GenISys
Advancing the Standard

# BEAMER

## Building Niemeyer-Dolan Bridges in *BEAMER*

using *3D E-Beam Edge PEC*

# Niemeyer-Dolan Bridge

- Niemeyer-Dolan Bridge technique

*Shadow evaporation (2x)*

*Evaporation mask*

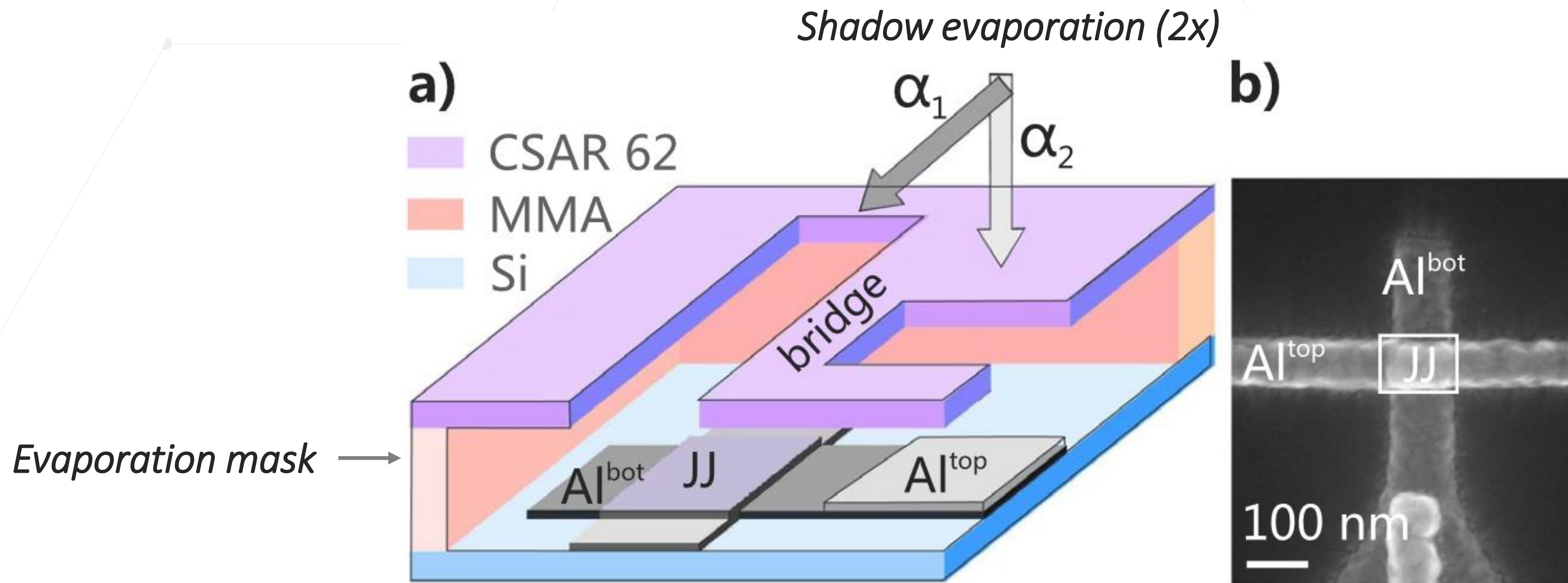
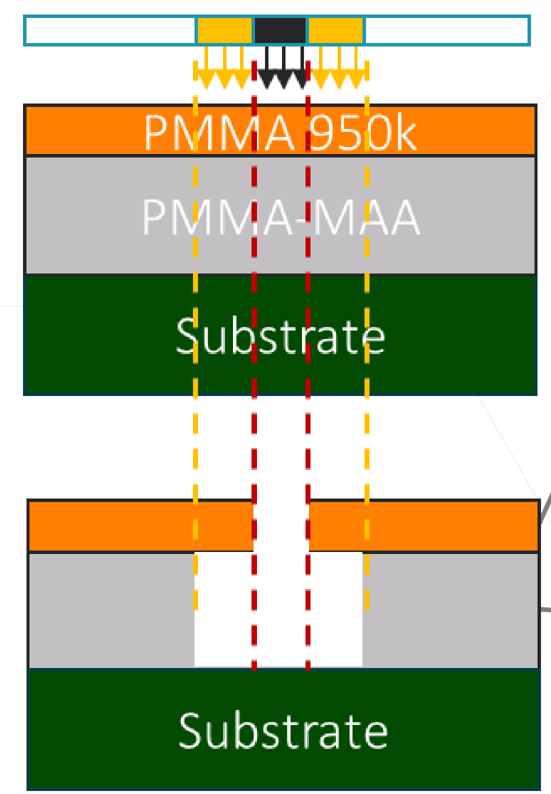


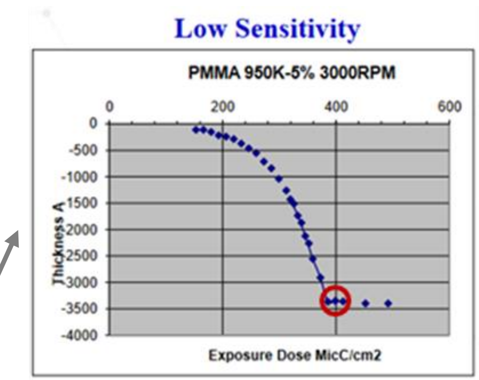

Figure 1. Niemeyer–Niemeyer-Dolan Bridge technique used in this paper. (a) Scheme of the used shadow evaporation process. The first metal layer was deposited at an angle (dark grey color) through two-layer resist mask MMA- CSAR, and the second layer at 0 angle (light grey color). Angular deposition was performed first, in order to avoid shading from the junction wall at the second deposition, causing electrode discontinuity. (b) Top view SEM image of the fabricated junction after the removal of the resist mask.

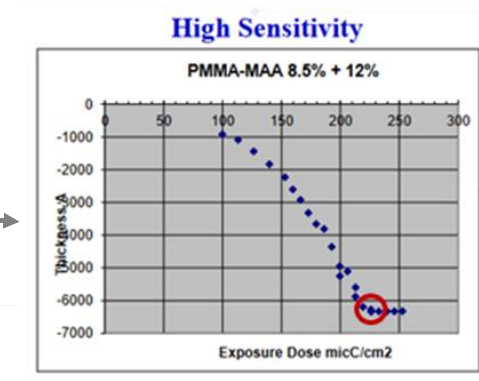
Ref [1]: Anastasiya A. et al., “Improving Josephson junction reproducibility for superconducting quantum circuits: junction area fluctuation”, natureprotfiolio (2023)13:6772

- Traditional E-beam lithography process for Niemeyer-Dolan Bridge

*Resist profile of Niemeyer-Dolan Bridge*

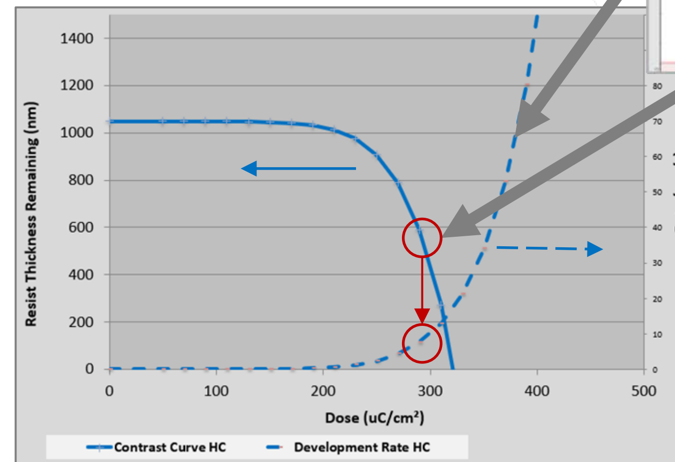


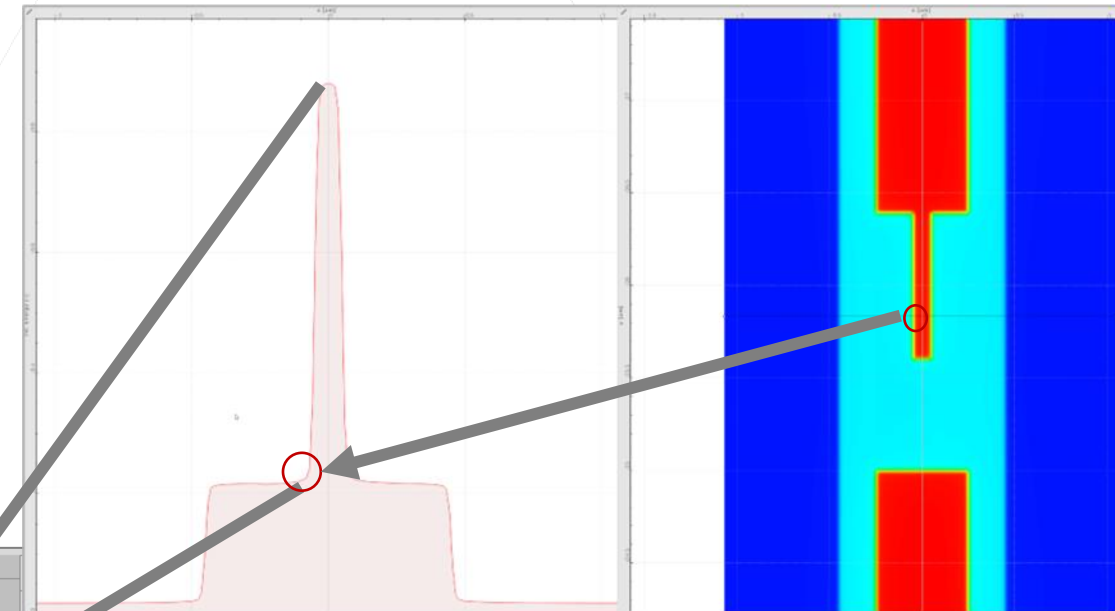




*Traditional E-beam lithography process for Niemeyer-Dolan Bridge*

- Critical CD is often oversized?
  - Next to the critical CD structure, additional dose is needed for the undercut clearing
  - The additional energy leading to unintended partial exposure of the critical layer
  - Resist of critical layer with finite contrast shows lateral development (Developer is moving both in depth and side direction and the lateral development rate is not 0)

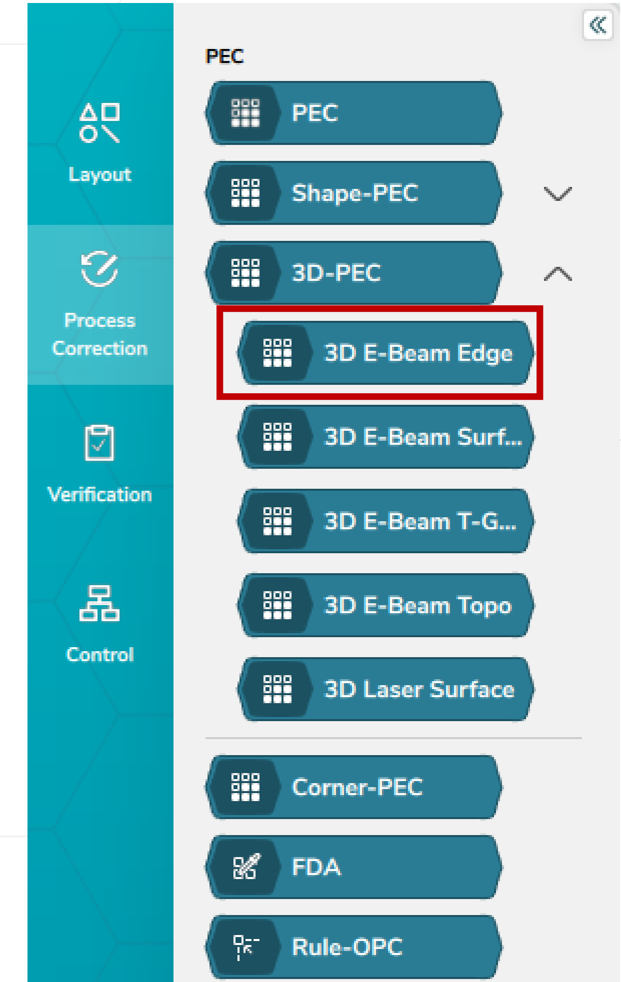


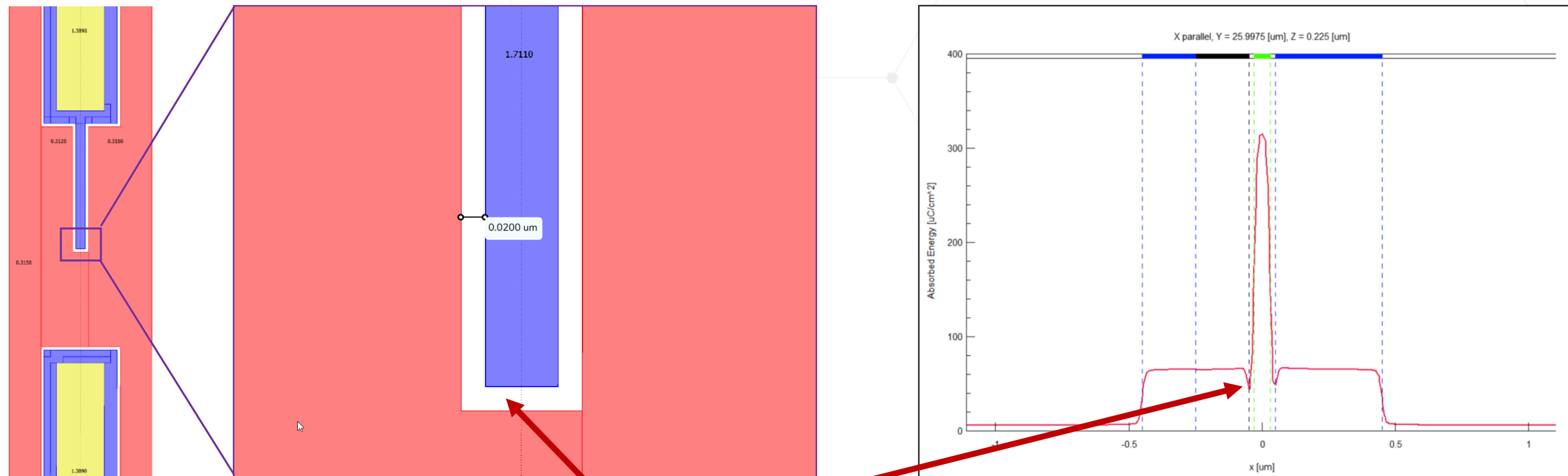
*Absorbed Engergy Image*

# What can we do?

- *3D E-Beam Edge PEC*: optimized for multi-layer process
  - considers proximity effect
  - considers resist lateral development for critical layer (the full resist contrast curves of all resists)
  - enables contrast enhancement (process stability) by using ODUS (Over Dose Under Size) method on the critical layer



- *3D E-Beam Edge PEC* (Bi-layer)
  - Compensation of lateral development
    - Generate gap between the critical layer and undercut layer. The size of the gap is computed to realize the lateral development front stop at the target position

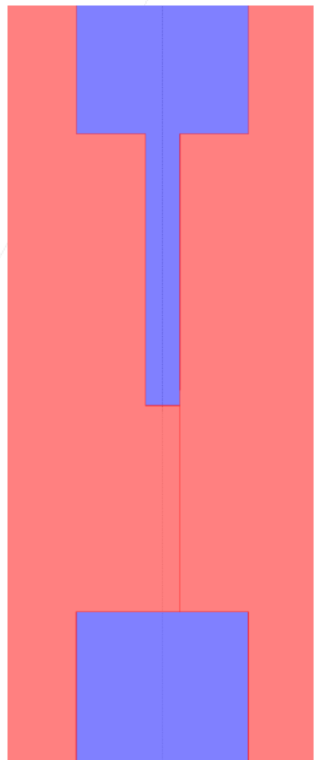



*Bias applied to critical structures to compensate for lateral development*

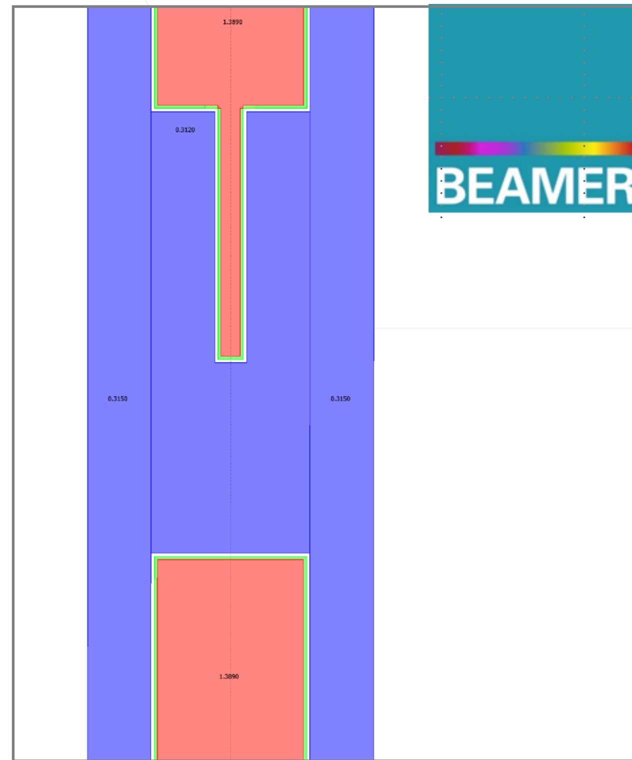
# Niemeyer-Dolan Bridge

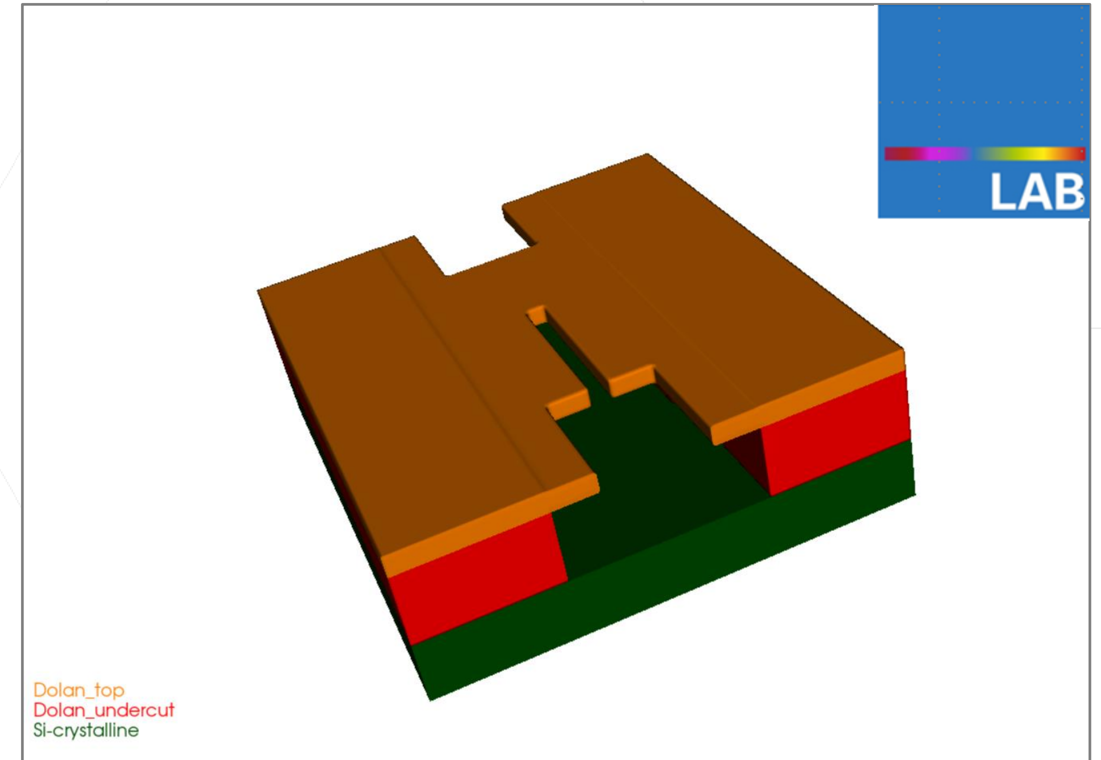
# Niemeyer-Dolan Bridge

- Let's start to build the bridge



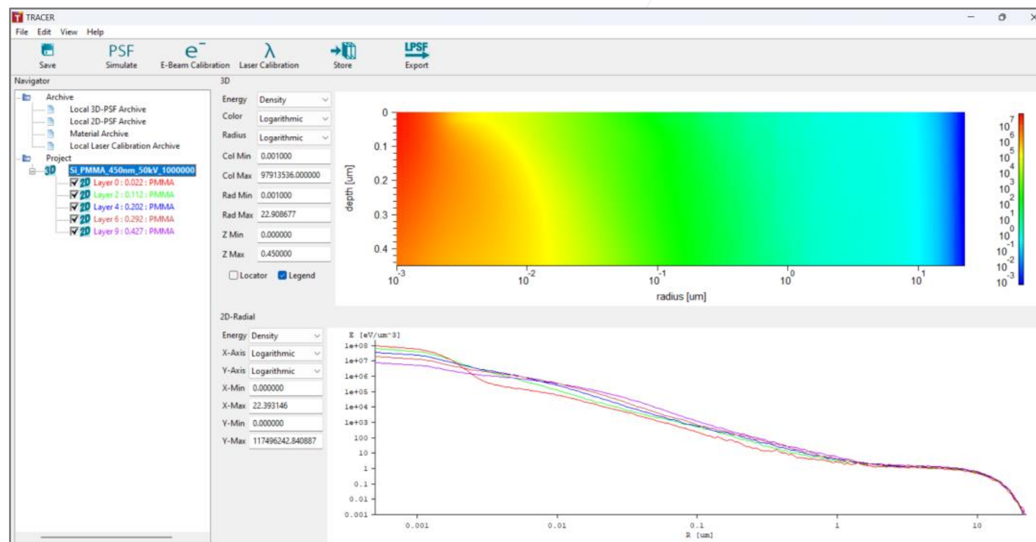
*Layout*

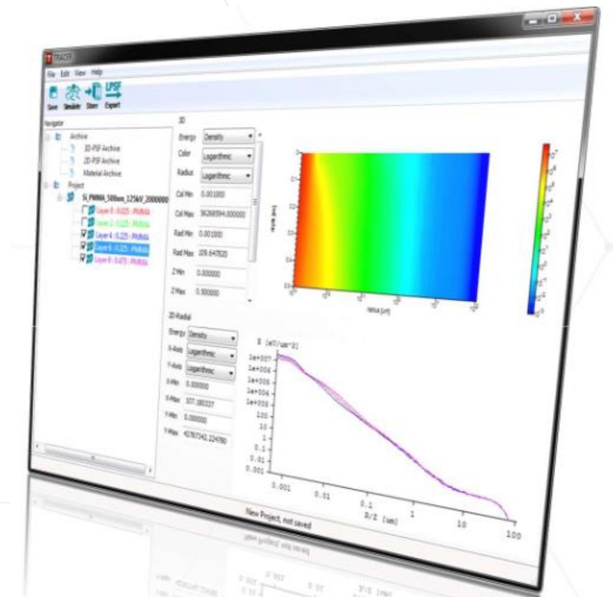




# Important work before *3D E-Beam Edge PEC*

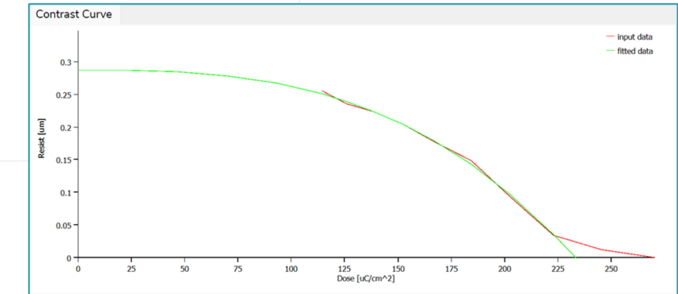
- Important work before *3D E-Beam Edge PEC* :
  - PSF: Monte Carlo simulation with ***TRACER***
    - Substrate definition
    - Resist stack and thickness
    - Beam energy, e.g. 50keV, 100keV
    - Number of electron to simulate, e.g., 1 million
    - Extract the PSF from the depth according to the critical layer

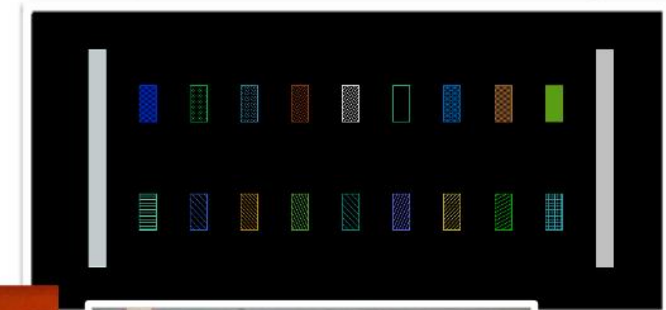


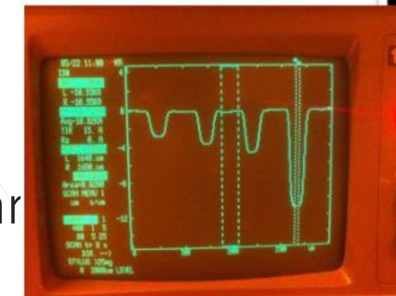


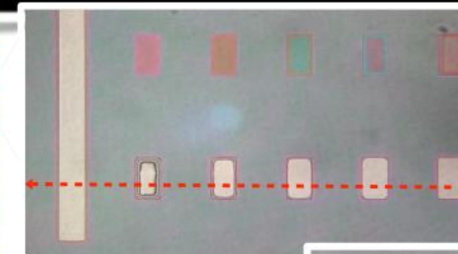
*TRACER calculates the absorbed energy spread over resist thickness and distance from the incident beam*

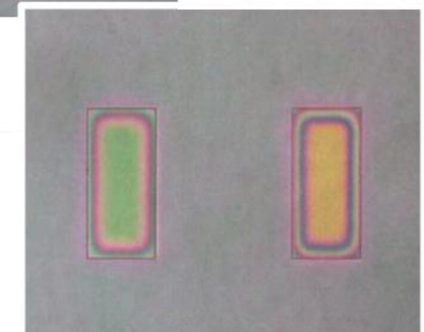
- Important work before *3D E-Beam Edge PEC*:
  - Contrast Curve measurement for each resist layer
    - Exposure voltage
    - Substrate stack
    - Pattern
      - Width & length > 3 × Beta
      - Length easily be measured with profilometer
      - Typical pattern: 150 µm x 300 µm
      - Separated pattern to avoid interaction
    - Resist thickness
      - Thicker resist layer with higher precision due to har
        inaccuracy



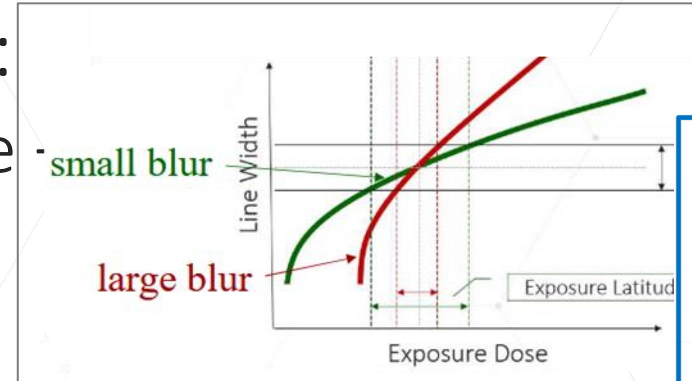









- Important work before *3D E-Beam Edge PEC*:
  - *Effective Short Range Blur* estimation (Beam size + Process Effect)
    - 1st order estimate
    - FWHM$= 0.76 \times \Delta CD\ /\Delta\% dose$
    - Calibrated by ***TRACER***




Typical values:
100keV, low current (~ 1nA), high contrast thin (100nm) PMMA: ~ 15nm

100keV, high current (~20nA), low contrast thick PMMA: ~ 30nm

50keV, high current (~50nA), low contrast thick PMMA: ~ 50nm

Application Note

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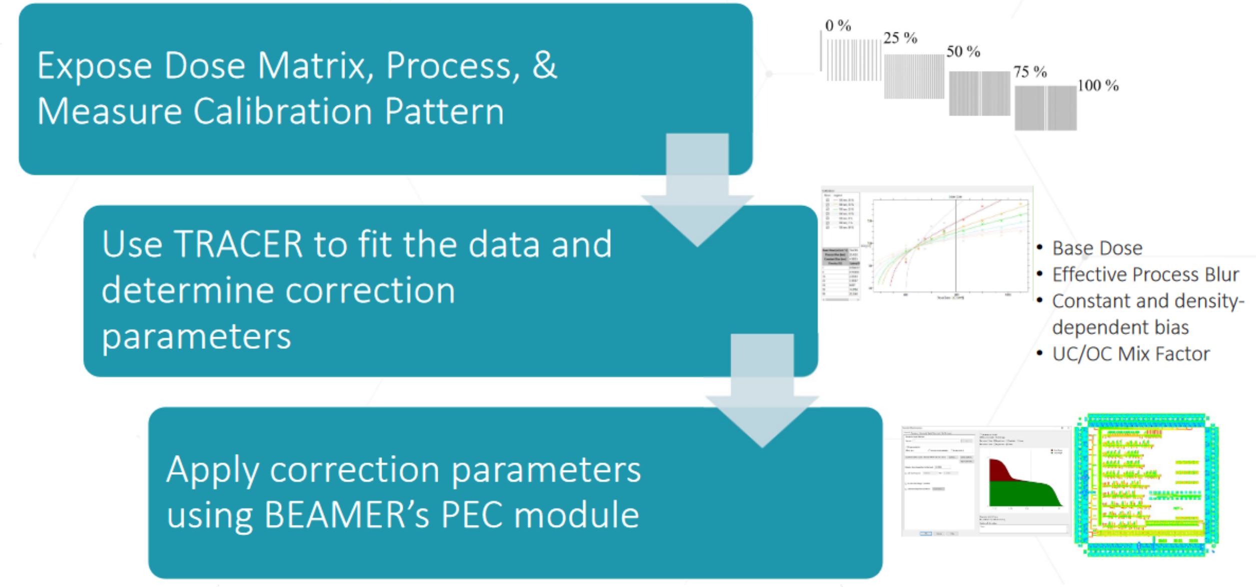
TRACER

**Full Process Calibration using TRACER: Experimental Procedure**

An optimized e-beam lithography data preparation process must take into account process effects beyond just the electron energy distribution point spread function (PSF) as computed by TRACER. These process effects include density-dependent development rate changes, resist lateral development, and size bias due to process or metrology. It is possible to characterize and subsequently correct for these effects using a set of empirical measurements. This note describes the experimental procedure and data analysis necessary for such a Full Process Calibration.




*Typical **TRACER** calibration procedure*

# 3D E-Beam Edge PEC

# 3D E-Beam Edge PEC

PEC

- PEC
- Shape-PEC
- 3D-PEC
  - 3D E-Beam Edge
  - 3D E-Beam Surf...
  - 3D E-Beam T-G...
  - 3D E-Beam Topo
  - 3D Laser Surface
- Corner-PEC
- FDA
- Rule-OPC

Layout
Process Correction
Verification
Control

Proximity Effect Correction - 3D E-Beam Edge

Configure Quick Access

General
3D-PEC
Accuracy
Advanced
Comment

Correction Layer Selection
Layer(s)
*
...

PSF Representation

Archive | Gaussian Approximation | Numerical PSF

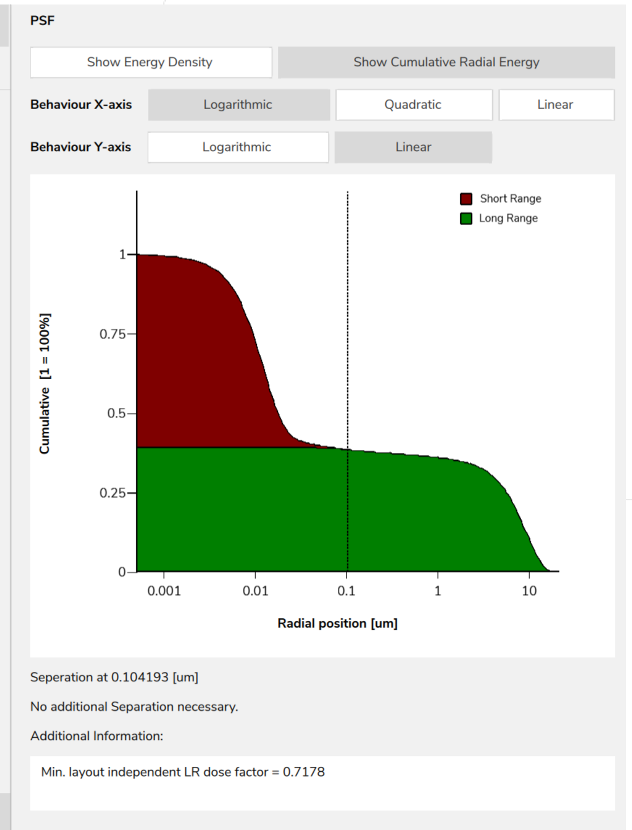
Tag: ; Substrate: Si; Layers: ; Resists: PMMA 450 nm; Energy [kV]: 50;

Archive... | Global Archive... | View Comment...

Effective Short Range Blur FWHM[um]
0.020000

Add Gamma [um] 1.000000
Nue 0.100000

OK Cancel



# 3D E-Beam Edge PEC

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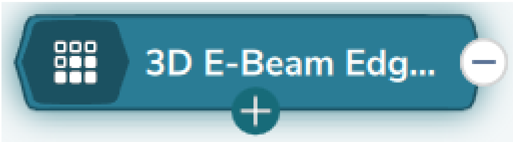



Proximity Effect Correction - 3D E-Beam Edge

Configure Quick Access

- General
- 3D-PEC
- Accuracy
- Advanced
- Comment

Mode

Threshold Model (Legacy) | Development Rate Model

Contrast Curve Mode

Material Archive | Numeric

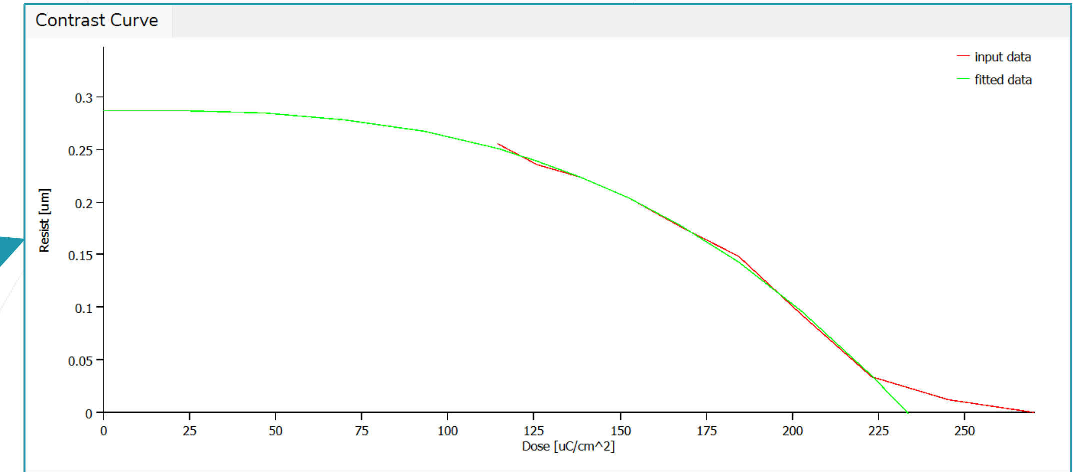
Material Database...

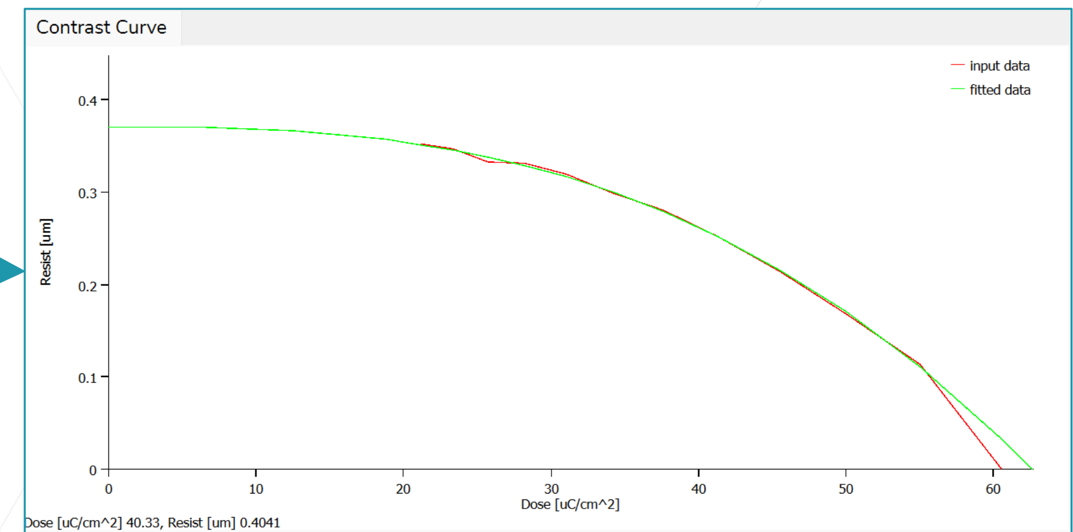
Base Dose [uC/cm^2]
300.000000

| Critical Resist Layer | Resist: Dolan_top | Developer: Default |
|---|---|---|
| Layer List: 1(0) Select... | Dose Factor [-]: 1 | Thickness [um]: 0.1 |
| No Lat. Dev. List: Select... | Dose Factor [-]: 1.000000 | |

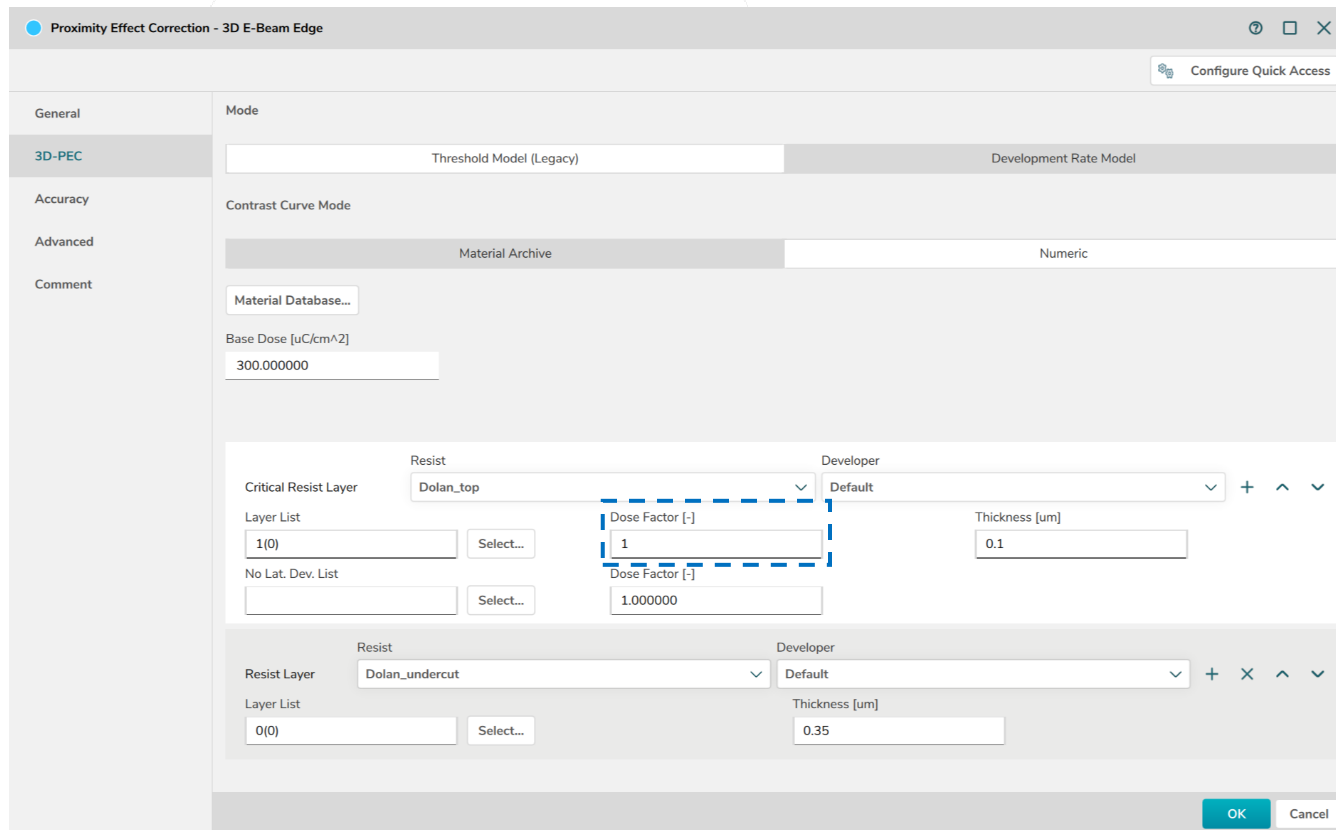
| Resist Layer | Resist: Dolan_undercut | Developer: Default |
|---|---|---|
| Layer List: 0(0) Select... | Thickness [um]: 0.35 | |

OK | Cancel



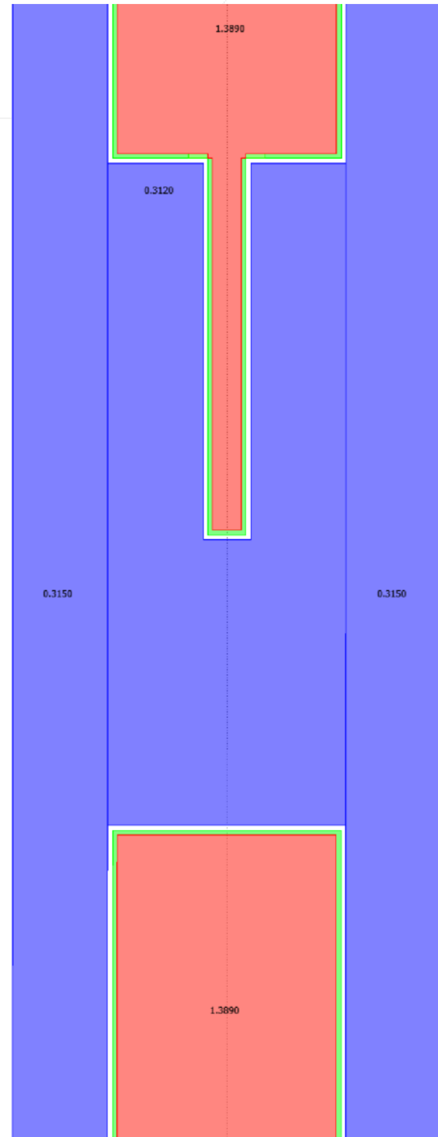



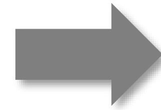
# 3D E-Beam Edge PEC




- The critical layer that includes exact lateral development compensation can be placed anywhere in the stack.
- The “critical” layer allows for overdose/undersize. Some regions, e.g. contacts, can be excluded from the lat. dev. computation. -> “No Lat. Dev. List”.
- The “non critical” layers, e.g. undercut, are optimized for resist removal (dose-to-clear from contrast curve) but do not exact CD. Lat. dev. is discarded there.

# 3D E-Beam Edge PEC

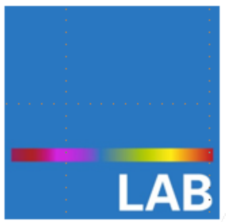


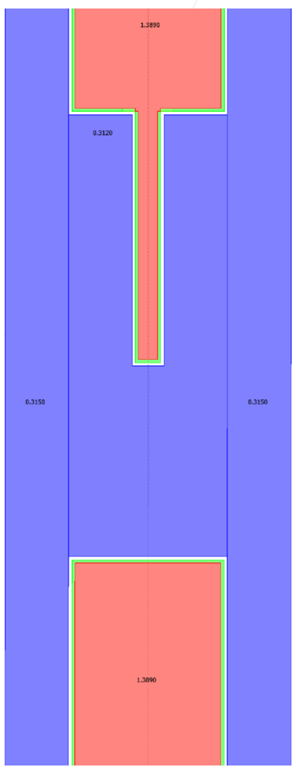
IMPORT
E-Beam 3D
Resist

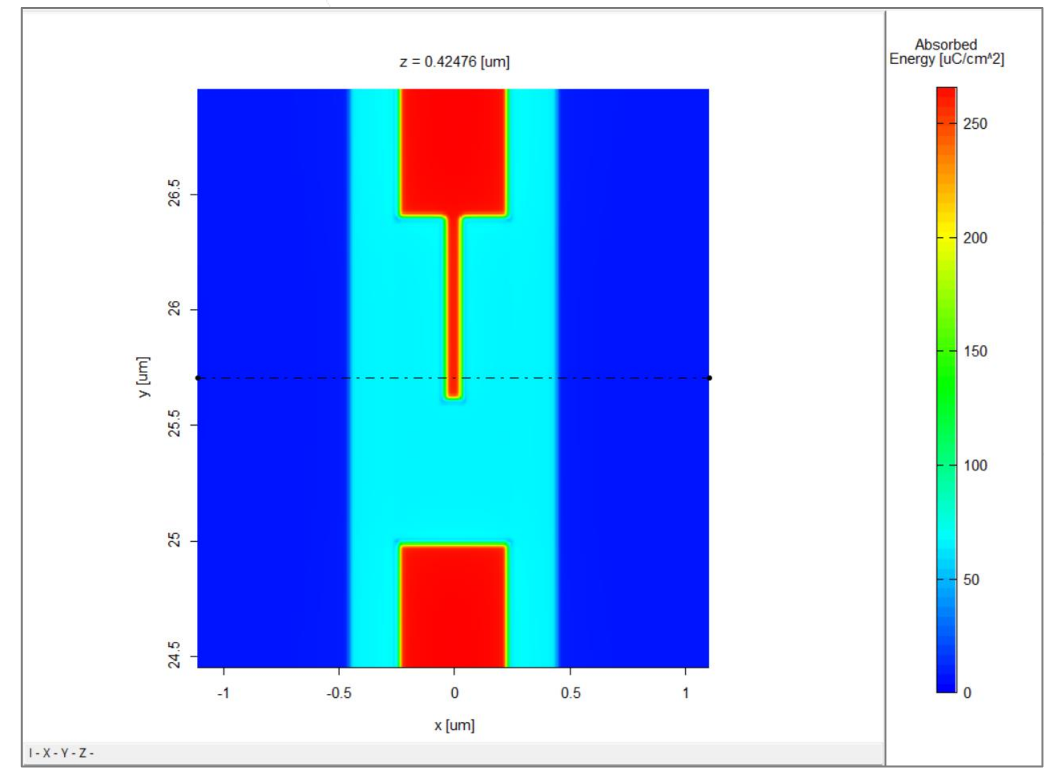
# LAB simulation

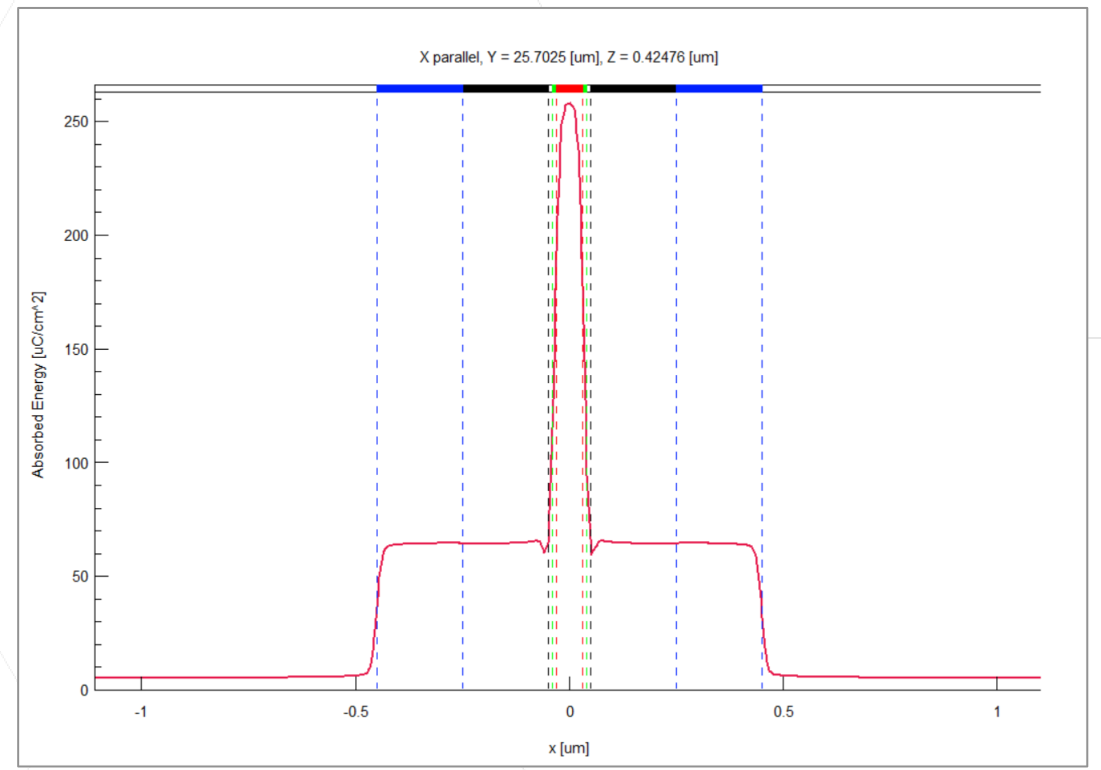
# Lab simulation




IMPORT
E-Beam 3D
Resist





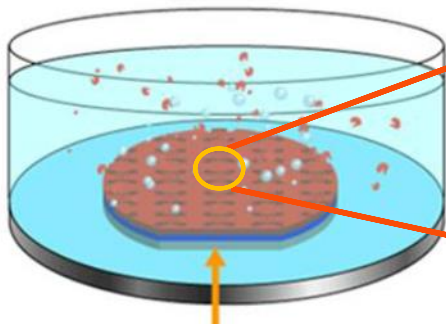

*IMPORT*

*Top-Down View of Absorbed Engergy Image*

*Absorbed Energy Image*

# Lab simulation

**Development process*



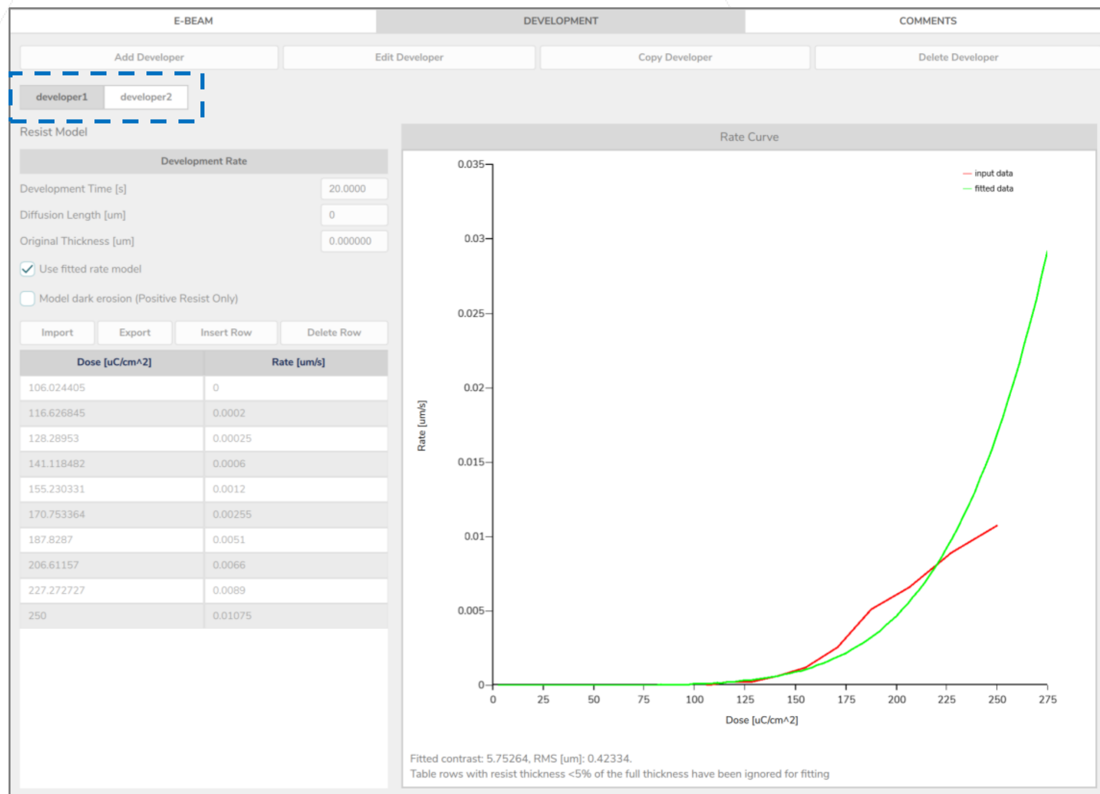
*Substrate*

*Image:
https://nanoscale.unl.edu/pdf/Photolithography_Participant_Guide.pdf

LAB

Dolan_top
Dolan_undercut
Si-crystalline

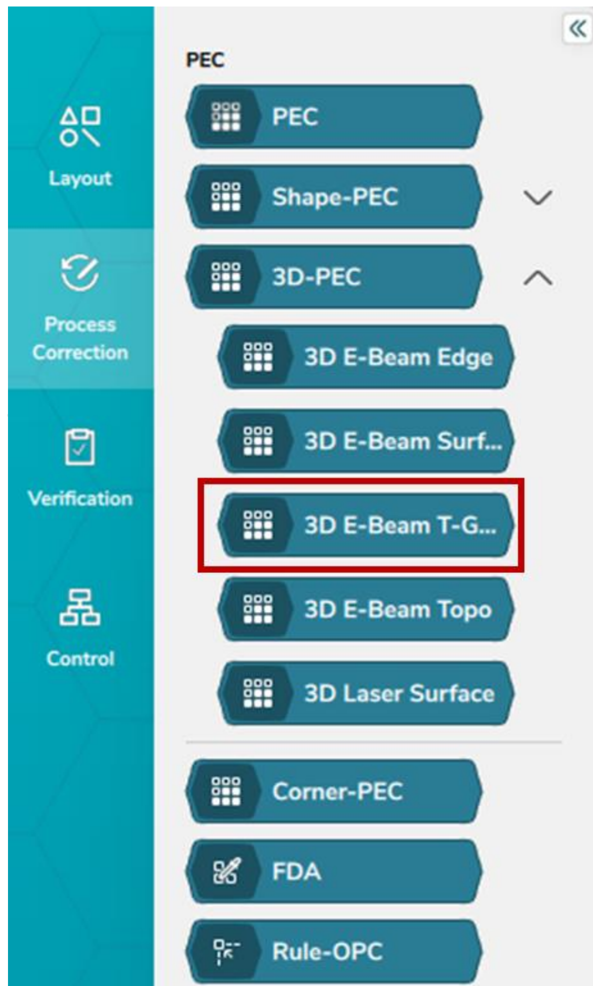
- *3D E-Beam Edge PEC* is suitable for multilayer resist systems:
  - Bi-layer system: one or two developers
  - Multi-layer system: one, two, three… development process

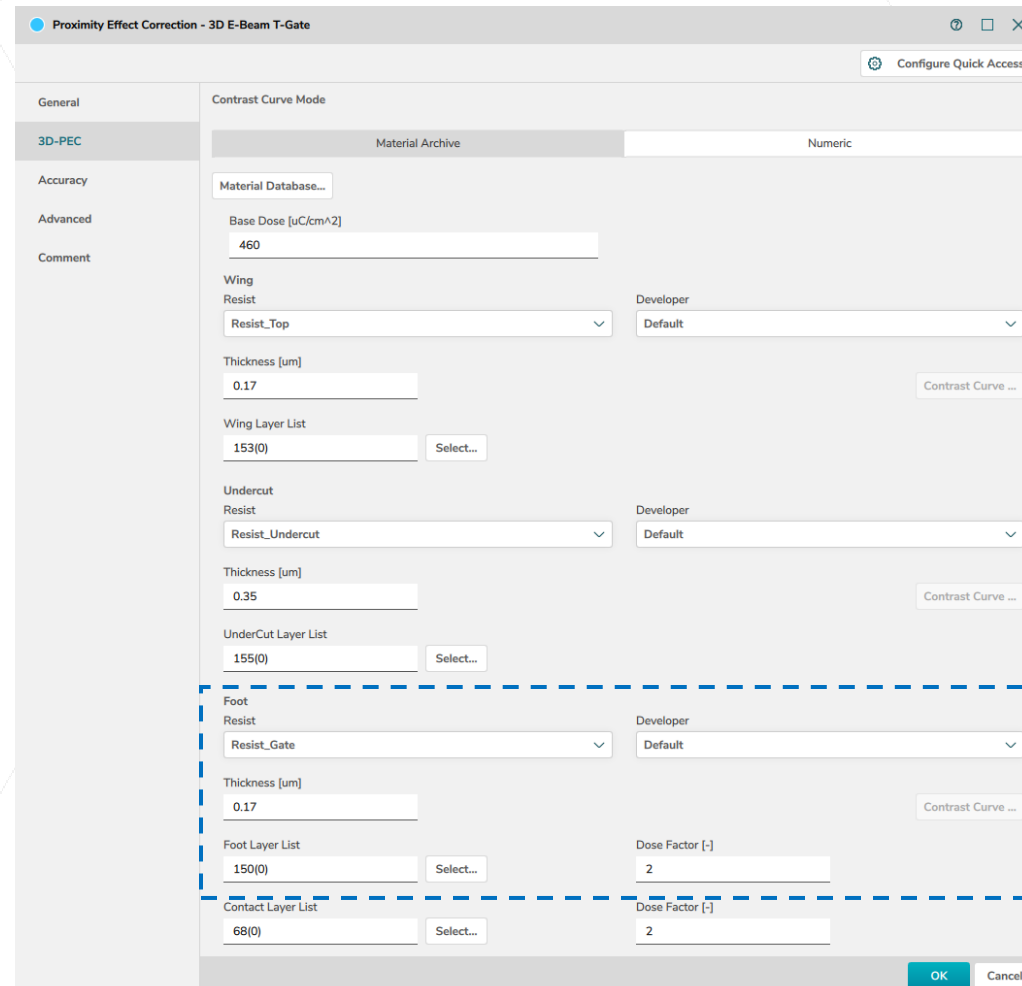


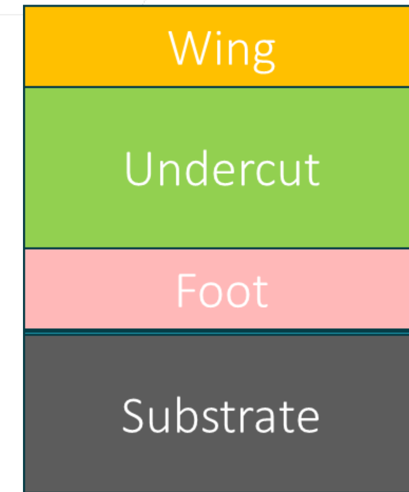
# T-Gate

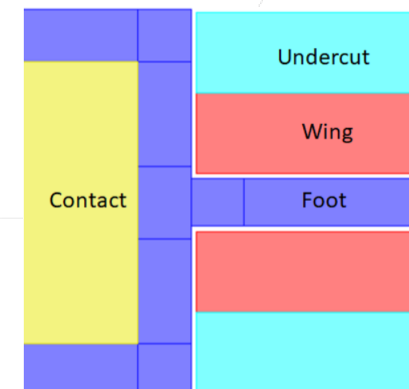
# T-gate

- Build T-gate with Tri-layer resist system



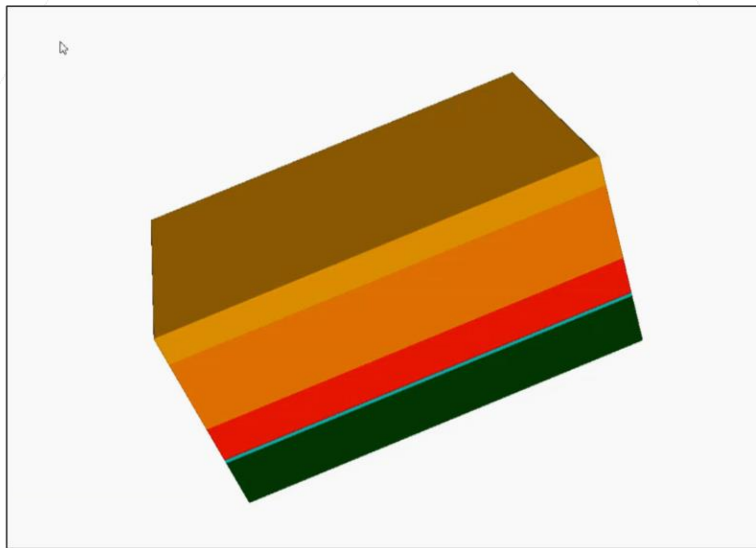



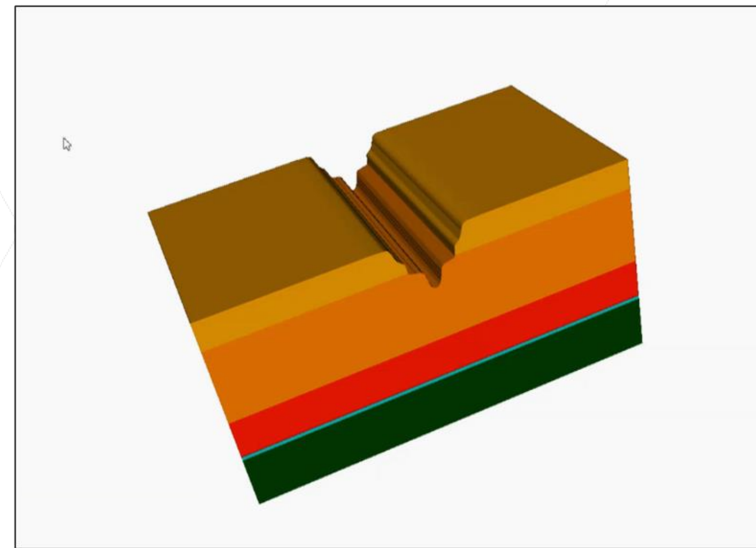



# T-gate

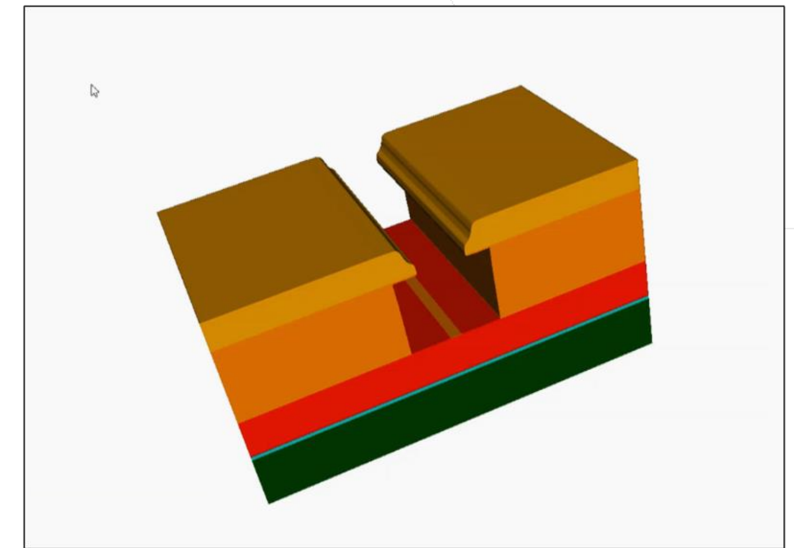
- Build T-gate with Tri-layer resist system with multiple development process



1st development



2nd development

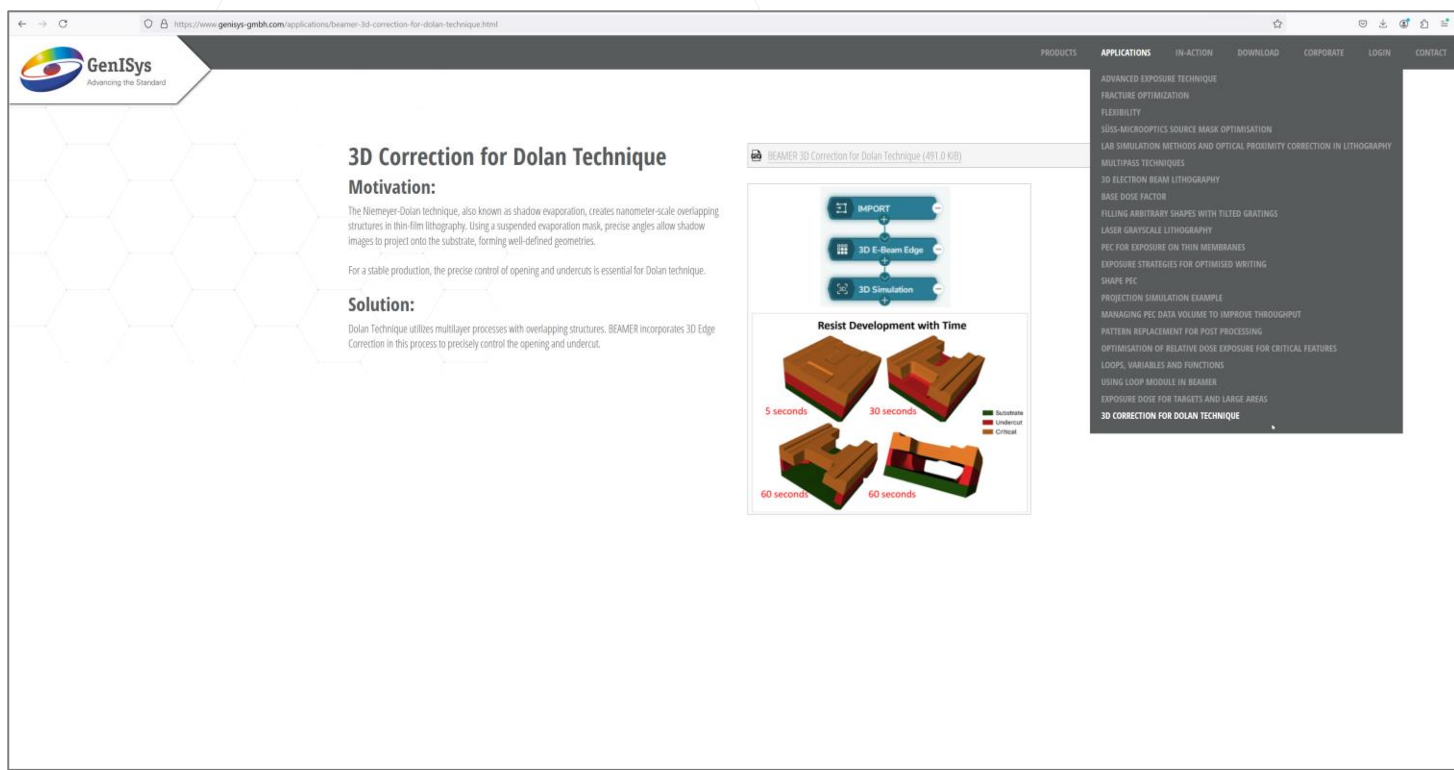


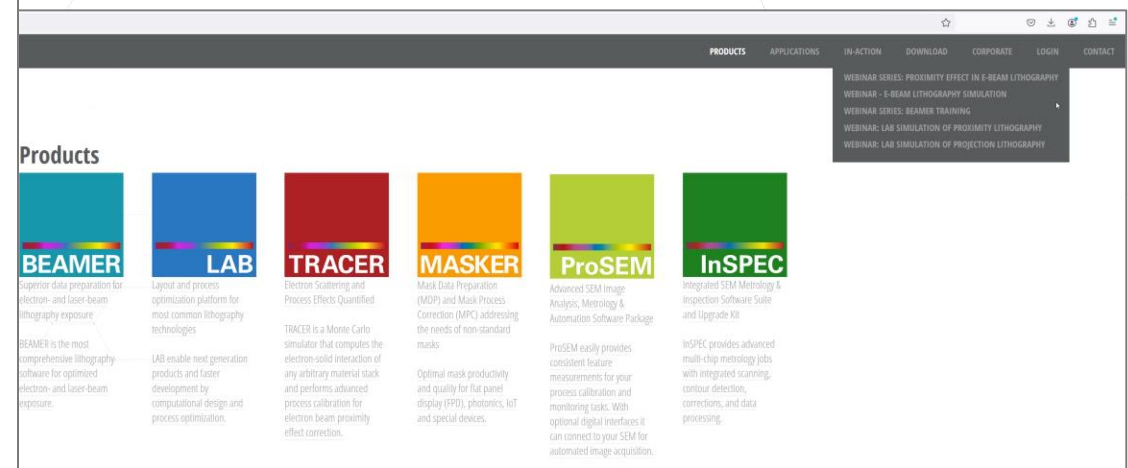
3rd development

LAB

- You can find useful information under:

https://www.genisys-gmbh.com/products.html



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# Thank You!

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