Strategy and Feasibility of Defect-free Mask Fabrication to Enable EUVL

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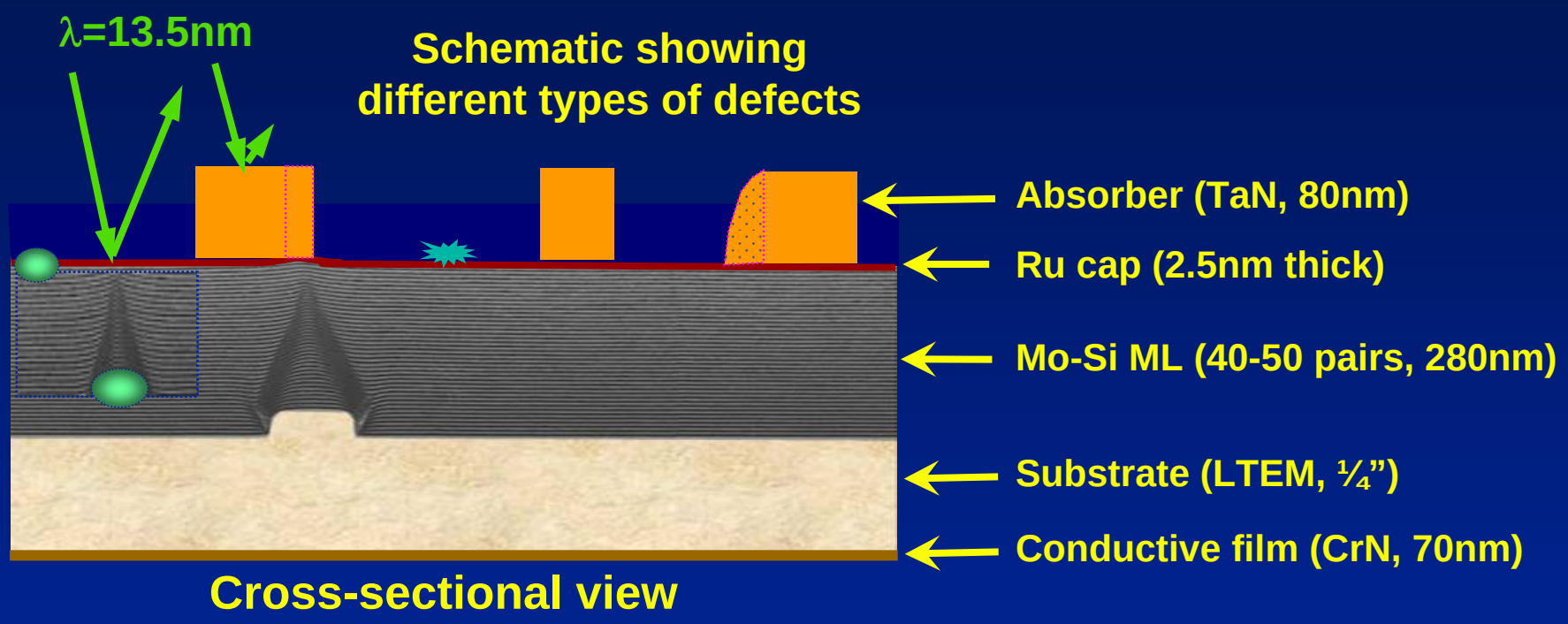
Outline

- Defect Types
- Quantitative defect analysis with existing tool set
- Achieving zero defect
- Summary

EUV Mask Defect Types

- Defects are more complex than those on 193nm mask



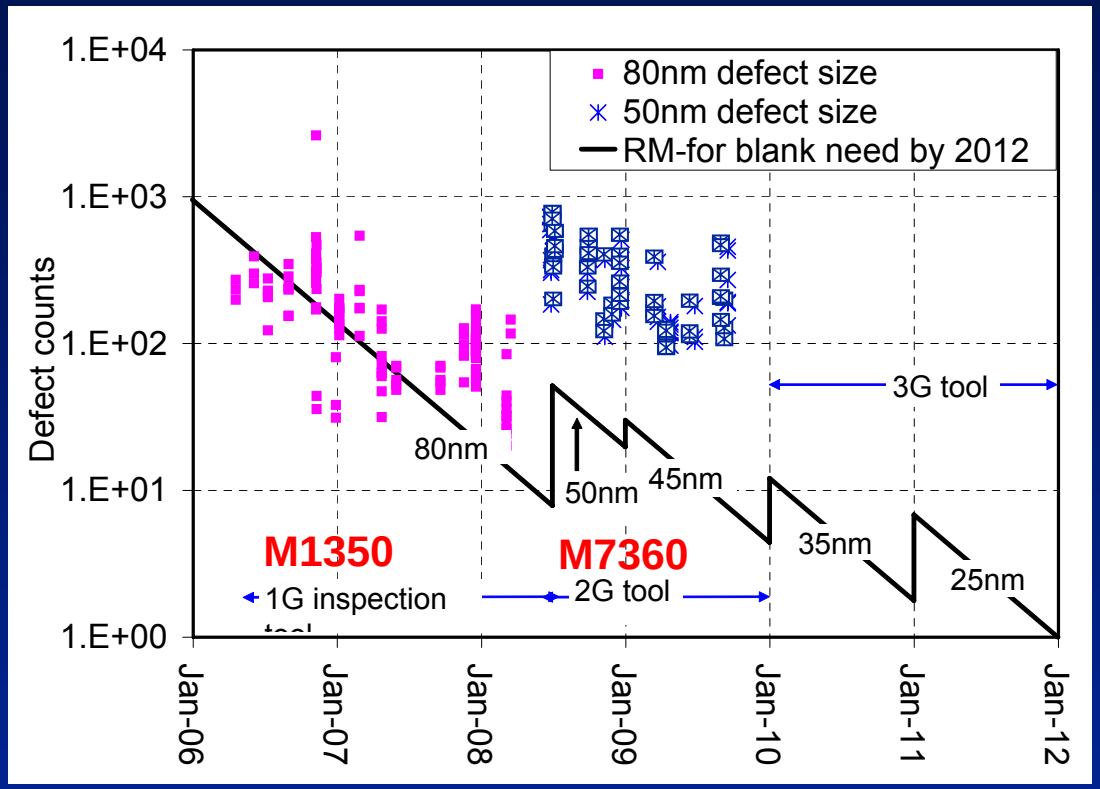
- EUV mask defects are complex
- Difficult to differentiate and disseminate by wafer print
- Necessary to measure directly on the mask

Mask Defect Challenges

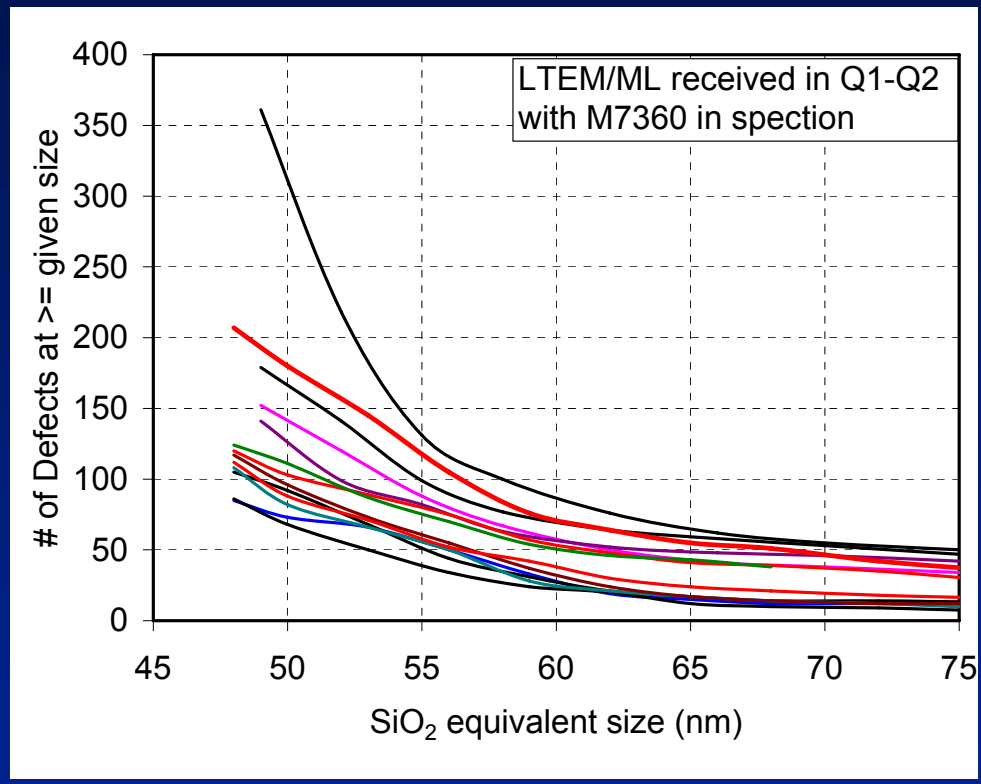
- **Achieving mask yield**
  - Detect every single defect above certain impact (e.g 10%ΔCD/CD)
  - Go after every defect
- **Quantitative defect analysis is necessary to develop best known method (process, tool, procedure) to enable mask yield**
  - Defect count, size, sources and disposition
  - Only way to enable effective/efficient defect reduction
- **Challenges in fast yield learning for EUV mask**
  - Blank defects: high count, majority with unknown property
  - No tool at mask shop to measure phase or amplitude, materials composition
  - Insufficient S/H infrastructure to keep mask clean for printing
- **We must progress with what we have today in lieu of the tool limitations**
  - Can we achieve zero defect to the limit of current tool capabilities?

Blank ML Defect Trend

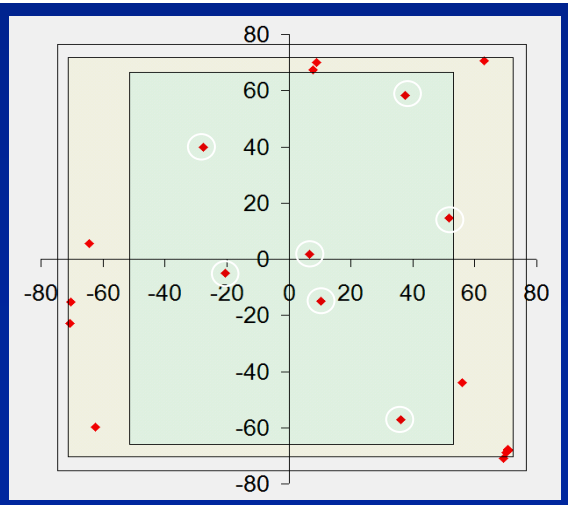
Total defect count



Size distribution



- ~100 defects @50nm+
- Best blank ~10 defects @70nm+
- Need ~100X defect reduction to reach current tool limit



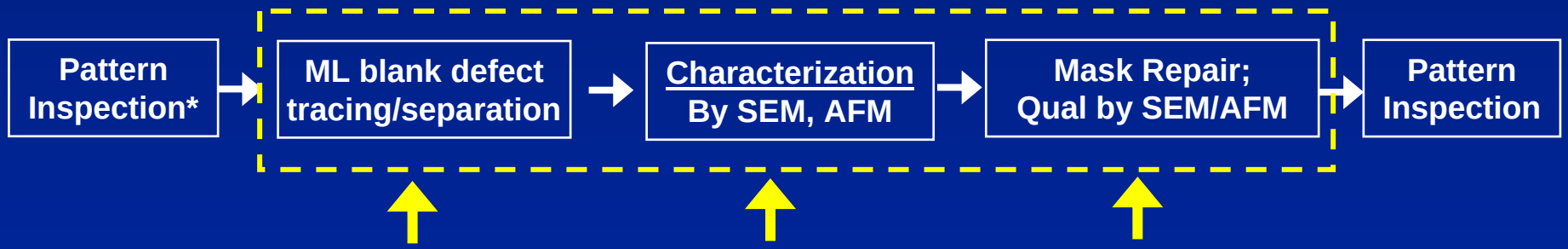
Strategy of Defect Study

- **Utilize full field mask as test vehicle:**
  - ML blank: full plate inspection to map out defects
  - Pattern mask: clear field to sensitize defects and maximize detection
- **Tools:**
  - Optimize current tool capability and develop BKM
  - Identify critical needs for HVM: Tools, process, procedure
- **Measurements – inspection and characterization metrology:**
  - Focus on direct measurements on mask (mask qualification is done at the mask shop, not at the wafer fab)
  - Verification with wafer print

Mask Defect Disposition Flow at Mask Shop

- **POR for 193nm mask**
  - All defects must pass AIMS in order to be dispositioned

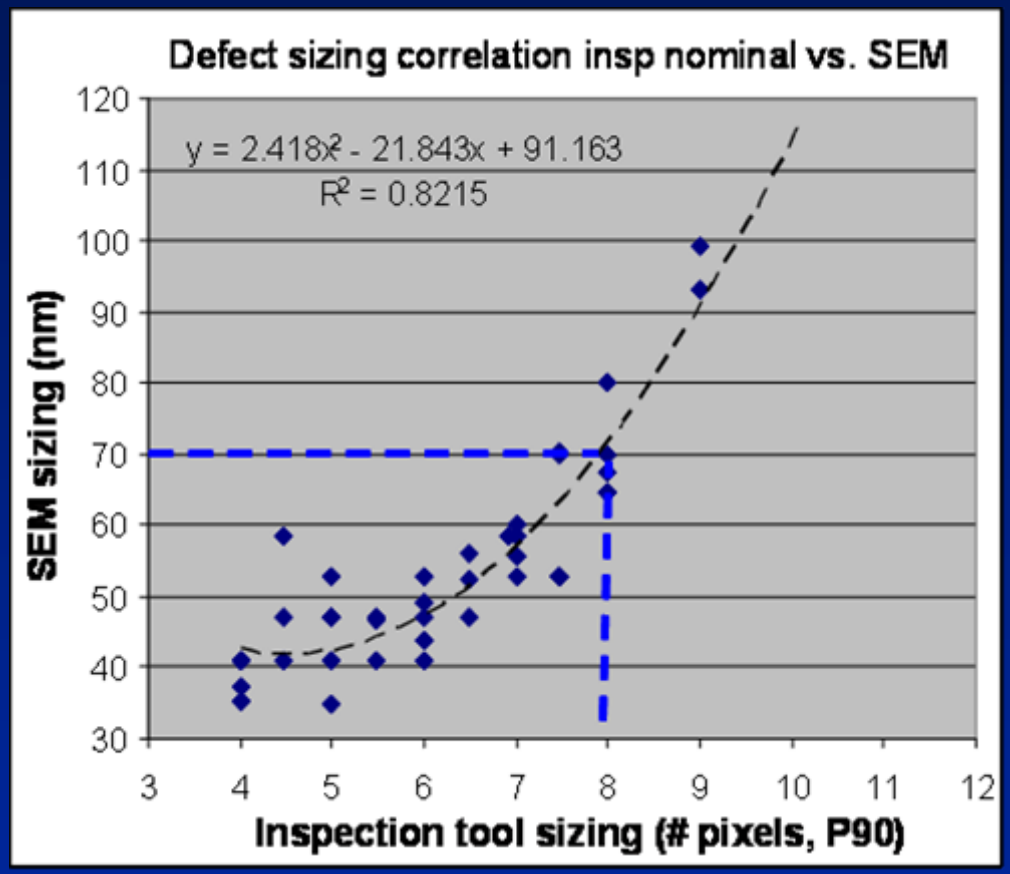
- **EUV mask, currently no AIMS**

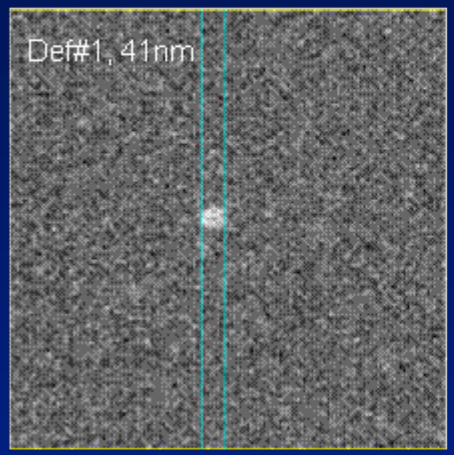


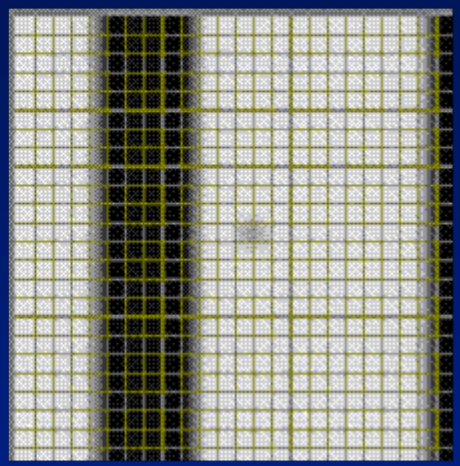
- **As a work-around without EUV AIMS, use physical tools – SEM, AFM, blank and pattern defect overlay**

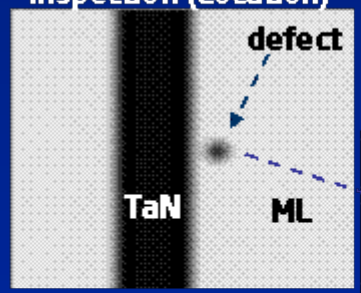
Pattern Inspection and Defect Sizing

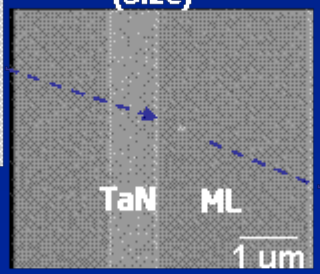
- **Defect sizing with SEM vs. pattern inspection tool**
  - Inspection tool does not size defects

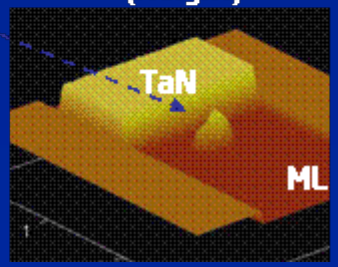










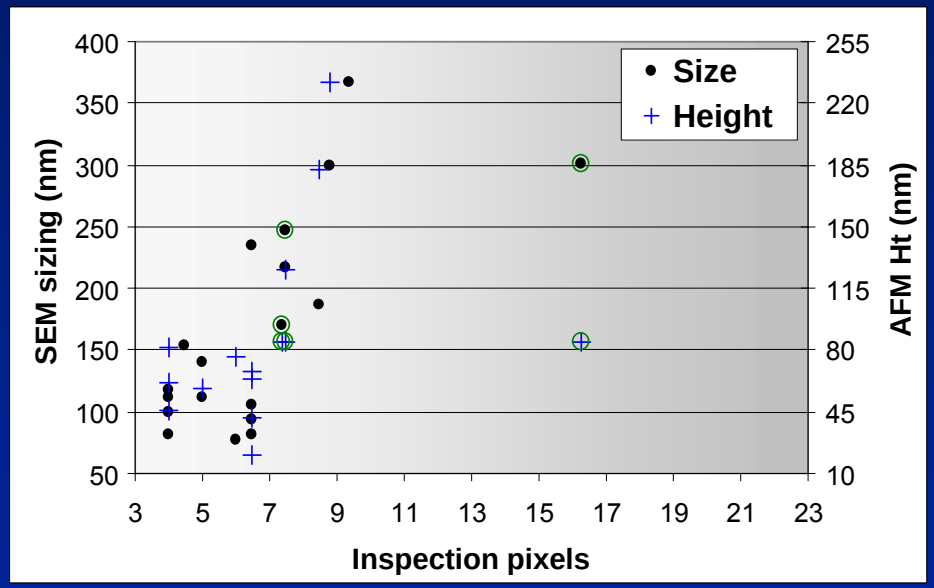


- **SEM and AFM are sufficient for <u>pattern</u> defect disposition with aid from printability modeling**

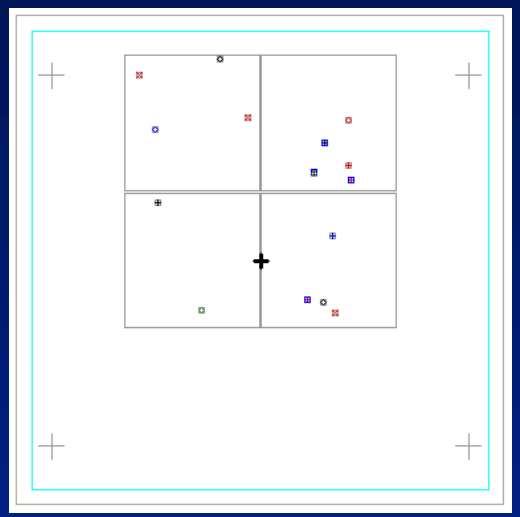
Automatic Defect Overlay for Defect Classification

- **Defect from pattern and blank**
  - 19 total defects from pattern inspection
  - 16 matched to ML blank defects
  - 3 are real pattern defects

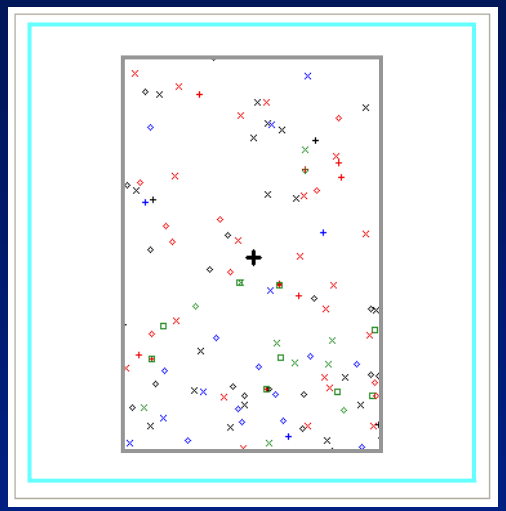
Defect size and height



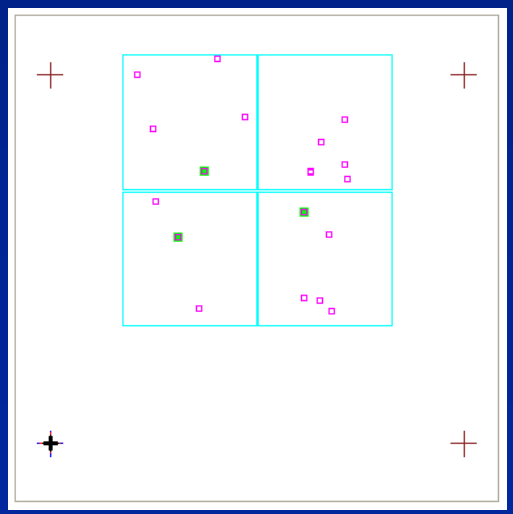
Pattern inspection 19 defects



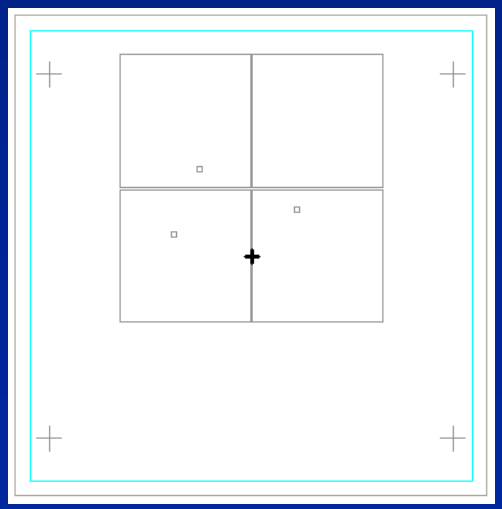
ML blank inspection ~100 defects



16 defects traced to ML blank



3 real absorber defects

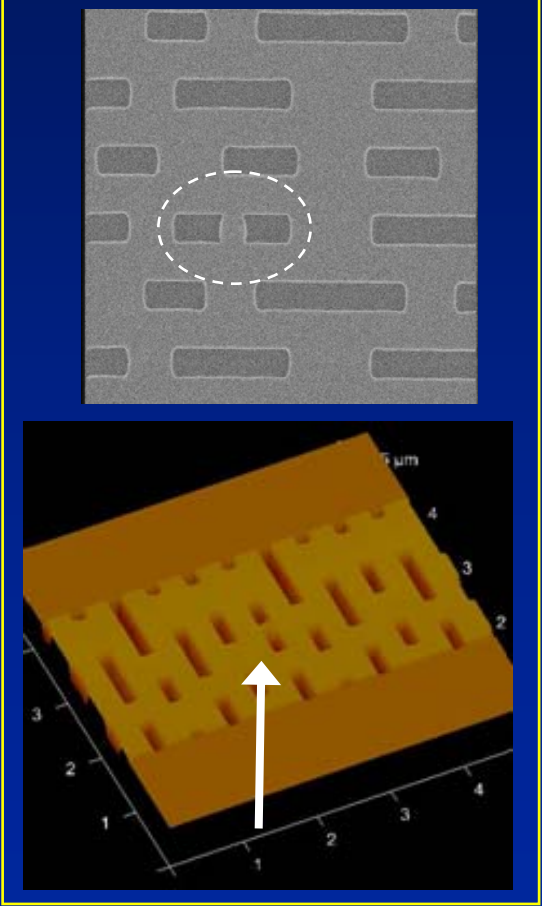


- **Pattern inspection detects most large blank defects (embedded particles)**

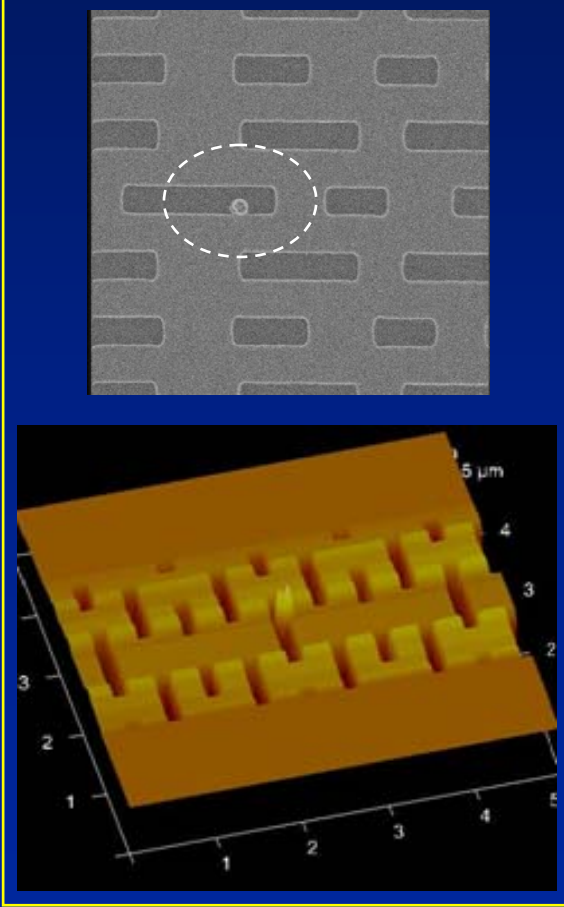
Assessing Potential Impact to Print

- Total of 19 total defects at pattern inspection

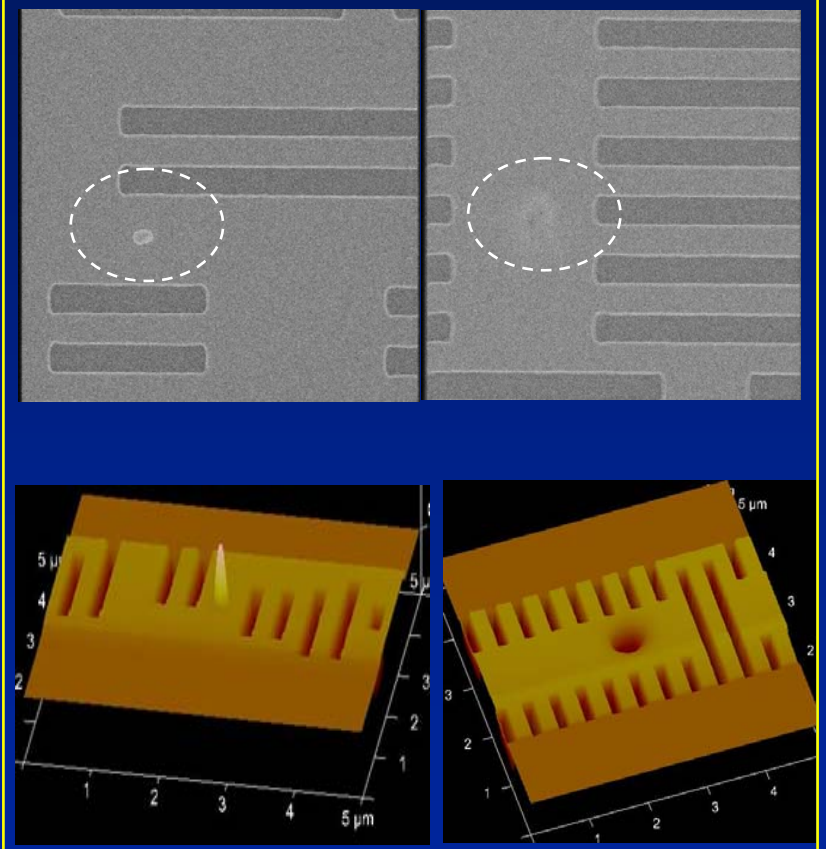
3 absorber defects are all repairable



9 of 16 ML blank defects are printable

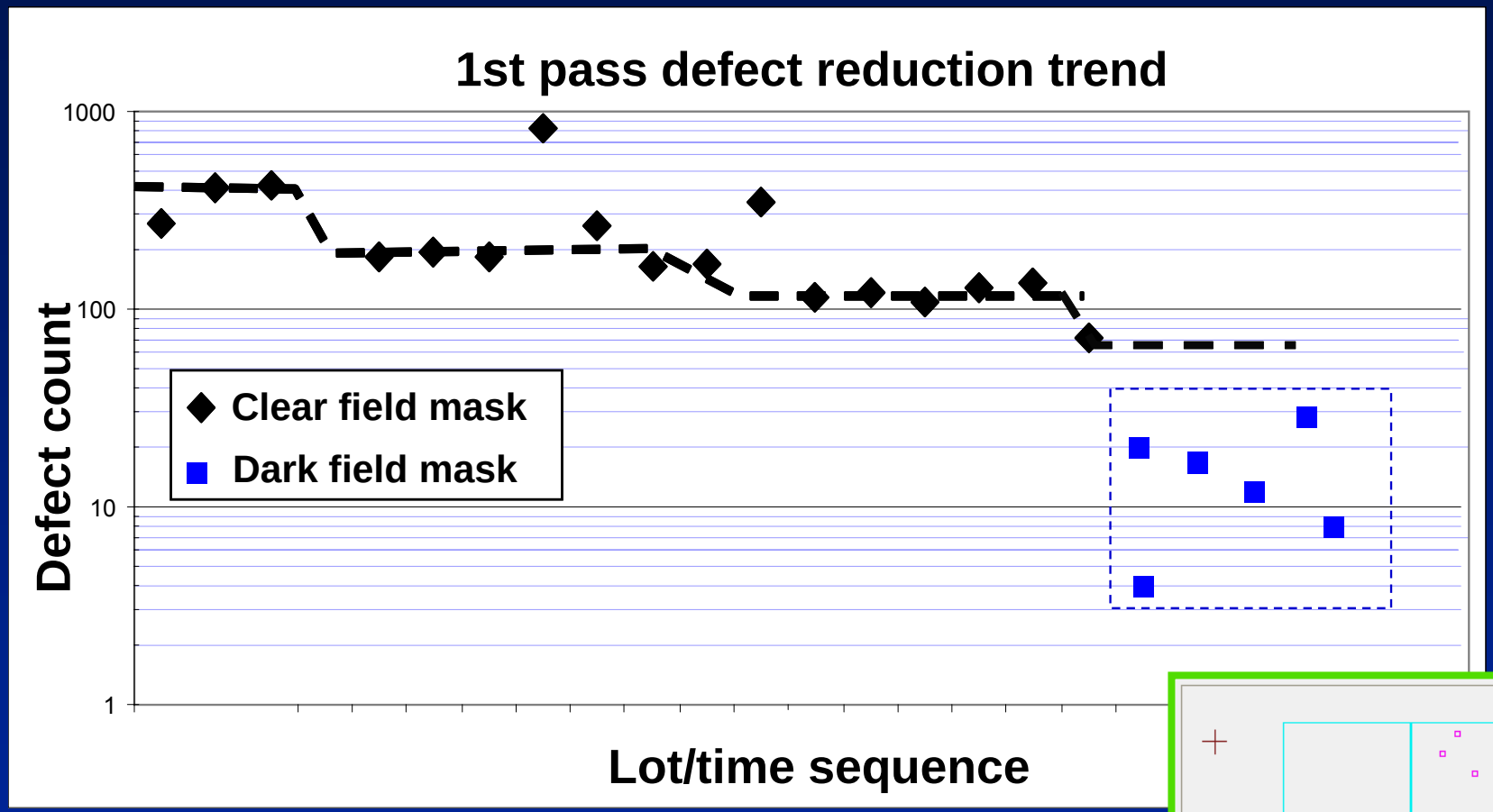


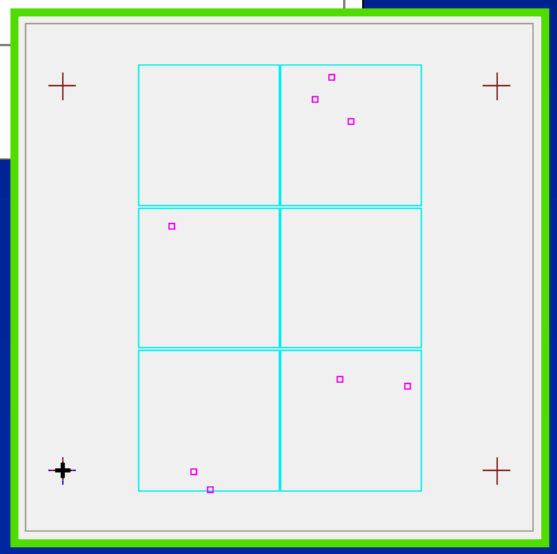
7 of 16 blank defects (covered by absorber)



- **Impact depends on location – Must eliminate every large defect**

Total Pattern Defect Reduction

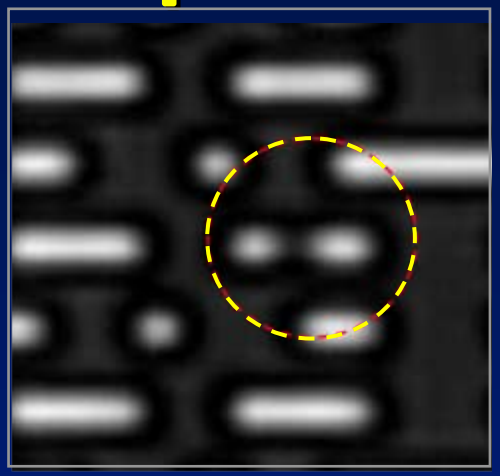


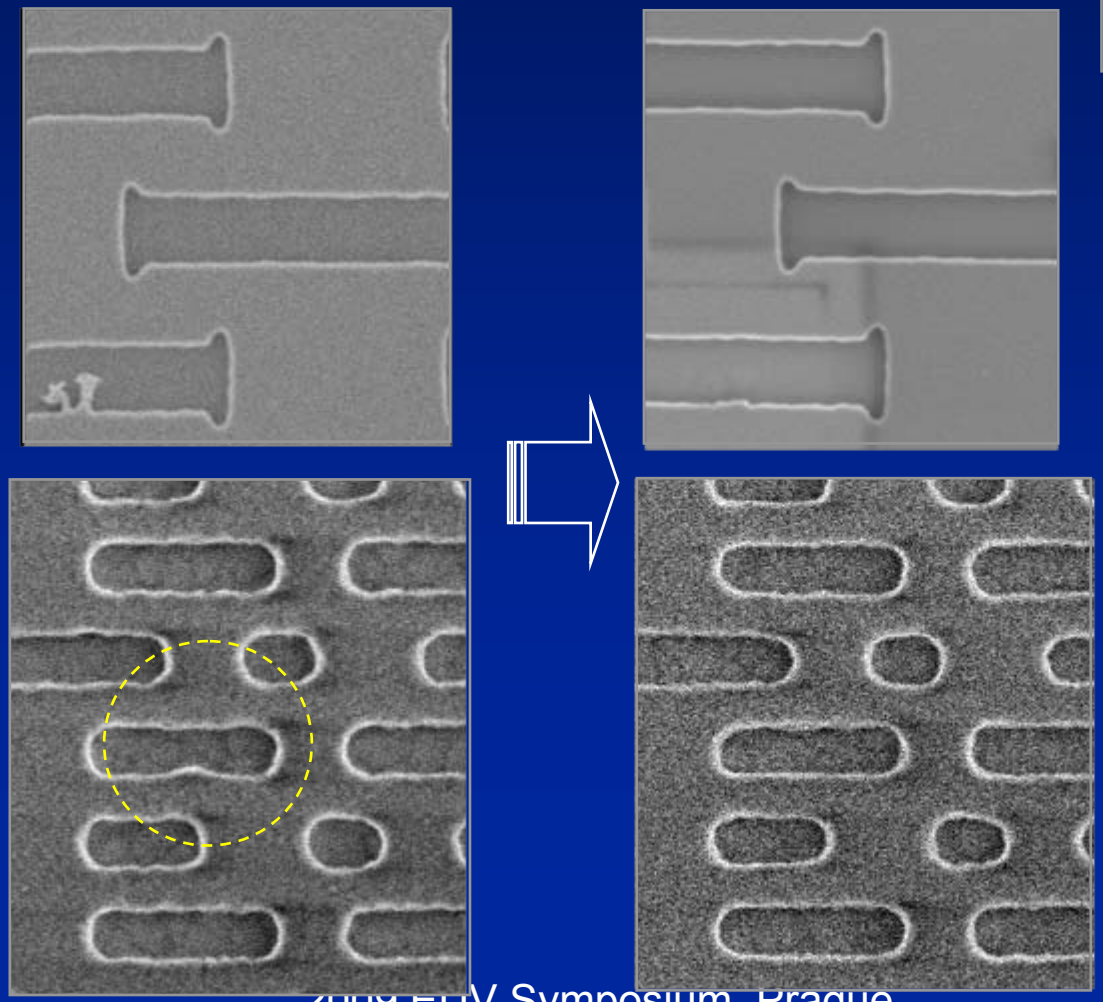


- >4X reduction in total defects >40nm
- Best achieved: 8 total defect >40nm

Achieving Zero Defect – Pattern Repair

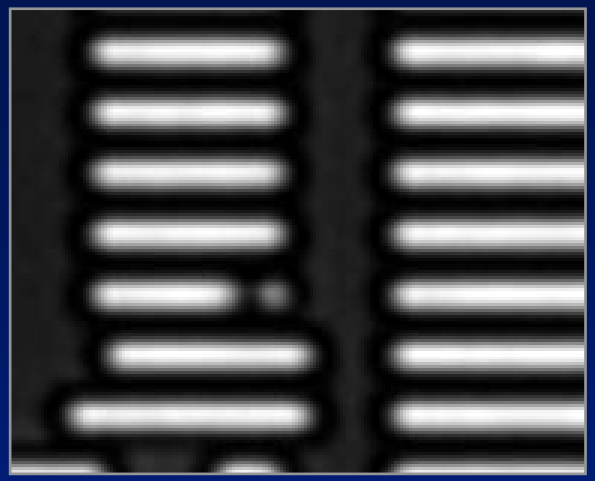
- Example 1: Defect caused 10% ΔCD/CD
- Fully repaired as by ADT print
- SEM + AFM sufficient for <u>pattern</u> repair validation

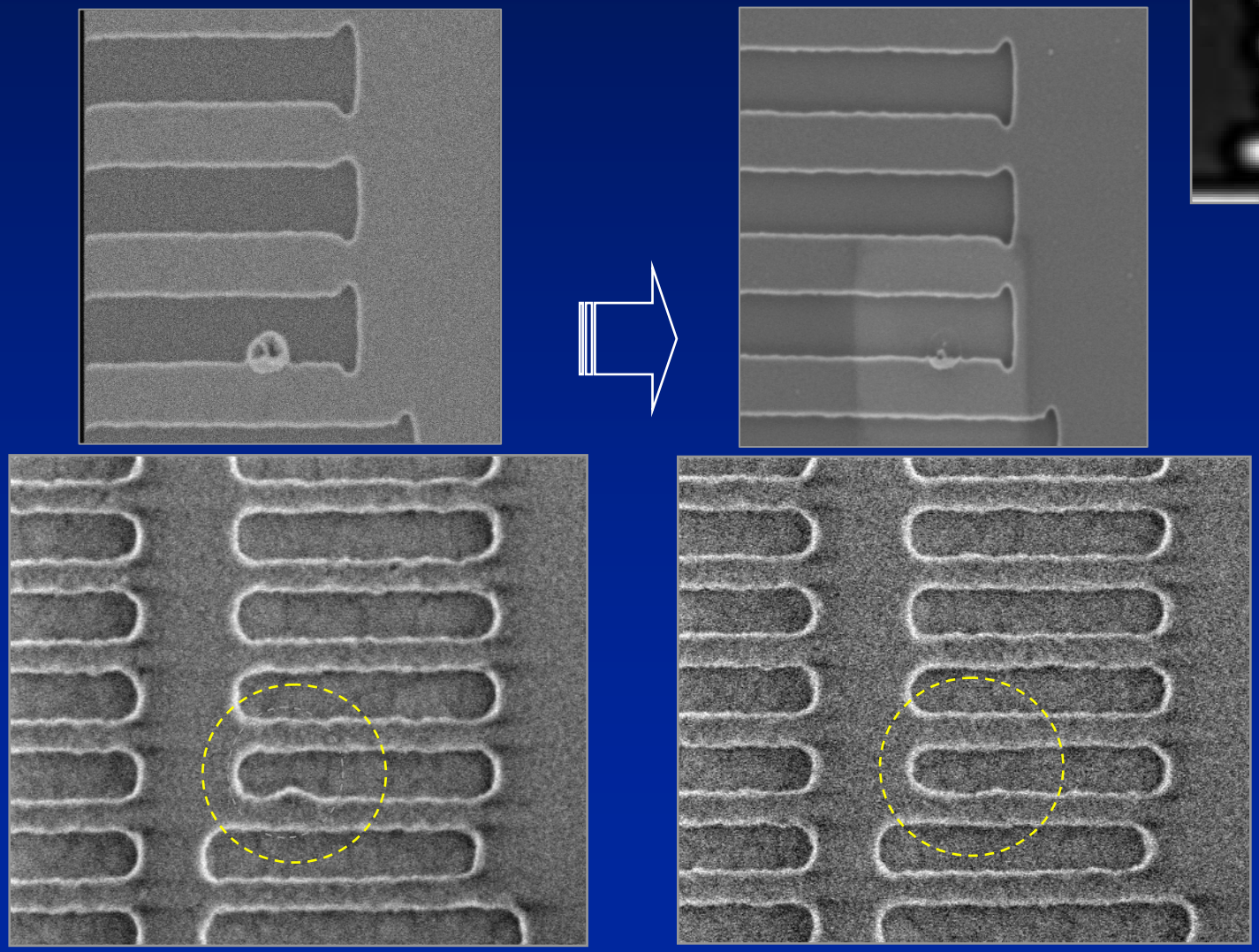




Achieving Zero Defect – Pattern Repair

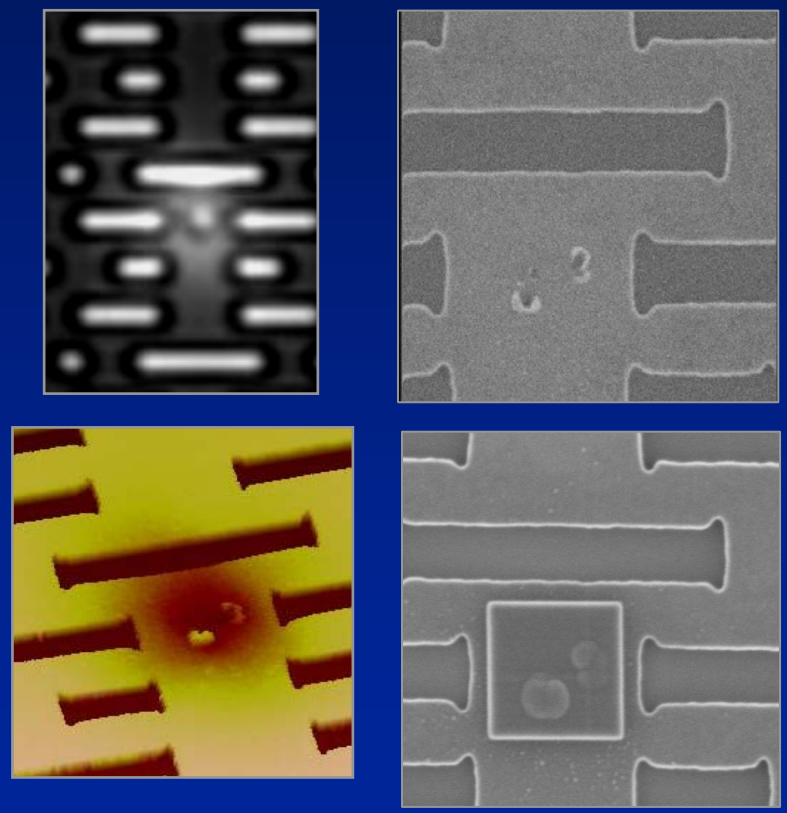
- Example 2: Defect caused 15% ΔCD/CD
- Fully repaired as by ADT print

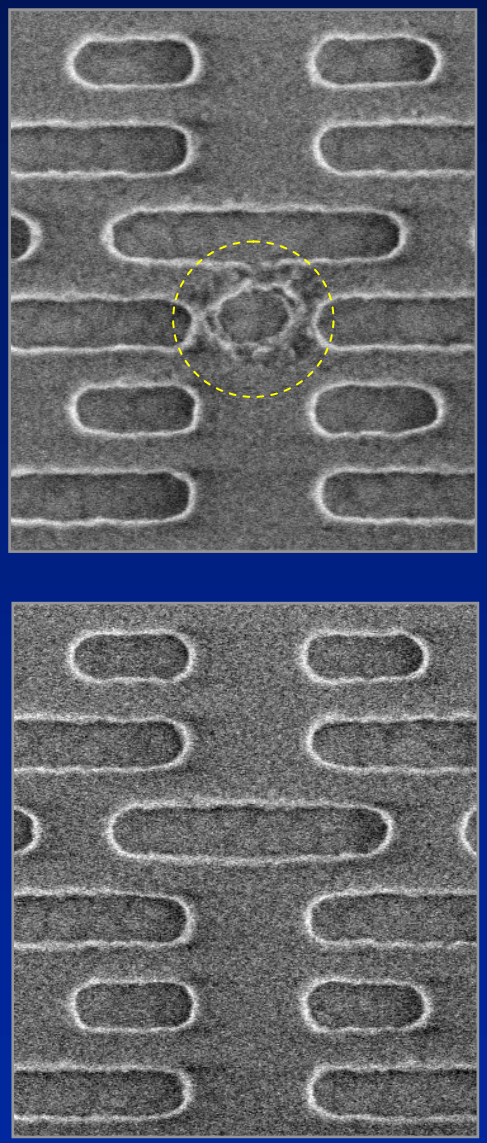




Repairing ML Blank-caused Defect

- **Complex defect**
- **SEM + AFM are used to guide repair**
  - Defect nature
  - Repair by deposition

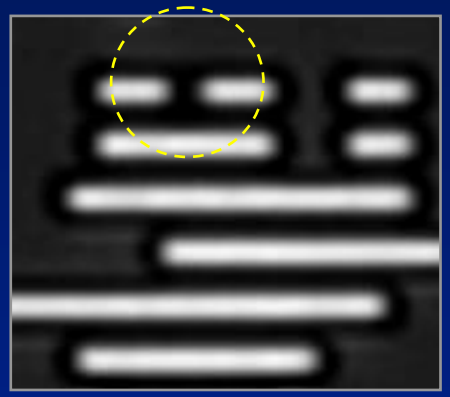
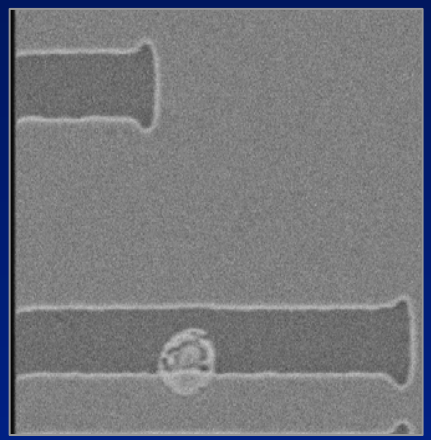
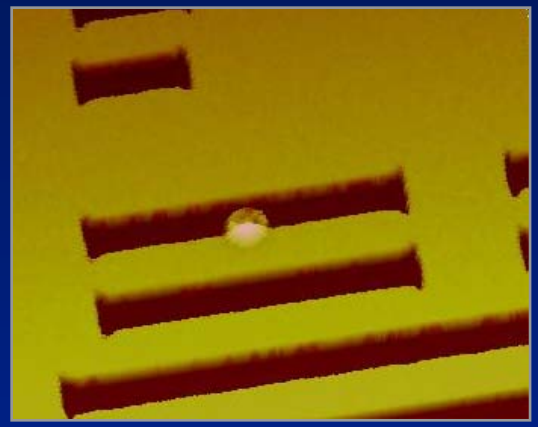
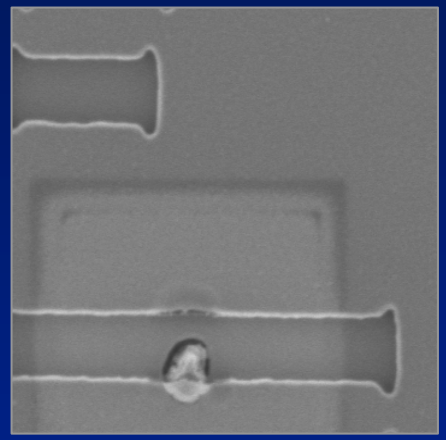




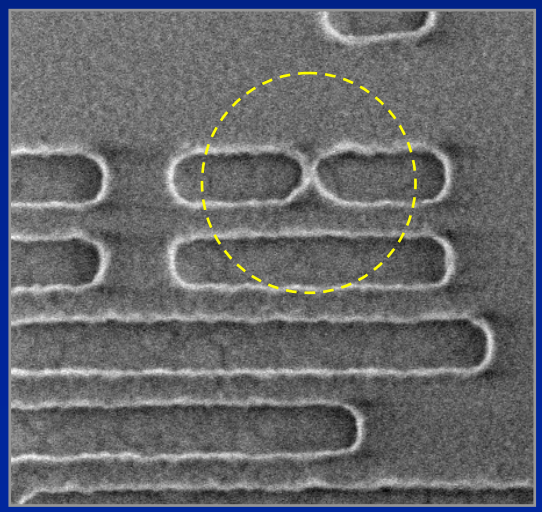
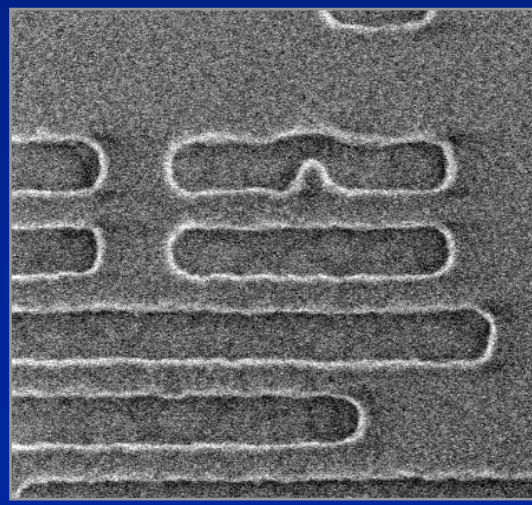
- **Defect caused by large C-containing particulate on ML blank resulting in thin absorber**

Repairing Embedded ML Blank Defect

- 120nm tall particle embedded in ML blank; Caused bridging
- SEM + AFM not sufficient to guide repair
- Need composition to dial in repair etch chemistry

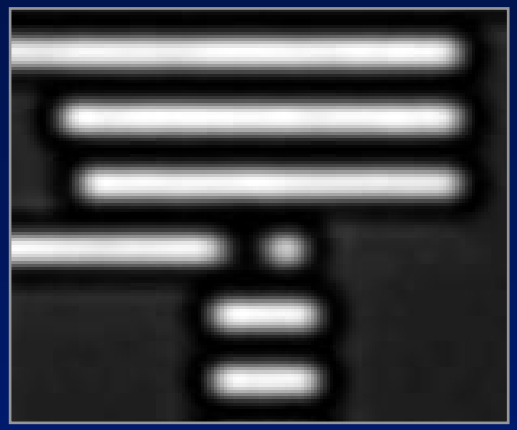





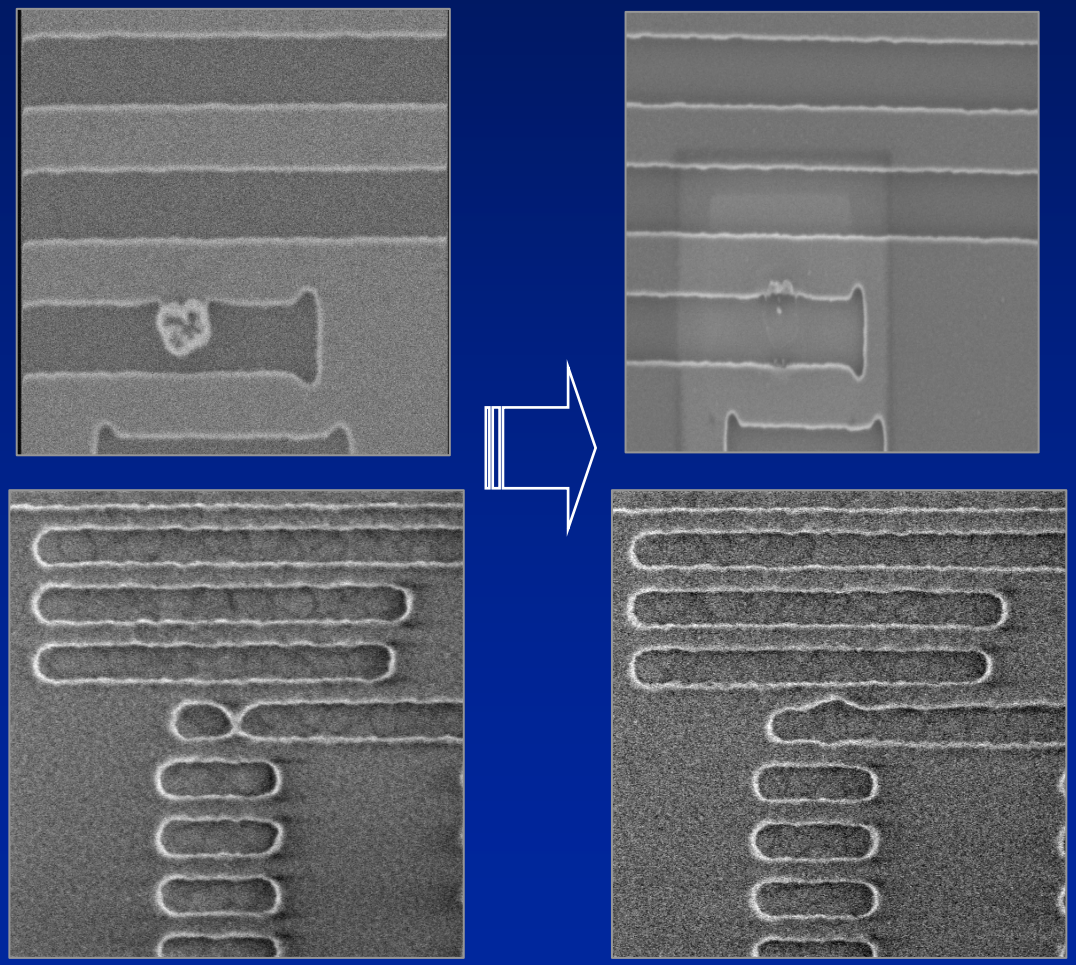
- Resist print improved
  - Pass/fail depends on device layer
- Compensation is needed for incomplete defect removal
- ML blank must be free of large embedded particles
- AIMS is a must-have to monitor and qualify repair

Repair Qualification Discussion

- Non-pure absorber defect, caused bridging
- Is repair good enough?

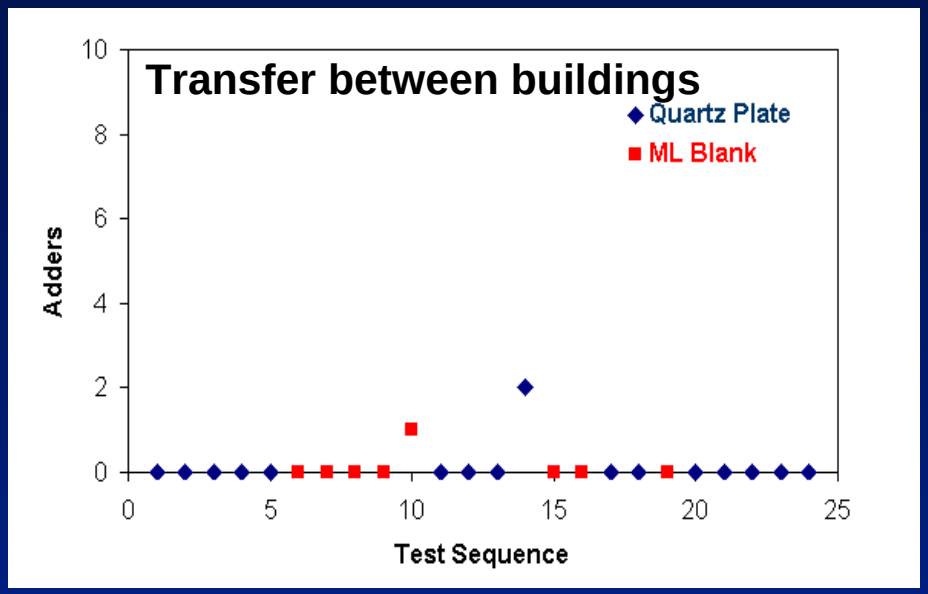




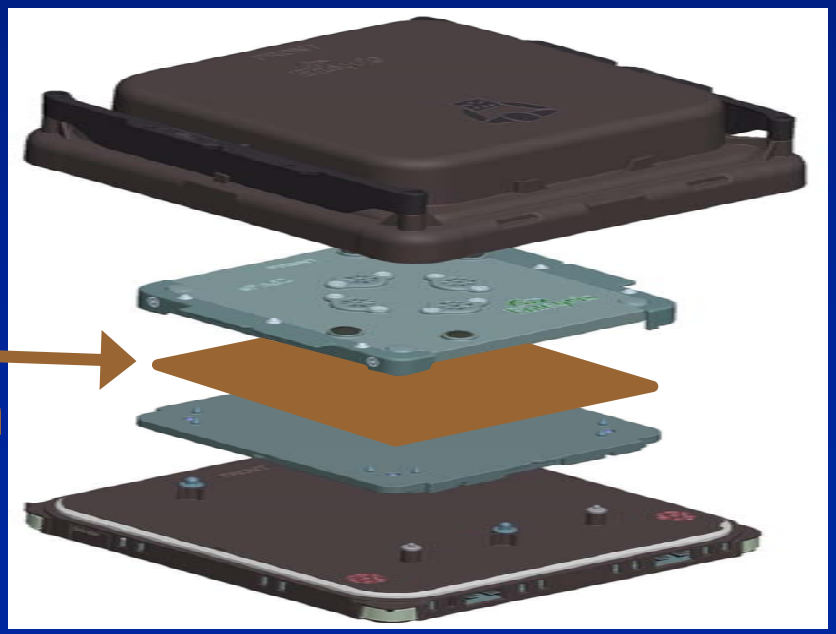
- SEM alone not sufficient
- AFM difficult to measure at the edge
- AIMS is needed to provide immediate feedback to ensure successful repair

Zero-defect Handling and Storage

- Zero particle adders can be achieved with RSP, but not always zero
- Standard EUV reticle carrier sPod with inner pod to further prevent particles
- Need to build and test infrastructure around ADT to facilitate learning
  - Including cleaning tool



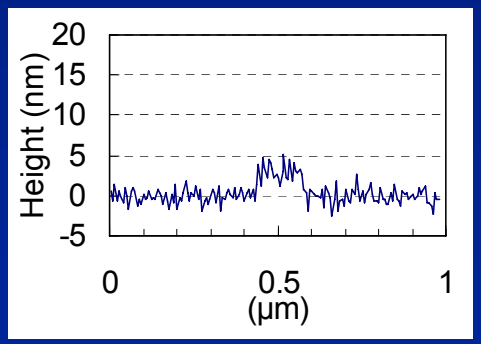
Reticle
Facing down

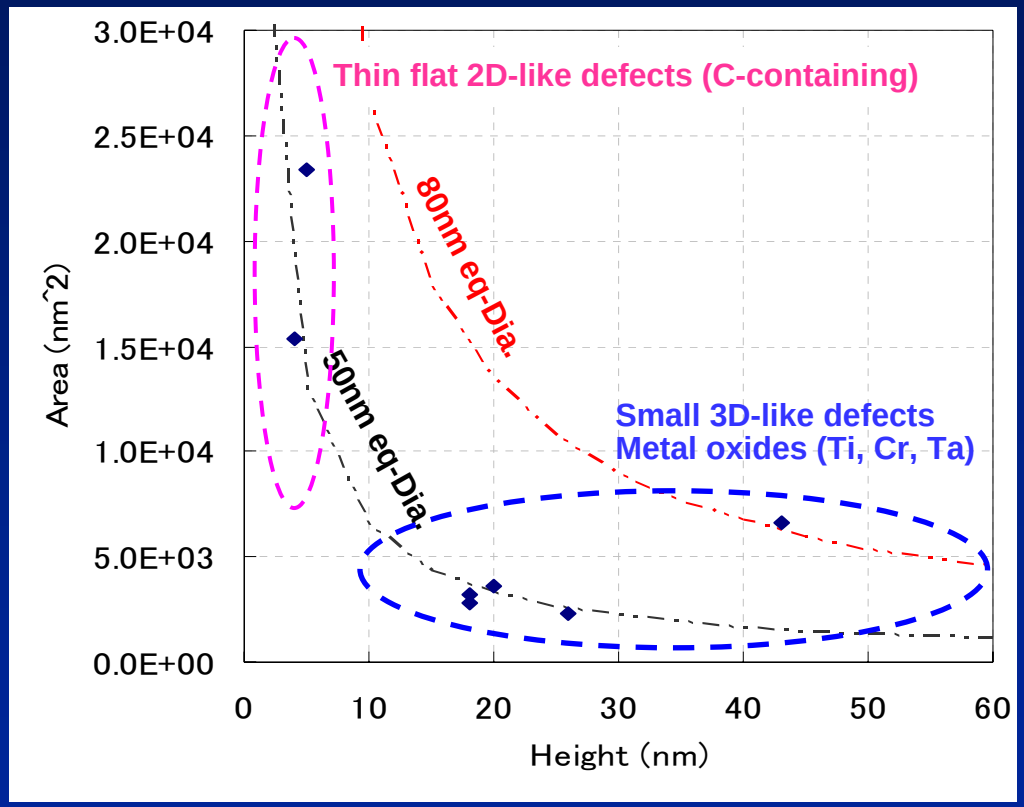


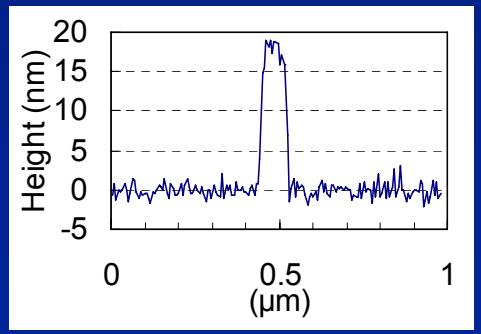
Challenges in Mask Cleaning

- **Frequent cleaning poses additional challenge to mask lifetime**
  - Avoid Ru-ML damage
- **Biggest challenge: avoiding adders**

2009 BACUS paper







- **Common adders are 2D-like carbonaceous and 3D-like oxides**
- **Key focus: Particle filtration and removal efficiency**

Summary

- **EUV mask defects are complex in types and root causes**
  - Direct measurements is necessary for defect reduction and mask qualification
- **We have developed best known methods for <u>quantitative</u> defect understanding and reduction by optimal use of current tool set**
- **We have demonstrated full loop device pattern repair as verified with ADT print**
  - SEM + AFM capable to guide repair for majority of defects, but not sufficient
  - AIMS is in critical need, the first priority tool for defect <u>disposition</u>
  - Repair + compensation is necessary for ML blank defects
- **ML blank defects must be reduced to <<10 and all need to be smaller than primary mask patterns to <u>be compensatable</u>**
  - Current inspection tool is deemed capable to support this effort for blank suppliers
  - Highest risk for ML blanks will likely be large embedded particulate defects vs. small phase defects

Acknowledgements

- **Intel Components Research**
  - Armando Cobarrubia, John Magana, Seh-Jin Park
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  - Nathan Wilcox, Andrew Jamielson, Chang-Ju Choi, Yi-Ping Liu
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  - Thorsten Hofmann, Klaus Edinger, Kinga Kornilov