

BEAMER

Building Niemeyer-Dolan Bridges in *BEAMER*
using *3D E-Beam Edge PEC*

- Niemeyer-Dolan Bridge technique

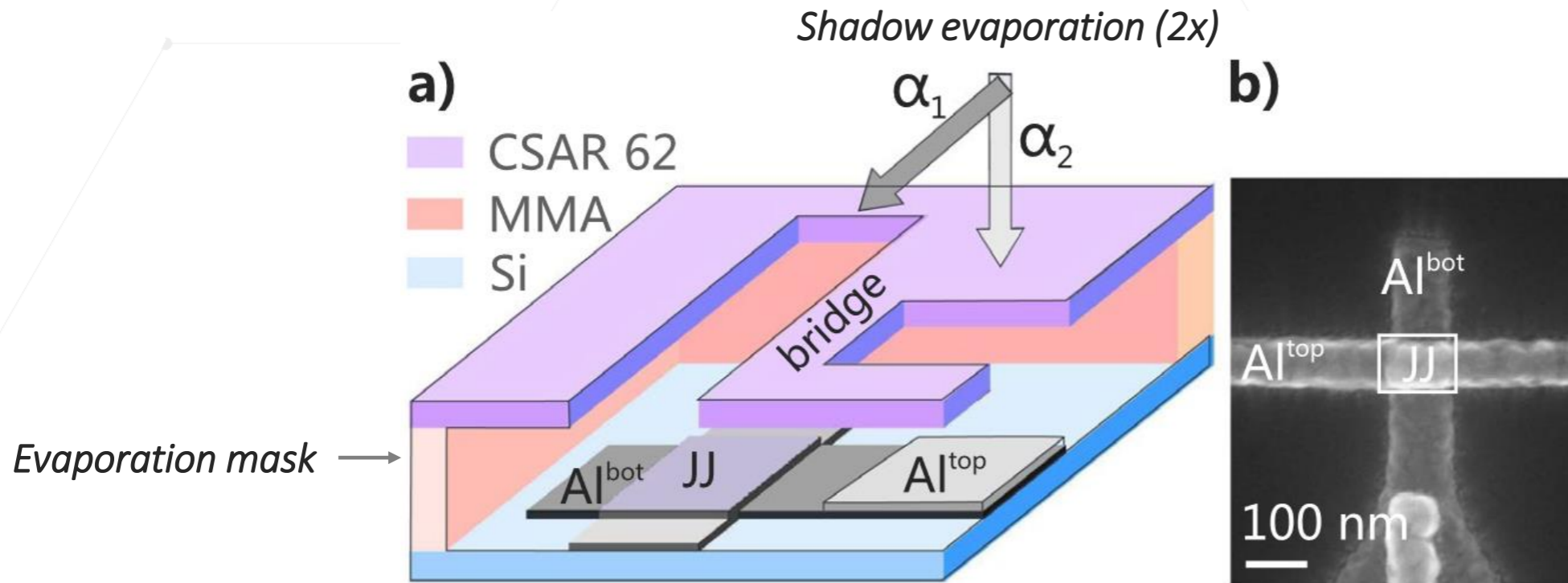


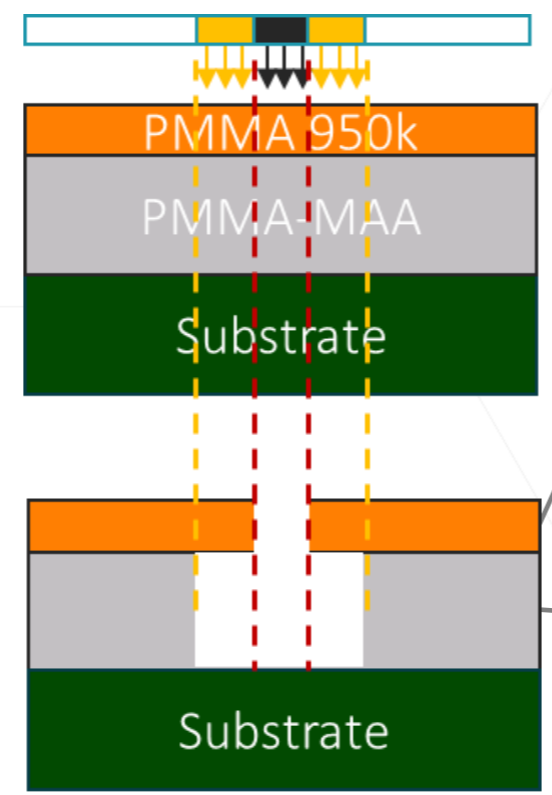
Figure 1. Niemeyer–Niemeyer-Dolan Bridge technique used in this paper. (a) Scheme of the used shadow evaporation process. The first metal layer was deposited at an angle (dark grey color) through two-layer resist mask MMA- CSAR, and the second layer at 0 angle (light grey color). Angular deposition was 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", natureprotfolio (2023)13:6772

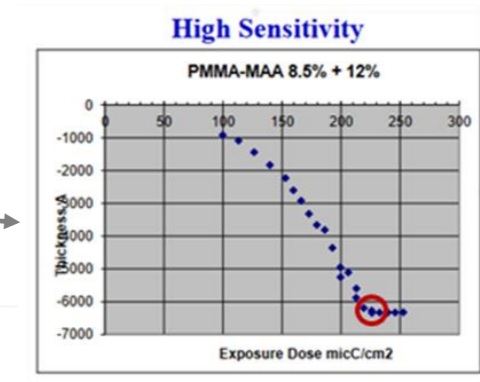
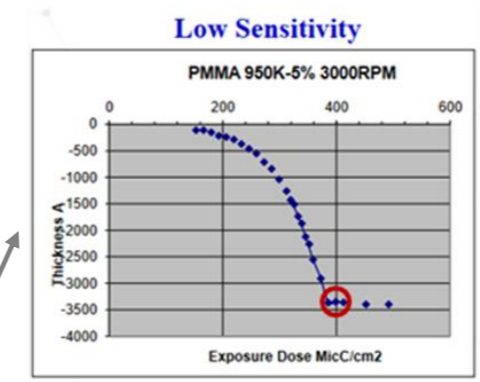
- Traditional E-beam lithography process for Niemeyer-Dolan Bridge



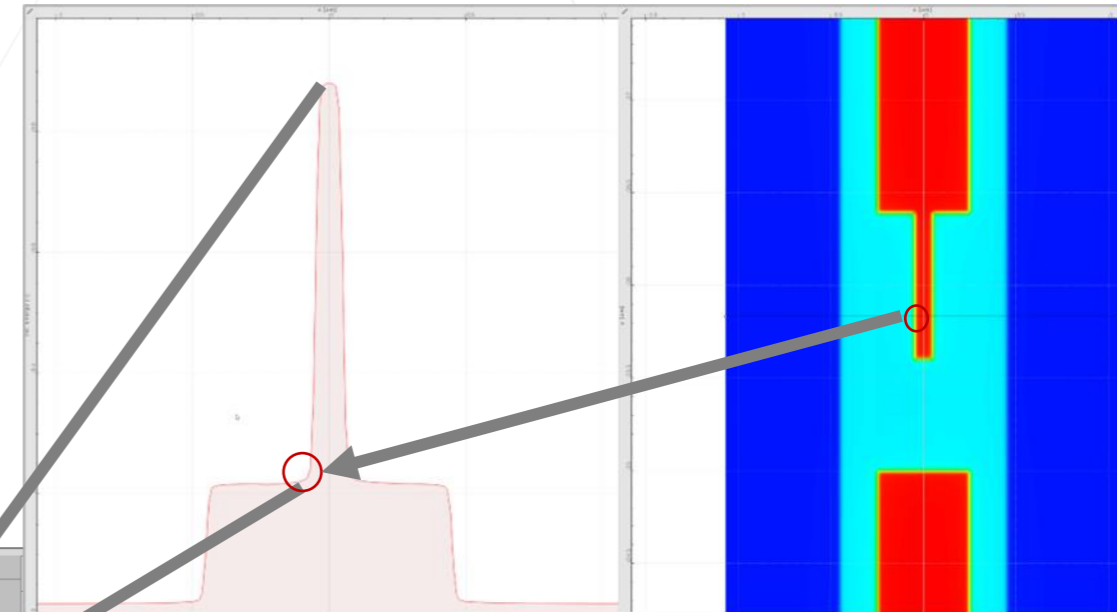
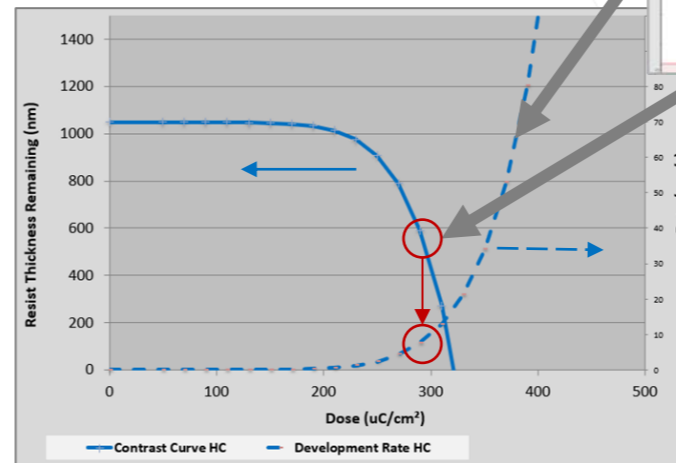
Resist profile of Niemeyer-Dolan Bridge



Traditional E-beam lithography process for Niemeyer-Dolan Bridge



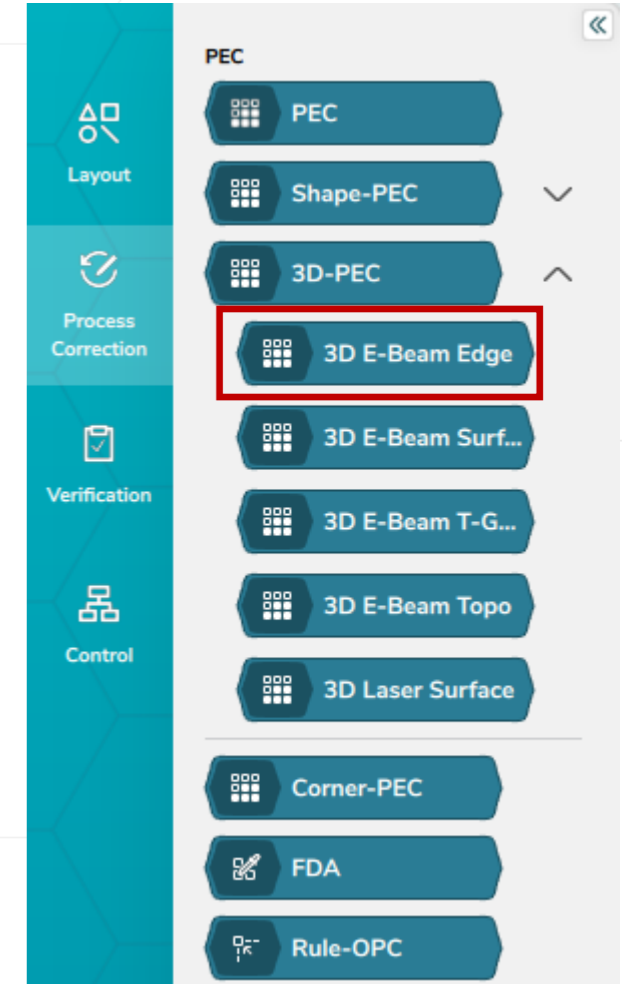
- Critical CD is often oversized?
 - Next to the critical CD structure, additional dose is needed for the undercut clearing
 - The additional energy leading to unintended partial exposure of the critical layer
 - Resist of critical layer with finite contrast shows lateral development (Developer is moving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



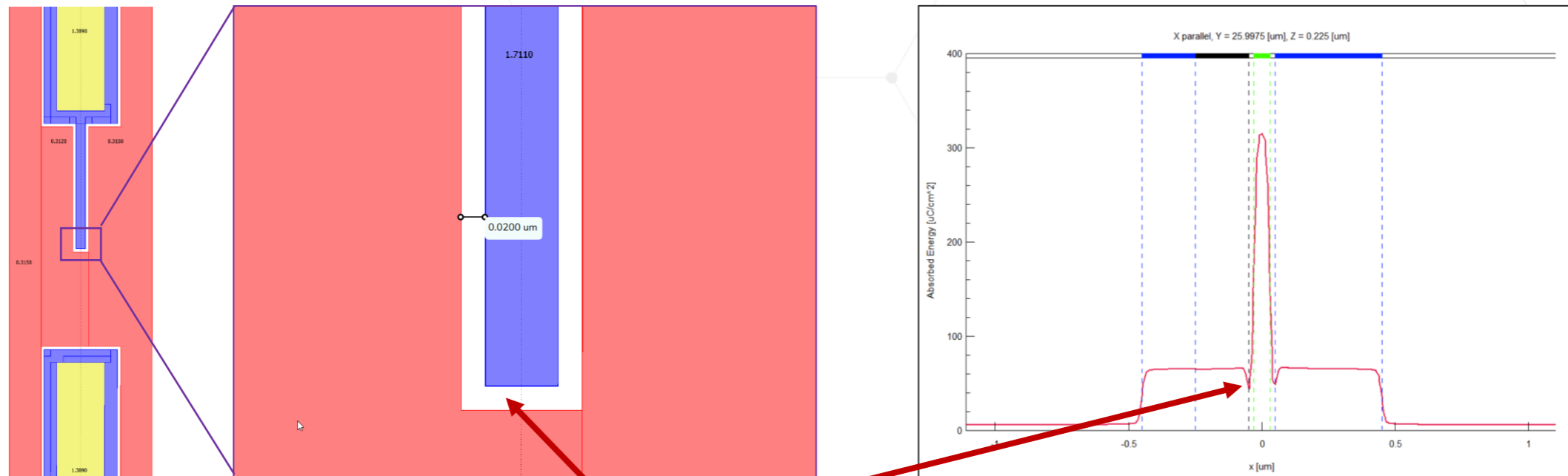
Absorbed Energy Image

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



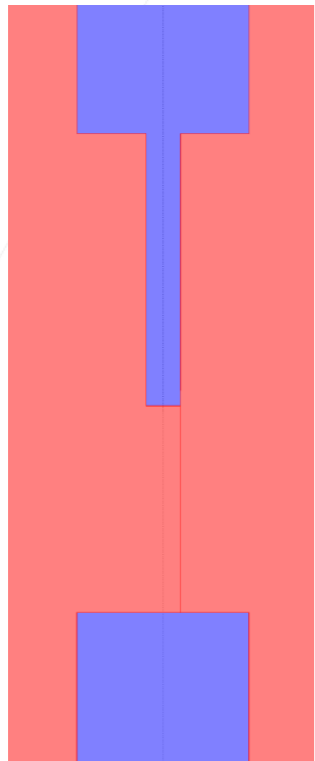
- *3D E-Beam Edge PEC (Bi-layer)*
 - Compensation of lateral development
 - Generate gap between the critical layer and undercut layer. The size of the gap is computed to realize the lateral development front stop at the target position



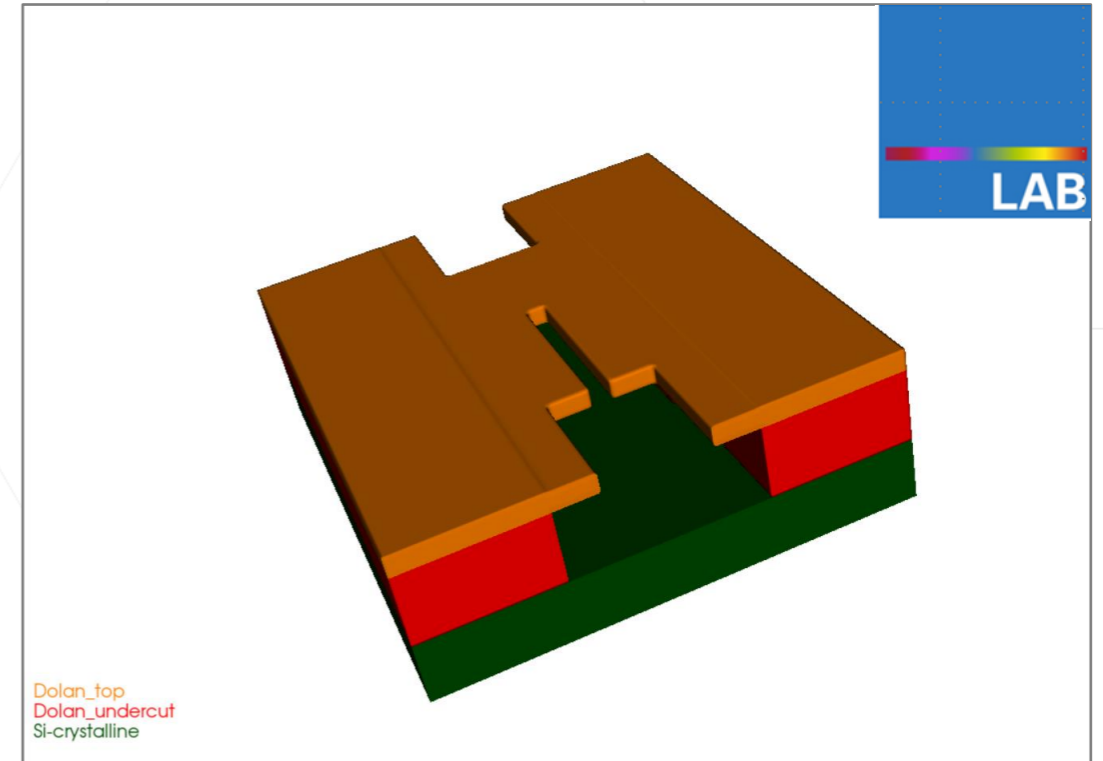
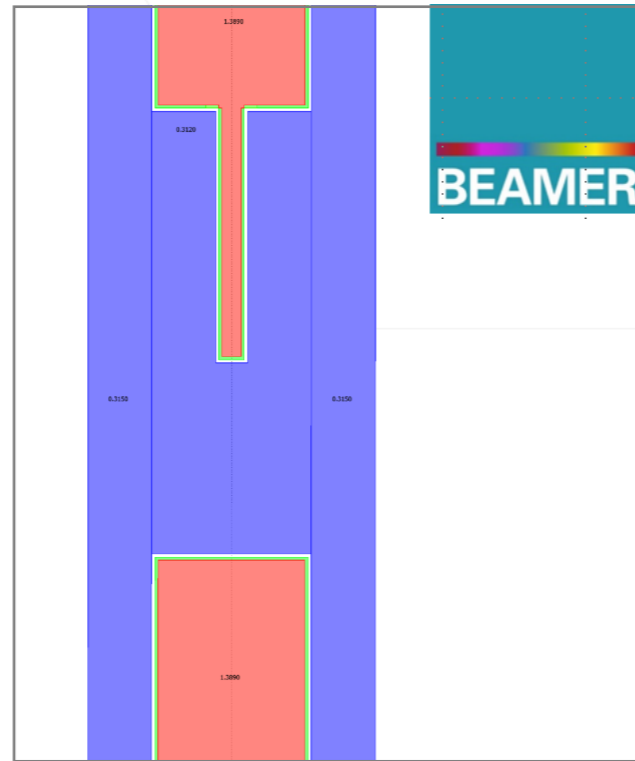
Bias applied to critical structures to compensate for lateral development

Niemeyer-Dolan Bridge

- Let's start to build the bridge

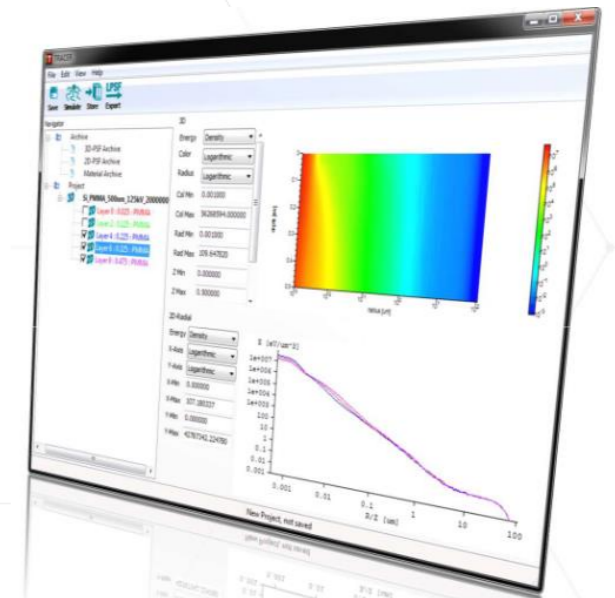
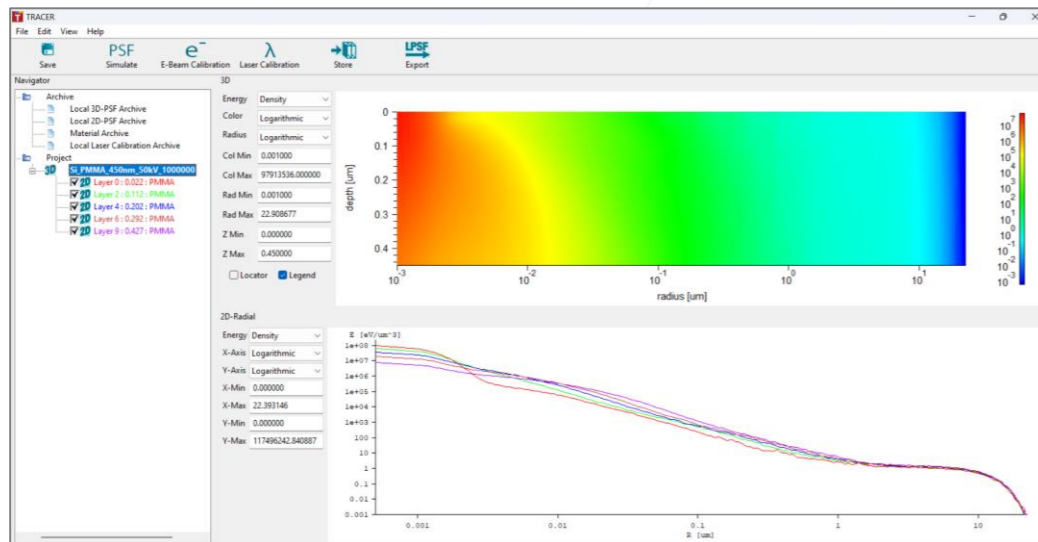


Layout



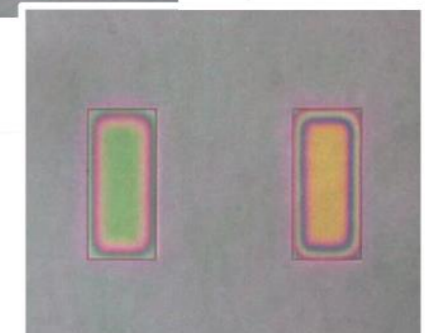
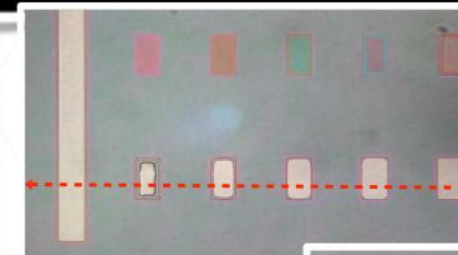
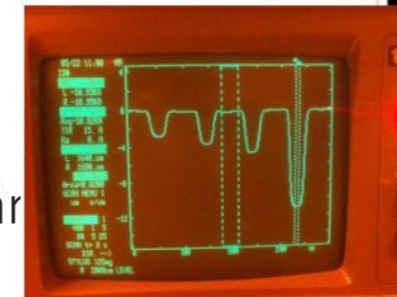
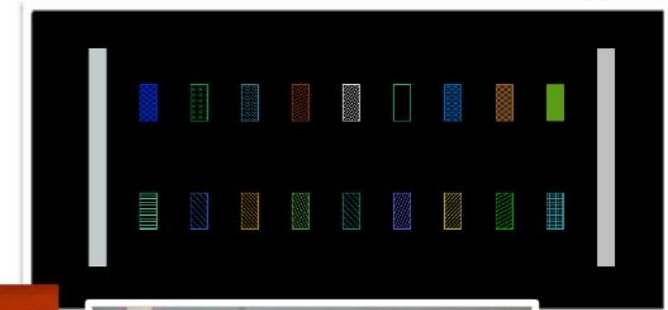
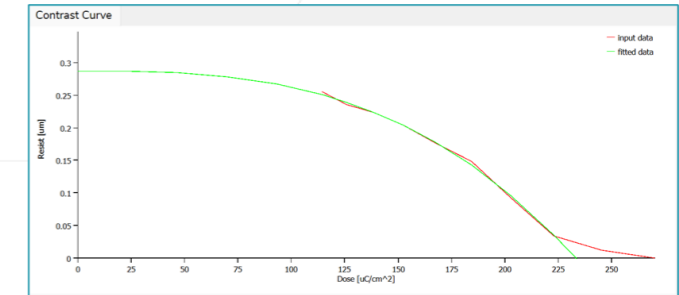
**Important work
before *3D E-Beam Edge PEC***

- 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

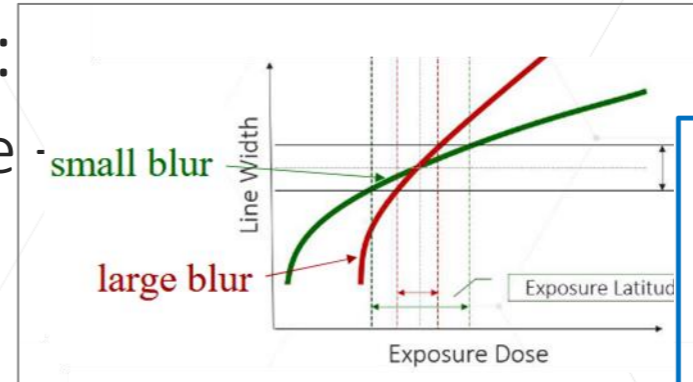


TRACER calculates the absorbed energy spread over resist thickness and distance from the incident beam

- Important work before *3D E-Beam Edge PEC*:
 - Contrast Curve measurement for each resist layer
 - Exposure voltage
 - Substrate stack
 - Pattern
 - Width & length $> 3 \times \text{Beta}$
 - Length easily be measured with profilometer
 - Typical pattern: $150 \mu\text{m} \times 300 \mu\text{m}$
 - Separated pattern to avoid interaction
 - Resist thickness
 - Thicker resist layer with higher precision due to hard 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*



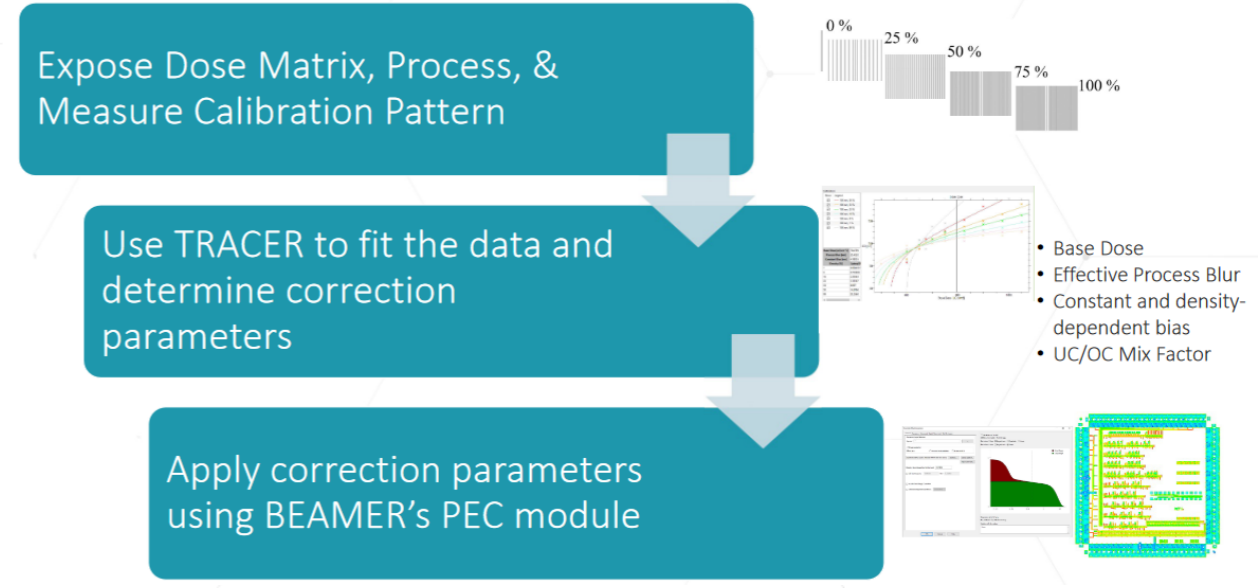
Typical values:
 100keV, low current (~ 1nA), high contrast thin (100nm) PMMA: ~ 15nm
 100keV, high current (~20nA), low contrast thick PMMA: ~ 30nm
 50keV, high current (~50nA), low contrast thick PMMA: ~ 50nm

Application Note

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

Layout

Process Correction

Verification

Control

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

Proximity Effect Correction - 3D E-Beam Edge

Configure Quick Access

General	Correction Layer Selection Layer(s)
3D-PEC	
Accuracy	
Advanced	
Comment	

PSF Representation

Archive	Gaussian Approximation	Numerical PSF
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Tag: : Substrate: Si; Layers: ; Resists: PMMA 450 nm; Energy [kV]: 50;

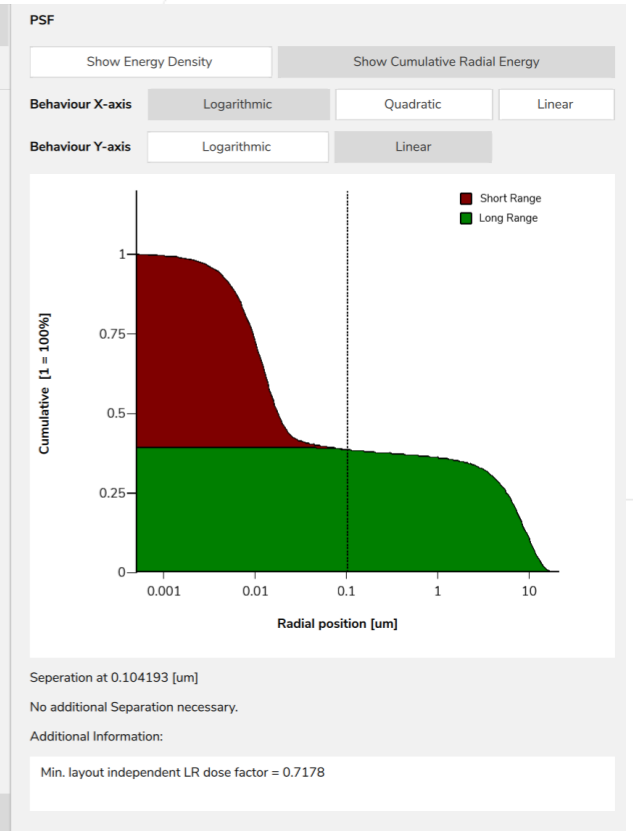
Archive... Global Archive... View Comment...

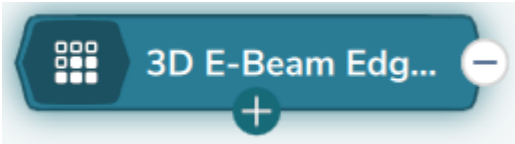
Effective Short Range Blur FWHM[um]

0.020000

Add Gamma [um] 1.000000 Nue 0.100000

OK Cancel





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 [$\mu\text{C}/\text{cm}^2$]

300.000000

Critical Resist Layer

Resist: Dolan_top | Developer: Default

Layer List

1(0) | Select... | Dose Factor [-]: 1 | Thickness [μm]: 0.1

No Lat. Dev. List

Select... | Dose Factor [-]: 1.000000

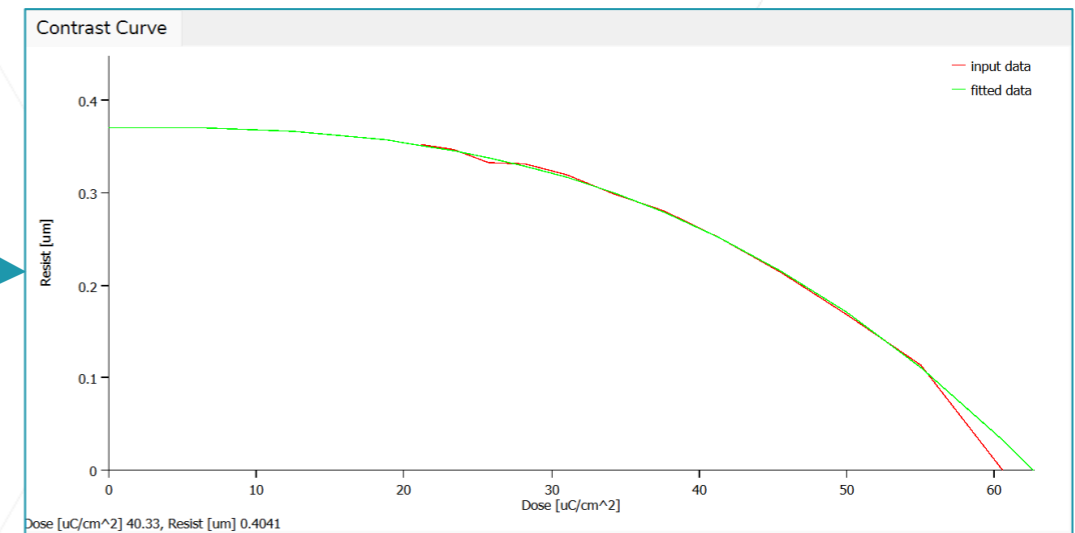
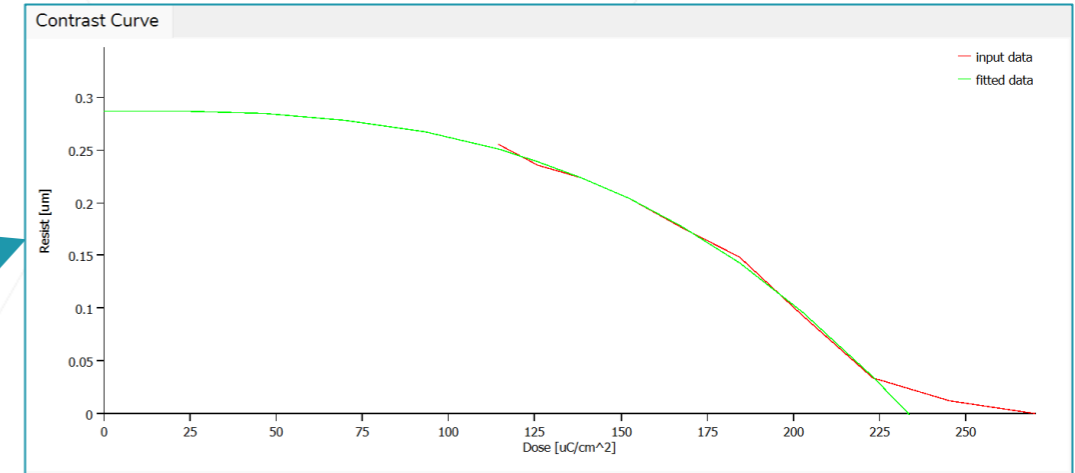
Resist Layer

Dolan_undercut | Developer: Default

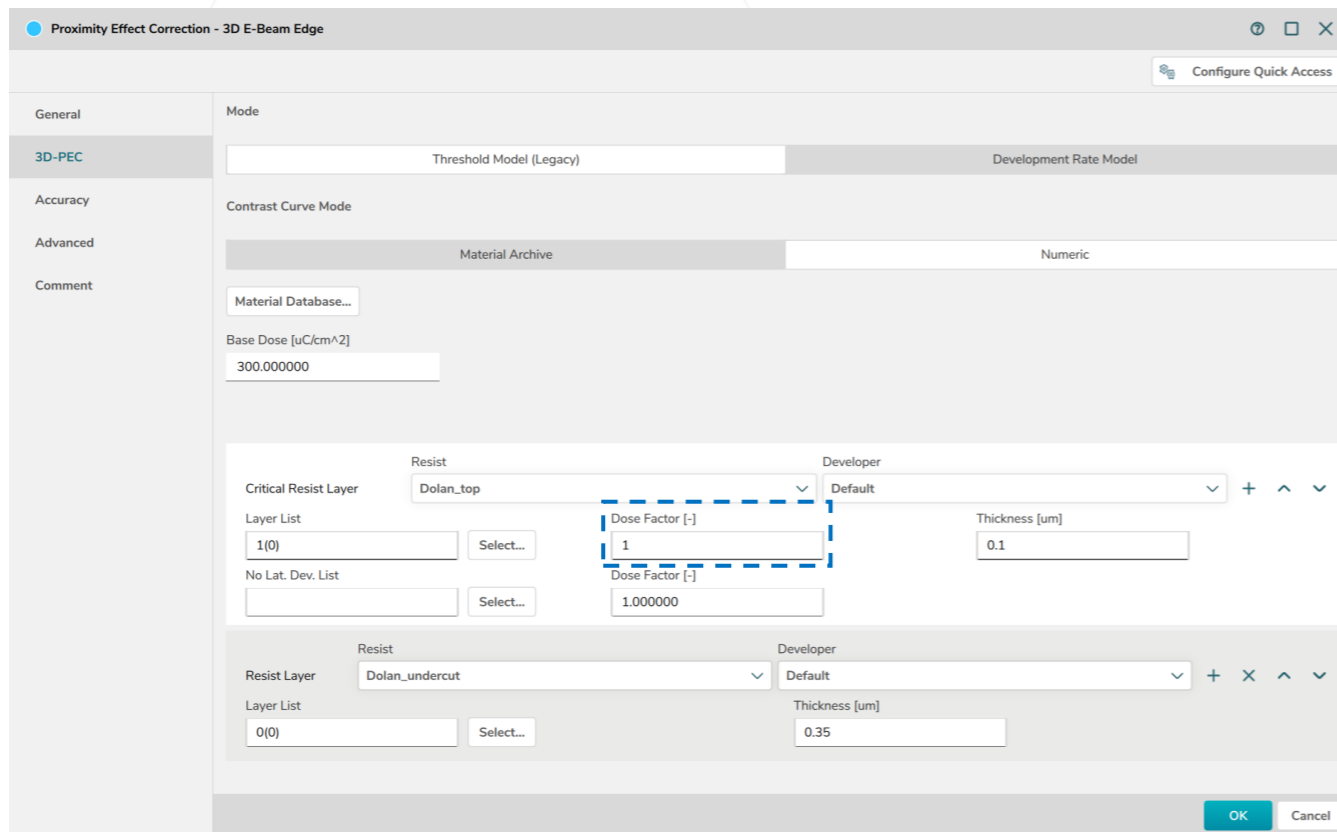
Layer List

0(0) | Select... | Thickness [μm]: 0.35

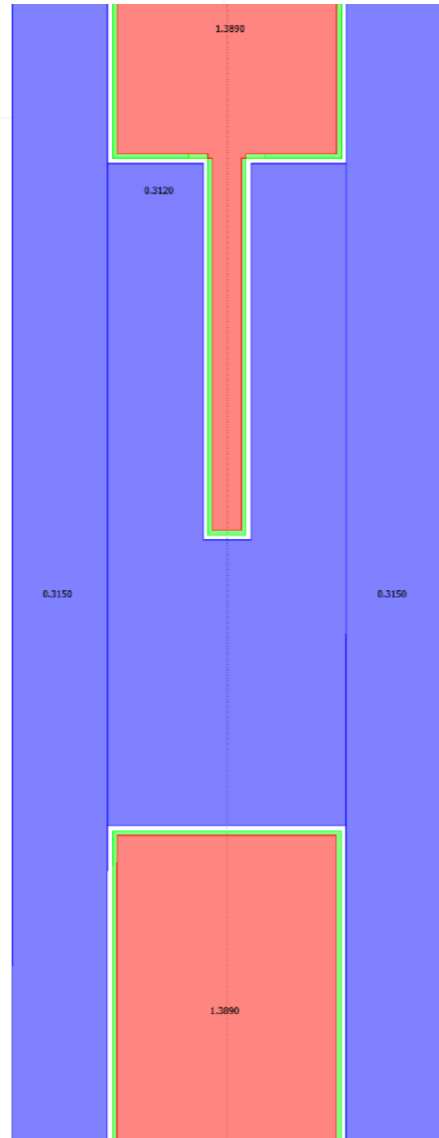
OK | Cancel



3D E-Beam Edge PEC

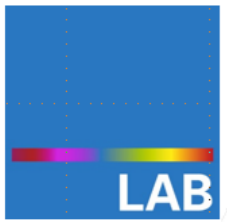


- The critical layer that includes exact lateral development compensation can be placed anywhere in the stack.
- The “critical” layer allows for overdose/undersize. Some regions, e.g. contacts, can be excluded from the lat. dev. computation. -> “No Lat. Dev. List”.
- The “non critical” layers, e.g. undercut,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

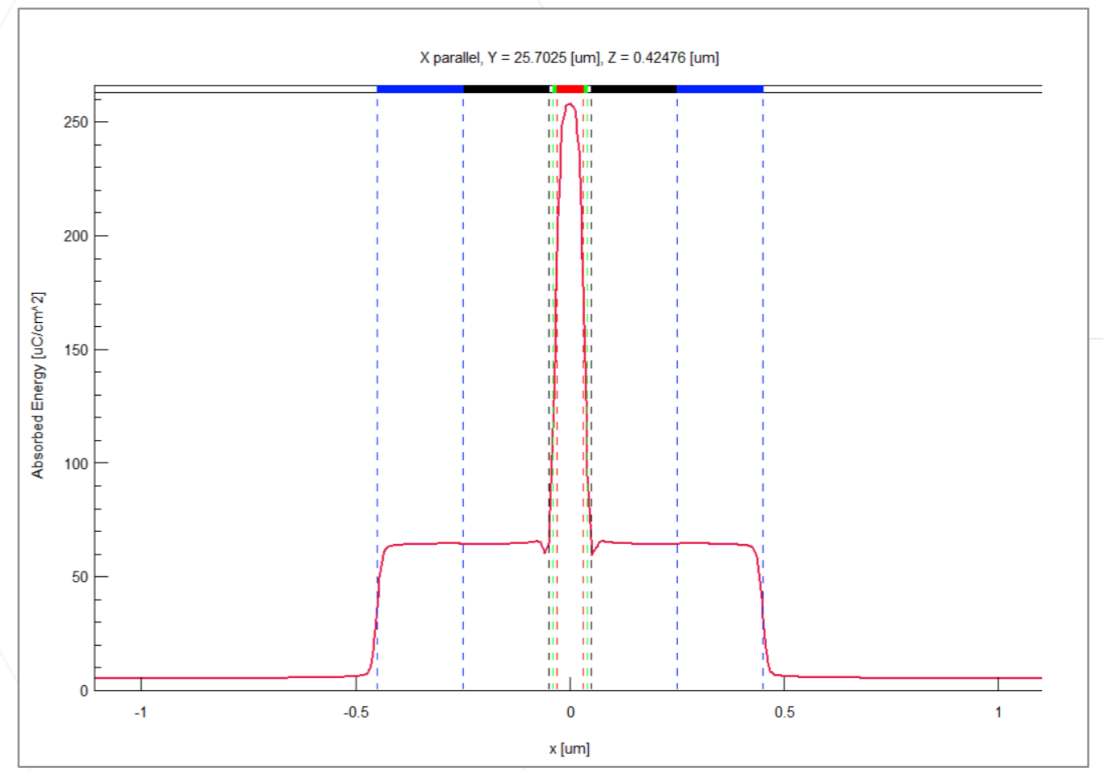
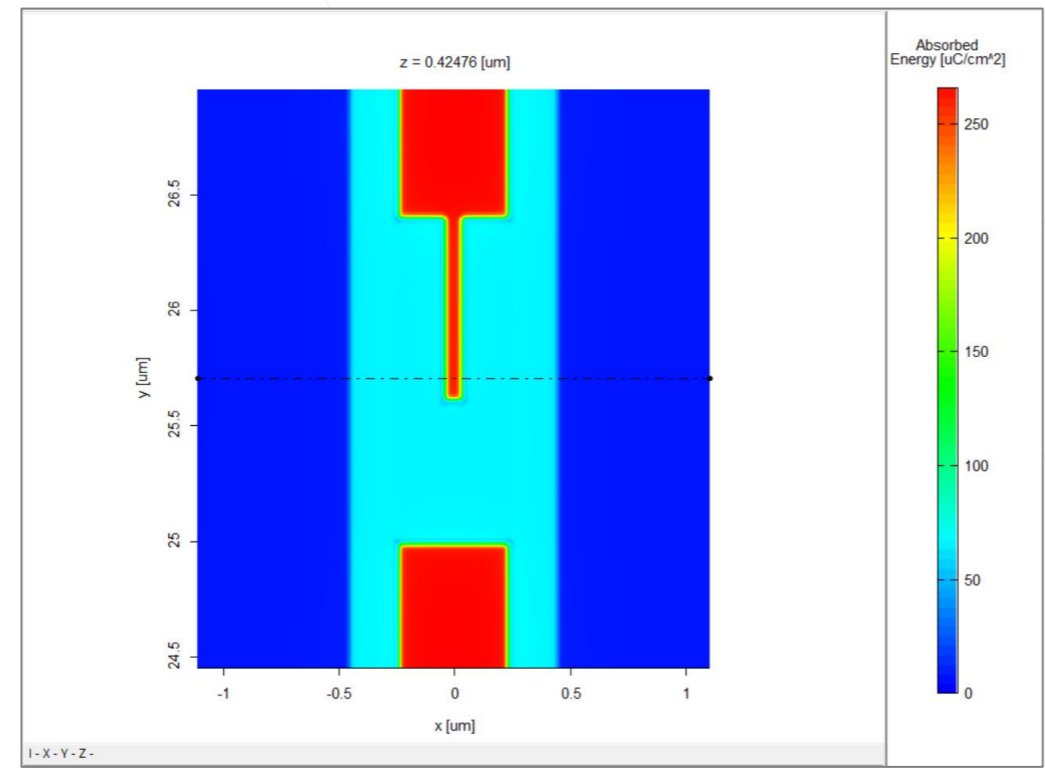
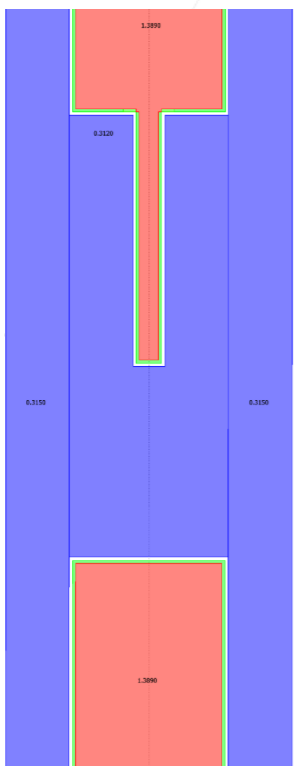


- IMPORT ▶|
- E-Beam 3D ▶|
- Resist ▶|

LAB simulation



- IMPORT ▶
- E-Beam 3D ▶
- Resist ▶

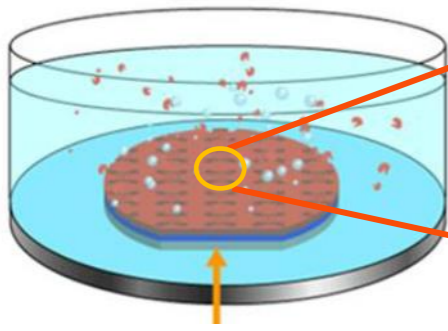


IMPORT

Top-Down View of Absorbed Energy Image

Absorbed Energy Image

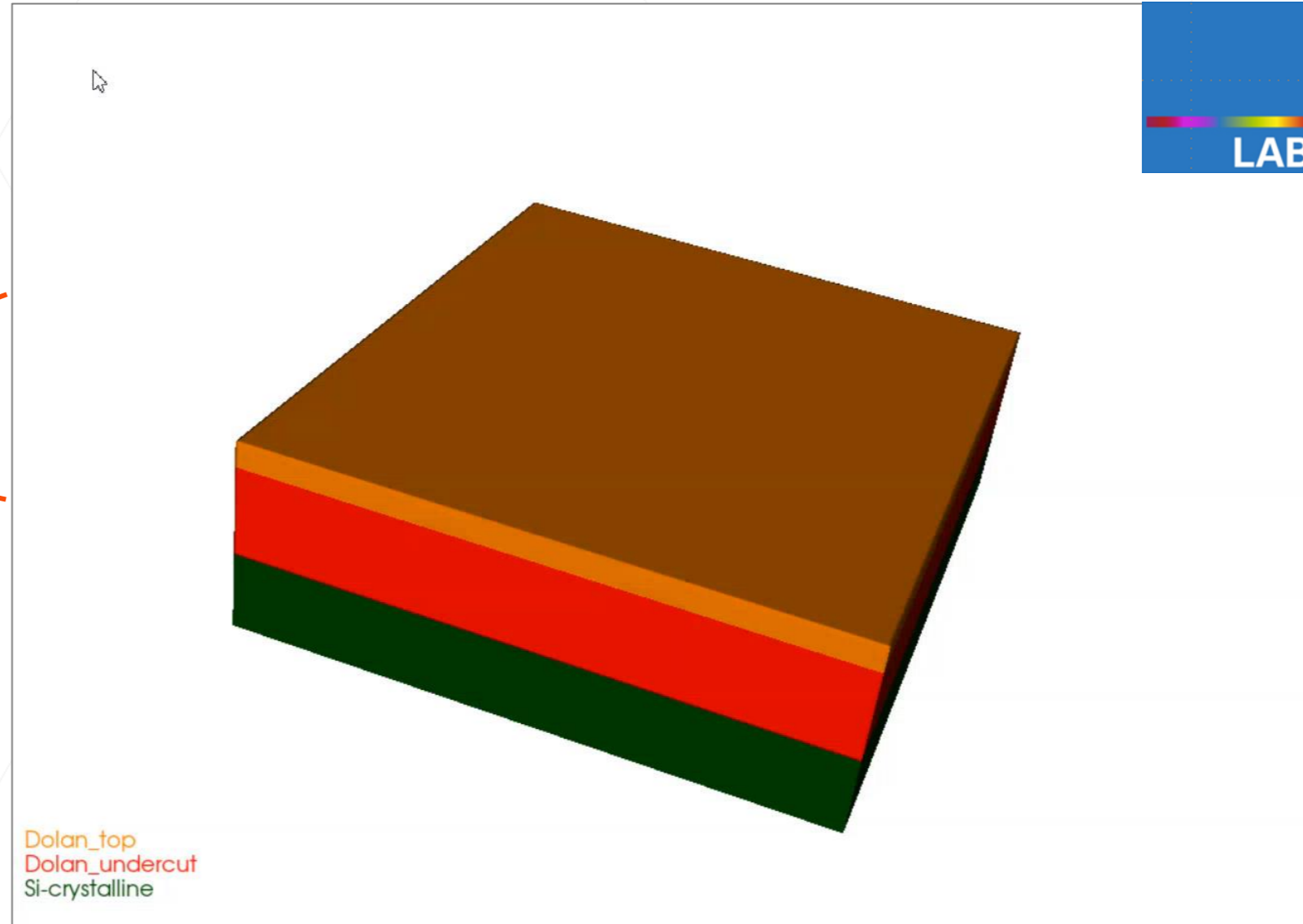
**Development process*



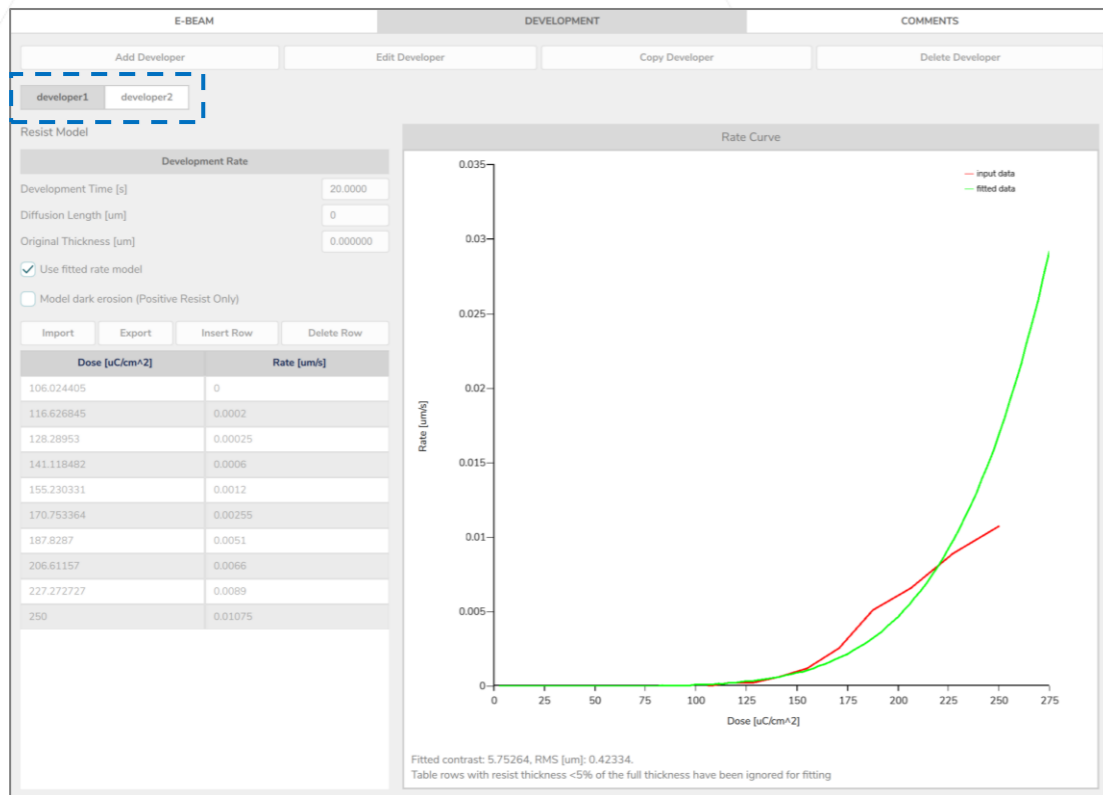
Substrate

**Image:*

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

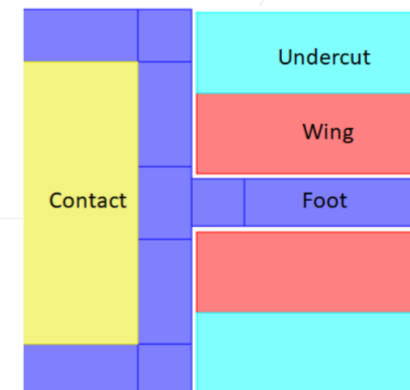
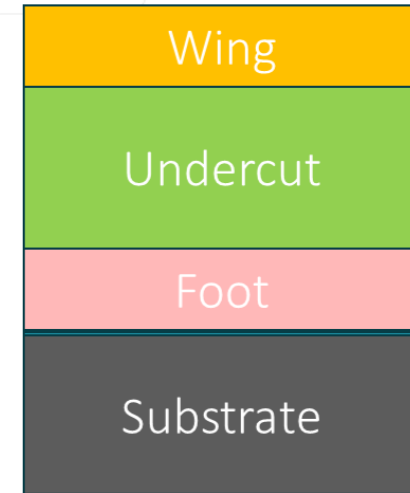
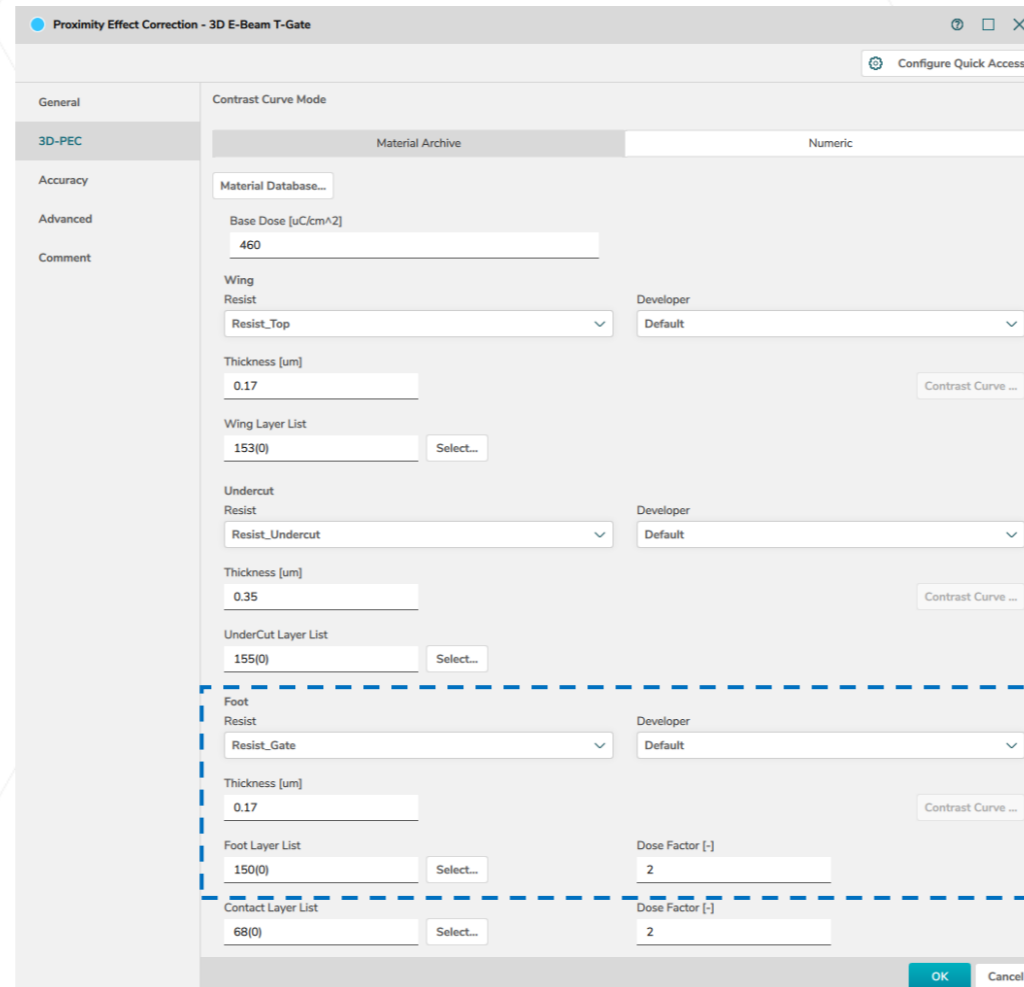
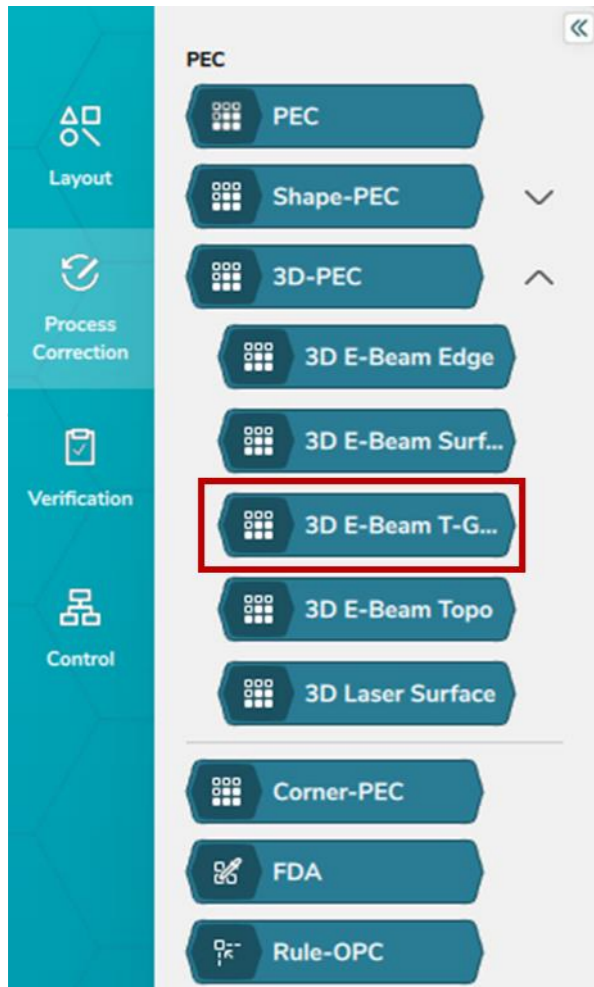


- *3D E-Beam Edge PEC* is suitable for multilayer resist systems:
 - Bi-layer system: one or two developers
 - Multi-layer system: one, two, three... development process

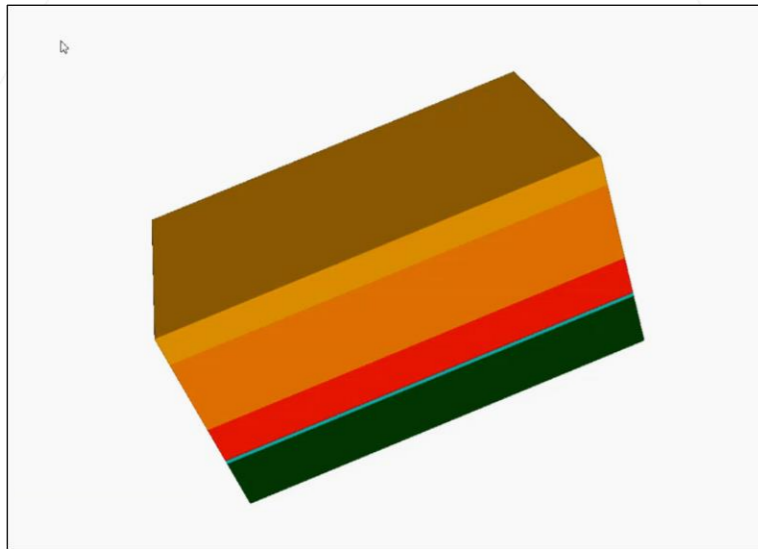


T-Gate

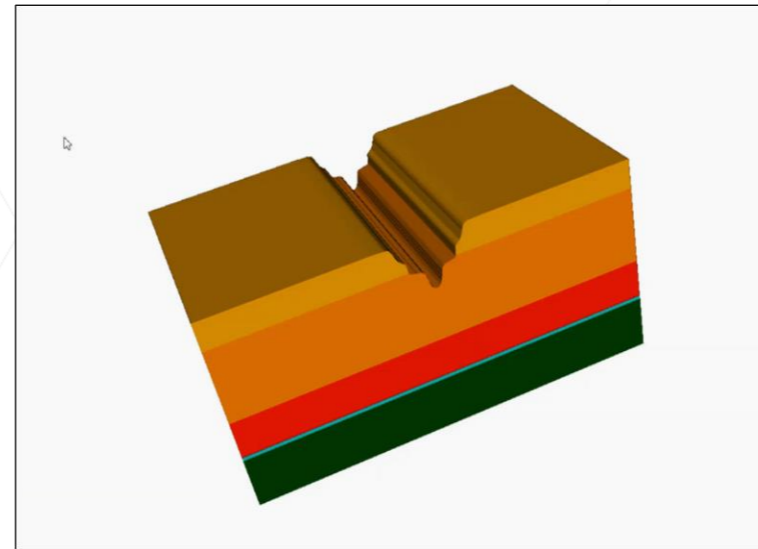
- Build T-gate with Tri-layer resist system



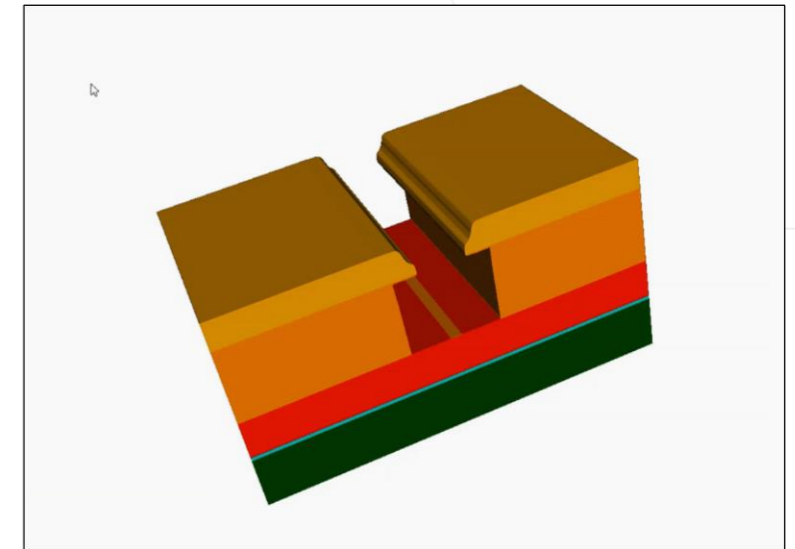
- Build T-gate with Tri-layer resist system with multiple development process



1st development

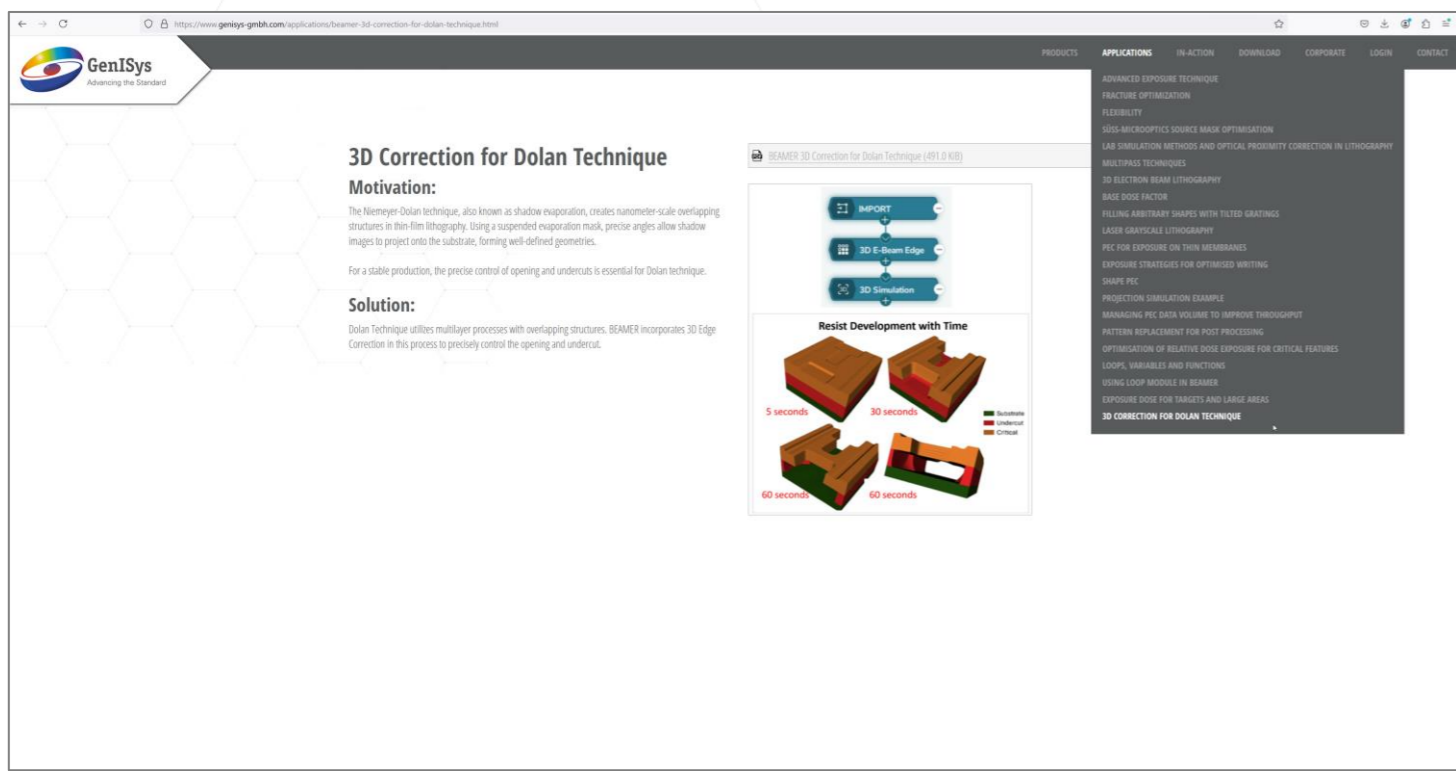


2nd development



3rd development

- You can find useful information under:
<https://www.genisys-gmbh.com/products.html>



3D Correction for Dolan Technique

Motivation:
 The Niemeyer-Dolan technique, also known as shadow evaporation, creates nanometer-scale overlapping structures in thin-film lithography. Using a suspended evaporation mask, precise angles allow shadow images to project onto the substrate, forming well-defined geometries.

For a stable production, the precise control of opening and undercuts is essential for Dolan technique.

Solution:
 Dolan Technique utilizes multilayer processes with overlapping structures. BEAMER incorporates 3D Edge Correction in this process to precisely control the opening and undercut.

BEAMER 3D Correction for Dolan Technique (491.0 KiB)

Workflow: IMPORT → 3D E-Beam Edge → 3D Simulation

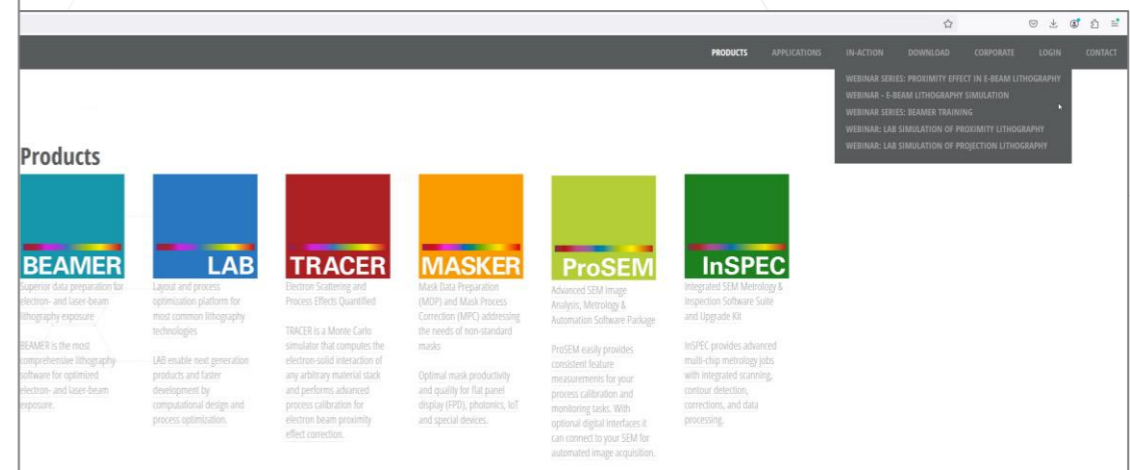
Resist Development with Time

5 seconds, 30 seconds, 60 seconds (repeated for two views)

Legend: Accurate (green), Undercut (red), Critical (orange)

Navigation: PRODUCTS, APPLICATIONS, IN-ACTION, DOWNLOAD, CORPORATE, LOGIN, CONTACT

Applications list: ADVANCED EXPOSURE TECHNIQUE, FRACTURE OPTIMIZATION, FLEXIBILITY, SUB-MICROOPTICS SOURCE MASK OPTIMISATION, LAB SIMULATION METHODS AND OPTICAL PROXIMITY CORRECTION IN LITHOGRAPHY, MULTIPASS TECHNIQUES, 3D ELECTRON BEAM LITHOGRAPHY, BASE DOSE FACTOR, FILLING ARBITRARY SHAPES WITH FILTED GRABINGS, LASER GRAPHICAL LITHOGRAPHY, PEC FOR EXPOSURE ON THIN MEMBRANES, EXPOSURE STRATEGIES FOR OPTIMISED WRITING, SHAPE PEC, PROJECTION SIMULATION EXAMPLE, MANAGING PEC DATA VOLUME TO IMPROVE THROUGHPUT, PATTERN REPLACEMENT FOR POST PROCESSING, OPTIMISATION OF RELATIVE DOSE EXPOSURE FOR CRITICAL FEATURES, LOOP, VARIABLES AND FUNCTIONS, USING LOOP MODULE IN BEAMER, EXPOSURE DOSE FOR TARGETS AND LARGE AREAS, 3D CORRECTION FOR DOLAN TECHNIQUE



Products

- BEAMER**: Superior data preparation for electron- and laser-beam lithography exposure. BEAMER is the most comprehensive lithography software for optimized electron- and laser-beam exposure.
- LAB**: Layout and process optimization platform for most common lithography technologies. LAB enable next generation products and faster development by computational design and process optimization.
- TRACER**: Electron-Scattering and Process Effects Quantified. TRACER is a Monte Carlo simulator that computes the electron-solid interaction of any arbitrary material stack and performs advanced process calibration for electron beam proximity effect correction.
- MASKER**: Mask Data Preparation (MDP) and Mask Process Correction (MPC) addressing the needs of non-standard masks. Optimal mask productivity and quality for flat panel display (FPD), photonics, IoT and special devices.
- ProSEM**: Advanced SEM Image Analysis, Metrology & Automation Software Package. ProSEM easily provides consistent feature measurements for your process calibration and monitoring tasks. With optional digital interfaces it can connect to your SEM for automated image acquisition.
- InSPEC**: Integrated SEM Metrology & Inspection Software Suite and Upgrade Kit. InSPEC provides advanced multi-chip metrology jobs with integrated scanning, contour detection, corrections, and data processing.

Navigation: PRODUCTS, APPLICATIONS, IN-ACTION, DOWNLOAD, CORPORATE, LOGIN, CONTACT

Webinars: WEBINAR SERIES: PROXIMITY EFFECT IN E-BEAM LITHOGRAPHY, WEBINAR - E-BEAM LITHOGRAPHY SIMULATION, WEBINAR SERIES: BEAMER TRAINING, WEBINAR: LAB SIMULATION OF PROXIMITY LITHOGRAPHY, WEBINAR: LAB SIMULATION OF PROJECTION LITHOGRAPHY

Thank You!

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