EUV mask defects and their modulation

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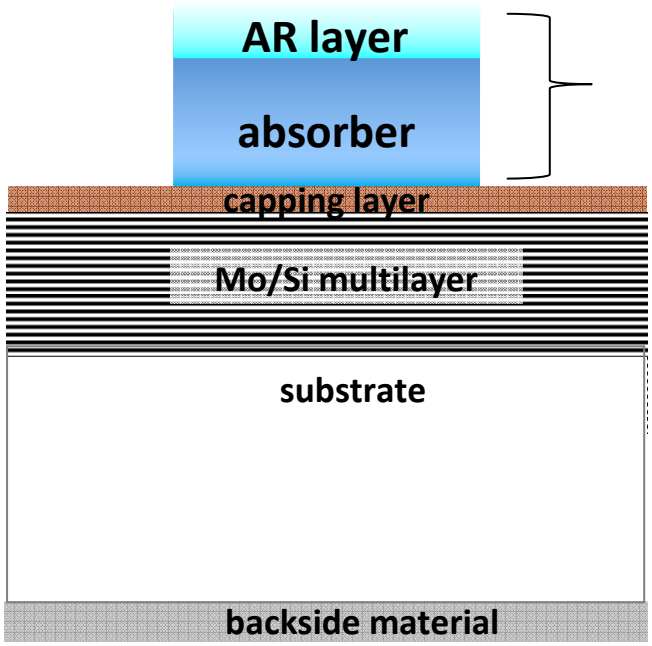
Background: EUVL mask films



Absorber of 13.5nm light

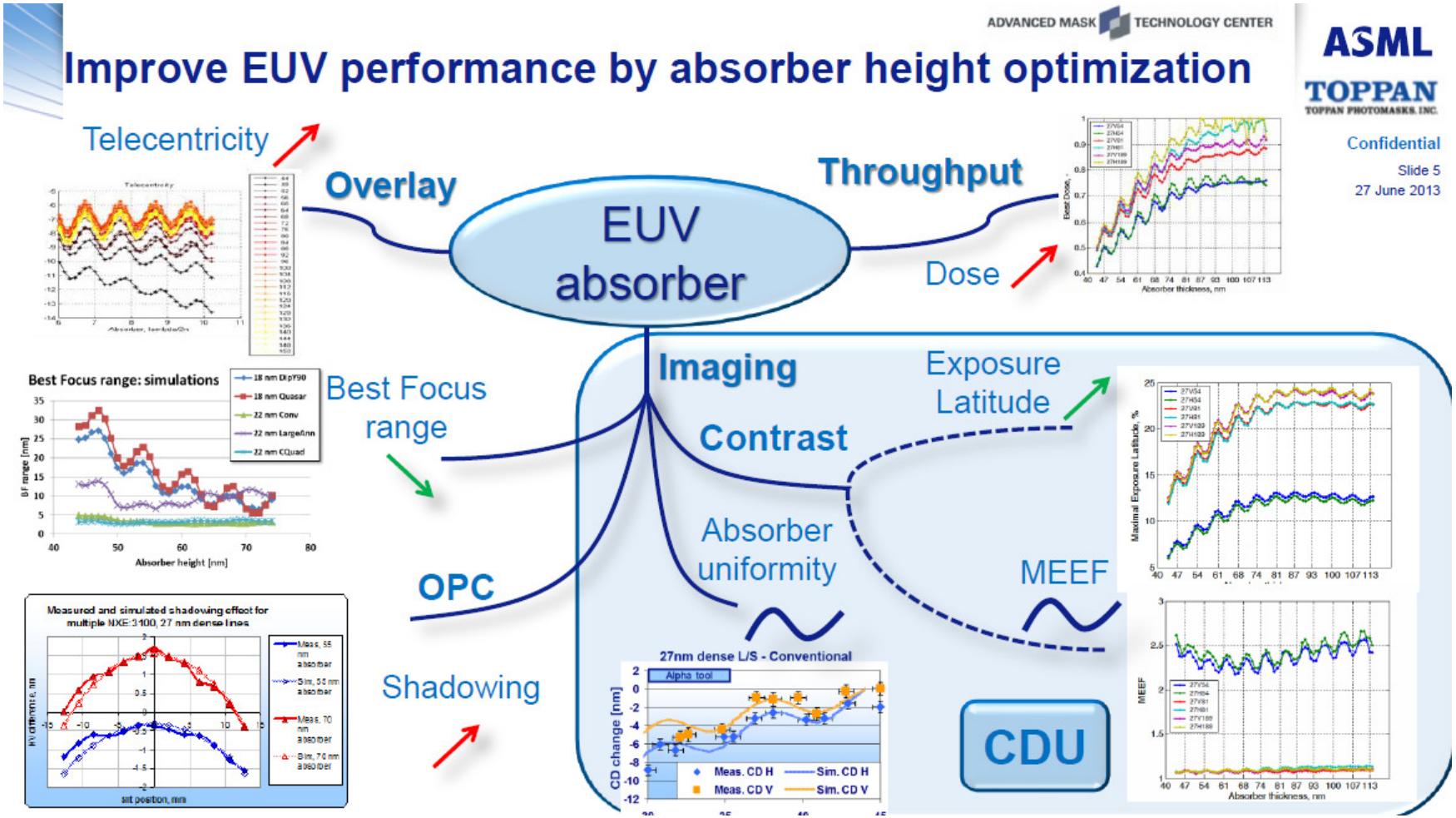
Adds durability

Reflects at 13.5nm

Provides stability

Enables electrostatic chucking

Absorber's primary role is lithographic



"Experimental Approach to EUV Imaging Enhancement by Mask Absorber Height Optimization", Natalia Davydova et al., ASML, AMTC, Toppan, EMLC 2013

Selecting an EUVL mask absorber

- Four basic criteria are required
- This paper evaluates four mask absorbers in four sections
  - Red, yellow, green used to indicate poor, reasonable and good performance

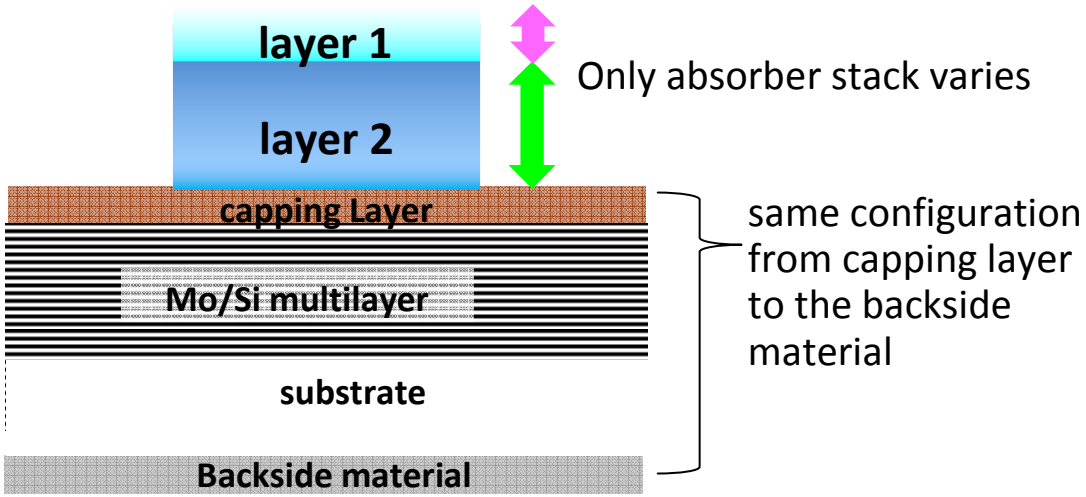
Area of impact	Goal	A	B	C	D
1. Wafer imaging	Ensure good performance				
2. Mask fabrication	Ensure good performance				
3. Blank inspection*	High sensitivity/low nuisance				
4. Mask pattern inspection*	High sensitivity/low nuisance				

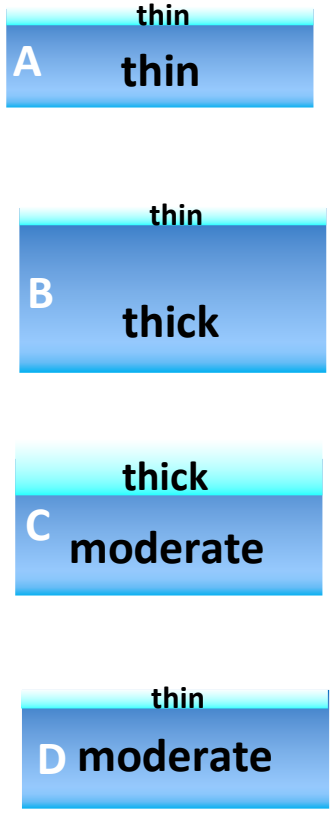
- Repair excluded because materials are the same
- Also of interest: does mask absorber change defect modulation at 13.5nm?

** Advanced commercially available 193nm inspection methods*

EUVL mask absorbers evaluated

- Fixed film composition and substrate
- Modified only the thicknesses of the absorber layers
- Tested effect of four different absorbers

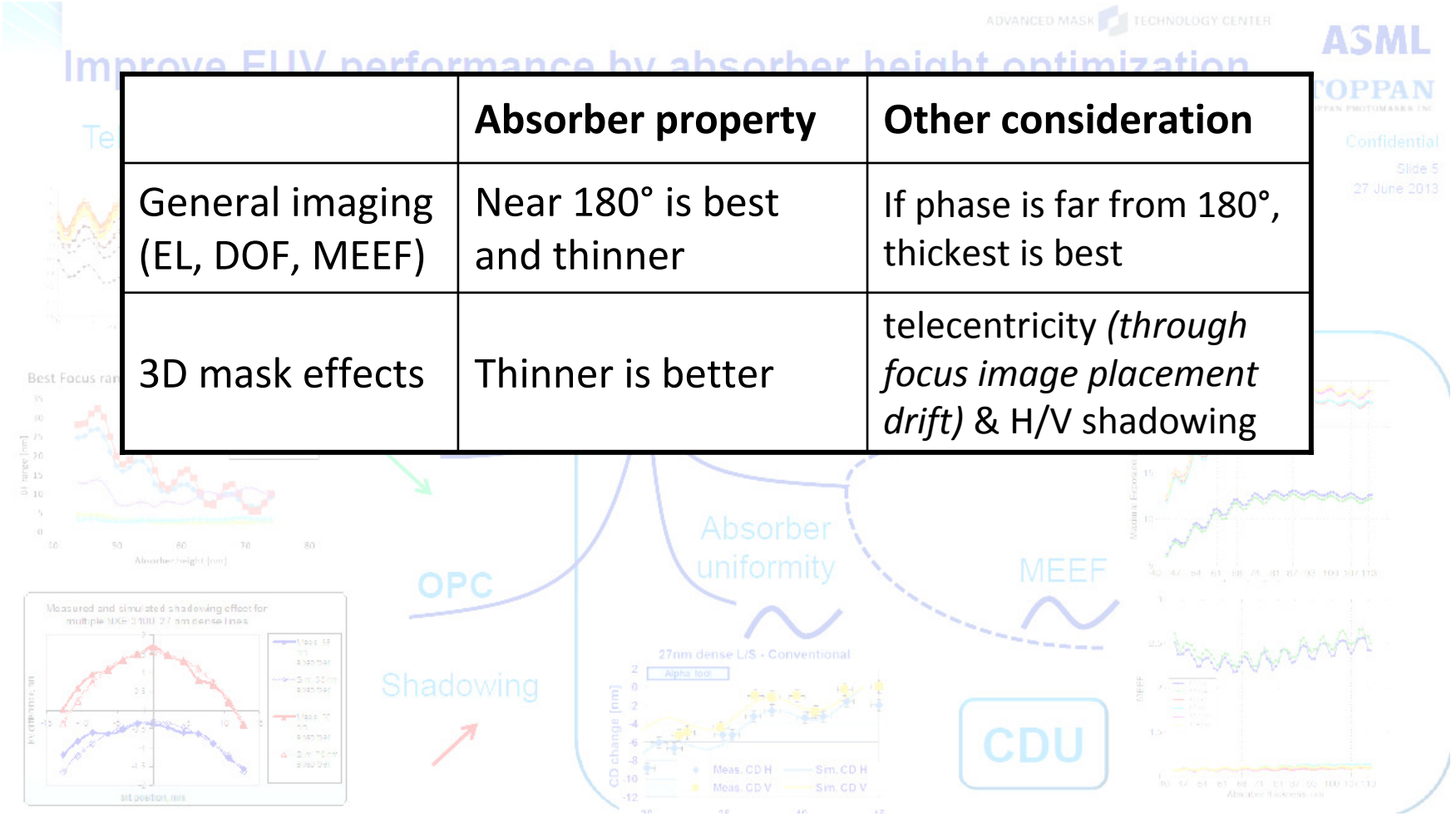




1. Wafer imaging

Optimal absorber thickness is a compromise

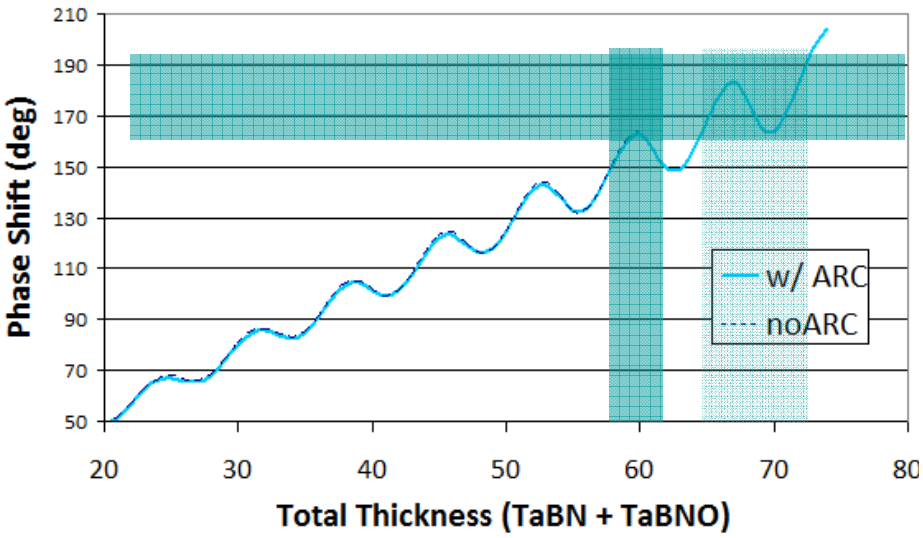
	Absorber property	Other consideration
General imaging (EL, DOF, MEEF)	Near 180° is best and thinner	If phase is far from 180°, thickest is best
3D mask effects	Thinner is better	telecentricity *(through focus image placement drift)* & H/V shadowing

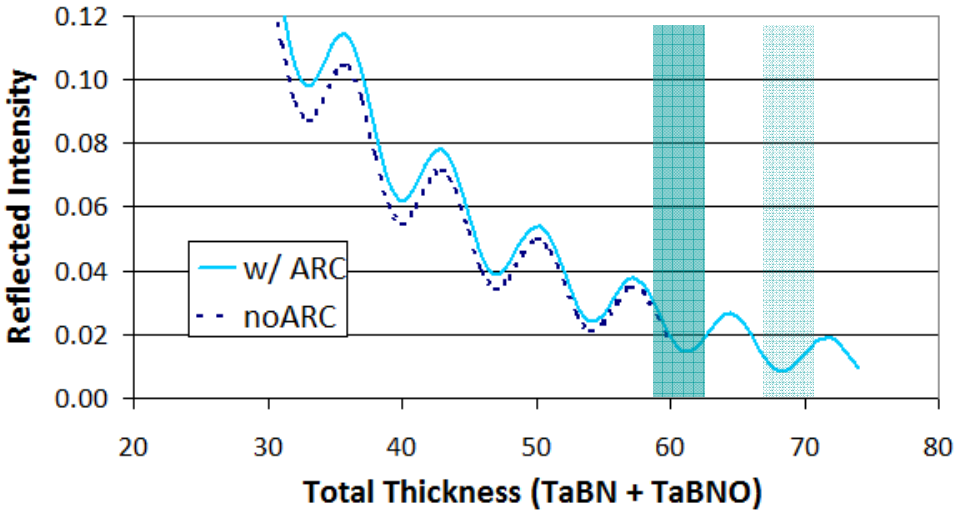


Wafer imaging at 13.5nm (theory)

- Reflected phase target ~180 degrees with thinnest film
- Reflected intensity must be minimized

Gregory McIntyre et al., IBM, SPIE 2011





- ~60nm stack is best - *must minimize film loss during mask lifetime*

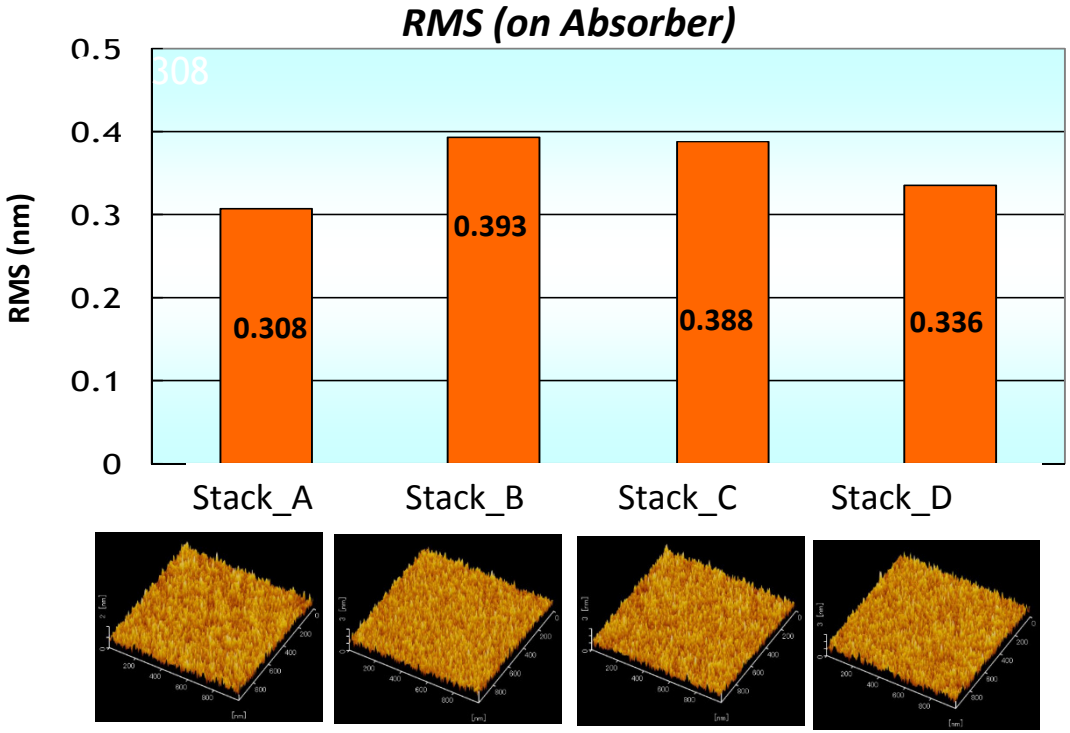
Area of impact	Goal	A	B	C	D
Wafer performance	Ensure good performance				

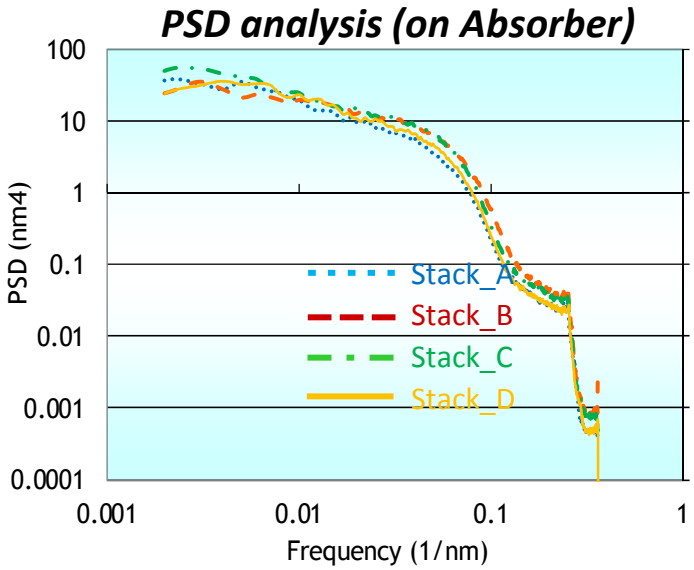
2. Mask fabrication

Absorber roughness and PSD analysis

- After mask build, blank roughness is similar
- No large difference in PSD analysis

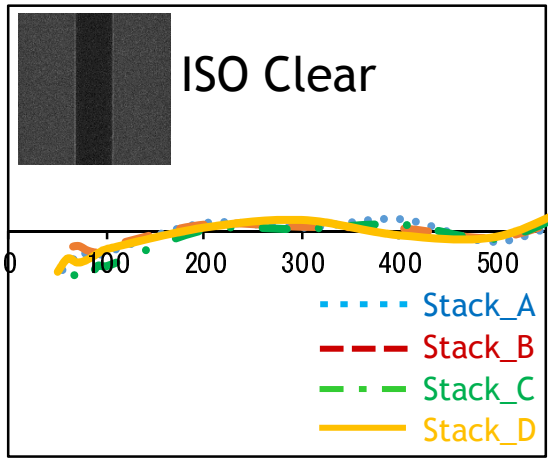
PSD = power spectral density

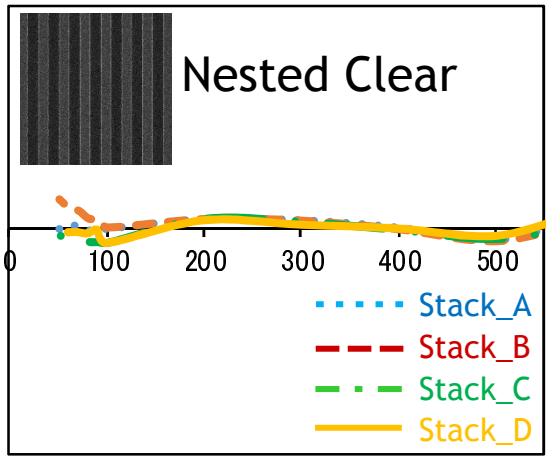


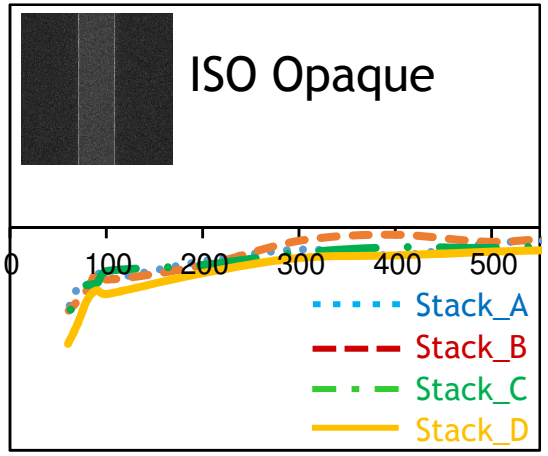


Mask patterning

- Compared 3D imaging: sidewall angle, corner rounding, etc.
- Verified 2D imaging: CDU, linearity, through-pitch, etc.







Area of impact	Goal	A	B	C	D
Mask fabrication	Ensure good performance				

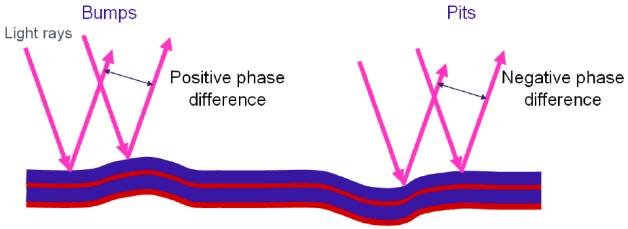
3. Blank inspection

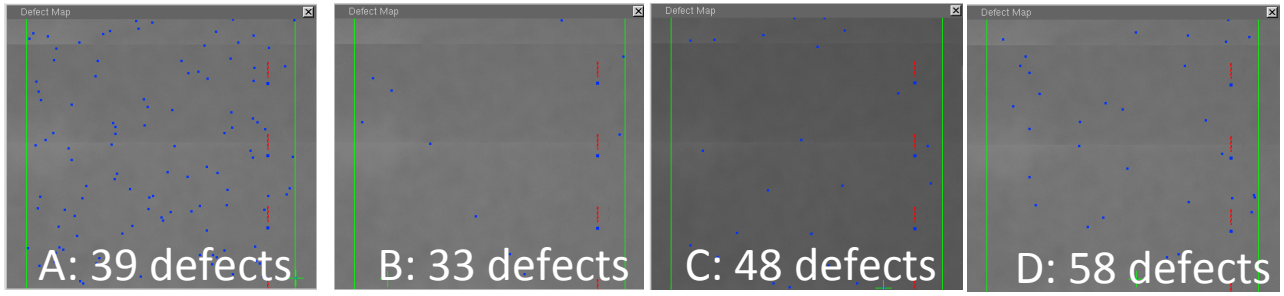
Blank inspectability

- Defect count is identical (within blank lot variation)

defect examples:

Phasur blank inspection capability





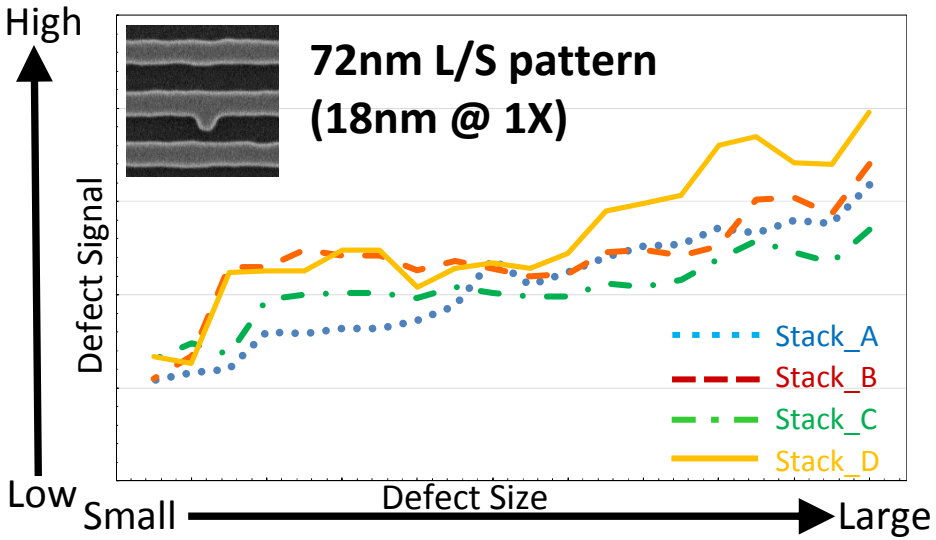
- Cannot distinguish printing from non-printing defects
- Reduction of overall blank defect levels required

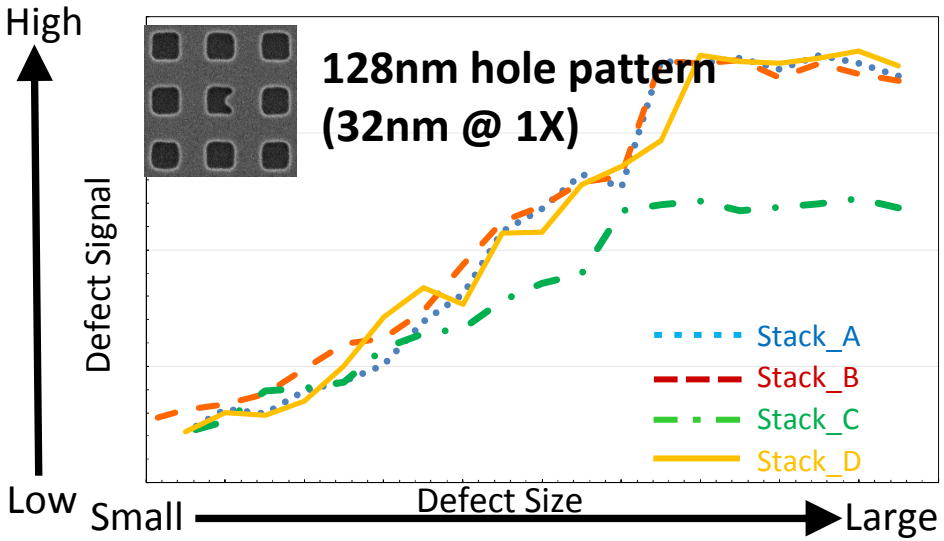
Area of impact	Goal	A	B	C	D
Blank inspection (193)	High sensitivity/low nuisance				

4. Patterned mask inspection

Mask patterned inspection: opaque defect

- 193nm inspection on programmed defect: opaque extension example
- Thinner antireflective layers show better sensitivity

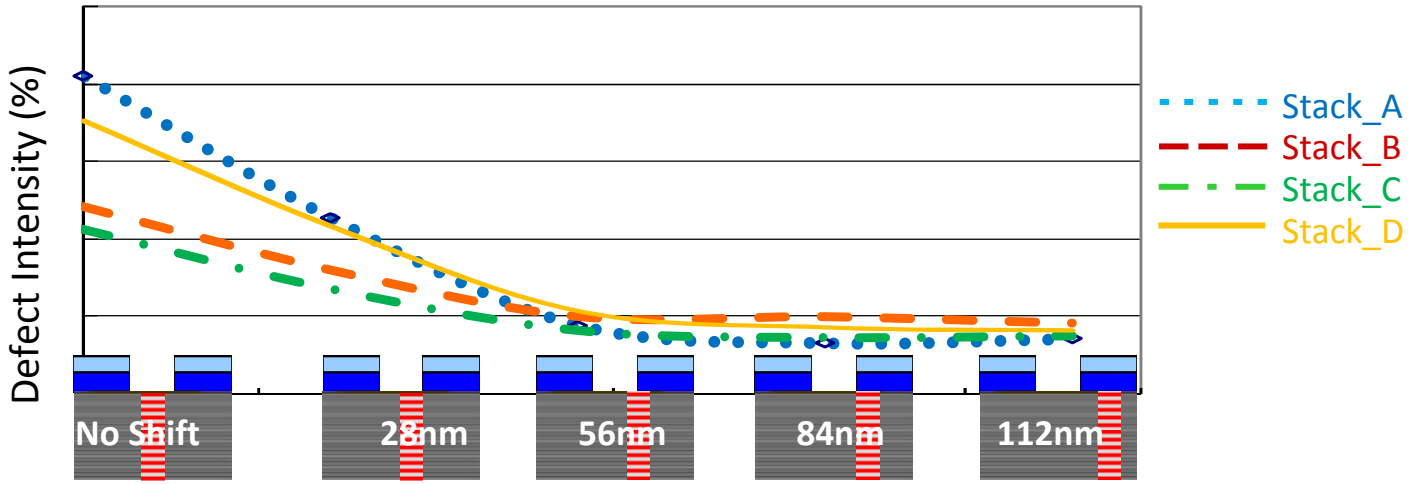




Area of impact	Goal	A	B	C	D
Mask pattern inspection (absorber defect)	High sensitivity/low nuisance				

Simulated sensitivity to mask multilayer defect

- 193nm inspection simulated for pure comparison: 112nm L/S (28nm @1X)
- Mask defect: 2nm pit with 47nm FWHM
- Thinner total absorber stacks (A, D) show better sensitivity



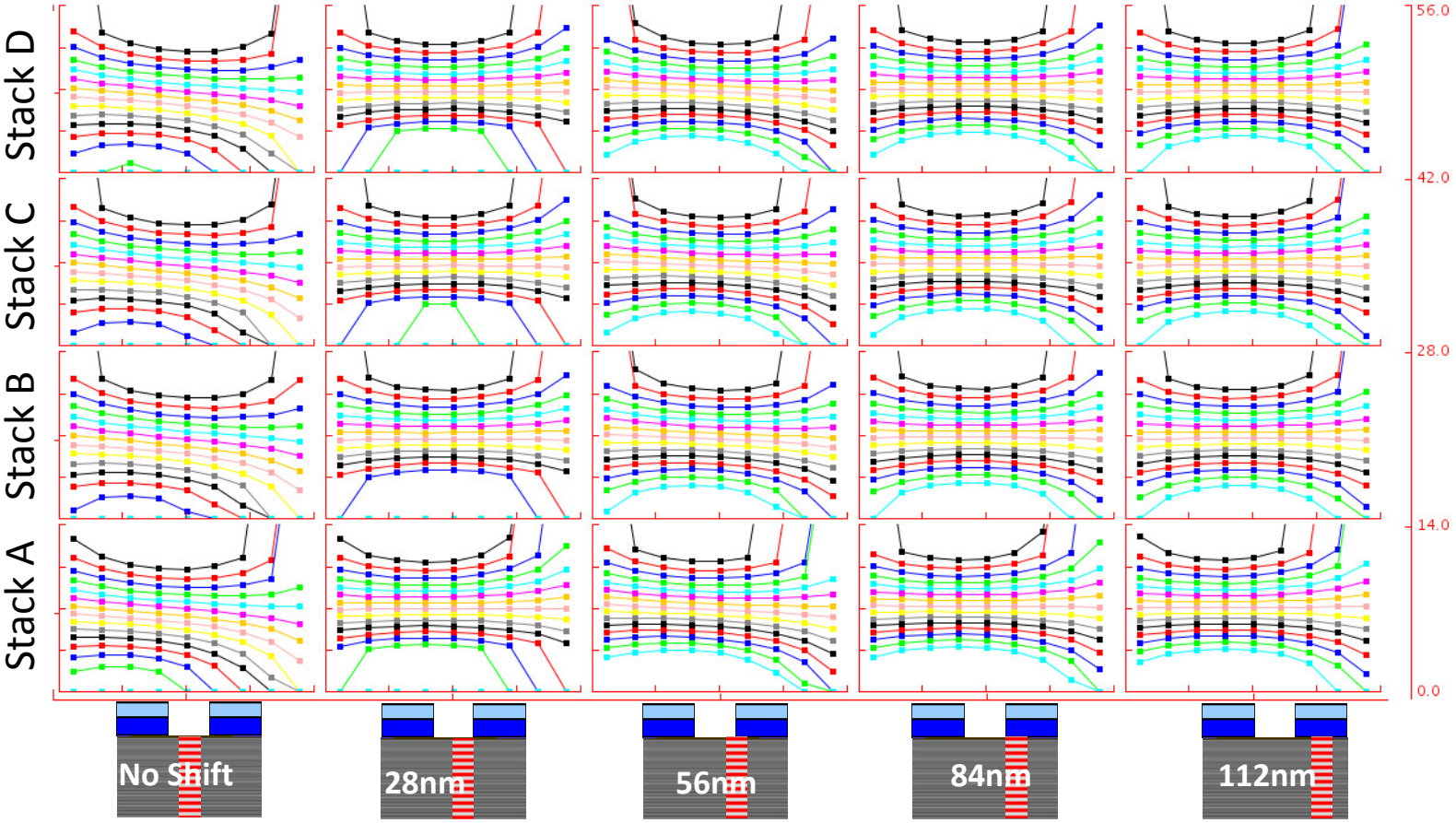
Area of impact	Goal	A	B	C	D
Mask pattern inspection (multilayer defect)	High sensitivity/low nuisance				

Wafer printability of opaque mask defect

- Revisit whether mask absorbers modulate defects at 13.5nm

EUV sensitivity to mask multilayer defect

- Simulated phase defect printability is comparable through focus & dose
- *Same mask inspection sensitivity needed, despite varied 193 inspection results*



Obtaining actinic images

- Leveraged SHARP microscope
- More description in session 9: "A sharper look at EUVL masks," Markus Benk, et al.

Source: Synchrotron

Optics: Zoneplate-lenses

4×NA: 0.25–0.625

σ: Programmable

Nav: Full-mask *xy*

Speed: 5–10 series/hr

Vibration Isolation

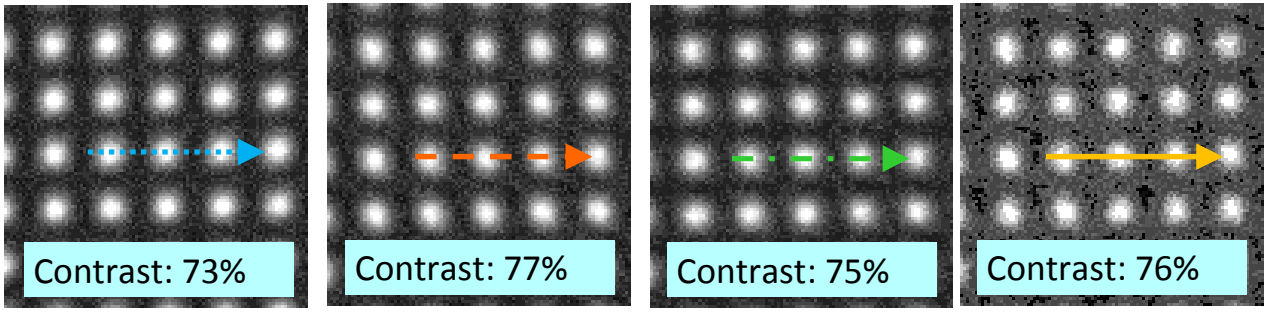
K. Goldberg, et al., "The SEMATECH high-NA actinic reticle review project, an EUV mask-imaging microscope", BACUS 2013.

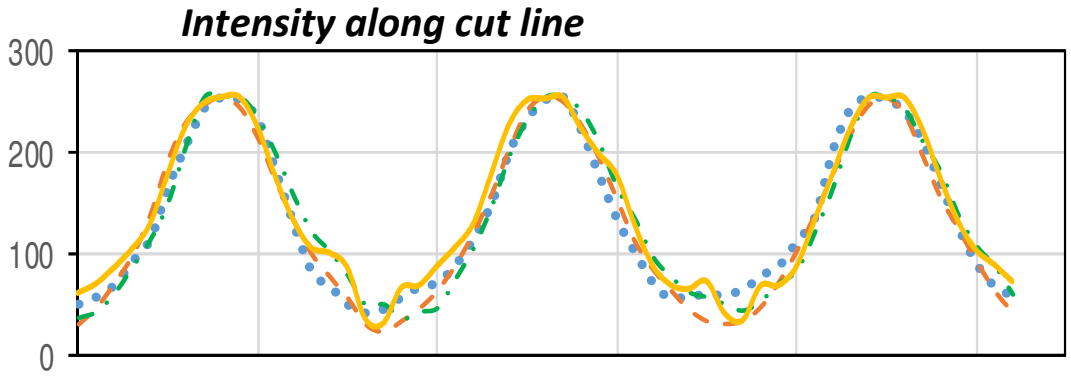
Mask imaging at 13.5nm (SHARP)

SHARP illumination

0.33 NA, quasar

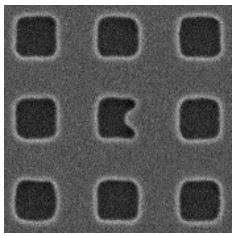
- Verified similar contrast through focus using SHARP
- 32nm hole pattern (128nm @4X)

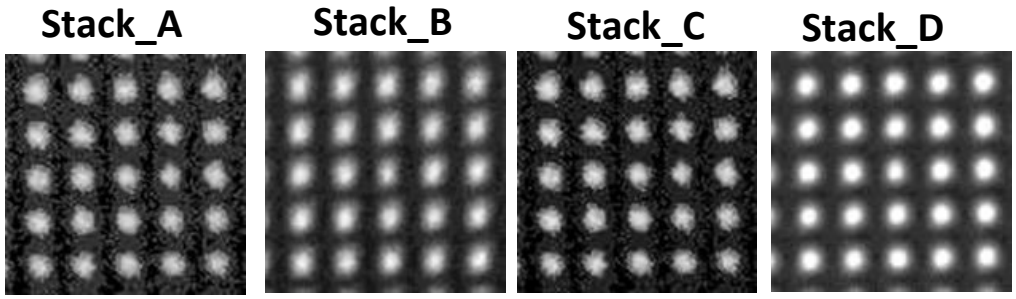


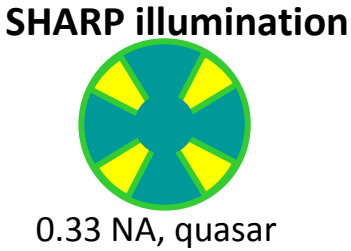


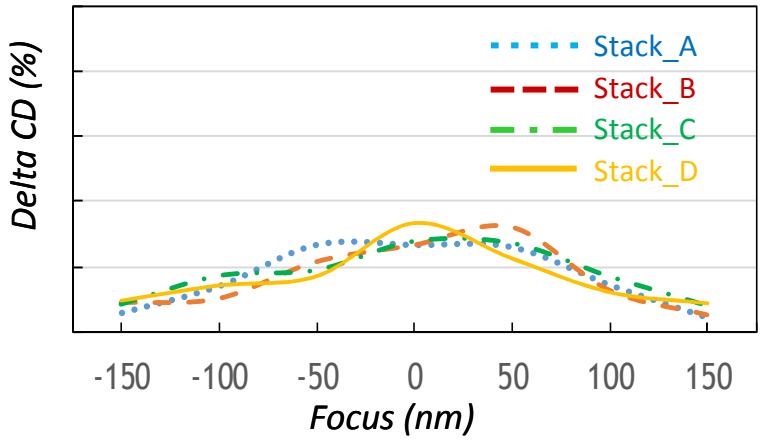
EUV mask defect printability: contacts

- 32nm hole (128nm@4X) evaluated with SHARP microscope







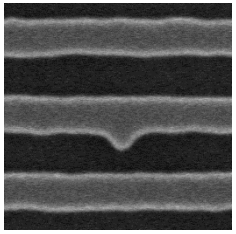


- Imaging is equivalent for all four absorbers
- No advantage offered by absorber choice

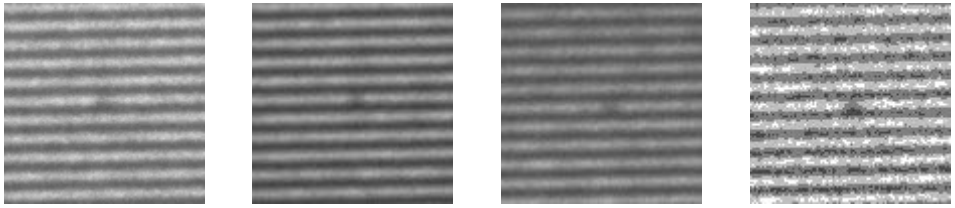
EUV mask defect printability: lines

- 18nm line/space (72nm @4X) evaluated with SHARP microscope

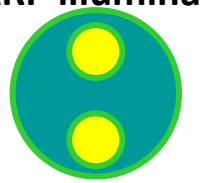
Mask defect



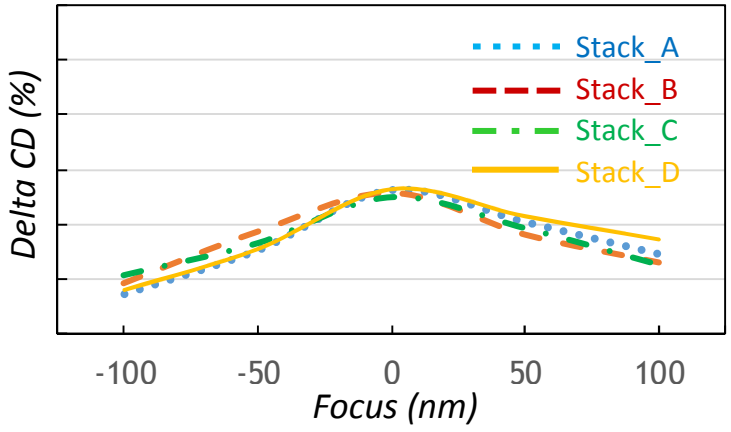
Stack_A Stack_B Stack_C Stack_D



SHARP illumination



0.33 NA, dipole



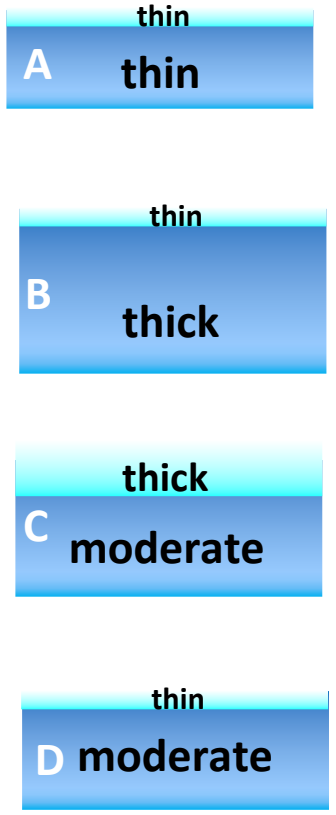
- Imaging is equivalent for all four absorbers
- No advantage offered by absorber choice

Summary

- Based on the impact assessment, absorber D is the best

Area of impact	Goal	A	B	C	D
Wafer imaging	Ensure good performance				
Mask fabrication	Ensure good performance				
Blank inspectability	High sensitivity/low nuisance				
Mask pattern inspection (abs)	High sensitivity/low nuisance				
Mask pattern inspection (ML)	High sensitivity/low nuisance				

- Absorber choice does not appear to impact wafer defect printability



Acknowledgments

- The authors would very much like to thank …
  - IBM/Toppan JDA team
  - KLA-Tencor Engineering and Application team

The SHARP work was funded by SEMATECH under agreement # LB08005006 performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Berkeley National Laboratory under management and operating contract DE-AC02-05CH11231