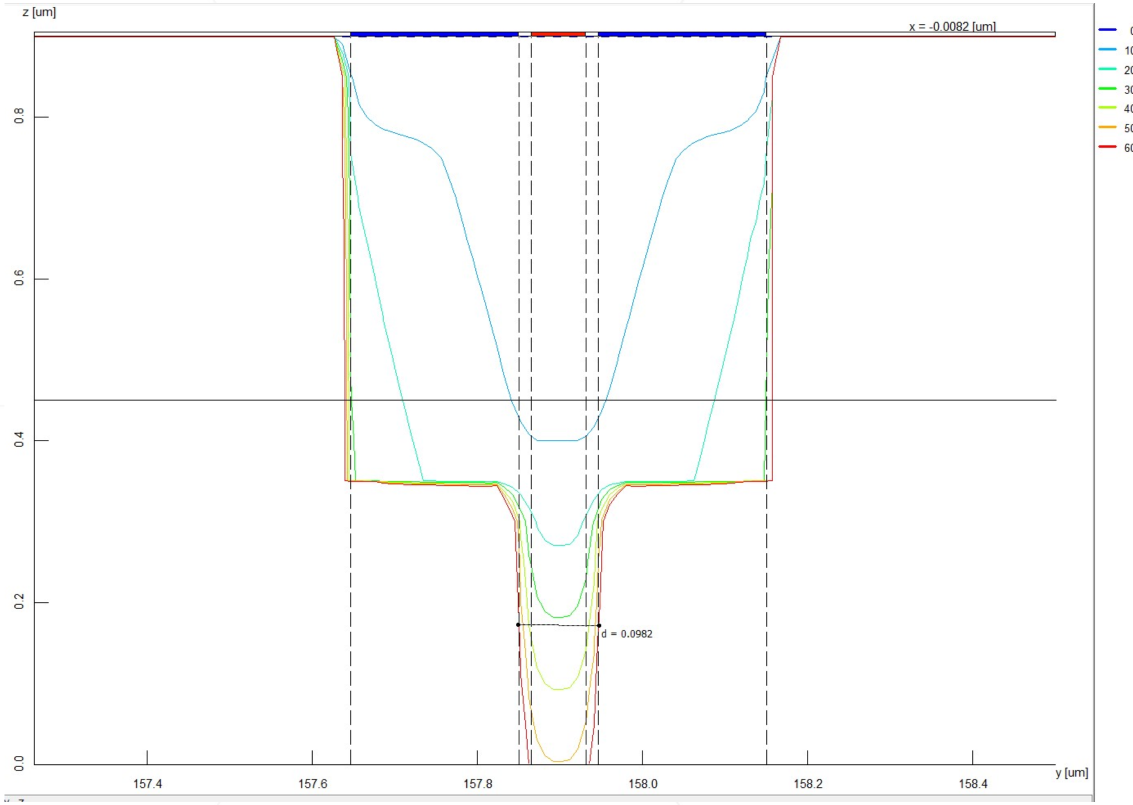


Lateral Development compensated by undersize

T-Gate Correction

- No Overdose!





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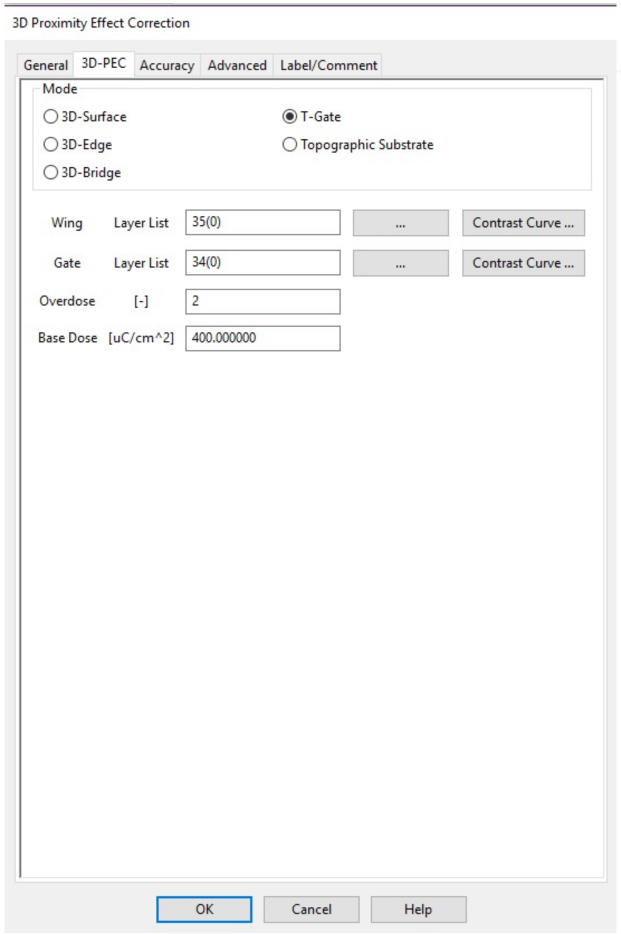
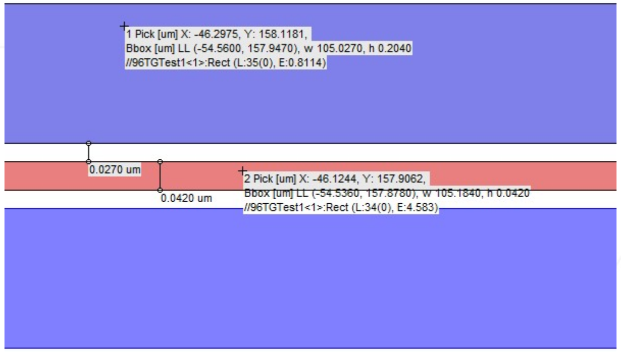
T-Gate Correction with ODUS

- With OverDose x 2, 36nm blur (from Tracer calibration!)


3D Proximity Effect Correction

Mode
○ 3D-Surface
○ 3D-Edge
○ 3D-Bridge
● T-Gate
○ Topographic Substrate

Wing Layer List: 35(0)
Gate Layer List: 34(0)
Overdose [-]: 2
Base Dose [uC/cm^2]: 400.000000


```
1 Pick [um] X: -46.2975, Y: 158.1181,
Bbox [um] LL (-54.5600, 157.9470), w 105.0270, h 0.2040
//96TGTest1<1>:Rect (L:35(0), E:0.8114)
```

```
2 Pick [um] X: -46.1244, Y: 157.9062,
Bbox [um] LL (-54.5360, 157.8780), w 105.1840, h 0.0420
//96TGTest1<1>:Rect (L:34(0), E:4.583)
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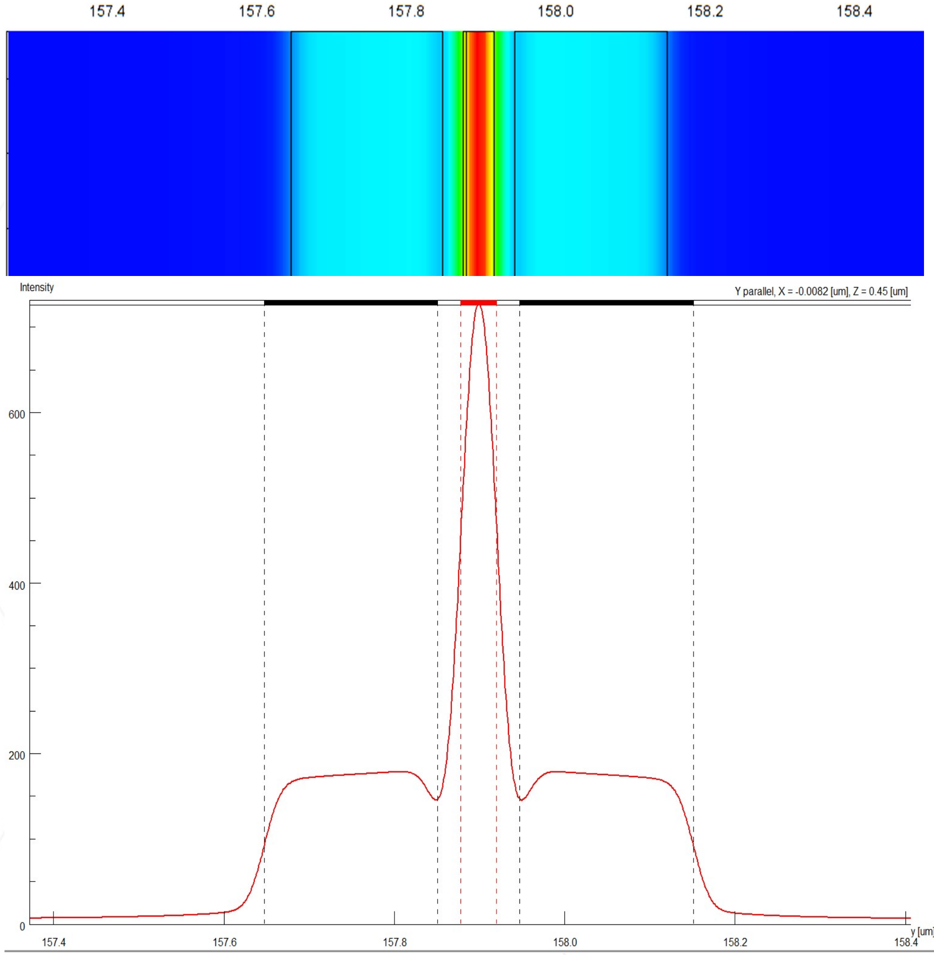
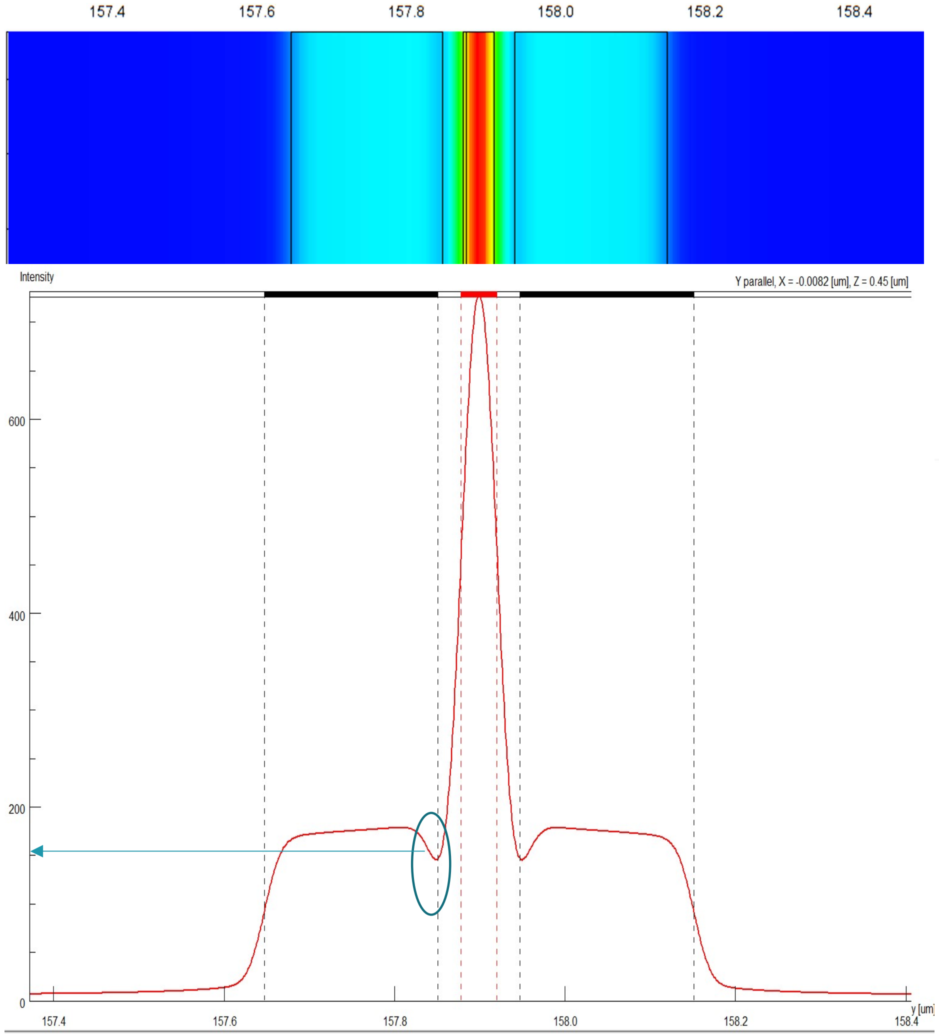
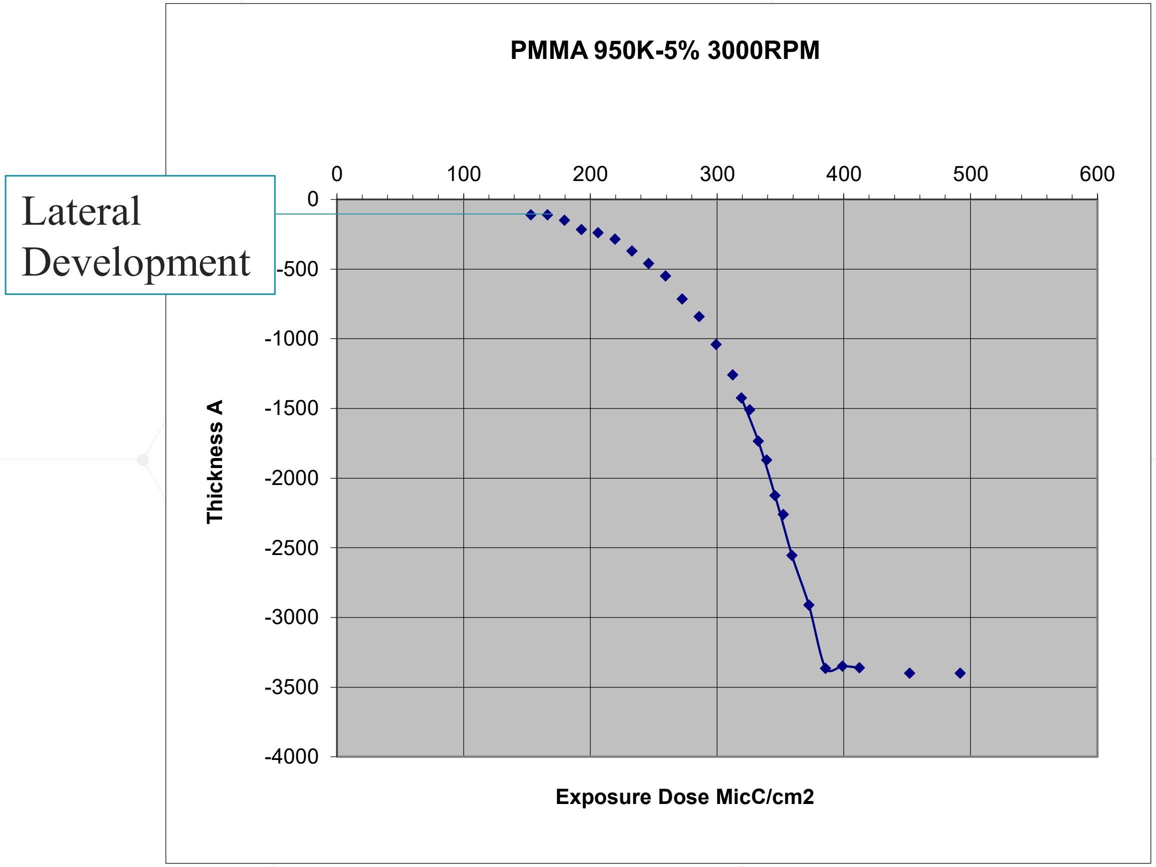


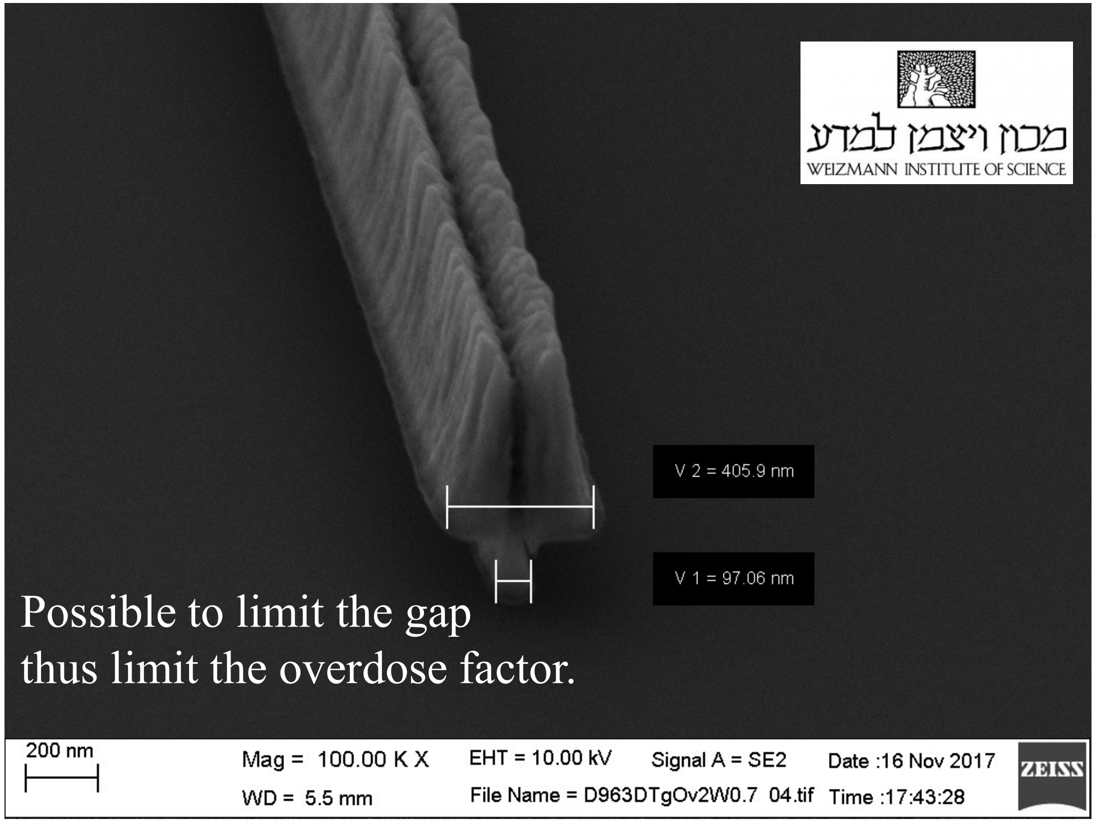
Higher contrast



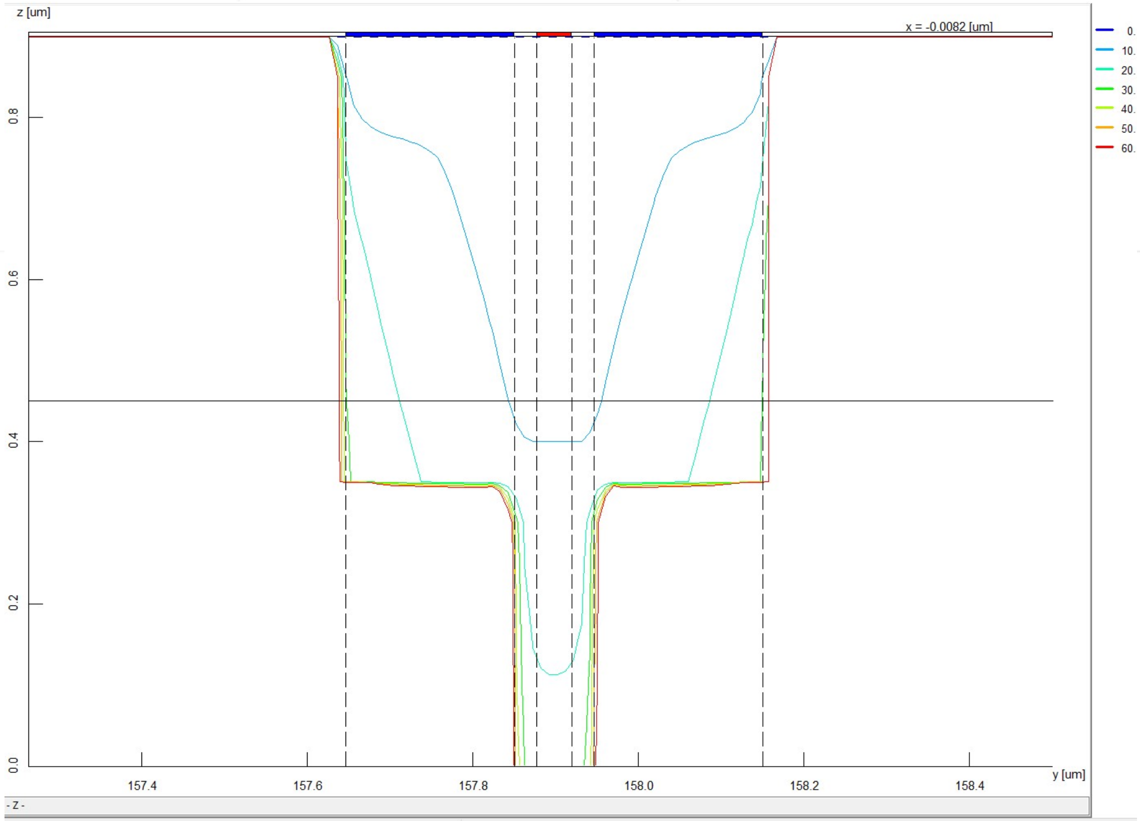


T-Gate Mode, 1min development

- Overdose 2! -> Higher contrast, more process window
- Develops gate fast by overdose
- More blocking of lateral development by larger gap



Possible to limit the gap thus limit the overdose factor.



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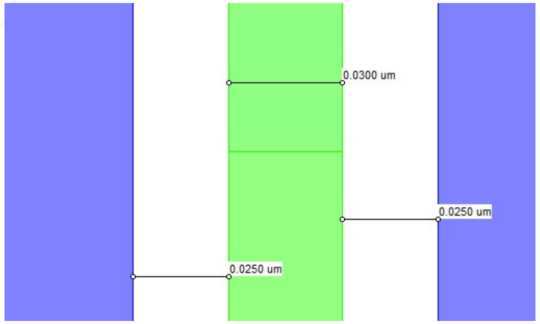
80nm Correction

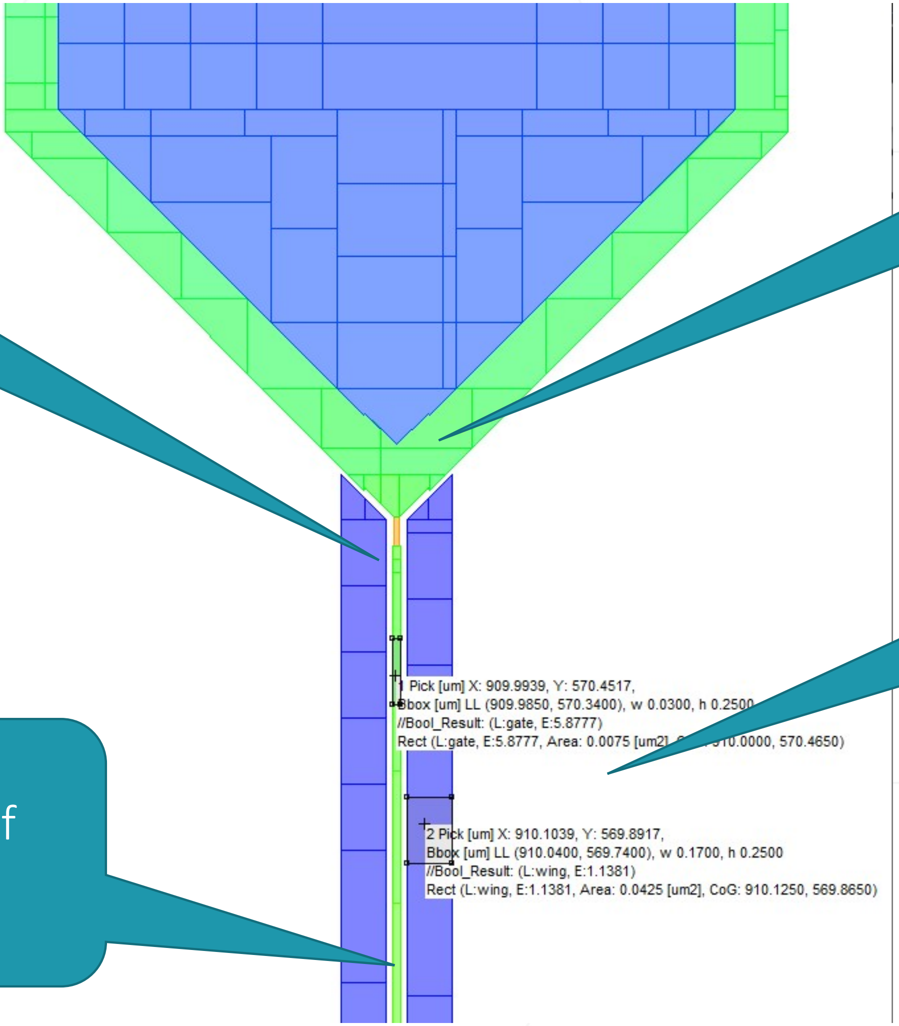
Gate Pullback of 25nm on each side

Gate & Contact pad get clearing dose

Dose Ratio between Gate and Wing of 5:1

Gate size of 30nm



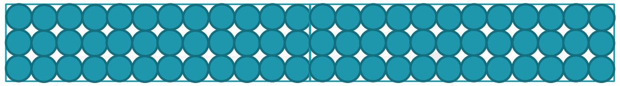


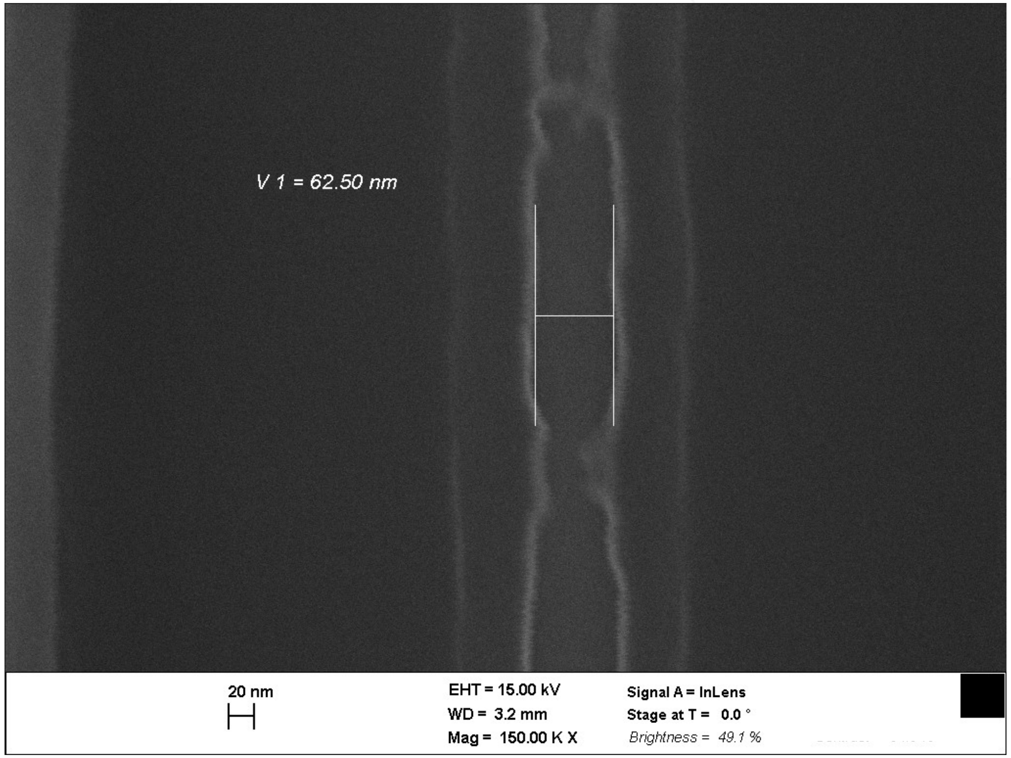
```
1 Pick [um] X: 909.9939, Y: 570.4517,
Bbox [um] LL (909.9850, 570.3400), w 0.0300, h 0.2500
//Bool_Result: (L:gate, E:5.8777)
Rect (L:gate, E:5.8777, Area: 0.0075 [um2] [illegible] 910.0000, 570.4650)

2 Pick [um] X: 910.1039, Y: 569.8917,
Bbox [um] LL (910.0400, 569.7400), w 0.1700, h 0.2500
//Bool_Result: (L:wing, E:1.1381)
Rect (L:wing, E:1.1381, Area: 0.0425 [um2], CoG: 910.1250, 569.8650)
```

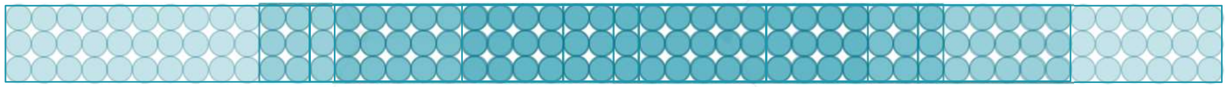
Writing optimizations

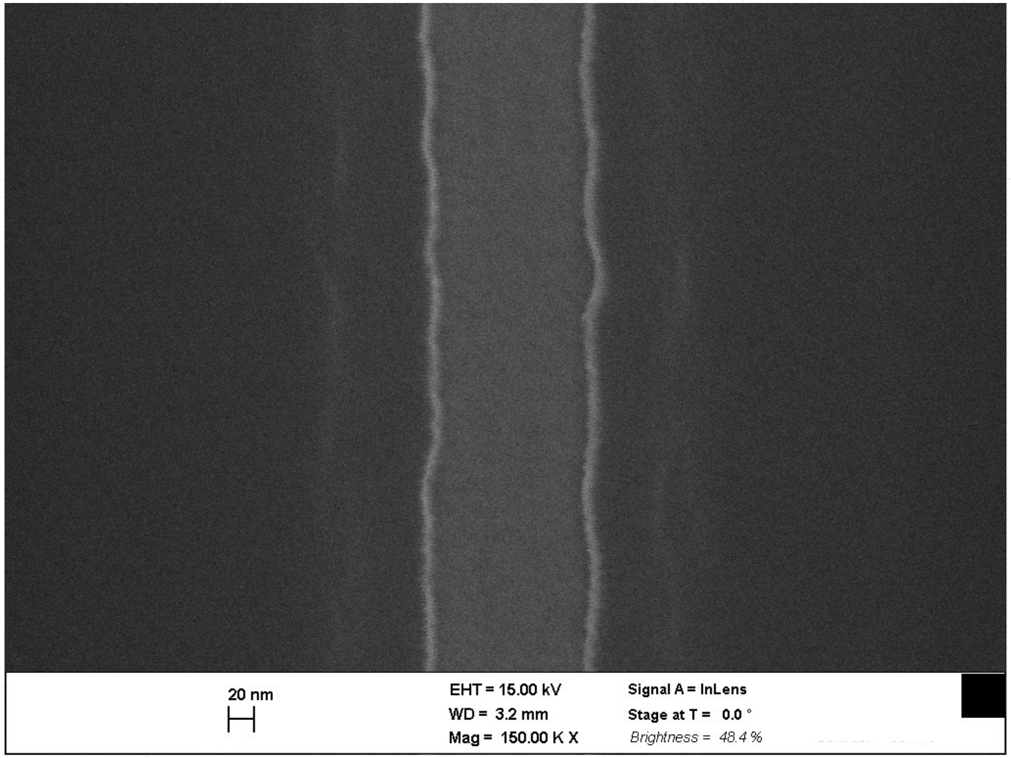
1x at 100% exposure of foot



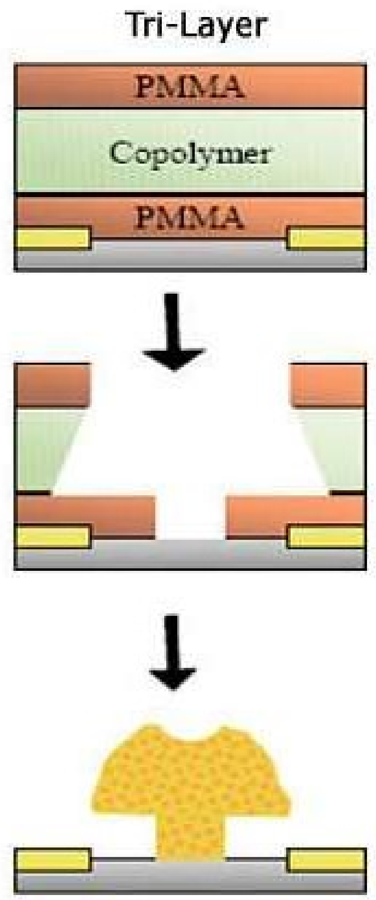


4x at 25% exposure of foot

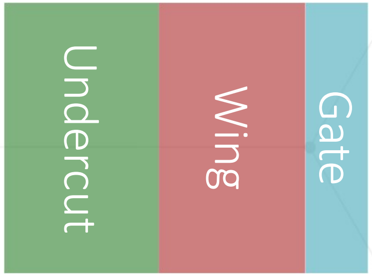


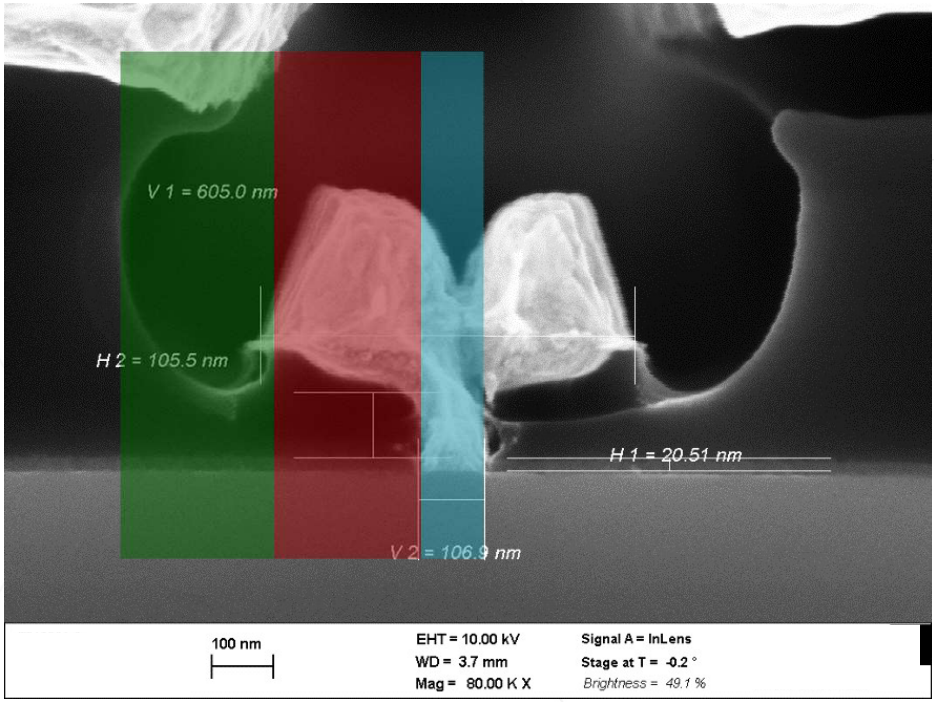


Undercut optimization



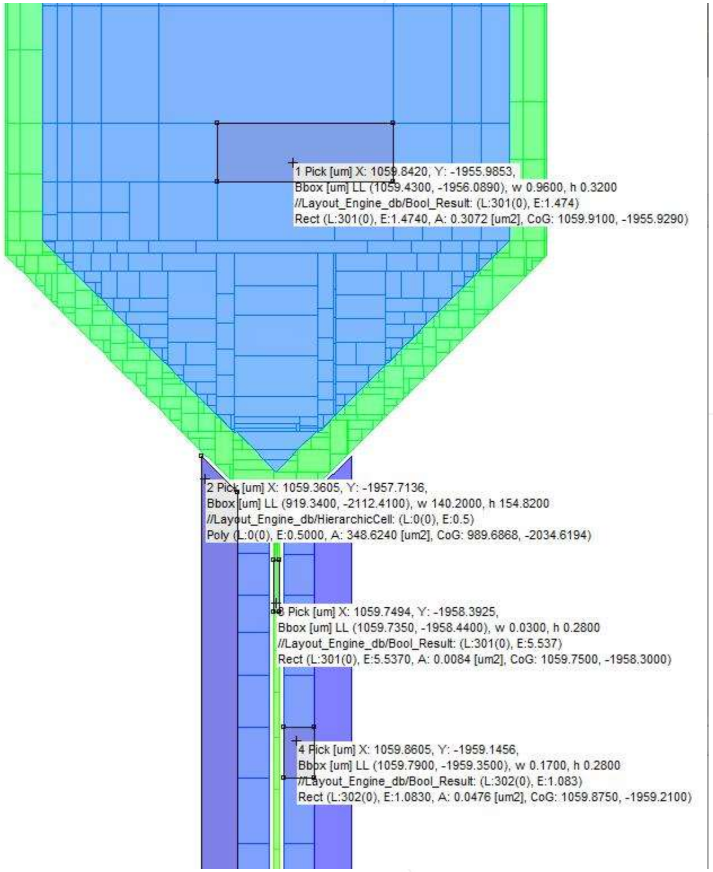
- Most processes use triple layer.
  - Top: Control wing size
  - Bottom: Control foot size
  - Middle: Create Undercut
- Advanced process need control of the undercut size and shape
  - using a 3rd exposure layer





Adding 3rd layer for Undercut-Control

- Current solution
  - Adjust the dose of 3rd layer (undercut-control) using FDA
- Future BEAMER version
  - Allow to define 3rd layer also by contrast curve
  - Energies and development front will be considered at correction



```
1 Pick [um] X: 1059.8420, Y: -1955.9853,
Bbox [um] LL (1059.4300, -1956.0890), w 0.9600, h 0.3200
//Layout_Engine_db/Bool_Result: (L:301(0), E:1.474)
Rect (L:301(0), E:1.4740, A: 0.3072 [um2], CoG: 1059.9100, -1955.9290)
```

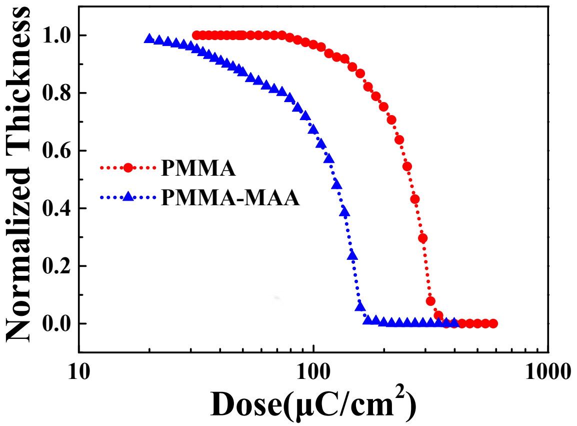
```
2 Pick [um] X: 1059.3605, Y: -1957.7136,
Bbox [um] LL (919.3400, -2112.4100), w 140.2000, h 154.8200
//Layout_Engine_db/HierarchicCell: (L:0(0), E:0.5)
Poly (L:0(0), E:0.5000, A: 348.6240 [um2], CoG: 989.6868, -2034.6194)
```

```
3 Pick [um] X: 1059.7494, Y: -1958.3925,
Bbox [um] LL (1059.7350, -1958.4400), w 0.0300, h 0.2800
//Layout_Engine_db/Bool_Result: (L:301(0), E:5.537)
Rect (L:301(0), E:5.5370, A: 0.0084 [um2], CoG: 1059.7500, -1958.3000)
```

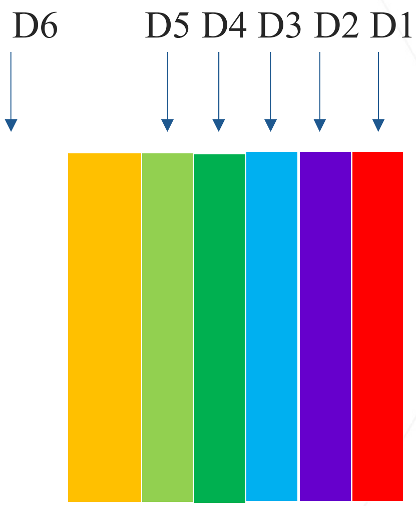
```
4 Pick [um] X: 1059.8605, Y: -1959.1456,
Bbox [um] LL (1059.7900, -1959.3500), w 0.1700, h 0.2800
//Layout_Engine_db/Bool_Result: (L:302(0), E:1.083)
Rect (L:302(0), E:1.0830, A: 0.0476 [um2], CoG: 1059.8750, -1959.2100)
```

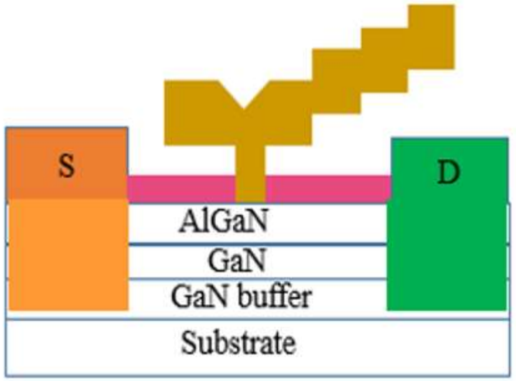
Assymetric T-Gate Example

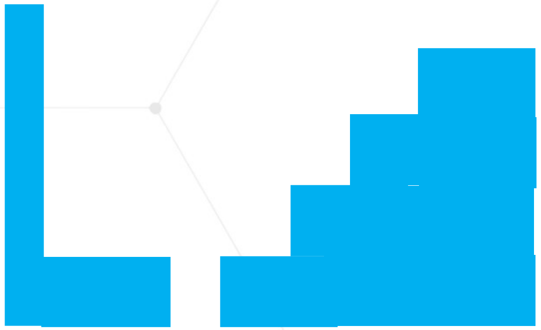
- Advanced wing (head) design for higher device performance
- Current correction supports assymetric designs (Gamma Gates)
- More complex Designs using 3D Edge PEC and Simulation



FUNARC
NANOLITH

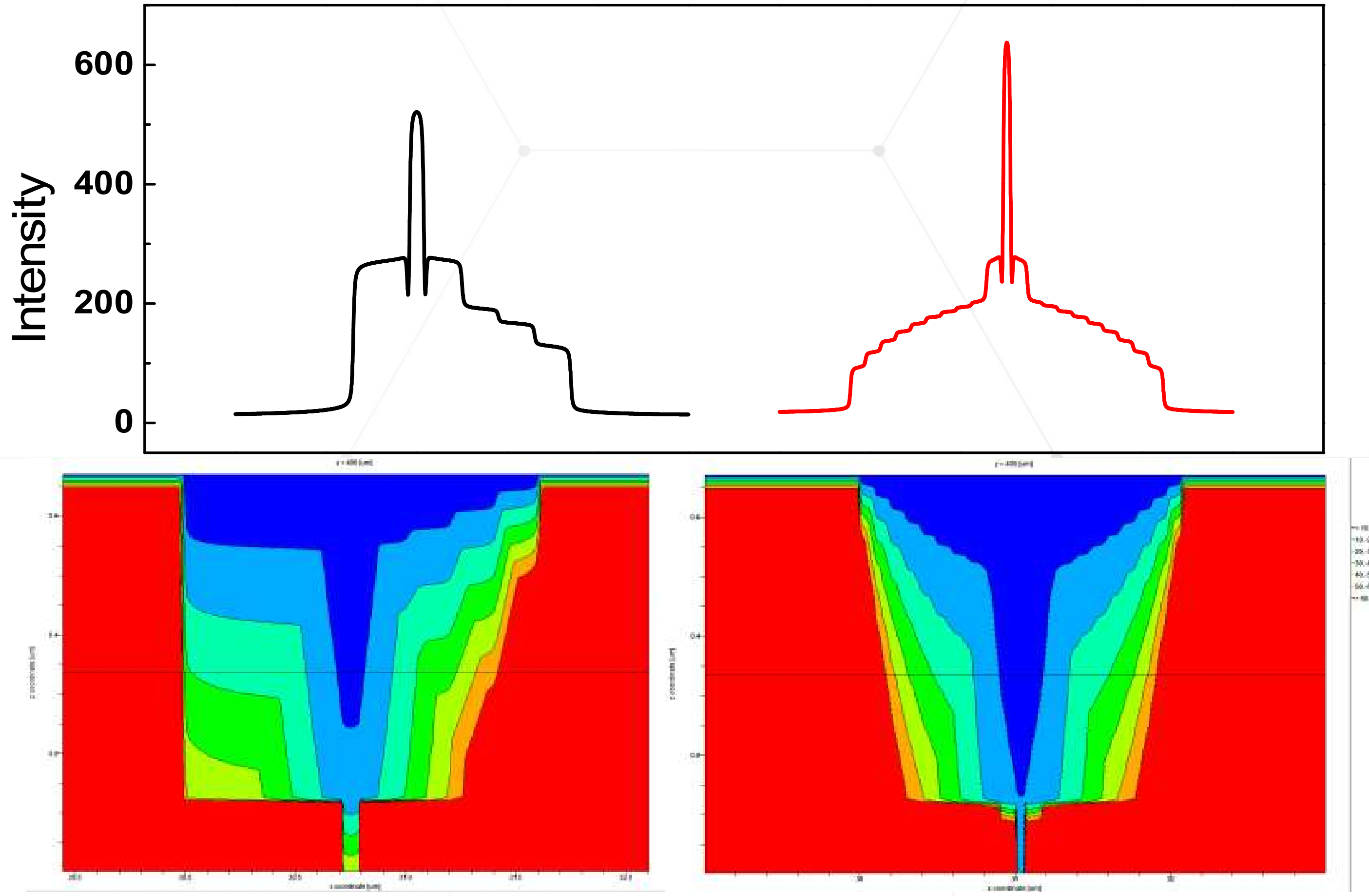




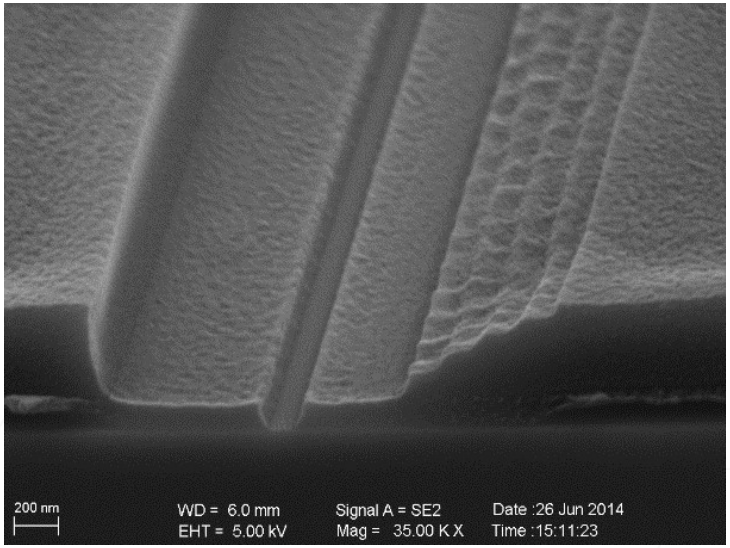


Optimization using LAB simulation

- Energy and resist development front after BEAMER correction

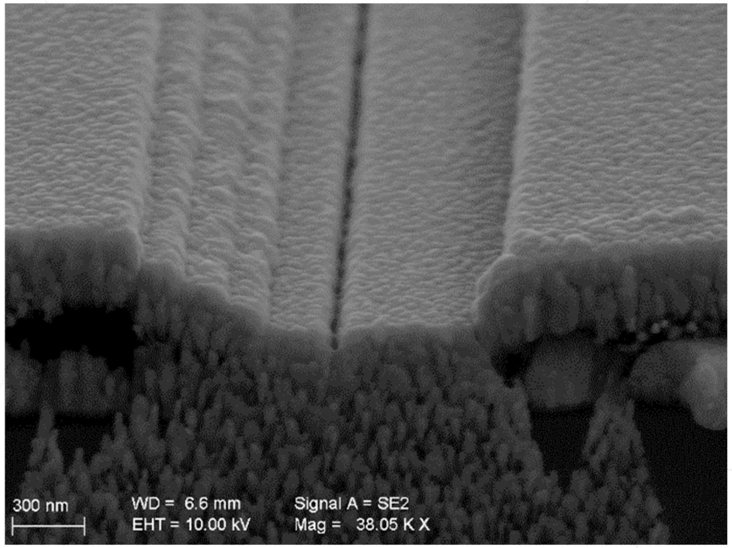


Lift-Off Process

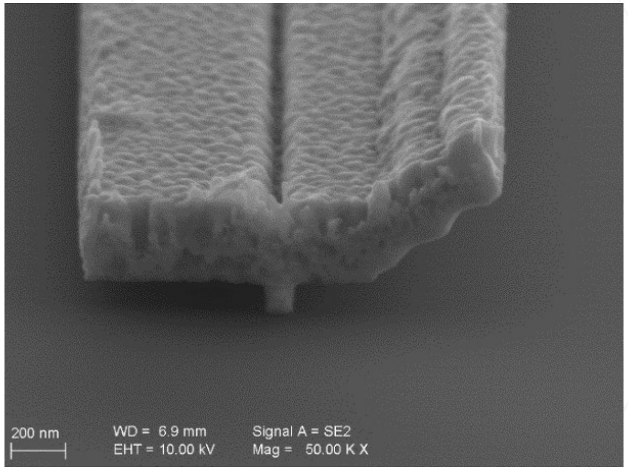


Evaporate

Cr/Au

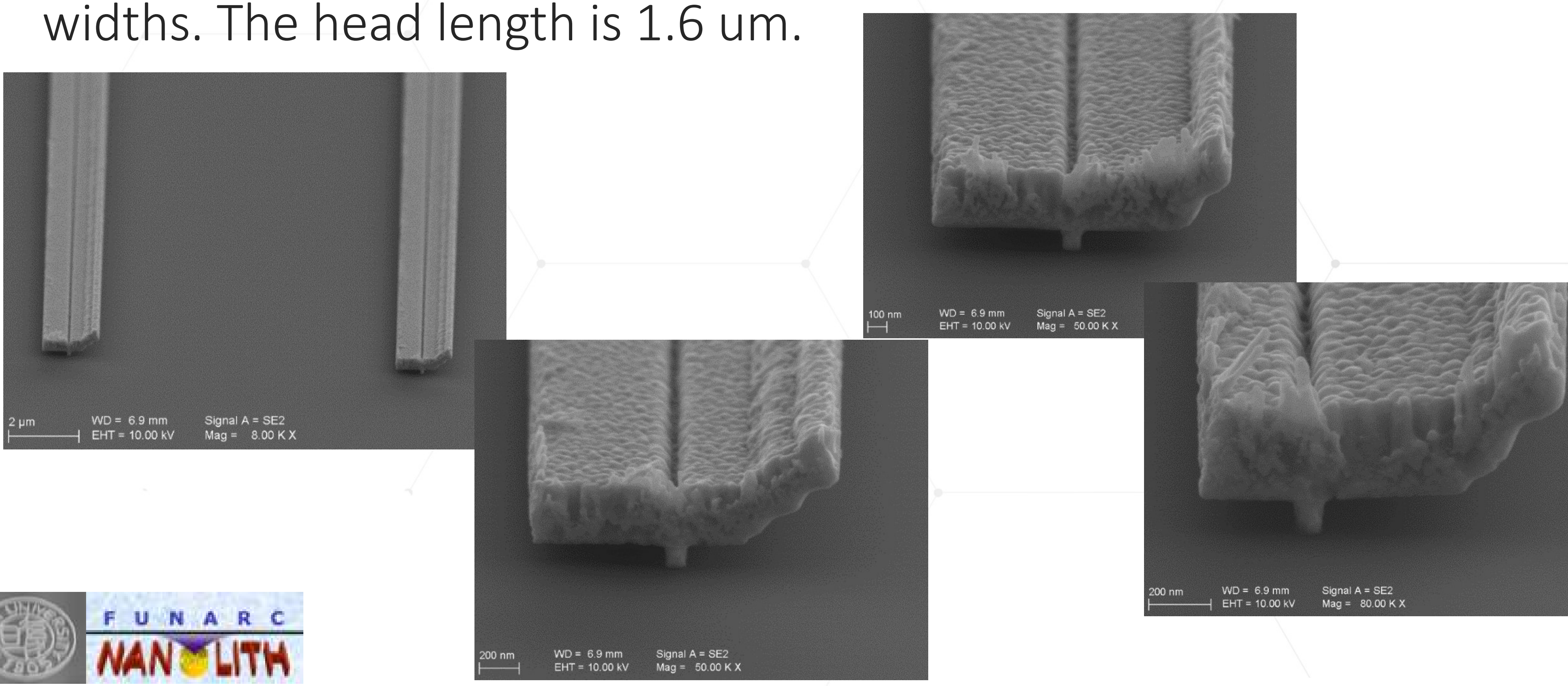


Lift-off



Results after lift-off

- SEM images for asymmetric T-shape gates with sub-100 nm foot-widths. The head length is 1.6 um.



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Summary of Part 7

- 3D Edge PEC correction for multi-layer resist process
  - 3D Edge PEC offers correction with multiple (more than 2!) layer
  - Bridges for interconnect and “Undercut-Control” are multilayer application
  - Works for T-Gate, but leads to oversize by lateral development
- T-Gate correction includes resist development, compensates lateral development by under-sizing the gate (leaving a gap between gate and wing)
  - ODUS (OverDose-UnderSize) enables contrast (process window) enhancement for the gate
  - Multi-layer resist process, where gate and wing size/shape need control
  - High density material with strong proximity effect
- Application example
  - Application example for asymmetric T-Gate design

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Summary of Webinar Series

- 7 hours on Proximity
  - Proximity effect
  - Correction Algorithm
  - Major parameter
  - Process calibration
  - Shape PEC with ODUS
  - 3D-Greyscale corection
  - T-Gate correction

Part	Subject	Date
1	Electron Scattering and Proximity Effect	07-Oct-2020
2	Dose PEC Algorithm and Parameter	14-Oct-2020
3	Optimization of Dose PEC Parameter	21-Oct-2020
4	Process Effect, Calibration and Correction	28-Oct-2020
5	Shape PEC – “ODUS” Contrast Enhancement	04-Nov-2020
6	3D Surface PEC for Grayscale Lithography	18-Nov-2020
7	3D T-Gate and Edge PEC for multilayer resist	02-Dec-2020

- All presentation and videos are available on GenISys Web-Site
- We can issue participation certificate on request
- Any comments & suggestion for additional technical webinars are welcome

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Thank You!

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