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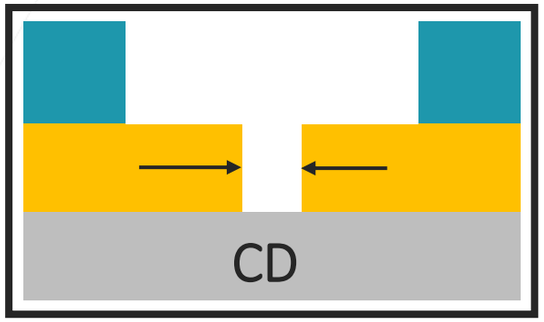
Development Rate Model in 3D PEC for Multilayer Resist Systems, details and application

Problem Statement

- Objective
  - CD control in multi-resist-layer systems



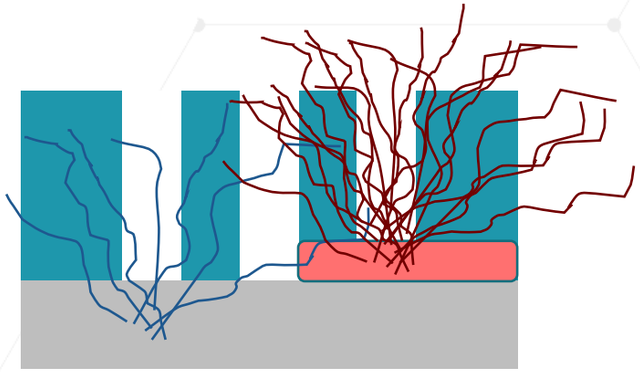
- Requirements
  - Knowledge about the development behavior in the resist system:
  - →Development Rate Model

Outline

- 3D PEC Applications Overview
- 3D Edge PEC
  - Examples
- Rate Model
- Lateral Development
- PEC Algorithm
- Q & A

3D PEC Modules

Single Layer Resist.



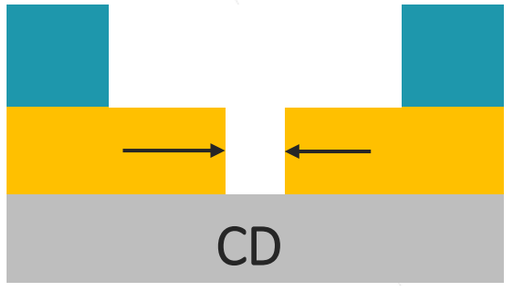
3D Topography

Basically a 2D application but considering the backscattering of the subjacent (3D) topology.

3D Surface

Grayscale Lithography using a thick layer of one low contrast resist.

Multi Layer Resist.



3D Edge (T-Gate PEC)

Multi-Layer System of high contrast resists with different sensitivities.

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3D Edge Scenarios

Scenario 1: high D2C* bottom layer

e.g. T-Gate

**D2C = Dose-to-Clear*

Scenario 2: high D2C top layer

e.g. Dolan (shadow evaporation) technique

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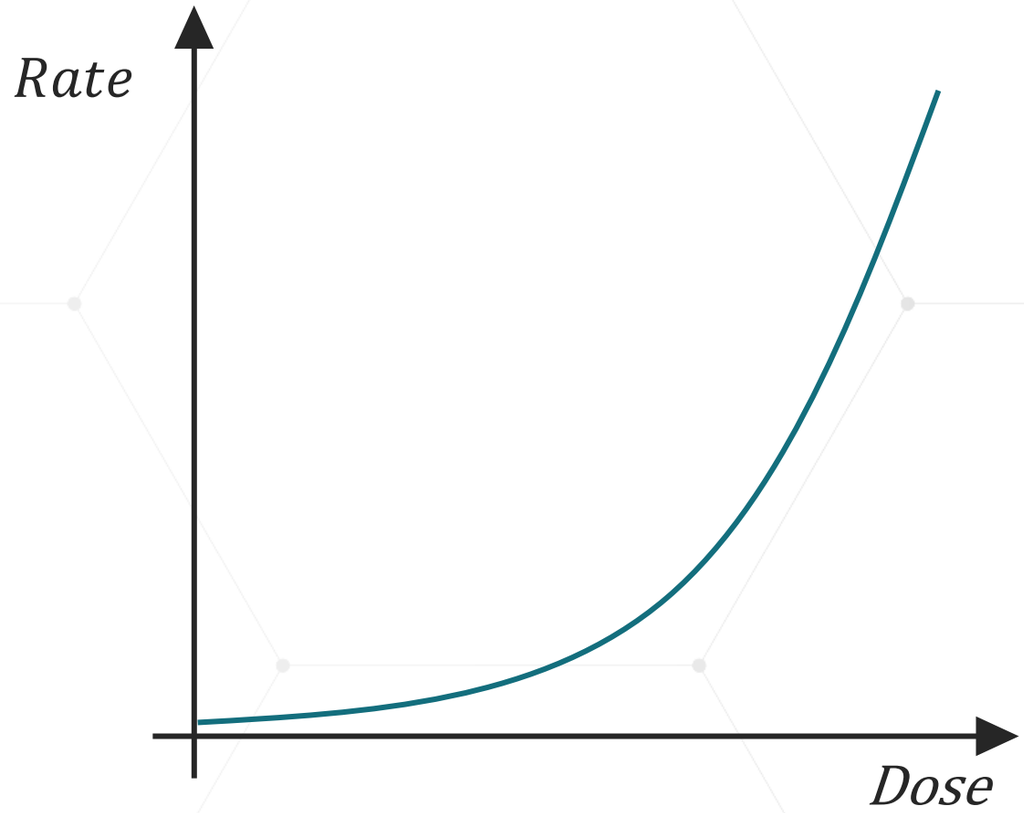
Development Rate Model (DRM)

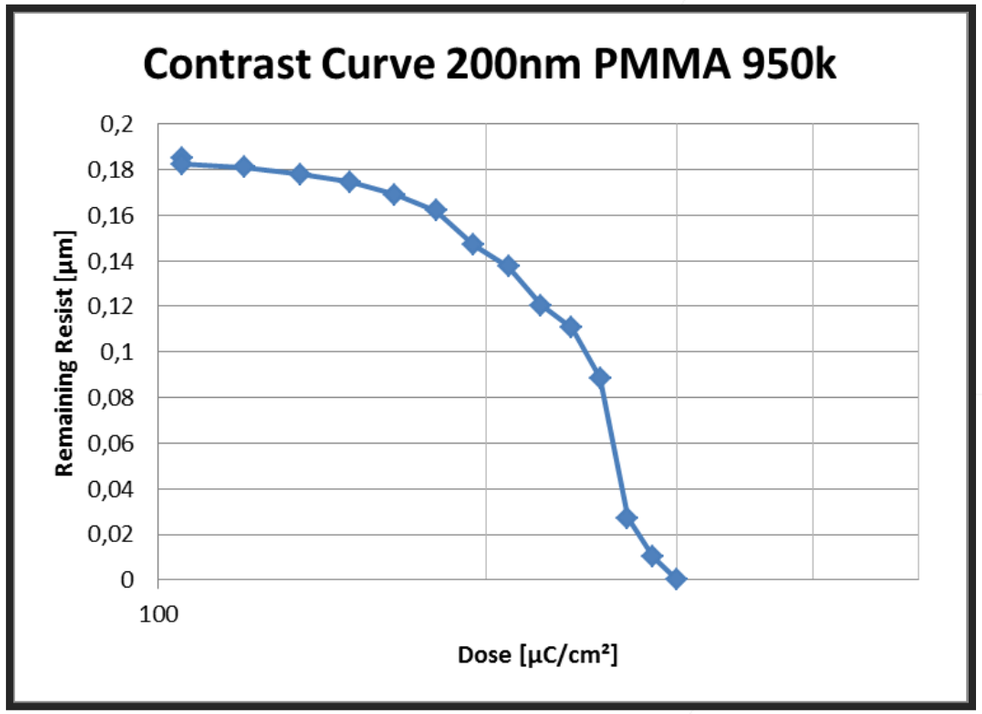
What is a DRM?

- Describes the relation between applied dose and resist development: Rate(Dose).

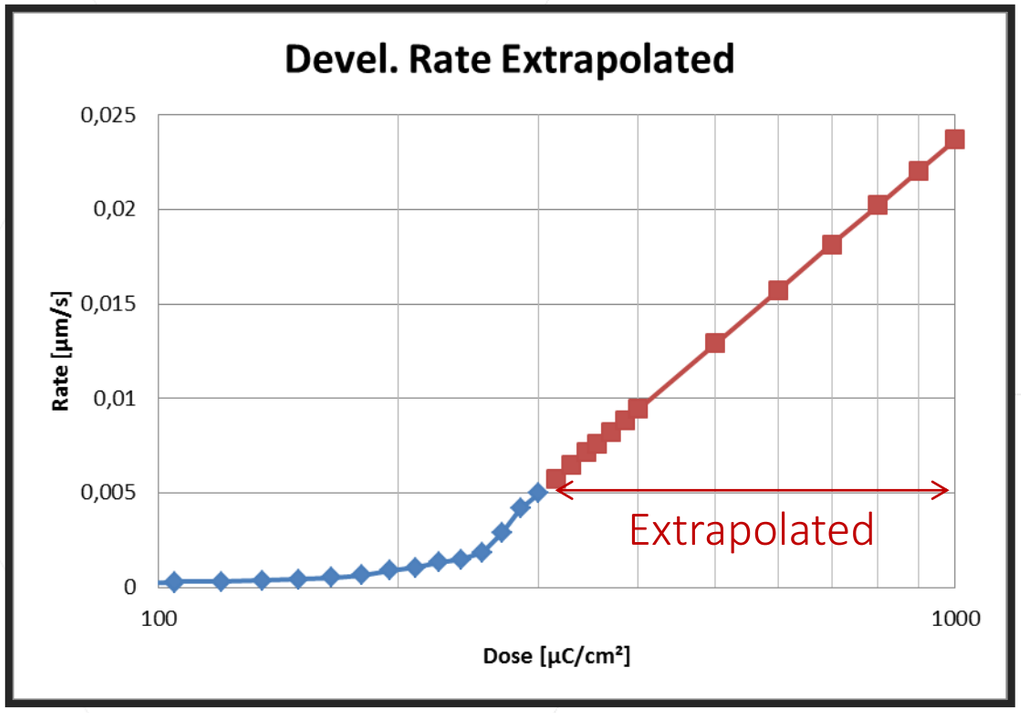


Development Rate Model (DRM)

- How do we get a DRM?



Fit



- Development Rates for higher doses have to be extrapolated from the given Contrast Curve.
- Knowing rates at higher doses is required as PEC might apply values higher than defined in CC

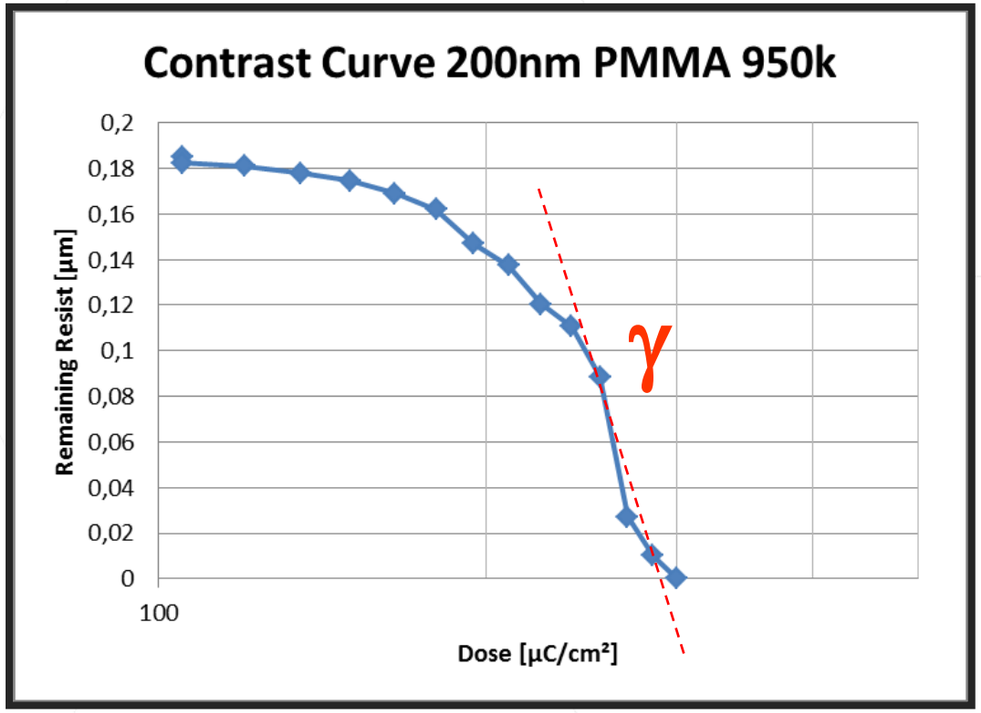
Development Rate Model (DRM)

Which DRM is used in 3D Edge PEC?

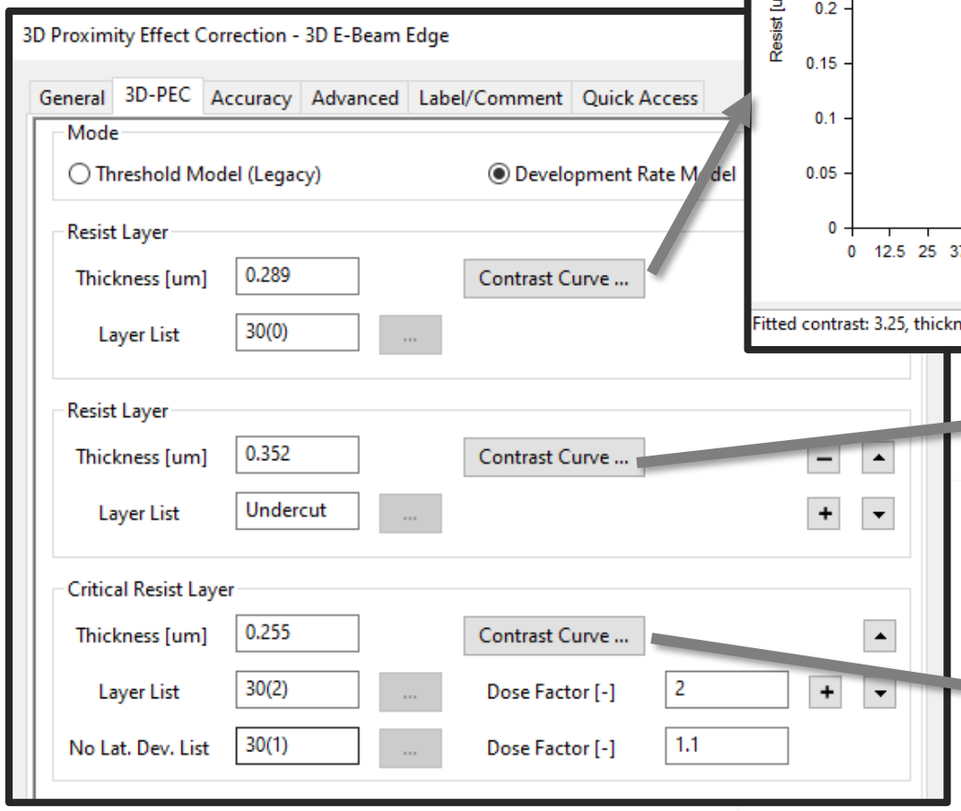
- Simple contrast model (Lumped Parameter Model):

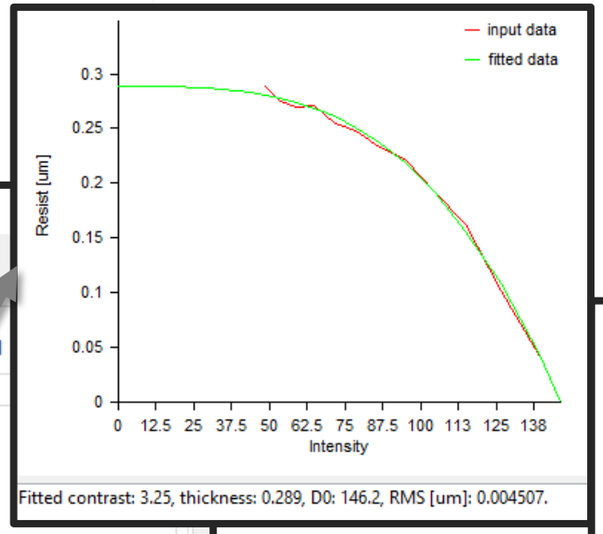
- $r = r_0 \left(\frac{D}{D_0}\right)^{\gamma}$;

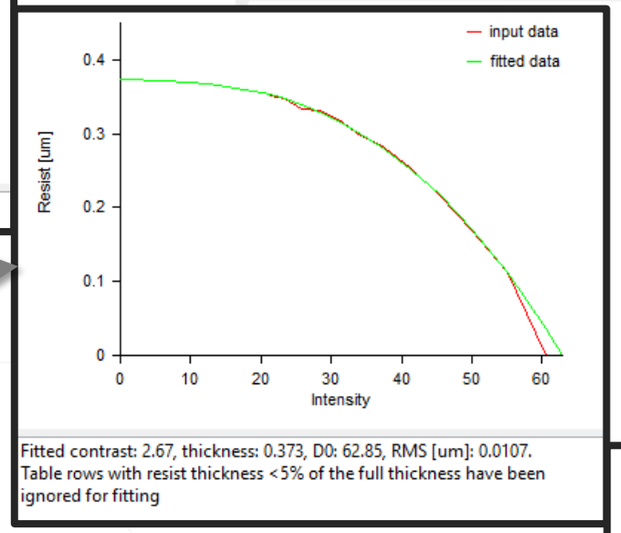
- D_0: Dose-to-Clear
- r_0 : rate at D_0
- γ : Contrast

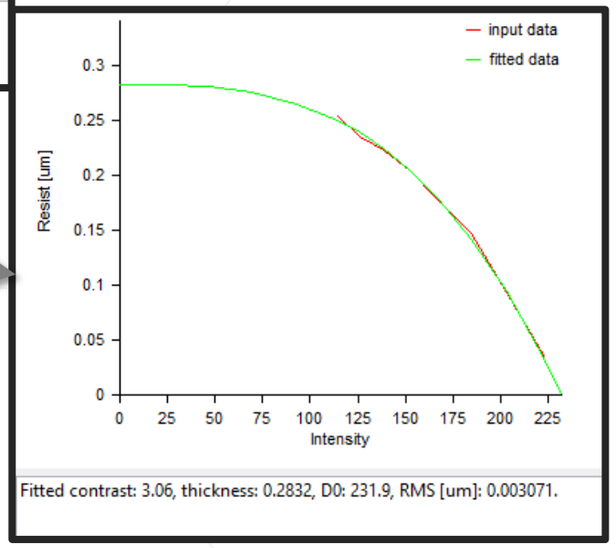


Dialog Detail









Dialog Example: 3-Layer process including undercut.
Note: The main difference between the Contrast Curves of the layers is the sensitivity described by the D0 (Dose-to-Clear) parameter.

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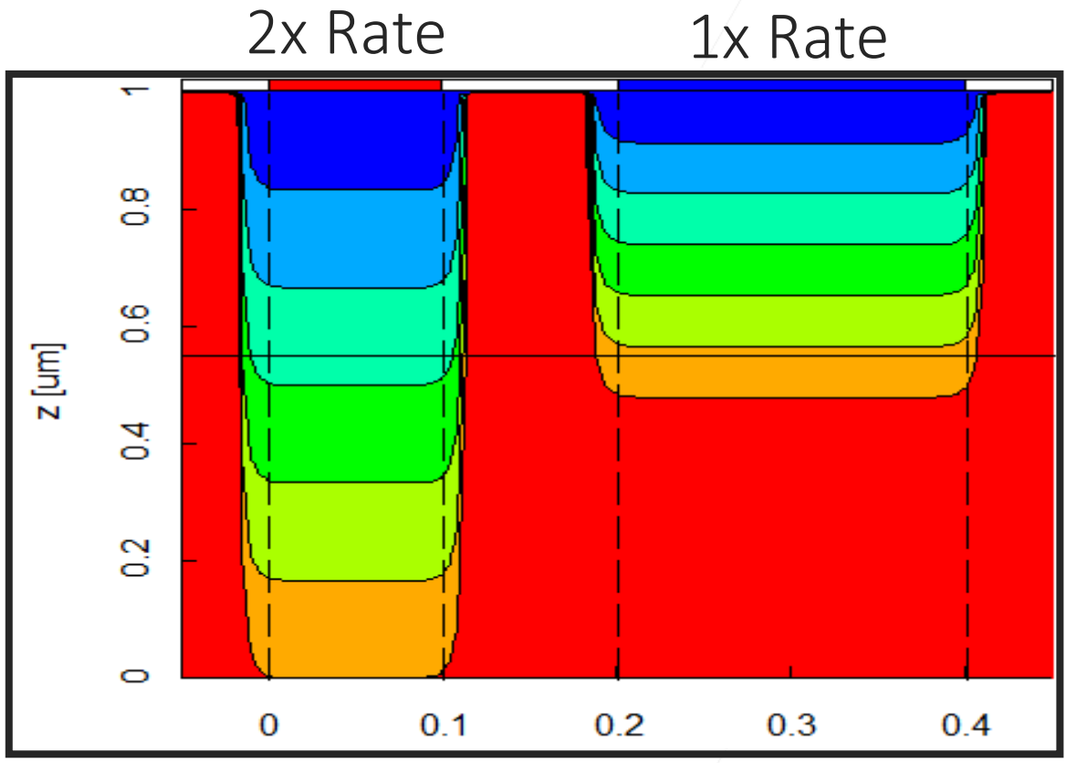
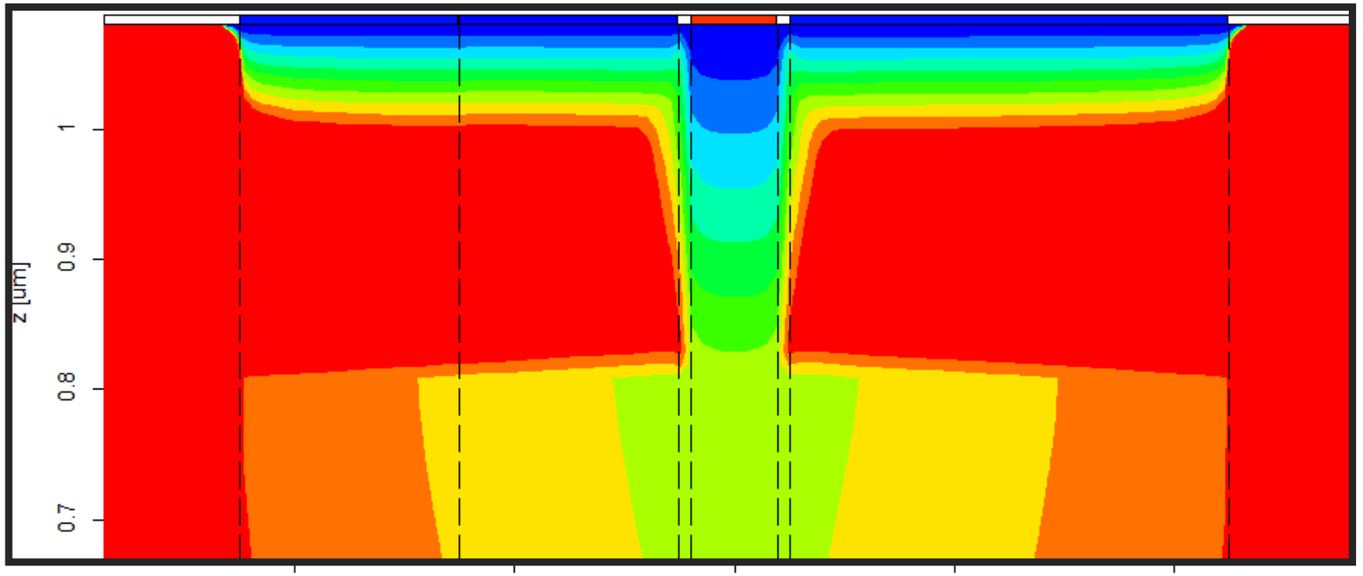
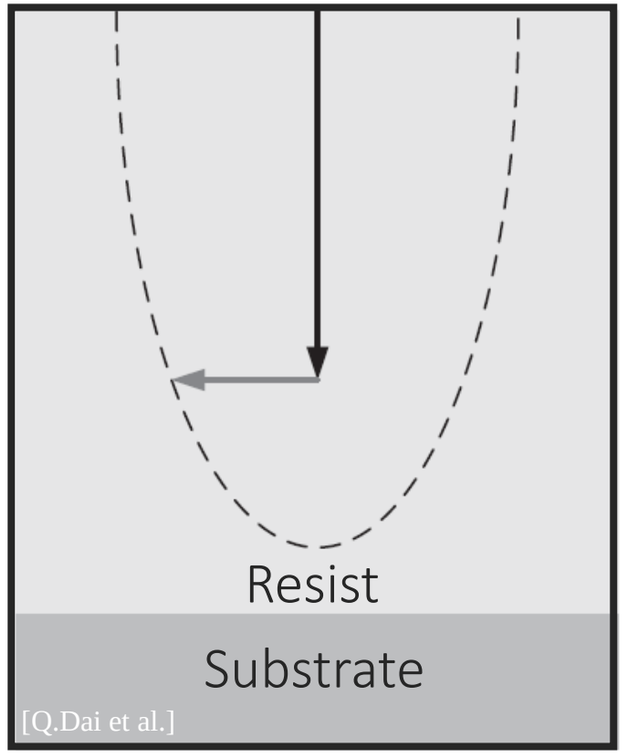
The Lateral Development



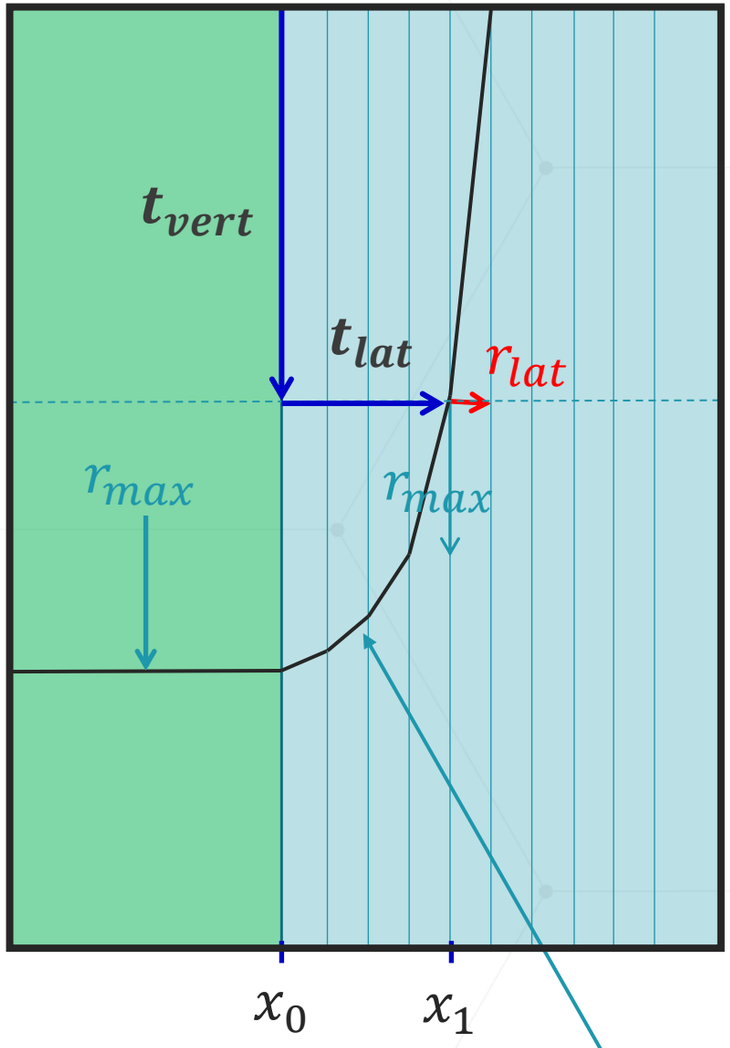


- Example 1 : Regions with different removal rates.
- Example 2 : In 3D applications regions with different rates are not separated, thus there‘s a huge impact!

Lateral Development Model



For the **development front** calculation, a **path based** method can be applied.
- Vertical path @ figure center with r_{max}.
- Horizontal path - lateral development using the rate profile $r_{lat}(x)$ obtained from dose profile.



t_{dev} : development time
t_{vert} : time for vertical path
t_{lat} : time for lateral path

$$t_{lat} = t_{dev} - t_{vert}$$

$r(x)$: local rate
r_{max} : max. rate in the middle
$r_{lat}(x)$: lateral rate

$$r_{lat} = r_{max} \tan\left(asin\left(\frac{r(x)}{r_{max}}\right)\right)$$

The amount of **lateral bias** (x1 – x0) at a defined resist depth is determined by integration:

$$t_{lat} = \int_{x_0}^{x_1} \frac{dx}{r_{lat}(x)}$$

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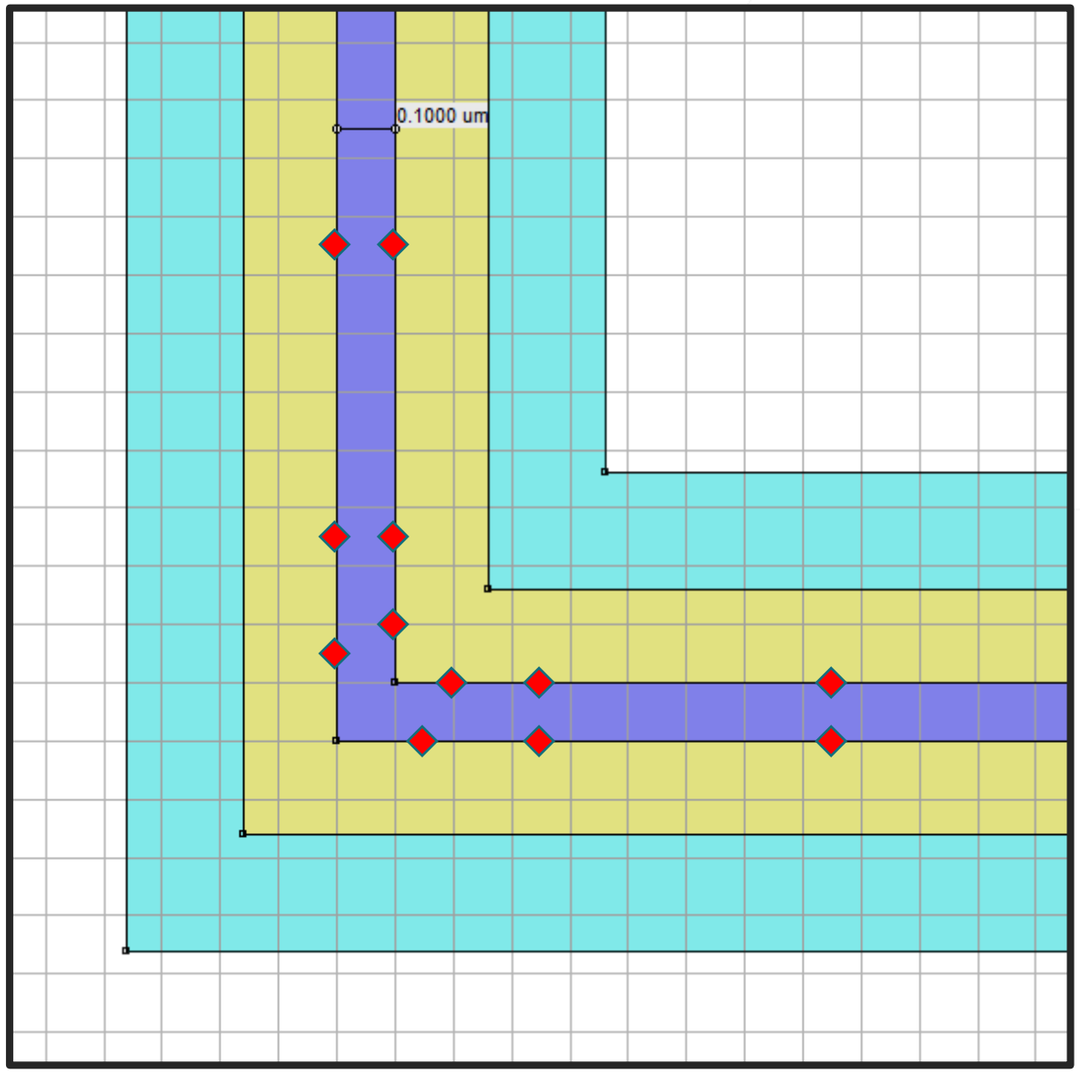
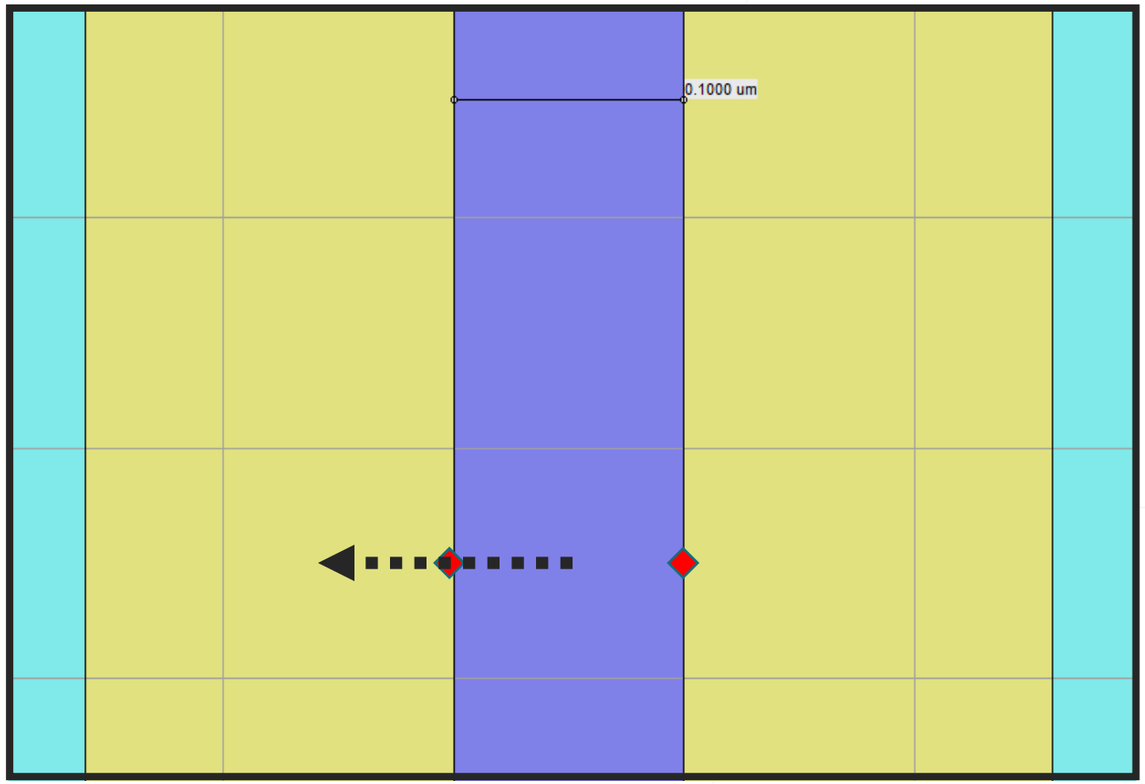
3D Edge PEC Algorithm



◆ = Evaluation Points

- Evaluation Points are placed along the edges of the critical layer.
- The respective Dose-to-Clear values are assigned to the non-critical layer figures.
- The critical layer gets its D2C multiplied by an optional Dose-Factor assigned.

PEC Steps



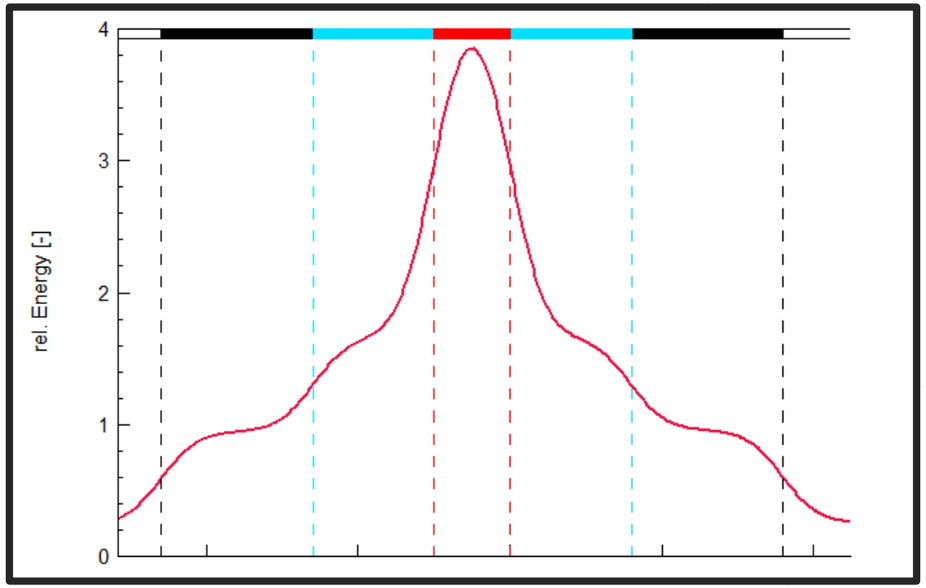
◆ = Evaluation Points

◀▪▪ = Evaluation Line

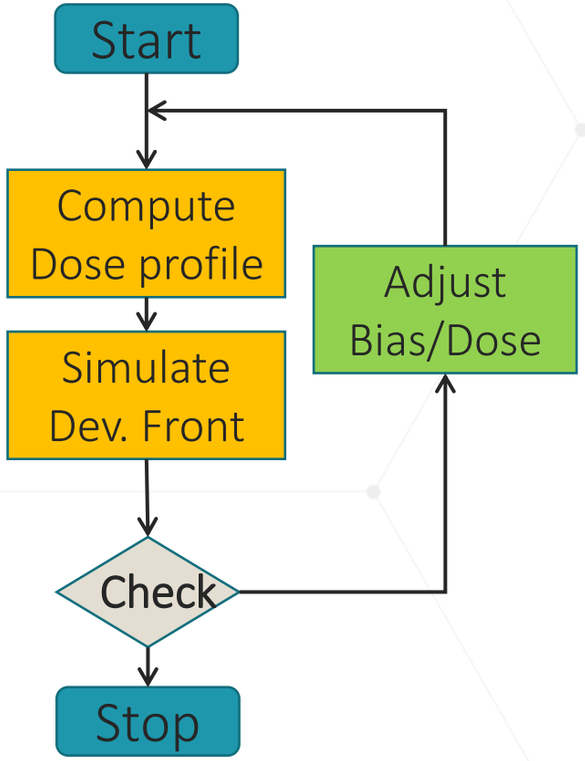
- Evaluations Lines are “drawn” from the center of the critical structure, through the eval. Points.
  - The eval. points are the correction targets: the positions where the development front should stop!

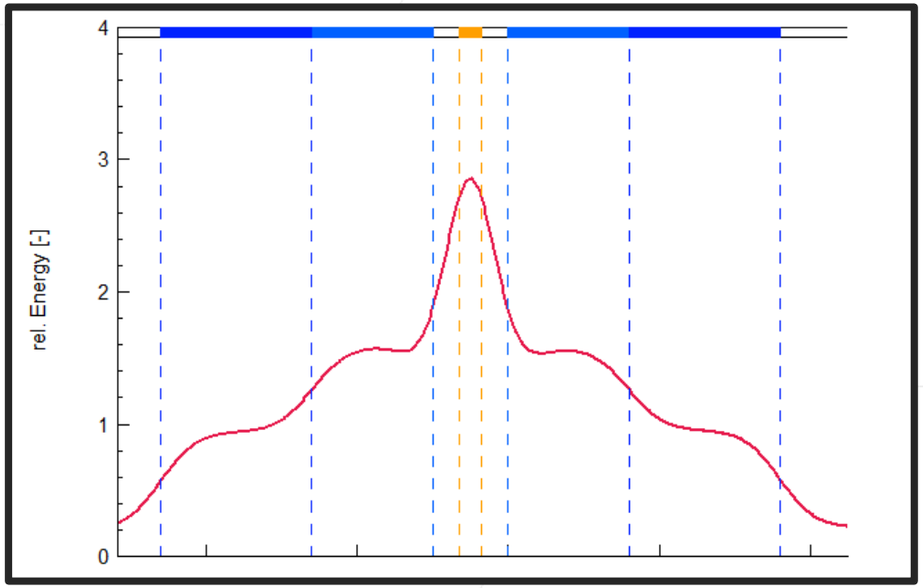
- **With this information a start dose profile along the eval. line can be computed.**

PEC: dose profile optimization



a) Start dose profile





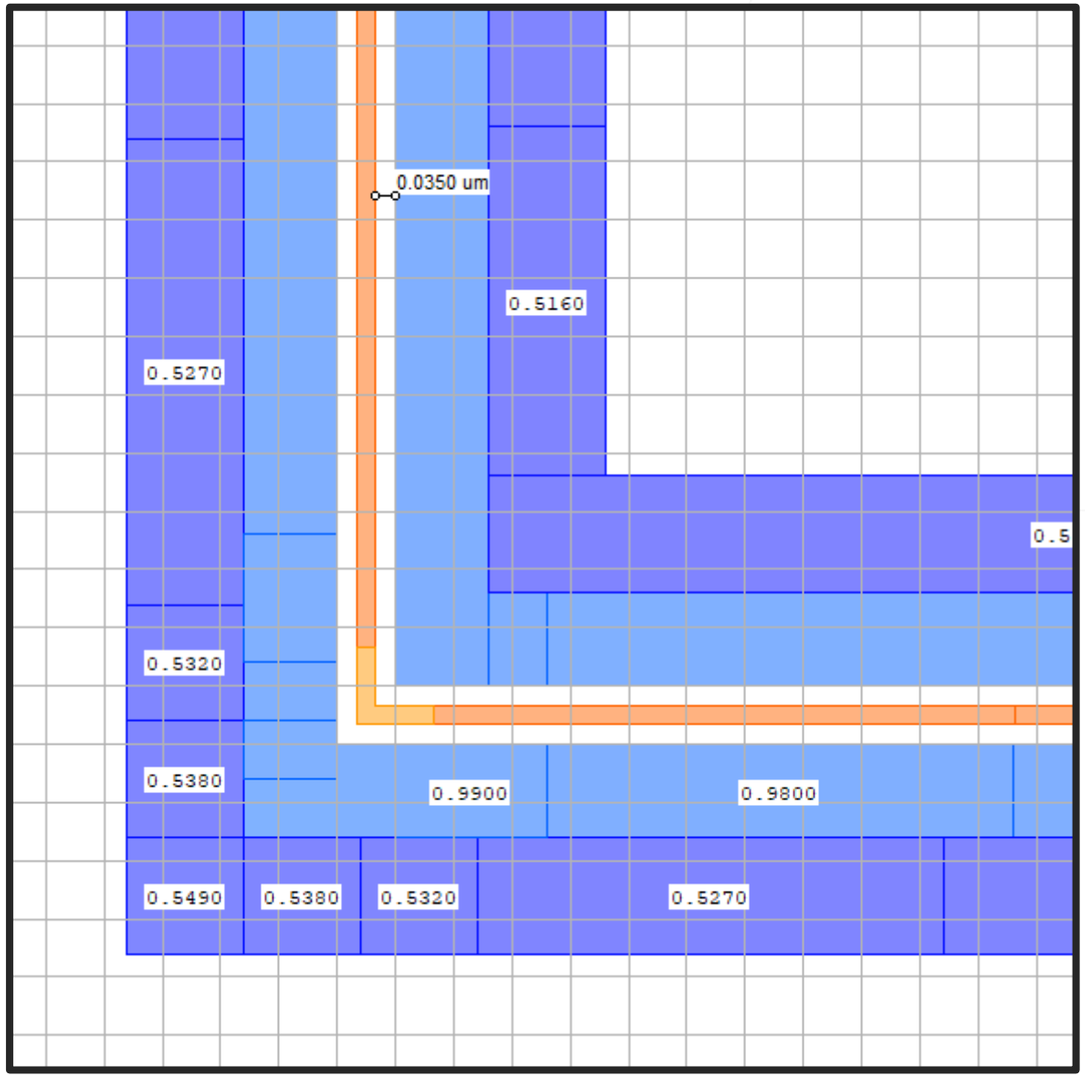
b) Final optimized dose profile

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.

PEC Result



PEC Result: Optimized doses and biases

Summary

- Rate Model can be obtained from measured Contrast Curve
- Rate Model allows for exact Development Front prediction
- In 3D Edge PEC the rate model is used for CD control of the critical layer in a multi resist system

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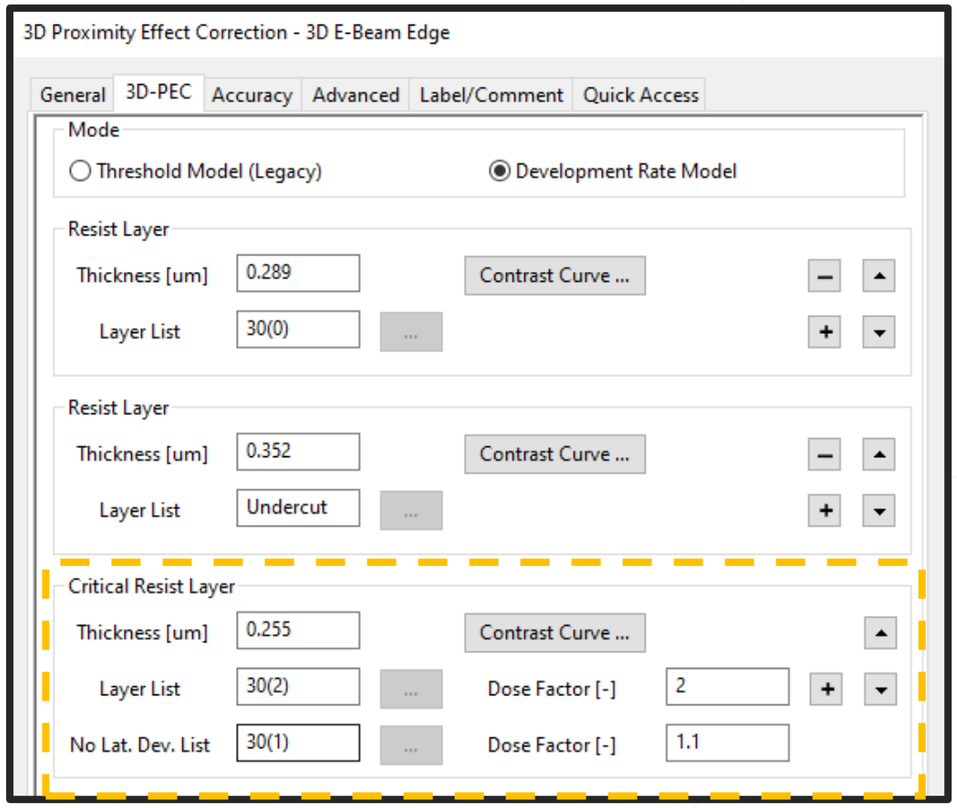
3D Modes in a nutshell

3D	Edge	Surface	Topography
Target	CD @ crit. layer	Dev. Front @ depth	Dose @ Edge
Resist Model	Lumped Parameter	Mack-4 / Segment Rate	-
Short Range Algorithm	Self consistent shape and dose @ eval. line	Fast Marching	Rule based @ topography edges
Long Range Algorithm	LR Convolution	LR Convolution	LR Convolution Multiple PSF

Critical Layer



- The critical layer that includes exact lateral development compensation can be placed anywhere in the stack.
- The “critical” resist layer allows for overdose/undersize. Still 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. So lat. dev. Is discarded there.

Thank You!

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