EUV Mask Inspection State Of The Art

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External Use

Acknowledgment

- Special thanks to imec team:

  Rik JONCKHEERE and Dieter VAN DEN HEUVEL

  for the excellent and successful collaboration

Outline

- Background and Problem Statement
  - Background: EUV mask defect types
  - Problem statement and objective
- EUV mask inspection State of the Art
  - Patterned Mask inspection (PMI)
  - Patterned Wafer Inspection (WI) with repeater analysis
  - e-Beam Patterned Mask inspection (EBPMI)
- Case studies:
  - ML defects detection with WI only
  - Combined PMI and WI inspection
- Summary

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Background: EUV mask defects type

Absorber defect

Particle

(Local) *cap deterioration*

Multilayer (ML-) defect

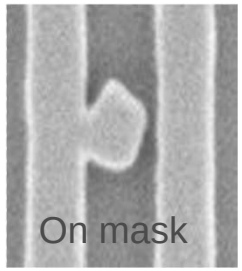
Problem Statement and Objective

- **Problem Statement:** Most probably not all multi layer (ML) defects are discovered by the current generation of blank inspection (BI) tools[1]

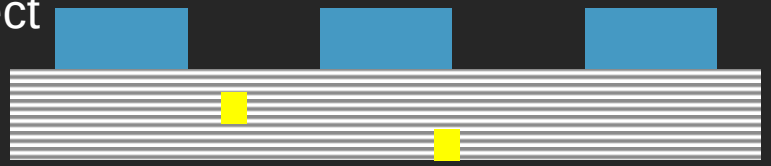
- **Objective:** Find evidence for multilayer defects, not discovered on blank, by advanced patterned mask and wafer inspections (PMI and WI)

Absorber defect
opaque or clear

All printing absorber defects can be found by PMI[2]



Multi-layer (ML))defect
cause in the ML
or on the substrate



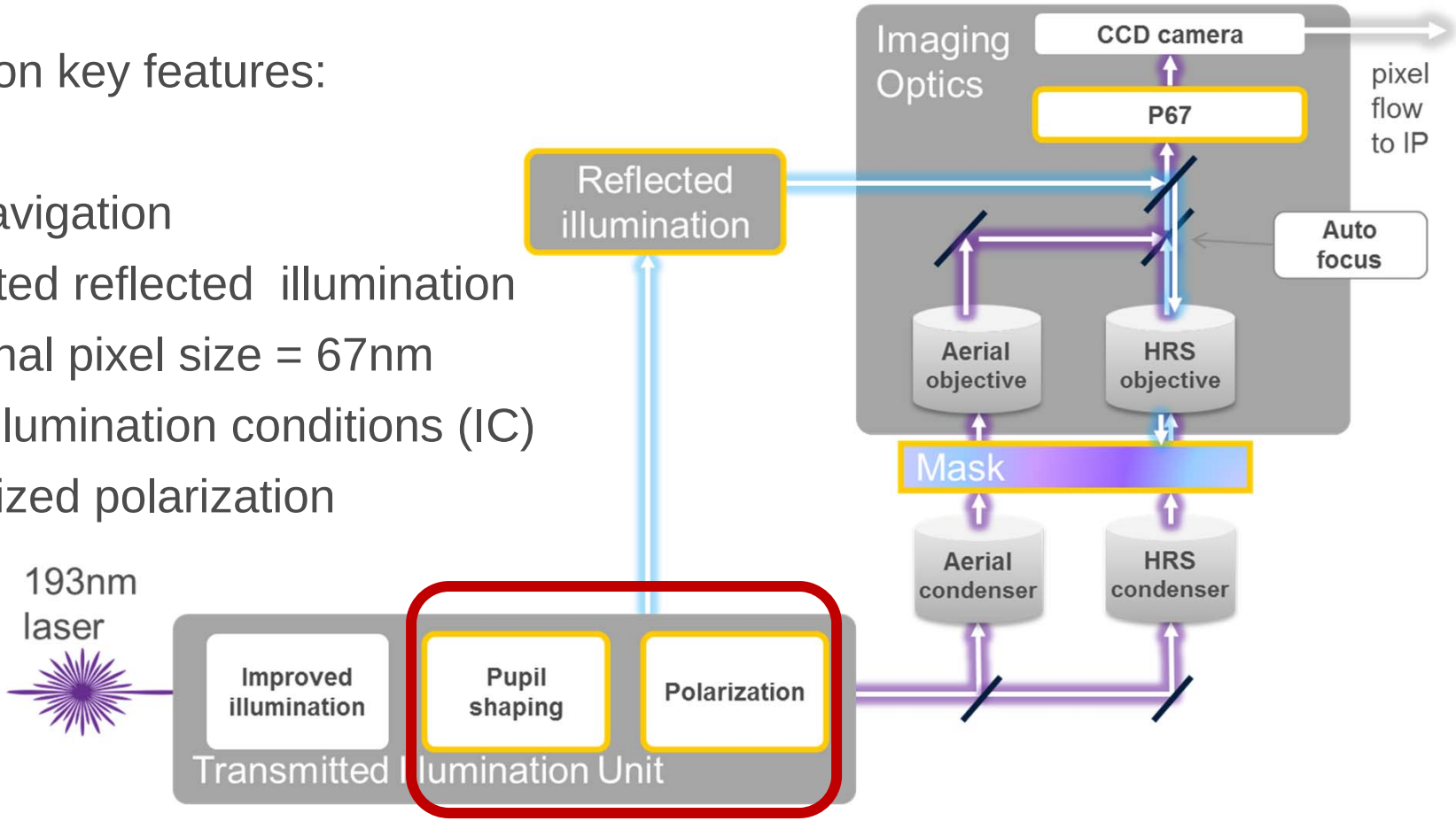
Printing absorber and ML defects can be found by WI[2]

1 Proc. EMLC7985, 2011, Jonckheere et al, "Evidence of printing blank-related defects on EUV masks, missed by blank inspection"
2 Proc. SPIE7823, 2010, Mangan et al, "EUV mask defectivity study by existing DUV tools and new E-beam technology"

Aera3 Patterned Mask Inspection (PMI)
DUV 193nm

EUV option key features:

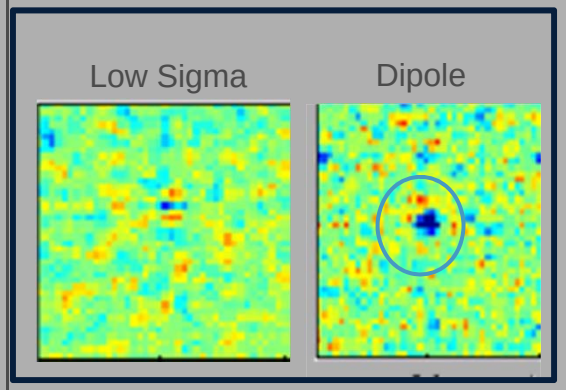
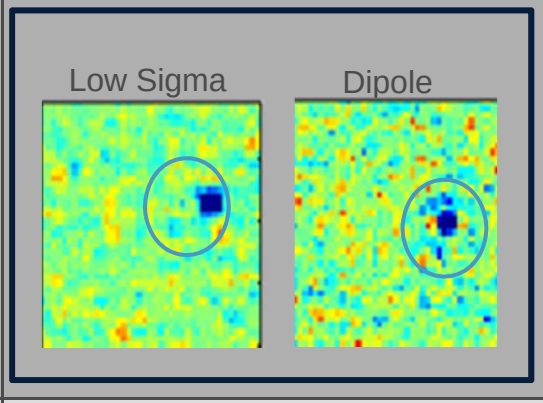
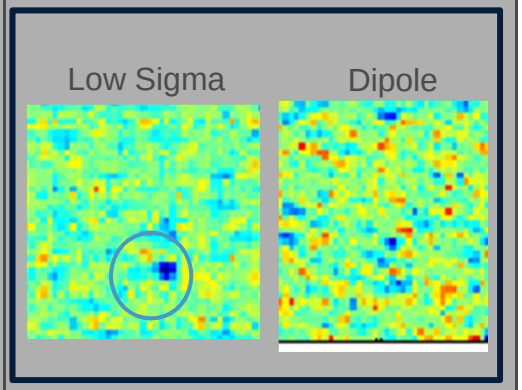
- EUV navigation
- Dedicated reflected illumination
- Additional pixel size = 67nm
- Multi illumination conditions (IC)
- Optimized polarization



Key Enablers: Illumination Shaping / Polarization

Illumination Control

Dual illumination impact on 20nm patterns

Type	Break	Bridge	Protrusion
Diff Image			
Low Sigma	X	√	√
Dipole-Y	√	√	X

- ✓ **Pattern dependent contrast/SNR optimization**
- ✓ **by using different Illumination Conditions**
- ✓ **combined with Polarization**

Dual illumination inspection scheme – for full coverage at 20nm

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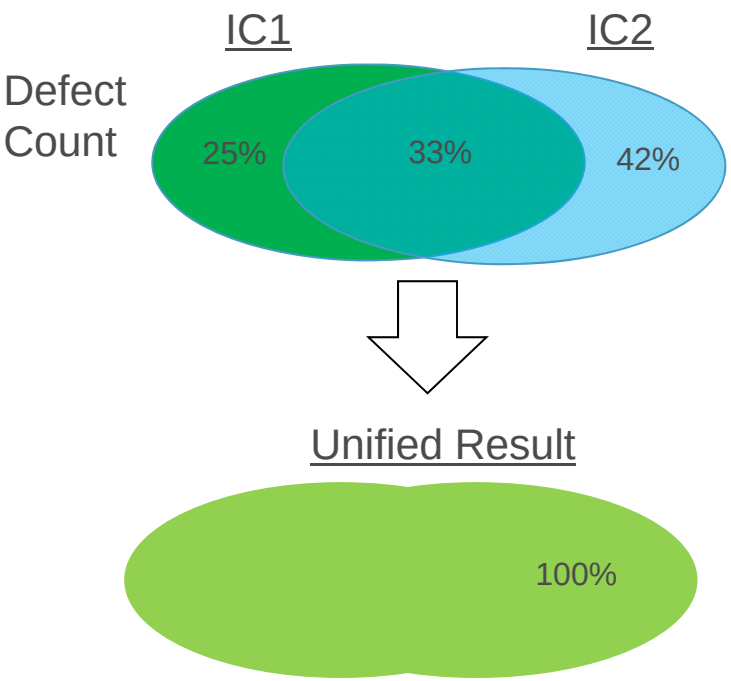
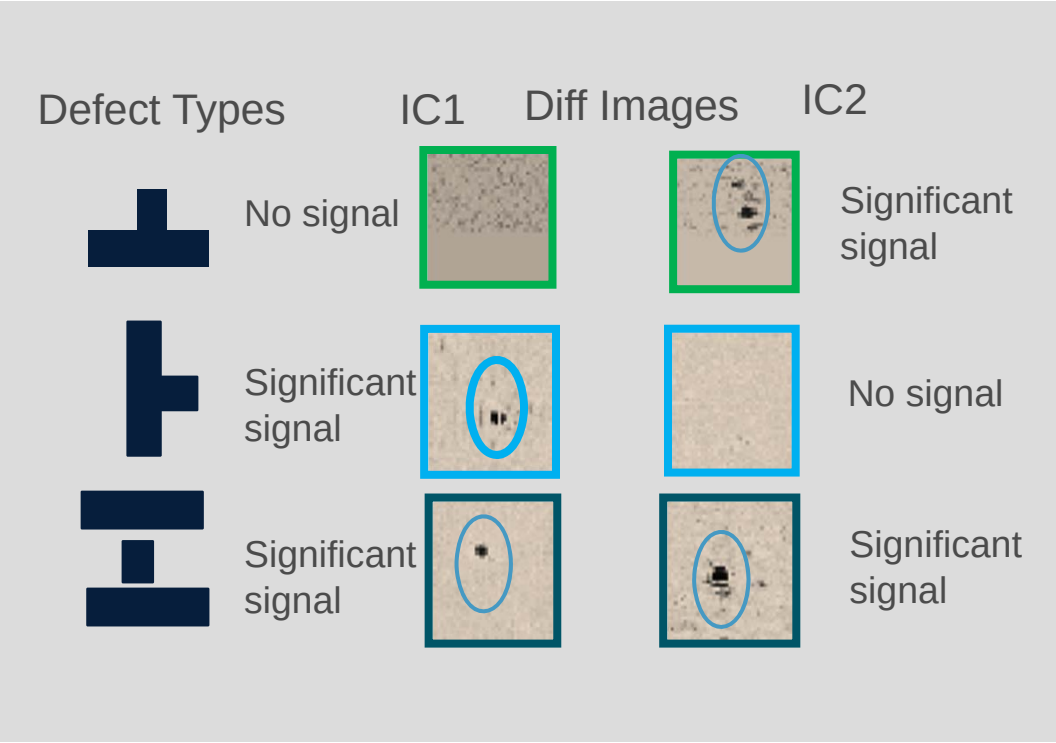
Two-Imaging Conditions Inspection

2xnm L/S programed defects

- Mask was inspected using two inspection conditions (ICs)
- Results are merged into a unified output

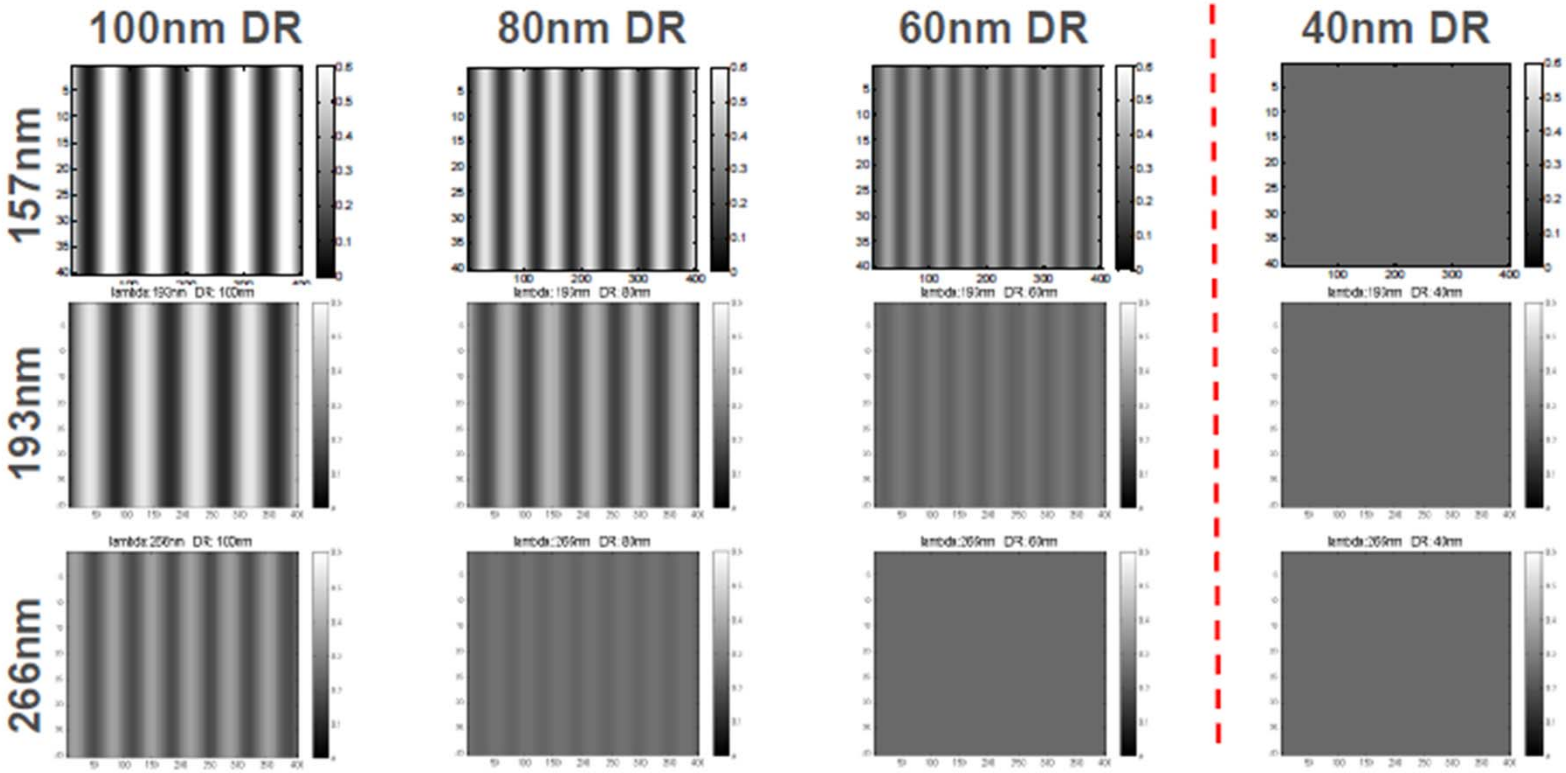




Full coverage at 20nm provided by dual illumination inspection

Wafer Inspection Resolution Road Block

Bright field is limited by low contrast



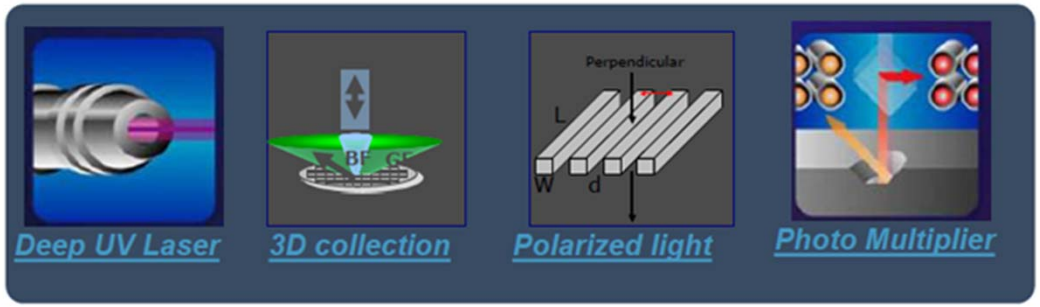
40nm design rule is the bright field resolution limit for all applicable wavelengths

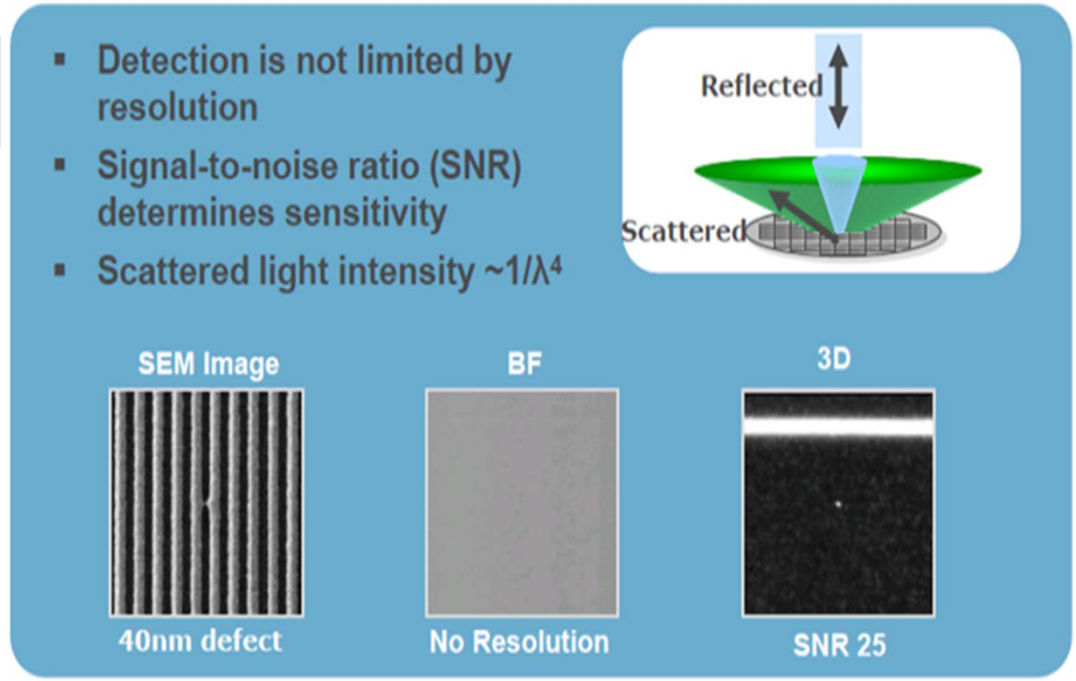
UVision5 Patterned Wafer Inspection (WI)

Beyond the resolution limit: Grey Field

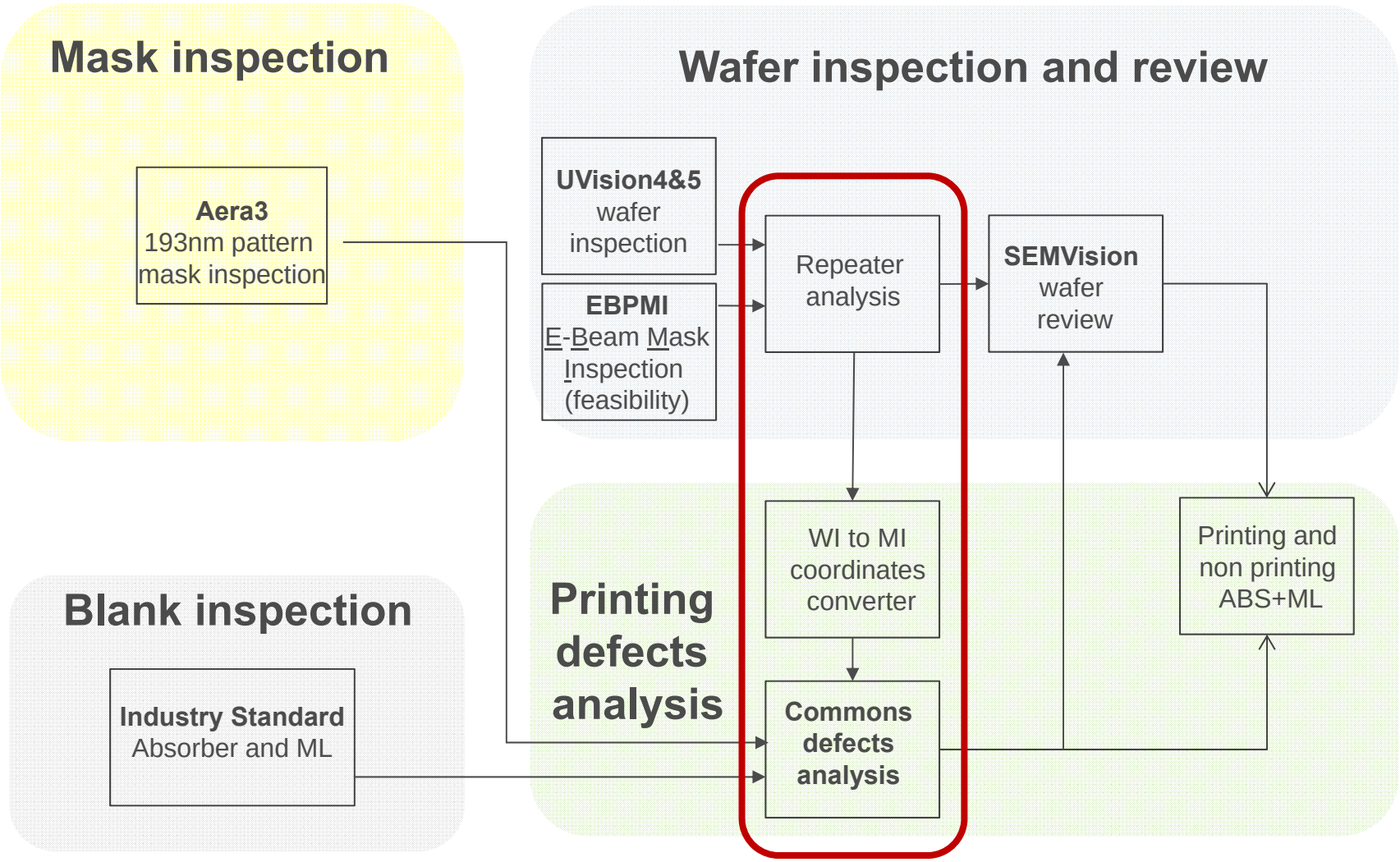
Key features:

- Smaller pixel sizes with high throughput (260..70nm, 10.2..1.7wph)
- Increased light in the Grey field channel
- Wide dynamic range Detectors and innovative noise reduction





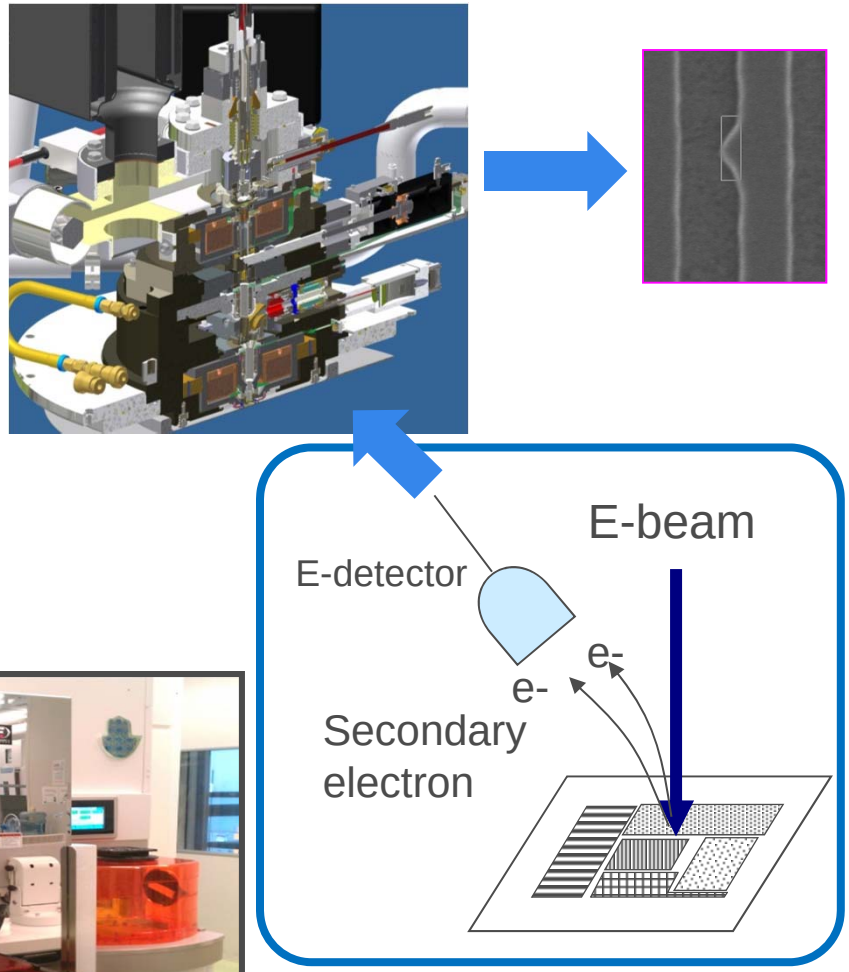
Pattern Wafer Inspection Repeater Analysis
Key Element of Defect Reduction Strategy



E-Beam Pattern Mask Inspection (EBPMI)

Key features:

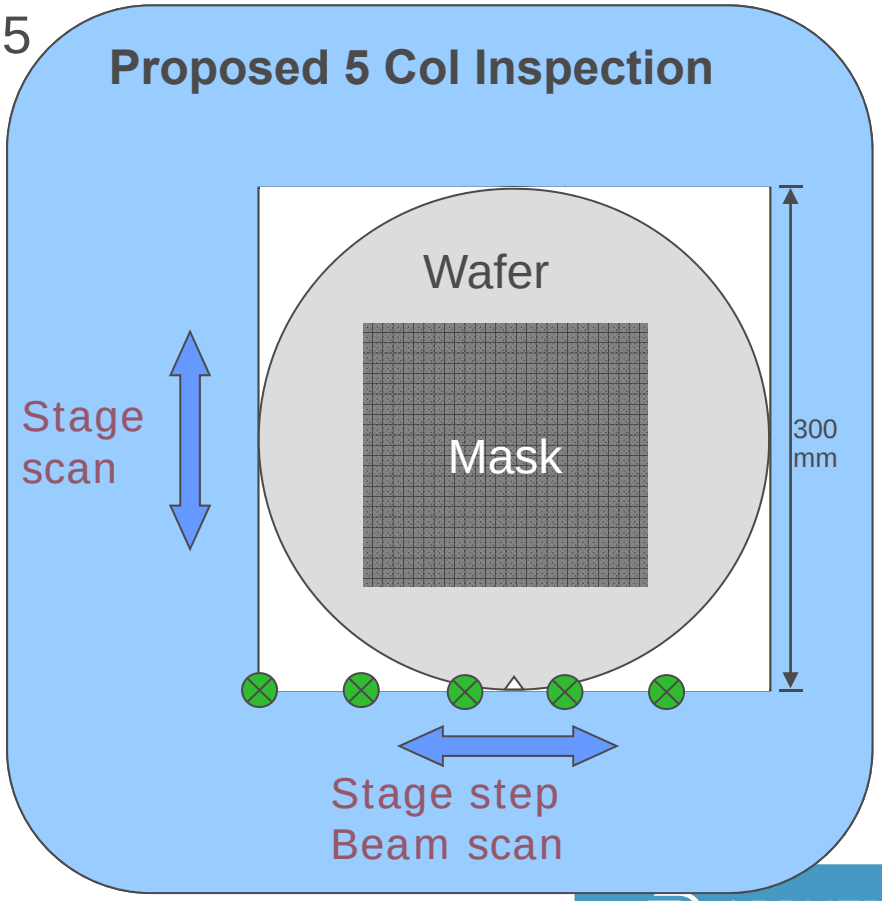
- High resolution inspection due to e-Beam small spot size
- High current density column technology
- Production worthy TPT by
  - High Beam Current
  - High Data Rate
- EUV mask handling



Multi e-Beam Inspection

Full mask and wafer scan

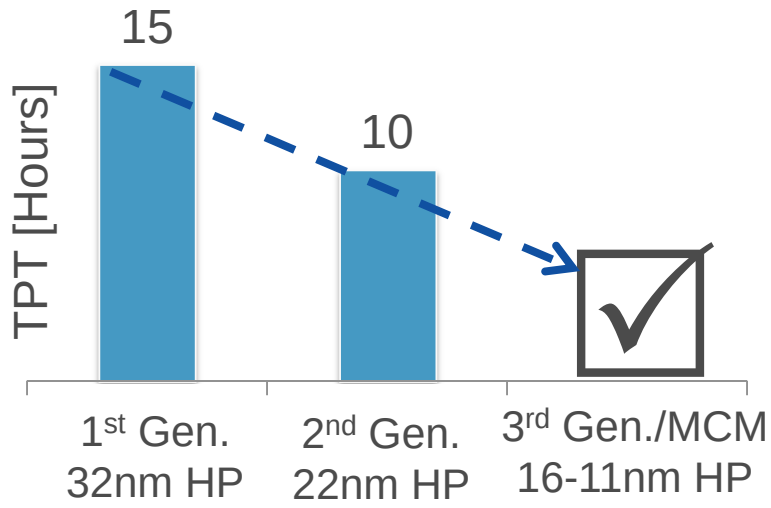
- Parallel slices
- Multi-Column Technology optimized for large care areas
  - full wafer, full die inspection
- Geometric TPT factor = $(\pi r^2 / 4r^2) \times 5$
  = approx 4.x



EBPMI Throughput Scalability – 3rd Gen

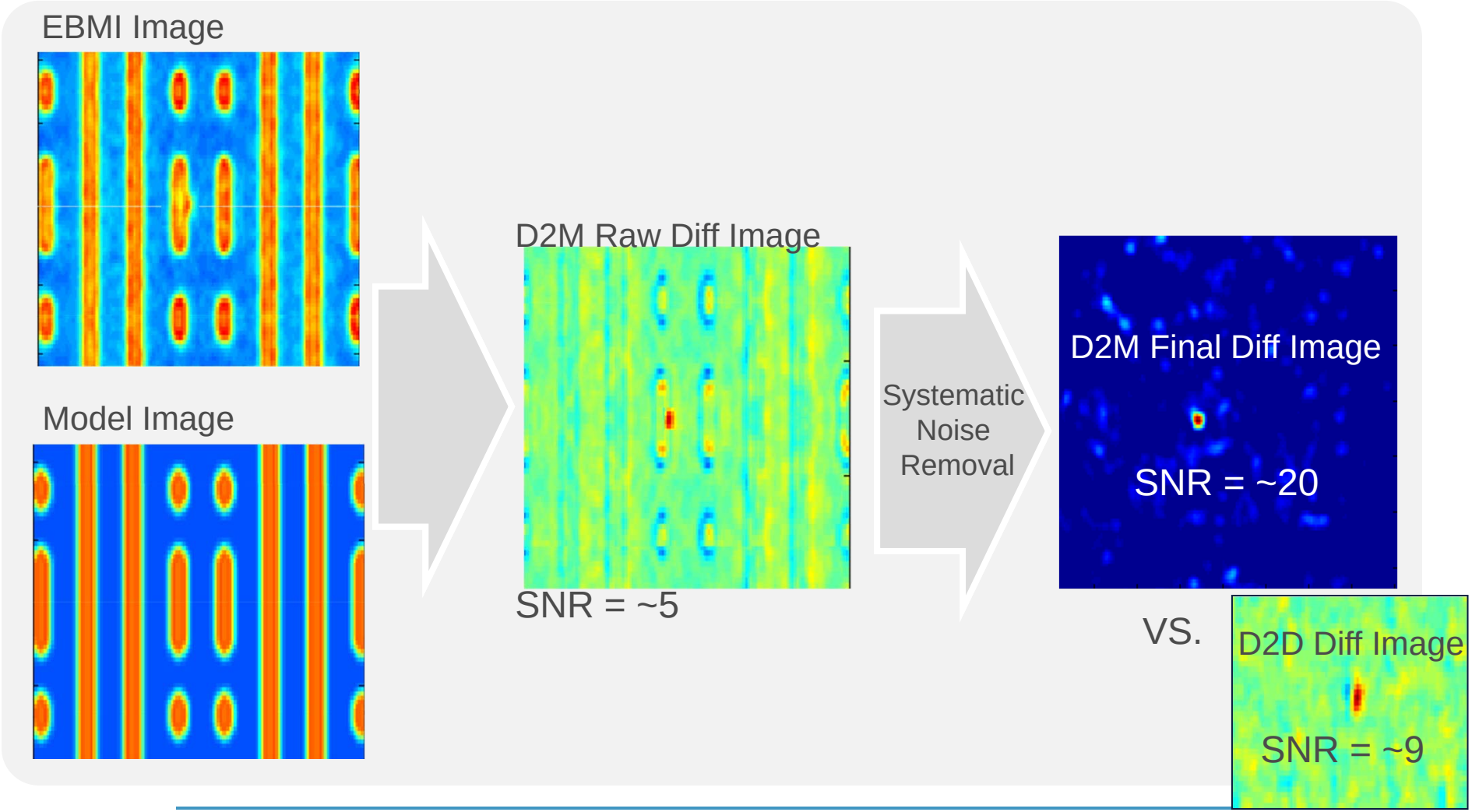
- Throughput is scalable:
  - Higher beam voltage
  - Higher beam current
  - Faster detectors
  - Multi column

EBMI TPT per Tech Generation (single column)



EBMI throughput scalable through engineering efforts

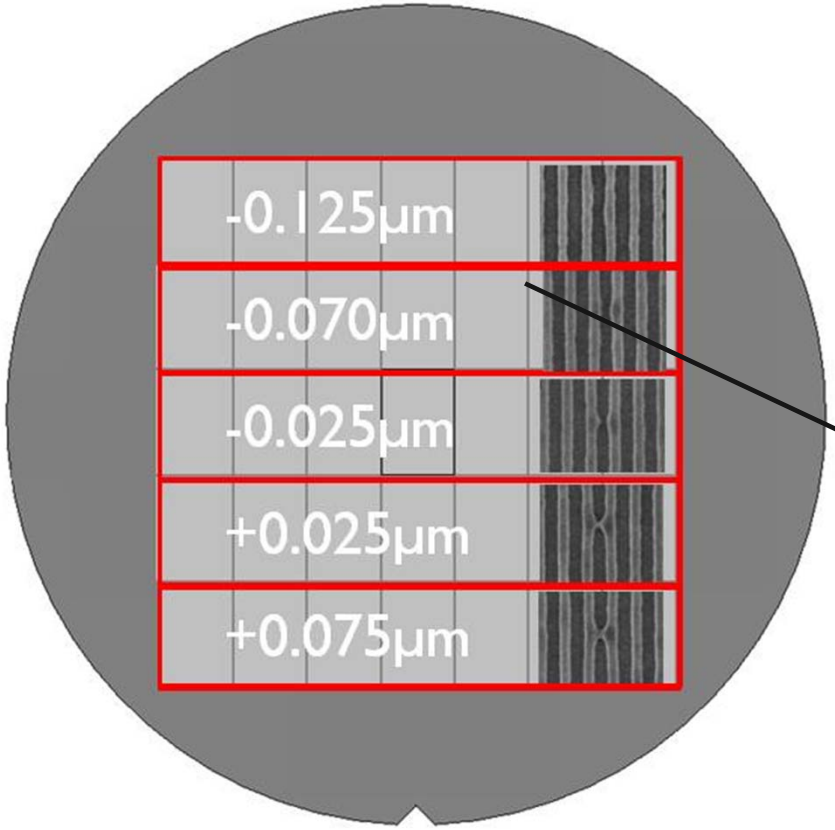
EBPMI Die-To-Model



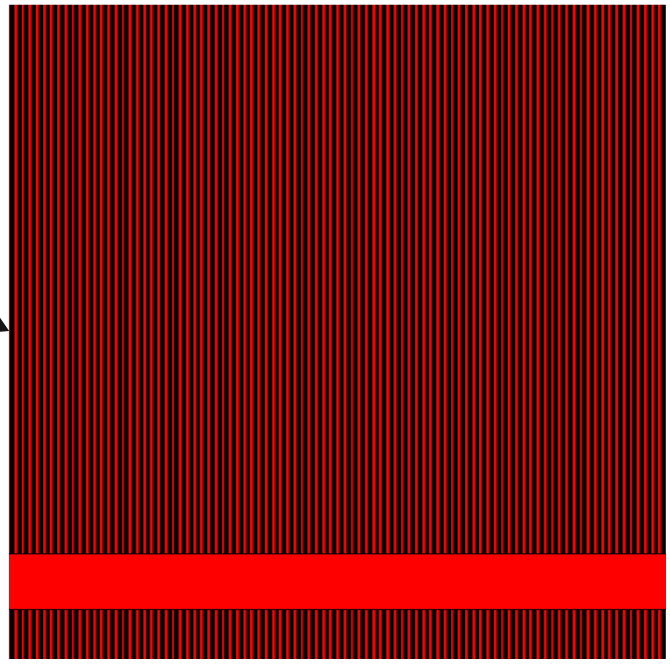
EBMI die-to-model yields better SNR than D2D

Case study 1*: ML defects detection with WI only

Can WI identify BI ML defects Missers ?



40nm L/S grating with support bar



Different focus exposure per row

(focus matrix wafer)

EMLC 2011, JONCKHEERE et al,* **"EVIDENCE OF PRINTING BLANK-RELATED DEFECTS ON EUV MASKS, MISSED BY BLANK INSPECTION" (invited to BACUS 2011 as best EMLC 2011 paper)

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Case study 1: Uvision4 WI TF Analysis

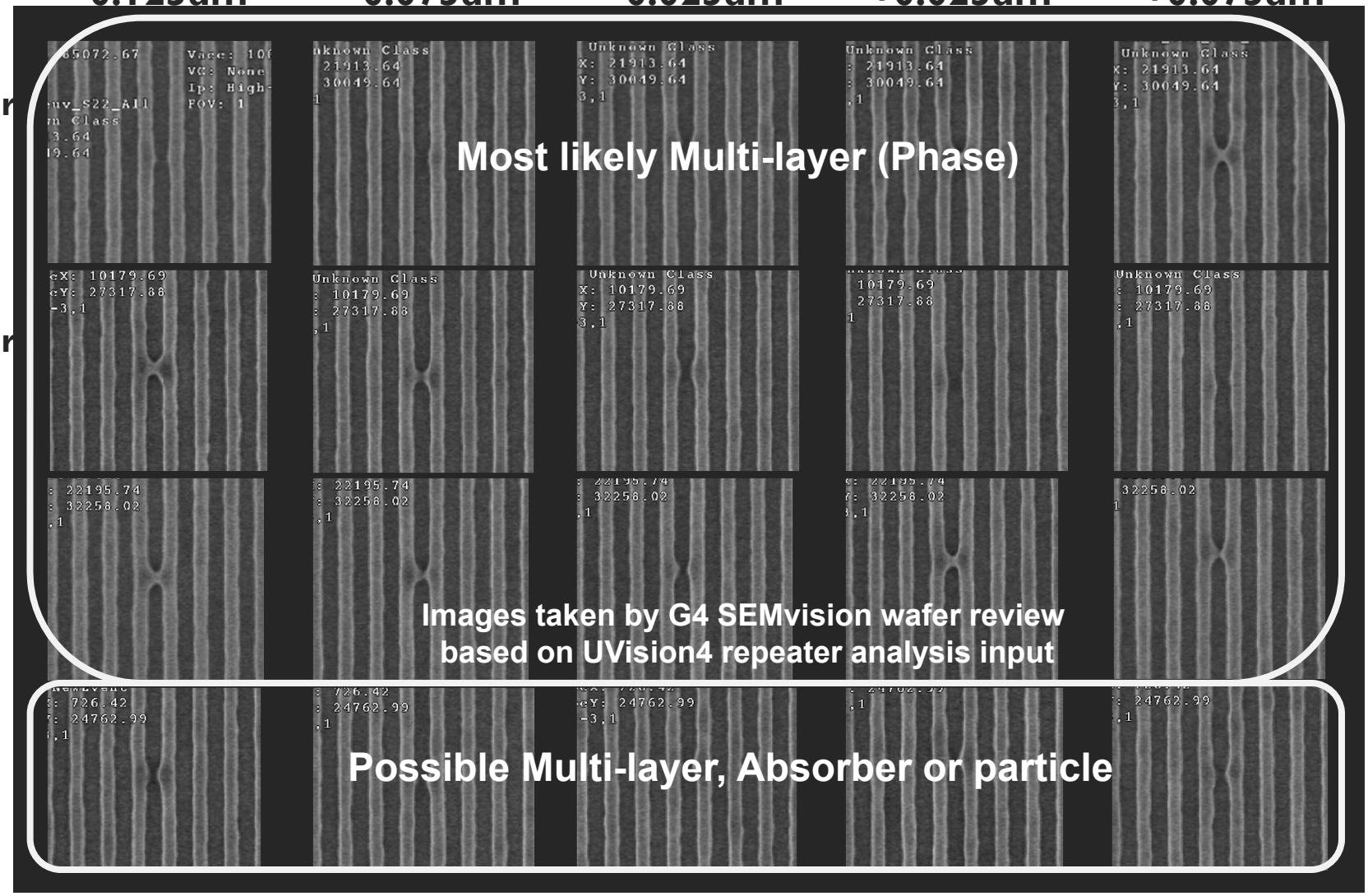
-0.125um | -0.075um | -0.025um | +0.025um | +0.075um

Prints better in + defocus

Prints better in – defocus

variation through focus

stable through focus



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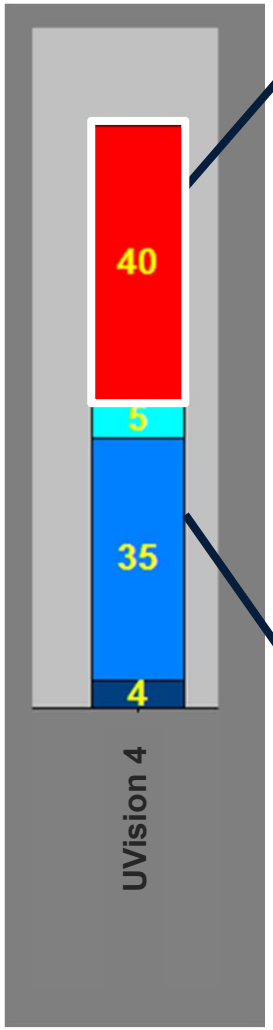
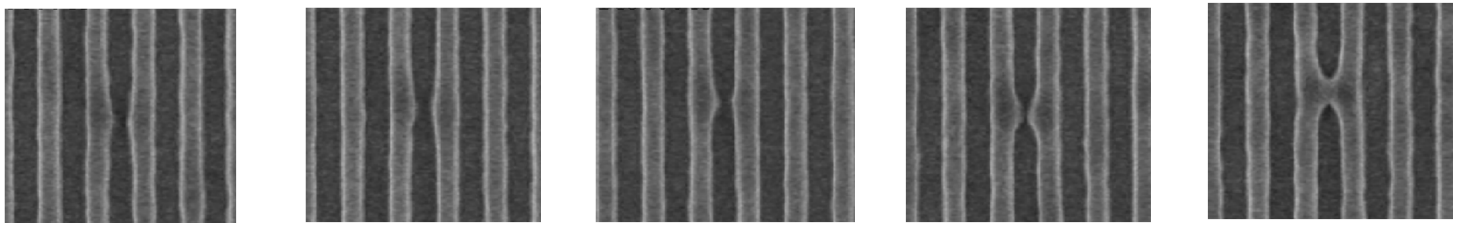
Case study 1: WI results summary



Additional 40 defects to imec's baseline found by UVision4
30 defects show through-focus behavior (most likely ML defects) :



From – to + focus offset

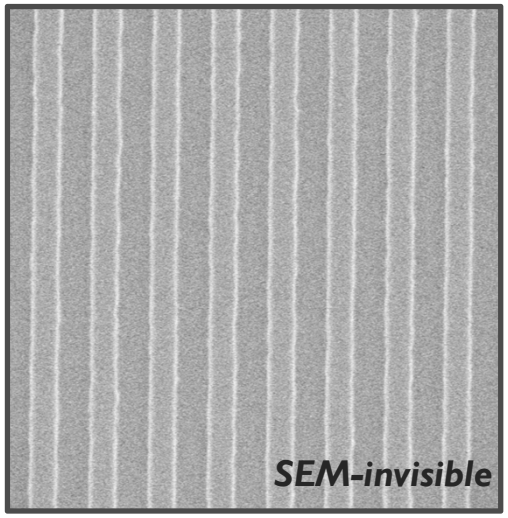
and 10 unchanged through focus

Common imec base line and UVision4

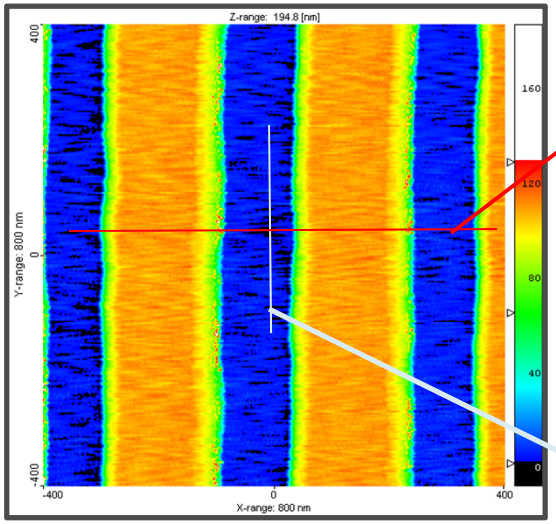
Case study 1: Results Verification with AFM

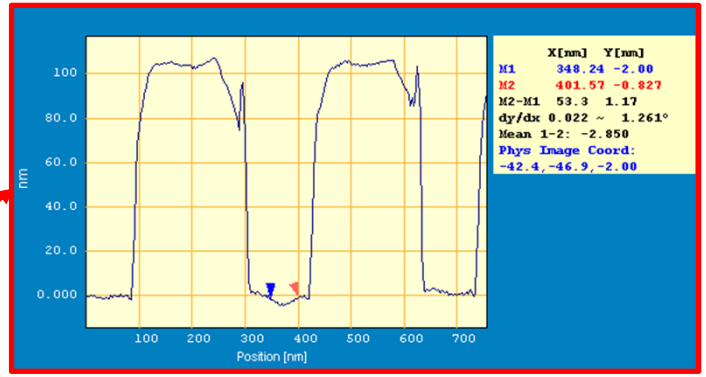
Uvision4 detection of blank inspection misser

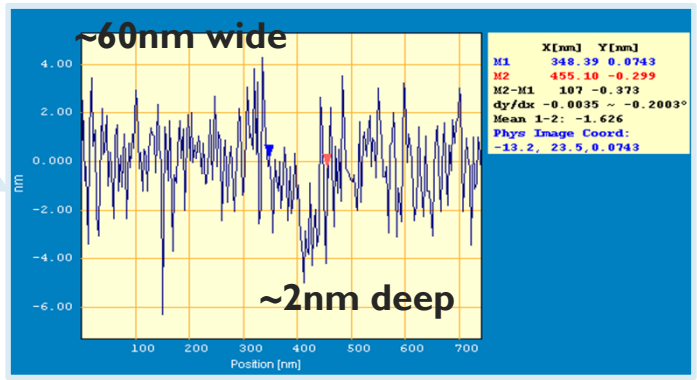
SEM-review on reticle



AFM-review on reticle

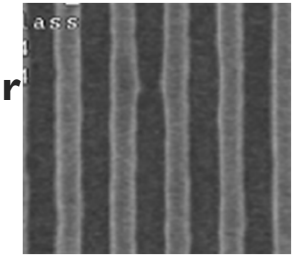




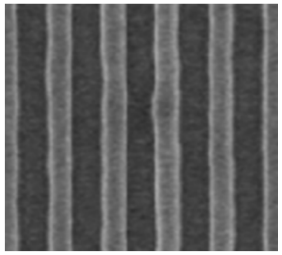


Review on wafer through focus

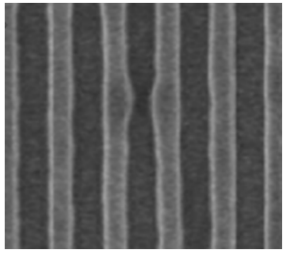
-0.125um



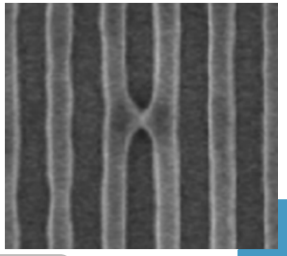
-0.075um



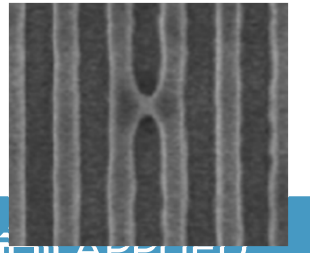
-0.025um



+0.025um



+0.075um

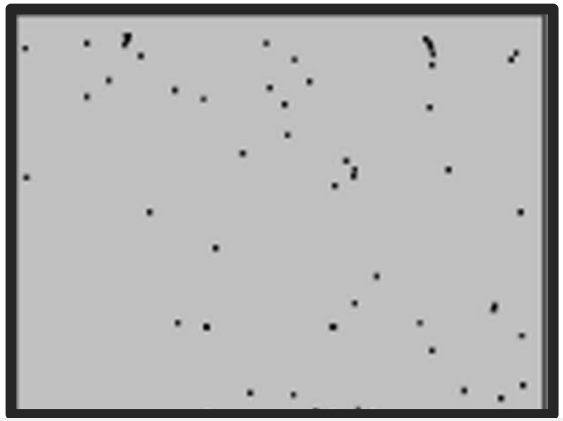


Case Study 2*: Combined PMI and WI inspection

Advance multi-layer defects detection

Patterned wafer inspections finds absorber and multi-layer defects

Patterned mask inspections finds **all printing** absorber defects



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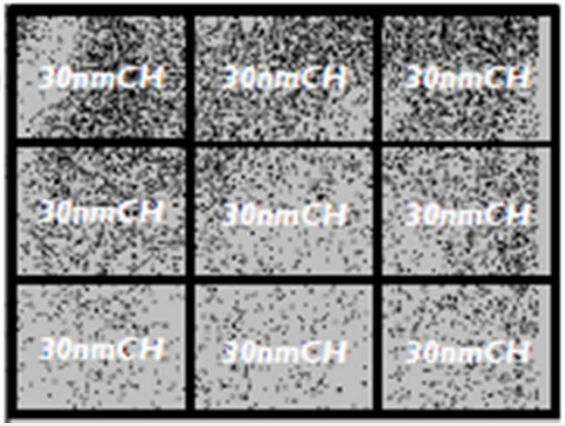

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Pure Multi-layer Defect Bin (which added to the blank inspection results)

30nm CH mask

UV5 WI :
Repeater analysis

Aera3 PMI :
Die-to-Die

*Presented by D. Van den Heuvel (imec), EUVL 2012, Session 4 and at the poster session: L. Shoval (AMAT), EUVL 2012

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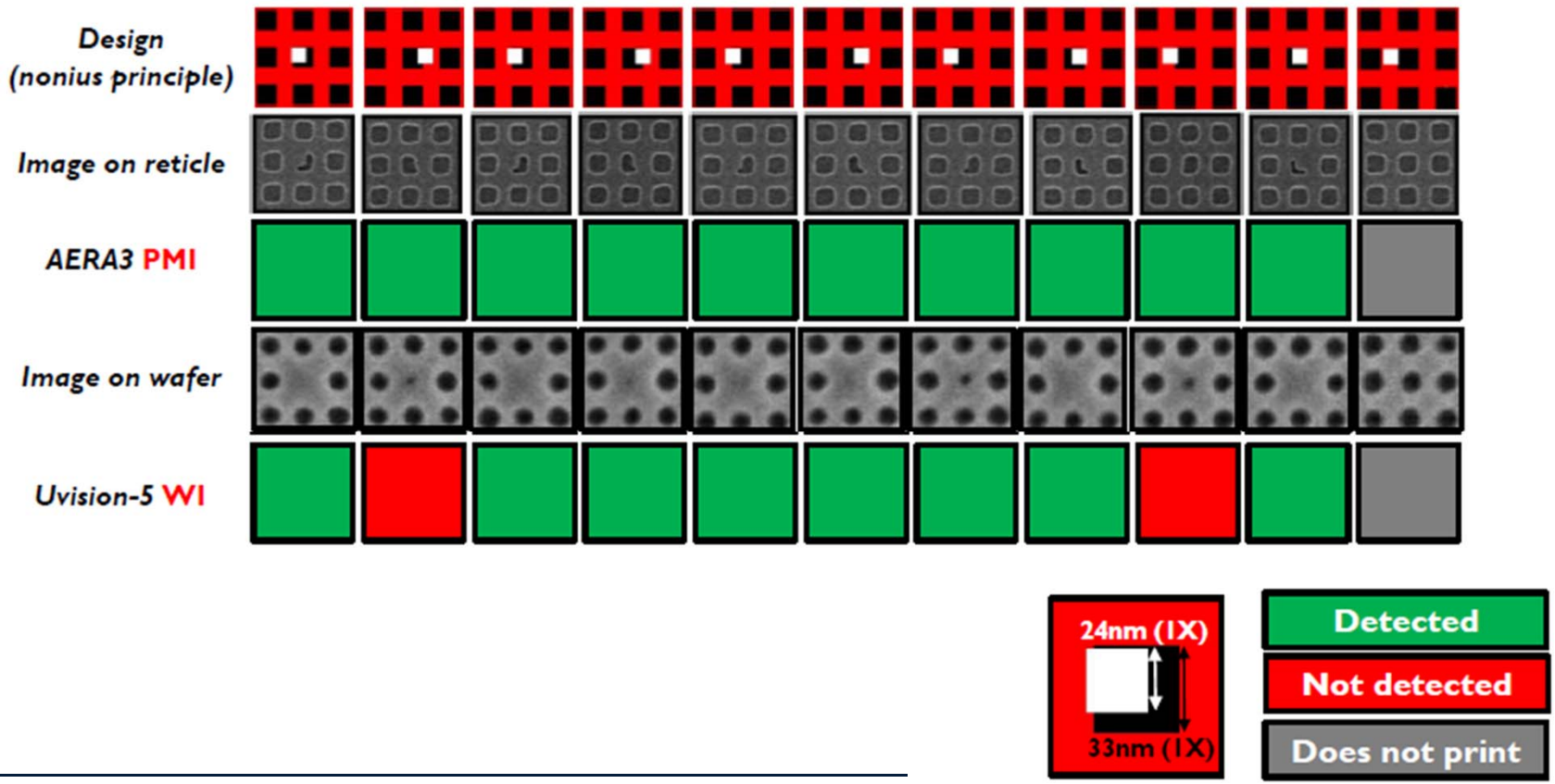
Case Study 2 Results: Programmed Defects

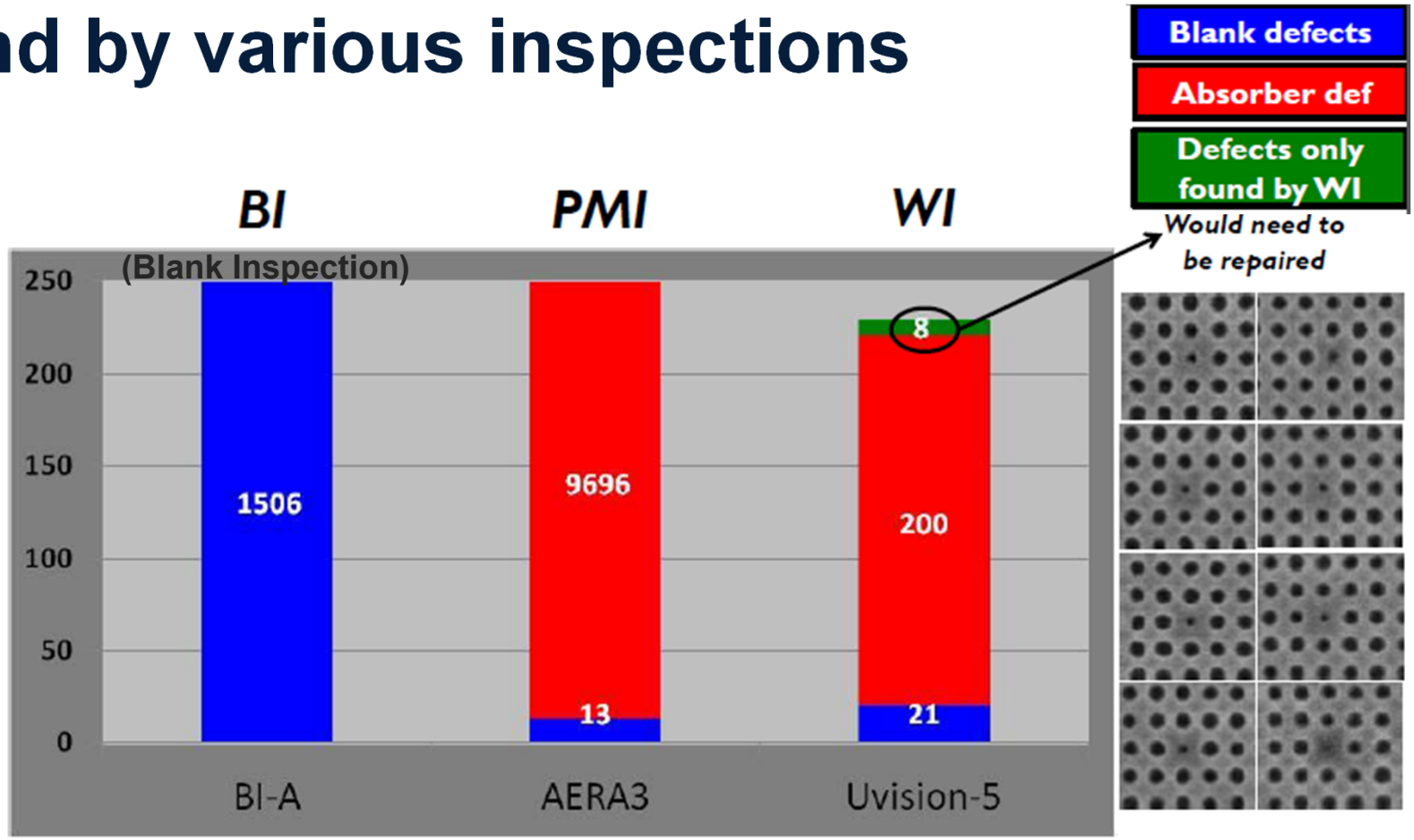
Uvision5 (WI) and Aera3 (PMI) performance



Both UVision5 and Aera3 are capable for detecting challenging printing absorber originated defects

Case Study 2 Results: Multi-layer Defects

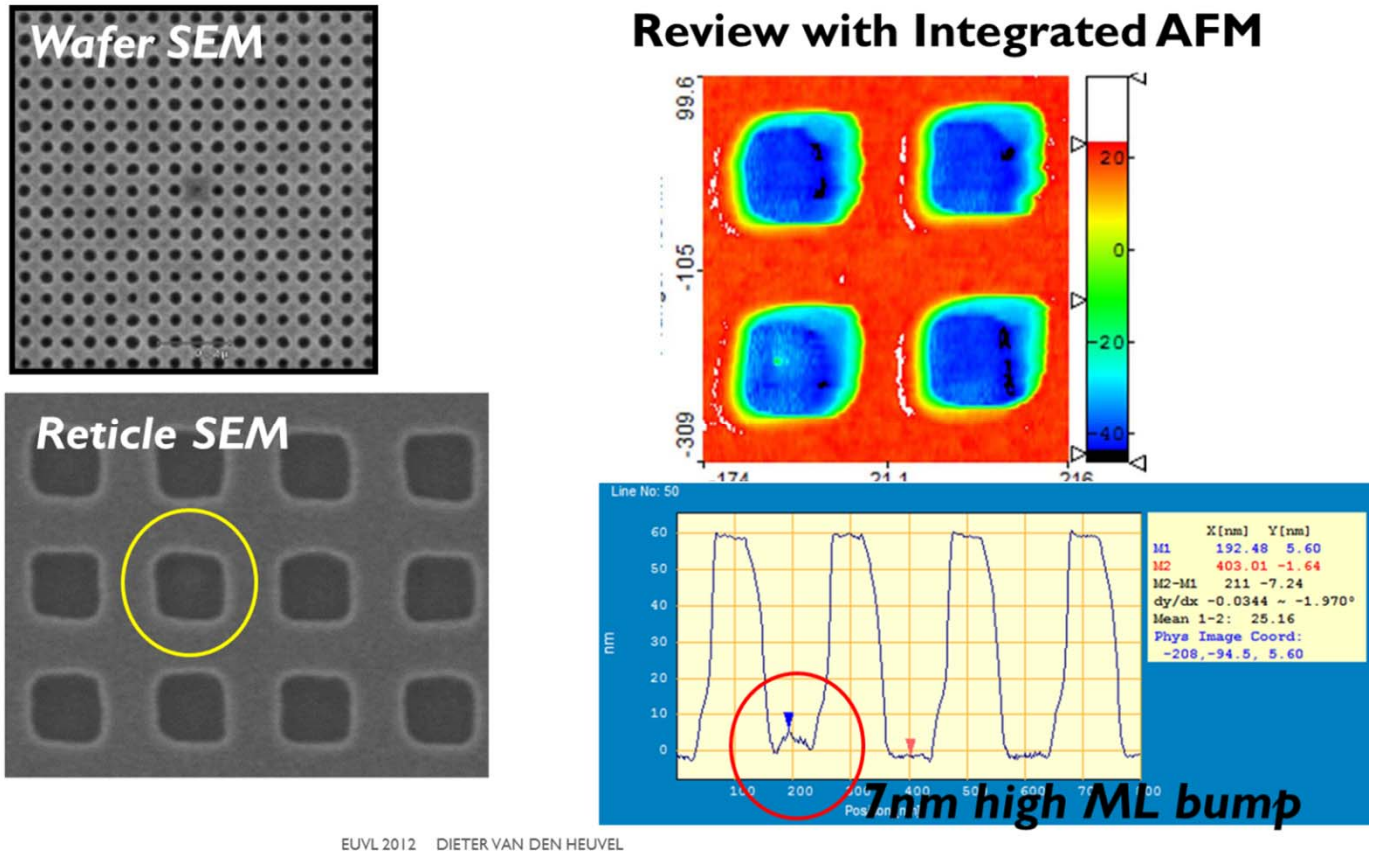
Found by various inspections



8 additional repairable Multi-layer defects detected by UVision5 (confirmed by mask SEM and AFM) which had not been obtained by BI and PMI

UVision5 Unique Multi-layer Defects

Defects Compensation repair*



*Presented by D. Van den Heuvel (imec), Session 4, Tuesday, October 02

Possible device killer Multi-layer defects, discovered only by WI, are being repaired*

Summary

- 2Xnm EUV mask inspection needs are covered by Aera3-EUV
  - Full coverage down to 20nm with one or two imaging conditions

- E-beam mask inspection technology can meet EUV production needs at <20nm HP
  - Throughput and Resolution/Sensitivity are scalable through technology evolution
  - Target <5hrs

- WI and PMI found evidence for multilayer defects, not discovered on blank:
  - UVision4 WI through focus analysis found 30 potential missing ML defects by blank inspection tools on 40nm L/S mask
  - Combined Uvision5 WI and Aera3 PMI methodology increased ML detection found 8 additional ML defects vs. BI base line on 30nm CH mask
  - The additional ML defects found by Uvision5 proven to be repairable *

*Presented by D. Van den Heuvel (imec), Session 4, Tuesday, October 02

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Dank U !
Merci !

Questions?