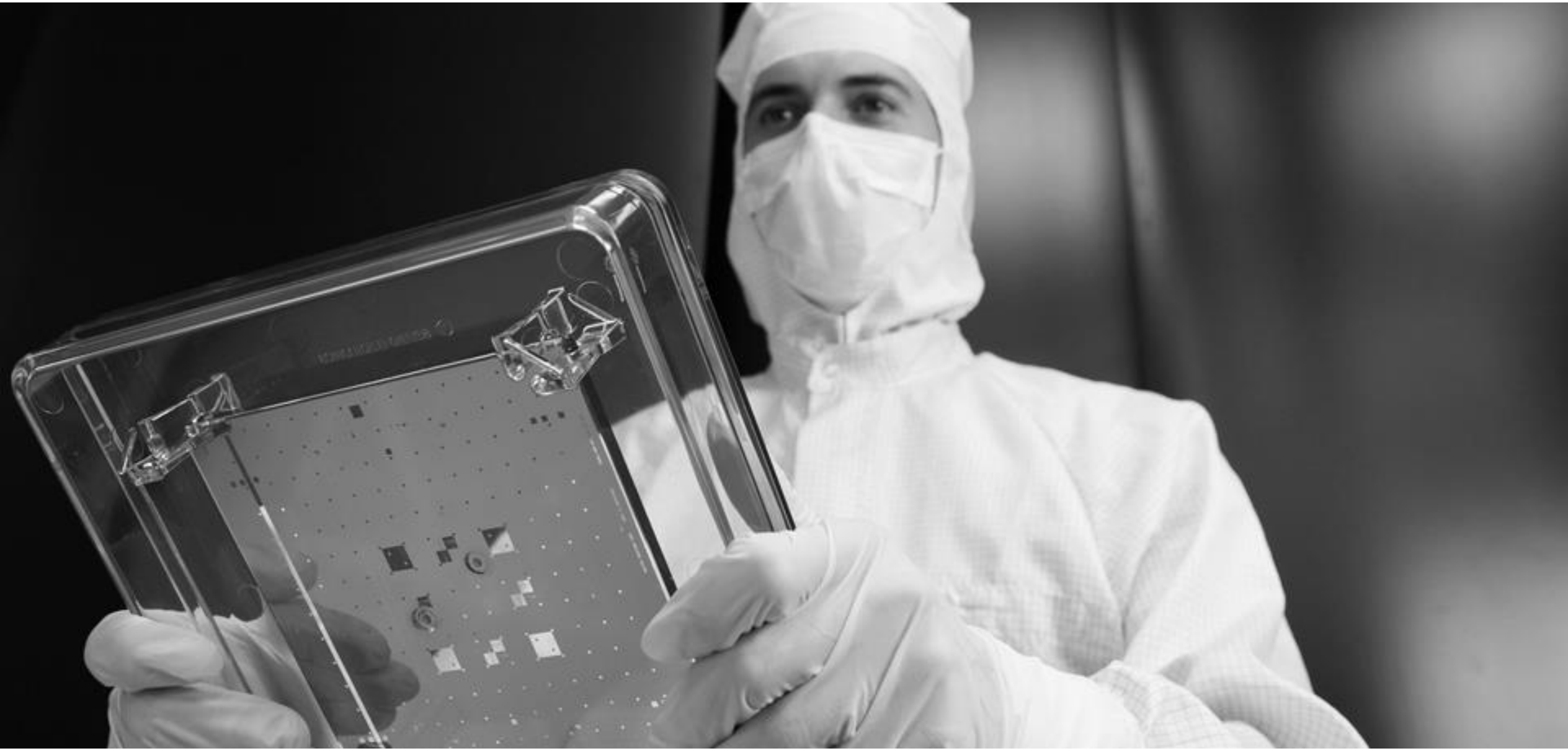
Challenges and Considerations associated with EUV photomask defectivity and repair



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Agenda

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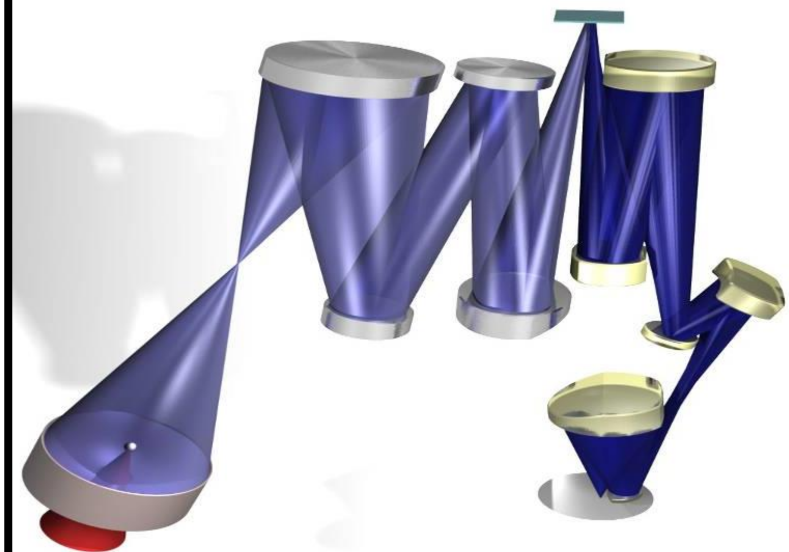
1	Introduction
2	Blank inspection and pattern shifting
3	Shadowing effects
4	Compensational repairs
5	Summary

Reflective optics for EUVL present many new aspects

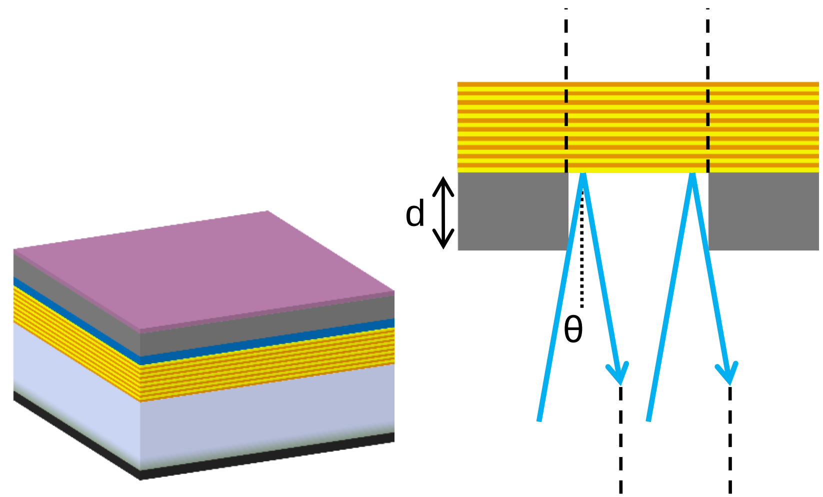
Differences in the illumination as well as the photomask must be taken into account

EUVL Scanner Reflective Optics



- Chief Ray Angle (CRA) of 6 degrees
- Scanner slit 'ring' shape

EUV Mask Challenges



- Much higher mask complexity
  - More layers/process steps
  - Shadowing effects

This presentation addresses new considerations for EUV photomask defect review and repair stemming from these aspects

Increased mask complexity presents new defect classes

1 Substrate defects

- Pits, bumps and scratches due to CMP and cleaning
- Particles due to storage and handling
- Residues due to cleaning

2 ML defects

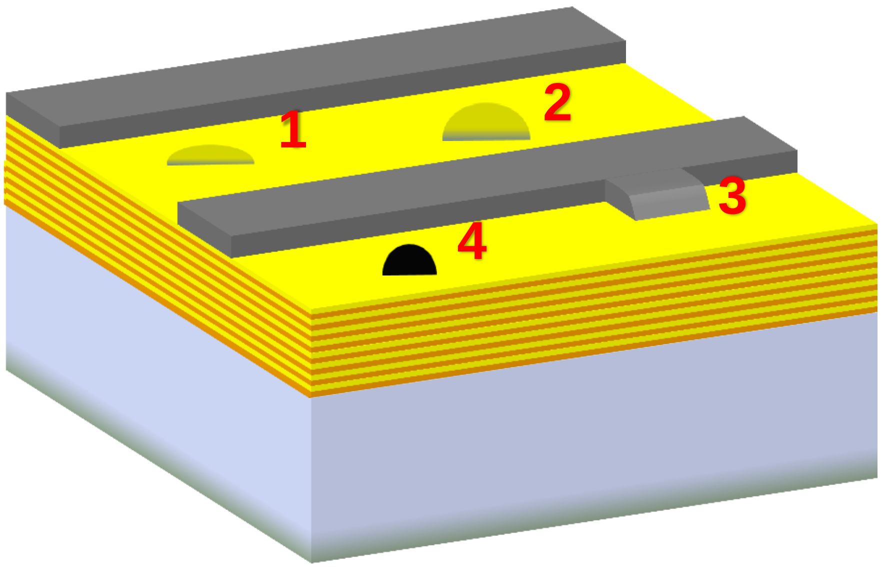
- Particles within or on top of the ML due to deposition process
- Pits or particles added from storage, cleaning and handling

3 Pattern transfer defects

- Absorber defects similar to transmission mask defects

4 Particles or residue

- From handling, cleaning and usage

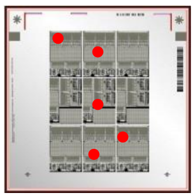


Rastegar, A., and Jindal, V., "EUV Mask Defects and Their Removal," Proc. SPIE 8352, 83520W (2012).

Teki, R., et al, "Material- and polishing induced defectivity on EUV mask substrates," EUVL Symposium Brussels (2012).

New approaches are required to handle new defect classes

Inspection → AIMS™ EUV → MeRiT® → AIMS™ EUV → Customer



- Patterned inspection

- Defect disposition

- Absorber defect repair

- Repair verification

- Defect free mask

New to EUV:

- Blank inspection
- Pattern shifting

- Provides data for compensational repair calculation

- ML defect mitigation with compensational repair

- Blank inspection and pattern shifting are closely tied to review and repair
  - AIMS™ EUV and repair tools must know blank inspection defect locations
- Shadowing effects introduce new restrictions
  - Die-to-die references for inspection and repair
  - Deposition repair height requirements are stringent
- AIMS™ EUV is required for compensational repair calculations

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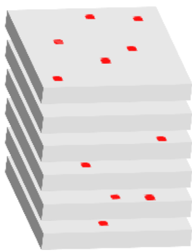
Blank Inspection and Pattern Shifting (1/2)
Finding a possible solution

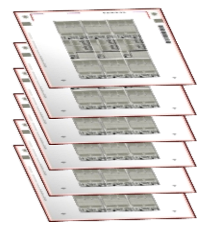
Library of mapped blanks

Classified by defect
- number
- location
- size
- type



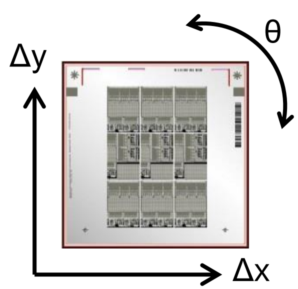
Library of layers/patterns

Classified by
- pattern density
- node
- layout



Pattern shift calculation

Degrees of freedom include
- orientation
- x and y shift (≤200 μm)
- Rotation by up to +/- 1°



Manual inputs allow enhanced solution finding

- Minimum absorber coverage area for defects
- Minimum number of defects to be covered

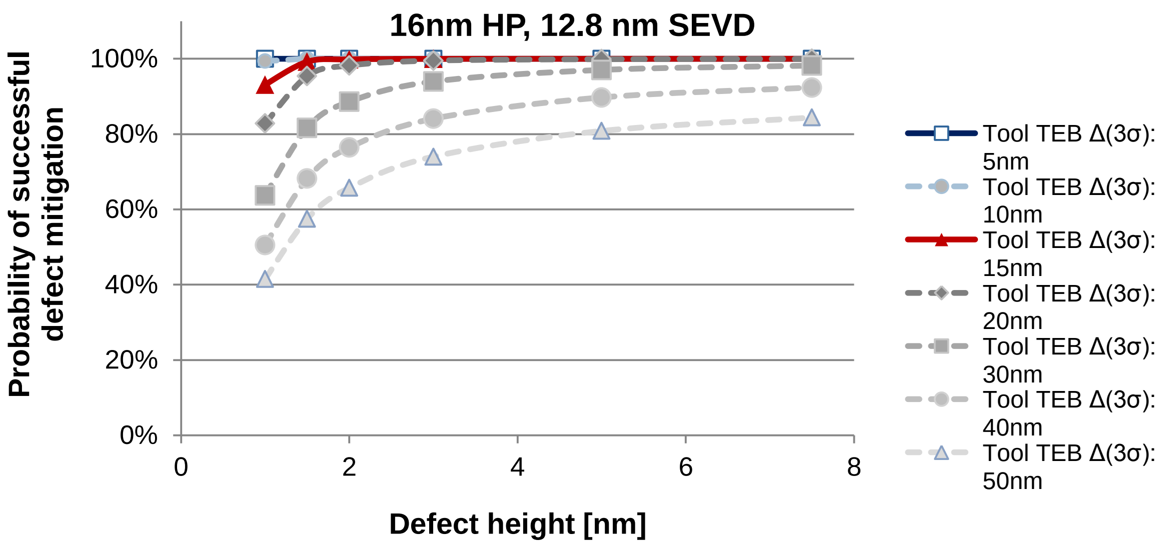
Runs	# of defects	coverage arrangement	Absorber size	Outcome
1	7	7	300nm	Failed
2	7	7	200nm	Failed
3	7	7	100nm	Failed
4	7	7	80	Failed
5	7	7	50	Successful
6	6	6	75	Successful
7	5	5	200nm	Failed
8	5	5	100nm	Failed
9	5	5	80nm	Failed
10	3	3	200nm	Failed
11	2	2	200nm	Successful
12	6	#1, #5, #6, #7 #2, #3	100nm 75nm	Successful

Table 2 Summary of defect mitigation data runs.

Yan, P., et al, "EUVL Multilayer Mask Blank Defect Mitigation for Defect-free EUVL Mask Fabrication," Proc. SPIE 8322, 83220Z (2012).

Blank Inspection and Pattern Shifting (2/2)
Success criteria

- Probability of successful pattern shift defect mitigation (*single defect*) depends on:
  - Lateral defect size, minimum absorber feature size (hp @ mask level) and tool total error budget (TEB)



For a single defect:

TEB ≤ 15nm (3σ) for BI and EB writing is required in order to achieve >90% successful mitigation

BUT. . .

- Currently this TEB cannot be achieved
- More than 1 defect is present on the blank – not all can be covered
- Impact area of defect can be larger than assigned absorber size

Pattern shift success must be verified by AIMS™ EUV and repaired if necessary

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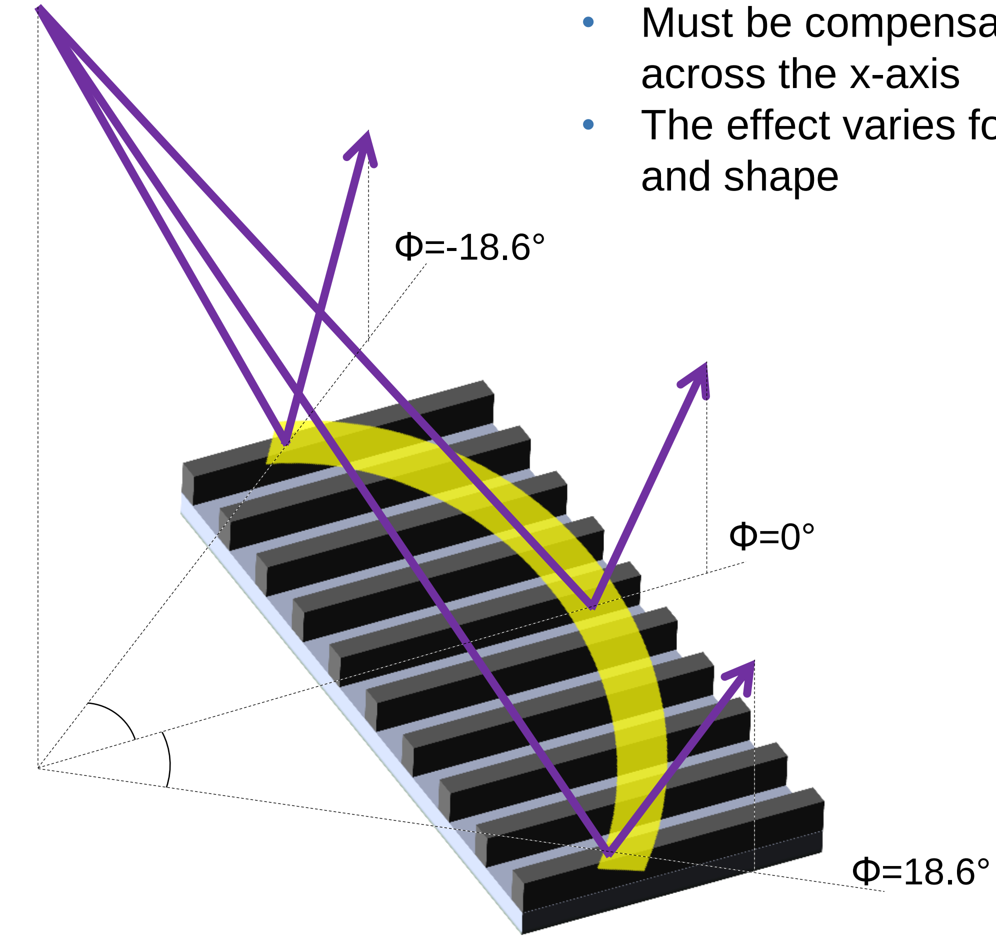
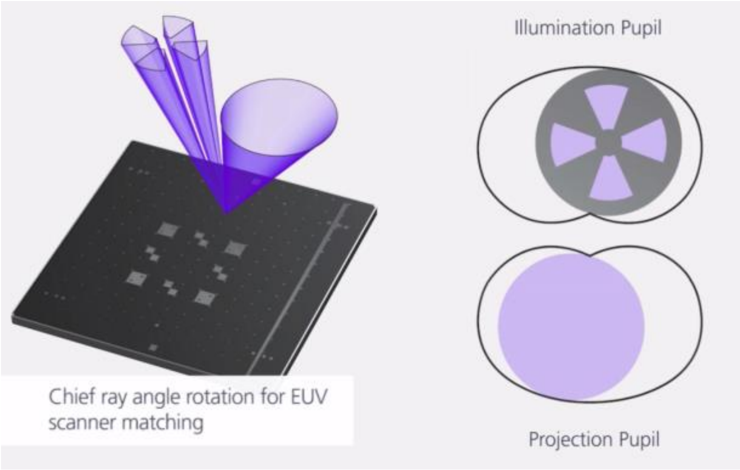
Die-to-die reference feature acquisition is limited (1/2)

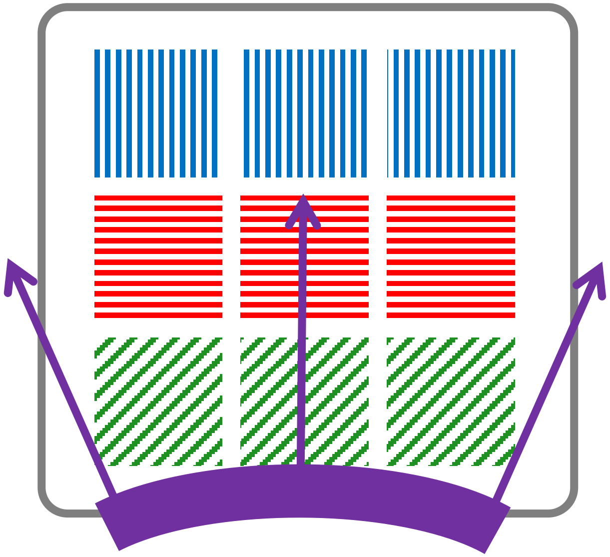


- Combination of CRA and azimuthal angle component results in an orientation and position dependent shadowing effect
  - Must be compensated for with OPC/biasing that varies across the x-axis
  - The effect varies for features of different orientation, size and shape

AIMS™ EUV fully emulates this effect



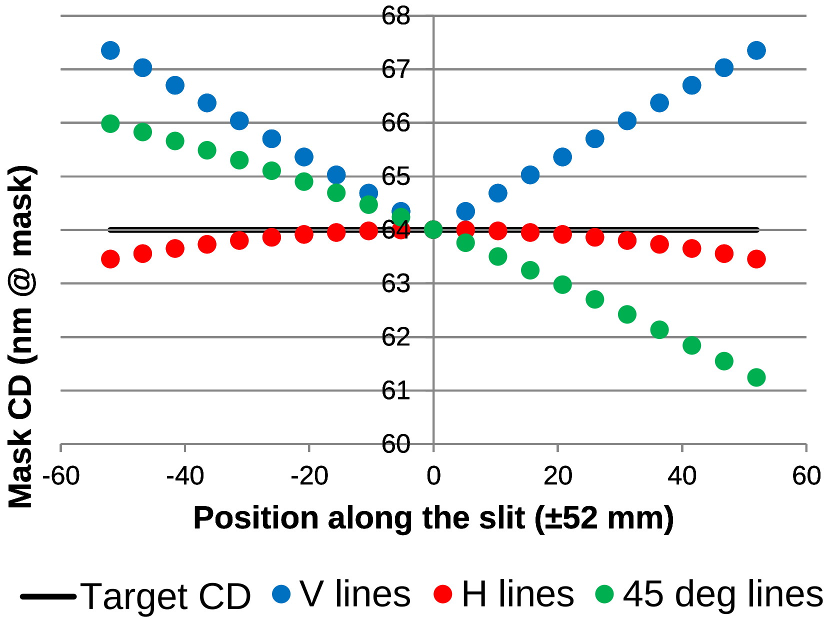
Die-to-die reference feature acquisition is limited (2/2)



Vertical features
- No bias at center
- Max bias at edges

Horizontal features
- Max bias at center
- Reduces at edges

Diagonal features
- Bias varies across entire reticle



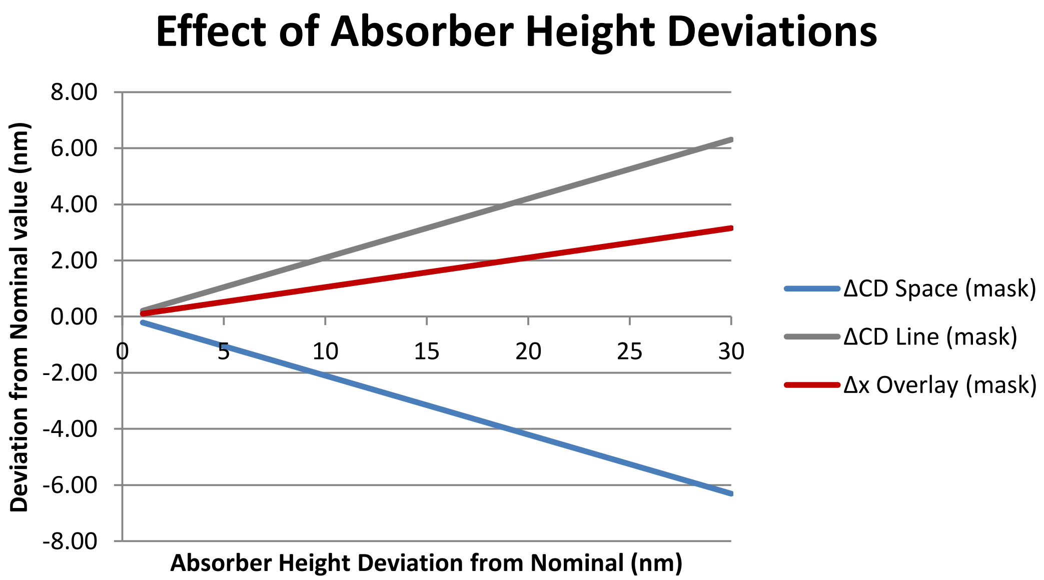
- Die-to-die references along the x-position may have different physical dimensions
  - Criticality depends on feature size, orientation, die step distance (number of die)

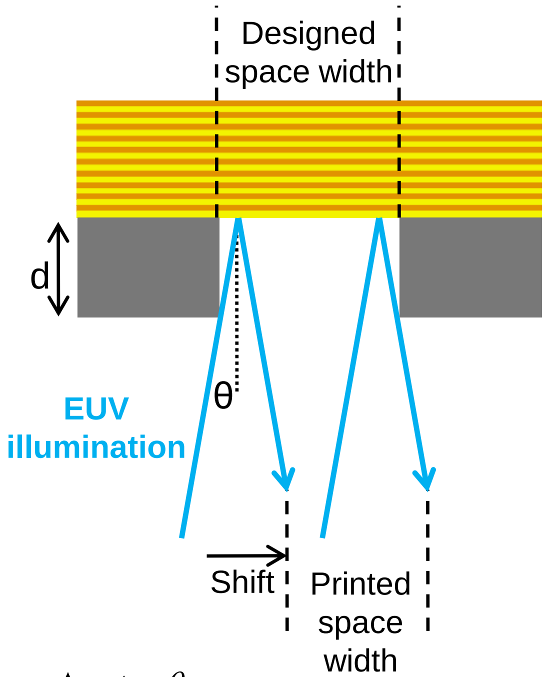
- Die-to-database references (i.e. inspection, repair) and AIMS™ EUV are unaffected

Die-to-die references for pattern inspection and repair tools have some restrictions

Repair height of deposition is critical

- The Shadowing Effect is due to the combination of CRA and absorber height
  - Spaces print smaller and lines print larger
  - Local overlay error is introduced





$$\Delta x = \frac{\Delta z \times \tan\theta}{M}$$

$$CD_{\text{printedspace}} = CD_{\text{design}} - (2d\tan\theta)\times M$$

$$CD_{\text{printedline}} = CD_{\text{design}} + (2d\tan\theta)\times M$$

Shadowing effect imposes stringent repair height restrictions

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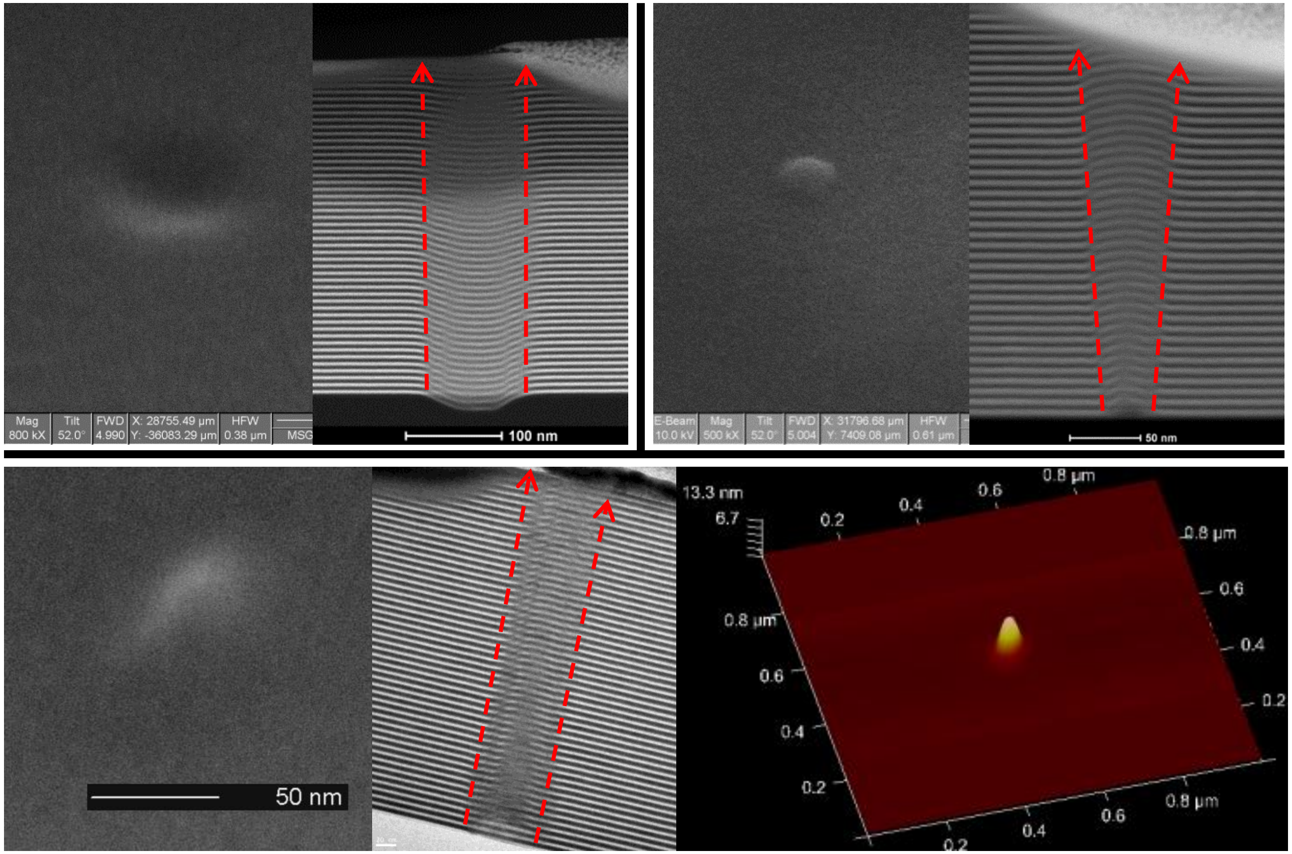
Compensational repair considerations (1/3)
Surface defect dimensions can be misleading

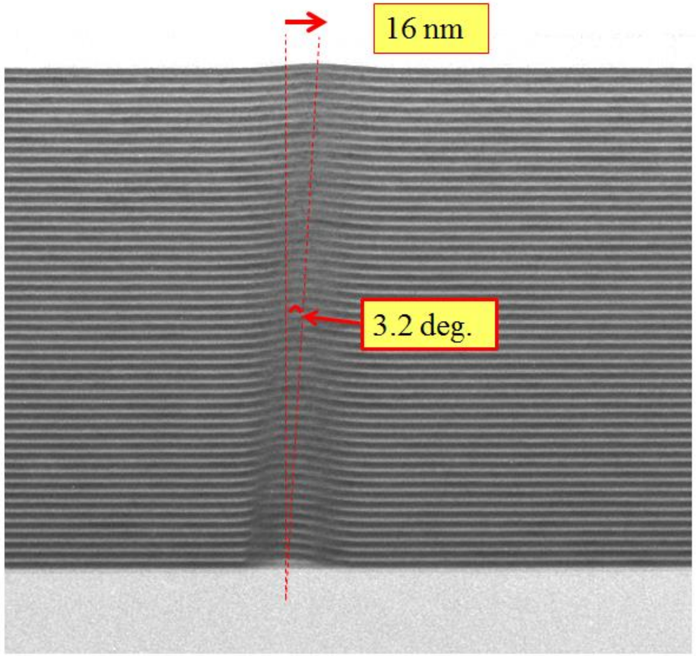
- SEM and AFM only provide surface information
- ML defects are more than just ‘skin deep’
- ML defect surface dimensions can be misleading



Goldstein, M., and Naulleau, P., Opt. Express 20(14), 15752-15768 (2012).
Kwon, H.J., “EUVL Defect Printability: An Industry Challenge,” SEMATECH Symposium Korea, 2011.

Compensational repair considerations (2/3)
Surface defect positions can be misleading

- Propagation of ML defects is not always vertical
- Where is the printability affected?
- What repair shape is required?



Amano, T., et al, "Impact of the phase defect structure on an actinic dark-field blank inspection signal and wafer printability," Proc. SPIE 8322, 832234 (2012).

Amano, T., and Terasawa, T., "Propagation of surface topography of EUV blank substrate through multilayer and impact of phase defect structure on wafer image," Proc. SPIE 8679, 86791P (2013).

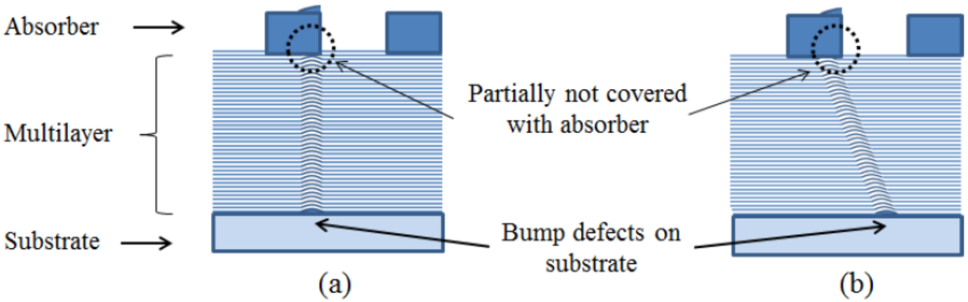


Figure 1. Cross-sectional view of the EUVL mask pattern with (a) vertical type of PD and (b) inclined type of PD.

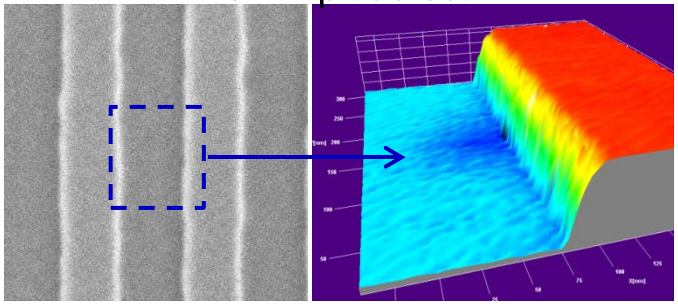
Compensational repair considerations (3/3)
Success criteria for a repair

What determines the success of the compensational repair?

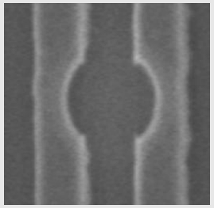
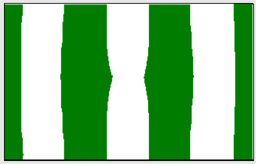
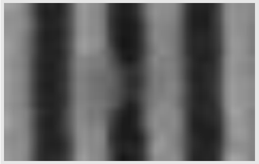
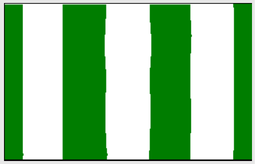
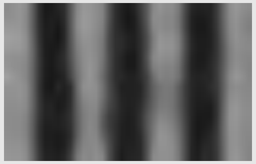
1) **Shape of compensation**
   - Defect characteristics
     - Only AIMS™ EUV provides aerial imaging information
   - Defect position w.r.t. features
     - AFM or AIMS™ EUV
   - Imaging conditions
     - Provided by AIMS™ EUV

2) **Placement of compensation**
   - AFM currently utilized
   - SEM is limited

5 nm pit defect



Invisible to top-down SEM | Clearly visible in AFM

Compensation repair shape	Illumination conditions	Simulation (-100 nm defocus)	Wafer print (-100 nm defocus)
	Incorrect illumination conditions used for shape calculation		
	Correct illumination conditions used for shape calculation		

Waiblinger, M., et al, "Ebeam based mask repair as door opener for defect free EUV masks," Proc. SPIE 8522, 85221M (2012).

AIMS™ EUV provides ALL information required for compensational repair calculations

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Summary

New challenges and considerations associated with photomask defectivity and repair are present with EUV

- Blank inspection and pattern shifting are closely tied to review and repair
  - AIMS™ EUV must verify pattern shifting was successful

- Shadowing effects introduce new restrictions
  - Die-to-die references for inspection and repair must be considered
  - Deposition repair height requirements are stringent

- Compensation repairs depend on defect characteristics and illumination conditions
  - Only AIMS™ EUV can provide this complete picture

Acknowledgements

The authors would like to thank the following for their contributions:

Dr. Renzo Capelli and Dr. Frederik Blumrich from Carl Zeiss SMS
SEMATECH
EMI member companies for their support

References

1. Waiblinger, M., Bret, T., Jonckheere, R. and Van den Heuvel, D., "Ebeam based mask repair as door opener for defect free EUV masks," Proc. SPIE 8522, 85221M (2012).
2. Pang, L., Satake, M., Li, Y., Hu, P., Peng, D., Chen, D. and Tolani, V., "EUV multilayer defect compensation (MDC) by absorber pattern modification, film deposition, and multilayer peeling techniques," Proc. SPIE 8679, 86790U (2013).
3. Elayat, A., Thwaite, P. and Schulze, S., " EUV mask blank defect avoidance solutions assessment," Proc. SPIE 8522, 85221W (2012).
4. Yan, P., Liu, Y., Kamna, M., Zhang, G., Chen, R. and Martinez, F., "EUVL Multilayer Mask Blank Defect Mitigation for Efect-free EUVL Mask Fabrication," Proc. SPIE 8322, 83220Z (2012).
5. Garetto, A., Peters, J., Perlitz, S., Matejka, U., Hellweg, D. and Weiss, M., "Status of the AIMS(TM) EUV Project," Proc. SPIE 8522, 852220 (2012).
6. Rastegar, A., and Jindal, V., "EUV Mask Defects and Their Removal," Proc. SPIE 8352, 83520W (2012).
7. M. Goldstein and P. Naulleau, Opt. Express 20(14), 15752-15768 (2012).
8. H. J. Kwon, “EUVL Defect Printability: An Industry Challenge,” SEMATECH Symposium Korea, 2011.
9. Jindal, V., Kearney, P., Antohe, A., Godwin, A., John, A., Teki, J., Harris-Jones, J., Stinzianni, E., and Goodwin, F., "Challenges in EUV mask blank deposition for high volume manufacturing," Proc. SPIE 8679, 86791D (2013).
10. Amano, T., and Terasawa, T., "Propagation of surface topography of EUV blank substrate through multilayer and impact of phase defect structure on wafer image," Proc. SPIE 8679, 86791P (2013).
11. Malloy, M., “12th Annual Mask Industry Survey,” BACUS Symposium, Monterey, CA, 2013.
12. Teki, R., John-Kadaksham, A., Ma, A., Goodwin, F., Yatsui, T., Ohtsu, M., Hariprasad, A., Lagudu, U., Babu, S., Dumas, P. and Jenkins, R., "Material- and polishing induced defectivity on EUV mask substrates," EUVL Symposium Brussels (2012).
13. Amano, T., Murachi, T., Yamane, T., Arisawa, Y., and Terasawa, T., "Impact of the phase defect structure on an actinic dark-field blank inspection signal and wafer printability," Proc. SPIE 8322, 832234 (2012).

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