EUV MET Printing and Actinic Imaging Analysis of The Effects of Phase Defects on Wafer CDs

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Outline

- **Program defect mask fabrication and structure**
- **MET exposure condition**
- **Analysis of substrate pit defect printability**
  - Focus & dose effect
  - Comparison with simulation
  - Programmed pit image from actinic imaging tool

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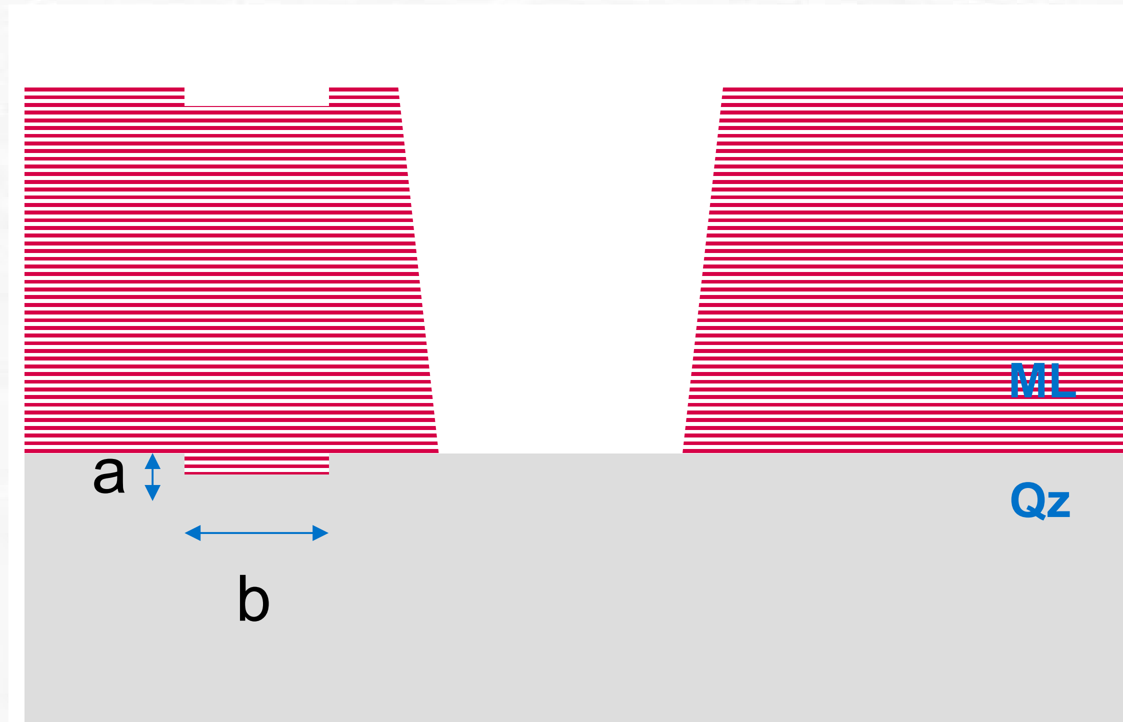
Printability Study Required for EUVL

- **Mask blank defect spec is a critical issue.**
- **When to introduce 3rd generation blank inspection tool.**
- **What size defect can be tolerated?**
- **SEMATECH has the necessary equipments for this study.**
  - **EUV printing using the EUV microexposure tool (MET)**
  - **Programmed defect mask fabrication and characterization using IBD, inspection, FIB and AFM at the MBDC**
  - **EUV imaging and scanning inspection using SEMATECH-Berkeley actinic inspection tool**

Mask Fabrication and Structure

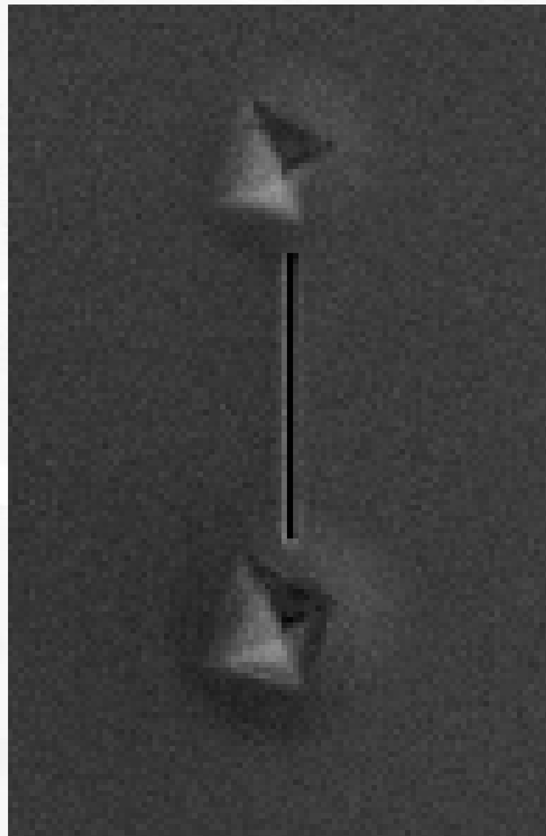
- **Using Facilities at SEMATECH North MBDC**
- **FIB milled substrate pits → ML deposition → FIB milled line**
- **9 pit sizes : Depth(a): 2,4,6 nm   Width(b): 50, 100, 150 nm**



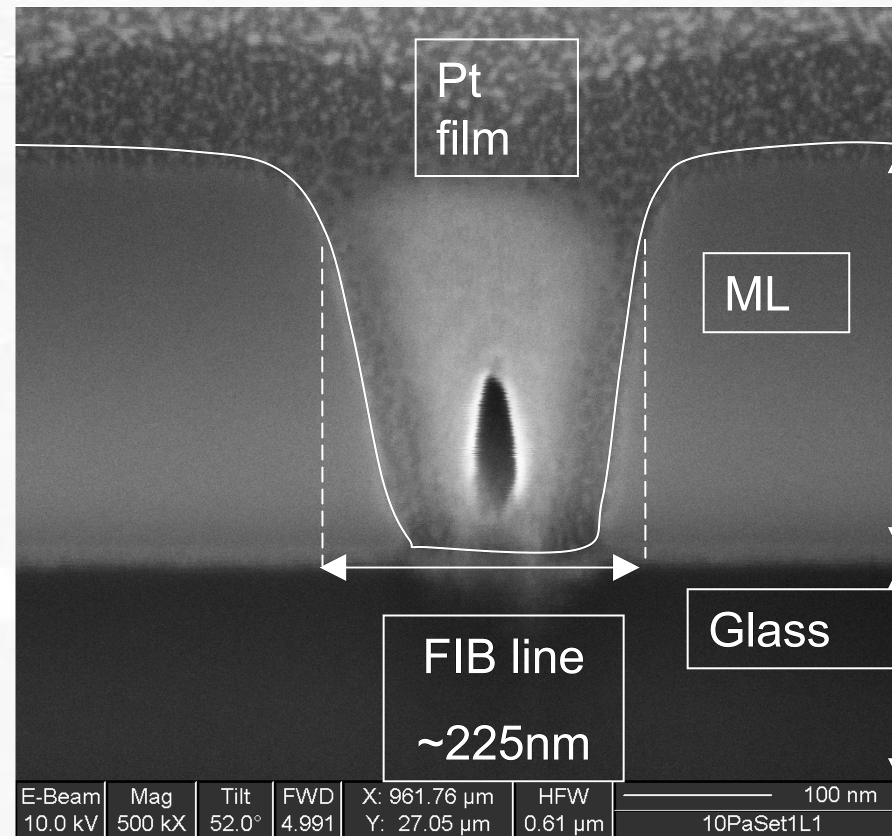
Mask Fabrication and Structure

- **Line image fabricated by FIB-milling of the multilayer**

Top View



Cross-section View



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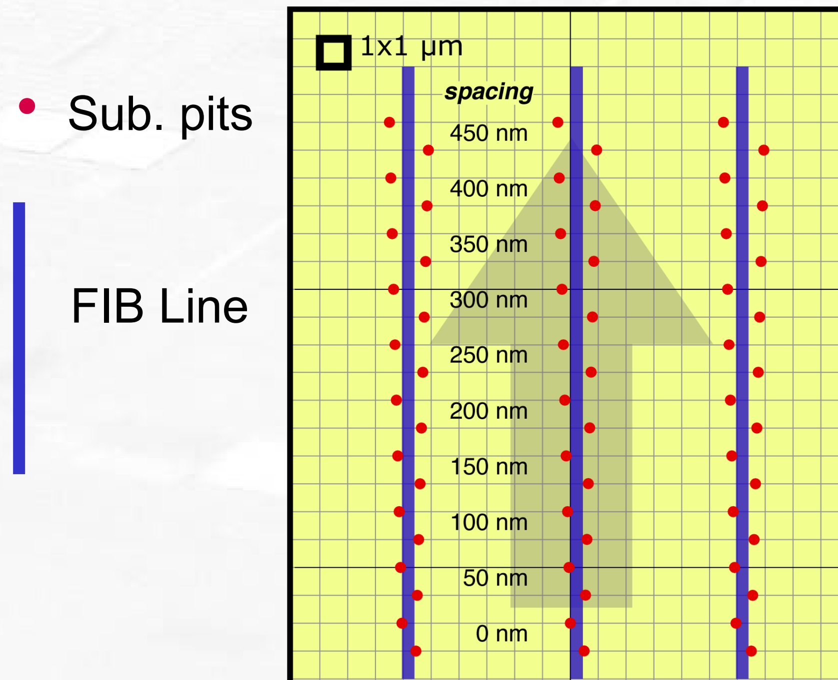
Mask Fabrication and Structure

- **Substrate pits in proximity to isolated line for CD change study**
  - **Lateral pit-to-line spacing varies in 50 nm steps**
  - **225 nm isolated line – 45 nm for 5X exposure**

Sub. pits

FIB Line

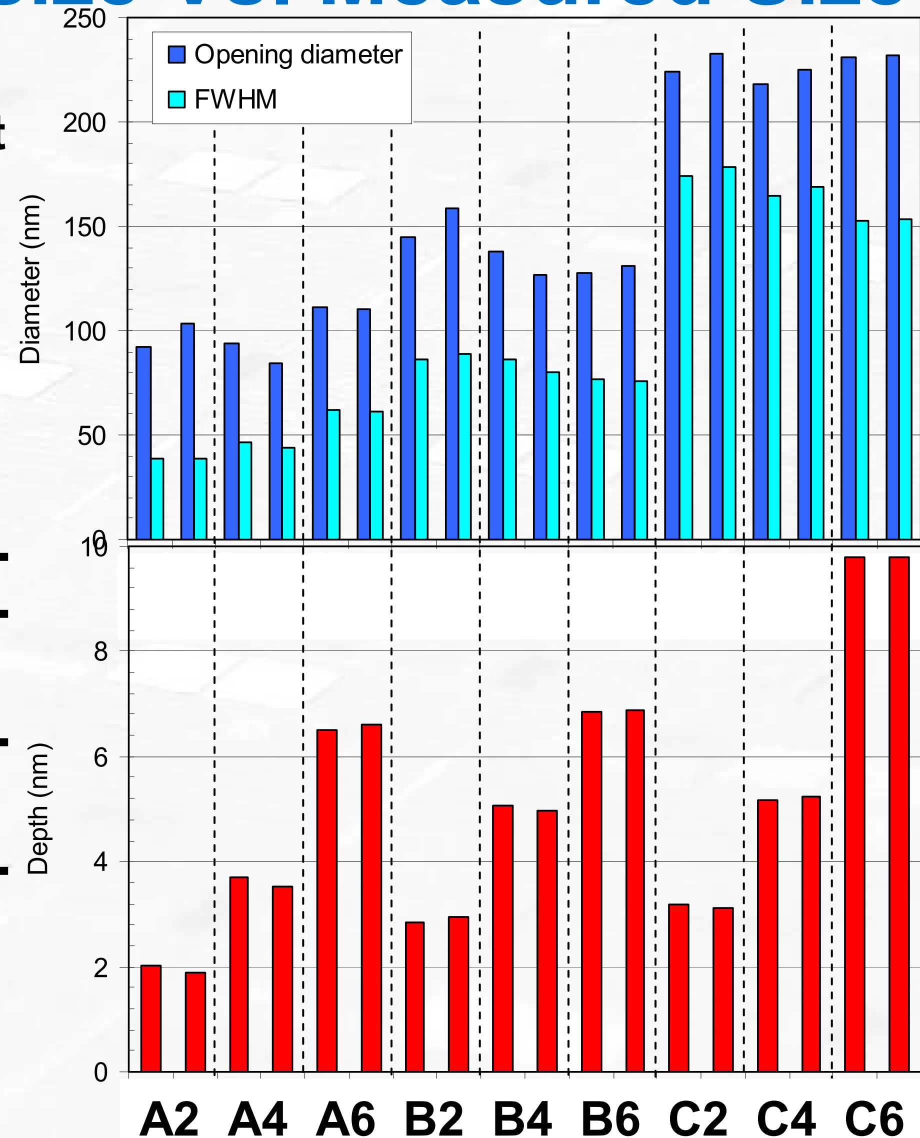


Isolated lines with pits

Substrate Pit Target size Vs. Measured Size

- Substrate pit size measurement (AFM)
- Almost the same as the target size

FWHM		Depth	
Target	Measured	Target	Measured
50 nm (A)	40-60 nm	2 nm	2-3 nm
100 nm (B)	75-90 nm	4 nm	4-5 nm
150 nm (C)	150-170 nm	6 nm	6-9 nm



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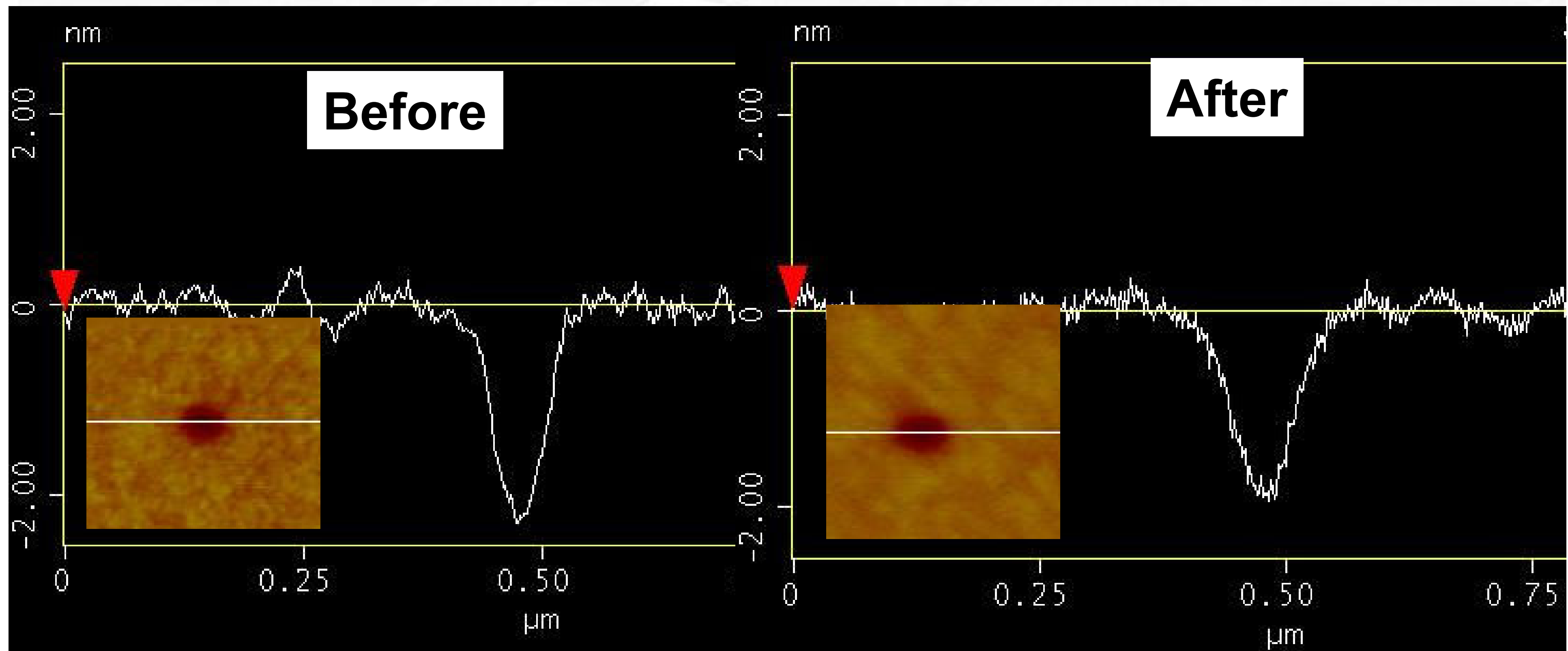
Substrate Pit Size Change After ML Deposition

- **Pit size before/after deposition - AFM scanned images**
- **Deposition by MBDC IBD tool: Wider FWHM and lower depth after depo. But the change is less than 20%.**



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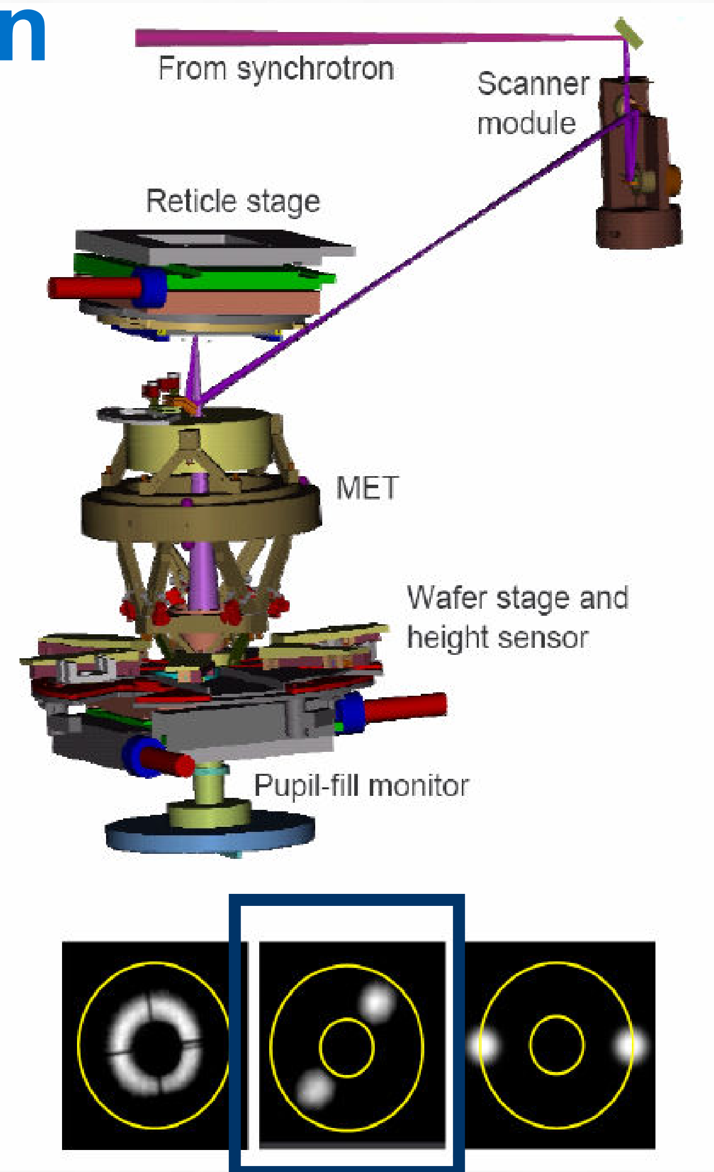
MET Exposure Condition

- Exposure
  - SEMATECH Berkeley MET
  - 5X demagnification, 0.3NA
  - Rotated Dipole, R&H resist
  - Dose focus split 19 x 11
    - Dose 10.6 / 5%
    - Focus 4675 / 50 nm



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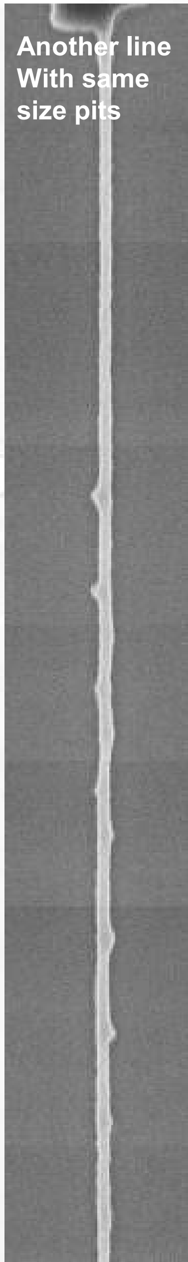
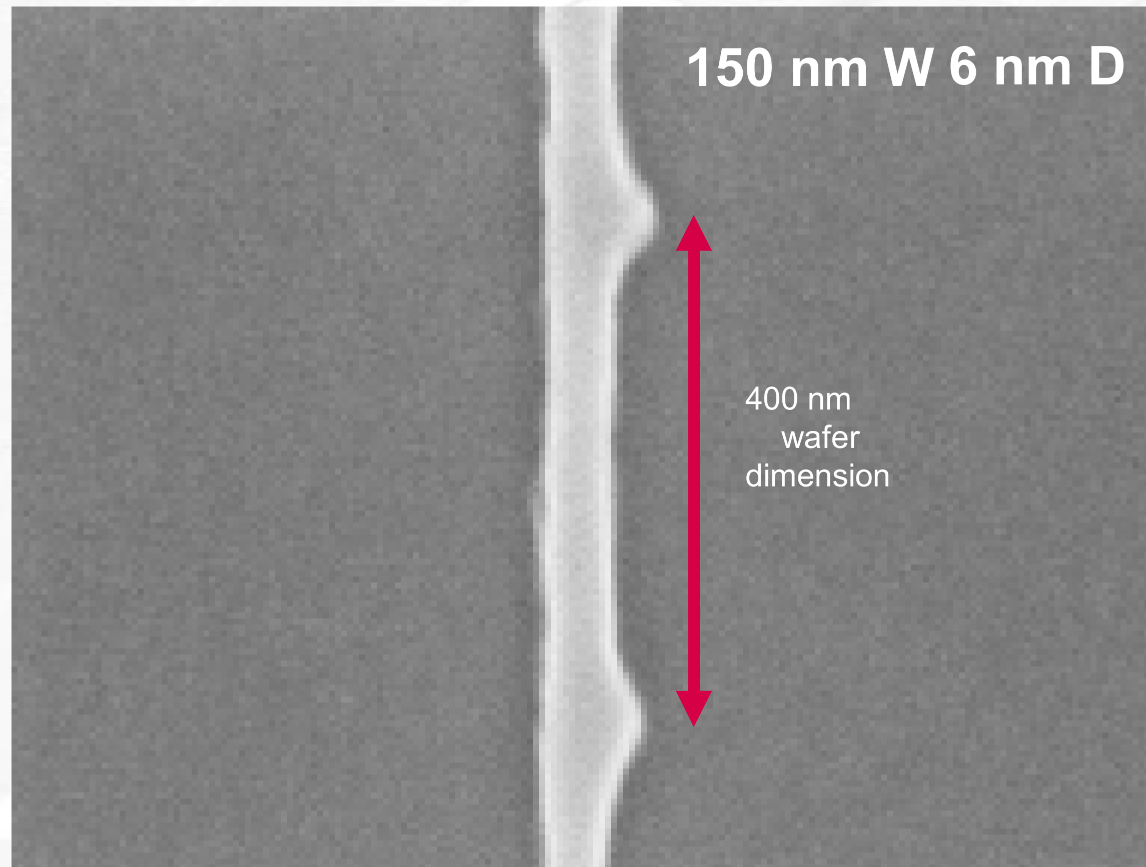
Printability of Substrate Pits



- Substrate pits 150 nm wide and 6 nm deep were clearly printed
- 6 pits printed on one side → Pits 200 nm from the line are printable
- All 150 nm wide pits were printed down to 2 nm deep



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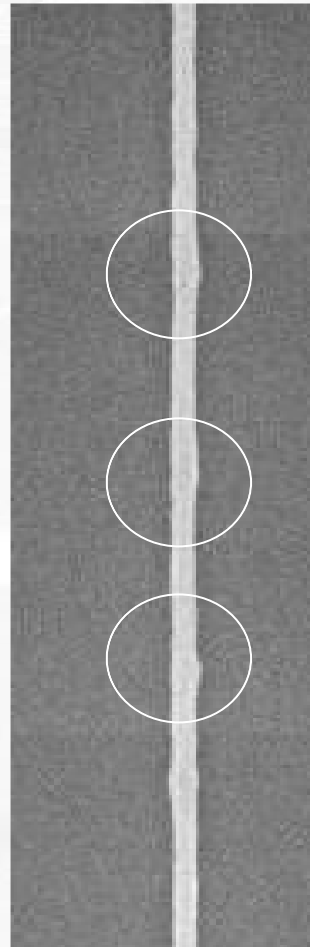
Printability of Substrate Pits

- **Substrate pits 100 nm wide and 6 nm deep**
- **Only 3 pits were printed. This means pits up to about 80 nm from the line are printable.**

100 nm W 6 nm D



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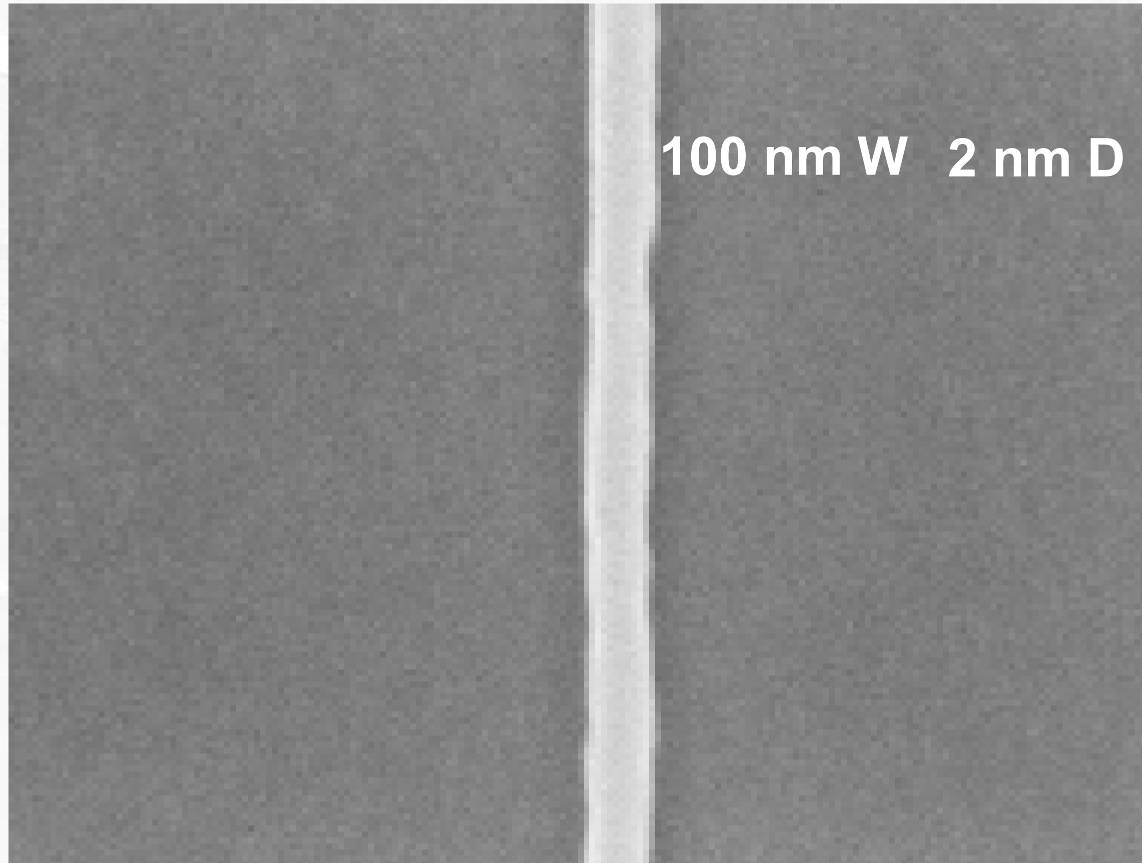
Printability of Substrate Pits

- **Substrate pits 100 nm wide and 2 nm deep**
- **Not printable but printability depends on focus and dose**

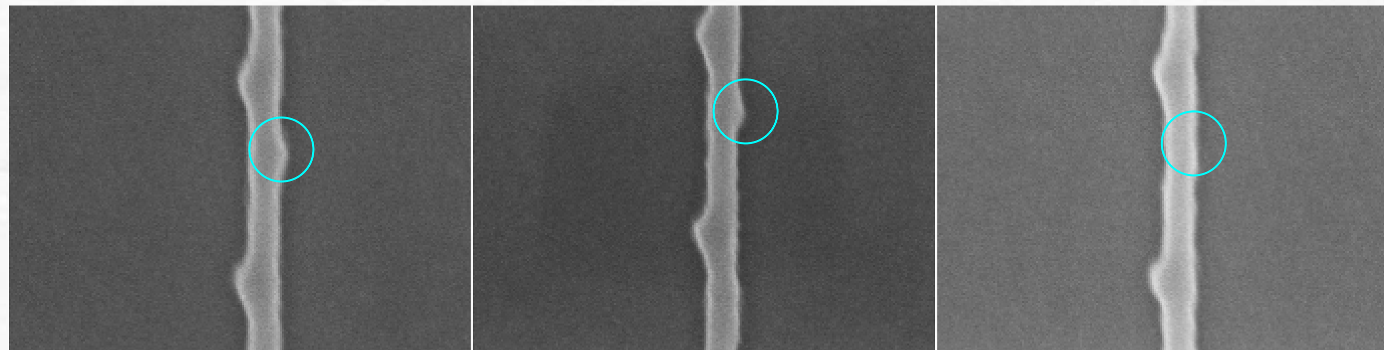


Focus & Dose effect

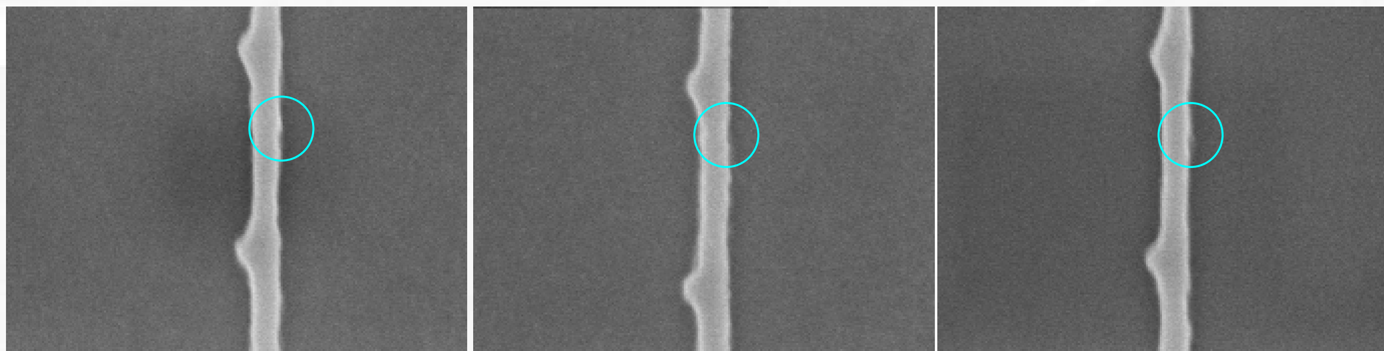
Through Focus

- **Defocus makes pits a little more printable**

150 nm W 6 nm D



-250 nm -200 nm -150 nm



-100 nm -50 nm 0 nm

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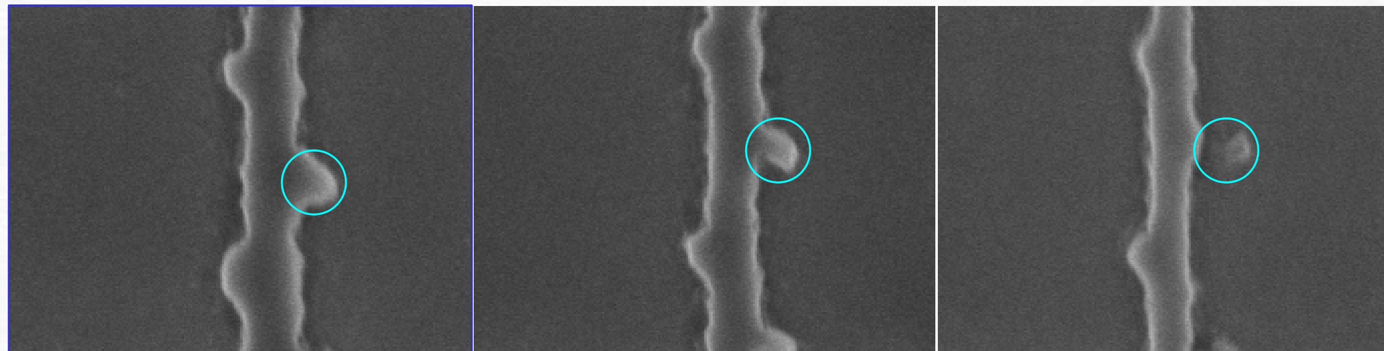
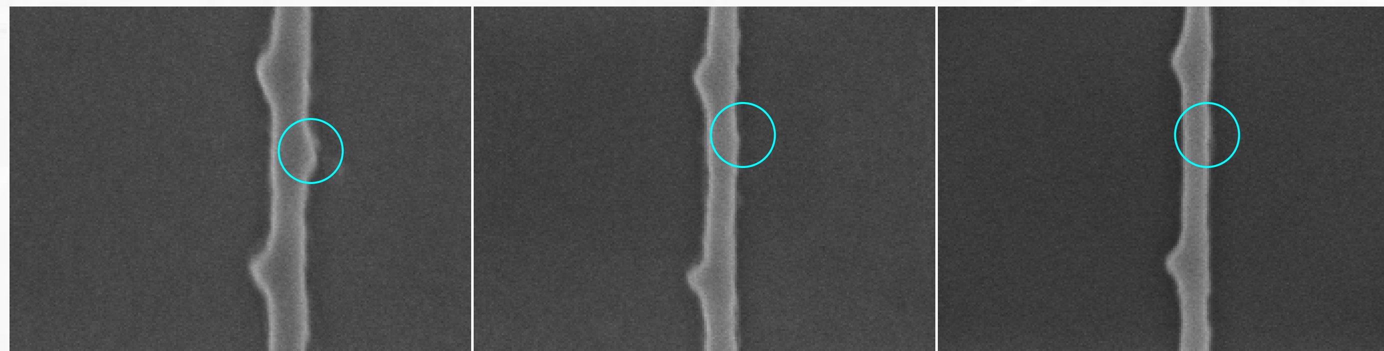
Through Dose

- **Low dose makes pits more printable**

150 nm W 6 nm D



-50% -40% -30%

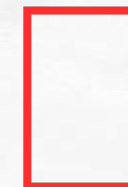


-20% -10% 0%

Printability According to Dose and Focus

- **Defocus images (-100nm)**
- **100 nm x 2 nm pits look printable only at -5% dose**

Focus	Dose	100 nm x 6nm	100nm x 4nm	100nm x 2nm	50nm x 6nm	50nm x 4nm	50nm x 2nm
	-5%						
	D0						
-100nm	5%						
	10%						



Printable

Assumption : two defects with 400 nm spacing regardless of CD change magnitude

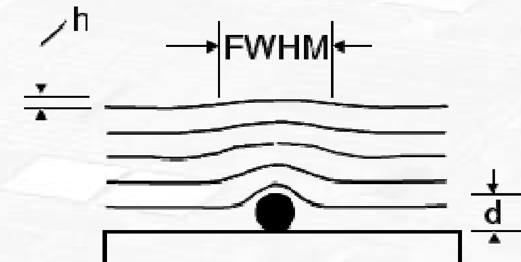
Printability According to Dose and Focus

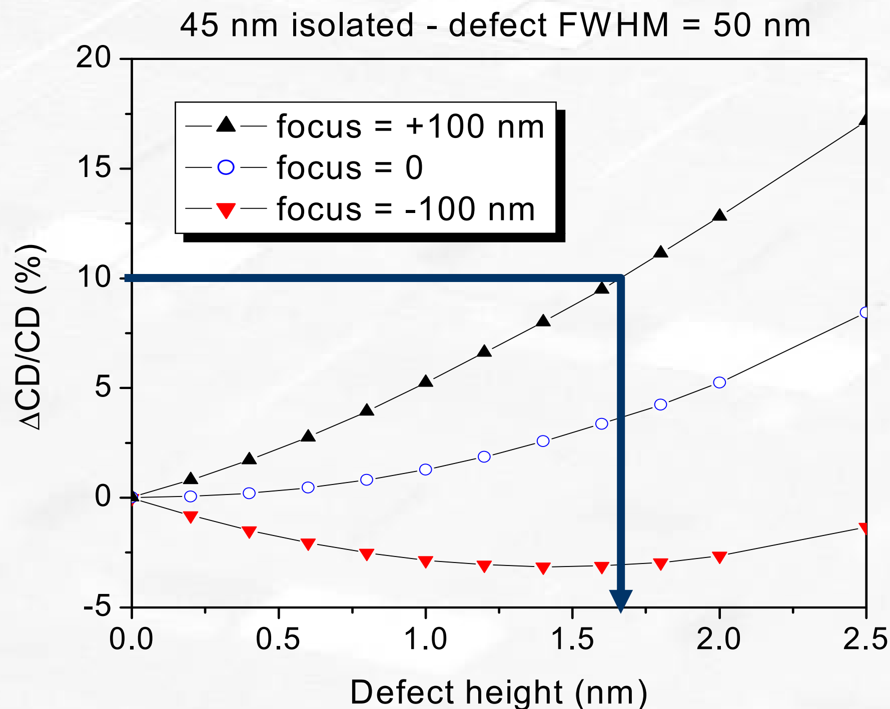
- **At just focus, some pits are not printable**
- **Only 2 pits are printable, pits 40nm from the line are printable.**
- **Printability depend more on depth than width**

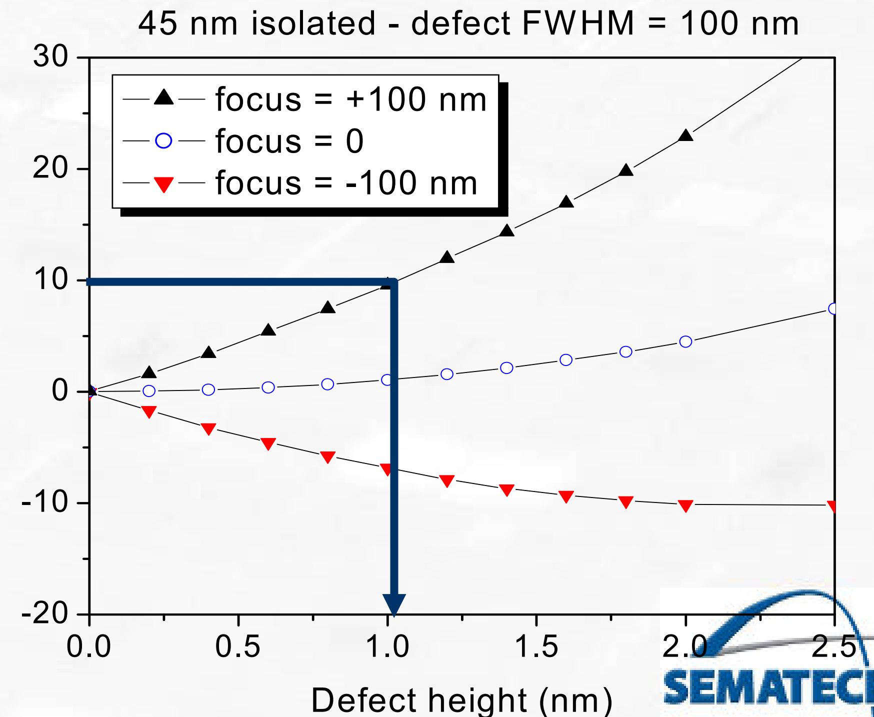
Focus	Dose	100 nm x 6nm	100nm x 4nm	100nm x 2nm	50nm x 6nm	50nm x 4nm	50nm x 2nm
F0	-5%						
	D0						
	5%						
	10%						

Defect Printability – Simulation

- **Aerial image simulation as a function of defect FWHM, height and focus**
- **Clearly showing printability change according to focus**







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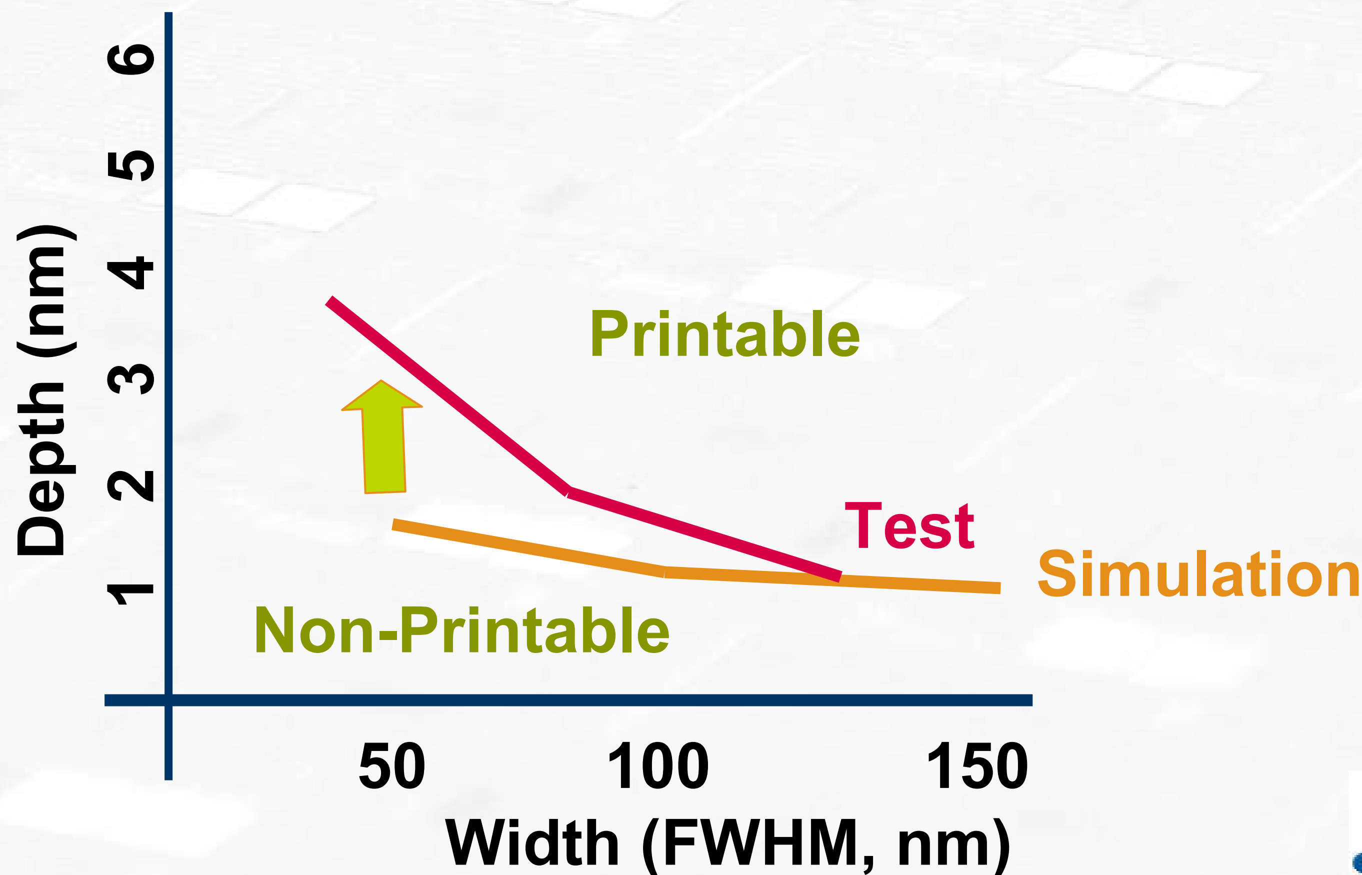
Comparison of Simulation and Real Test

- **Comparison at 100 nm defocus**
- **Well matched at large defect sizes, 1-2 nm difference at smaller defects**
- **Bake diffusion, develop process OR exposure condition difference btw simulation and test**

Printable
Printable only in defocus, Low dose
Non Printable
Printable
Non-Printable
Test
Simulation
Depth (nm)
1 2 3 4 5 6
50 100 150
Width (FWHM, nm)

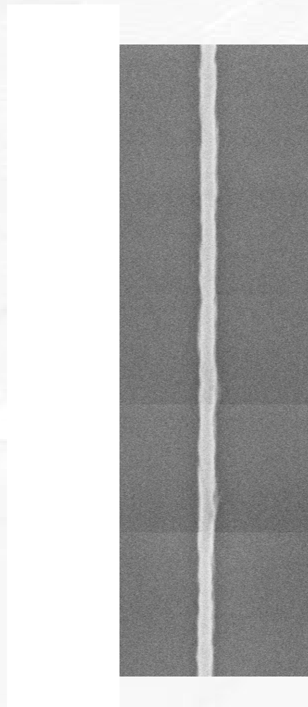
Comparison of Simulation and Real Test

- Comparison at 100 nm defocus
- Well matched at large defect sizes, 1-2 nm difference at smaller defects
- Bake diffusion, develop process OR exposure condition difference btw simulation and test

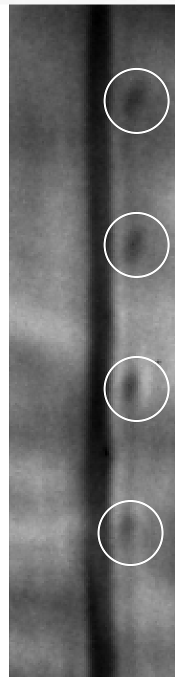


Comparison with EUV Imaging

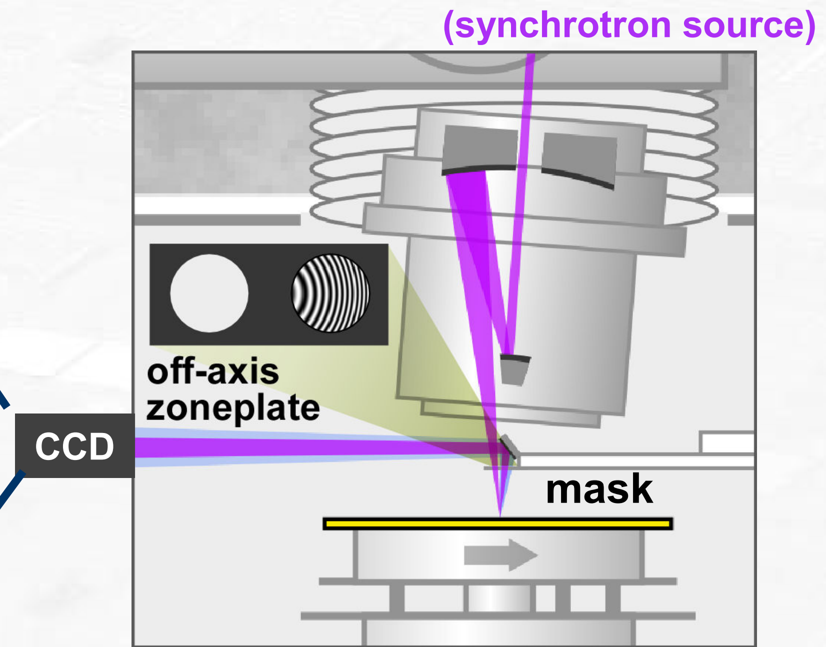
- EUV image from SEMATECH-Berkeley actinic tool
- Clearly shows substrate pits
- Upgrading to get reliable CD measurement



Resist SEM image
On a wafer



EUV imaging
On a mask



SEMATECH-Berkeley
Actinic Inspection Tool

Summary

- **Printability study using SEMATECH EUV infrastructure**
- **Below 100nm x 6nm pit size, printable pit-to-line edge spacing is only 40nm**
- **50 nm wide substrate pits up to 4 nm deep were not printable**
- **More optimistic than aerial image simulation**
- **Planning comparison study of printing image and EUV image with New program defect mask and upgraded actinic inspection tool.**
- **Ultimately determining exact 32 nm HP printable blank defect size and spec.**

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Acknowledgement

- **SEMATECH MBDC deposition, integration and cleaning team.**
- **Berkeley EUV MET team.**

Thank You !

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