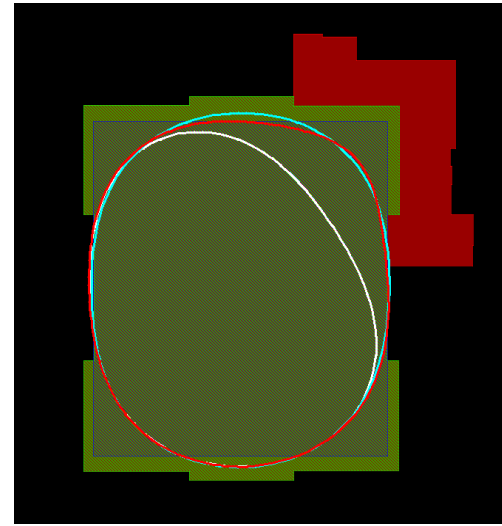
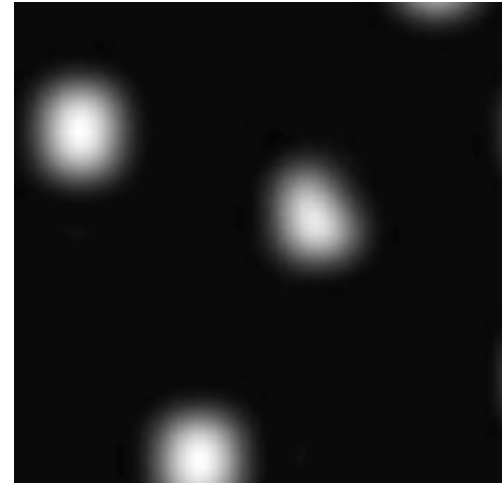
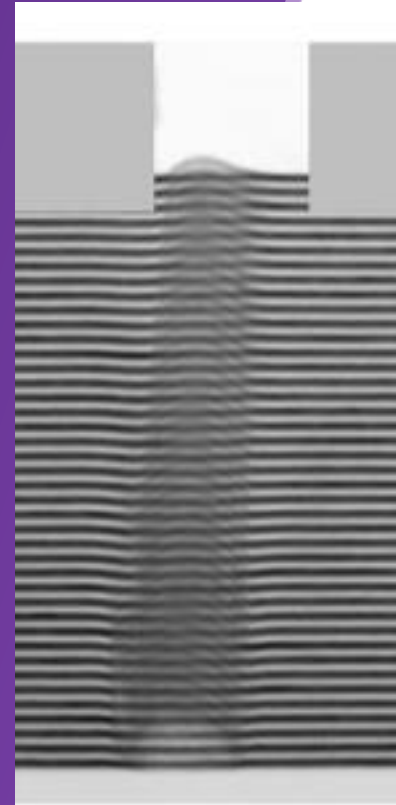


EUV multilayer defect repair for advanced masks using rigorous aerial image-based modeling

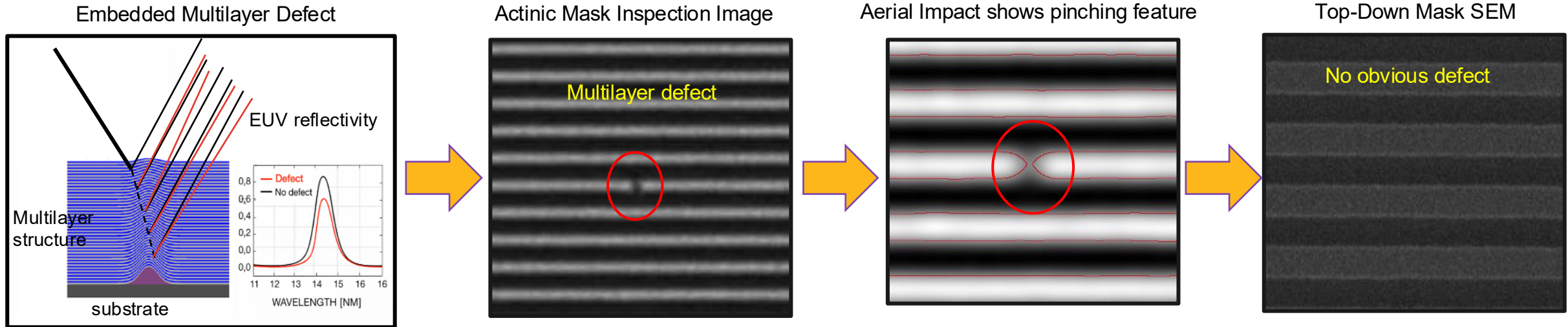
Kyoung Min Yoo¹, Andrew Dawes¹, Joseph Rodriguez²,
Andrew Elliott², Rafaela Brinn², Arvind Sundaramurthy²,
Safak Sayan², Guangming Xiao¹

¹ Synopsys Inc.; ² Intel Corporation



Motivation

- Embedded Multilayer Defects in EUV masks disrupt image formation, but are not visible on SEM

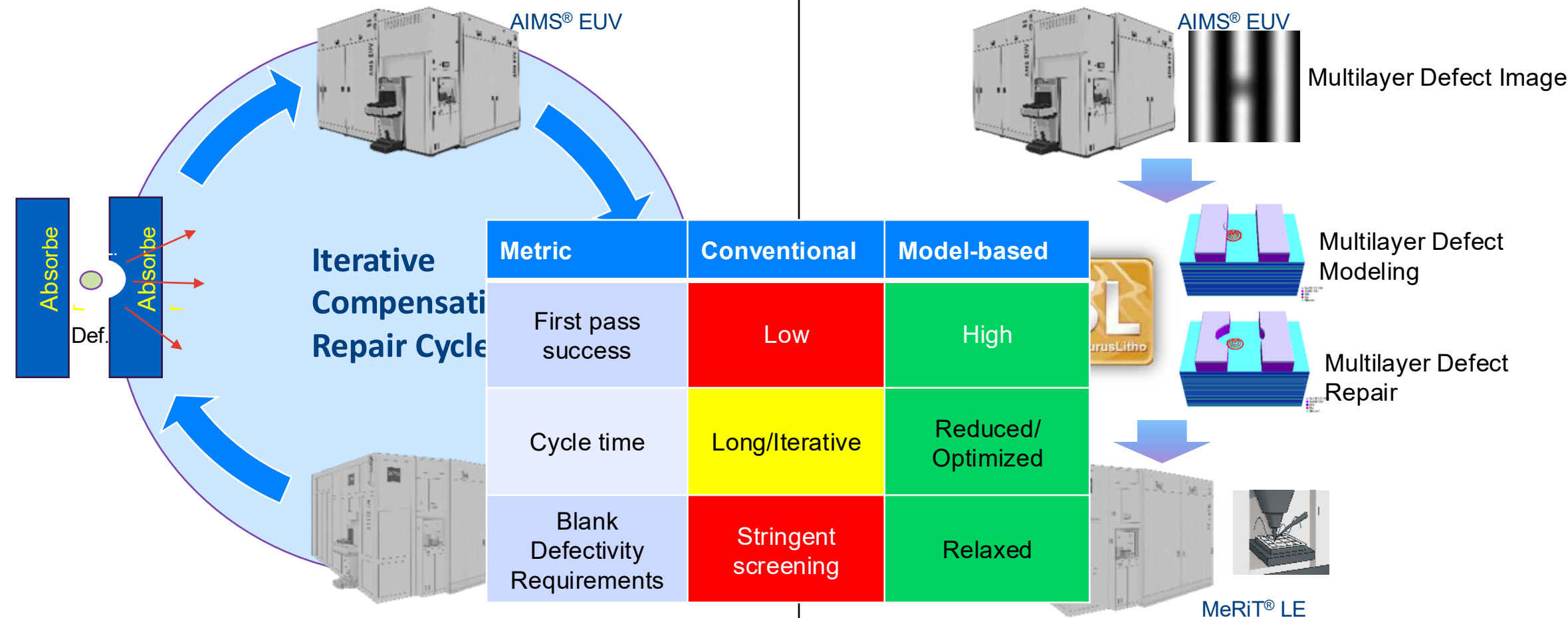


- Defect mitigation strategy for embedded Multilayer (ML) defects:
 - Defect avoidance with pattern shifting
 - Compensation repair by removing adjacent absorber to allow more reflected light

Compensation Repair of Adjacent Absorber to Allow More Reflected Light

- Conventional compensation repair is a manual iterative approach takes long time to repair with low first pass success.

- Model-based repair eliminates guesswork
- Use an accurate **multilayer defect model** and a localized absorber-modification with **model-based repair correction**

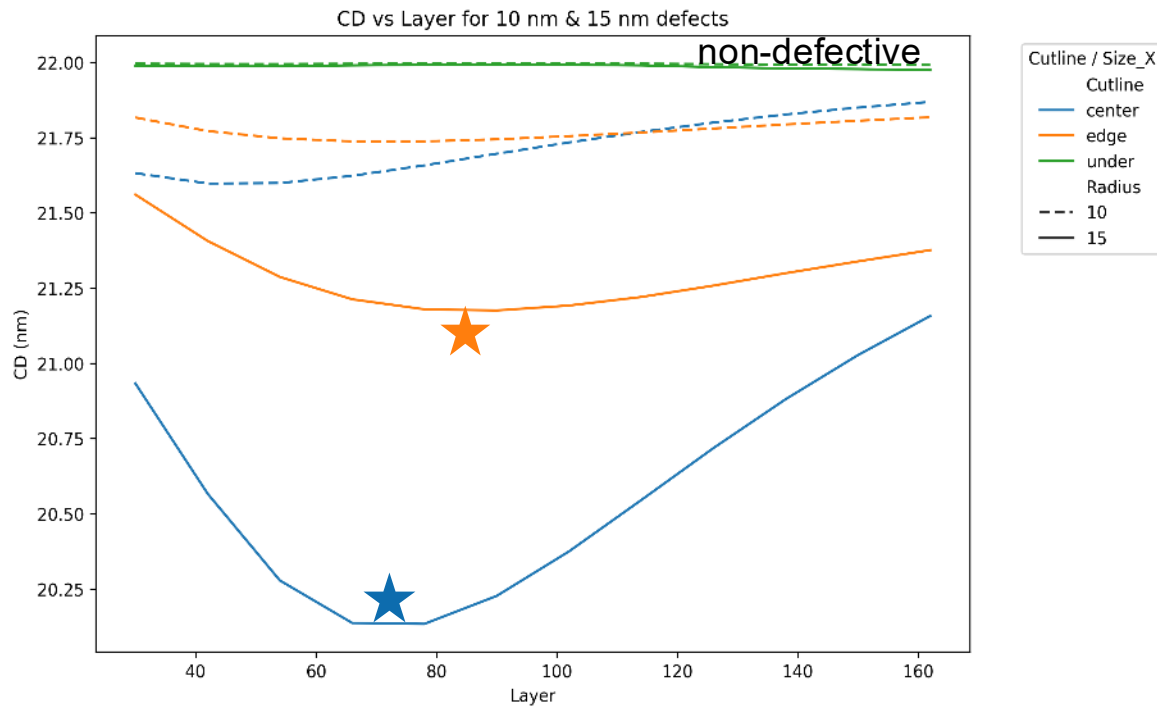


Outline

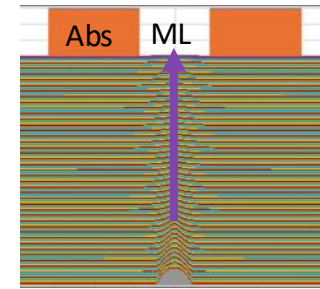
- Motivation for Repairing Multilayer Defects in EUV Photomasks
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Rigorous Simulation of Multilayer Defects under Different Conditions

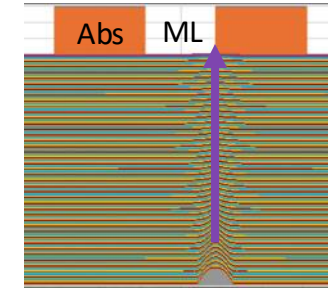
CD Impact vs. Depth for ML Defects



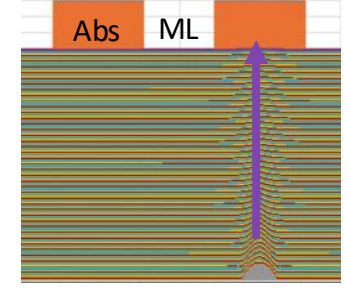
Position



Center

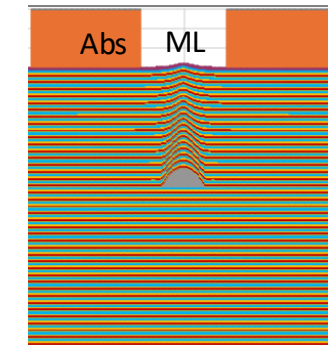


Edge



Under

Depth



ML Top: Layer 0-30
Shallow: Layer >30
Middle: Layer >60
Deep: Layer > 90
Substrate: Layer 162

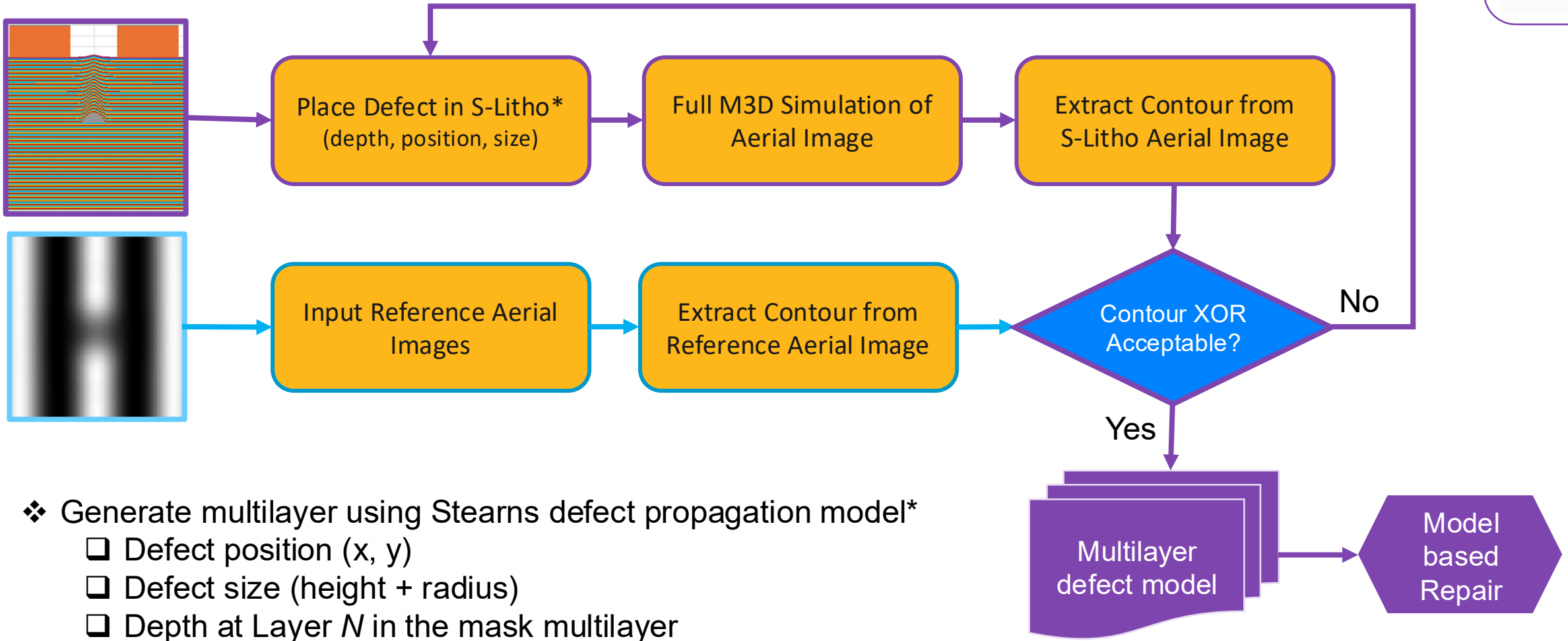
- Defect position and size are primary drivers for CD impact
- Mid-depth defects have more influence on CD compared to deeper and top defects.

“Multilayer defects: impact on aerial image through focus”

Andrew M. C. Dawes, Joseph Rodriguez, Rafaela Brinn, Safak Sayan, Arvind Sundaramurthy, Guangming Xiao
Photomask Technology 2025, Proc. SPIE 13687 (2025)

Rigorous Model Regression Flow for EUV Multilayer Defect

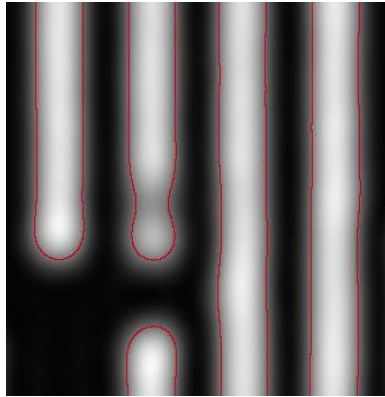
S-Litho Simulation approach: MultiLayer Defect Optimization (MLDO)



*D.G. Stearns, P.B. Mirkarimi, E. Spiller, "Localized defects in multilayer coatings", *Thin Solid Films*, Vol. 446(1), 2004, p 37-49

S-Litho Multilayer Defect Model Matches Experiment

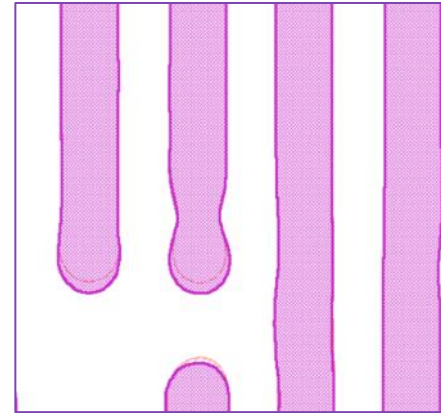
Center defect:



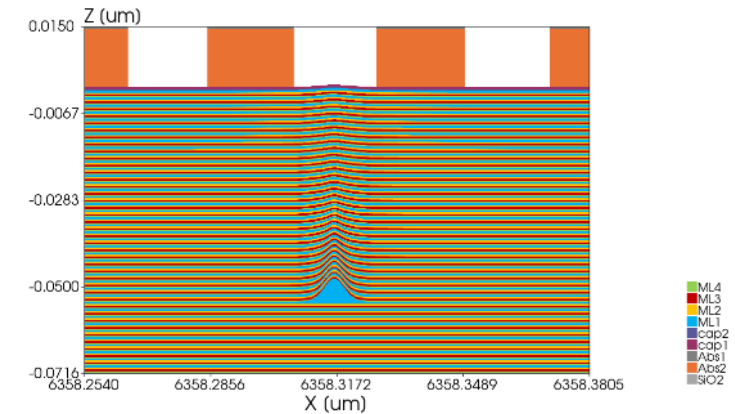
Reference



S-Litho simulated

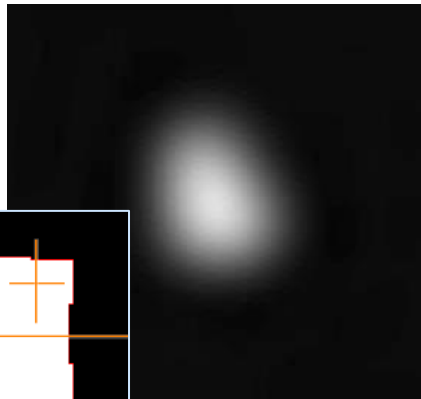


Overlay of contours

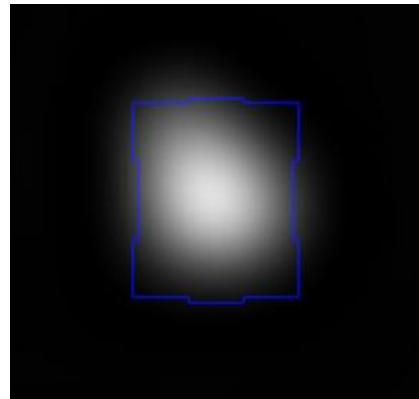


Multilayer defect from model regression

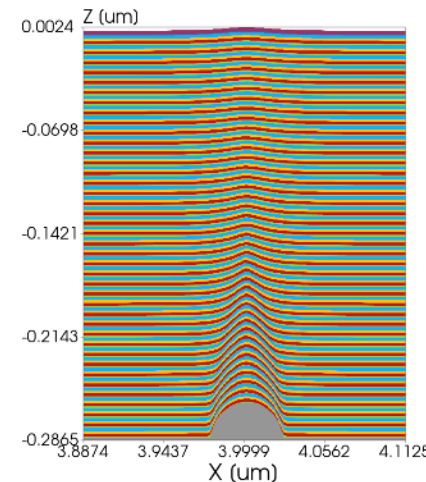
Corner defect:



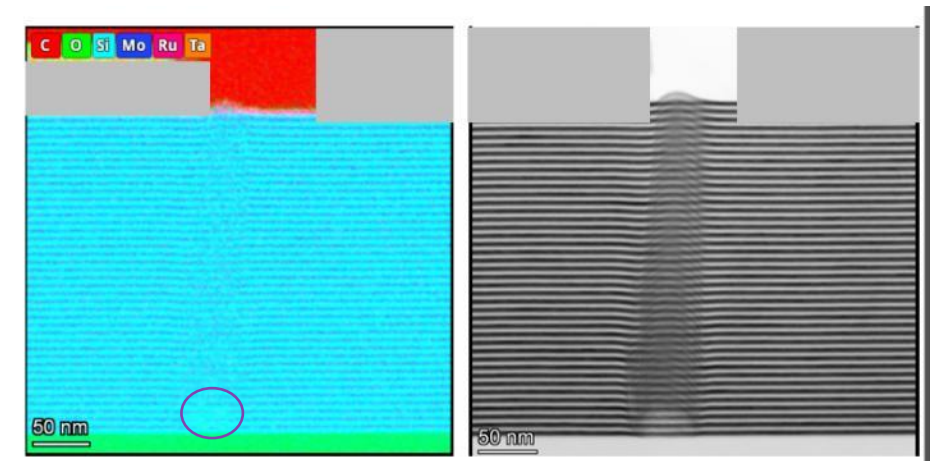
Reference



S-Litho simulated

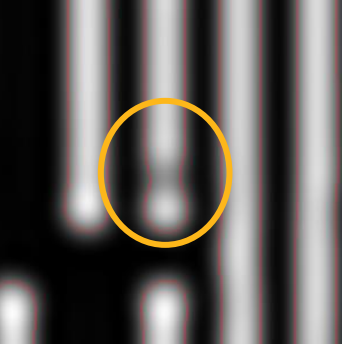


Multilayer defect model

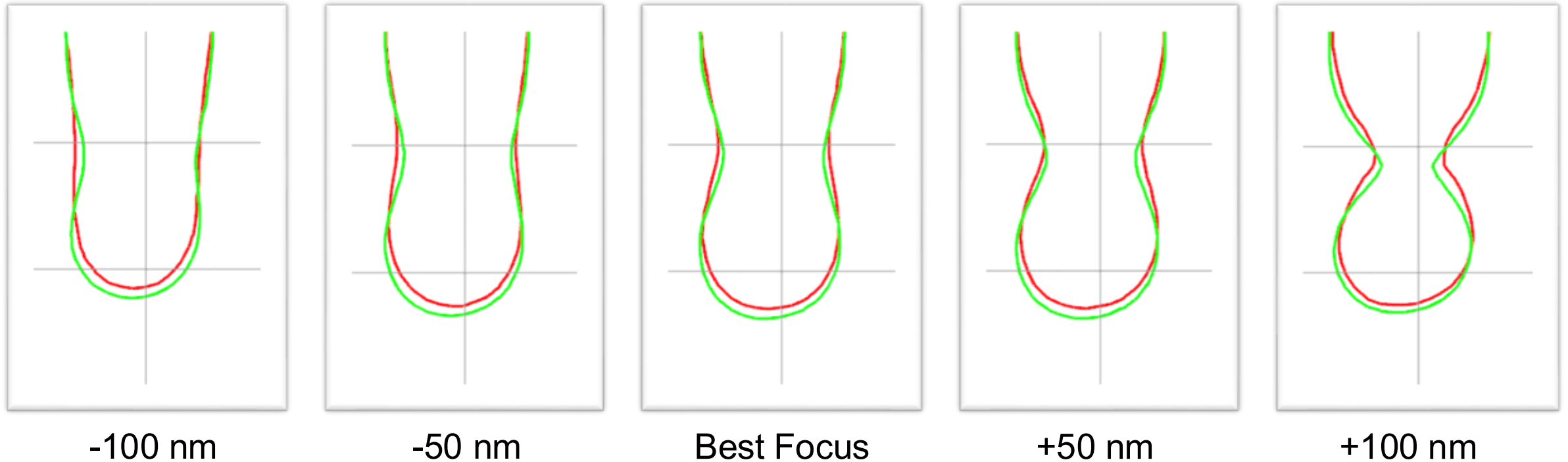


Cross section analysis of multilayer defect

Contour comparison, simulation vs AIMS®



S-Litho Aerial Image



S-Litho ML Defect Optimizer (MLDO): defect placement using 5 AIMS® focus planes

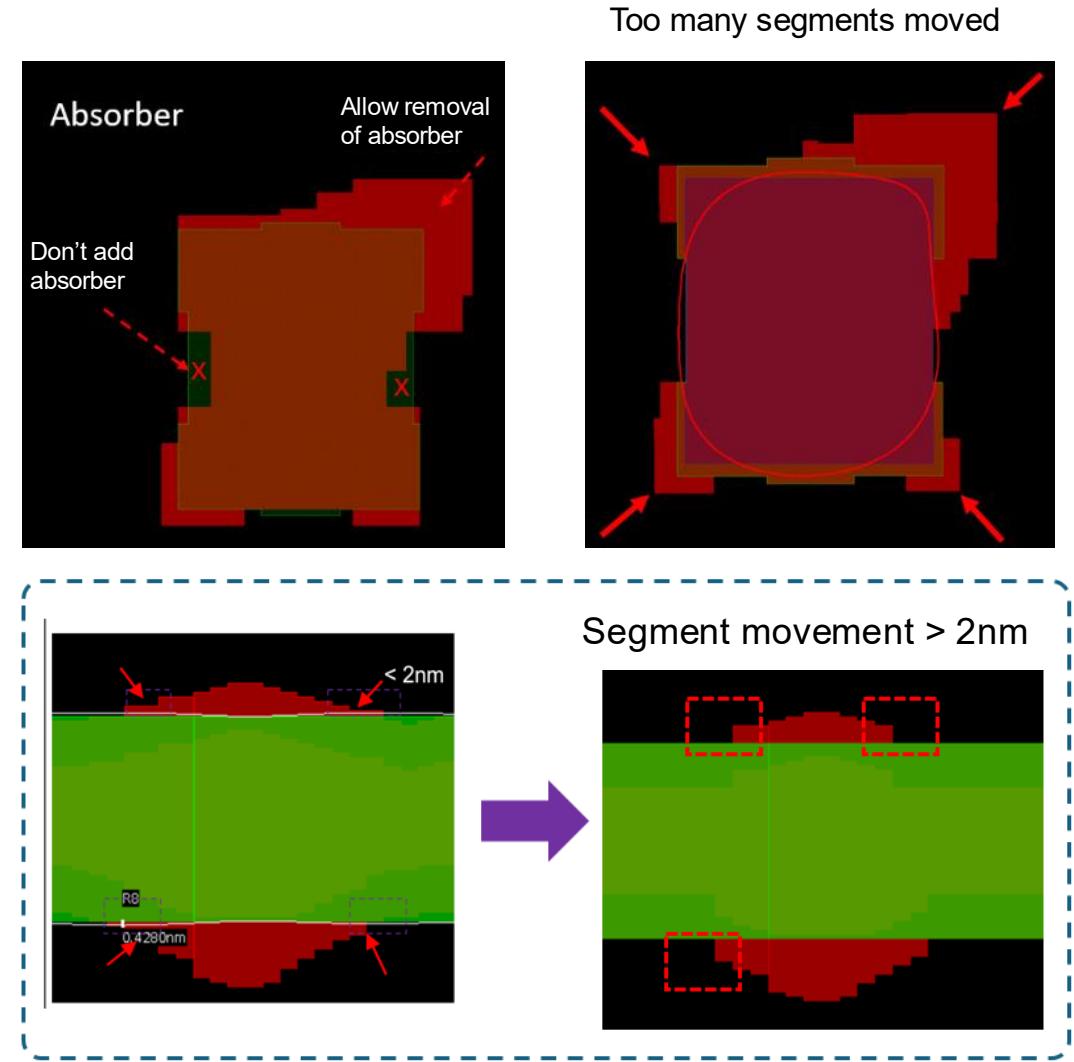


Outline

- Motivation for Repairing Multilayer Defects in EUV Photomasks
- EUV Multilayer Defect Modeling using S-Litho Simulation
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The Constraints and Requirements: Repair-Tool-Friendly Solution

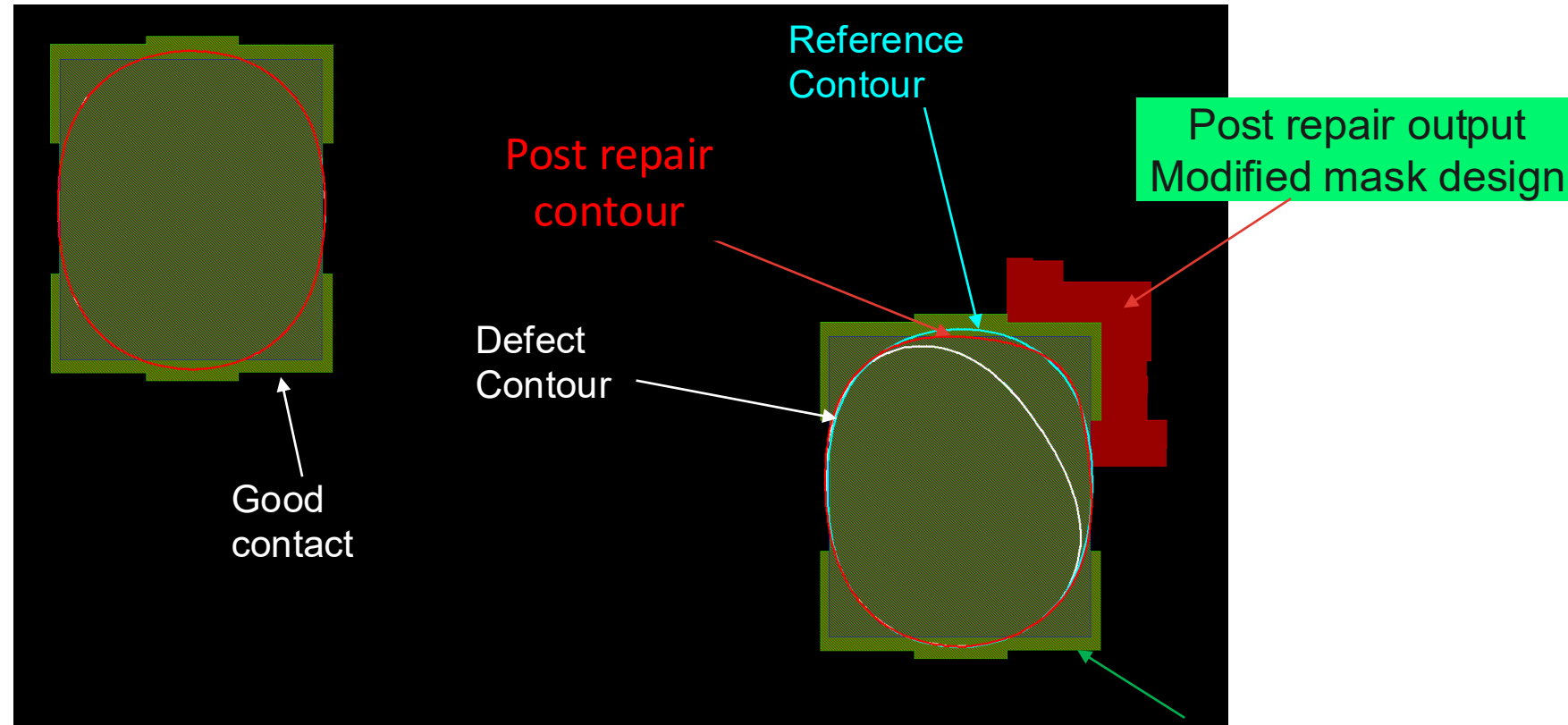
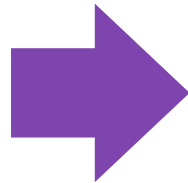
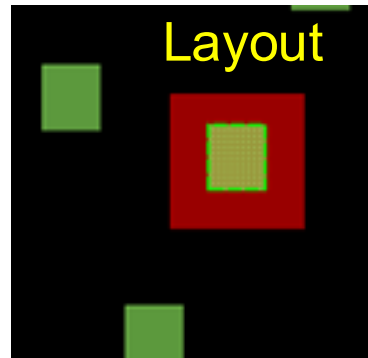
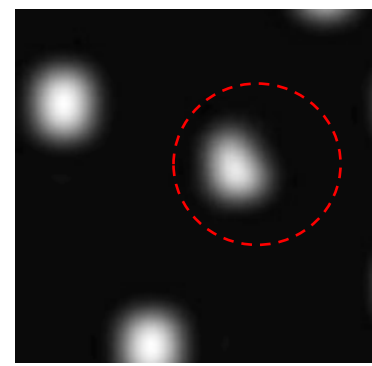
- ❑ Localized absorber modification only:
 - Repairs confined to a **small region**
- ❑ Repair strategy optimized for tool-specific capabilities:
 - Supports bi-directional edge movement, including additive repair and absorber removal.
 - Accommodates **single-edge movement** for tools with directional repair constraints.
- ❑ Minimum-movement requirement:
 - Each adjustment must be larger than the Repair tool's **minimum removable amount**.
- ❑ Simple mask shape
 - Avoid mask with **too many segments**



Ensures the repair solution mask shapes comply with repair-tool capability limits

Multilayer Defect Repair with Rigorous Model

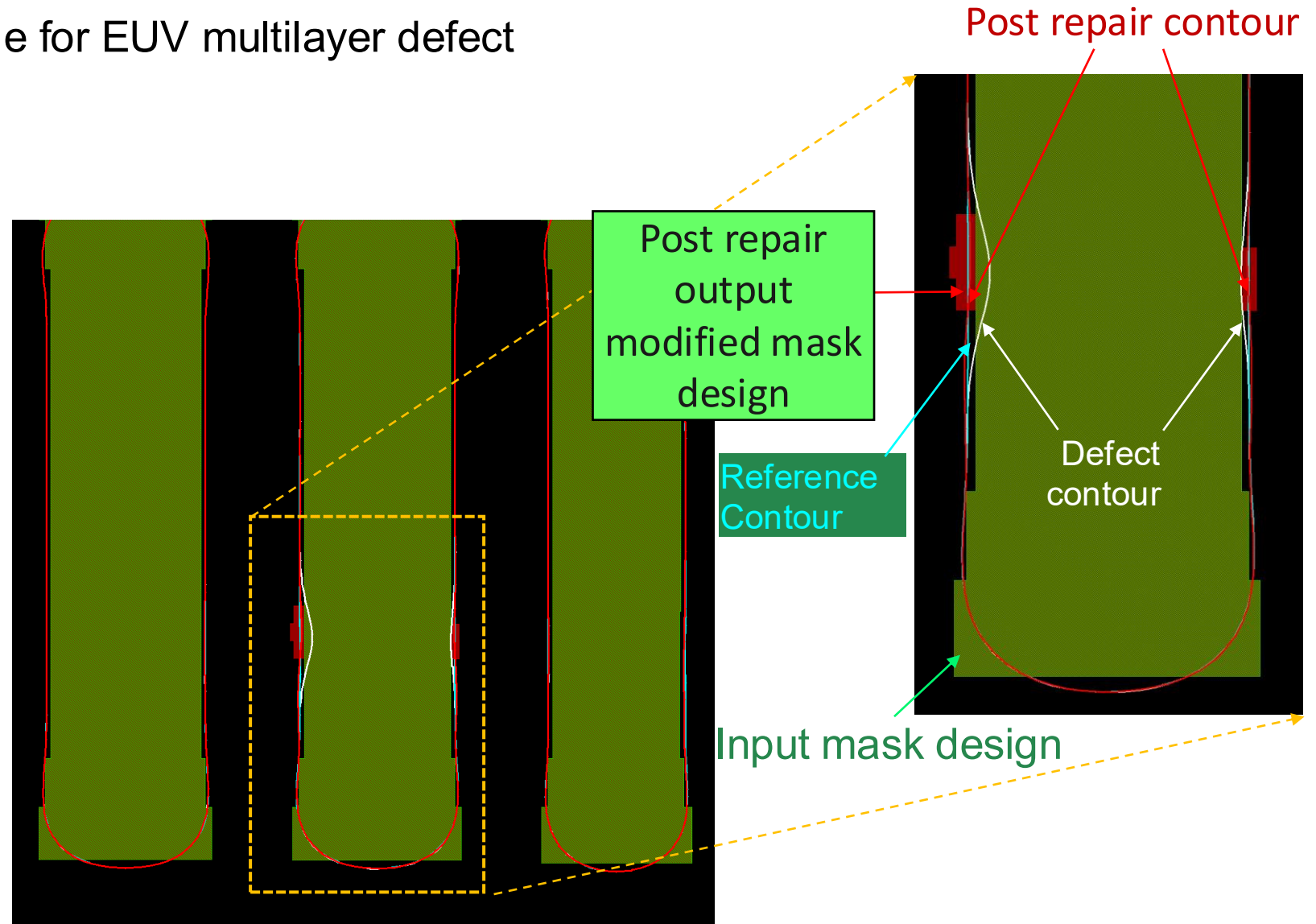
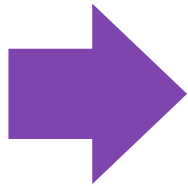
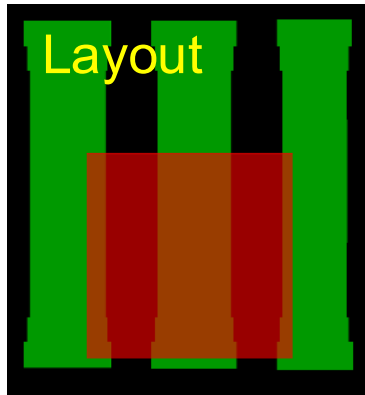
- Undersized contact example for EUV multilayer defect



Input mask design

Multilayer Defect Repair with Rigorous Model

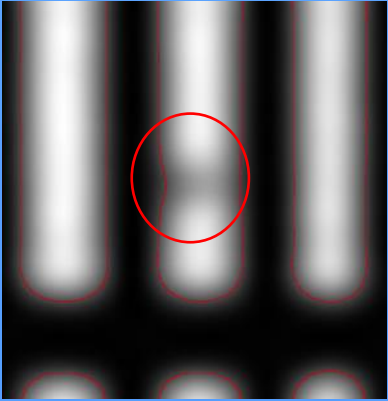
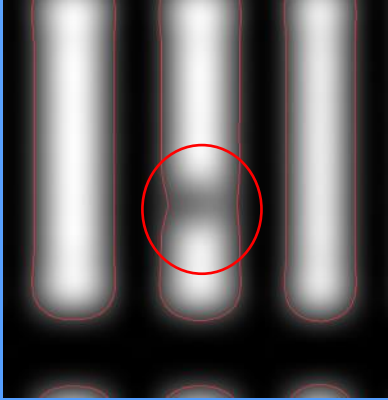
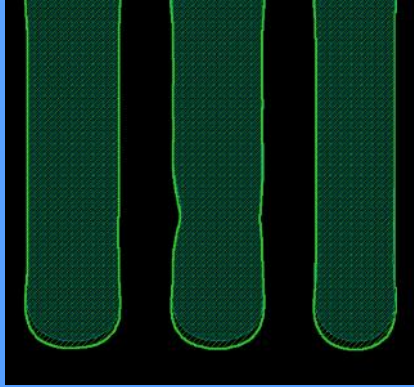
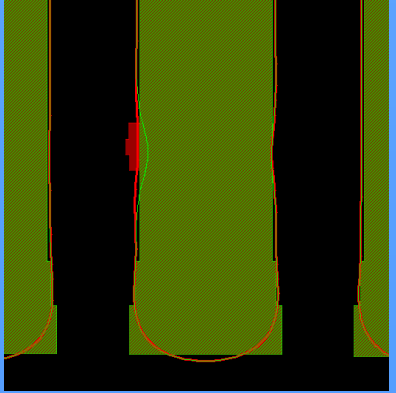
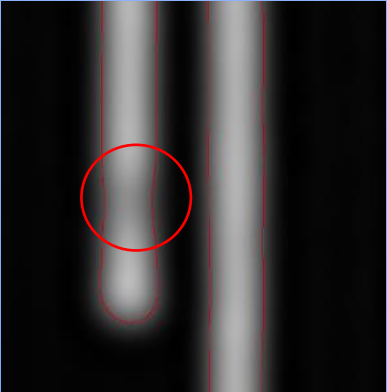
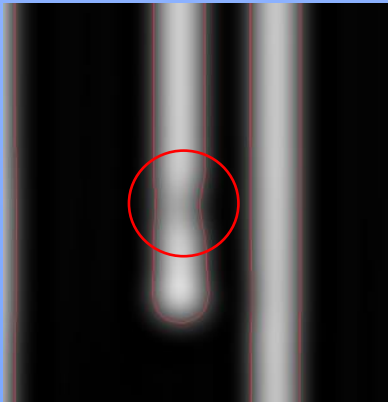
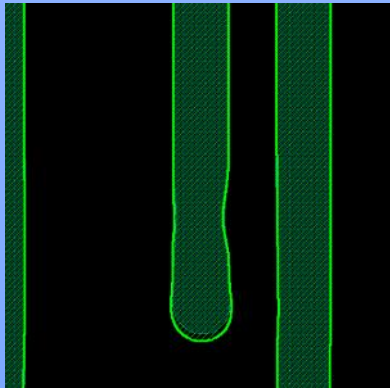
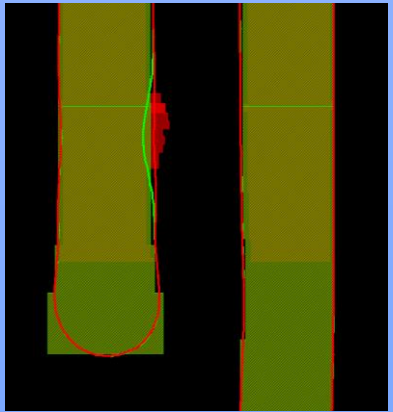
- 2-sided example for EUV multilayer defect



Outline

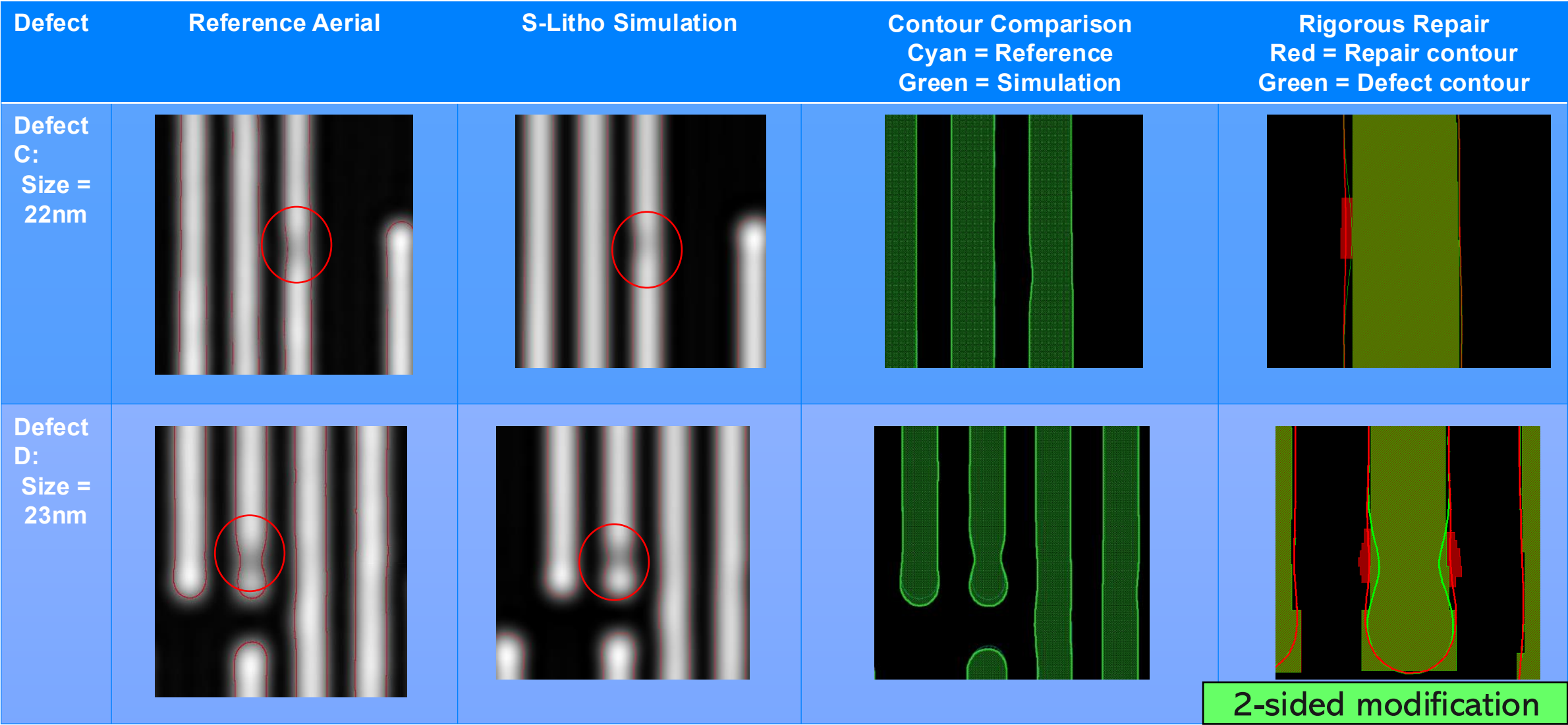
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Experimental Verification of Model-based Multilayer Defect Repair

Defect	Reference Aerial	S-Litho Simulation	Contour Comparison Cyan = Reference Green = Simulation	Rigorous Repair Red = Repair contour Green = Defect contour
Defect A: Size = 21nm				
Defect B: Size = 22nm				

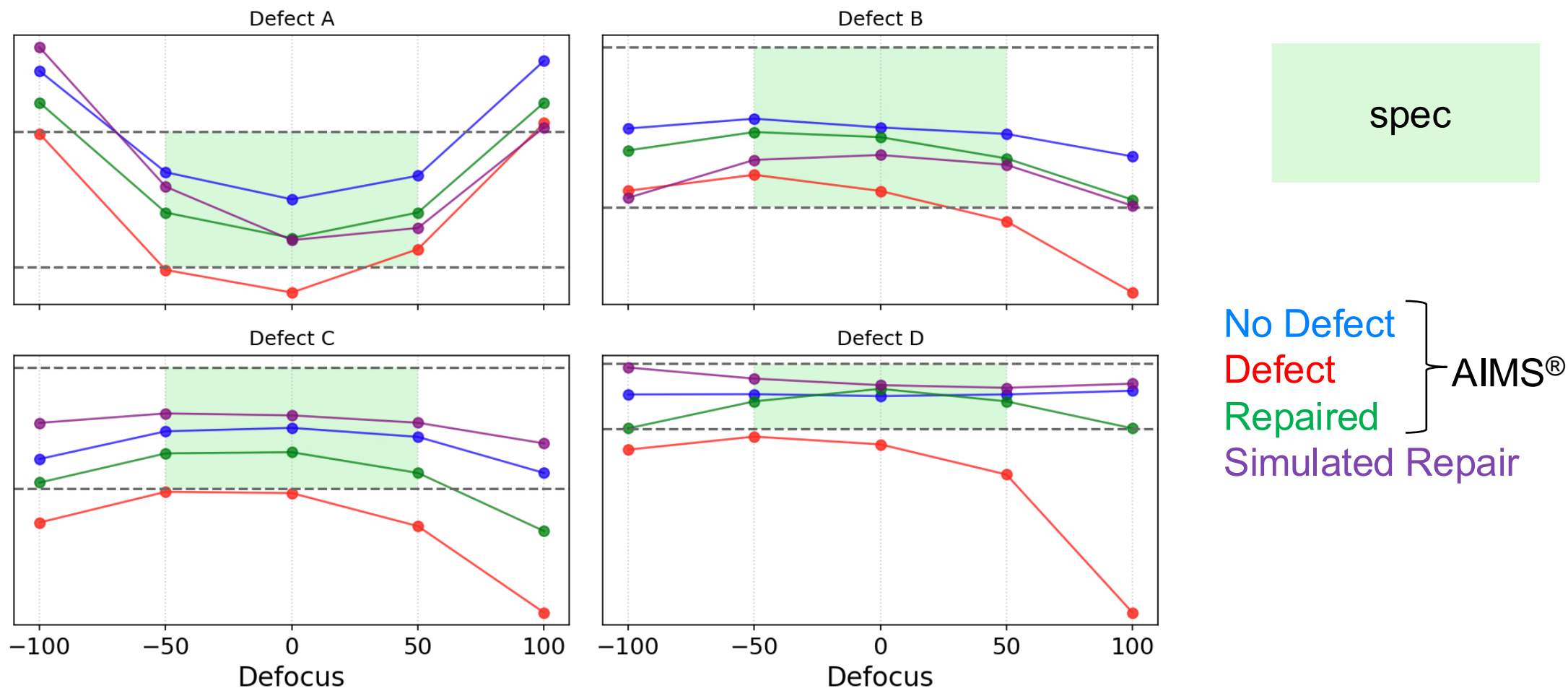
Joseph M. Rodriguez, Kyoung Min Yoo, Andrew M. C. Dawes, et al. "Rigorous modeling and repair of EUV multilayer defects", Proc. SPIE 13980, (2026)

Experimental Verification of Model-based Multilayer Defect Repair



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Overlay: model accurately predicts repair is on target thru-focus



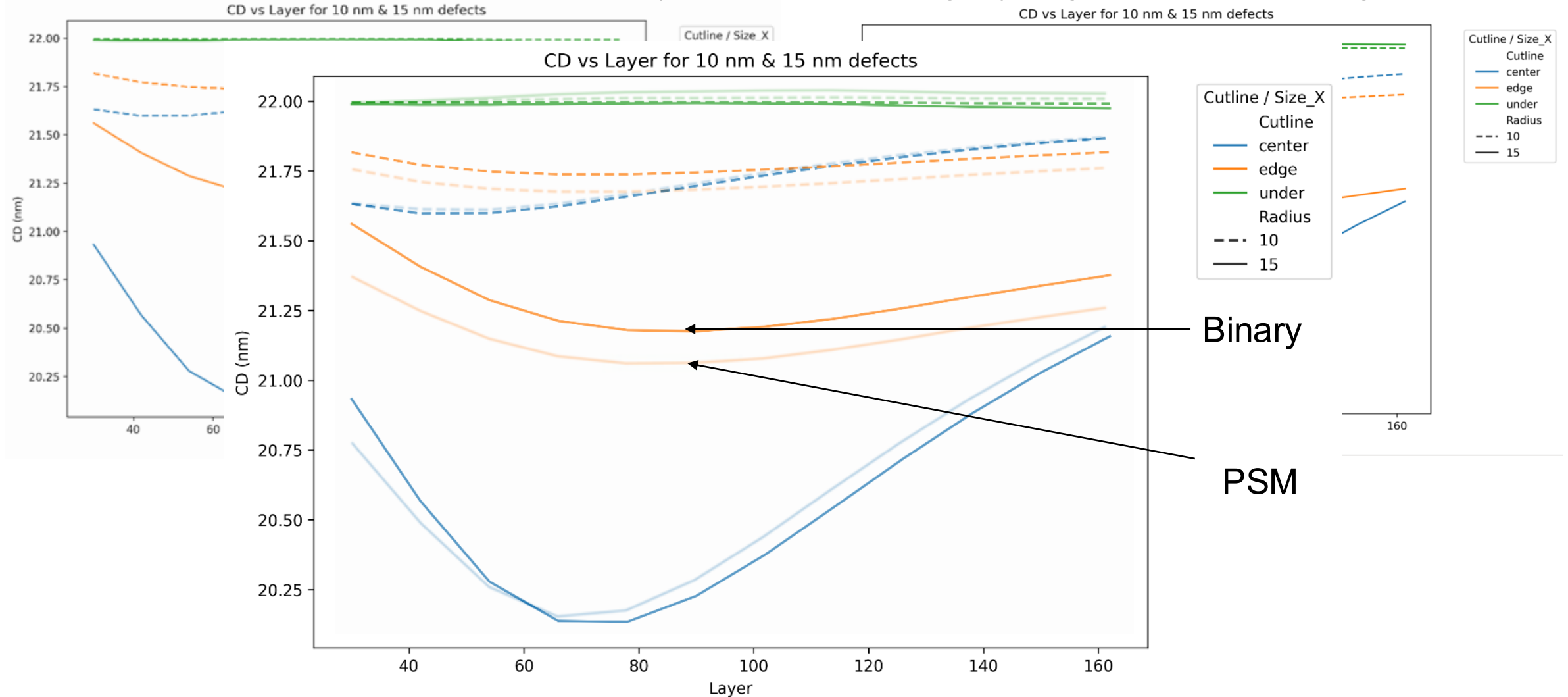
Joseph M. Rodriguez, Kyoung Min Yoo, Andrew M. C. Dawes, et al. "Rigorous modeling and repair of EUV multilayer defects", Proc. SPIE 13980, (2026)

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Comparison of Multilayer Defect Impact to EUV Binary and PSM masks

PSM mask has similar impact to binary mask but with slightly larger impact from edge defect



Comparison of Multilayer Defect Repair of Different Mask Types



Comparison of Multilayer Defect Repair of Different Mask Types



Summary

- Model-based compensation repair approach of EUV multilayer defects has substantially improved 1st pass success rate
- S-Litho enables model-based multilayer defect repair with accurate rigorous modeling
- Rigorous model-based repair solution has successfully been applied to real multilayer defects
- Repair-tool-friendly solutions generated for both Manhattan and Curvilinear masks
- PSM absorber: CD response is similar to binary mask on multilayer defects
- December 2026 release of S-Litho includes MultiLayer Defect Optimizer (MLDO)



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Thank you!