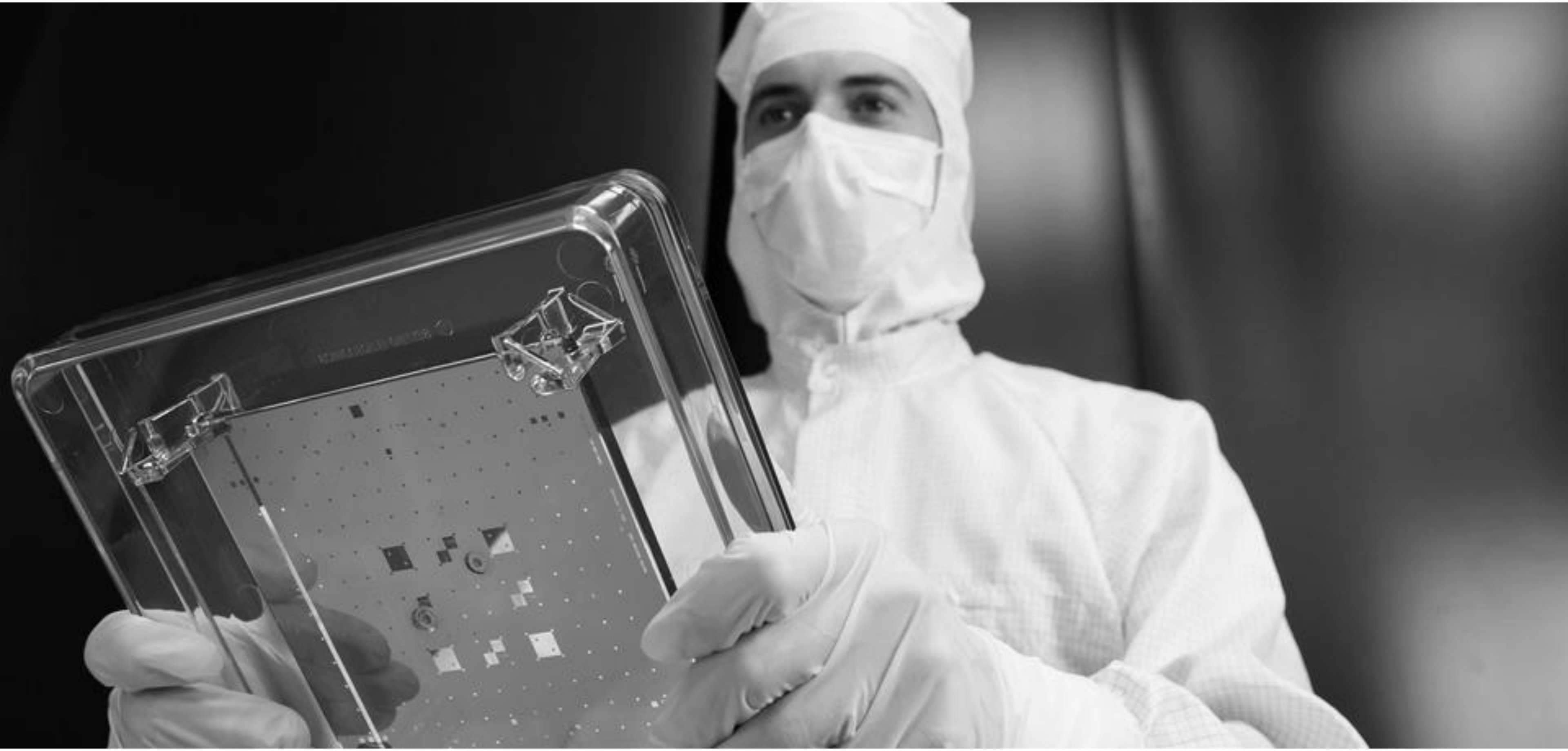
FCMN 2013:
Metrology Tools for Photo Mask Repair and Mask Performance Improvement

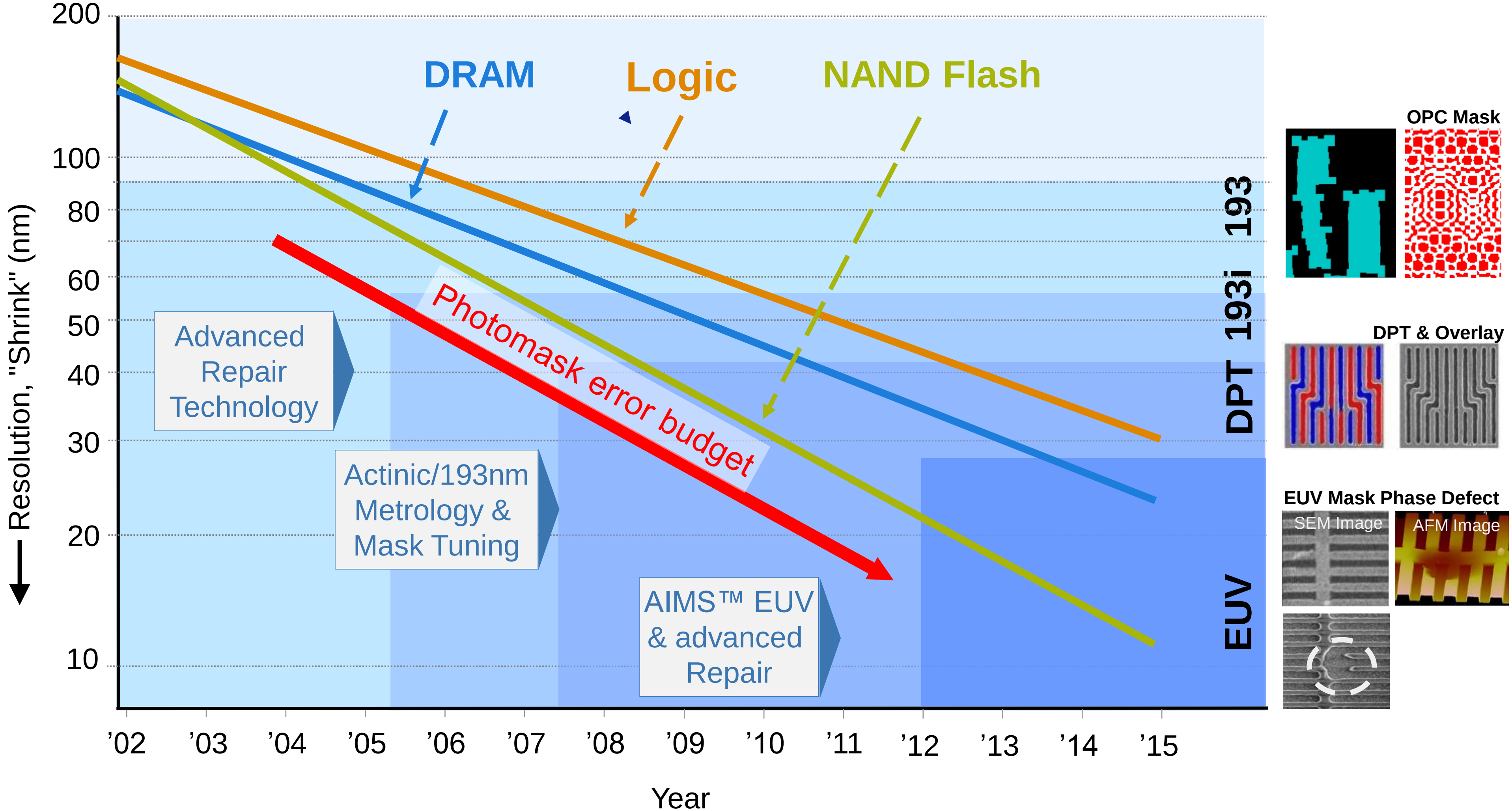
ZEISS



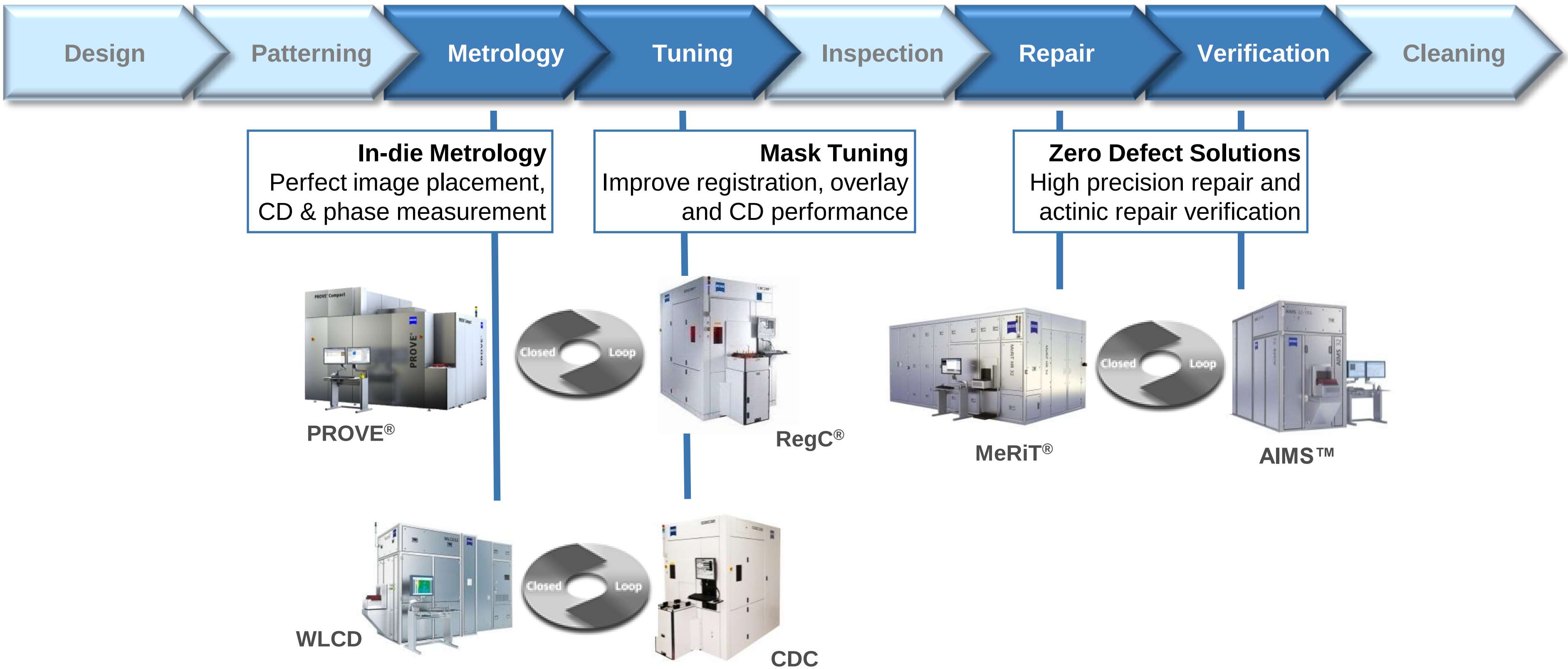
Klaus Edinger Carl Zeiss SMS

March 28th, 2013

Lithography Roadmap & Key Mask Challenges



Carl Zeiss „Perfect Mask Solutions“



Motivation

ITRS 2011 – Optical mask requirements

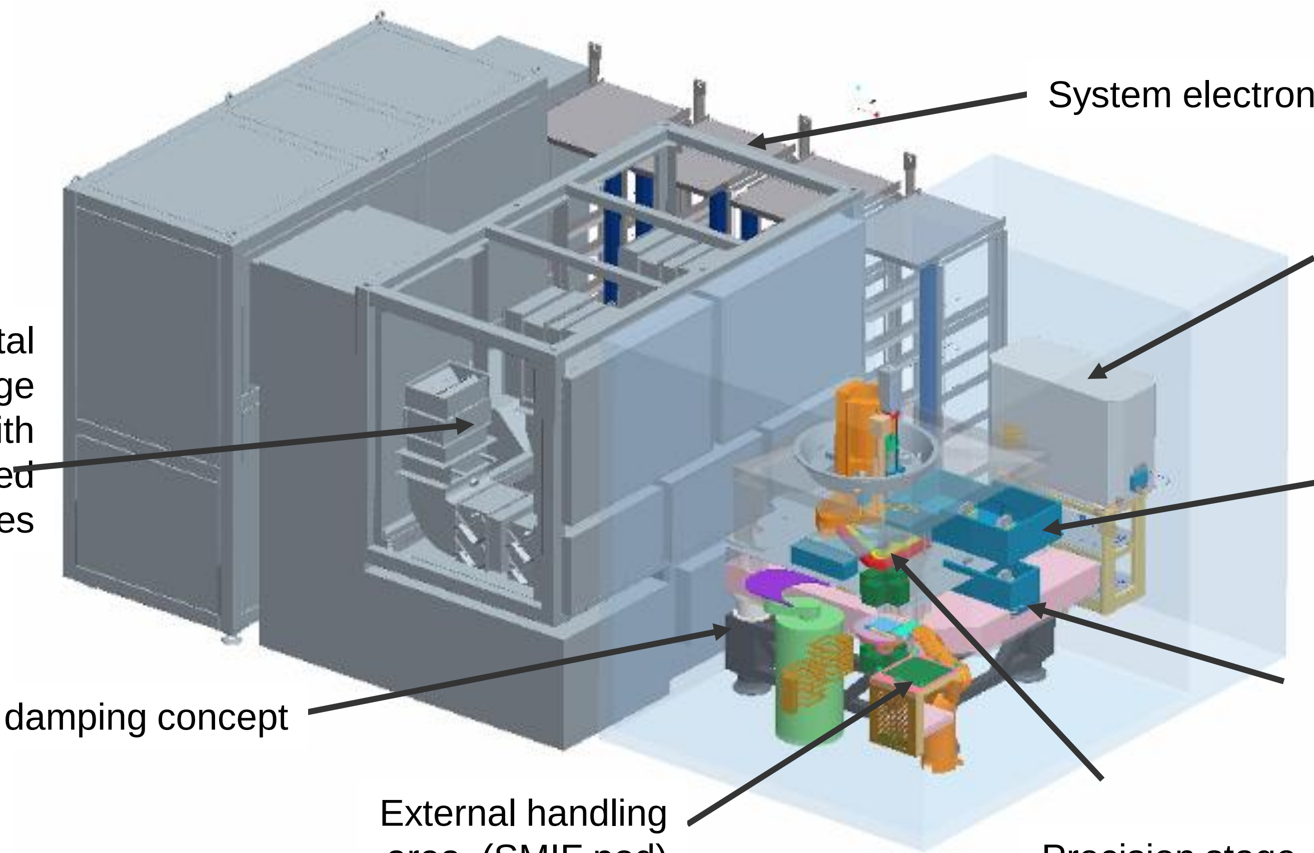
Year	2011	2012	2013	2014	2015	2016
DRAM ½ pitch (nm)	36	32	28	25	23	20
Flash ½ pitch (nm)	22	20	18	17	15	14
MPU/ASIC Metal 1(M1) ½ pitch (nm)	38	32	27	24	21	19
Generic Mask Requirements						
Mask minimum primary feature size	**99**	**88**	**80**	**80**	**80**	**80**
CDU isolated lines (nm 3S)	**2.3**	**2.1**	**1.7**	**1.5**	**1.2**	**1.1**
CDU dense lines (nm 3S)	**3,0**	**2,4**	**1.9**	**1.5**	**1.3**	**1.0**
Image placement* (S/O removed)	**4,3**	**3.8**	**3.4**	**3.0**	**2.7**	**2.4**
Image placement for double patterning* (S/O removed) **	3,4	3,0	2,7	2,4	2,1	1,9

* Not including pellicle induced errors * *ITRS 2010

- The current and the near future registration specs are very challenging for mask manufacturers.
- Emphasized with the appearance of the Double Patterning (DP) techniques.

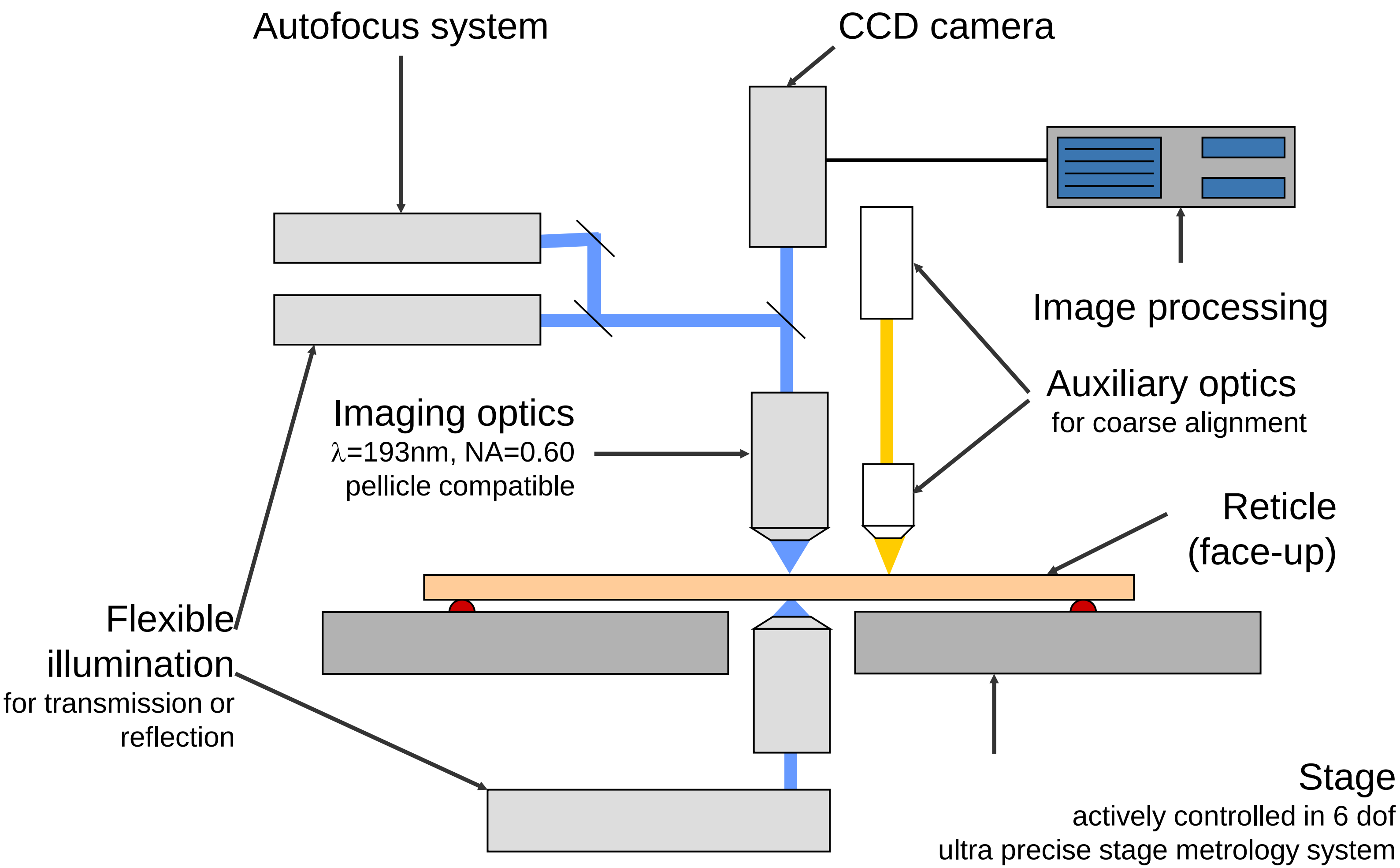
PROVE®

Tool Overview



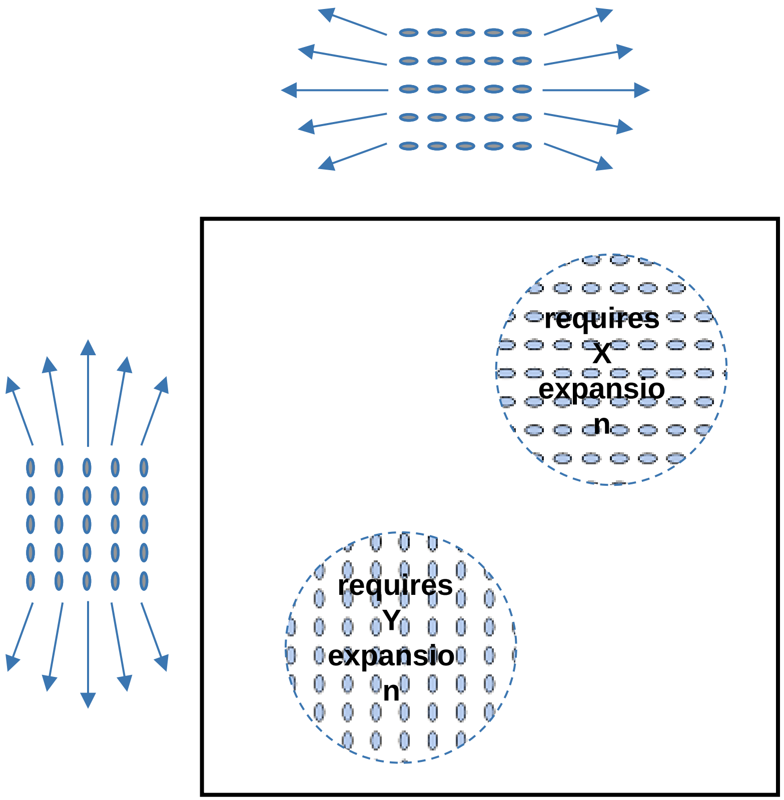
PROVE®

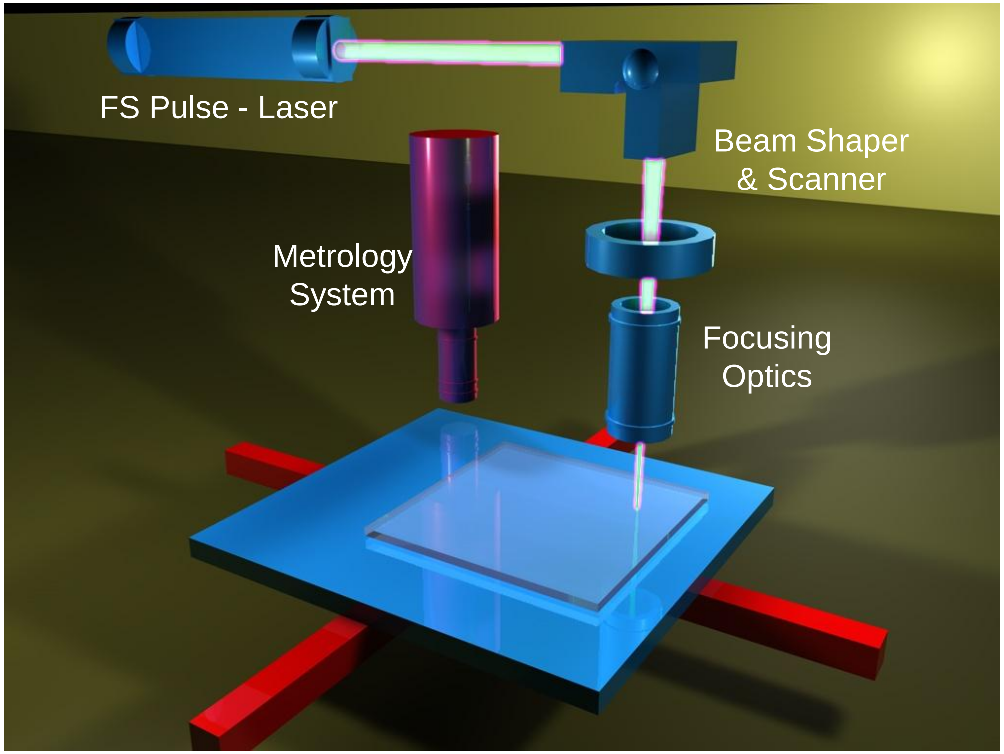
Schematic optical layout



RegC® Process Concept

- Deformation of the mask bulk on the level of few PPM’s is done by writing special deformation elements utilizing ultra short laser pulses.
- Calibration of the deformation magnitude and direction is done with a special in situ metrology system that determines the induced deformation properties.

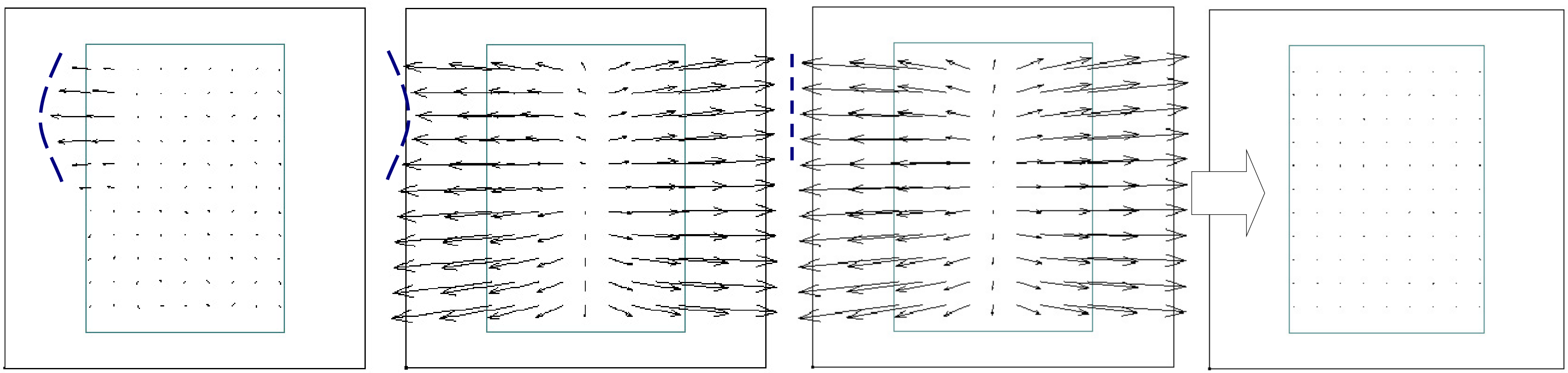




Target of the RegC® Process

RegC® target: Bring all registration errors to a correctable systematic field.

Raw Reg error | RegC® process | Simulated best correctable error | S/O of best correctable error



[nm]	X	Y
Abs Max	12.0	1.5
3S	7.3	1.5

[nm]	X	Y
Abs Max	0.1	0.5
3S	0.1	0.3

- The RegC® algorithm allows to simulate the best correctable field.
- The RegC® process generates local deformations to compensate for local registration errors.
- The errors magnitude is increased but all are correctable by the scanner.
- After scanner S/O removal the residual registration will be minimized.

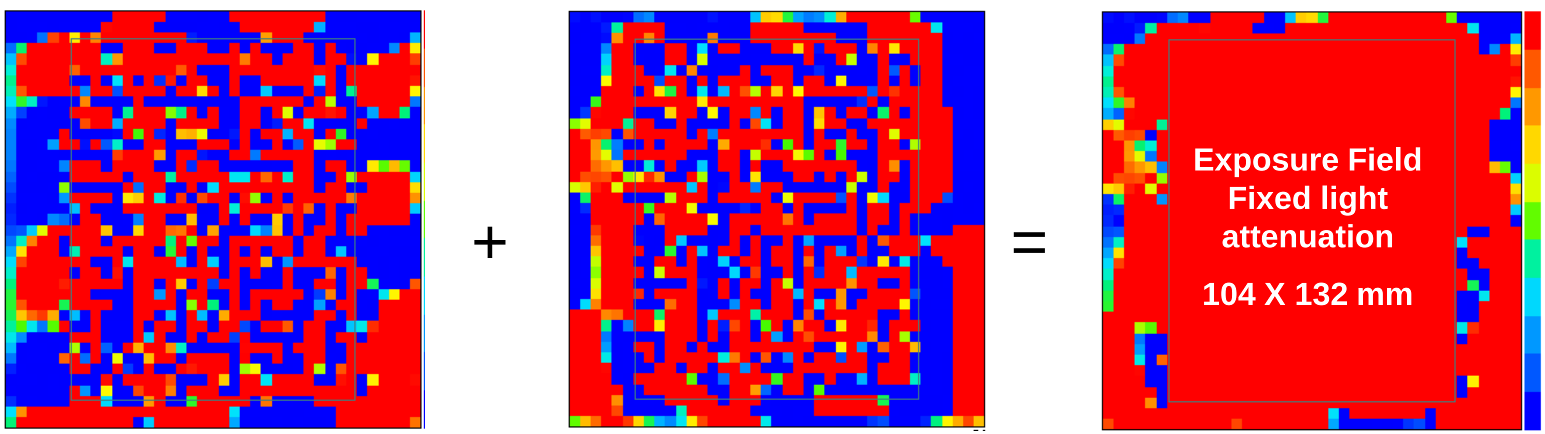
RegC® CDU Neutral - Process Steps

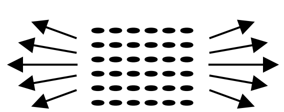
- Utilizing the full mask area, including the exposure field increases the RegC® efficiency.
- By writing RegC® with two modes it is possible to maintain a constant attenuation across the exposure field and thereby maintaining CDU.

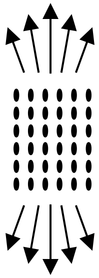
Step 1 , X - axis

Step 2 , Y - axis

Sum of steps 1&2







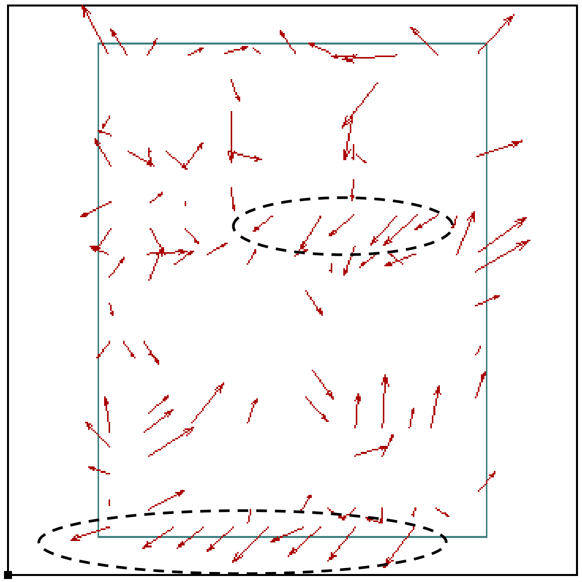
Transmission uniformity in the exposure field is maintained >> CDU unchanged

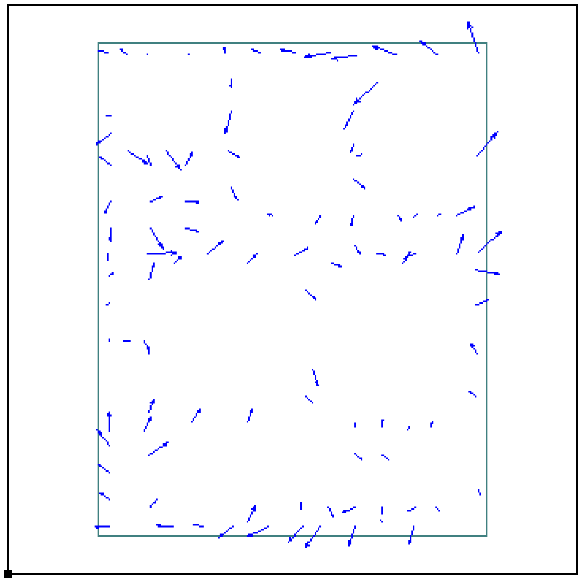
RegC® CDU Neutral – Results

Pre RegC®
Scale/Ortho removed

Post RegC®
Scale/Ortho removed

Systematic residuals





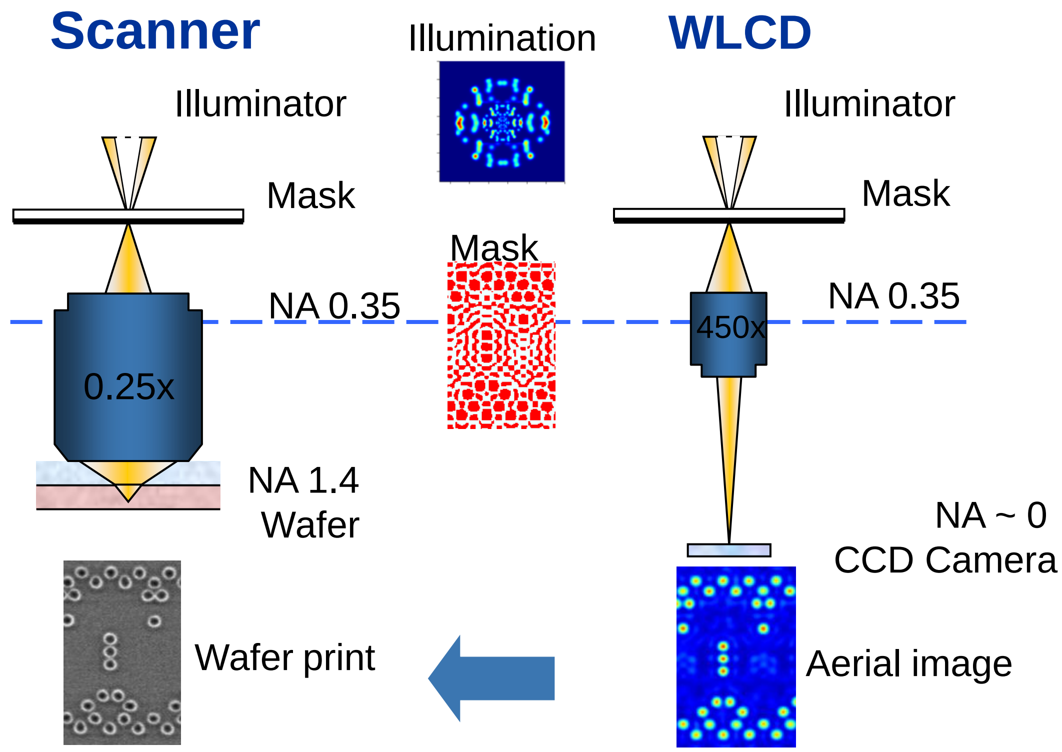
Reduced systematic residuals

	3S (S/O removed)		Improvement	
	Pre [nm]	Post [nm]		
X	8.21	4.12	4.09	50 %
Y	8.55	3.95	4.60	54 %

Enables double patterning specifications !!!

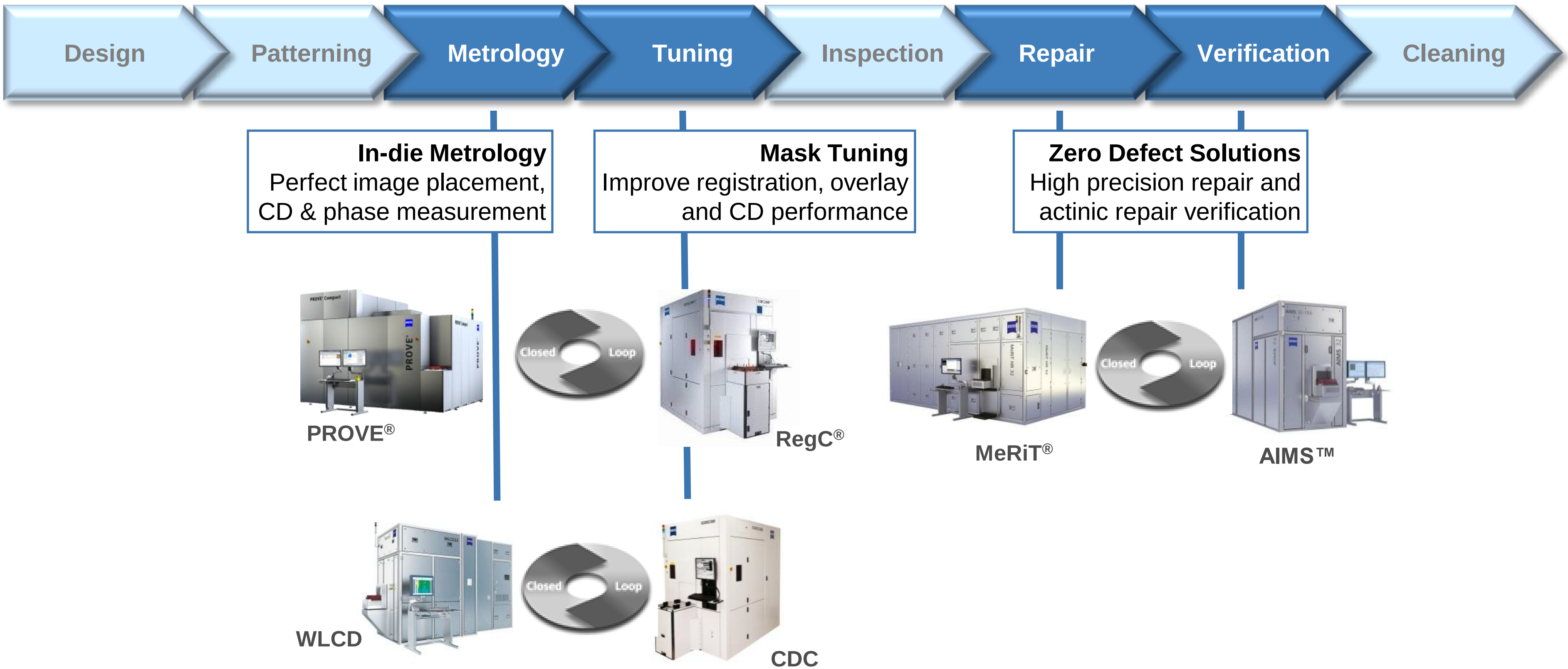
Mask Metrology: WLCD – CD Metrology based on proven Aerial Image Technology

- WLCD is based on proven Aerial Image Technology
- WLCD measures under the same conditions as the scanner
- WLCD captures OPC and optical MEEF effects
- Simplifies measurement for complex 2D features
- FreeForm Illumination supports SMO technology
- Applied illumination conditions: same as for wafer print



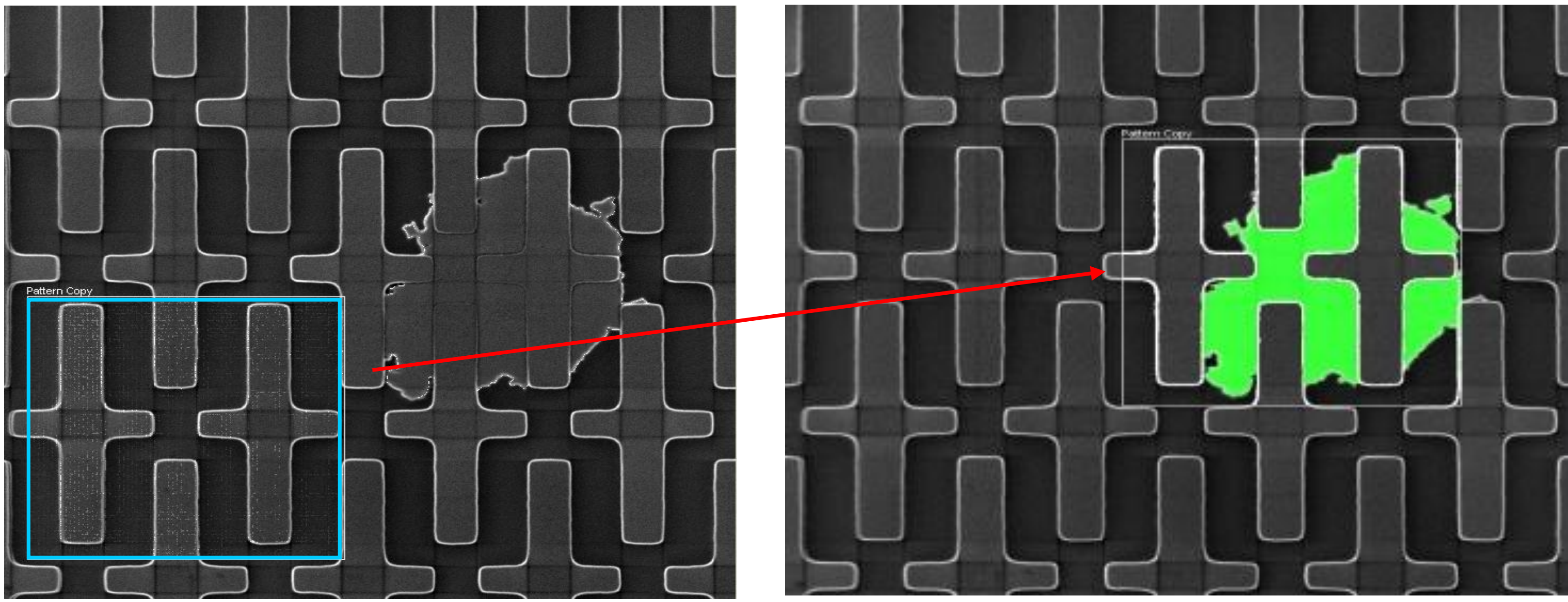
Equivalent image formation for Scanner and WLCD

Carl Zeiss „Perfect Mask Solutions“



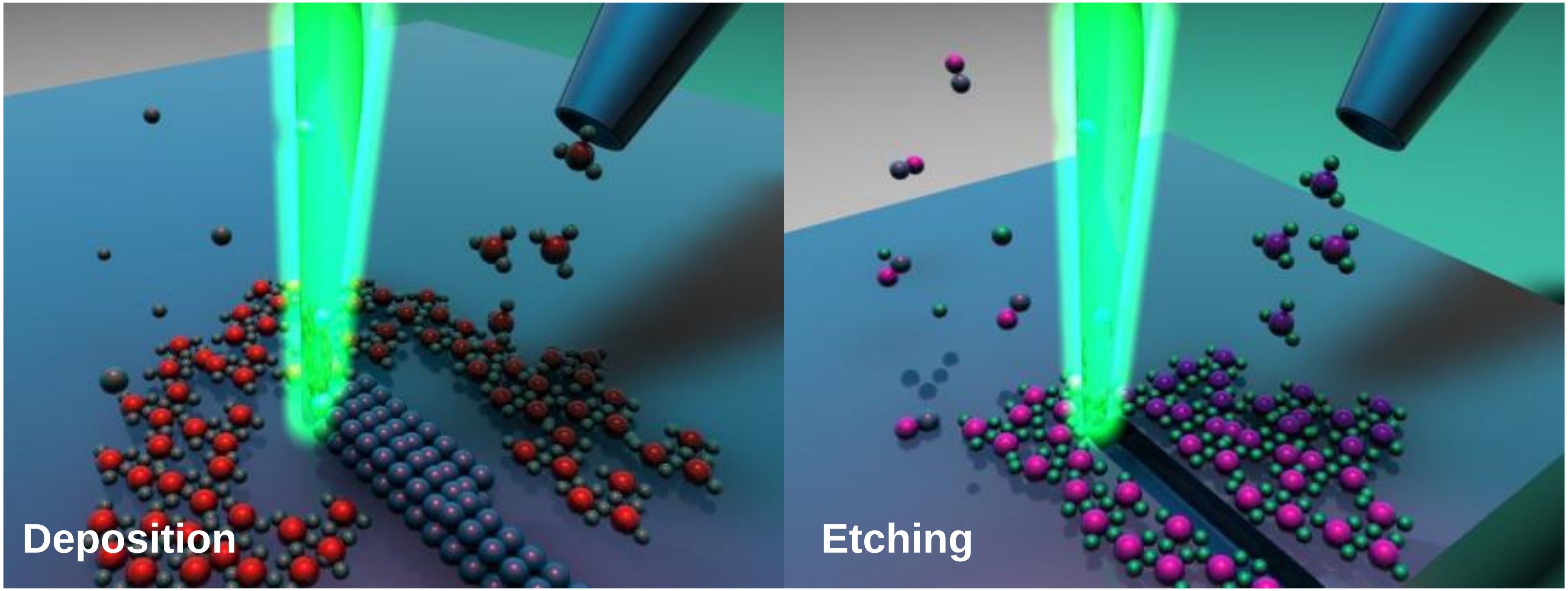
Focused electron beam based mask repair

Real defect **Repair shape(s)**



➔ **Computer-assisted shape generation, modification and placement**

Electron beam induced deposition and etching



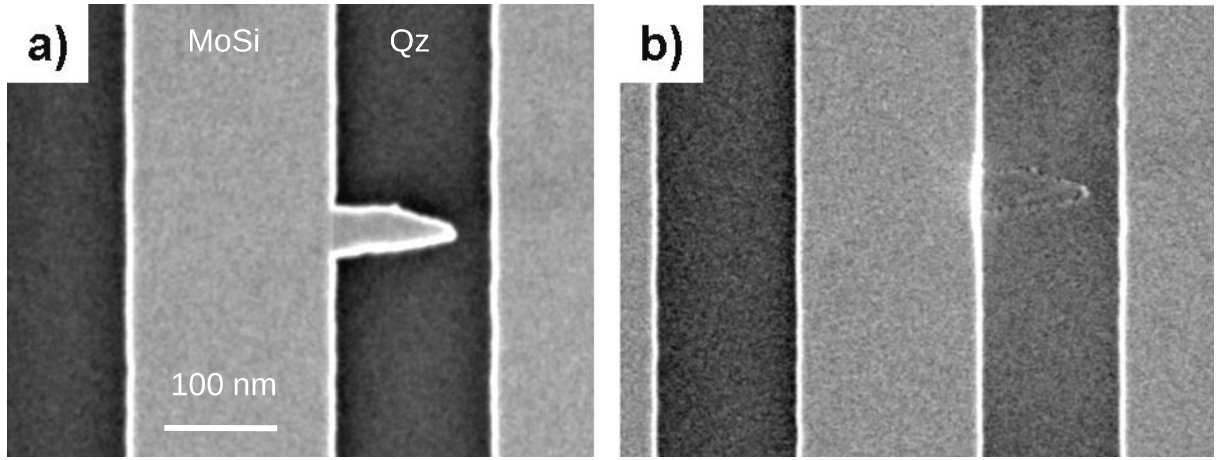
Adsorption of precursor molecules:

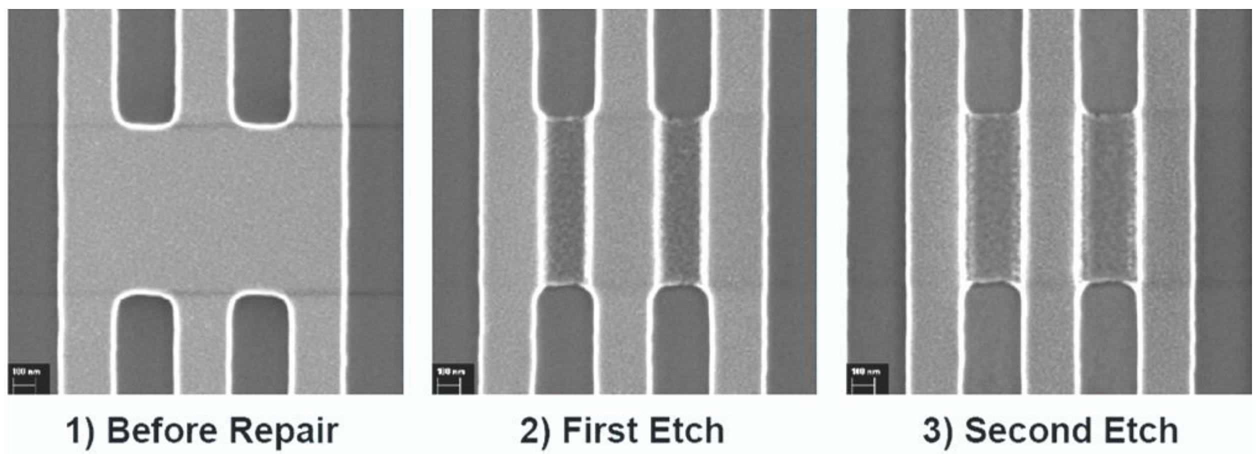
- Exposure with electron beam
- Reaction and immobilization of precursor → **Deposition**
- Reaction with substrate and volatilization → **Etching**

State-of-the-art achievements with the MeRiT

Statistics over 2 months at a customer's site:

- 74% yield on 1st attempt;
- 24% increase on further attempts





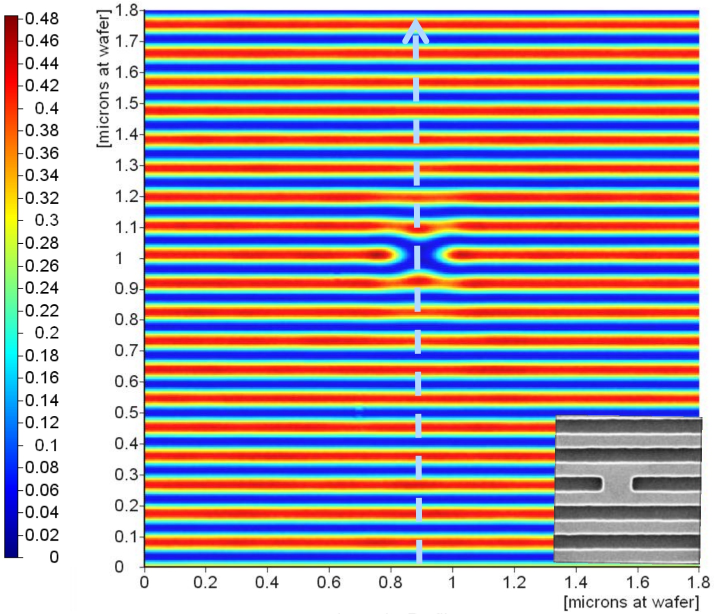
A. Garetto *et al*., Proc. SPIE (2009)

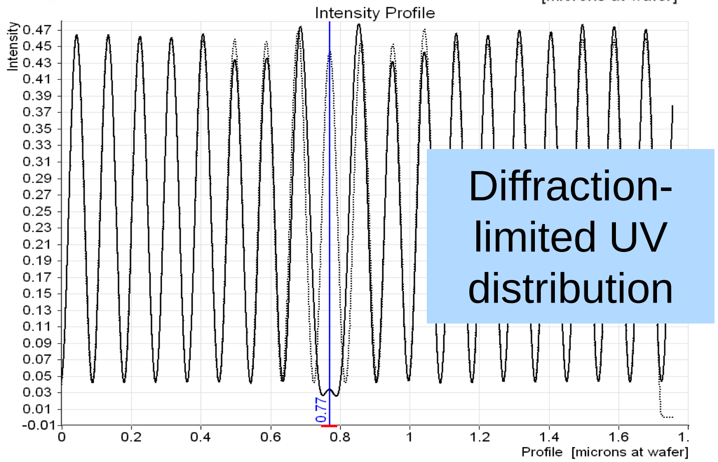
Optical repair qualification by aerial imaging

No wafer stepper in the mask-shop

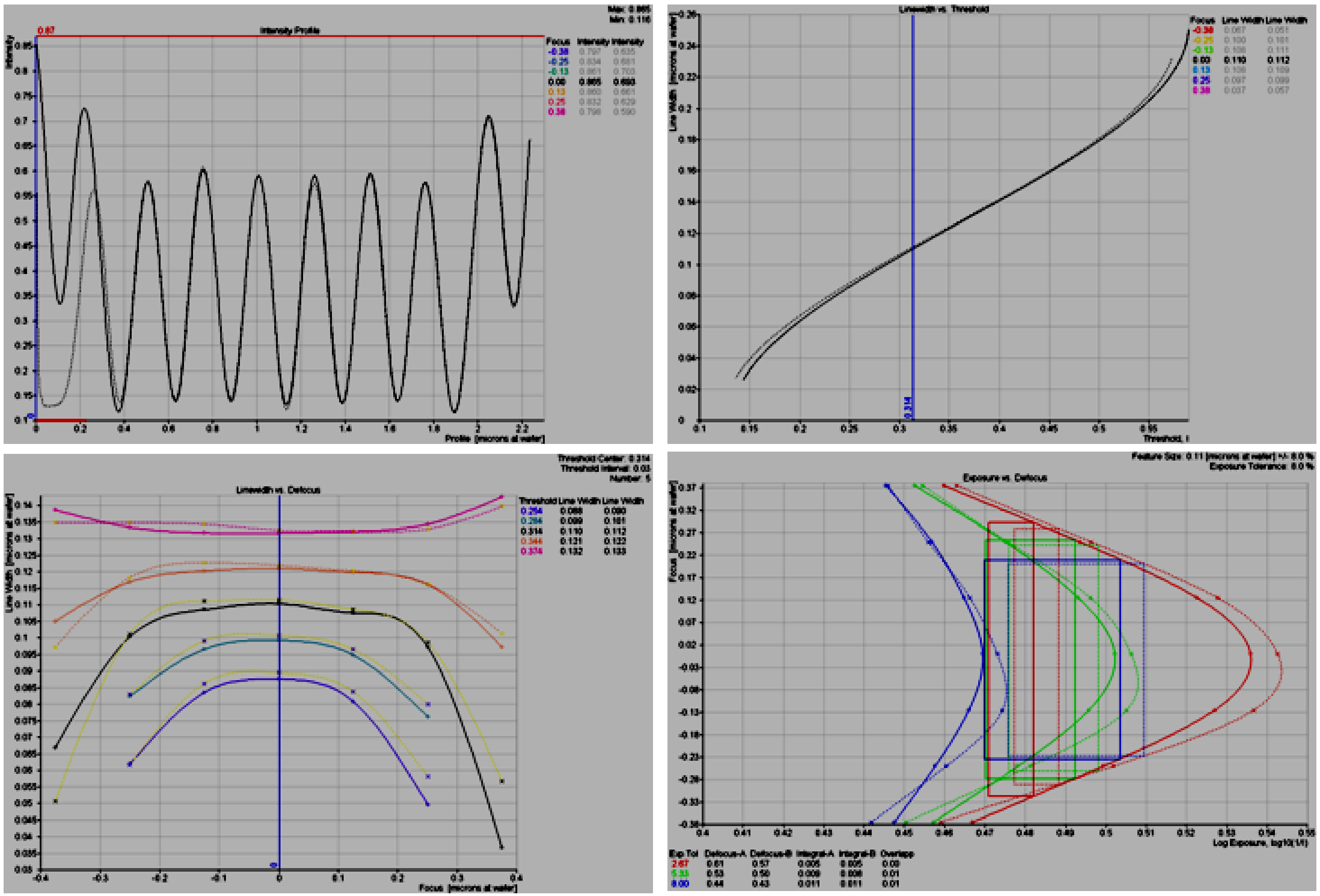
→ 193 nm CCD exposure with „Aerial Imaging Metrology System“ (**AIMS**™)

→ Detailed phase & intensity information on 10 x 10 µm areas

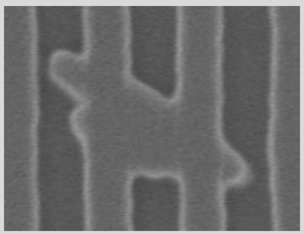
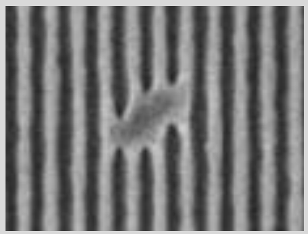
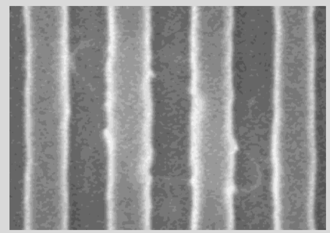
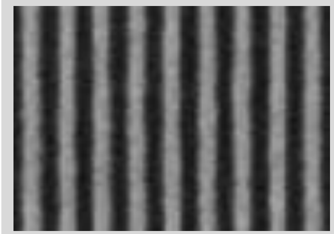
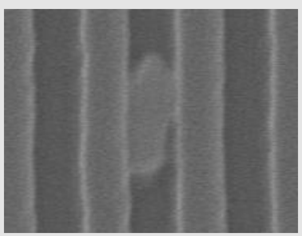
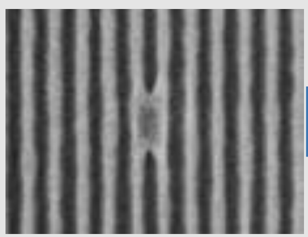
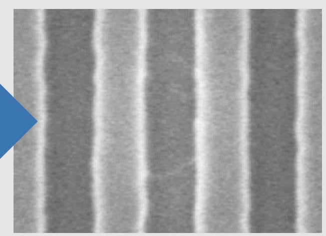
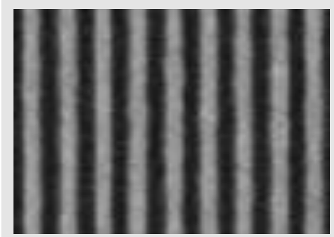
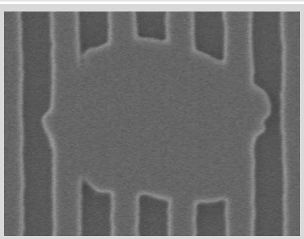
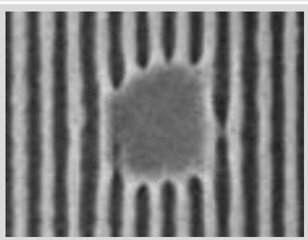
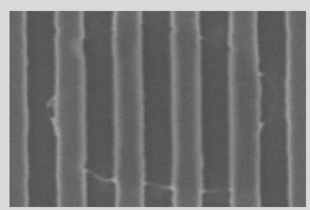
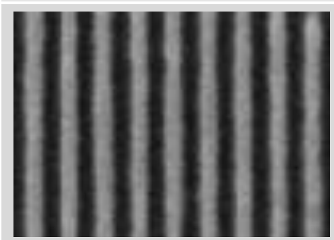




AIMS: Process window evaluation



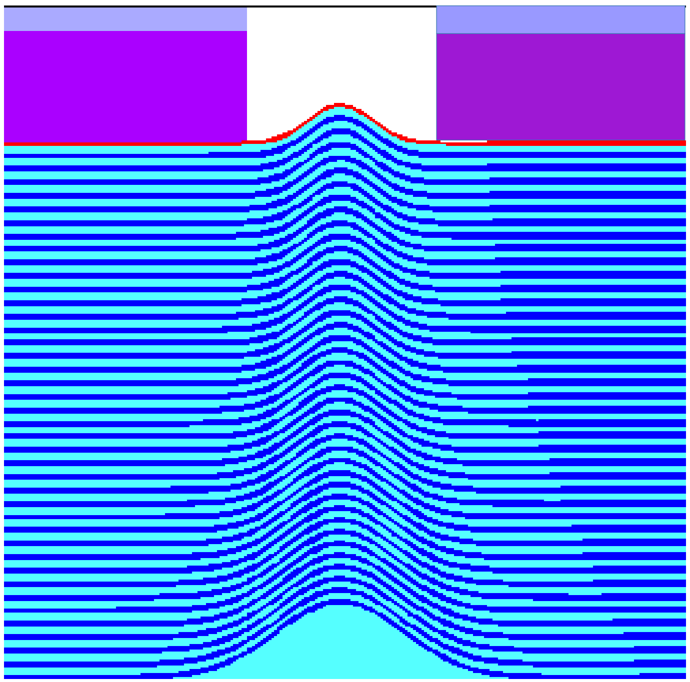
EUV absorber e-beam repair
25 nm real defects

25 nm real defects		After e-beam repair		
Mask SEM	**NXE: 3100**	**Mask SEM**	**NXE: 3100**	**Comment**
				Complex OK
				Half height OK
				Multiline OK

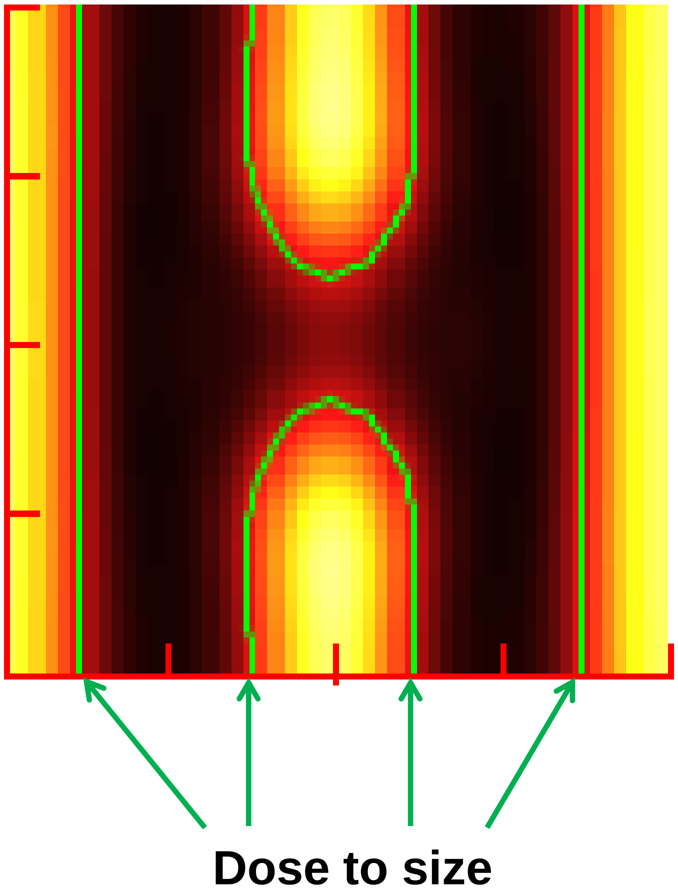
➔ **Repair success on real defects validated on NXE:3100 scanner**

EUV multilayer defect

Cross-sectional profile

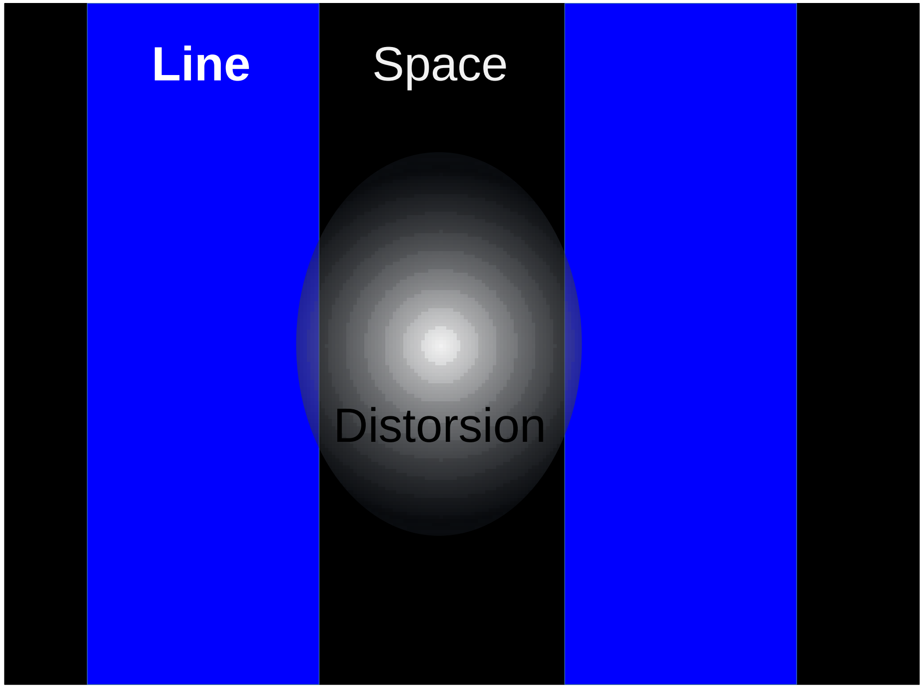


Simulated aerial image

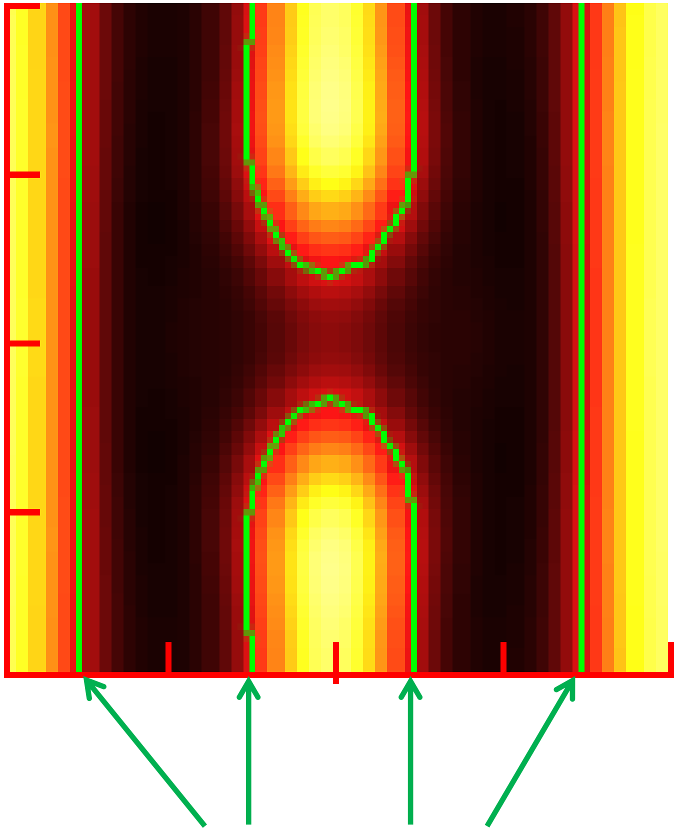


EUV multilayer defect
Compensational repair simulation

LS pattern with bump

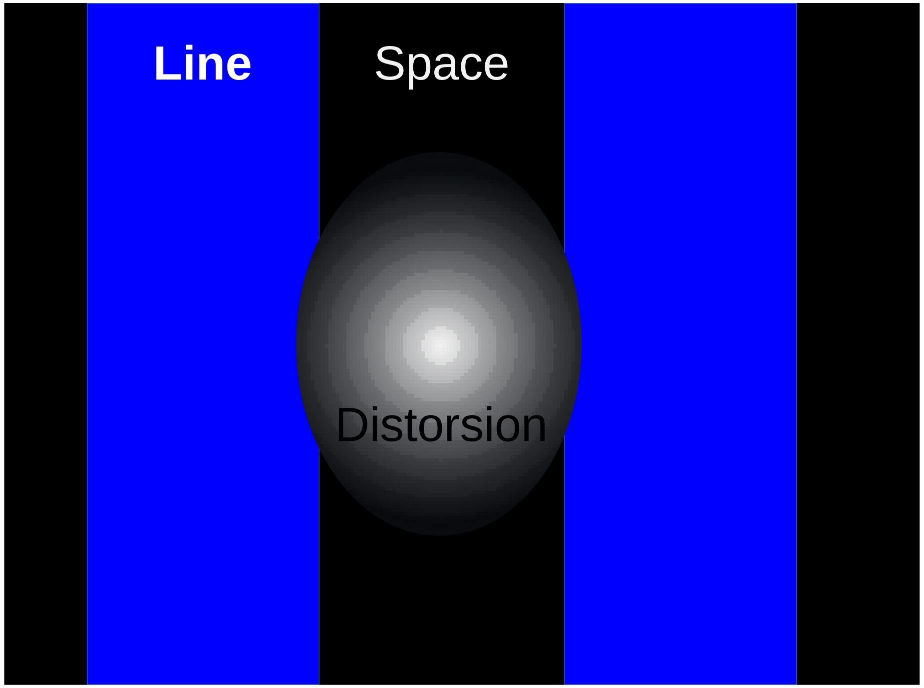


Aerial image



EUV multilayer defect
Compensational repair simulation

LS pattern with bump



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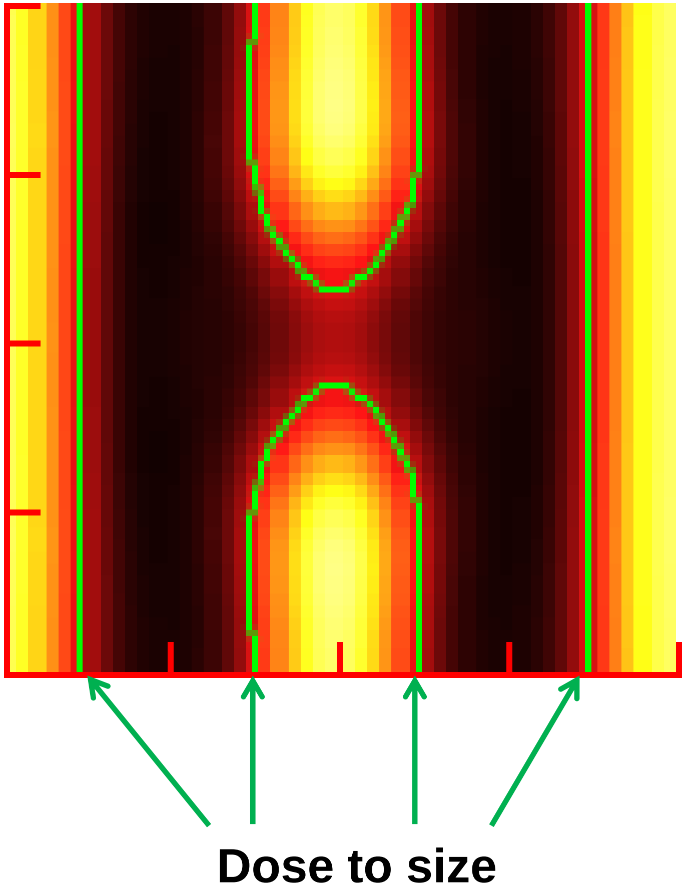

EUV multilayer defect
Compensational repair simulation

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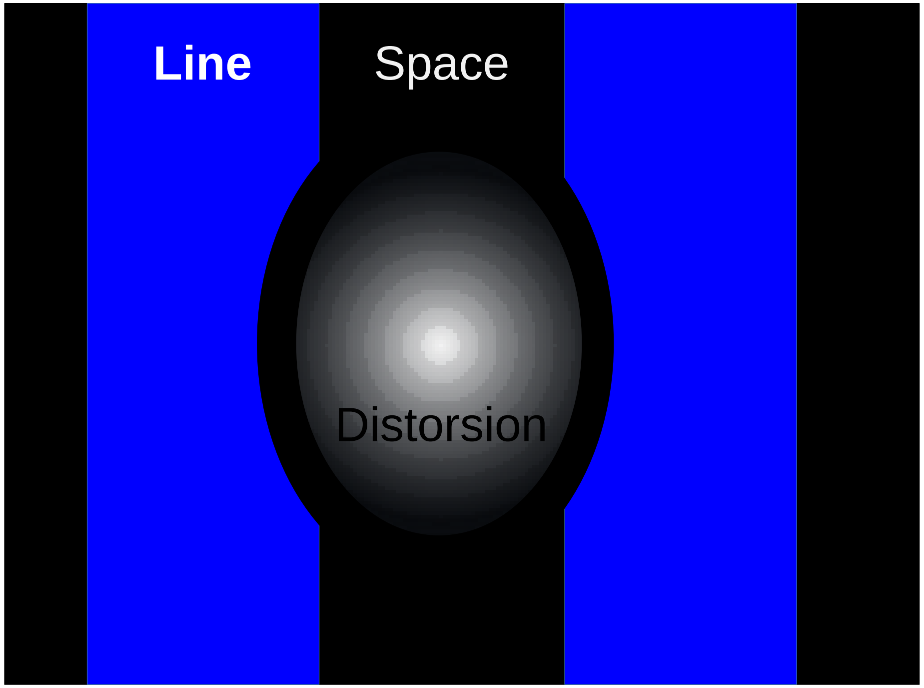

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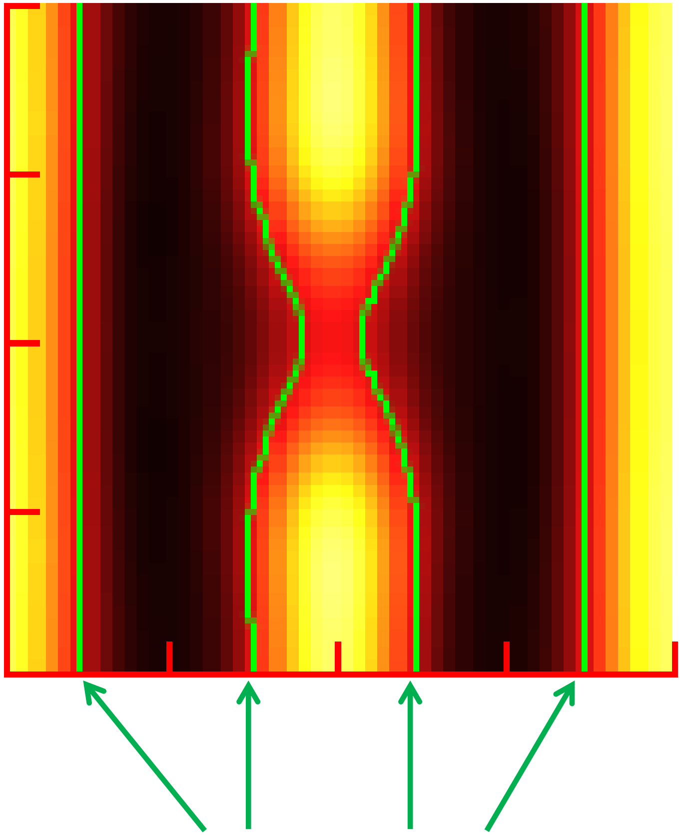
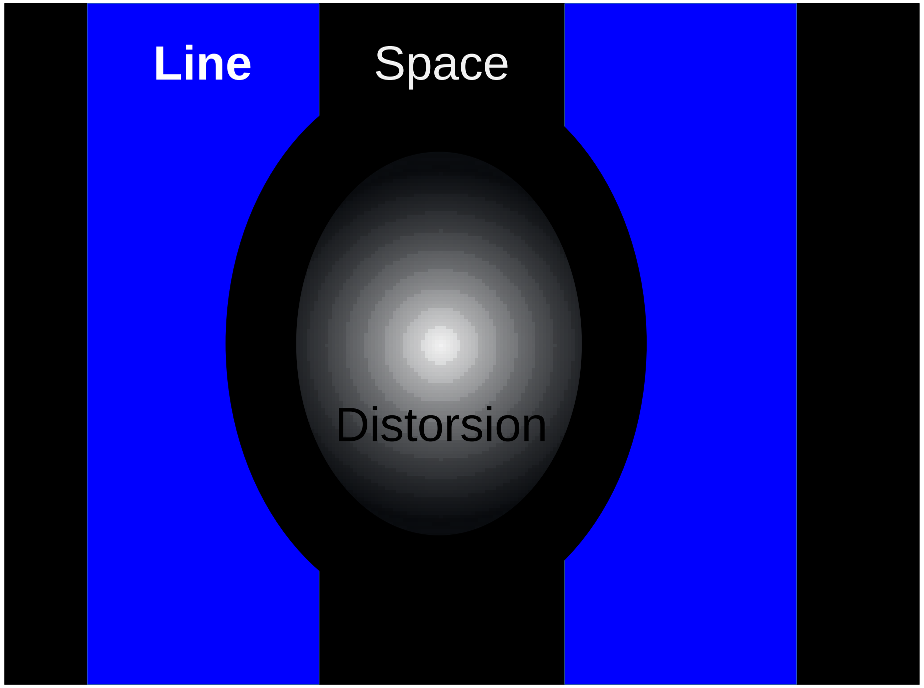


EUV multilayer defect
Compensational repair simulation

LS pattern with bump



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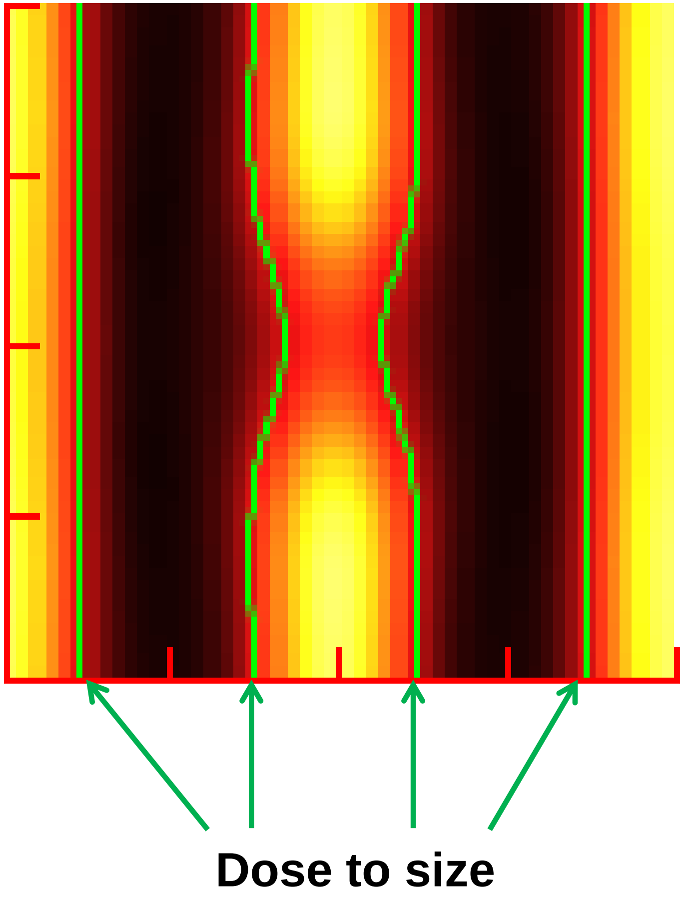

EUV multilayer defect
Compensational repair simulation

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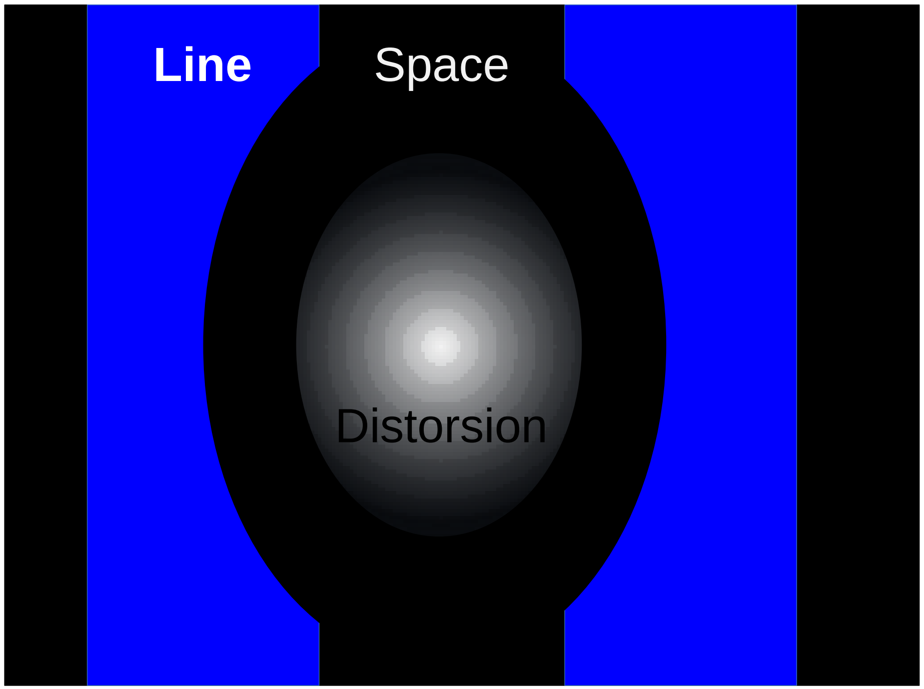

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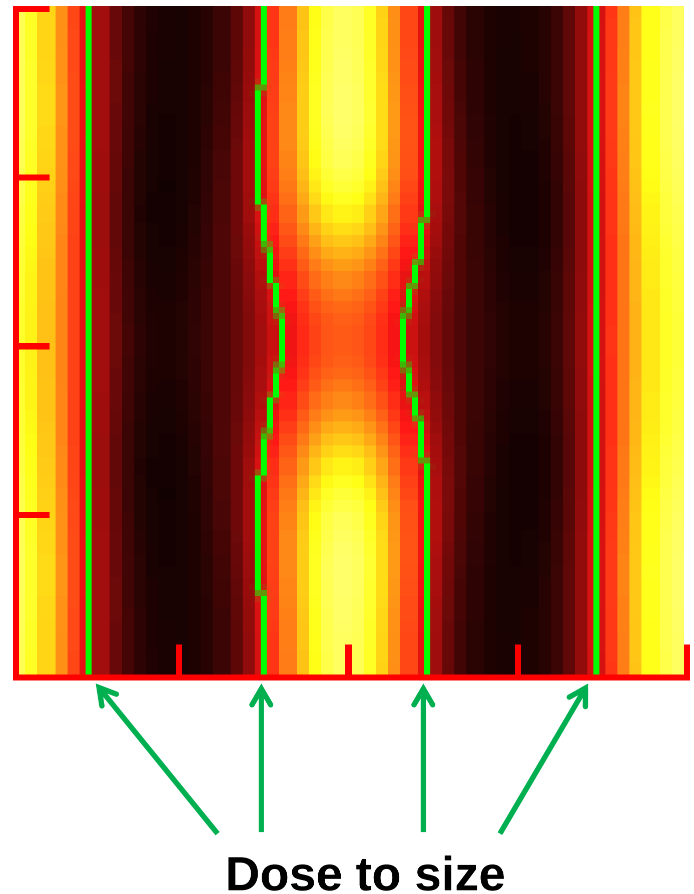

EUV multilayer defect
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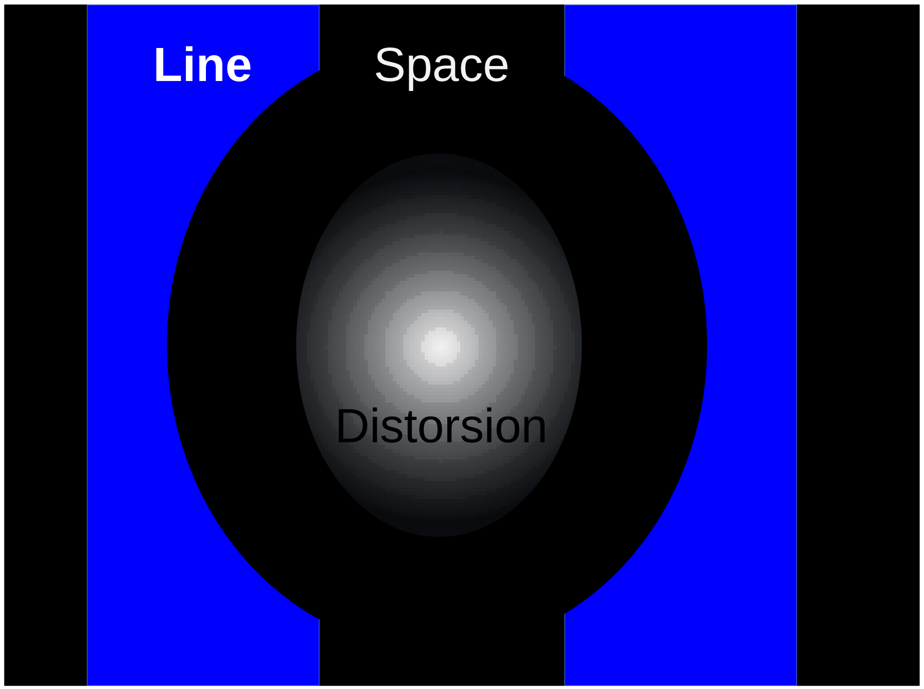
LS pattern with bump



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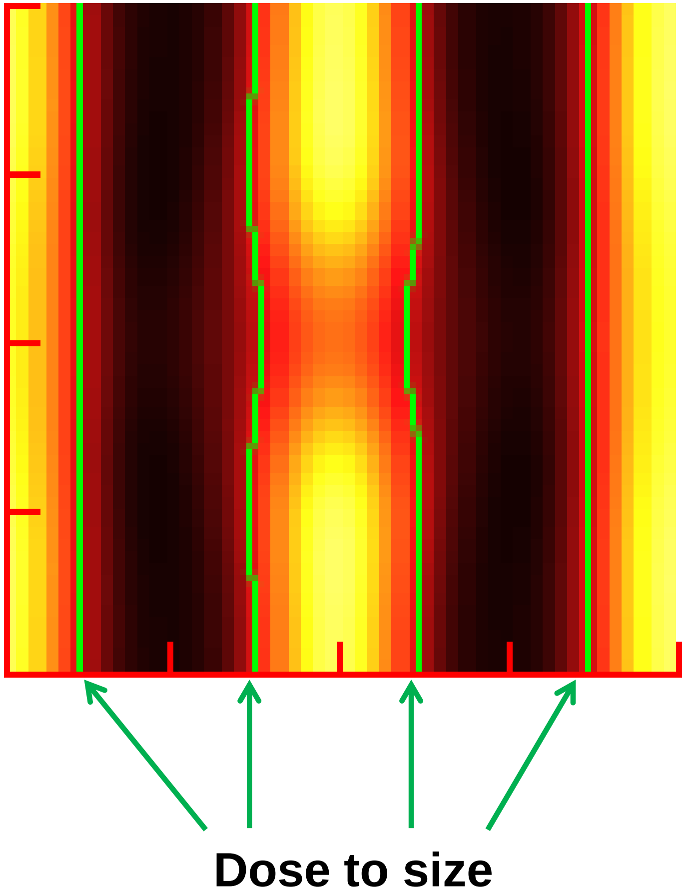
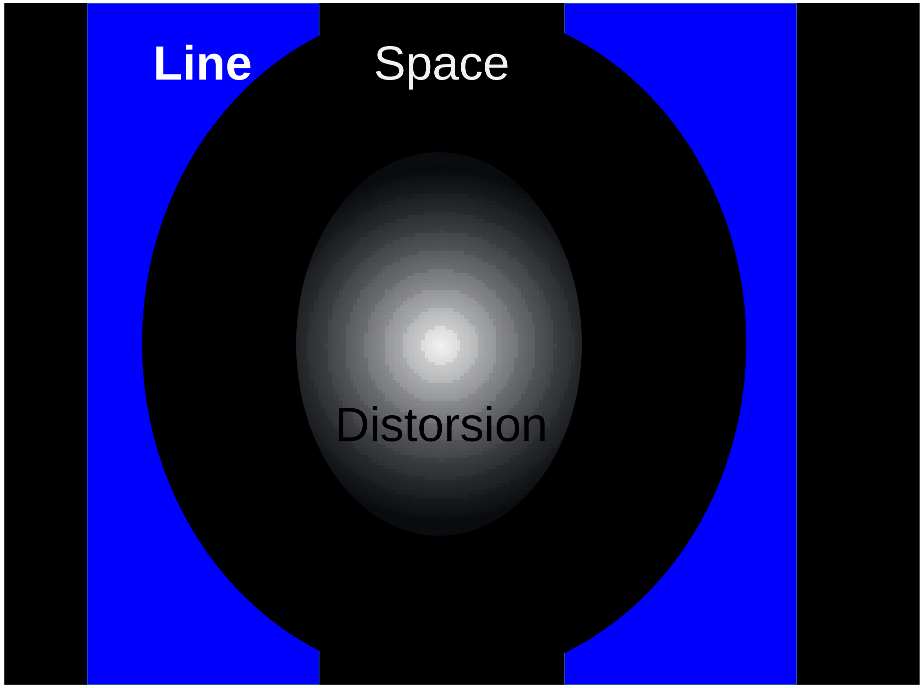


EUV multilayer defect
Compensational repair simulation

LS pattern with bump



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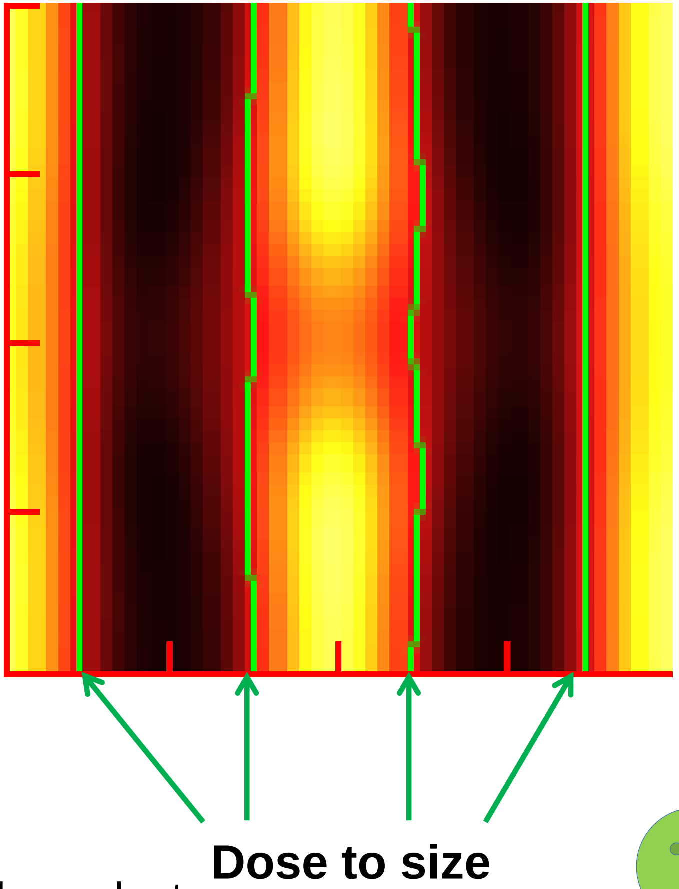
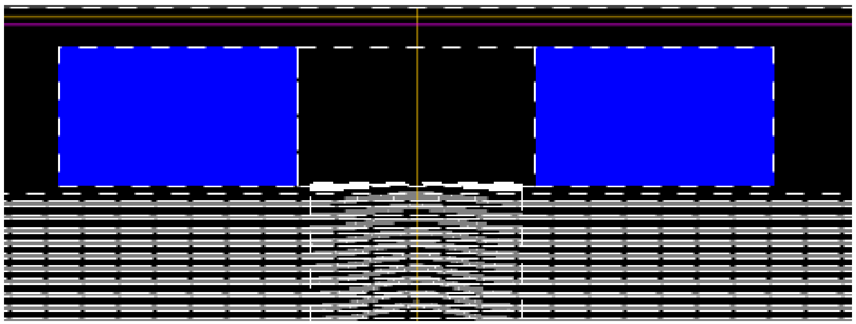


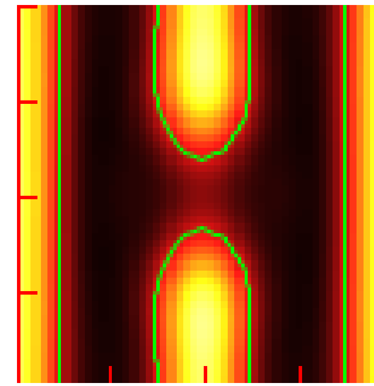
Note: Printability of ML defects is strongly focus dependent

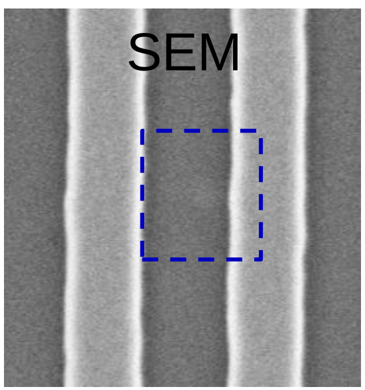
EUV multilayer defect

ML bump: reticle cross-section

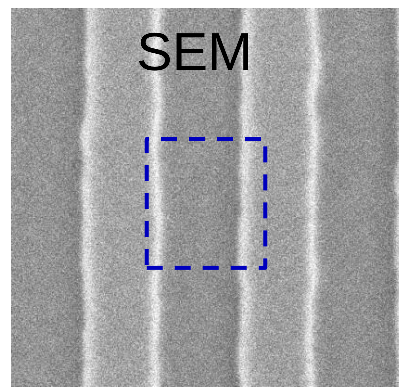


Simulated aerial image





5 nm „bump

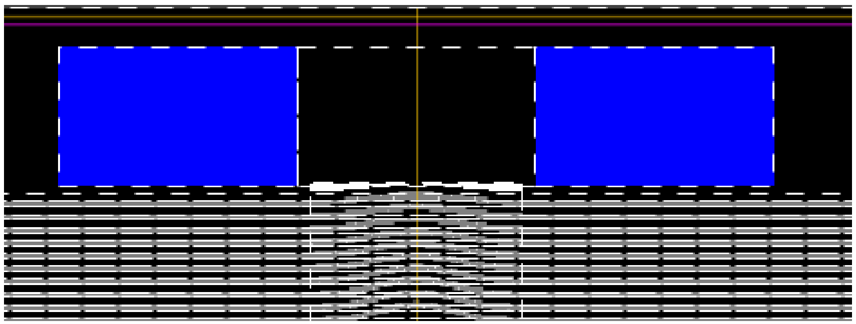


3 nm „pit“

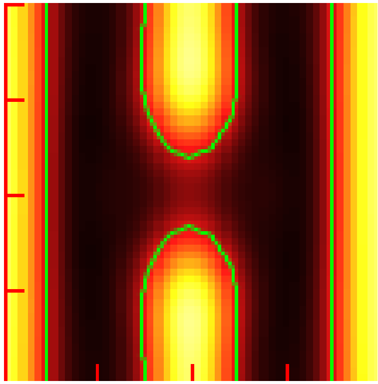
➔ **Problem: Many mirror distortions that print are invisible in SEM!**

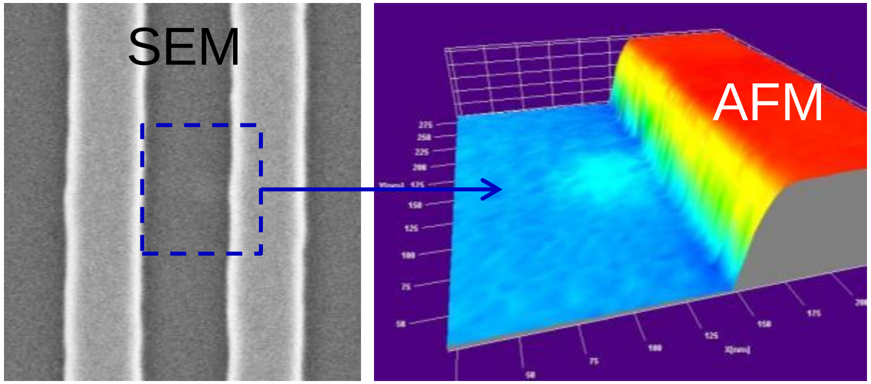
EUV multilayer defect:
Detection by integrated AFM

ML bump: reticle cross-section

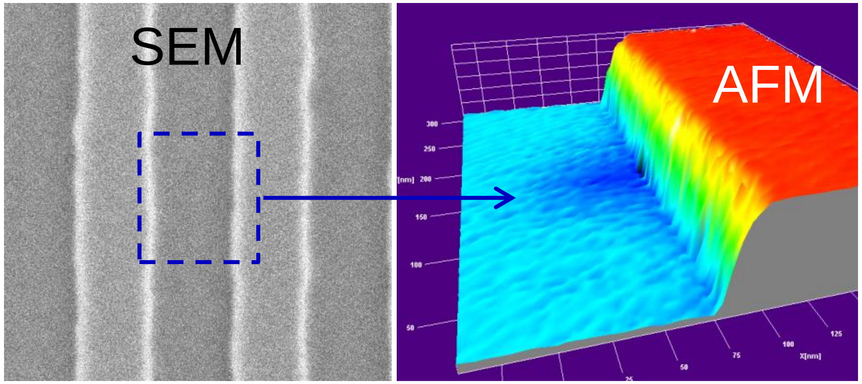


Simulated aerial image





3 nm „bump



5 nm „pit“

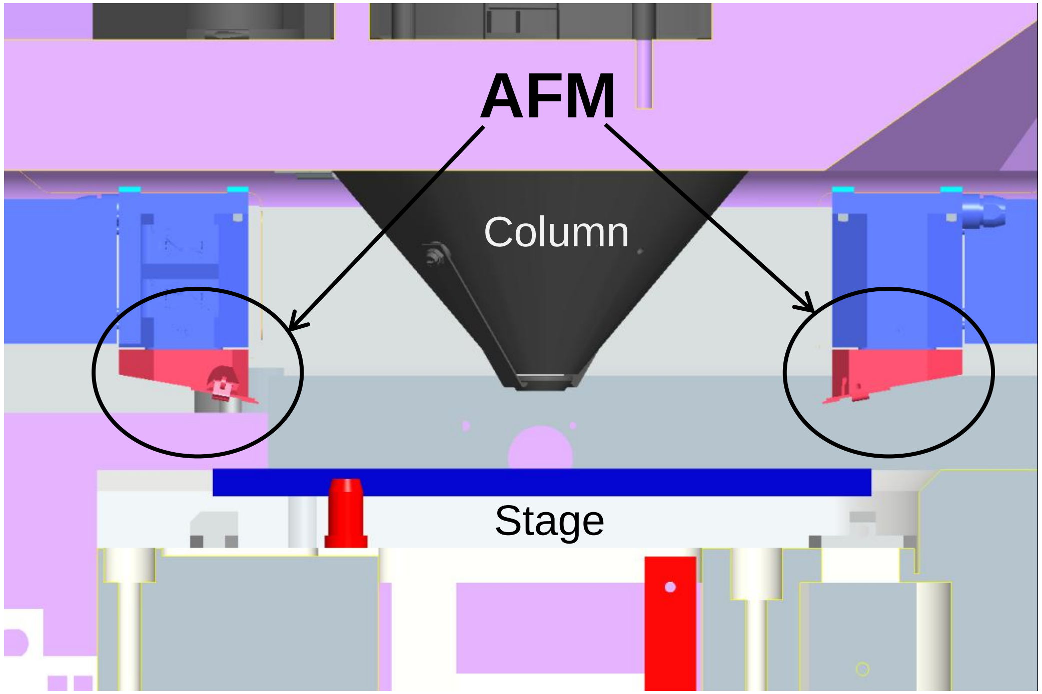
➔ But: All ML defects found so far by wafer printing could be successfully visualized by AFM!

Integrated AFM system

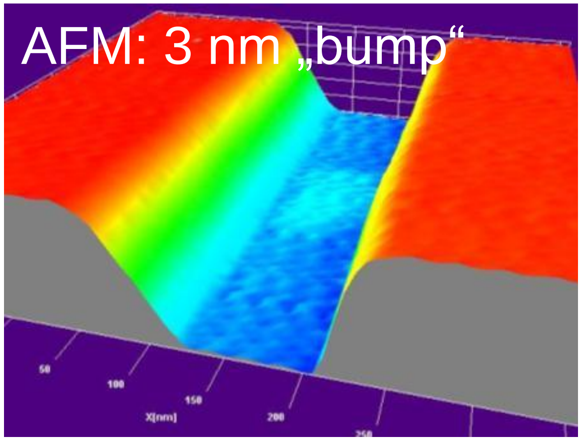
- Dual head AFM system
    - Faster turnaround since mask stays in vacuum
    - Closed loop with repair software

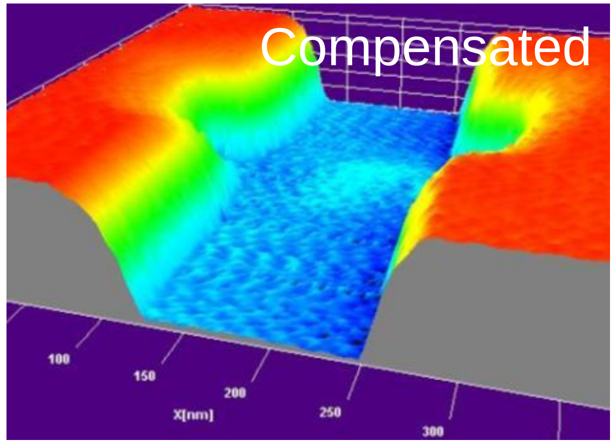
- Automated tip exchange system
    - Tip exchange < 120 min

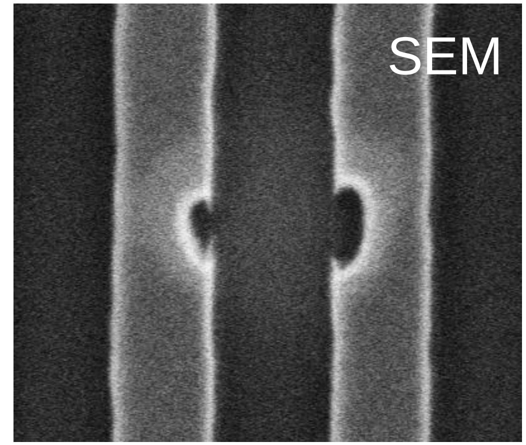
- Applications
    - Fast process tuning
    - 3D defect repair shape generation
    - EUV compensational repair



Compensational repair: “Bump defect”



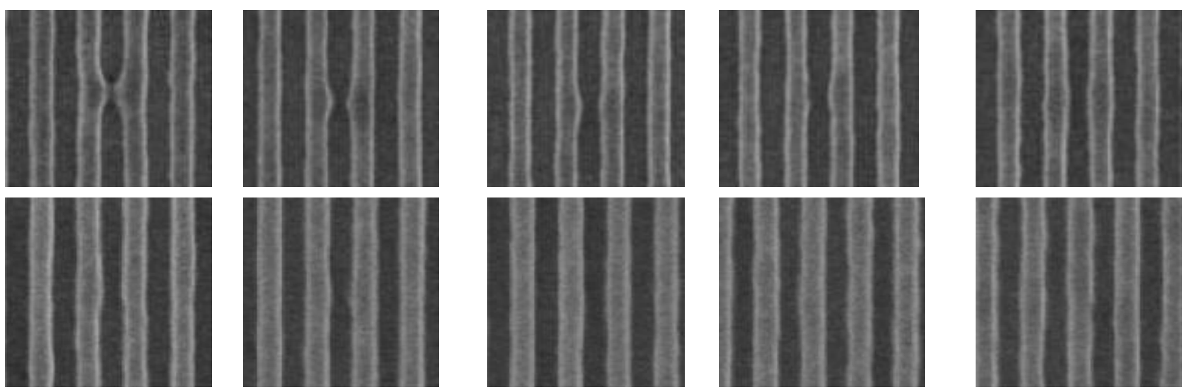




BF -100 nm　BF -50 nm　BF　BF +50 nm　BF +100 nm

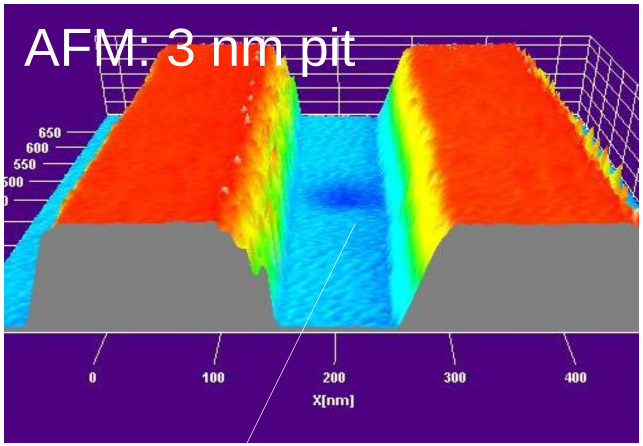
Wafer before repair

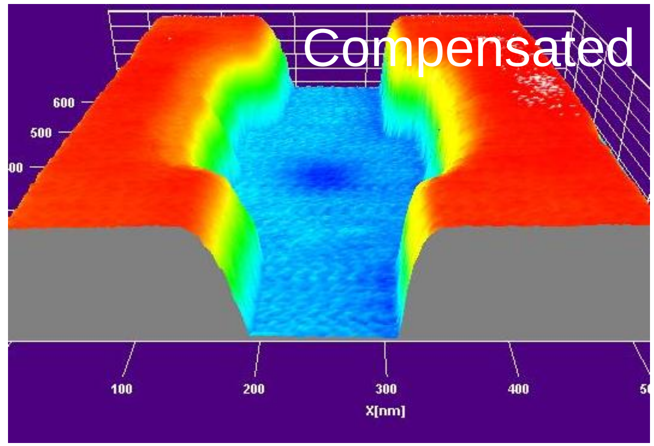
Wafer after repair

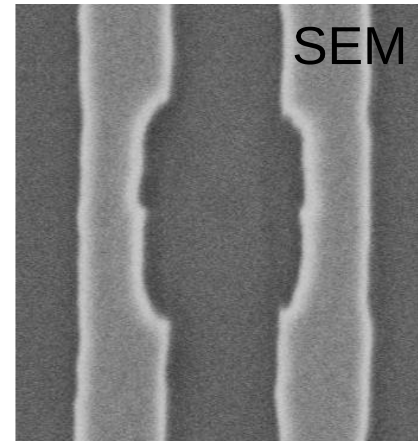


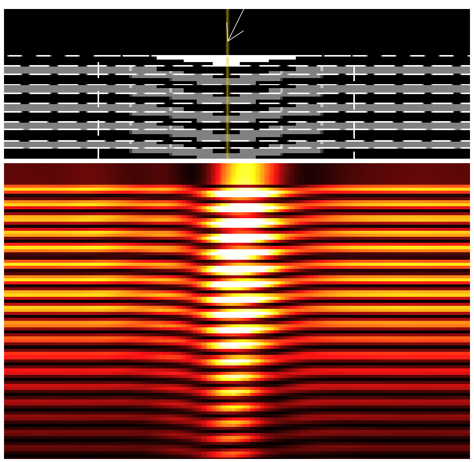
40 nm HP performed on the ASML Alpha Demo Tool

Compensational repair: „Pit defect“







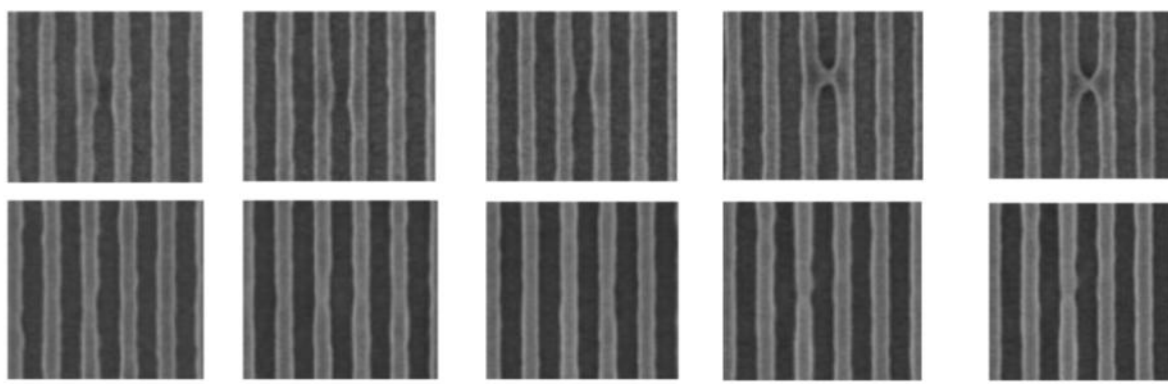


Propagating
ML pit simulation

BF -100 nm | BF -50 nm | BF | BF +50 nm | BF +100 nm

Before repair (wafer)

After repair (wafer)



Through-focus ML pit compensation repair
(see R. Jonckheere *et al*., Proc. SPIE 8166, 81661G (2011))

Summary

- The extension of optical lithography has strongly increased the demands on advanced photo masks
- Carl Zeiss SMS has developed dedicated tools sets to improve photo mask registration, overlay and CD uniformity based on femto second laser writing in two closed loop applications with registration and wafer level CD measurements.
- MeRiT® e-beam mask repair ready for 32 nm, 27nm and 25nm EUV absorber defects
- MeRiT® e-beam mask repair is capable for ML defect repair utilizing data of an integrated AFM for placement and compensational shape generation
- Compensational repair has its limits. Defect reduction during blank manufacturing is strongly recommended

ZEISS

We make it visible.