

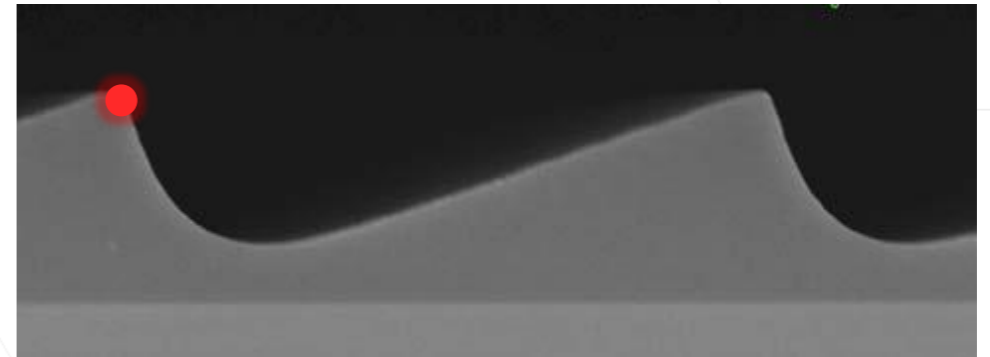
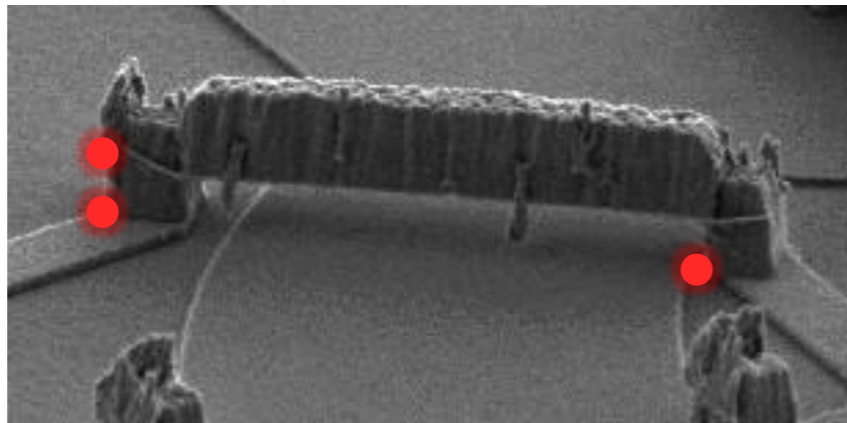
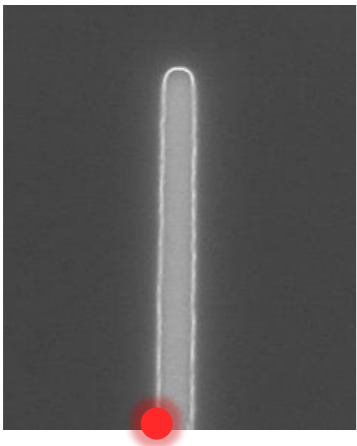
BEAMER

Living on the edge
Corrections using PEC

- The Edge...
- Edge PEC
- Surface PEC
- Lateral development
- In depth look

We all are driving our processes towards the edge of the possible.

It may be the edge of a design or the edge of a surface or multilayer-stacks leading to multiple-edges ...

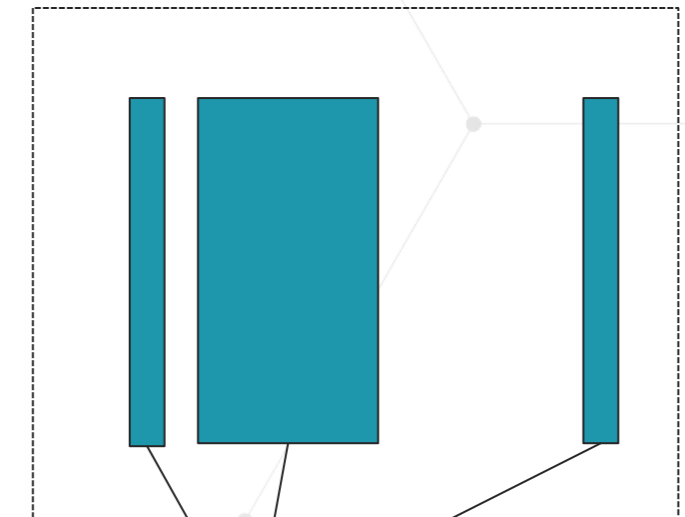


Let us dive in the **setup** and **purpose** of each correction method in **BEAMER** and let us then go further into some **algorithmic details** to **understand** better the **mechanism** of each

- The Edge...
- Edge PEC
- Surface PEC
- Lateral development
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Proximity Effect Correction (PEC)

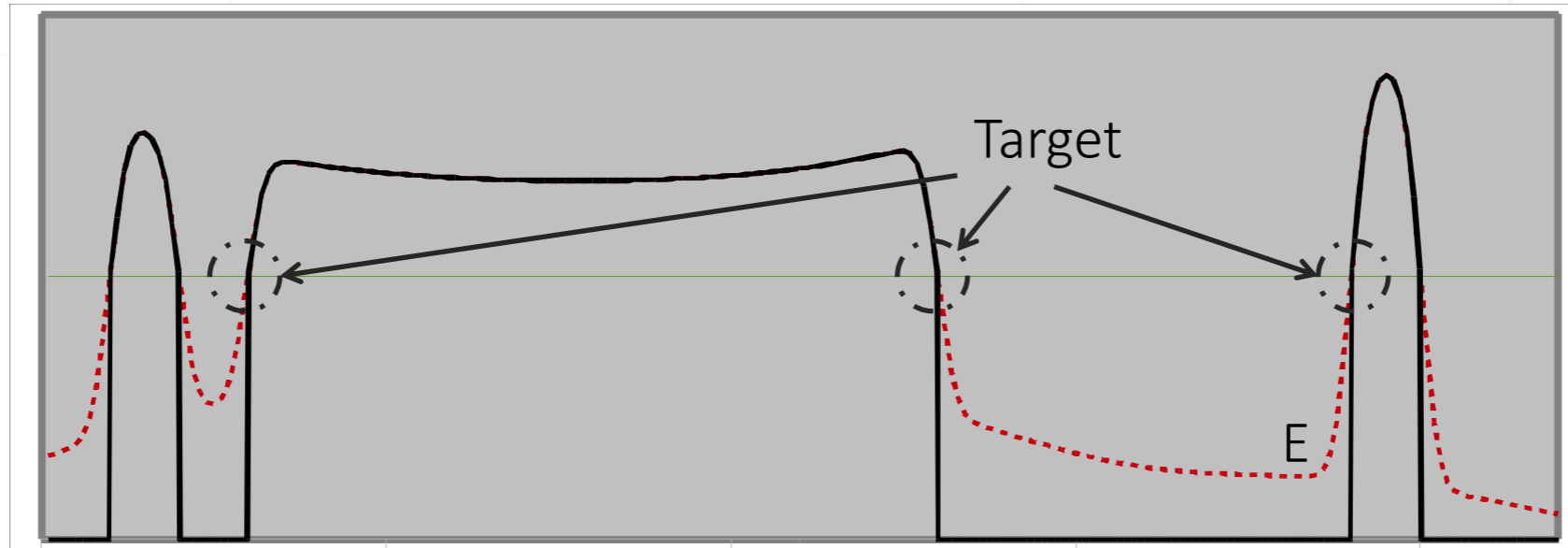
- Correction's target
 - Adjust all feature edges to the same absorbed energy:
Set-On Dose of resist
 - **Inside** the feature $E(x) > \text{Set-On Dose}$:
 - Resist **remains** (negative)
 - **Outside** the feature $E(x) < \text{Set-On Dose}$:
 - Resist is **removed** (negative)
- Correction's equation
 - $E(\text{edge}) = 0.5 = D(x) \otimes \text{PSF}$



Dose factor = 0.5

J. Pavkovich, *J. Vac.Sci. Technol., B*, Vol.4, No.1, Jan/Feb 1986.

- PEC works for any layout condition and shape

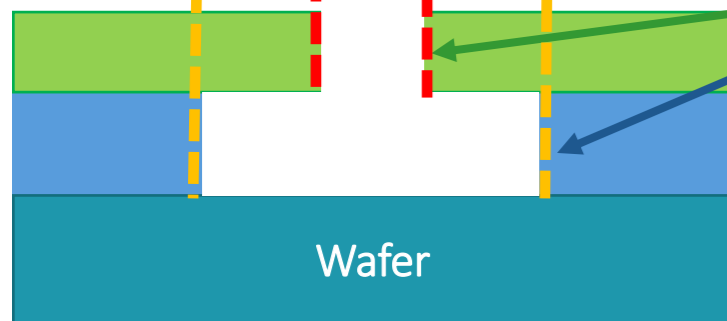
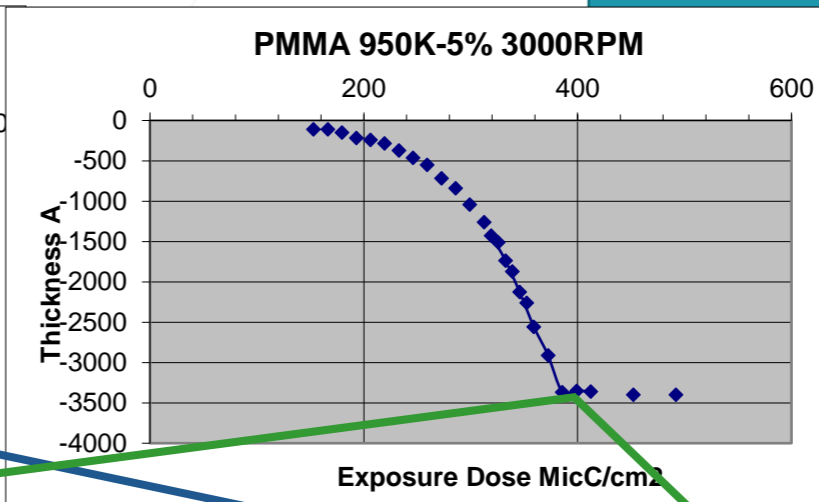
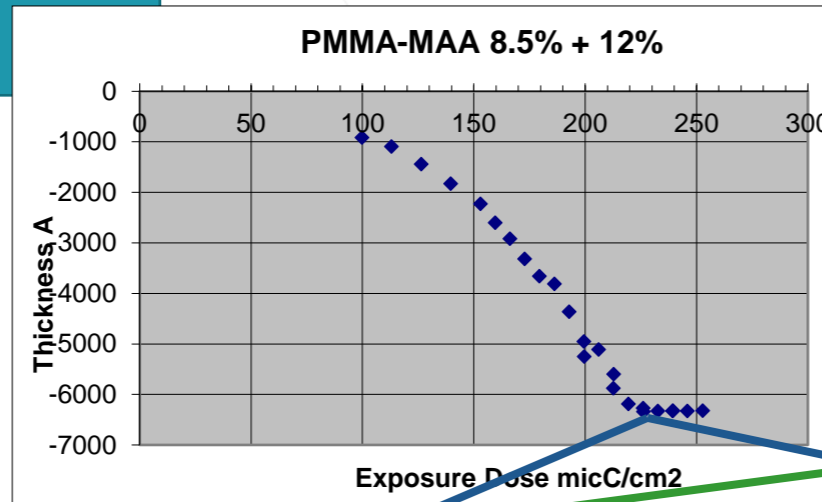
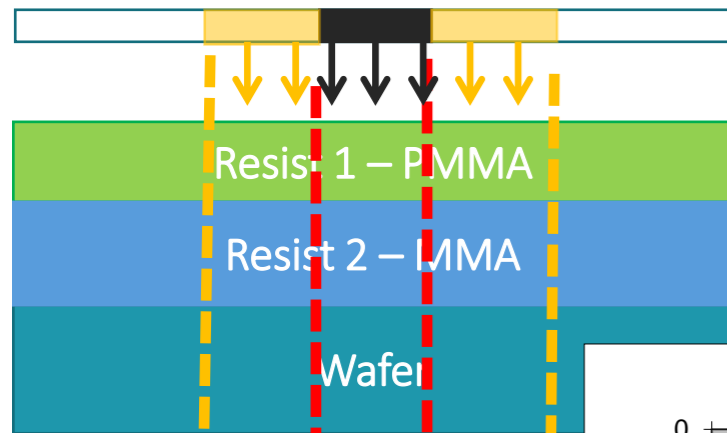


- Yields excellent **CD control** at best process latitude
- Resolves lines and gaps **symmetrically**
 - Reduces exposure dose in large areas lowering the scattering within gaps
 - Sets “Isofocal” correction – insensitive to blur variation

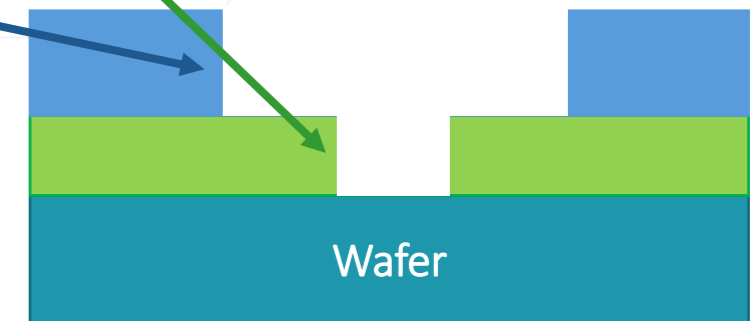
- The parameters of the **exposure beam** define the PEC result ...
 - Point Spread Function (PSF)
 - Determines **area of interaction** between the beam and the substrate
 - Ideally **Gaussian Beam** shaped described using the **FWHM**
 - Blur
 - **Extension** of the beam **beyond** its FWHM
 - Includes **interactions** with **substrate** → Secondary Electrons, Process Effects
- Applications need diverse **substrate** conditions ...
 - Single layer
 - Multiple layers
 - Several layer **thicknesses**
 - Resist heights imply significant transition angles
 - Various **materials** → Different responses

Multi Layer Resist Process

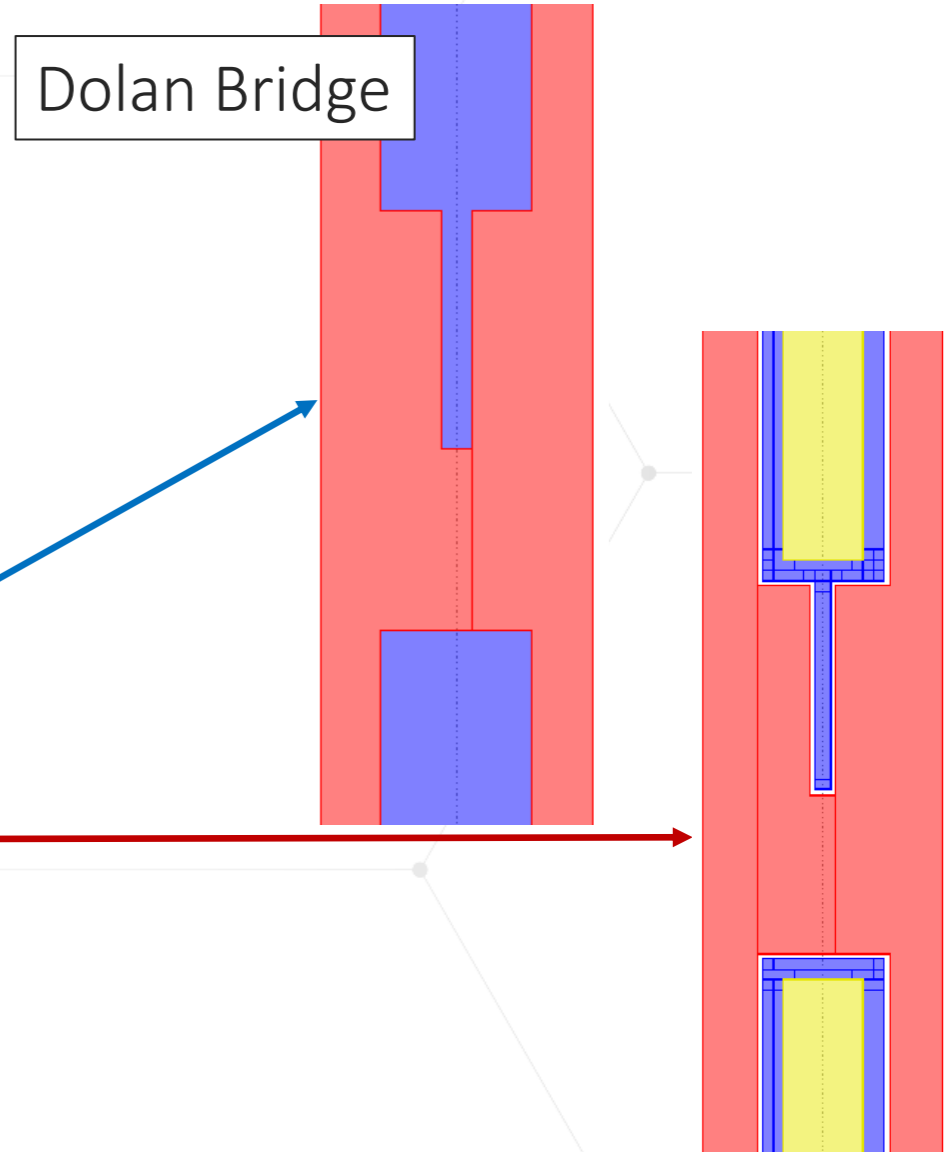
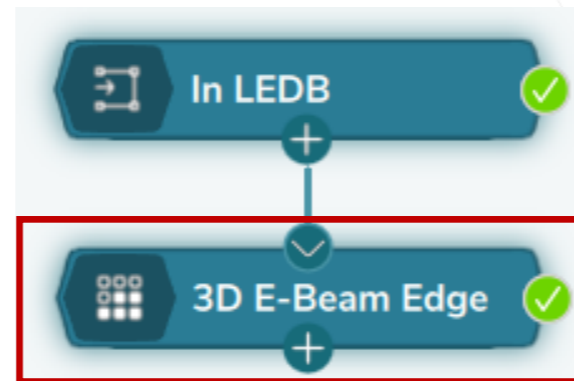
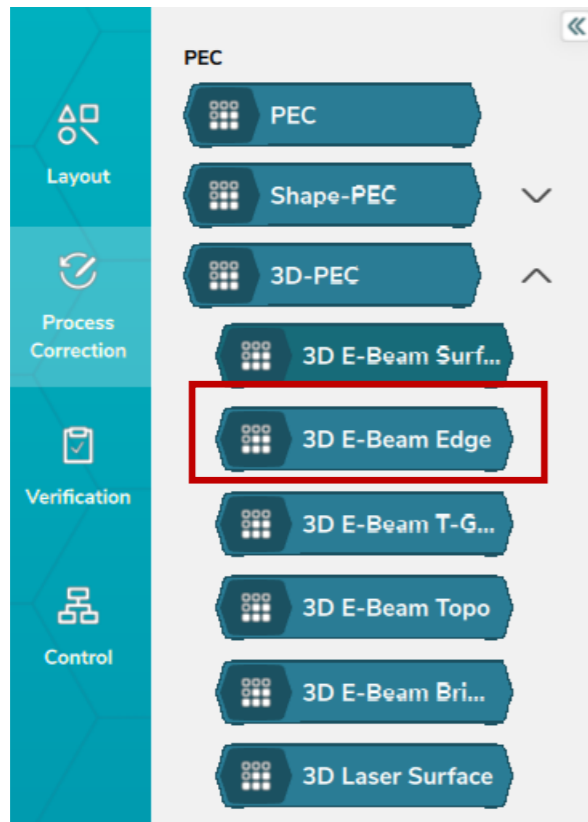
- Exposure of two or more layers
- **PEC adjust** targets **depending** on number of layers



- The ratios of D2C control the threshold for correction
- D2C of resist 1 at one exposure layer
- D2C of resist 2 at second exposure layer



- Calculates **dose corrections** based on **individual contrast curves** ensuring resist removal for every layer
- Mode allowing **bridge-like** structures



- General:
 - Control on **beam features**
 - PSF Representation
 - Blur
- 3D-PEC
 - Control on **dose settings**
 - Contrast curves definition
 - Base Dose

General

Correction Layer Selection
Layer(s)
* ...

PSF Representation
Archive Gaussian Approximation **Numerical PSF**

PSF File Name:
ing_Garching\dolan_bridge(Si_PMMA_450nm_50kV_z22nm.lpsf Browse

Effective Short Range Blur FWHM[um]
0.020000

Add Gamma [um] 1.000000 Nue 0.100000

3D-PEC

Mode
Development Rate Model Threshold Model (Legacy)

Contrast Curve Mode
Material Archive **Numeric**
Material Database...

Base Dose [uC/cm^2]
300.000000

Critical Resist Layer Contrast Curve ... + ^ v

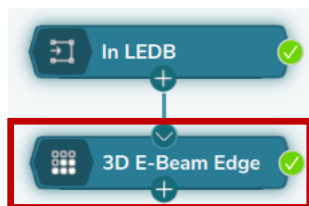
Layer List	Dose Factor [-]	Thickness [um]
1(0) Select...	2	0.1
No Lat. Dev. List	Dose Factor [-]	
Select...	1.000000	

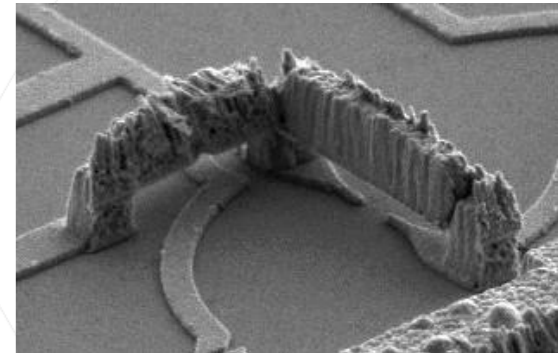
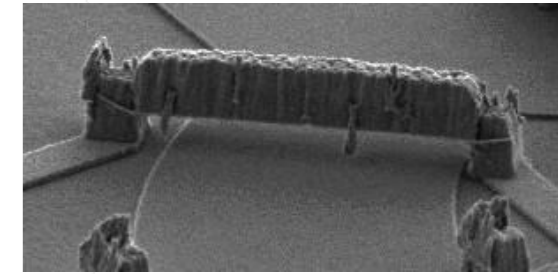
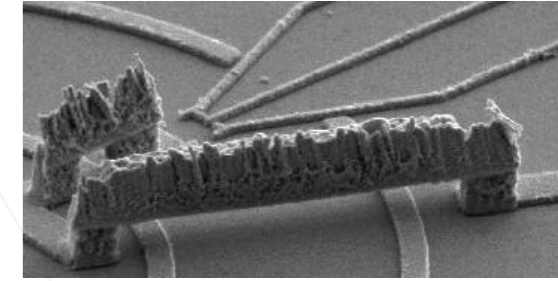
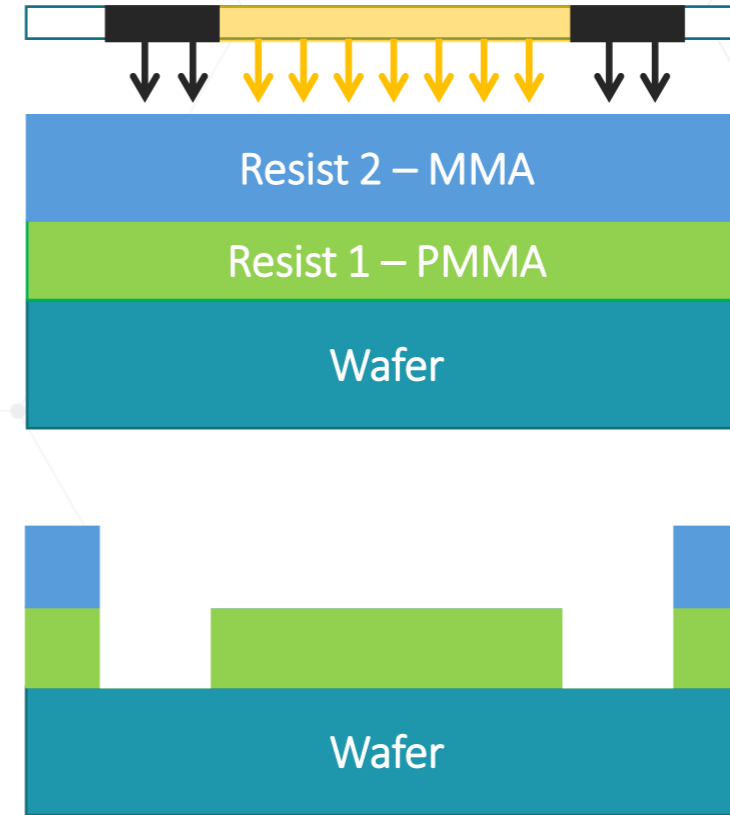
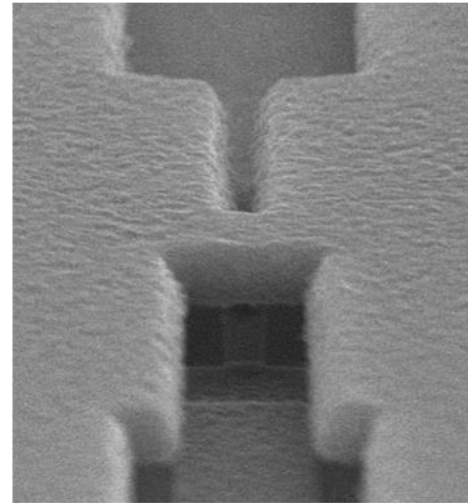
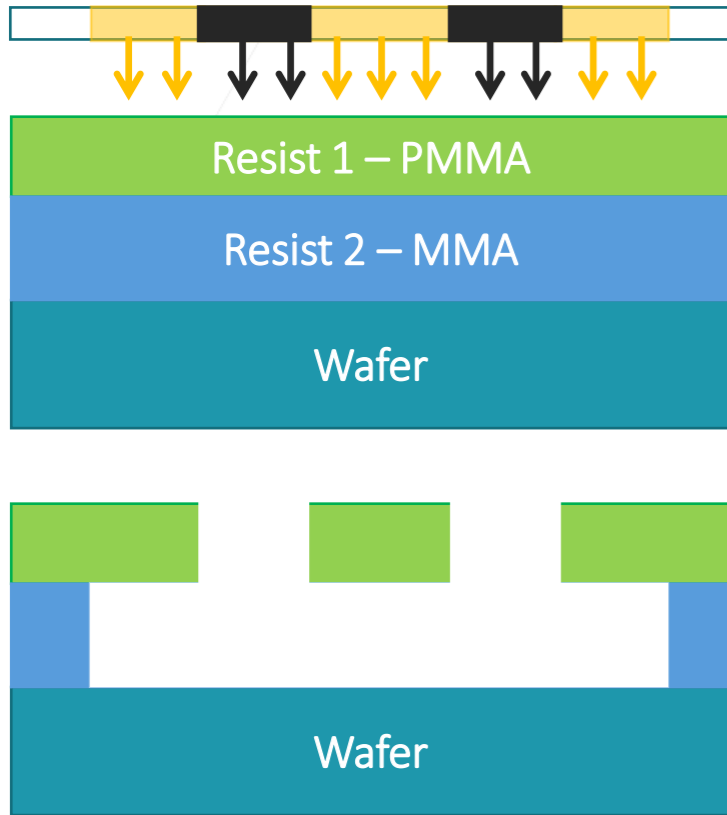
Resist Layer Contrast Curve ... + x ^ v

Layer List	Thickness [um]
0(0) Select...	0.35

Top layer – feature dimension

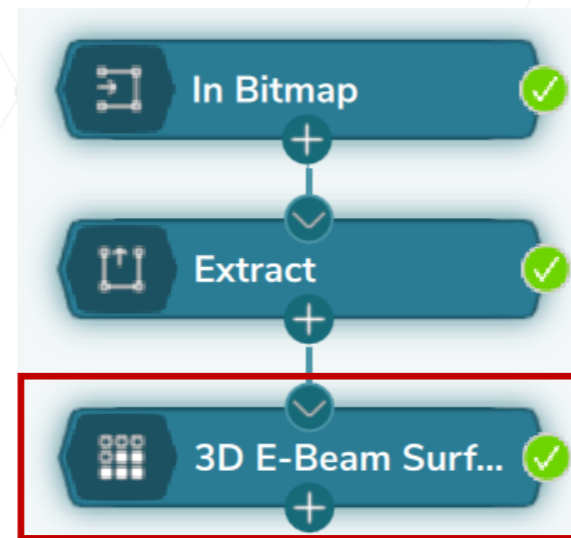
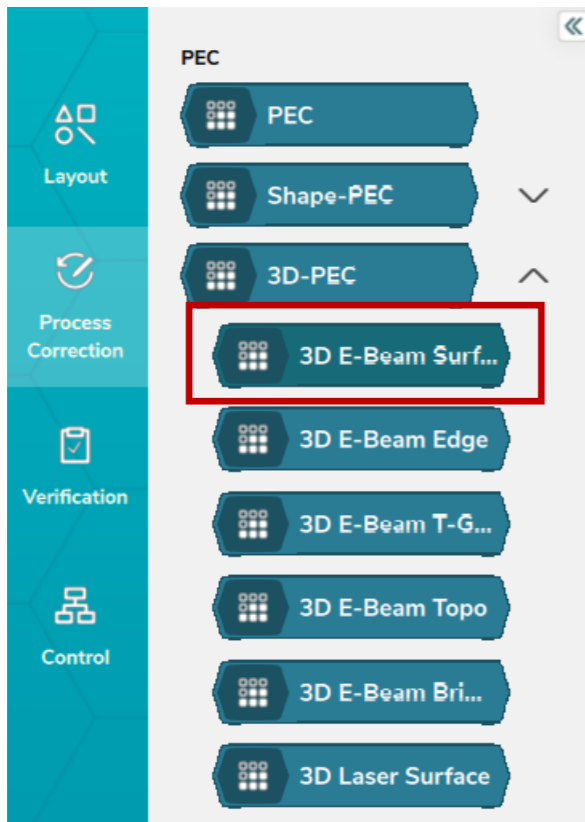
Bottom layer – undercut



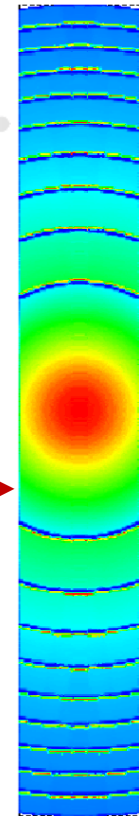
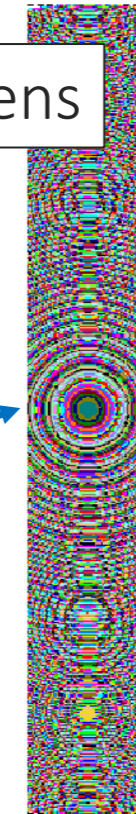


- The Edge...
- Edge PEC
- Surface PEC
- Lateral development
- In depth look

- Calculates **dose corrections** to **compensate** for process effects in 3D **single layer exposure**
- Mode allowing **gray-tone** lithography
- **Short-range** correction **not included**



Fresnel Lens



- General:
 - Control on **beam features**
 - PSF Representation
 - Blur
- 3D-PEC
 - Control on **dose requirements**
 - Contrast curve definition
 - Base Dose
 - Lateral development
 - Surface Definition Type

General

Correction Layer Selection
Layer(s)
* ...

PSF Representation
3D Archive Archive Gaussian Appro... Numerical PSF

PSF Parameter

Alpha [um]
0.005000

Beta [um] Eta
30.000000 0.600000

Gamma 1 [um] Nue1
 0.300000 0.010000

Gamma 2 [um] Nue2
 2.000000 0.010000

Import Values from PSF file...

Effective Short Range Blur FWHM[um]
0.02

3D-PEC

Contrast Curve Mode
Material Archive Numeric
Material Database... Contrast Curve...

Resist Contrast Parameter
Base Dose [uC/cm^2]
300

Work Range Min. [-] Work Range Max. [-]
0.000000 1.000000

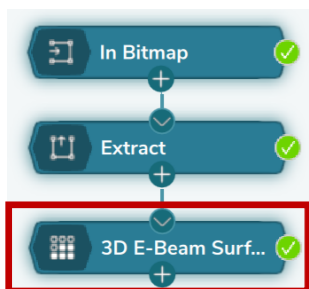
Include Lateral Development: Pixel Size[um]:
0.1

Surface Definition Type
Absolute Height

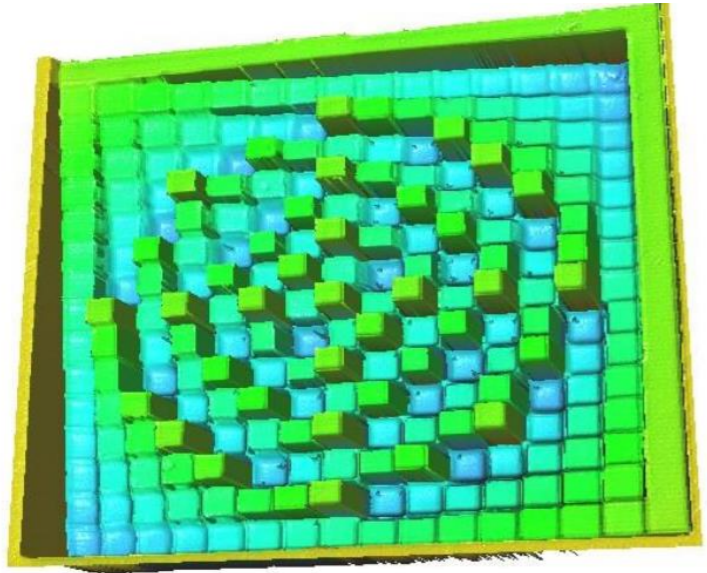
Surface Definition
 Use Layer assignment file Browse...

Import Export Insert Row Delete Row

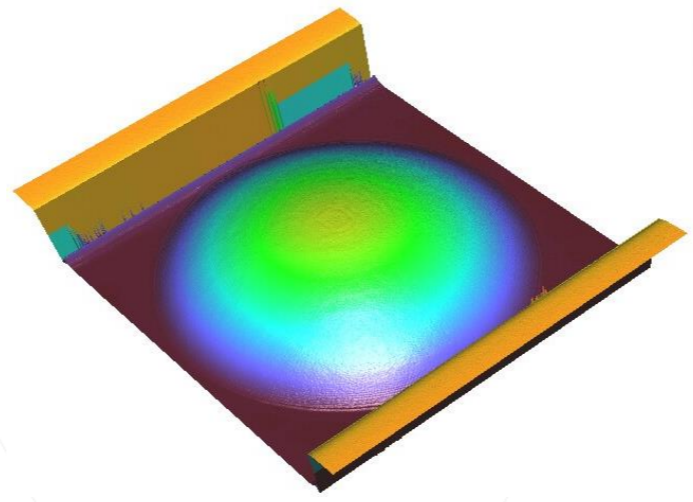
Layer	Height [um]	rel. Height [-]	rel. Dose [-]	Dose [uC/c...
1	5.395552	0.606	0.206652	61.9956
2	5.377258	0.604	0.207954	62.3863
3	5.358964	0.602	0.209265	62.7796
4	5.340671	0.600	0.210574	63.1723
5	5.322377	0.598	0.211879	63.5637
6	5.304083	0.596	0.213192	63.9575



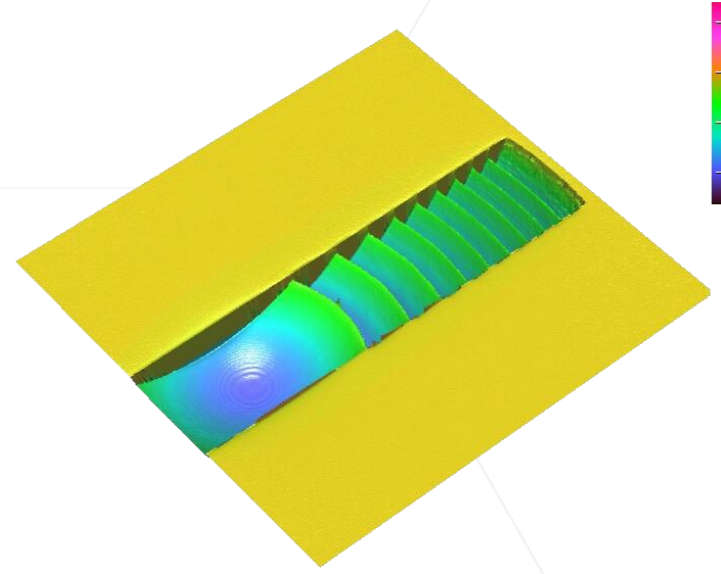
3D Surface Examples



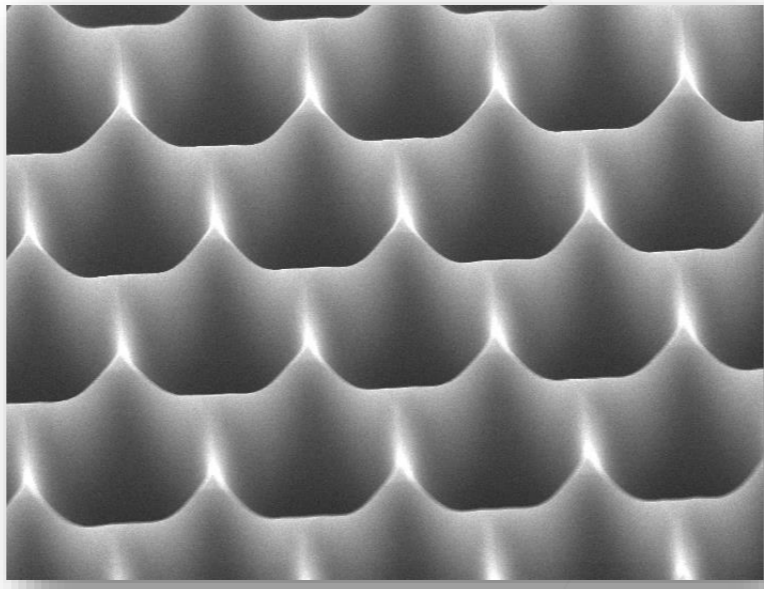
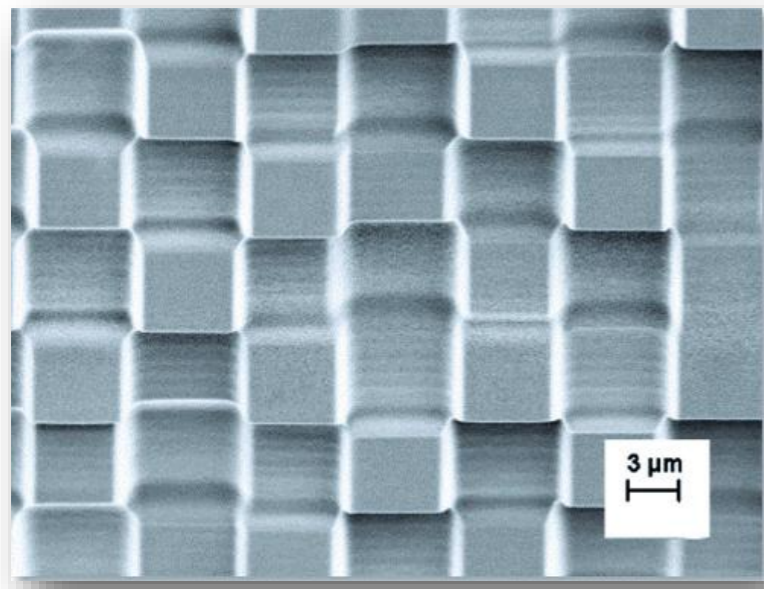
DOEs



Convex lenses

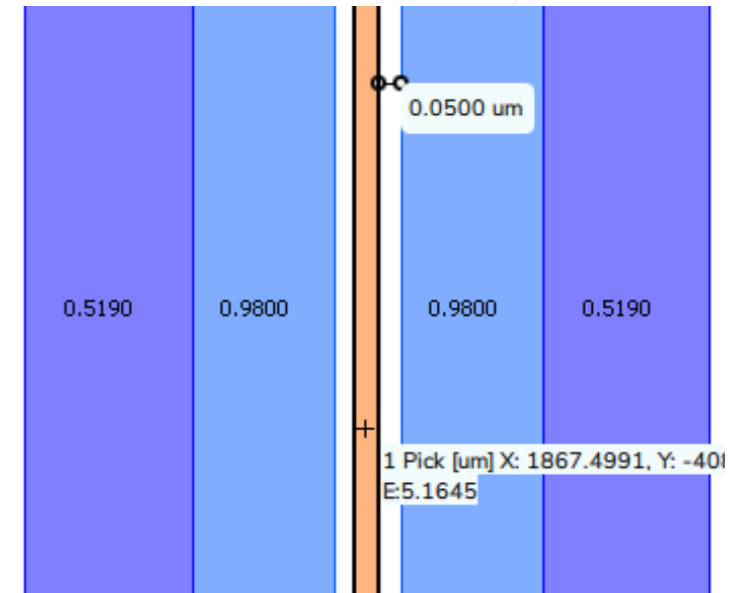
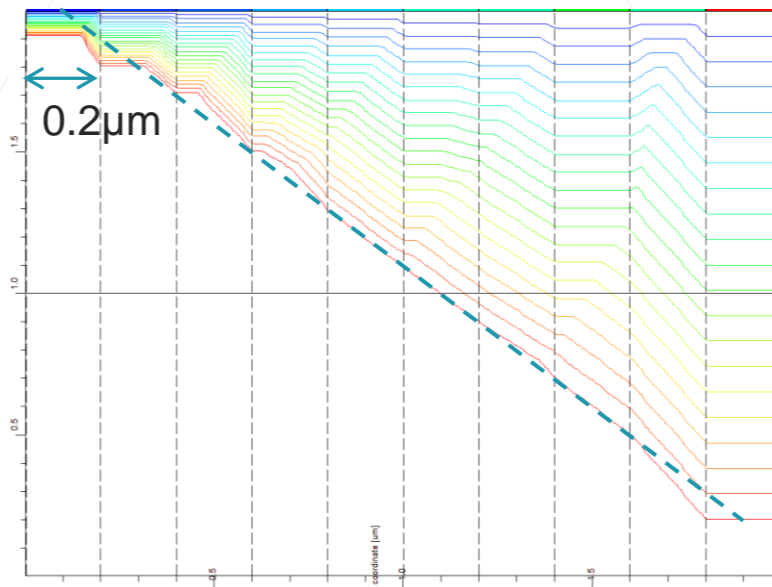
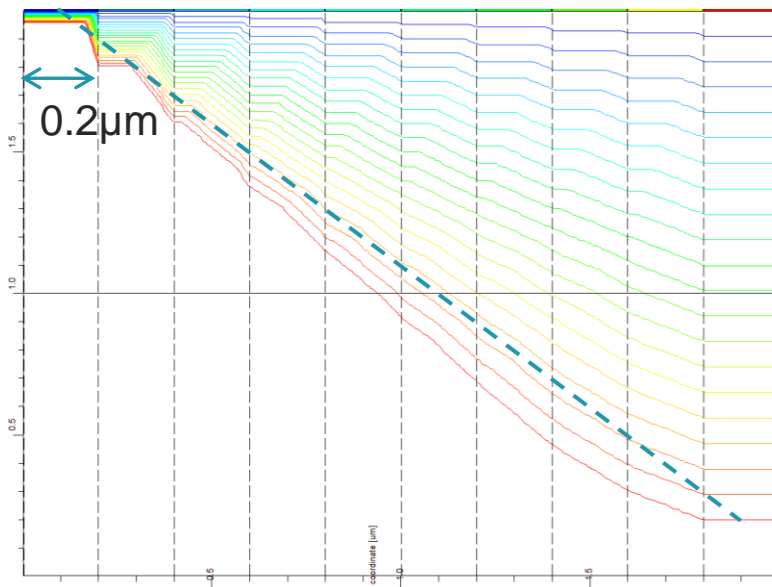


Fresnel lenses



- The Edge...
- Edge PEC
- Surface PEC
- Lateral development
- In depth look

- Surface and other larger area correction add energy to the critical neighbours.
- This additional energy influences the development behaviour causing the lateral development.
- For surfaces the energy influence is recalculated, for edges a buffer created



- The Edge...
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3D PSF - Varying Rates in Z

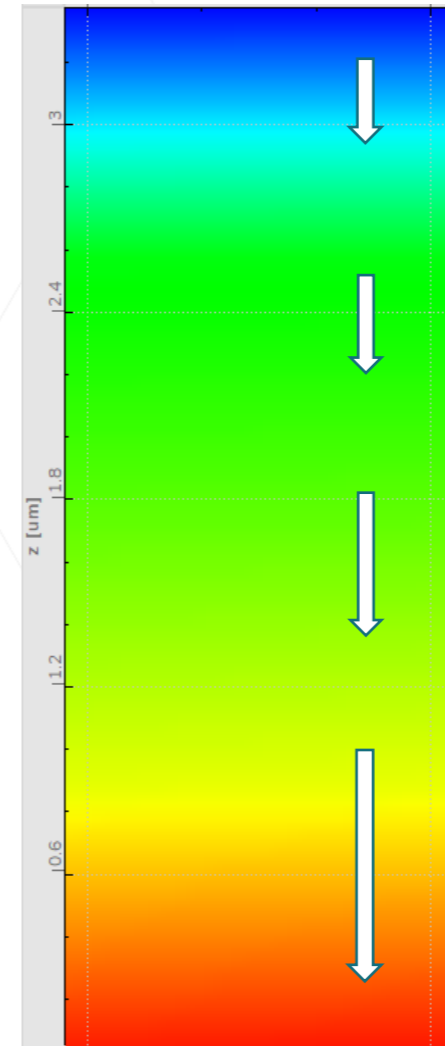
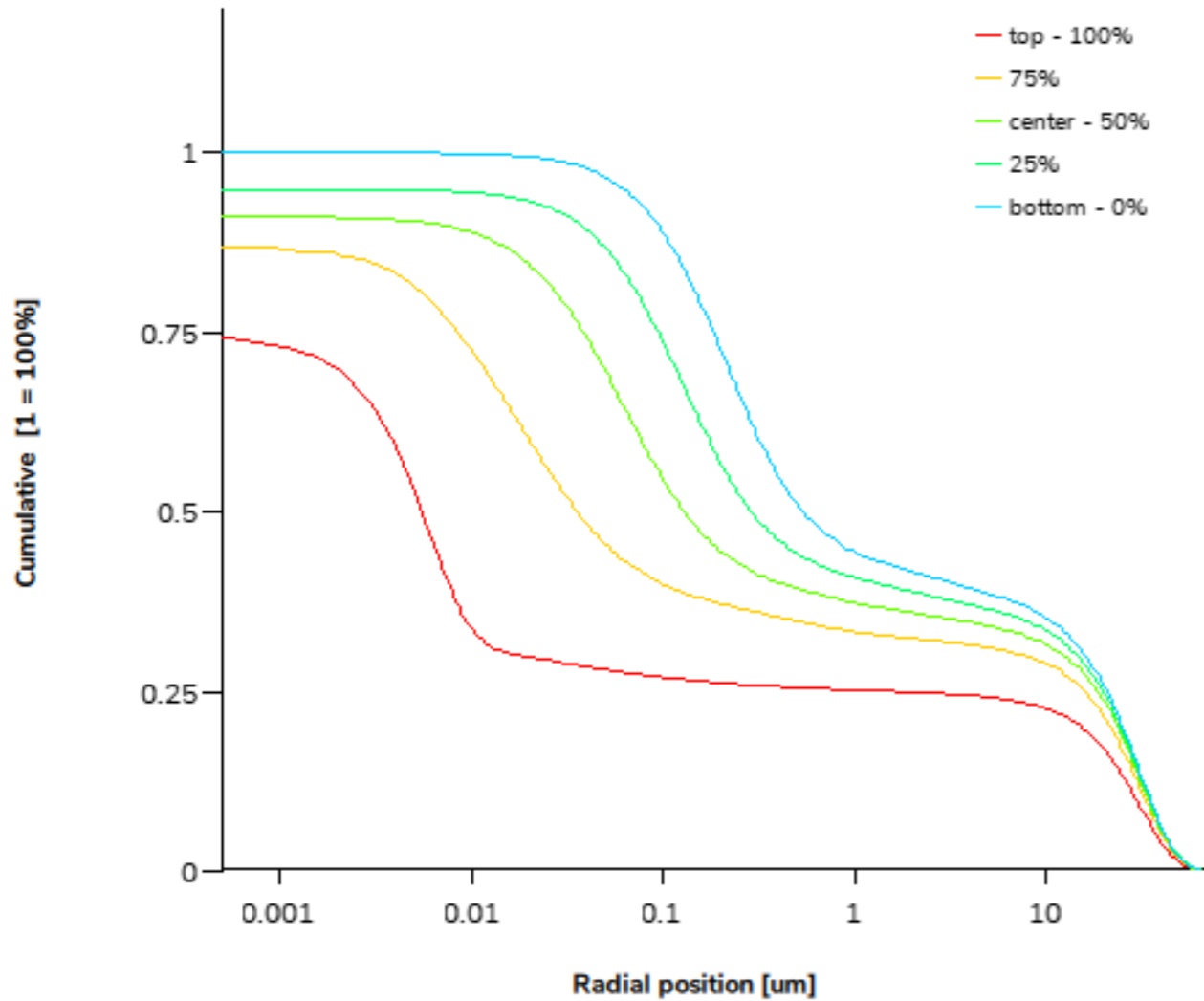


Fig. z-dependent dose deposition in the resist. The length of the arrows illustrates the increasing development rate towards the bottom.

Fig. 3D-PSF (z-dependency) [3.4um PMMA, 100kV]

Fitted Development Rate Model

- A dev. rate model is optimized to fit the experimental contrast curve

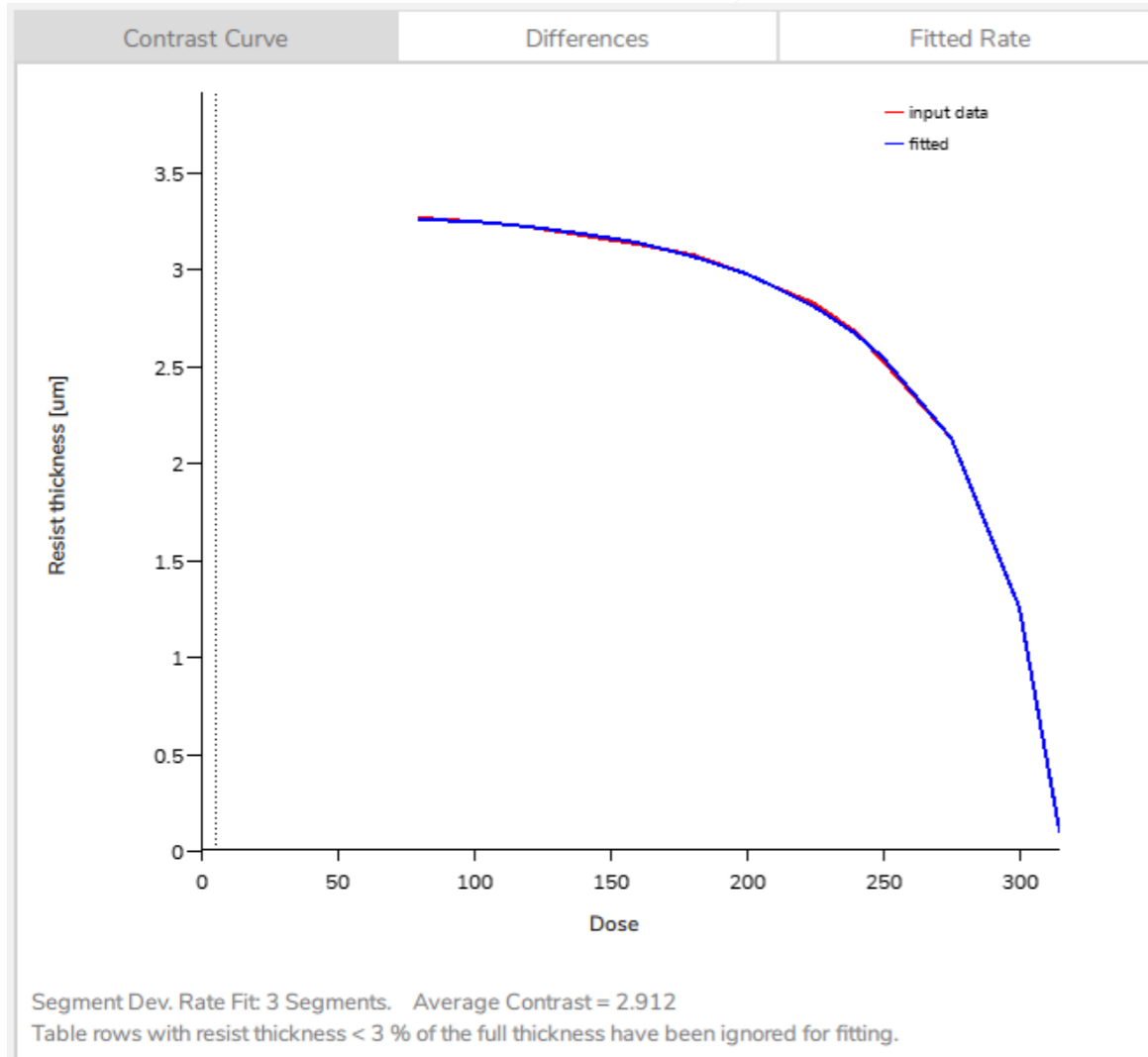


Fig. Contrast Curve Fit

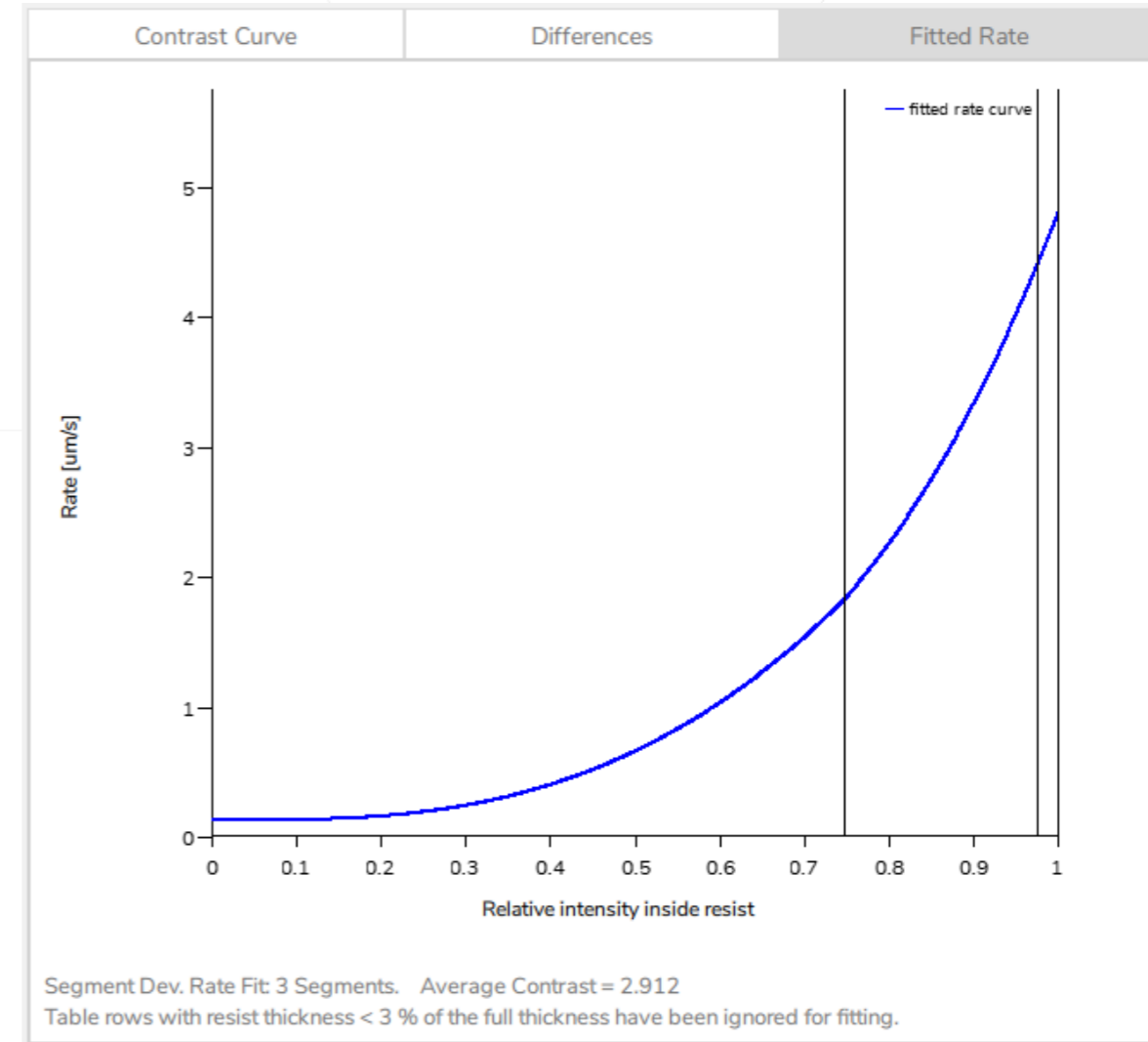


Fig. Fitted Development Rate

Knowing the Development Rates

- One exposure dose forms a unique absorbed energy image in the resist.

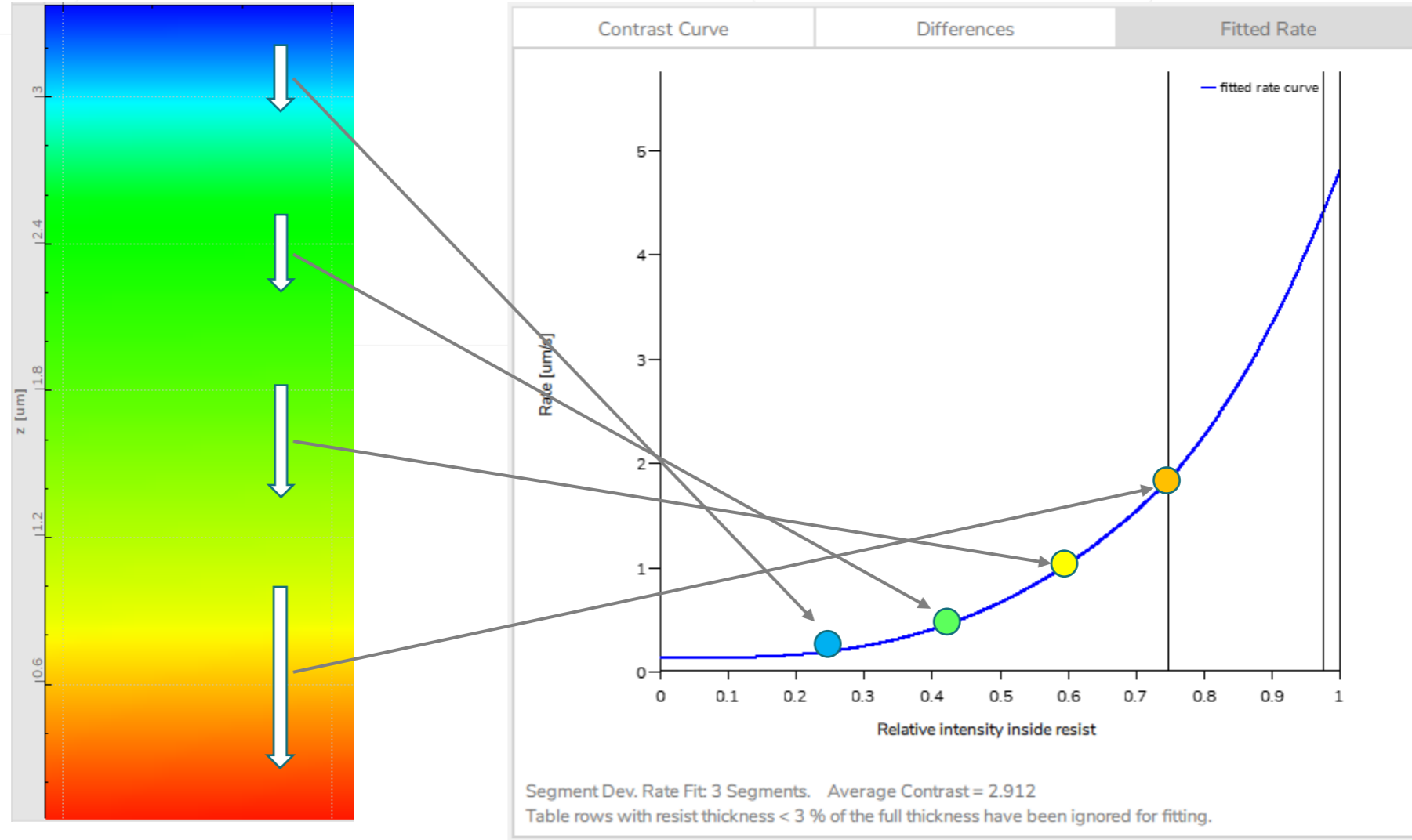


Fig. Fitted Development Rate

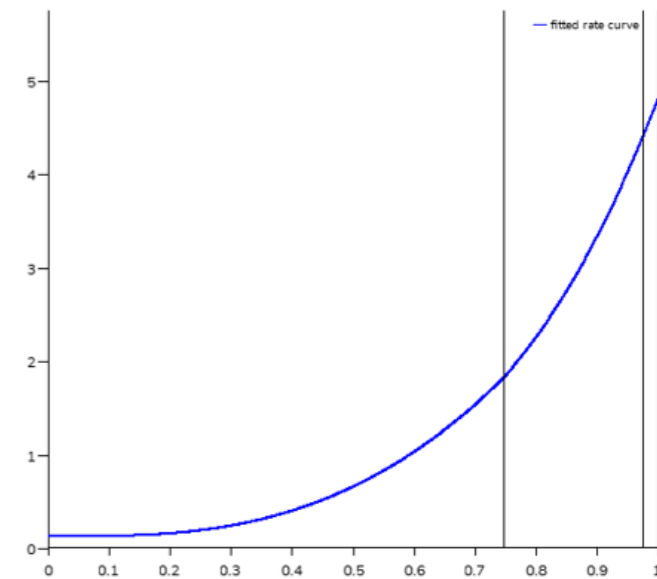
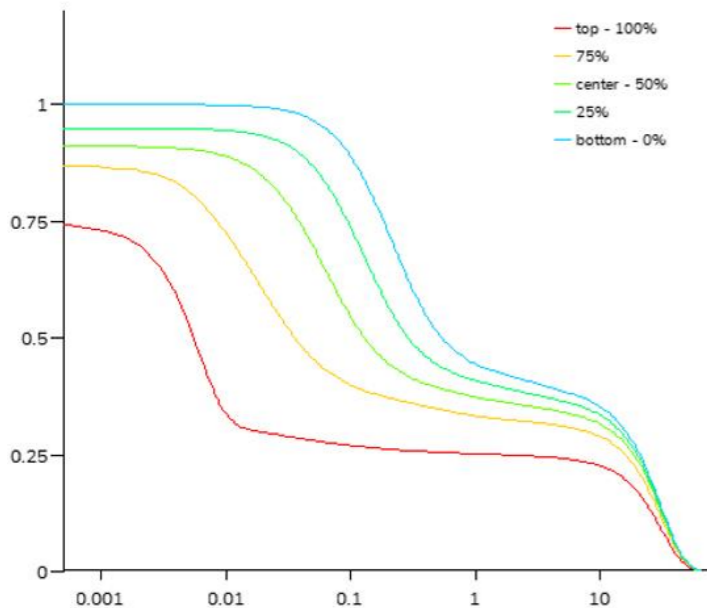
Putting the things together

- Knowing the energy distribution in the Resist (3D PSF) + how the energies translate into Rates (Dev. Rate Model) → enables us to simulate and correct for the development effects.

3D PSF

Dev. Rate Model

3D Simulation and PEC



- Lateral development is directed. It moves from pixels with higher resist removal to the adjacent pixels with lower rates.
 - Once a pixel is optimized it has not to be revisited.
- Optimizing a pixel:
 - An exposure dose change @ position(x,y) causes a propagating rate(z) change.
 - Iteration finishes when the pixel height is on target.
 - In addition to the CC optimization also lateral propagation from already visited neighbors is considered.
- The performance of the algorithm is highly depending on the pixel size!

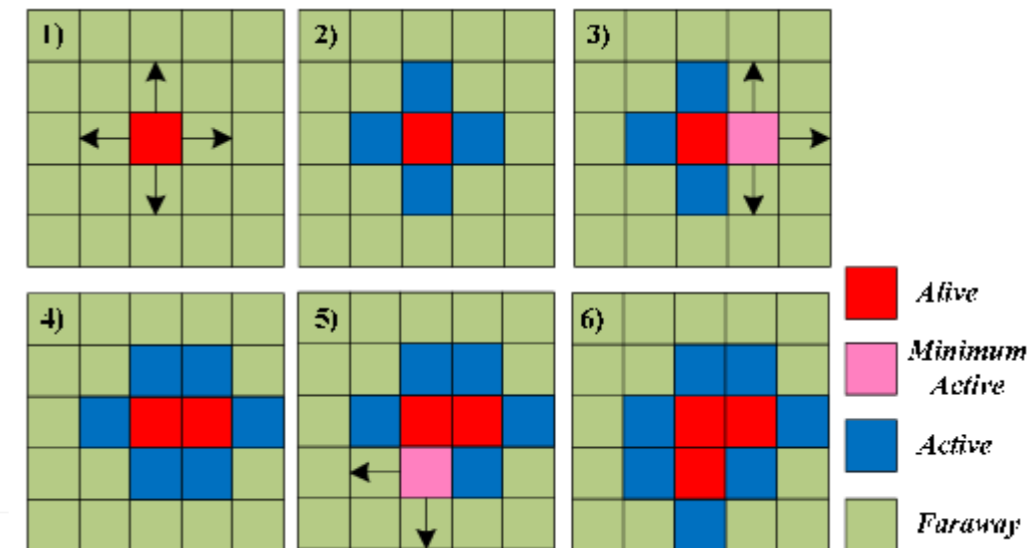


Fig. Schematic representation of a fast marching method.

T-Gate PEC Algorithm

- The local rates are integrated in lateral direction along an **evaluation line** as long as lat. dev. time (t_{lat}) is completed, yielding the **lat. dev. bias**.
- PEC dose and bias are adjusted iteratively until the resist front stops at the original gate width.

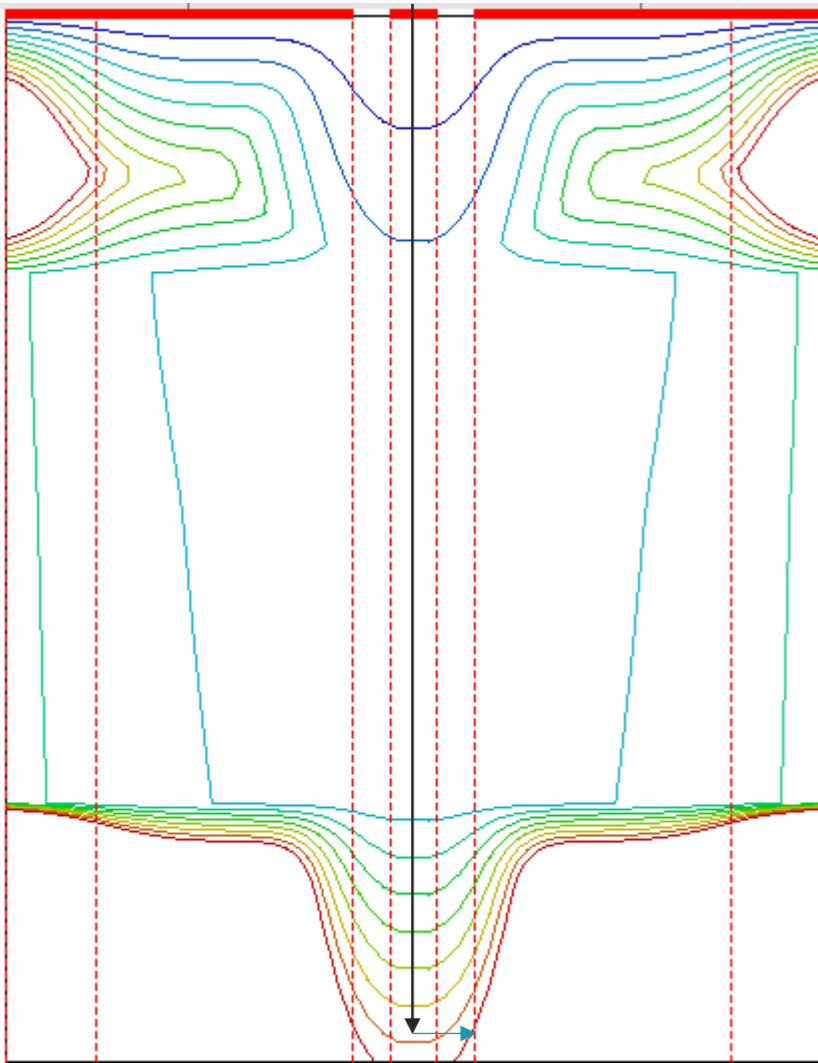


Fig. Development simulation of the exposed structure

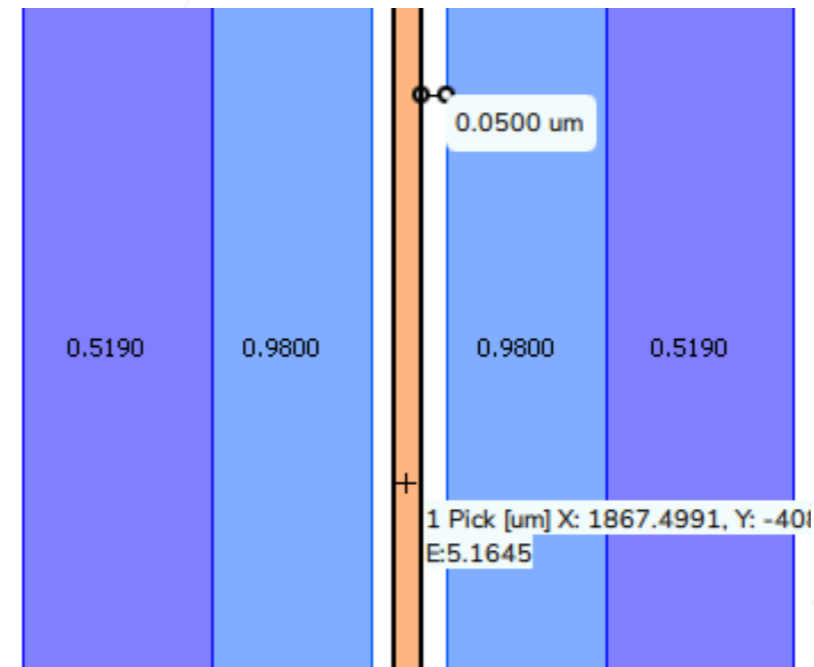
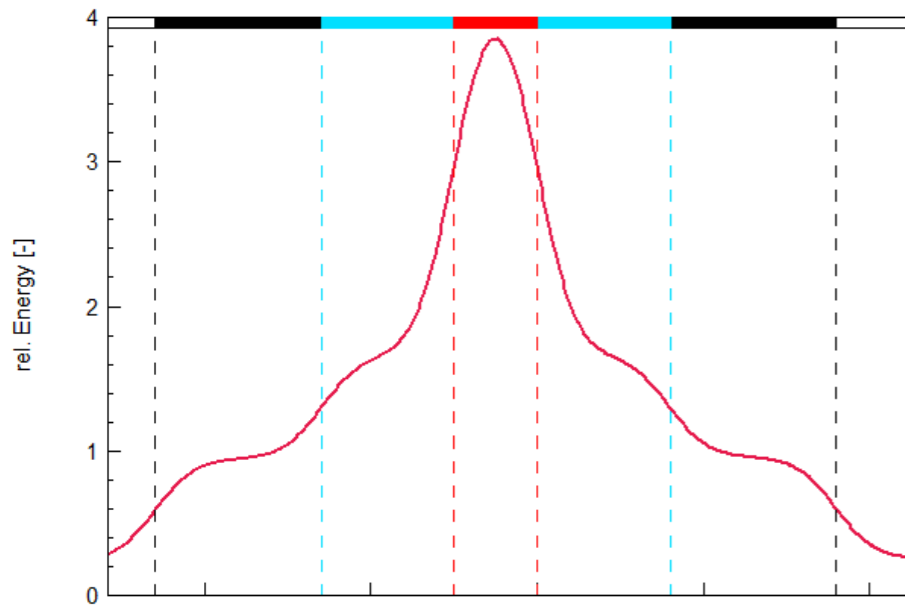
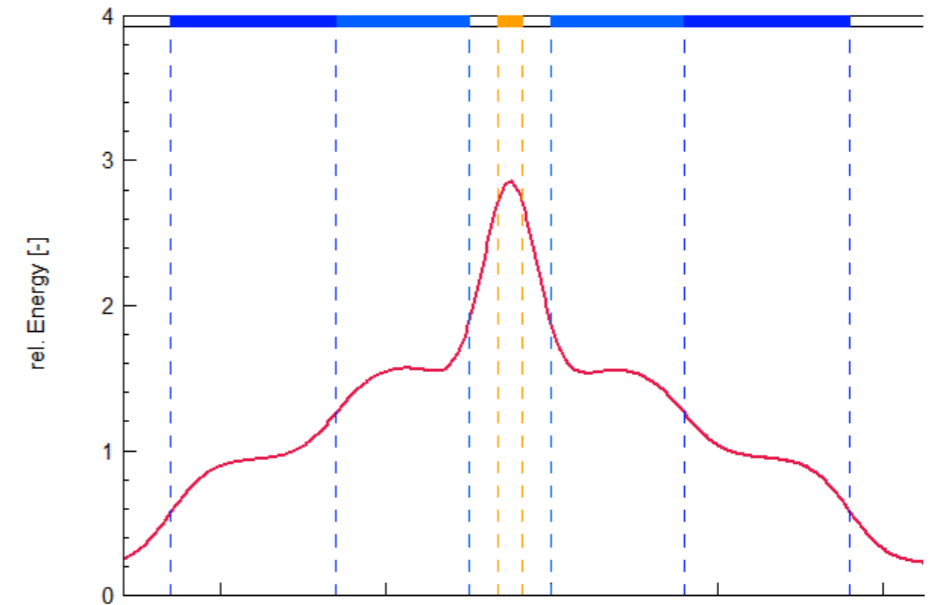
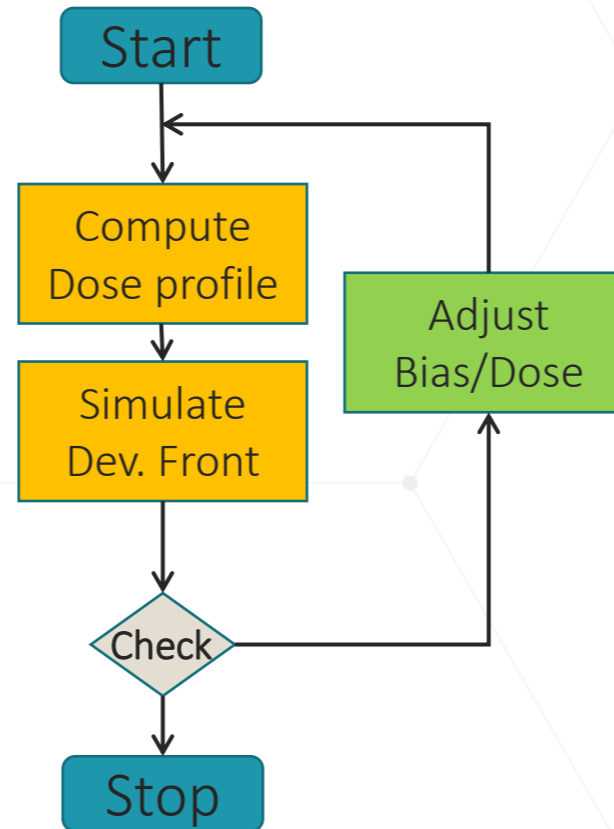


Fig. Optimized PEC layout with dose and bias adjustments.



a) Start dose profile



b) Final optimized dose profile

The dose profile determines where the development will stop.
 The PEC result is obtained by iteratively optimizing bias and dose of the critical structures.
 It is accomplished when the fronts stop at the targets.

- Advanced PEC applications require information about the resist development process
- BEAMER uses the PSF (2D or 3D) and a Contrast Curve measurement to fit a Development Rate Model
- The model is then applied during simulation PEC

Thank You!

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