GenISys

Advancing the Standard

Thursday, January 25, 2024

APPLICATIONS

Projection Simulation Example

App Note

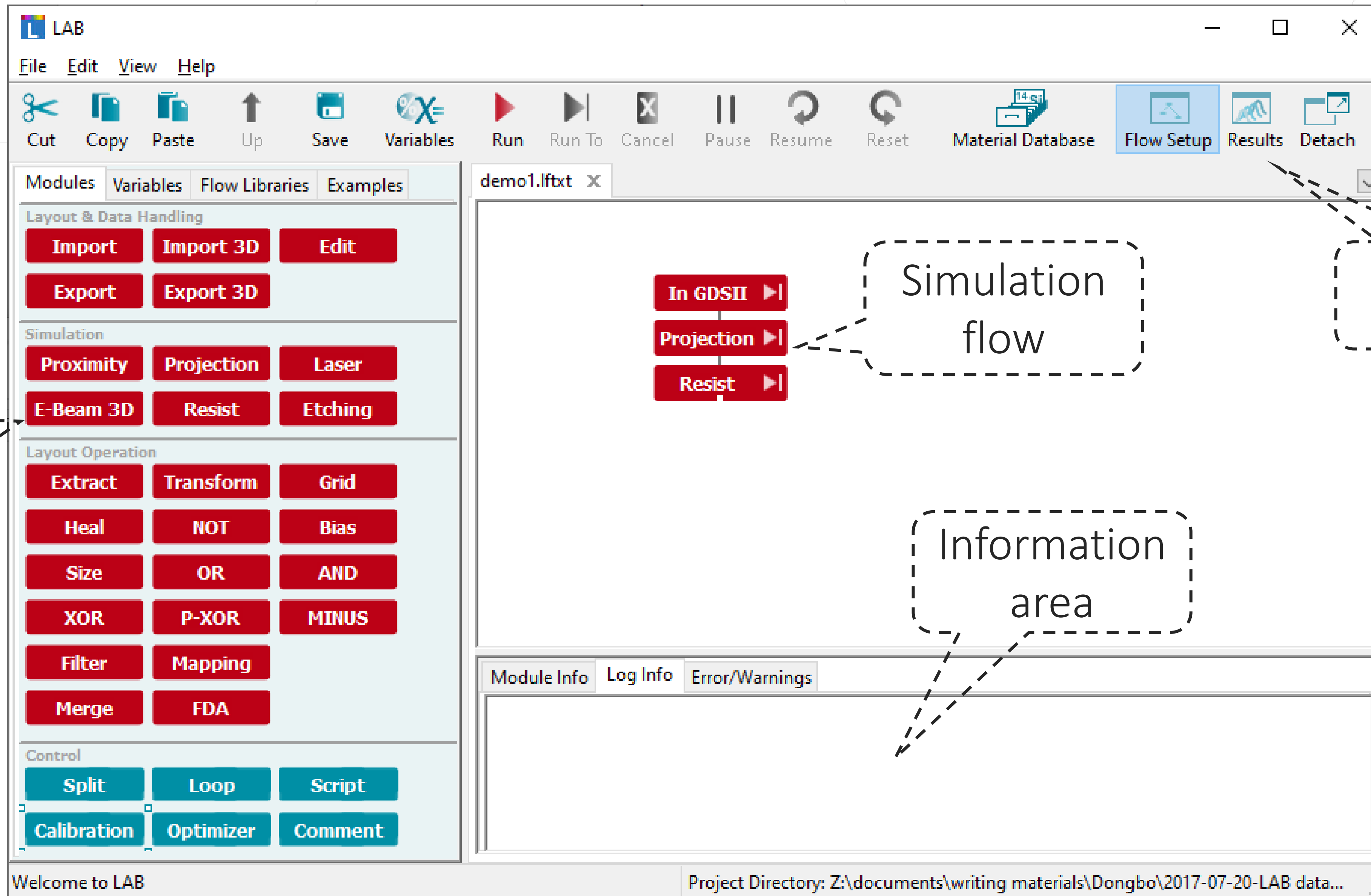
Introduction

- **LAB** simulates projection lithography from a light source giving 3D photoresist profile information.

- Simulations track **exposure problems** and **provides solutions** efficiently.

- This application note uses examples on projection-simulation showing major functionalities of **LAB** for projection lithography:
  - The basic modeling process of LAB is explained.
  - The analysis functions are then depicted, based on the intensity distribution inside the photoresist.

User Interface



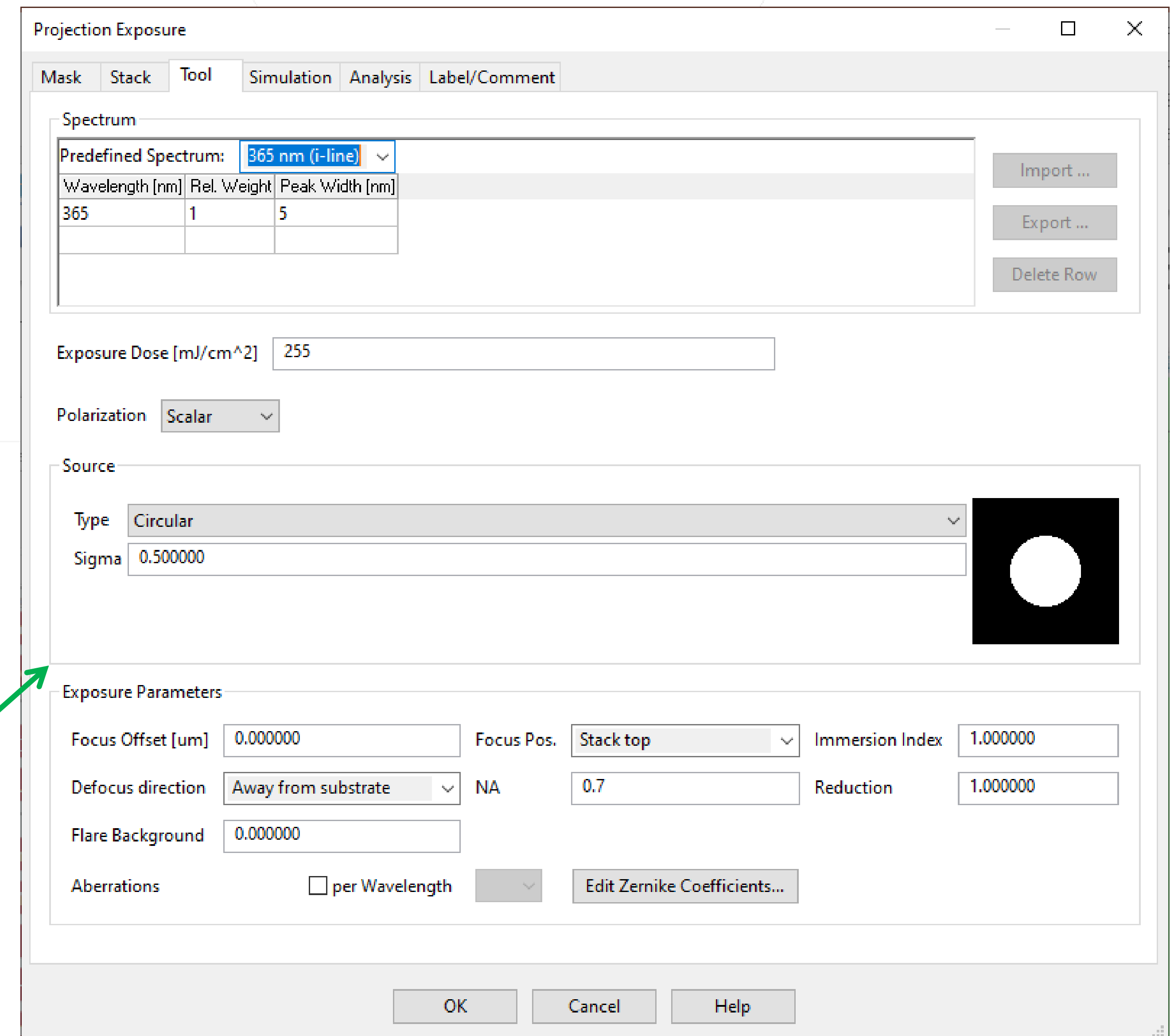
Basic Flow

- The basic flow is as follows:
  - **Import** module to load a layout
    - A layout is defined as the mask in wafer scale
  - **Projection** module simulates the exposure process
  - **Resist** module simulates the development of the photoresist

VIEWER - In GDSII - C:\Users\tanqi\Desktop\LAB_demo_guide\LAB_Demo_June2018\acmos_300nm.gds
File View E-Beam Properties Help
90 or 45 degree
Drawing Speed: 4096x
Layer Tree Doses
In GDSII - acmos_300nm.gds (C:\Users\tanqi\De...
1(0)
All Hide Show
Cell Information Measurement Information
Mouse position (Layout Origin) [um]: -28.9356,427.0360
View Area [um]: -43.874, -12.344; 529.956, 499.973

Projection Module

- Mask
  - Stablishes the region of interest
- Stack
  - Defines the materials involved in the wafer
- Tool
  - Sets source and exposure parameters
- Simulation
  - Sets numerical resolution and periodicity
- Analysis
  - Evaluation settings



Resist Module

- Three **resist models** available:
  - **Mack 4** model relates the dissolution rate to the photoactive compound concentration (PAC) of the resist.
  - **Threshold** model describes the ideal resist performance
  - **Development Rate** model imports data that relates intensity and development rate
- Each set of resist parameters works for specific process conditions

Resist
General | Result Settings | Label/Comment
Database Parameters
Load Parameters from Database
Developer MEGAPOSIT-MF26A
Resist Model
Mack 4 | Threshold | Development Rate
Development Time [s] 45.000000
PEB Time [s] 60.000000
PEB Temperature [deg C] 110.000000
Edi
OK | Cancel | Help

Mack 4 - Ultra_i123
Resist Type
DNQ | CAR

Parameter	Value	Parameter	Value
Ln (Acid Diffusivity Rate) [nm^2/s]	-1000.000000	Acid Activation Energy [kcal/mol]	0.000000
Ln (Base Diffusivity Rate) [nm^2/s]	-1000.000000	Base Activation Energy [kcal/mol]	0.000000
Ln (PEB Amplification) [1/s]	-1000.000000	PEB Ampl. Act. Energy [kcal/mol]	0.000000
Ln (Bulk Acid Loss) [1/s]	-1000.000000	B. Acid Loss Act. Energy [kcal/mol]	0.000000
Quencher Loading	0.000000	Coupling Steps	0
Diffusion Length[um]	0.037450		

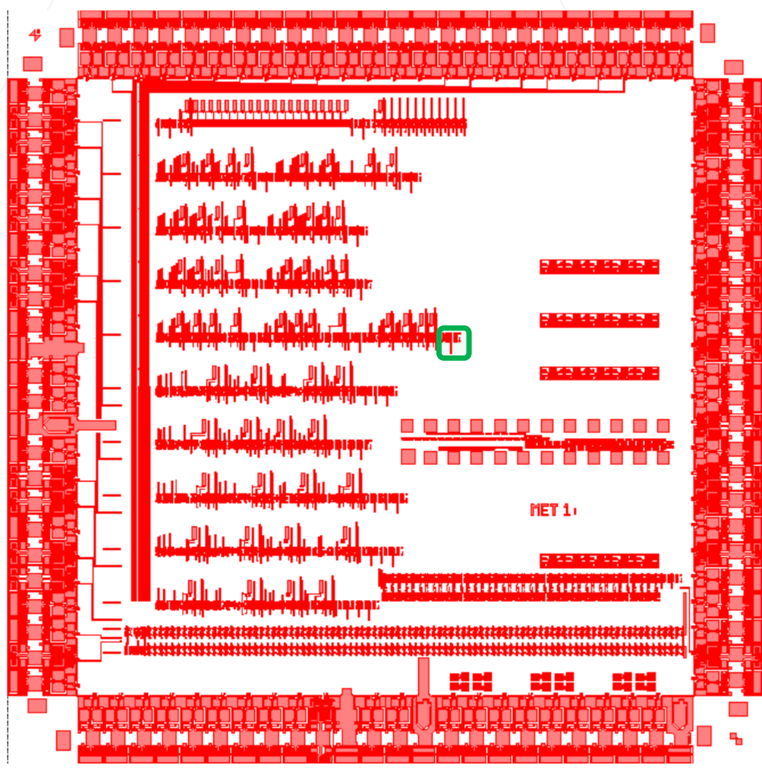
InOutDiffusion | Edit...

Parameter	Value	Parameter	Value
Rmin [µm/s]	0.000060	Rmax [µm/s]	0.067500
Slope	11.528000	Mth	0.560000

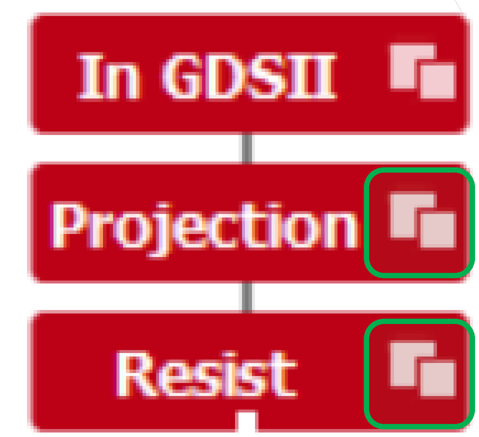
Resist Tone
Positive | Negative
Depth Model
None | Surface inhibition
r0 1.000000 | Inhibition depth [µm] 0.000000
OK | Cancel | Help

Accessing the results

- Let us simulate a critical feature in the layout



- After running the flow results are available in the View icons

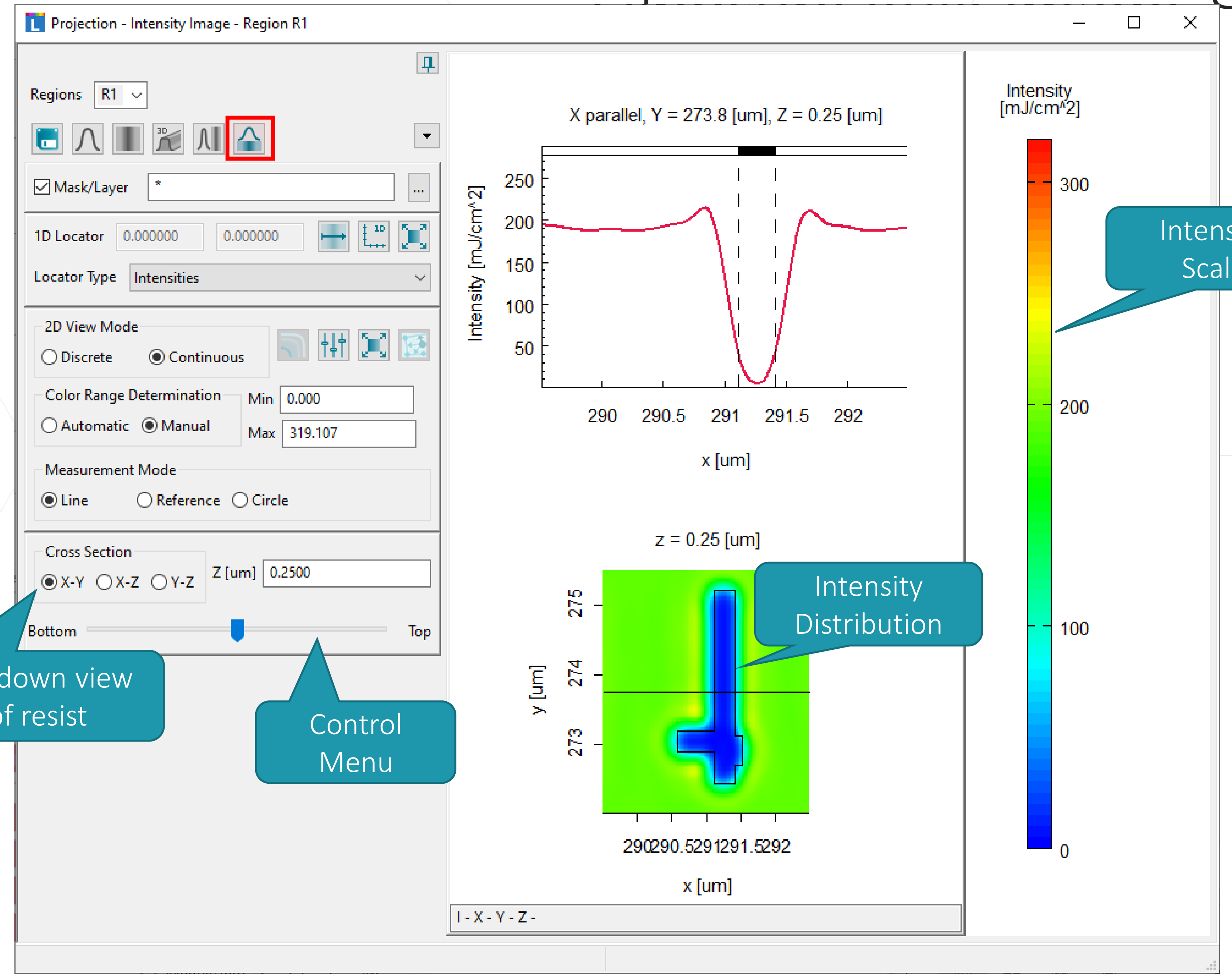


Exposure Bulk Image

- **Bulk intensity** image is available in the Projection module.
- The intenisty image is visible in 1D, 2D or 3D.

View icon

Projection



Resist Profile

- Resist profile can be viewed from:
  - Several angles
  - Different developments times

  - **Note:** Without a suitable resist model, bulk intensity image can not be used to analyse the exposure quality.

Resist - Resist Profile - Region R1

User Settings Applied

DAT [s]

45

Z-Scale

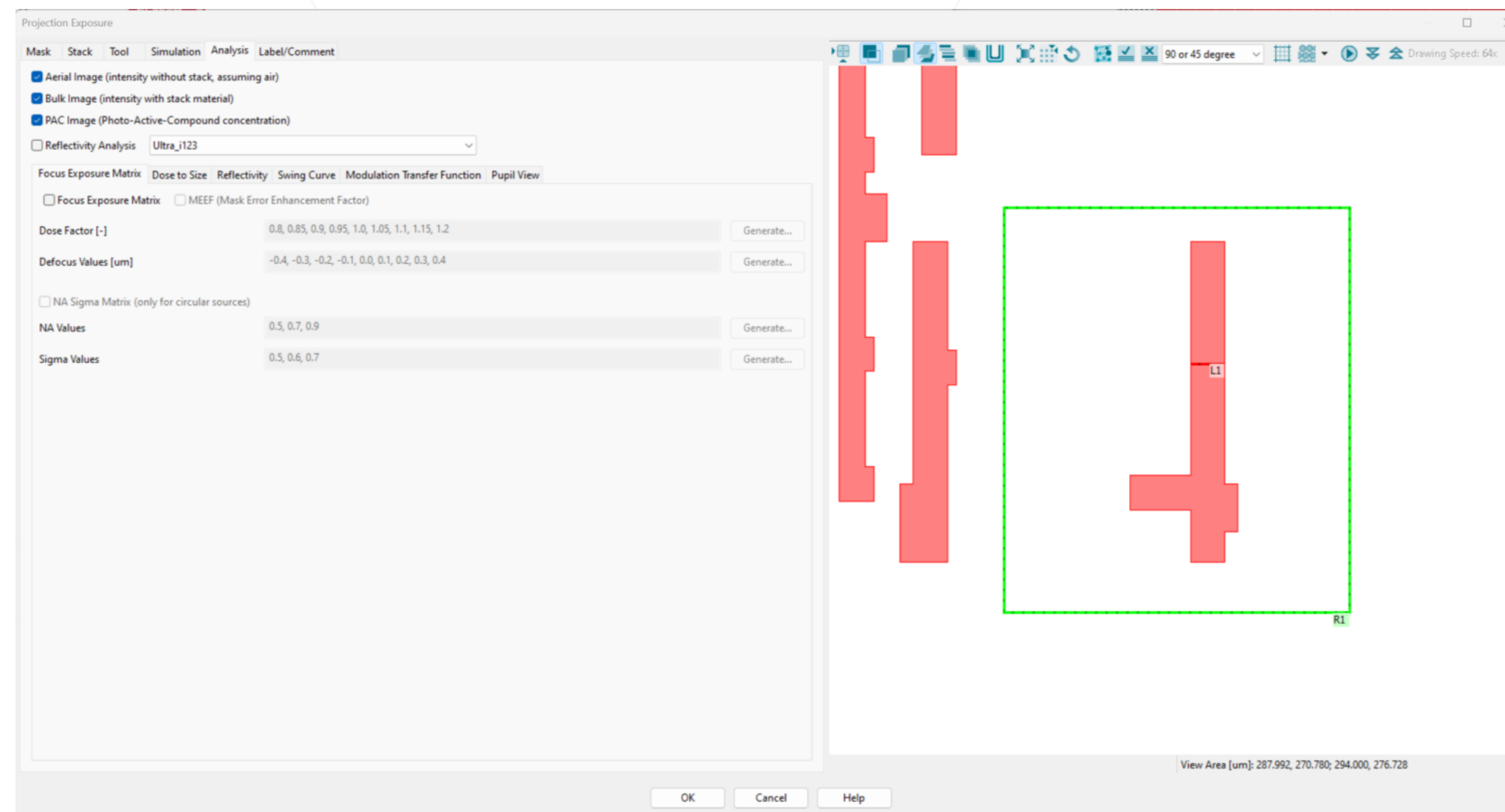
100

Ultra_i123

SiO2

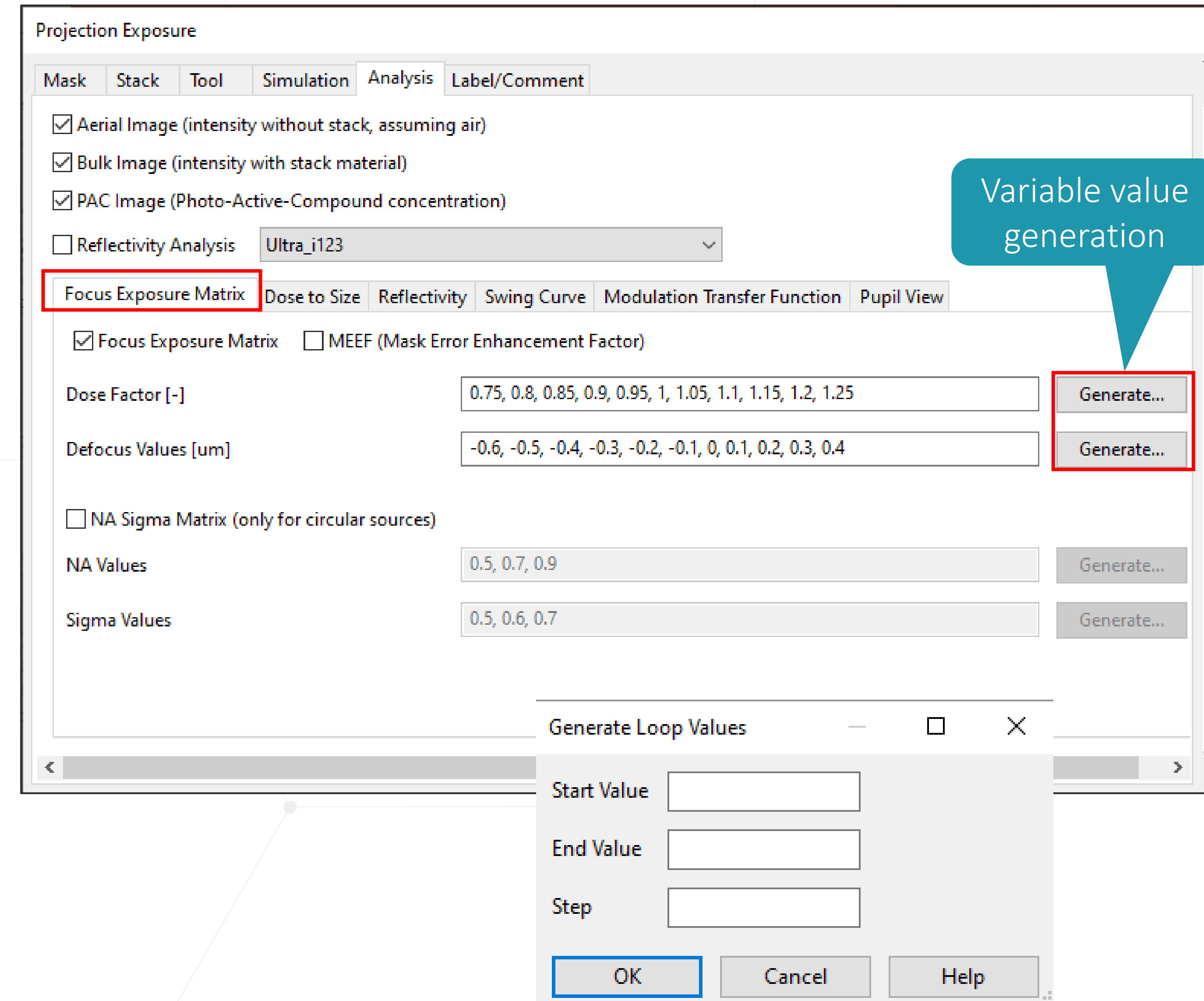
Analysis Functions

- The analysis functions in the projection module are presented in the following:
  - Focus Exposure Matrix to analyse the process feasibility
  - Dose-to-Size to decide the proper exposure dose
  - Reflectivity for bottom anti-reflection layer design → Reduces interference



Focus Exposure Matrix

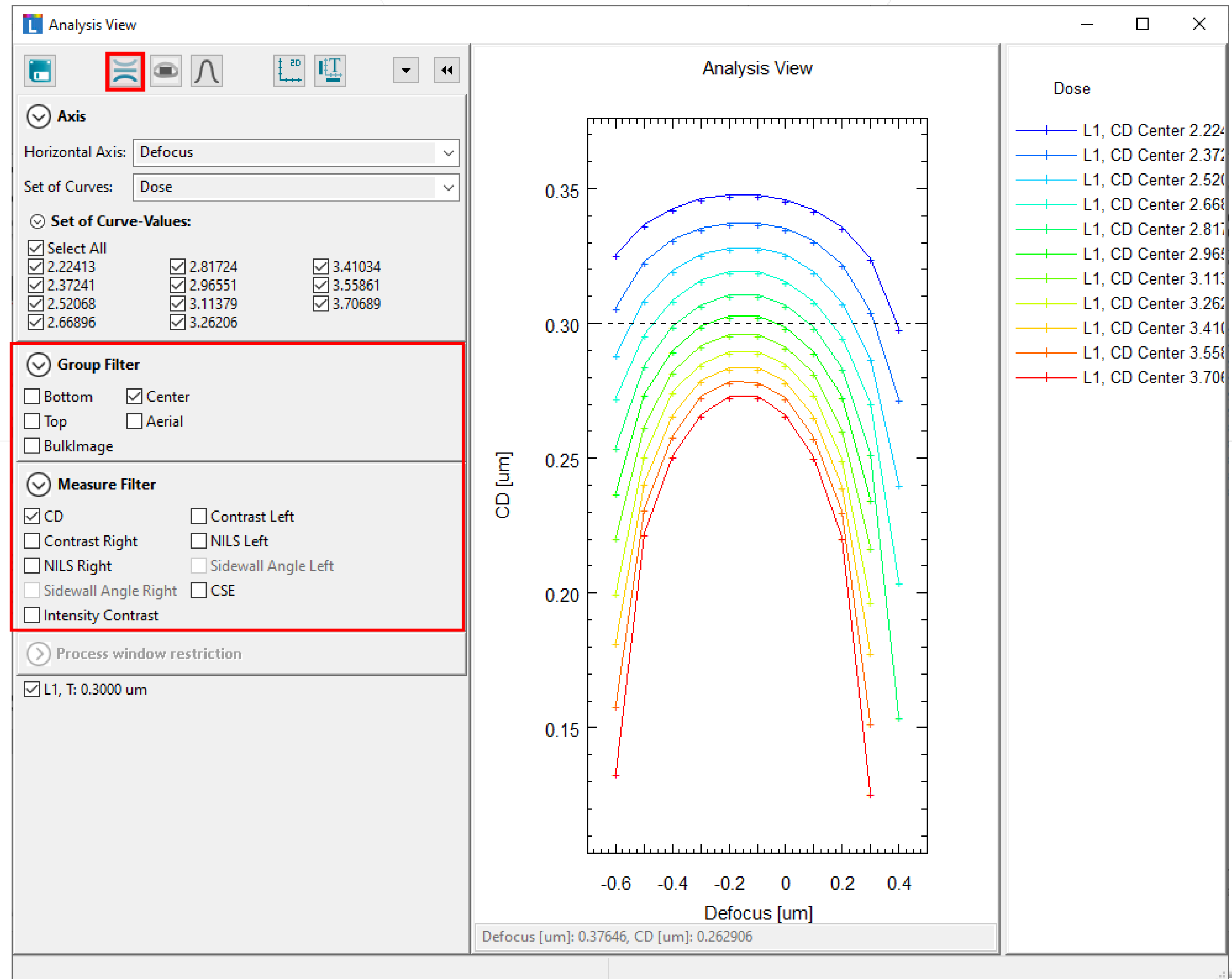
- **Select** Focus Exposure Matrix **checkbox**
- Dose [-] and Defocus [um] can be variables
- The values can be *generated* or entered manually
- Optimal exposure dose is obtained using first the **Dose to Size** analysis



Focus Exposure Matrix

- Click on the view icon of the Projection module
  - In **Group Filter**, different planes along Z plane are analzsed
  - In **Measure Filter**: CD, Contrast, or NILS as the analysis parameter.

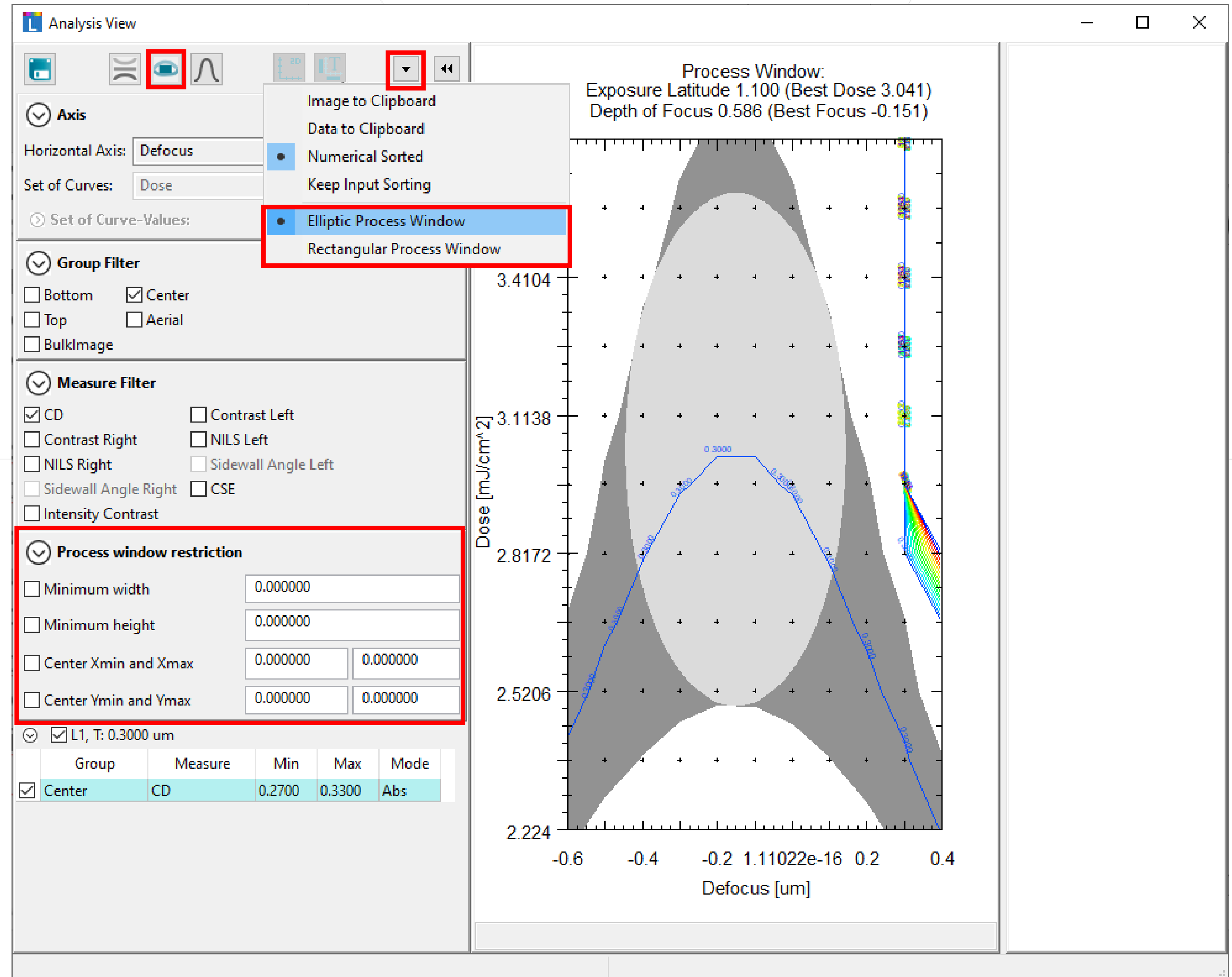
- The right image shows the **Bossung** curves from FEM analysis.



Process Window

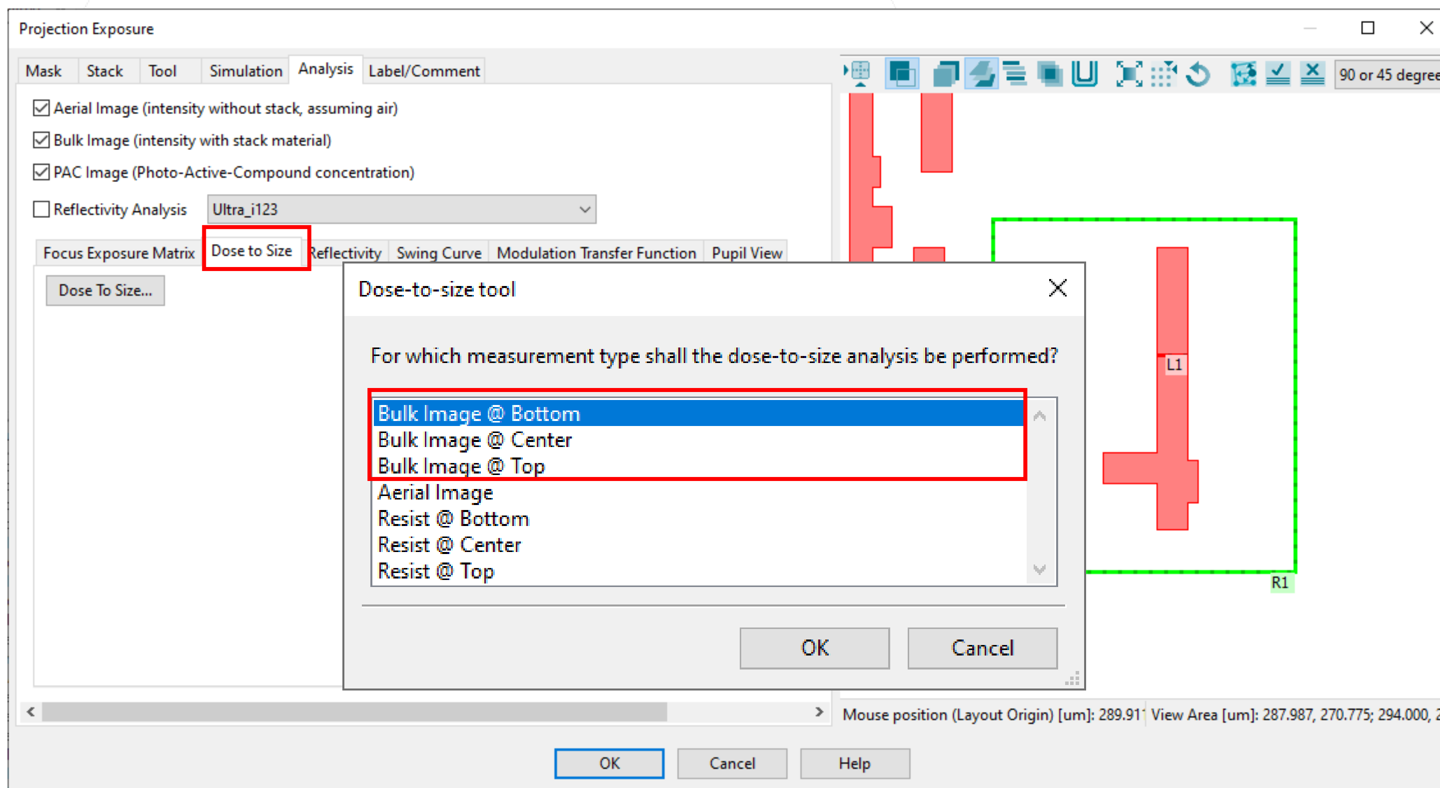
- Bossung curve is converted to a **process window**.
  - Exposure Latitude, Depth of Focus and optimal process conditions are displayed

- Process window restriction allows user to decide the practical process window positions



Dose to Size Analysis

- **LAB** gives the exposure dose when the metrology defined CD matches exactly the expected size
- The CD is calculated with the user defined threshold in the **Mask** tab.
- The CD is measured in different locations (bottom, center or top) of the resist.



Metrology Definition

	Center X [um]	Center Y [um]	Orientation	Target CD [um]	Name
☑	291.263000	274.151000	XParallel	0.300000	L1
☐					

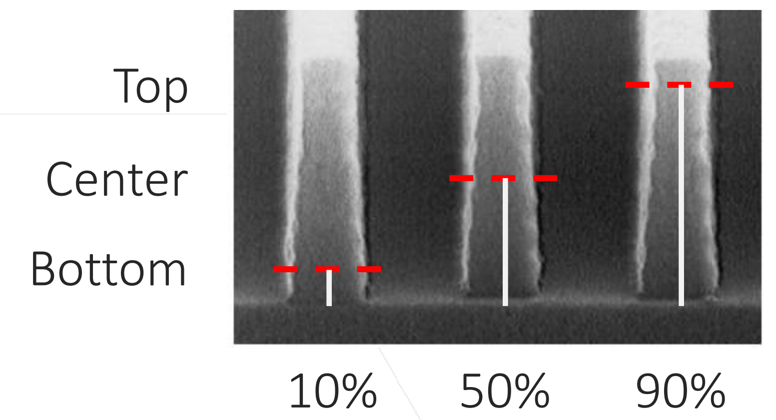
Threshold [mJ/cm^2]: 0.500000 Reference layer (CSE): *

Metrology position settings

Bottom (%): 10.000000 Center (%): 50.000000 Top (%): 90.000000

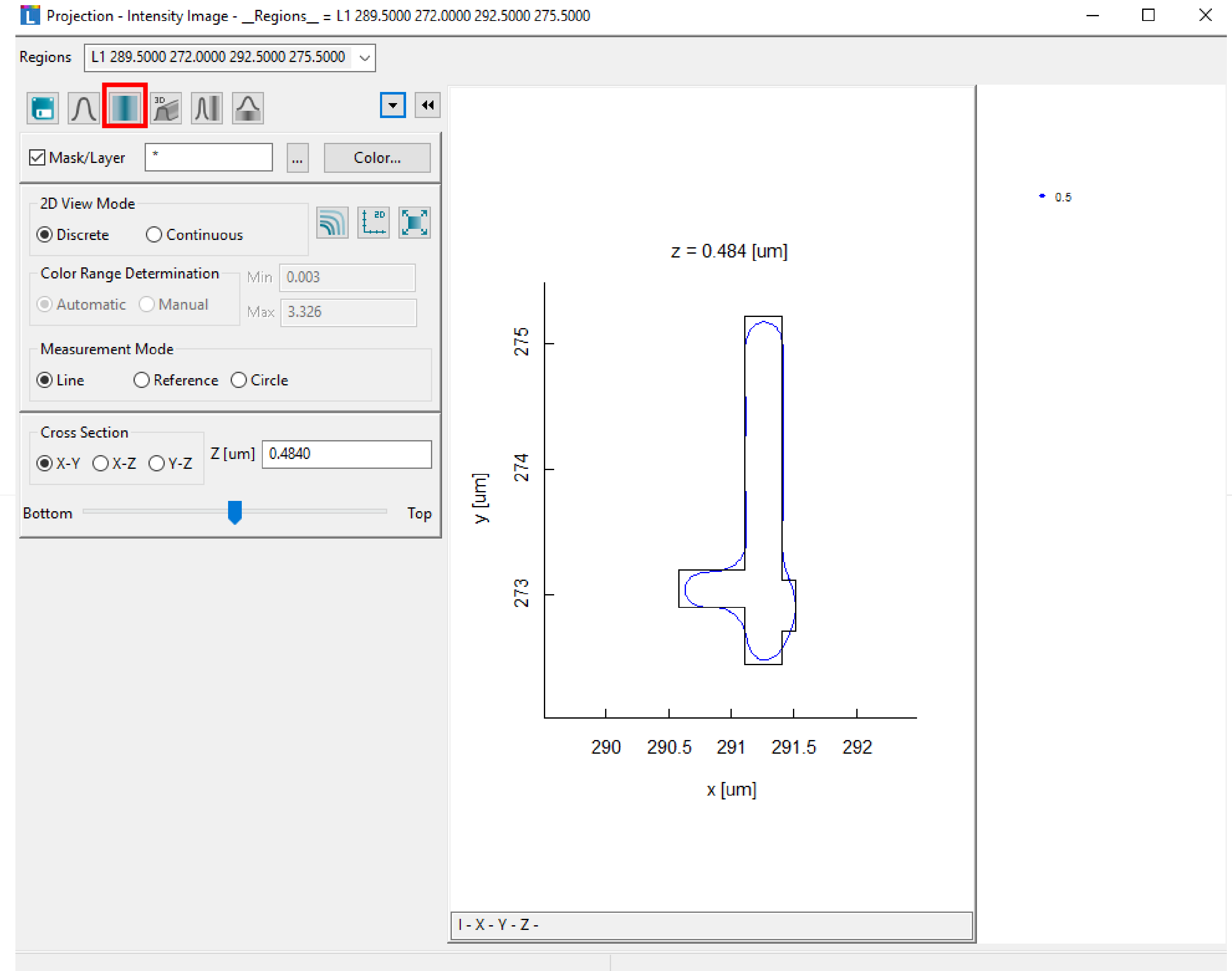
Sidewall angle

Bottom (%): 45.000000 Top (%): 55.000000



Dose to Size view

- The discrete 2D view mode @ light intensity = 0.5 shows that the CD at the metrology line matches exactly the mask.



Stack with Strong Interference

- Interference is strong in stacks with a large refractive index difference

Stack ➡

Type	Material	Thickness [um]	Top-Z [um]
Resist	Ultra_i123	0.5	0.5
Substrate	Si-crystalline	--	--

Ultra_i123 | SiO2

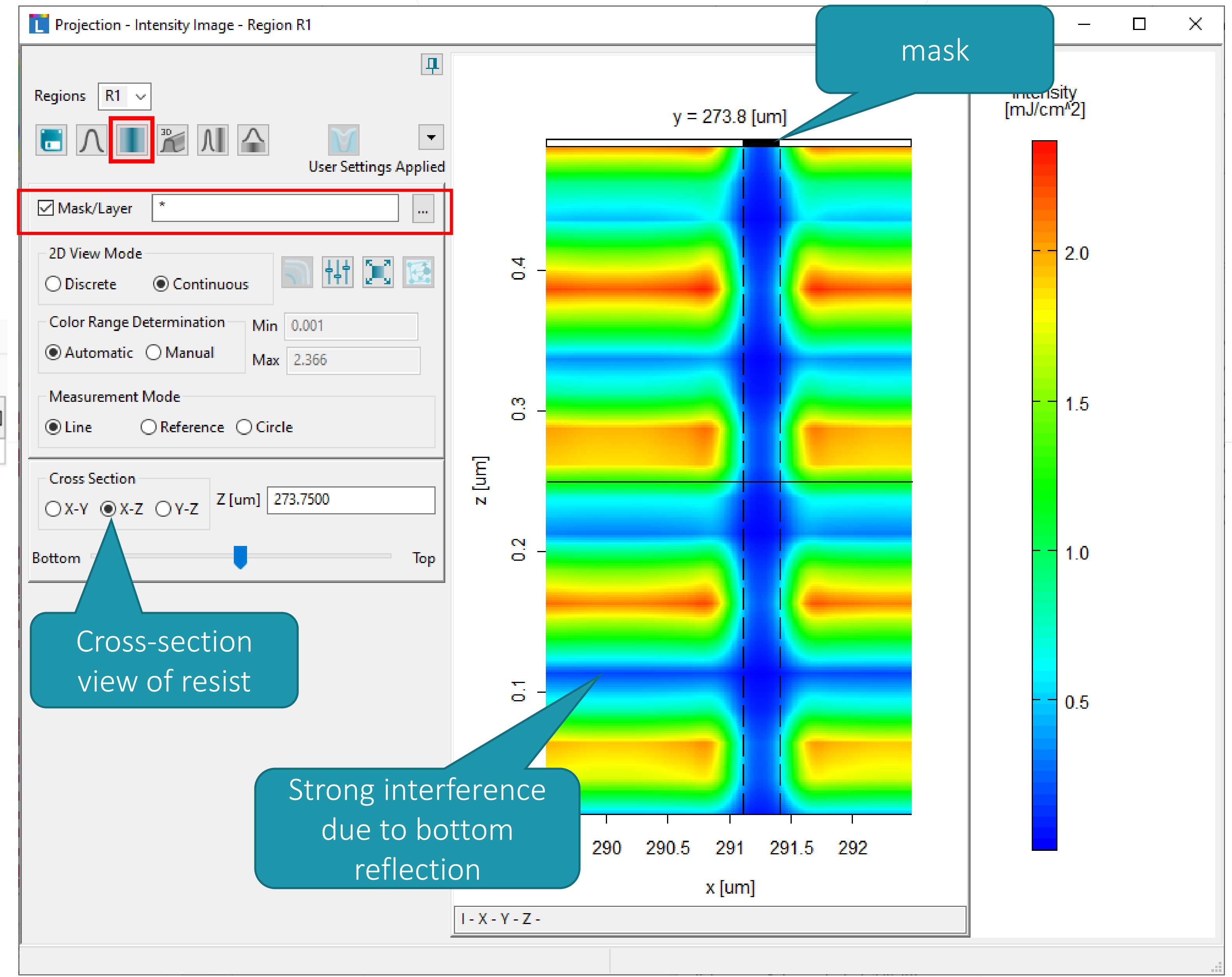
☐ Use Post Apply Bake Model

Wavelength [nm]	n unbleached	k unbleached	n bleached	k bleached	Dill C Abs [cm^2/mJ]	Dill C Rate [cm^2/mJ]
365	1.6522	0.024	1.6522	0.0011	0.0078	0.0078

Ultra_i123 | SiO2

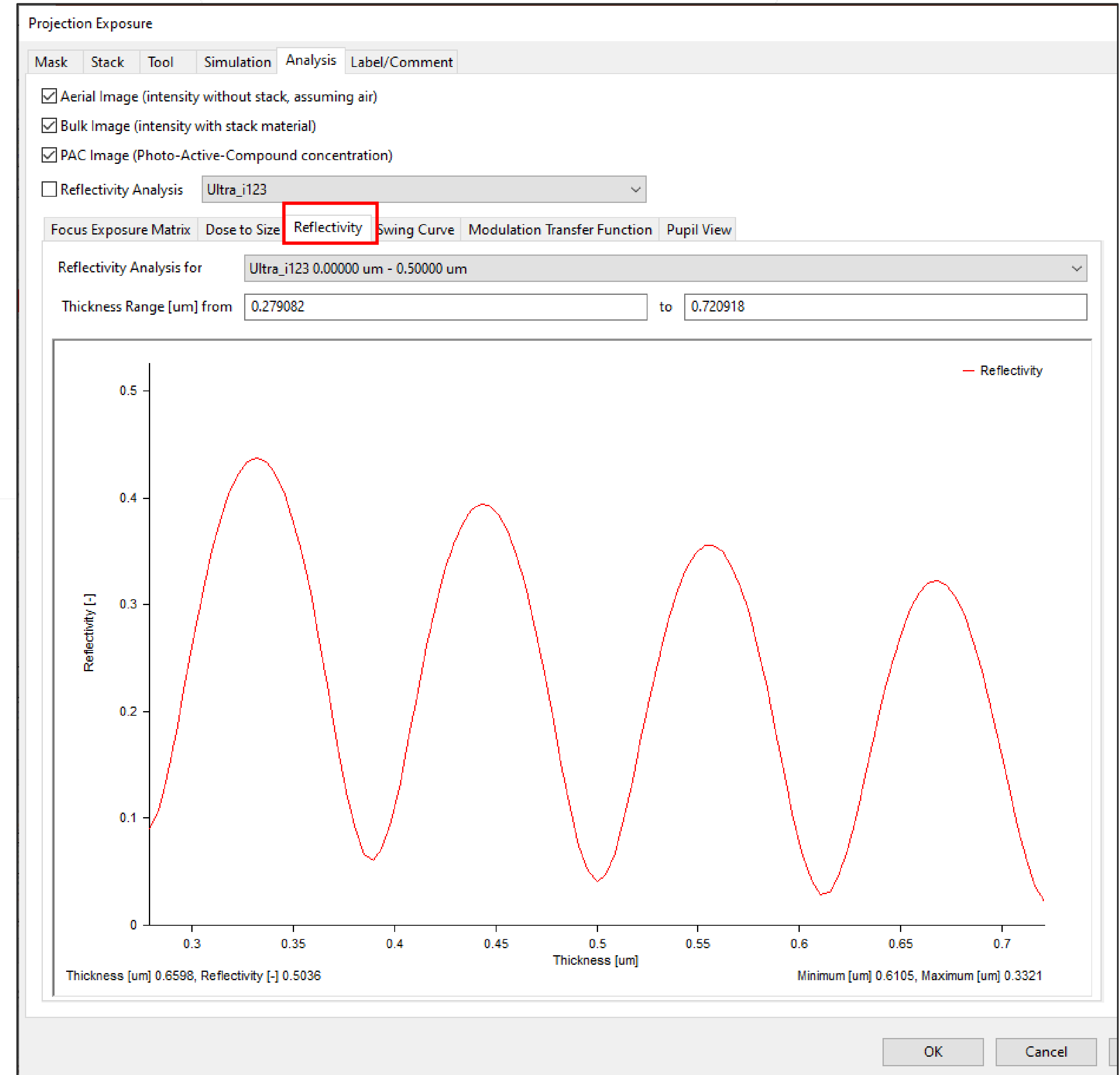
Wavelength [nm]	n	k
365	1.4747	0

- 2D intensity image view can be switched to **cross section view** (X-Z plane).



Reflectivity

- The reflectivity analysis curve helps to check the bottom reflection.
- The reflectivity curve is shown around a predefined thickness range (swing curve). This range can be manually entered.

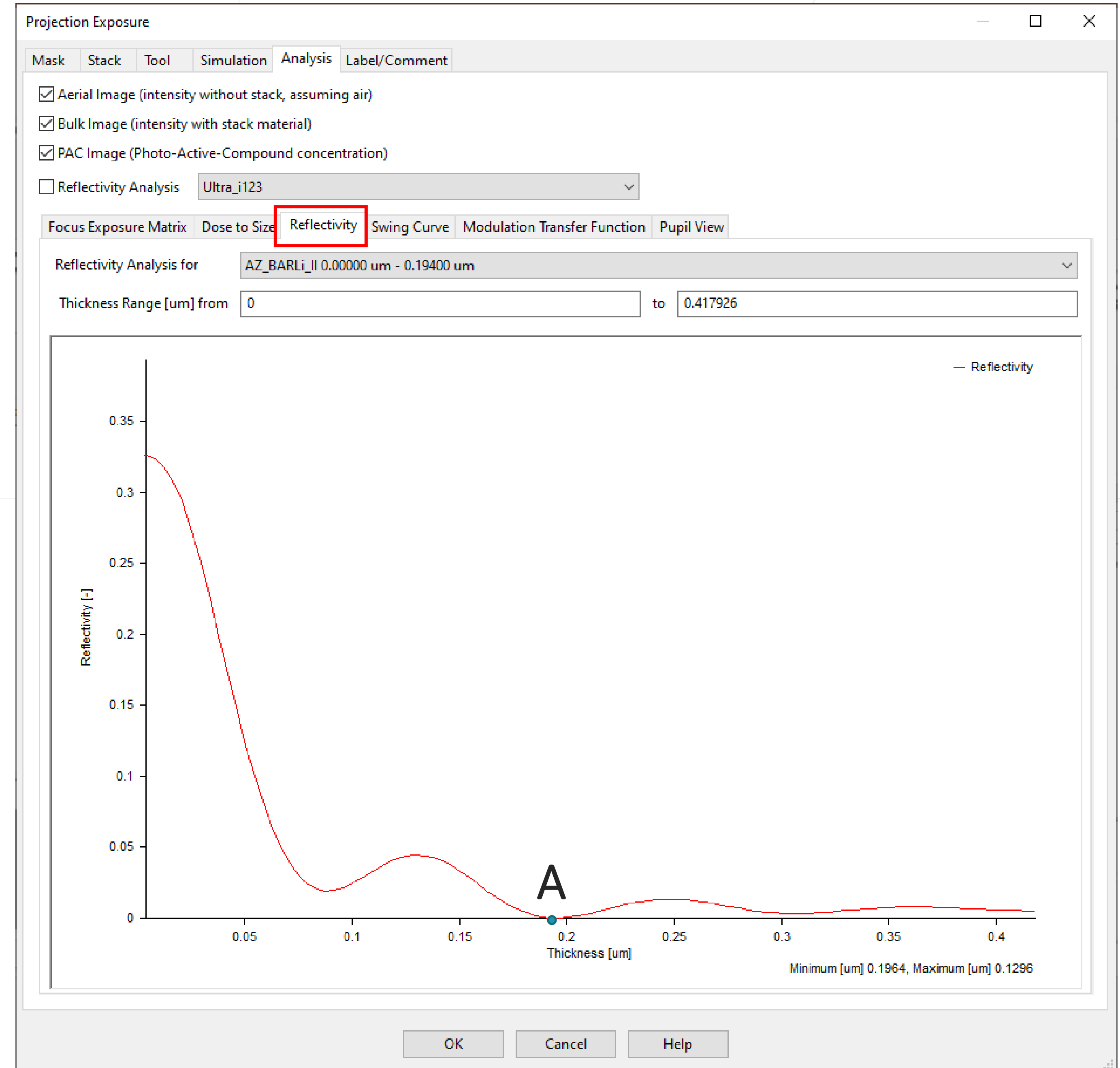


Bottom Anti-Reflective Coating

- An bottom antireflection coating (BARC) can be added to minimize reflection.
- Adding a BARC layer between resist and substrate

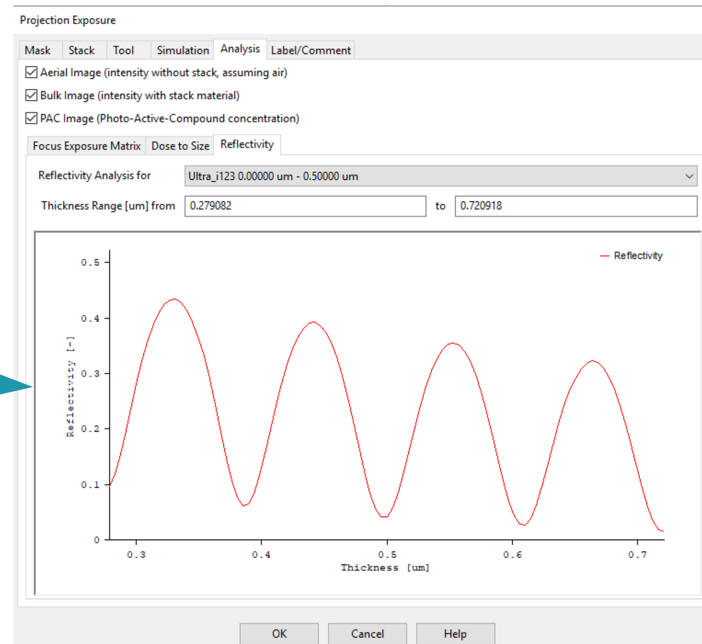
Type	Material	Thickness [um]	Top-Z [um]
Resist	Ultra_i123	0.5	0.6
ARC	AZ_BARLi_II	0.1	0.1
Substrate	Si-crystalline	--	--

- AZ_BARLi_II layer thickness is **first** optimized to have minimum reflection. The thickness value 194 nm (Point A) is selected from the reflectivity curve.



Resist Thickness Optimisation

- Thickness of resist Utra_i123 is then optimised to be 580nm (point B).
- In comparison with the swing curve of resist without anti-reflective coating, the reflection of resist decreases.



Original swing curve

Projection Exposure

Mask | Stack | Tool | Simulation | Analysis | Label/Comment

Aerial Image (intensity without stack, assuming air)
Bulk Image (intensity with stack material)
PAC Image (Photo-Active-Compound concentration)
Reflectivity Analysis Ultra_i123

Focus Exposure Matrix | Dose to Size | Reflectivity | Swing Curve | Modulation Transfer Function | Pupil View

Reflectivity Analysis for Ultra_i123 0.19400 um - 0.77400 um
Thickness Range [um] from 0.359082 to 0.800918

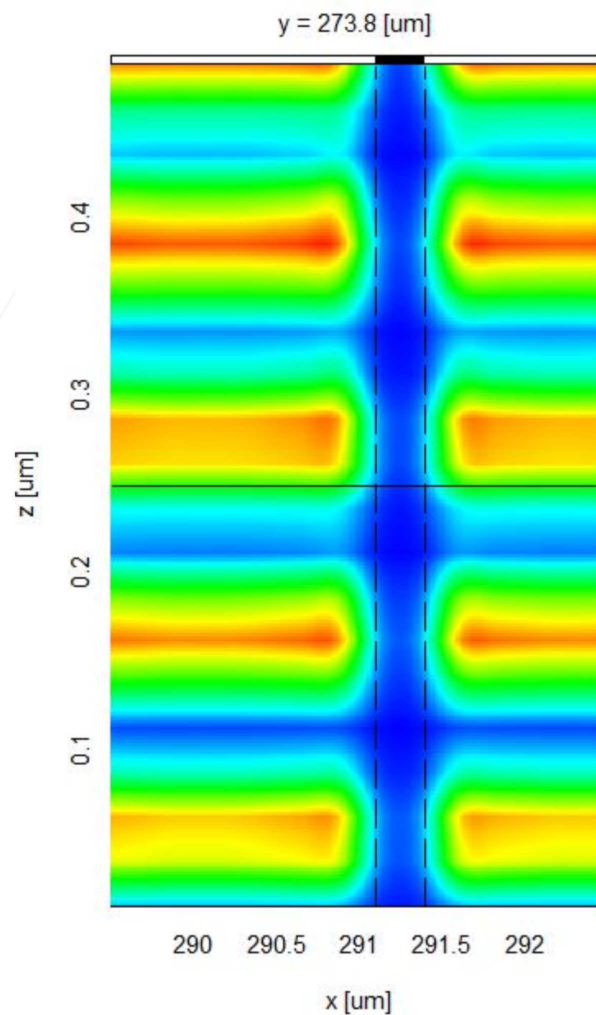
Reflectivity
Reflectivity [-]
Thickness [um]
B
Minimum [um] 0.4651, Maximum [um] 0.4121

Swing curve of resist

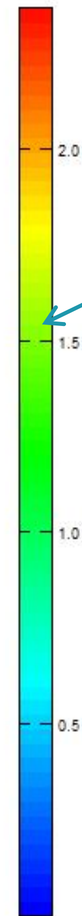
OK | Cancel | Help

Light interference Comparison

- The light interference inside the resist is compared as follows.



Intensity cross-section before BARC

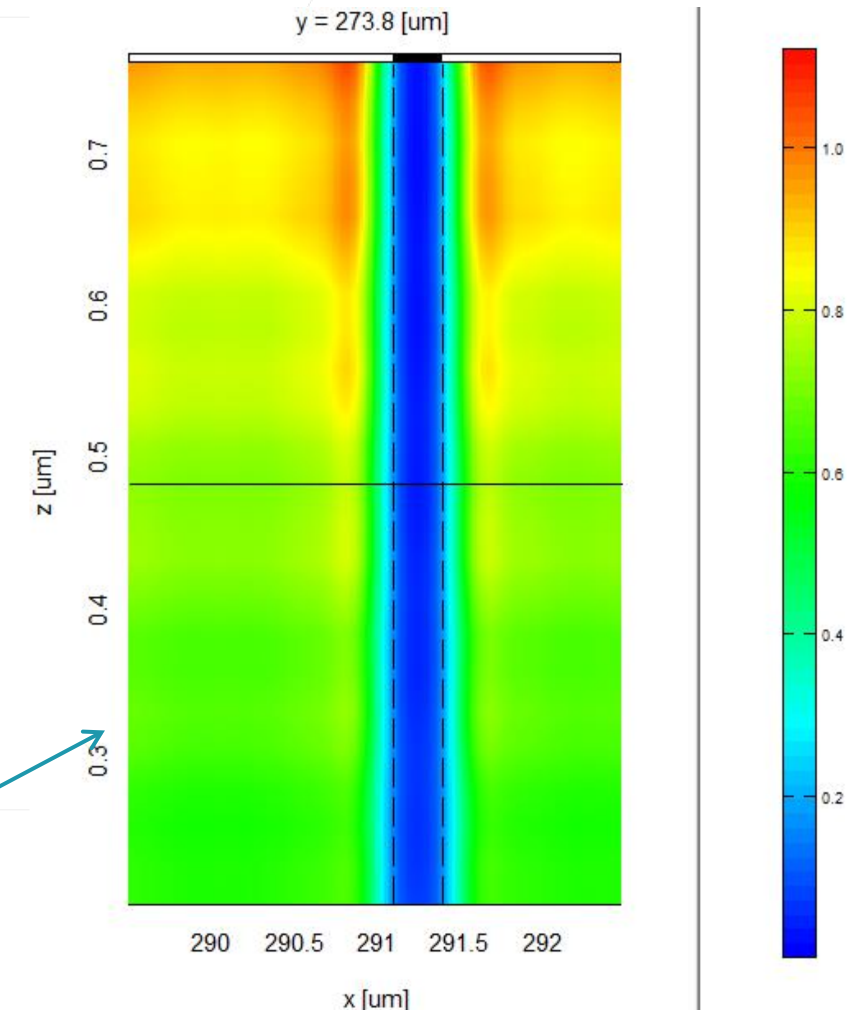


Type	Material	Thickness [um]	Top-Z [um]
Resist	Ultra_i123	0.5	0.5
Substrate	Si-crystalline	--	--

Stack without BARC

Type	Material	Thickness [um]	Top-Z [um]
Resist	Ultra_i123	0.58	0.774
ARC	AZ_BARLi_II	0.194	0.194
Substrate	Si-crystalline	--	--

Optimized stack with BARC



Intensity cross-section after BARC

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Bulk Image Analysis

- Without a good resist model, **bulk intensity** image is important for analysis.
- How to analyse the bulk image?
  - **Threshold model** is defined in Metrology definition of exposure module.

Metrology Definition

	Center X [um]	Center Y [um]	Orientation	Target CD [um]	Name
☑	291.263000	274.151000	XParallel	0.300000	L1
☐					

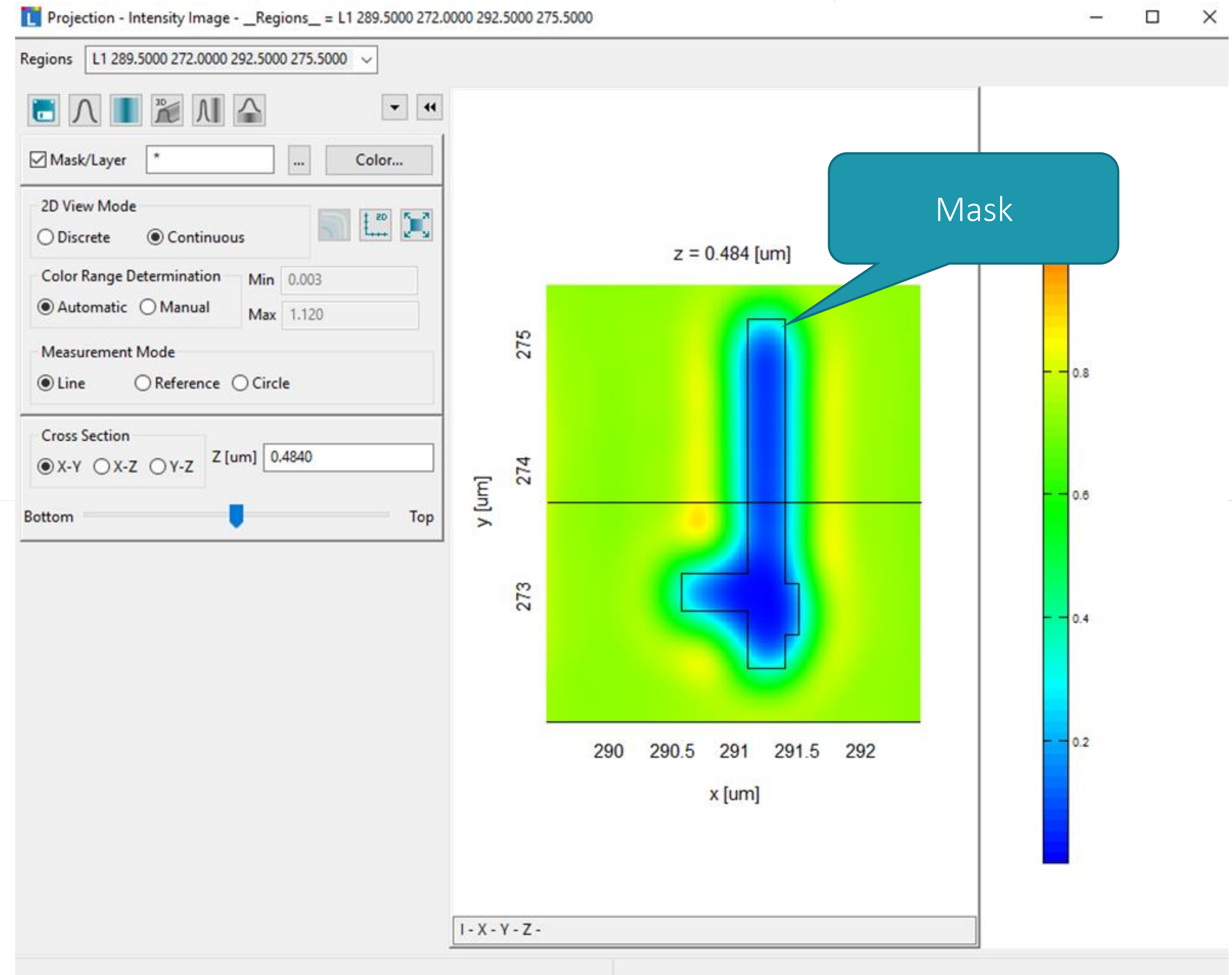
Threshold [mJ/cm^2]: 0.500000   Reference layer (CSE): *

Metrology position settings

Bottom (%): 10.000000   Center (%): 50.000000   Top (%): 90.000000

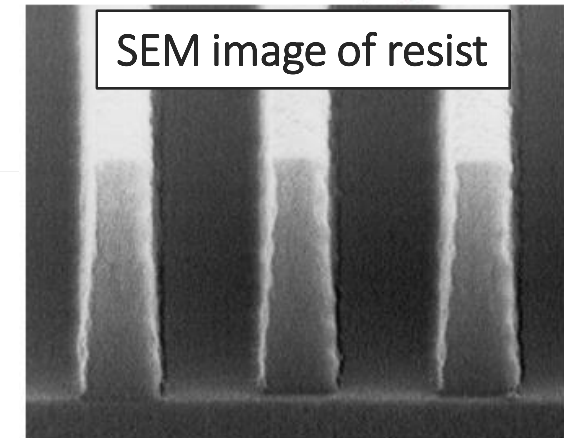
Sidewall angle

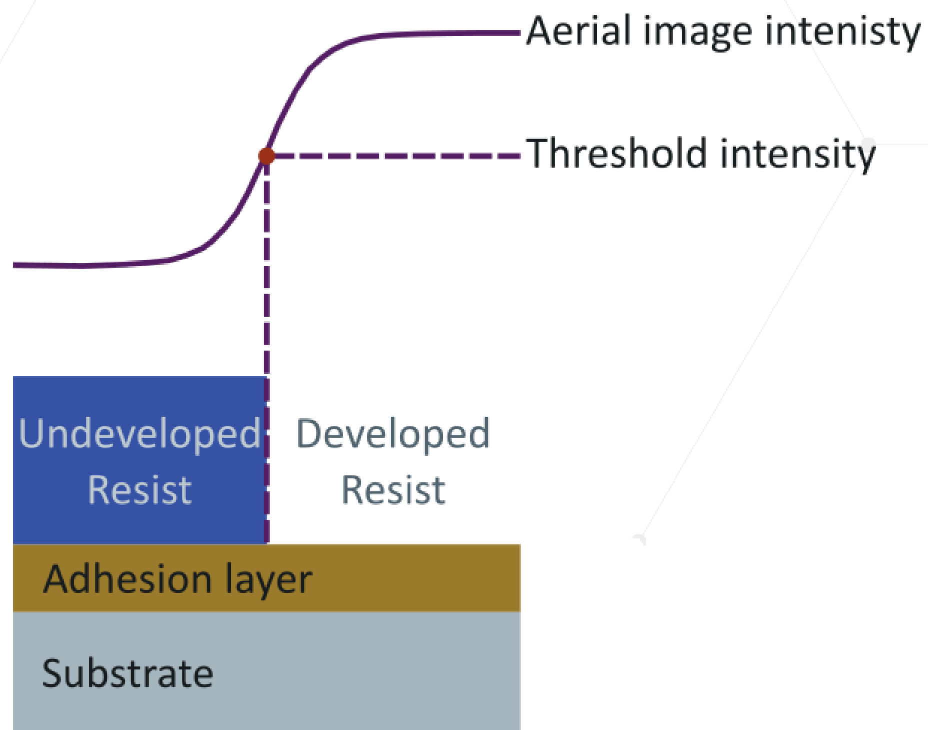
Bottom (%): 45.000000   Top (%): 55.000000

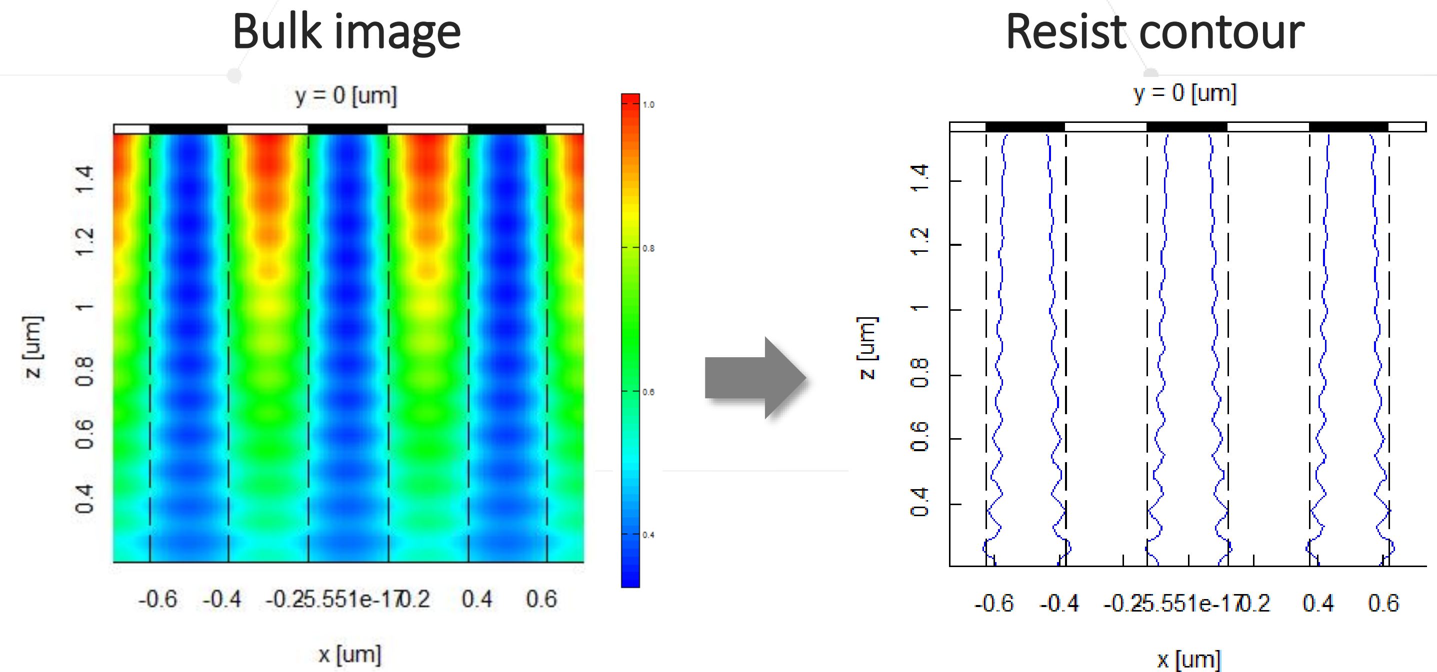


Threshold Model

- Hypothesis: Ideal resist
- Threshold on light intensity
- **3D bulk image is converted to 3D resist contour**
- The example shows the critical feature representation by threshold model.



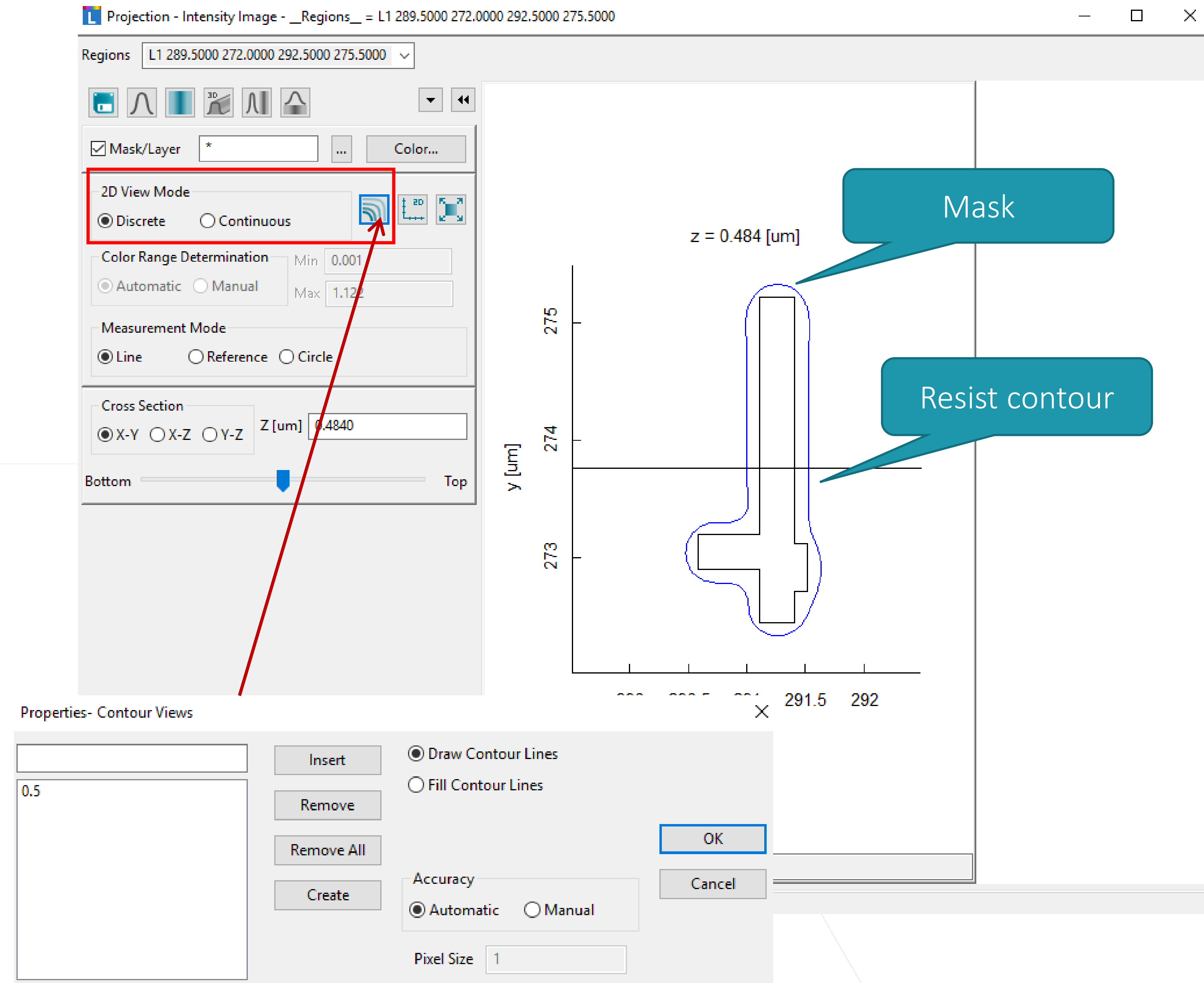




Stanley H. Chan, Alfred K. Wong, and Edmund Y. Lam, "Initialization for robust inverse synthesis of phase-shifting masks in optical projection lithography“, Opt. Express **16**, 14746-14760 (2008)

Bulk Image Analysis

- How to apply the threshold model?
  - The exposure dose is initially assigned to be relative 1.
  - The bulk image is switched to discrete 2D view mode with resist contour line @ light intensity = 0.5.
  - The pattern image on the right is the pattern formation with the threshold model.
  - The resist contour does not match the mask. Thus the present exposure dose is not optimal to achieve the expected size.



Thank You!

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