

Thursday, January 25, 2024

# APPLICATIONS

Projection Simulation Example





#### 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





#### 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



ask Sta	ck Tool	Simulation Analysis Lab	el/Comment				
C							
Spectrum	1					_	
Wavelen	a spectrum	Weight Peak Width [pm]				Import	
365	1 gar (riin)	5				France	
						Export	
						Delete Row	/
Exposure	Dose [mJ/ci	m^2] 255					
		-					
Polarizatio	on Scalar	~					
Source							
Туре	Circular				~	/	
Sigma	0.500000						
Exposure	Parameters	5					
		0.000000		<b>C</b>		1 000000	
Focus C	ffset [um]	0.00000	Focus Pos.	Stack top V	Immersion Index	1.00000	
Defocus	direction	Away from substrate $\sim$	NA	0.7	Reduction	1.000000	
Flare Ba	ckaround	0.000000	]				
nare ba	enground						
Aberrati	ions	per Wavelength	$\sim$	Edit Zernike Coefficients			

LAB Demo



#### 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

In GDSII	M	
Projection	►I	Y
Resist	ÞI	

Resist General

esist	×			
General Result Settings Label/Comment				
Database Parameters				
Load Parameters from Database				
Developer MEGAPOSIT-MF26A	~			
Recist Model				
	Ionment Rate			
Development Time [s] \$5,000000	Mack 4 - Ultra_i123			×
DEP Time (a) 60 00000	Resist Type			
PEB TIME [s]	DNQ     O	CAR		
PEB Temperature [deg C] 110.000000	Ln (Acid Diffusivity Rate) [nm^2/s]	-1000.000000	Acid Activation Energy [kcal/m	nol] 0.000000
Edi	Ln (Base Diffusivity Rate) [nm^2/s]	-1000.000000	Base Activation Energy [kcal/n	0.000000
	Ln (PEB Amplification) [1/s]	-1000.000000	PEB Ampl. Act. Energy [kcal/m	0.000000
OK Cancel Help	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		
	Denie (um (1) 0.000050		Berry (	
$\langle \rangle$	Kmin [µm/s] 0.000000		Kmax [µm/s] 0.06/300	
$\langle \rangle$	Slope 11.528000		Mth 0.560000	
	Resist Tone			
	Positive     ONegative			
	Depth Medel			
		O Surface inhibit	ion	
	O Home			
	r0 1.000000 Inhibition	depth [µm] 0.0000	000	
		OK C:	ncel Help	
/ l			Tich	.i.



## • Let us simulate a critical feature in the layout



#### Accessing the results

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





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







#### Resist Profile

- Resist profile can be viewed from:
  - Several angles

Resist

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

View icon



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#### 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 provide 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

	/	
Projection Exposure		
Mask Stack Tool Simulation Analysis L	abel/Comment	•
Aerial Image (intensity without stack, assuming	air)	
Bulk Image (intensity with stack material)		
PAC Image (Photo-Active-Compound concentr	ration) Varia	able value
Reflectivity Analysis Ultra_i123	↓ ge	neration
Focus Exposure Matrix Dose to Size Reflectivit	y Swing Curve Modulation Transfer Function Pupil View	
Focus Exposure Matrix 🗌 MEEF (Mask Erro	or Enhancement Factor)	
Dose Factor [-]	0.75, 0.8, 0.85, 0.9, 0.95, 1, 1.05, 1.1, 1.15, 1.2, 1.25	Generate
Defocus Values [um]	-0.6, -0.5, -0.4, -0.3, -0.2, -0.1, 0, 0.1, 0.2, 0.3, 0.4	Generate
NA Sigma Matrix (only for circular sources)		
NA Values	0.5, 0.7, 0.9	Generate
Sigma Values	0.5, 0.6, 0.7	Generate
	Generate Loop Values — 🗆 🗙	-
<	Chart Victory	> 1
	End Value	
	Step	
	OK Cancel Help	
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- 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.

T Analysis View		
⊘ Axis		ليتبلينا
Horizontal Axis: Defocus		
Set of Curves: Dose 🗸		0.35
⊙ Set of Curve-Values:		
Select All         2.22413       2.81724       3.41034         2.37241       2.96551       3.55861         2.52068       3.11379       3.70689         2.66896       3.26206		0.30
⊖ Group Filter		[ <sup>1</sup> / <sub>1</sub>
Bottom Center		[ 4/]
L Top L Aerial BulkImage		· · //
Measure Filter	E E	0.25
☐ CD ☐ Contrast Left	8	· · · · · · · · · · · · · · · · · · ·
Contrast Right NILS Left		+ 4//
Sidewall Angle Right CSE		0.20
Intensity Contrast		·····
> Process window restriction		· · · · · //
☑ L1, T: 0.3000 um		[ ]
		0.15
		1
		-
		-0.6
	Defocu	s [um]: 0.37646, C

#### Focus Exposure Matrix



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- 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

L Analysis View			_	×
Analysis View  Analysis View  Axis  Horizontal Axis: Defocus  Axis  Horizontal Axis: Defocus  Set of Curve-Values:  Set of Curve-Values:  Set of Curve-Values:  Group Filter Bottom Center BulkImage  Measure Filter CD Contrast Right Arial BulkImage  Minimum width O.0 Minimum width O.0 Minimum height O.0	Image to Clipboard Data to Clipboard Data to Clipboard Numerical Sorted Keep Input Sorting Elliptic Process Window Rectangular Process Win Left Angle Left	Process Window: Exposure Latitude 1.100 (Best Dose 3.041) Depth of Focus 0.586 (Best Focus -0.151)		×
Center Xmin and Xmax 0.0	0.000000 0.000000			
○ Center Ymin and Ymax     0.0       ○ □ L1, T: 0.3000 um     0.0       Group     Measure       ○ Center     CD       0.2	000000 0.000000 Min Max Mode 2700 0.3300 Abs	2.3200 2.224 -0.6 -0.4 -0.2 1.11022e-16 0.2 0.4 Defocus [um]		

Process Window



#### Dose to Size Analysis

letrology Definition

- 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.

	Center X [um]	Center Y [um]	Orientation	Target CD [um]		Name
	291.263000	274.151000	XParallel	0.300000	L1	
ask Stack Tool Simulation Analysis Label/Comment	ree					
Aerial Image (intensity without stack, assuming air)	Threshold [mJ/cm^2]: 0.5	00000	Refere	ence laver (CSE): *		
⊴ Bulk Image (intensity with stack material)						
	<ul> <li>Metrology position settings</li> </ul>					
Ketlectivity Analysis Ultra_123 V	Bottom (%): 10.000000		Center (%): 50.00000	)	Top (%):	90.000000
Focus Exposure Matrix Dose to Size Reflectivity Swing Curve Modulation Transfer Function Pupil View	Sidewall angle					
Dose To Size Dose-to-size tool X	Bottom (%): 45.00000			Top (%): 55.000000		
For which measurement type shall the dose-to-size analysis be performed?          Bulk Image @ Bottom         Bulk Image @ Center         Bulk Image         Aerial Image         Resist @ Dottom         Resist @ Center         Resist @ Center         Resist @ Top         Resist @ Top         Resist @ Top         Resist @ Top		Ce Bot	Top nter tom			
Mouse position (Layout Origin) [um]: 289.91 <sup>1</sup> View Area [um]: 287.987, 270.775; 294.000	0, 27					
OK Cancel Help			-	10% 50	%	90%
					0	



the mask.

• The discrete 2D view mode @ light

intensity = 0.5 shows that the CD at

the metrology line matches exactly

#### Dose to Size view

Projection - Intensity Image - \_\_Regions\_\_ = L1 289.5000 272.0000 292.5000 275.5000  $\times$ Regions L1 289.5000 272.0000 292.5000 275.5000 <u>™</u> ∧ ∧ - 4 ... Mask/Layer Color... • 0.5 2D View Mode a 🟥 🔀 O Continuous Discrete z = 0.484 [um] Color Range Determination Min 0.003 Automatic Manual Max 3.326 275 Measurement Mode ○ Reference ○ Circle Line Cross Section ● X-Y ○ X-Z ○ Y-Z Z [um] 0.4840 274 ۲ [um] Тор Bottom 273 290 290.5 291 291.5 292 x [um] I - X - Y - Z -

LAB Demo



#### Stack with Strong Interference

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

<u> </u>	1		Туре	Mate	erial T	[hickness [	[um] Top-Z [um	]
St	ack		Resist	Ultra_i123	0	.5		
			Substrate	Si-crystall	ine -			
	Ultra_i123	SiO2						
	Use Pos	st App	ly Bake Mode	I.				
	Wavelengt	h (nm)	n unbleached	k unbleached	n bleached	k bleached	Dill C Abs [cm^2/mJ]	Di
	365		1.6522	0.024	1.6522	0.0011	0.0078	0.0

- Ultra\_i123 SiO2 Wavelength [nm] 365 1.4747
- 2D intensity image view can be switched to cross section view (X-Z plane).





- 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.

Projection Exposure	
Mask Stack Tool Simulation	Analysis Label/Comment
Aerial Image (intensity without stac	k, assuming air)
Bulk Image (intensity with stack ma	terial)
PAC Image (Photo-Active-Compou	nd concentration)
Reflectivity Analysis Ultra_i123	~
Focus Exposure Matrix Dose to Size	Reflectivity Swing Curve Modulation Transfer Function Pupil View
Reflectivity Analysis for Ultra	j123 0.00000 um - 0.50000 um 🗸 🗸
Thickness Range [um] from 0.279	0082 to 0.720918
0.5 -	— Reflectivity
0.4 -	
L- 0.3 - Metectivity	
0.2 -	
0.3 Thickness [um] 0.6598, Reflectivity [-]	0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7 Thickness [um] 0.5036 Minimum [um] 0.6105, Maximum [um] 0.3321
	OK Cancel

Reflectivity



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

Туре	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.





- 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.

Projection Exposure

Mask Stack Tool Simulation Analysis Label/Comment

#### Resist Thickness Optimisation

Projection Exposure	-	- 0	×
Mask Stack Tool Simulation Analysis Label/Comment			
<ul> <li>Aerial Image (intensity without stack, assuming air)</li> <li>Bulk Image (intensity with stack material)</li> <li>PAC Image (Photo-Active-Compound concentration)</li> </ul>			
Reflectivity Analysis Ultra_i123 V			
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			$\sim$
Thickness Range [um] from 0.359082 to 0.800918			
0.08 -	— Re	eflectivity	
0.07 -	$\frown$		
0.06 B			
2.05 - Swing curve of ₹			
0.03 -			
0.02 -			
0.01 -			
0 0.4 0.45 0.5 0.55 0.6 0.65 0.7 Thickness [um] Minimum [um] 0.4	0.75 4651, Maximum [ur	0.8 m] 0.4121	
OK Cancel Help			
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### Light interference Comparison

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





#### 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	ı			
	Center X [um]	Center Y [um]	Orientation	Ta	rget CD [um]		Name
$\checkmark$	291.263000	274.151000	XParallel	0.300000		L1	
hre	schold [m]/cm^2]; 0.5000	00	Referer	ce laver (CSE	). *		
hre	eshold [mJ/cm^2]: 0.5000	00	Referer	ce layer (CSE	): *		
'hre Me	eshold [mJ/cm^2]: 0.5000	00	Referen	ce layer (CSE	): *		
hre Me	eshold [mJ/cm^2]: 0.5000 trology position settings ttom (%): 10.000000	00	Center (%): 50.000000	ce layer (CSE	): *	Top (%):	90.00000
hre Me Bot	eshold [mJ/cm^2]: 0.5000 trology position settings ttom (%): 10.000000 ewall angle	00	Center (%): 50.00000	ce layer (CSE	): *	Top (%):	90.000000





- 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.

#### 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.



I AB Demo

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## Thank You!

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