Status and Gaps of EUV Mask Pattern Inspection Using DUV Light

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Components Research

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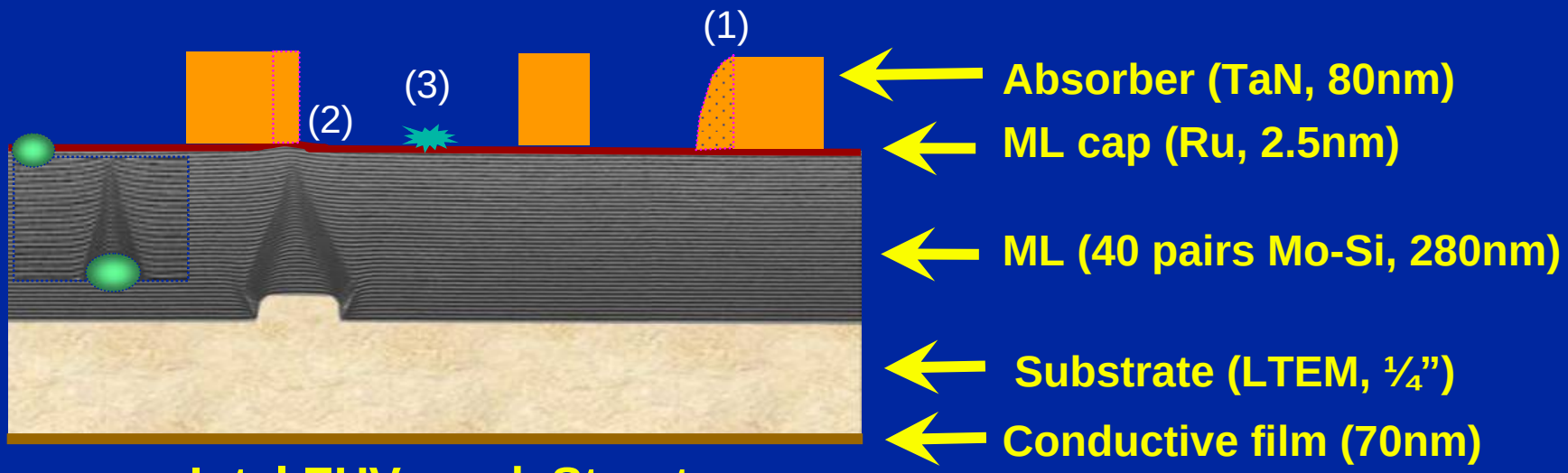
Outline

- **EUV mask pattern inspection**
  - Defects on finished mask
  - Pattern inspection with DUV light
- **Status of pattern inspection for TD needs**
  - Integrated approach at Intel
  - Examples of full mask inspection
- **Gaps in pattern inspection for production needs**
  - Pattern resolution
  - Required development
- **Summary**

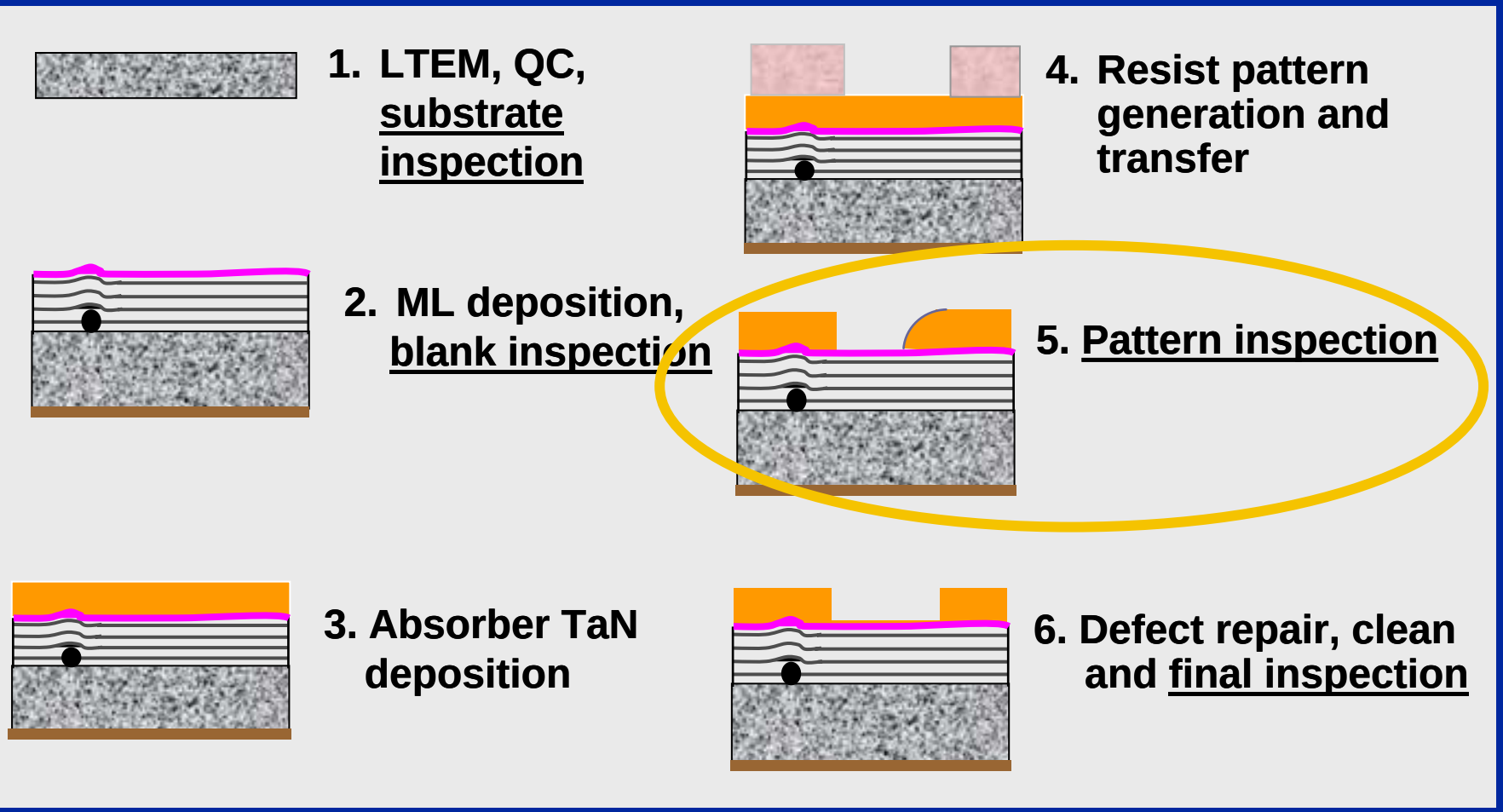
General Defect Requirements

- **Zero printable defect on a finished mask**
  - ~20nm on mask for anticipated production requirements
- **Non-cleanable 'hard' defects**
  - Pattern defect (1): repair
  - Residual ML defect (2): compensate
- **'Soft' defects: cleanable**
  - Particulates and hydrocarbons (<1nm layer) (3)



Intel EUV mask Structure
(Cross-sectional view)

EUV Mask Flow Pictorial (Selected Steps)

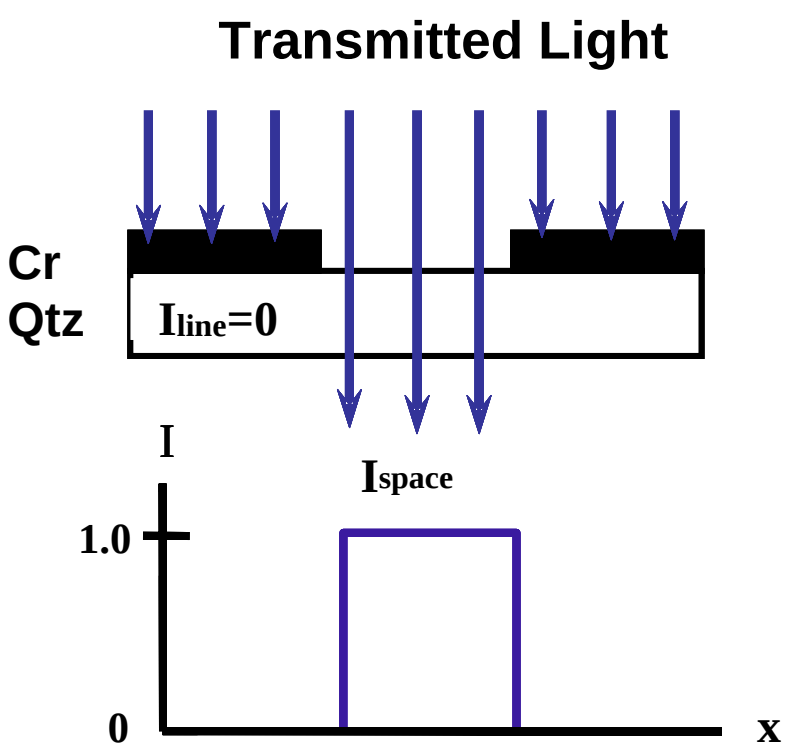


- Use of Ru-cap layer simplified mask fabrication process

EUV Pattern Inspection with Reflected Light

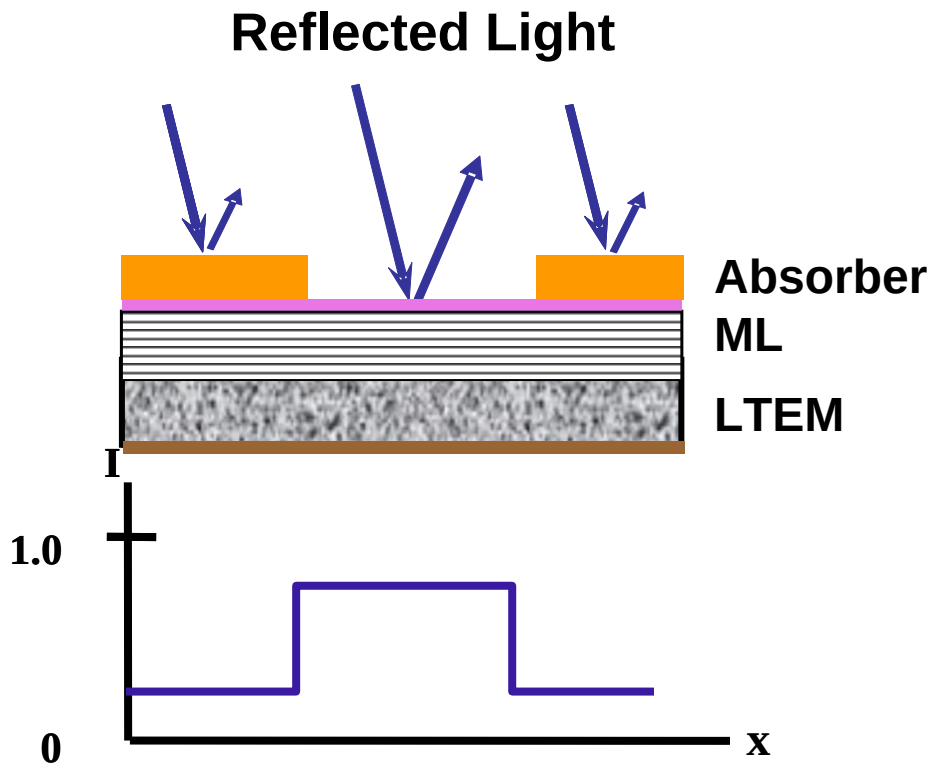
- **Pattern inspection of reflective vs. transmission**
  - Absorber reflectivity must be low (<10%)
  - Avoid edge interference effects

$$\text{Contrast} = \frac{I_{space} - I_{line}}{I_{space} + I_{line}}$$



$I_{space} \cong 100\%$

$I_{line} = 0$

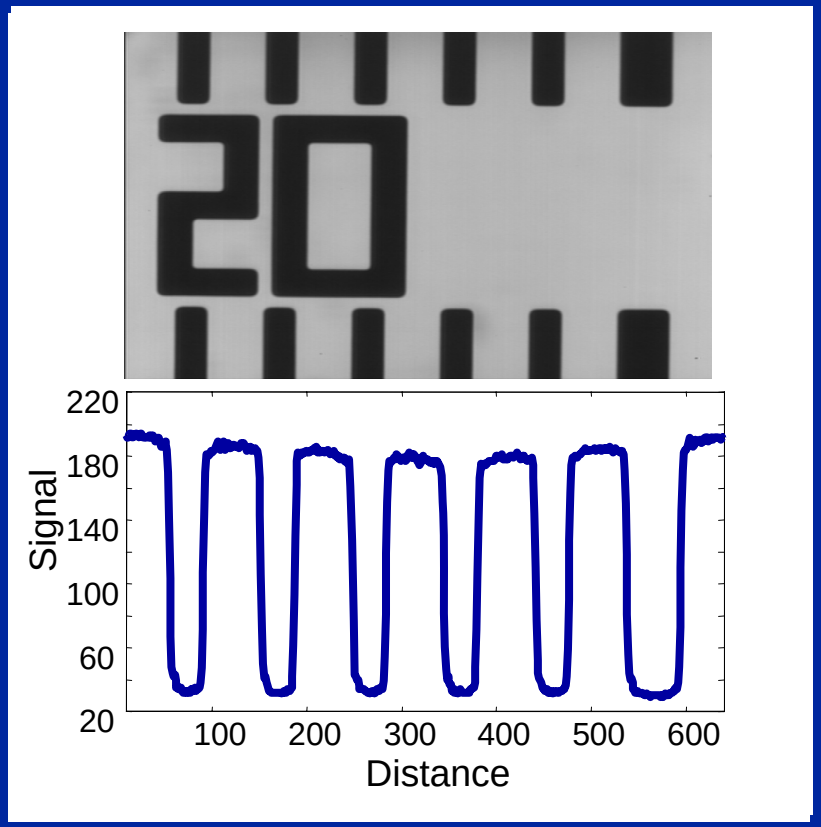


$I_{space} \cong 60\ \%$

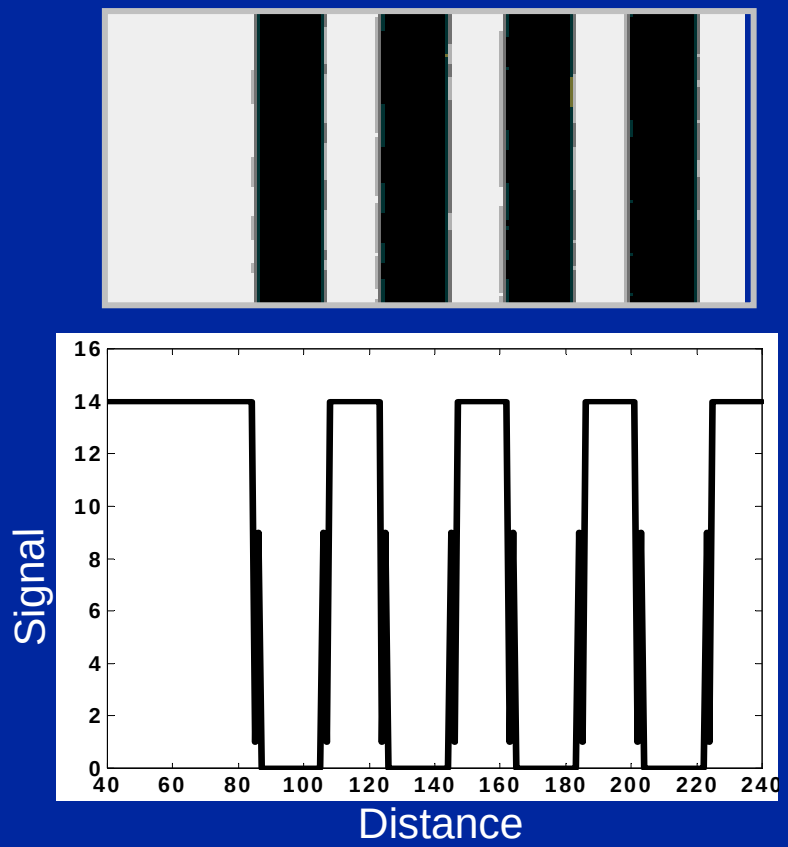
$I_{line} \cong 5 - 10\ \%$

Contrast Optimization Key to Inspectability

EUV Reflective Mask



Binary Transmission COG



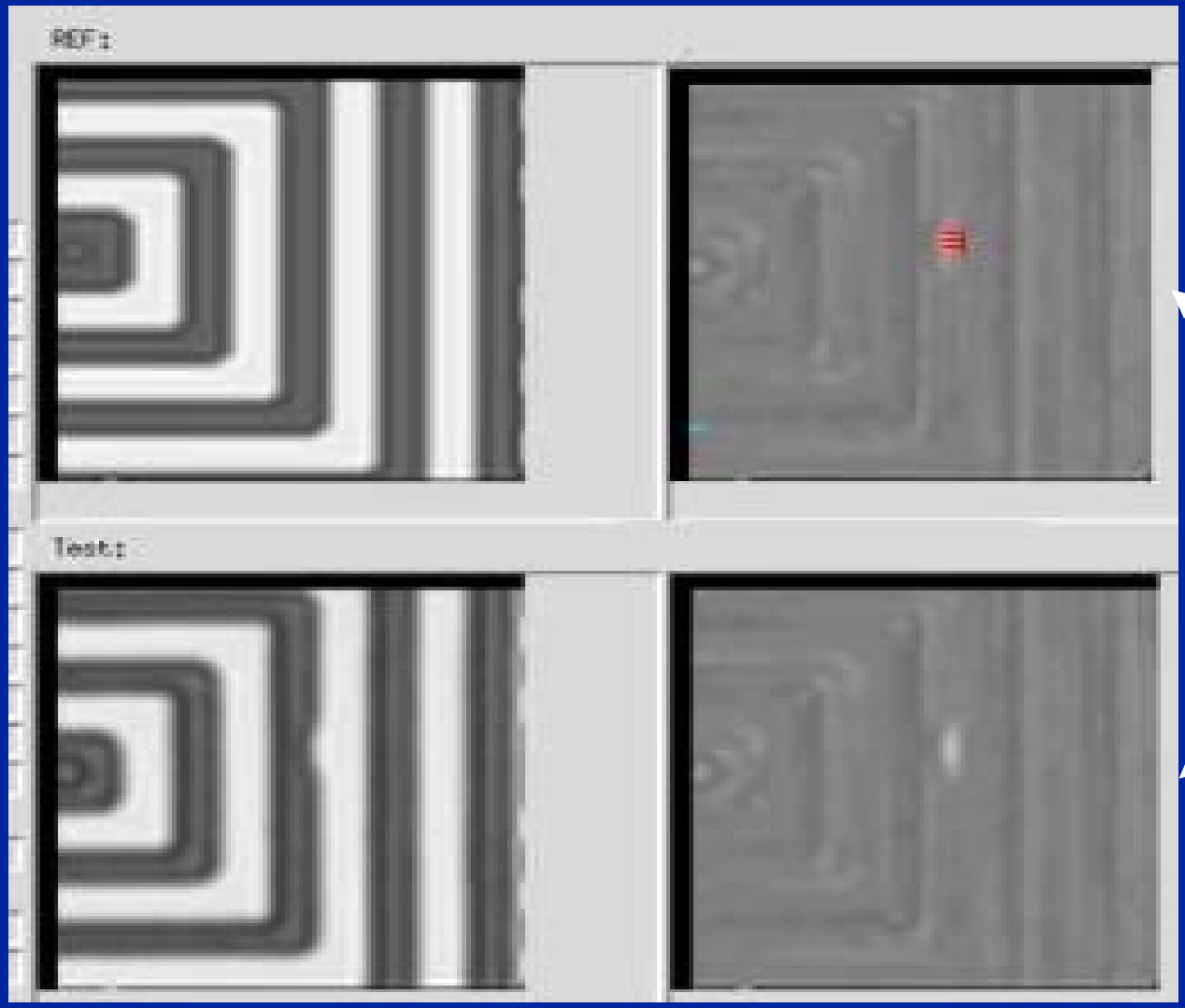
- **RL image quality <u>close to</u> TL image**
  - Edge interference can be eliminated with low reflective absorber (<5%)
  - Reflective noise: lower sensitivity

RL Image Rendering for D:DB Inspection

- 20nm edge defect on 100nm lines (1X)

Rendered image

Inspection image



Difference of rendered and inspection images

D. Pettibone
KLA-Tencor

Integrated Tool Set for Defect Studies

Mask clean room

Factory Control System

Mask info

Server Central Database

Front-end Client

Defect data fed to repair tools

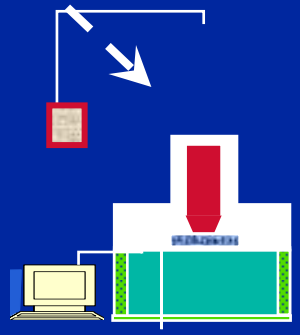
Inspection data

Inspection Tools

Metrologies

AIM

AFM



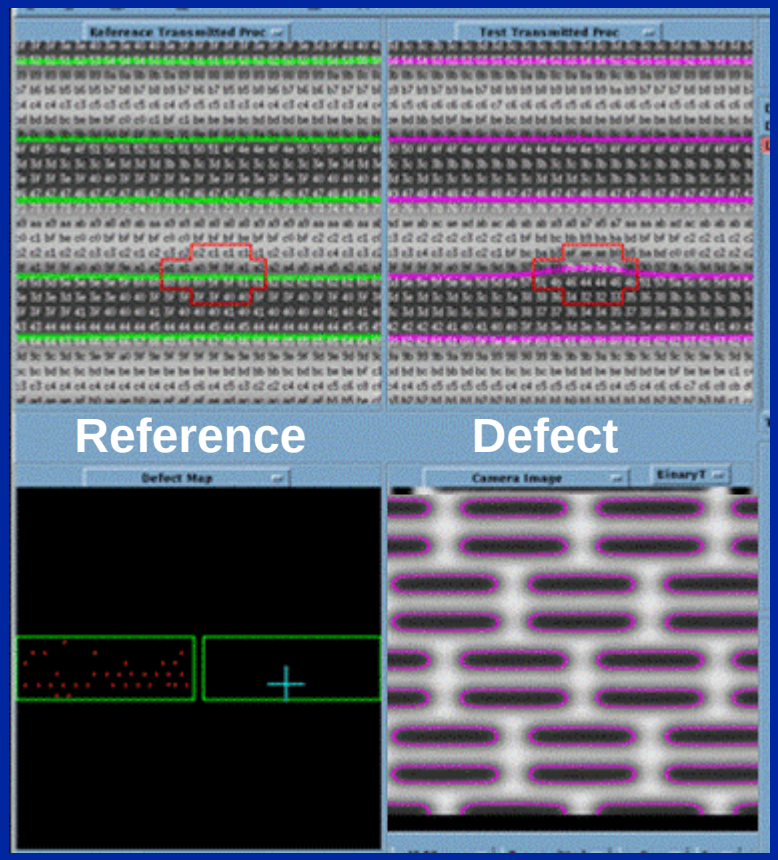
SEM

- Allows efficient and comprehensive defect understanding

Liang, et al, SPIE 2005

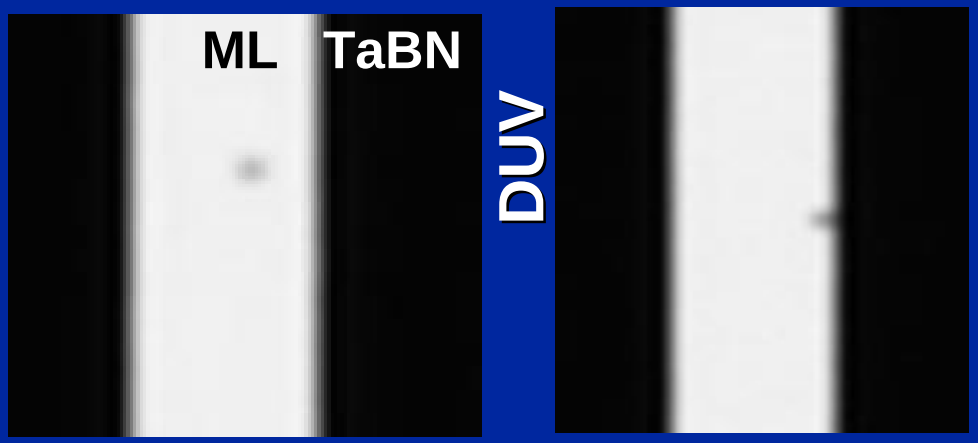
Full Sensitivity Inspection Possible

- **80nm sensitivity with 125nm inspection pixel**
  - EUV mask Die:Die inspection mode



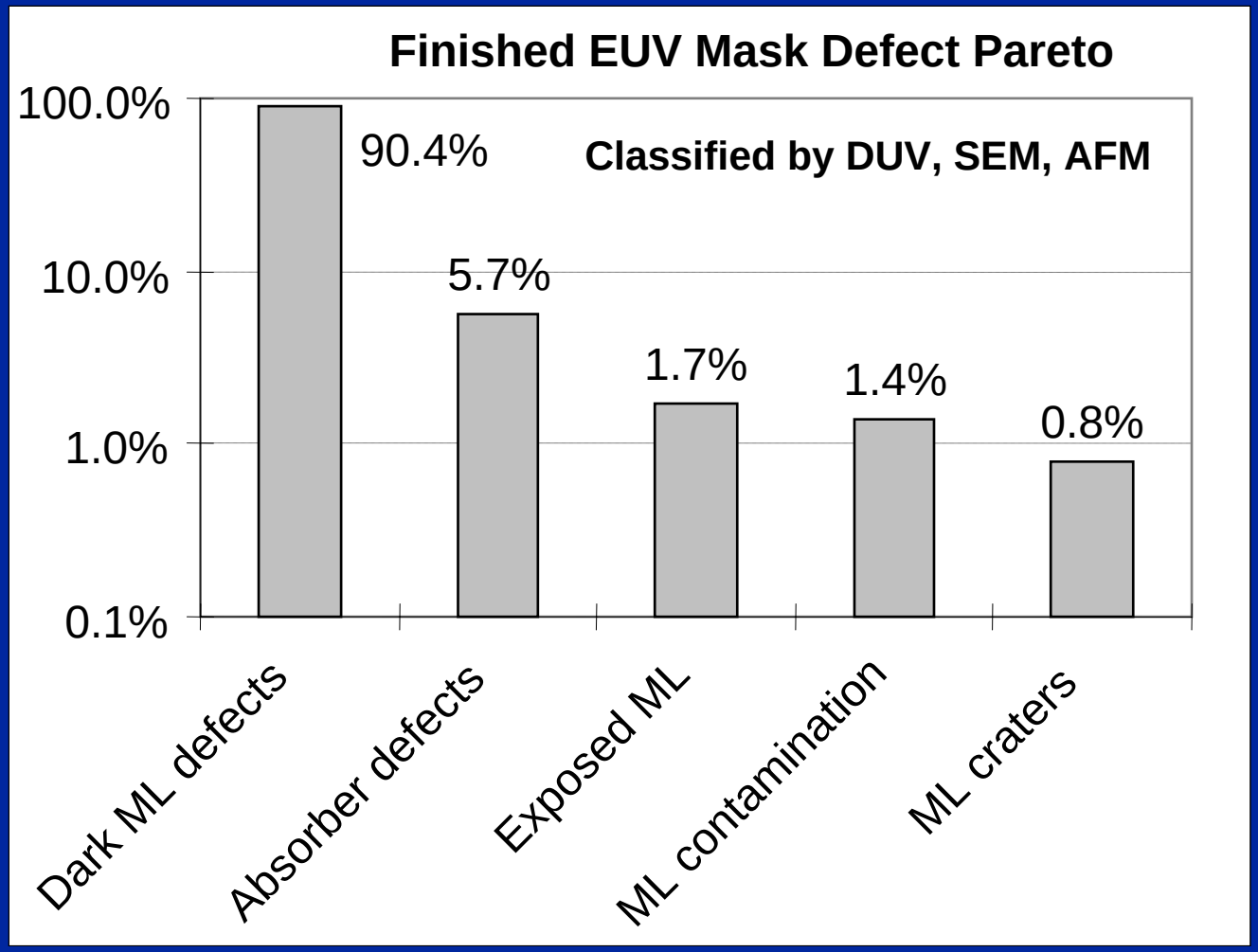
Defect map Review image

Natural defects



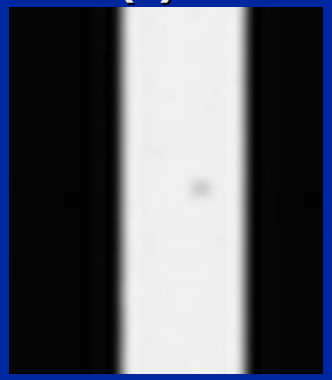
Defect Classification from Full Mask Inspection

- **5 classes of defects**
  - **Majority related to ML blank and contamination**

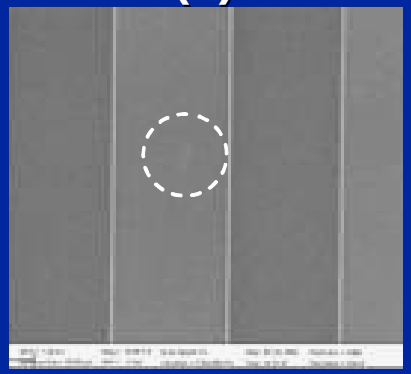


Dark ML Defects and Contamination

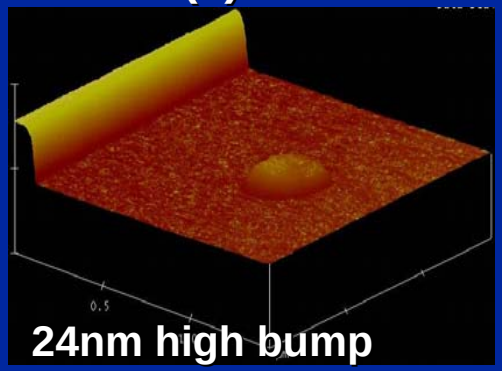
(a) DUV



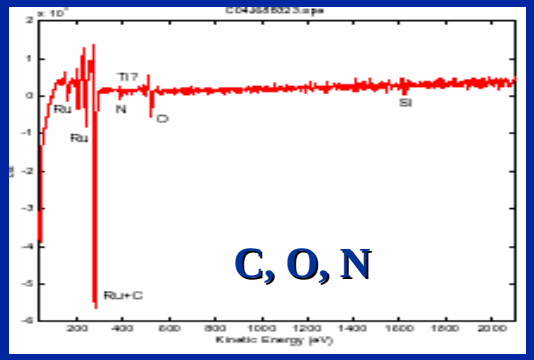
(b) SEM

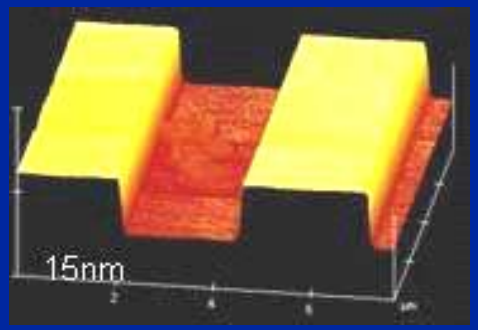


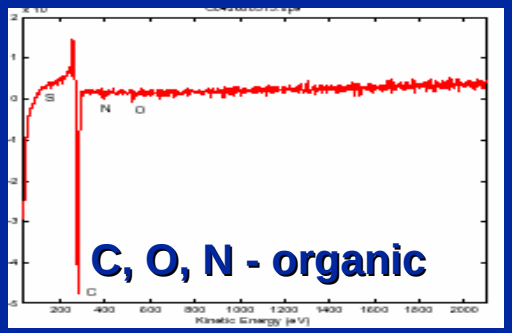
(c) AFM



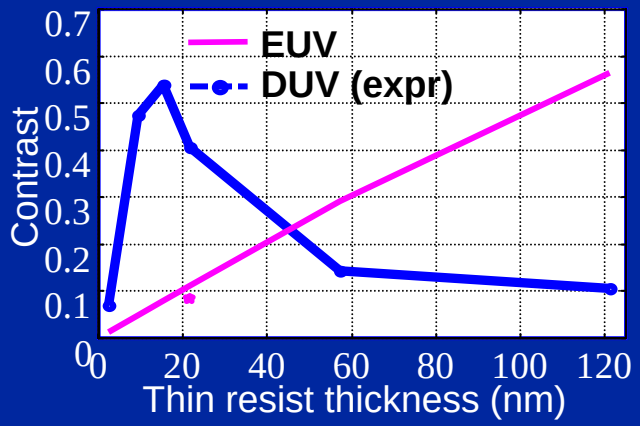
d) AES





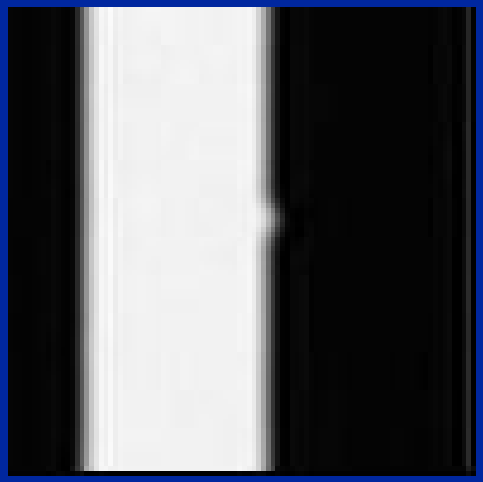


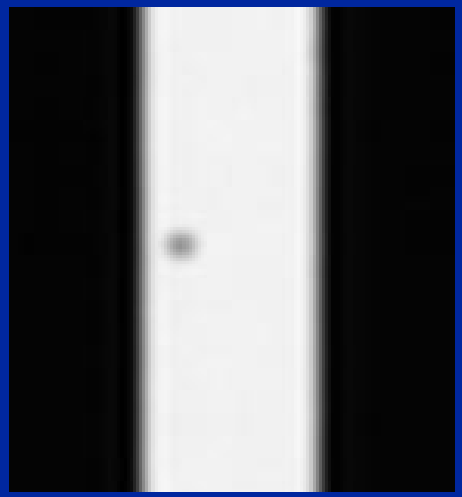
- **'Soft' defects from process/handling**
  - 10nm – 20nm typical thickness
  - Typical organic signature
  - Sensitive detection of organics by DUV!
  - Removal ineffective by standard wet clean

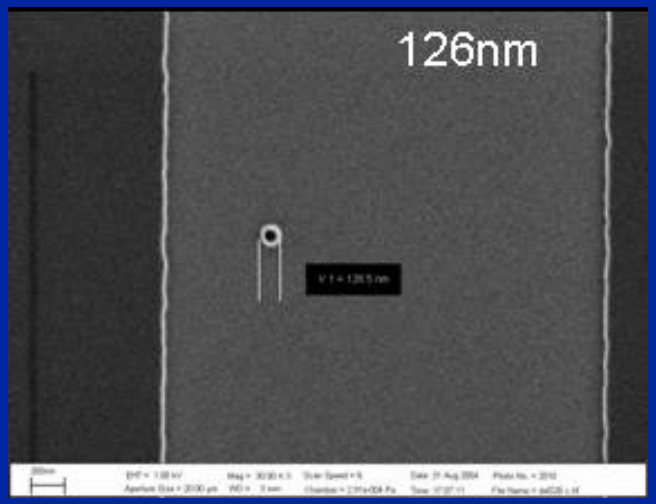


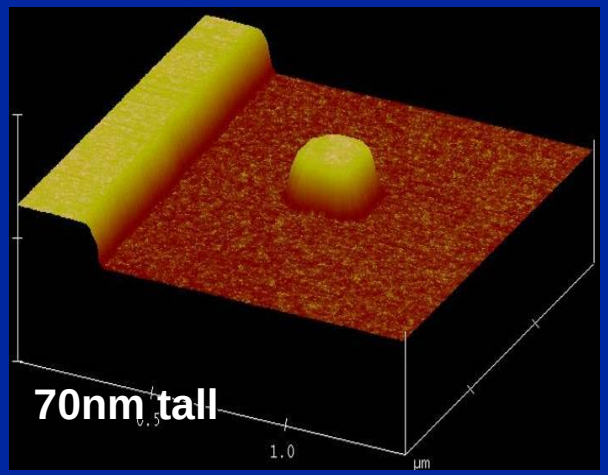
Absorber Pattern Defects

- Absorber intrusion and pindot defects



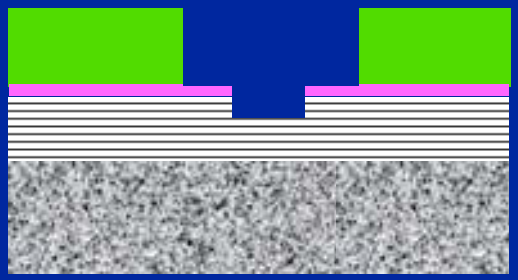


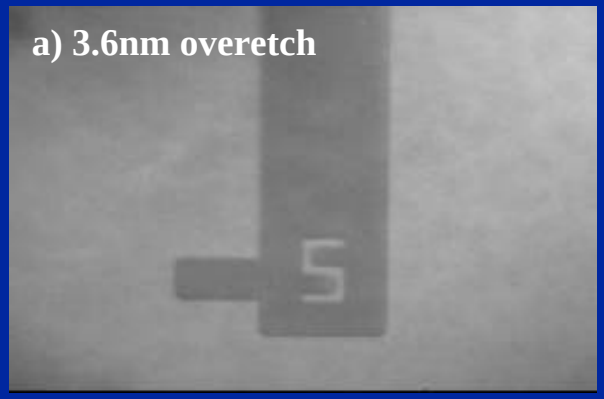


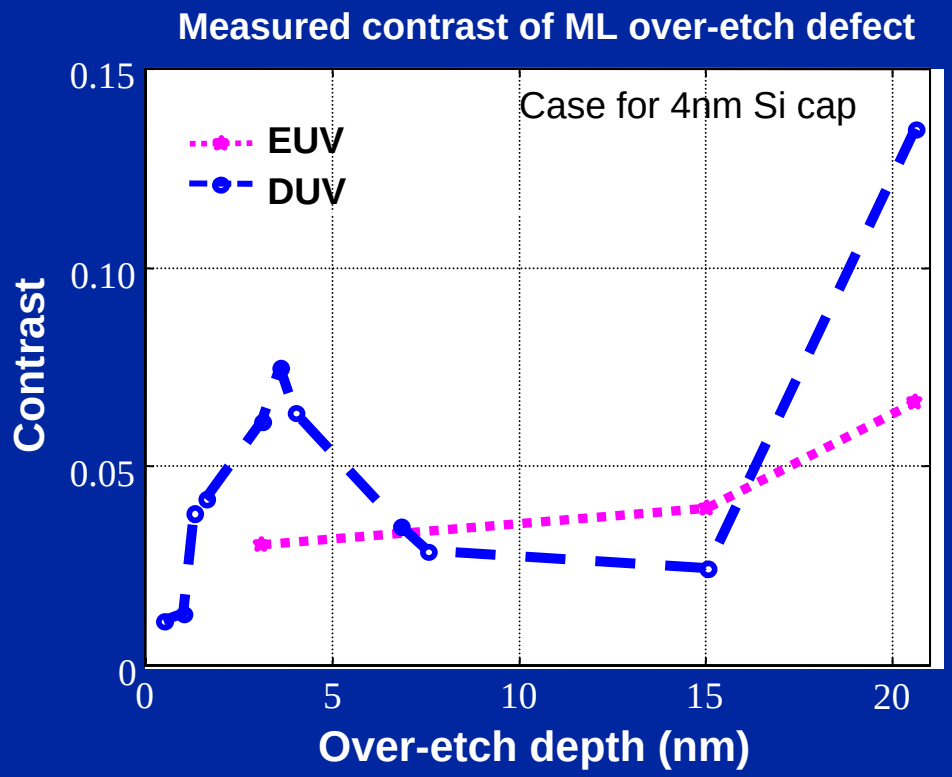


Other Surface Defects Detectable by RL

- ‘Pitting’ or over-etch into ML



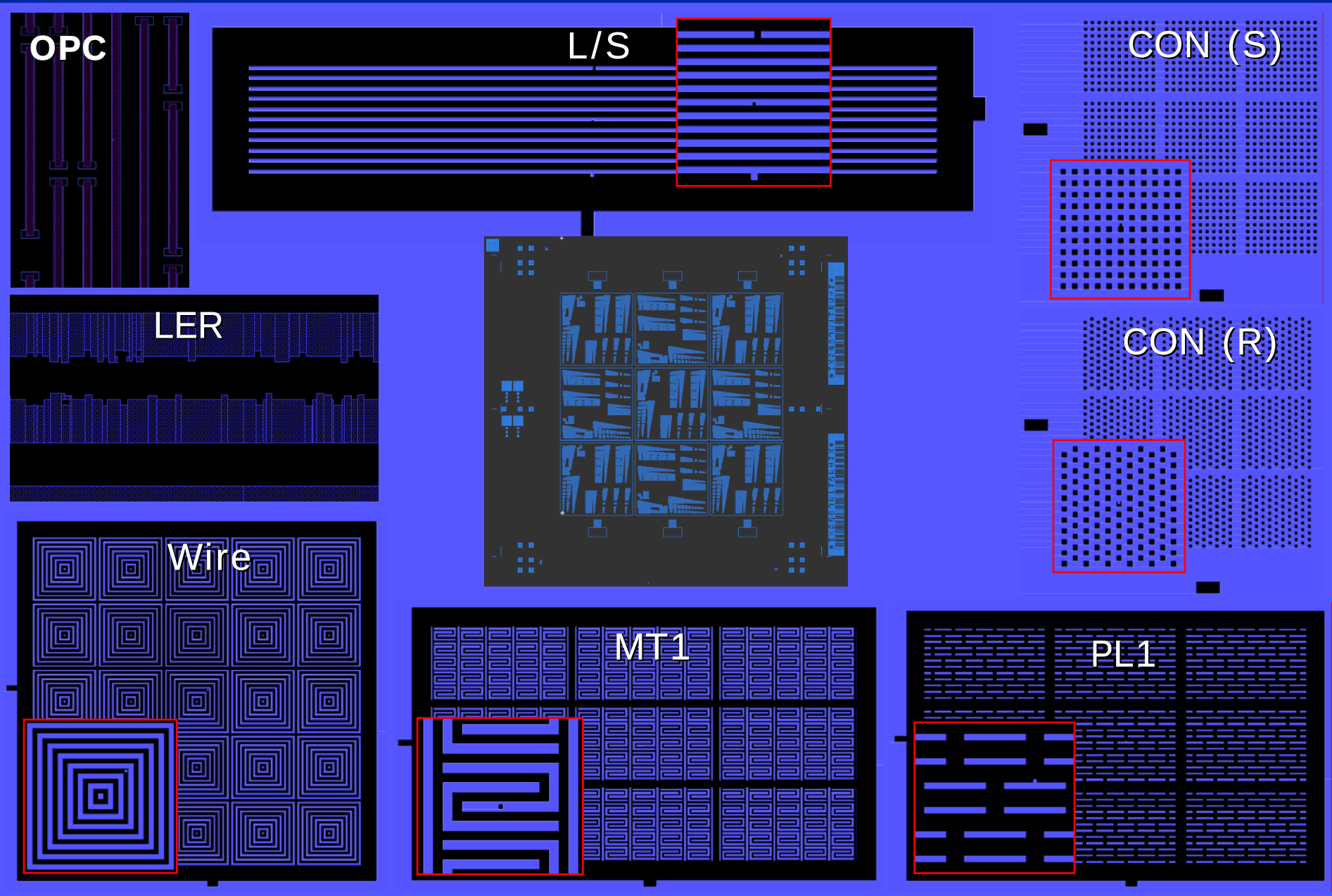




- **Actinic inspection has no advantage**
  - This type of defects are less printable

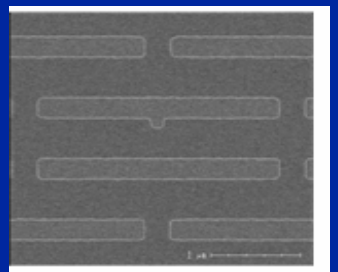
Liang, et al, Proc. SPIE 2002

Comprehensive PDM for Inspection Development

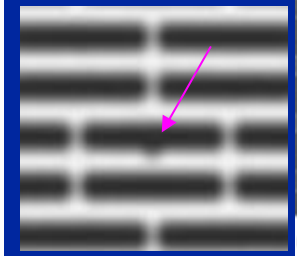


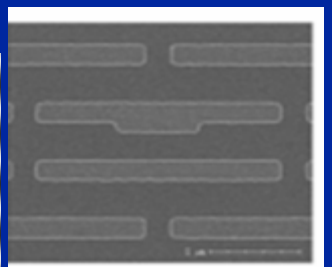
Types of Defects with 100% Capture Rate

- Inspection tool sensitivity and recipe development with test mask
  - Pattern dependent

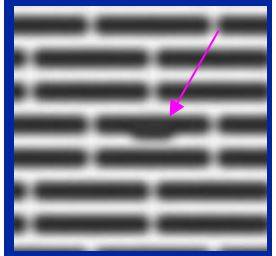


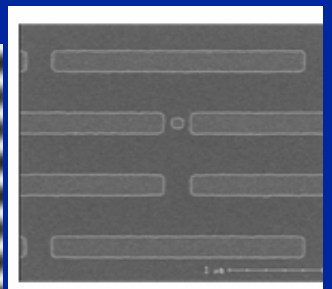
(A) Localized Edge Protrusion - Down



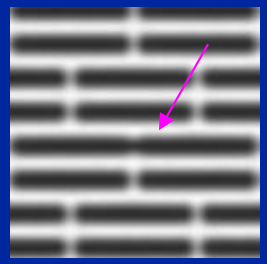


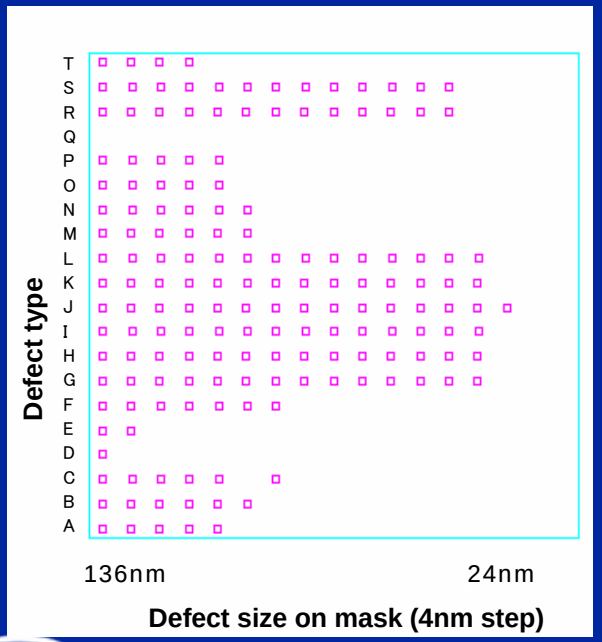
(G) Extended Edge Protrusion - Down

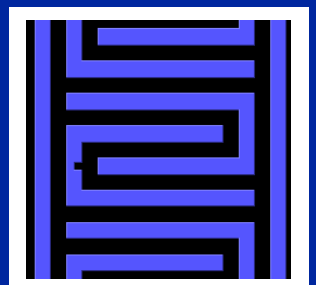




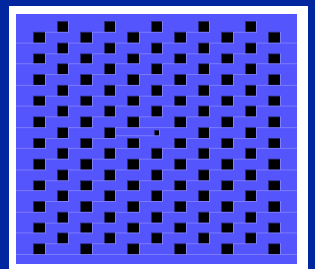
(O) Pin-Dot 3



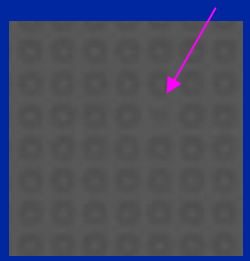




(D) Localized edge intrusion 2



(F) Under-size



- Inspection sensitivity similar to optical binary mask for edge defects

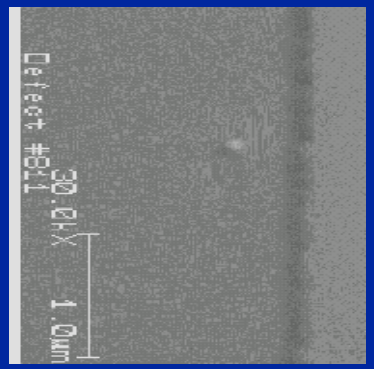
Standard Industry Infrastructure 'Sufficient' to Meet TD Needs

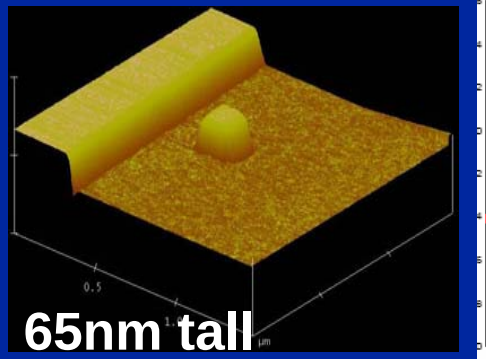
- **Assumptions for pattern inspection**
  - Mask patterning will not cause 'embedded' ML defects: pattern inspection only detects defects on ML surface
  - EUV mask pattern defects are not EUV-specific: non-actinic
- **EUV mask must be made inspectable with RL DUV light**
  - Standard tools/algorithms can be used (minor modification)
- **Dependency of pattern inspectability**
  - Inspection tool pixel size: *f* (λ, NA, σ, detector)
  - Defect sensitivity: System S/N ratio; Inspection algorithm
  - Mask pattern contrast
  - Mask pattern edge roughness/phase effect
- Defect classification more complex than 193nm optical mask
  - Multiple metrology tools needed

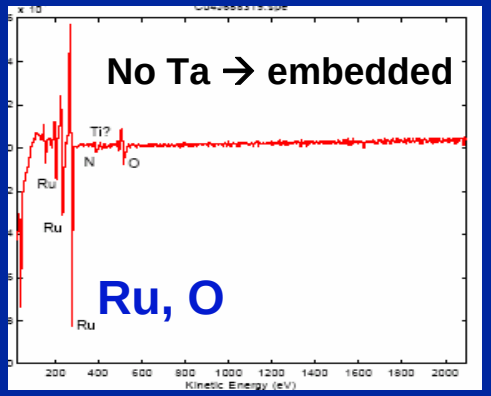
Challenges in Defect Classification

- **In many cases, definite classification difficult**
  - AFM height not sufficient; Need elemental probe

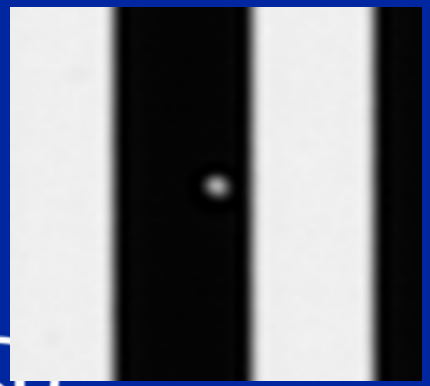
Absorber defect or embedded ML defect

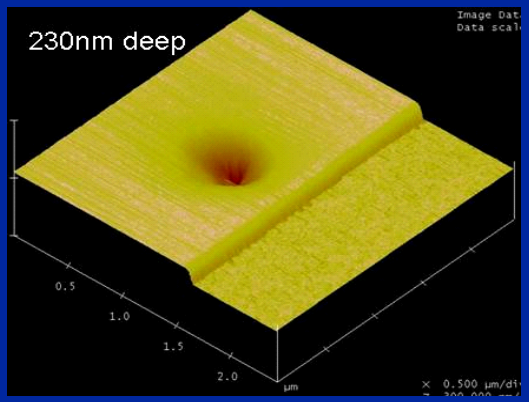






- **Definite classification required for defect repair**
  - 'Pinhole' – May not need repair

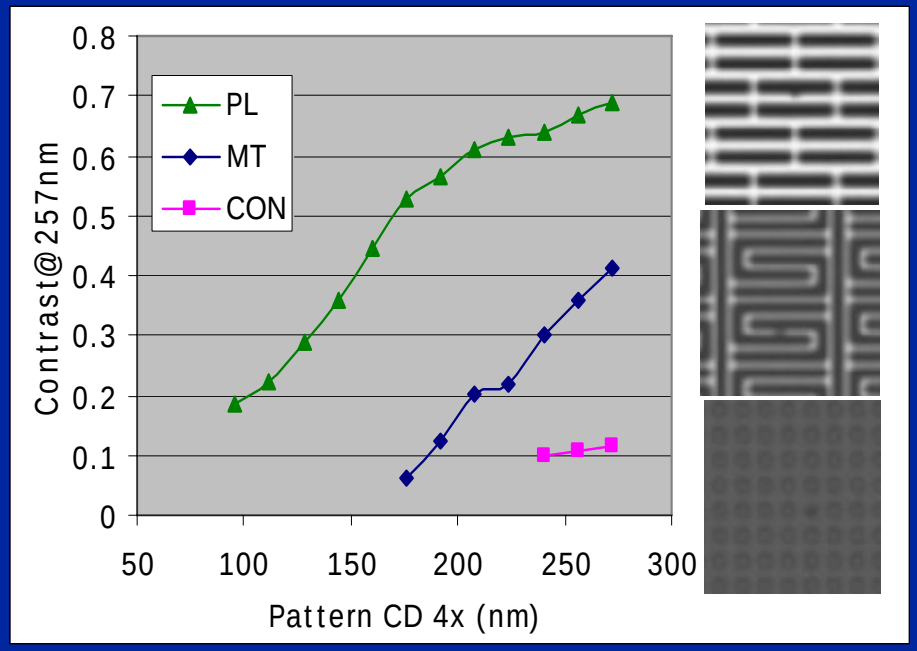




Extendability of RL Inspection to Meet Production Needs

- **Are resolution and contrast sufficient to *'see' the device patterns*?**
  - Determined by $R = k_i \lambda / NA$
  - ~ 100nm for a high NA, diffraction-limited optical system $\lambda \approx 200$nm

DUV inspection contrast



- **Is sensitivity sufficient to *'see' the defects*?**
  - Scale to $S = k_d \lambda / NA$, $k_d \approx 15\%$ possible for edge defects
  - Requires good contrast and low noise
- **Key challenge: Insufficient resolution from NG DUV inspection tools**

Develop Options for EUV Pattern Inspection

- There are gaps between NG DUV inspection tool capability and the anticipated device geometries and defect requirements
- Need to evaluate alternatives to supplement DUV tools
- Actinic tool will be difficult
  - Need high repetition rate (>100's kHz)
  - EUV source not available
- Electron beam
  - High resolution
  - Basic tool platform exists
  - EUV mask is conductive

Summary

- **Industry standard DUV tools have been successfully applied for EUV mask pattern inspections in reflected light mode**
  - EUV mask made as inspectable as transmission mask
- **Current and NG tools are expected to meet the need during EUVL development**
  - Critical for defect reduction
  - Defect understanding requires integrated approach/tools
- **However, substantial gaps exist for meeting the anticipated needs of EUVL production**
- **Need to evaluate alternative technologies**
  - Electron beam is an option

Acknowledgements

- Intel: Emily Shu, Changhan Kim, Gil Vandentop, Pei-Yang Yan, Alan Stivers
- KLA-Tencor: Don Pettibone, Andrew Cao, Aditya Dayal, Stan Stokowski