Lessons Learned from Correlation between EUV Mask Inspection, Blank Inspection and Wafer Print Analysis

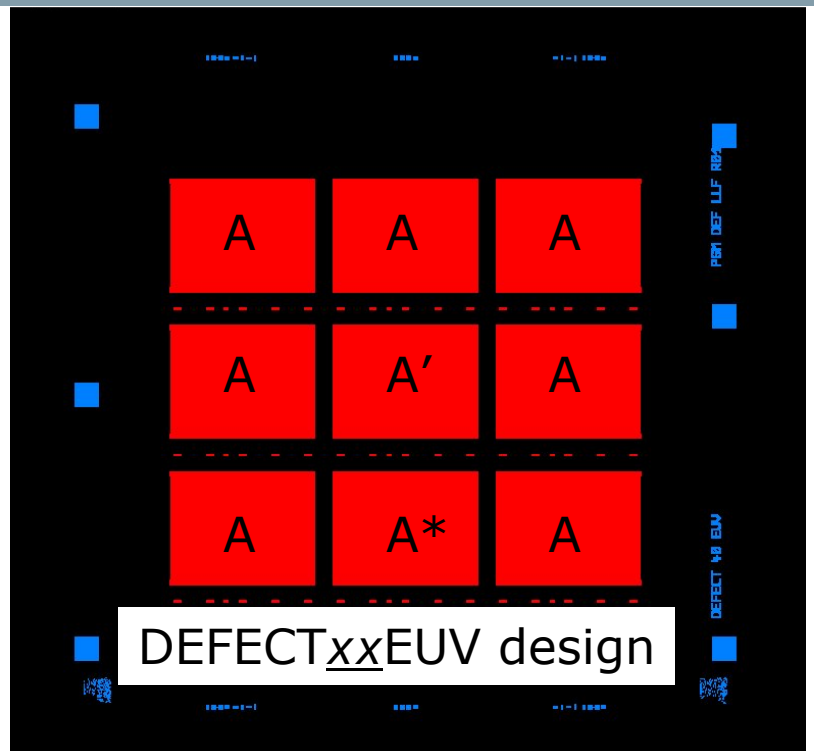
R. Jonckheere, D. Van den Heuvel,
T. Abe[1], H. Hashimoto[2], C. Holfeld[3],
J. Hermans, E. Hendrickx, A. Goethals,
G. Vandenberghe, K. Ronse

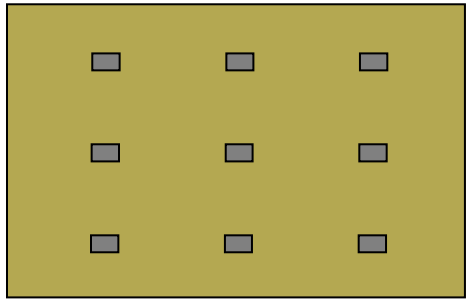
([1] DNP, [2] NuFlare, [3] AMTC)

IMEC's EUV mask defectivity work **in 1 slide**

- Use **inspection of printed wafers** + repeater analysis
  - Try to capture multiple wafer inspection tools available
- Evaluate masks from multiple sources
- Focus on **natural defects**,
  but learn through programmed defects.
- Correlate to **blank inspection**
  - Try to capture multiple blank inspection tools available
- Correlate to what **mask inspection**
  - Try to capture multiple mask inspection tools available
- **2 goals:**
  - Evaluate defectivity level of state-of-the-art EUV reticle supply
    (presentation of yesterday)
  - **Visualize tool capability gaps (if any)**
    + learn why tools missed printing defects
    (THIS presentation)

Methodology:
Detection of mask defects via wafer inspection





Detail of A'

9 blocks of programmed defects

- Subdie (A) consists of vertical *xx* nm L/S, with 3 variations:
  - A: without programmed defects
  - A': with opaque absorber defects
  - A*: intended for substrate defects
- Wafer inspection on KLA2800
  - Broadband DUV (260-380nm)
  - 0.28µm pixel size
  - Detection by cell-to-cell comparison
  - Very sensitive setting possible
  - Analysis is confined to **repeating defects** among #dies printed (= **reticle** defects)

(EUVS2008)

Defect density benchmarking

- **Based on wafer printing + wafer inspection**

- Defect density based on defects detected by KLA2800 (@ ~80nm)
  - ***DEFECT32*** *(area = 66 cm²)*
    *# defects = 14 → **density = 0.21 defects/cm²***

    (PMJ2009)

    Still best result

  - ***DEFECT40FF*** *(area = 132 cm²)*

    yesterday

    - RET A: # defects = 91 → **density= 0.68 defects/cm²**
    - RET B: # defects = 110 → **density= 0.83 defects/cm²**
    - RET C: # defects = 37 → **density= 0.27 defects/cm²**

  - **TARGET: ~0.036 defects/cm² (@ ~30nm)**

    = 5 defects for the full field

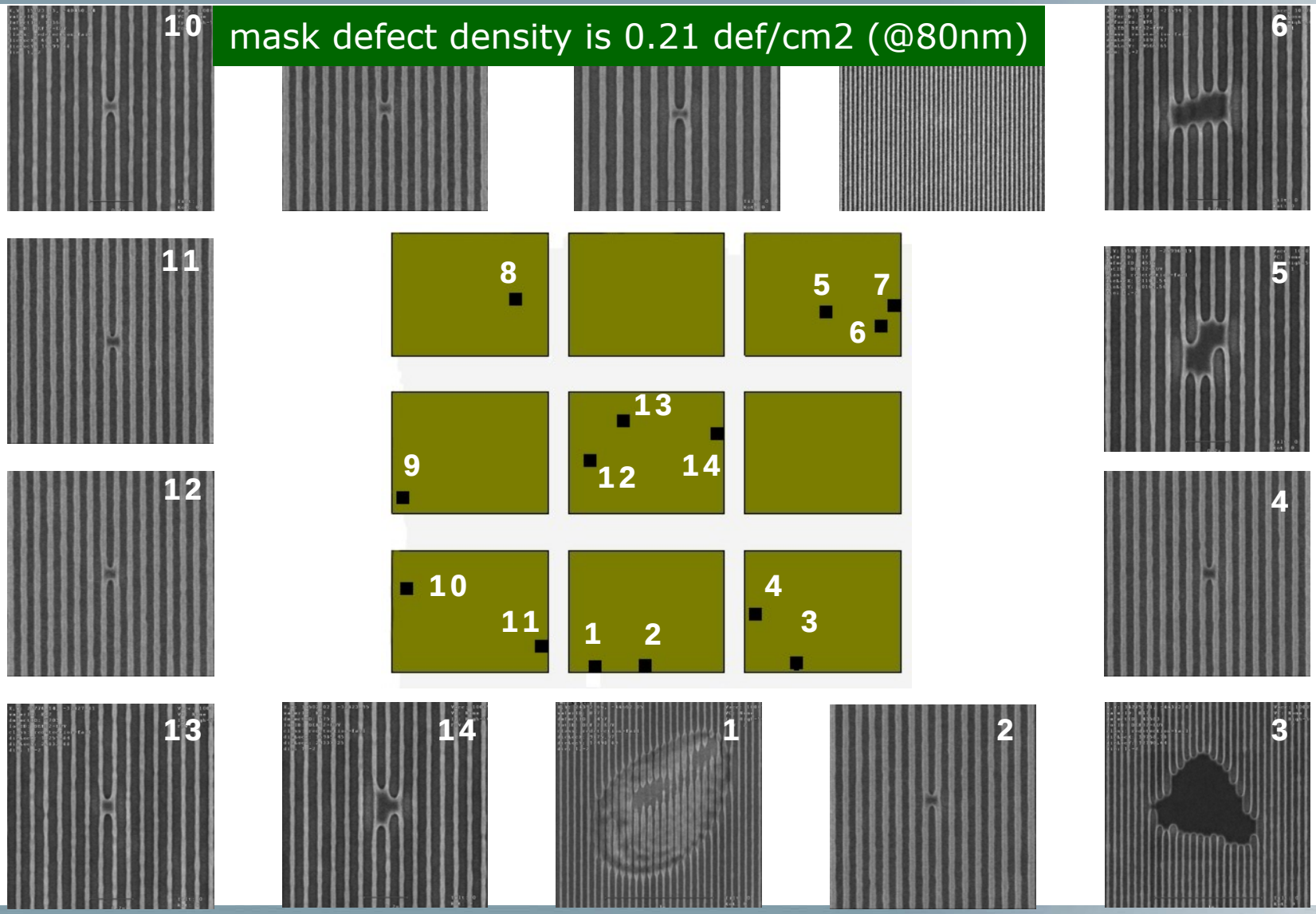
Outline

- Introduction
- **First correlation of printed image to blank inspection AND patterned mask inspection (Defect32 reticle)**
  - Wafer inspection vs patterned mask inspection
  - Additional comparison to blank inspection
  - Improved wafer inspection
  - Update on defect density
- Defect Source Analysis (Defect40FF reticle)
- Conclusions

Defect32EUV

wafer inspection found only 14 defects (area ~ 50% of ADT field)

mask defect density is 0.21 def/cm2 (@80nm)

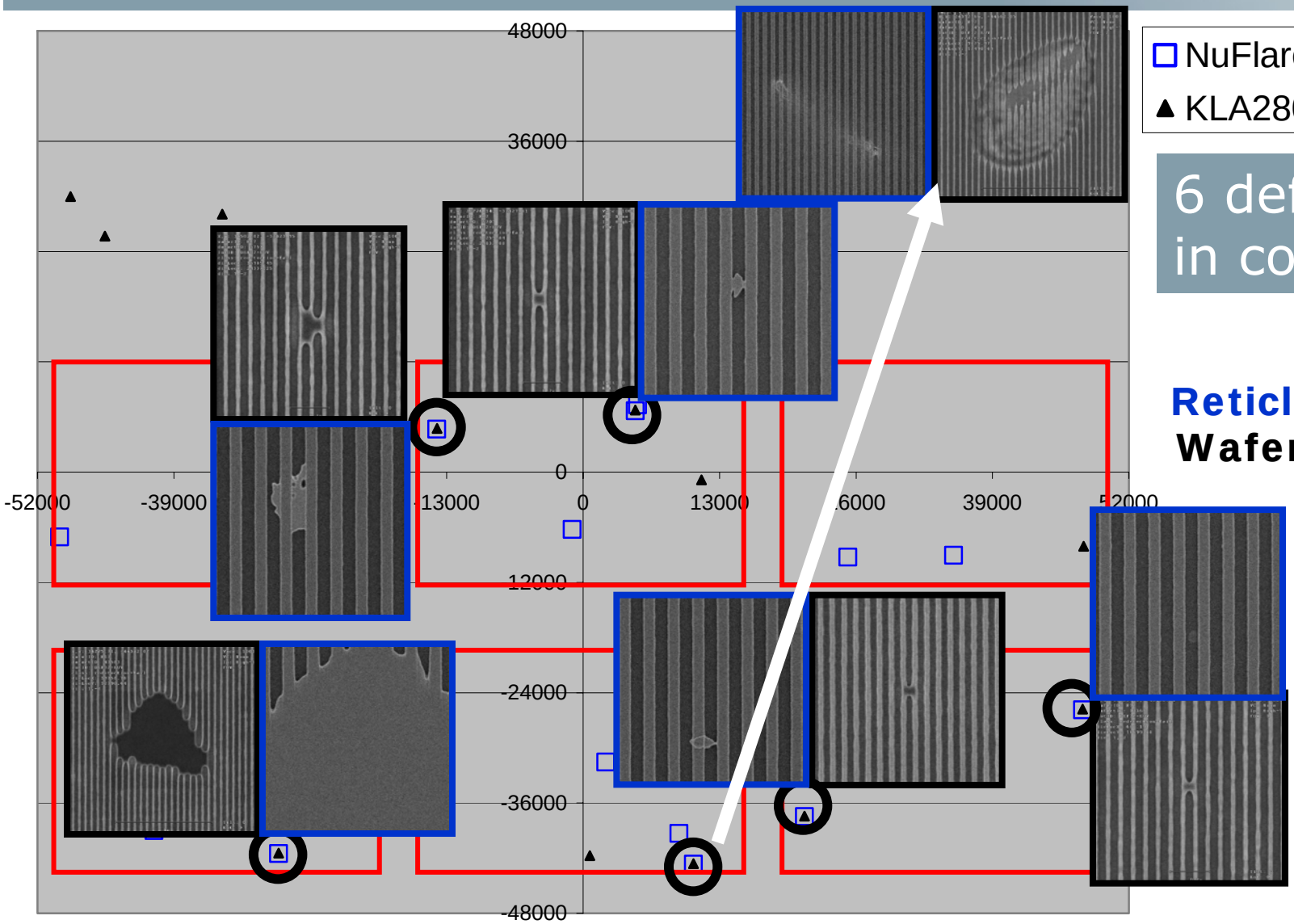


Sequence of evaluations used so far (DEFECT32 reticle)

- Hoya
  - Blank inspection (Lasertec tool)
  - Both after ML deposition, and after absorber deposition
- DNP
  - Mask fabrication
- NuFlare:
  - Patterned mask inspection on NPI5000+
    - die:die, 50nm pixel size
- Back at DNP:
  - SEM review + AFM on reticle, based on NPI defect map
  - Clean
- At IMEC:
  - ADT exposure
  - Wafer inspection on KLA 2800 and repeater analysis
  - Correlation of defect maps
  - Wafer review on AMAT SemVision G3 for all defects found by any of the 3 techniques
- Further analysis by AMTC:
  - Tilted SEM review on reticle for all defects found by any of the 3 techniques

Inspection = searching defects
Review = investigating defects found

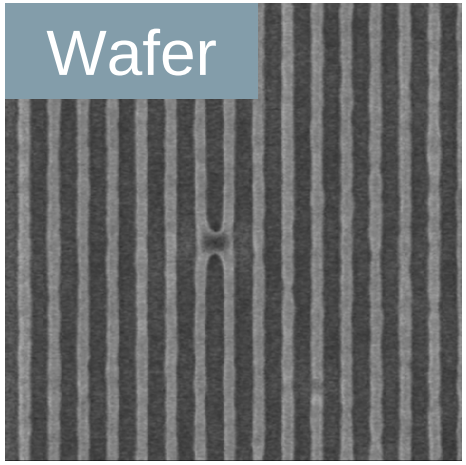
Wafer inspection (KLA2800) vs mask inspection (NuFlare NPI5000plus)

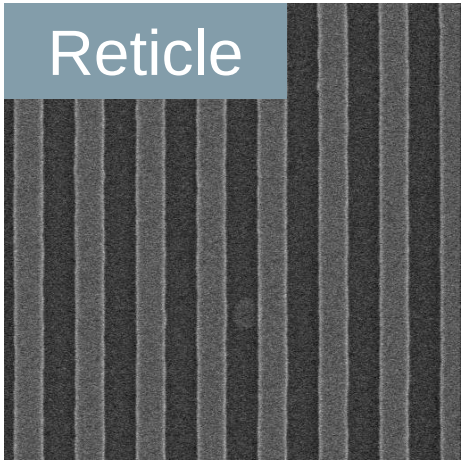


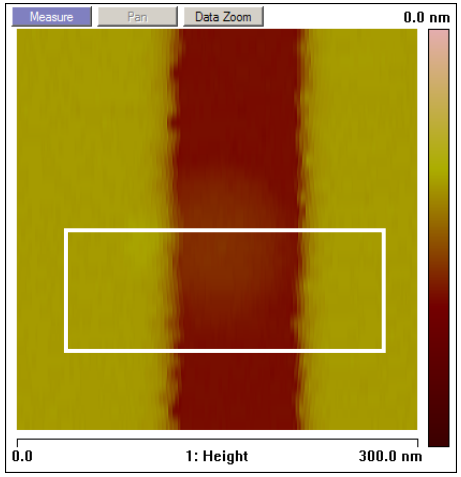
6 defects in common

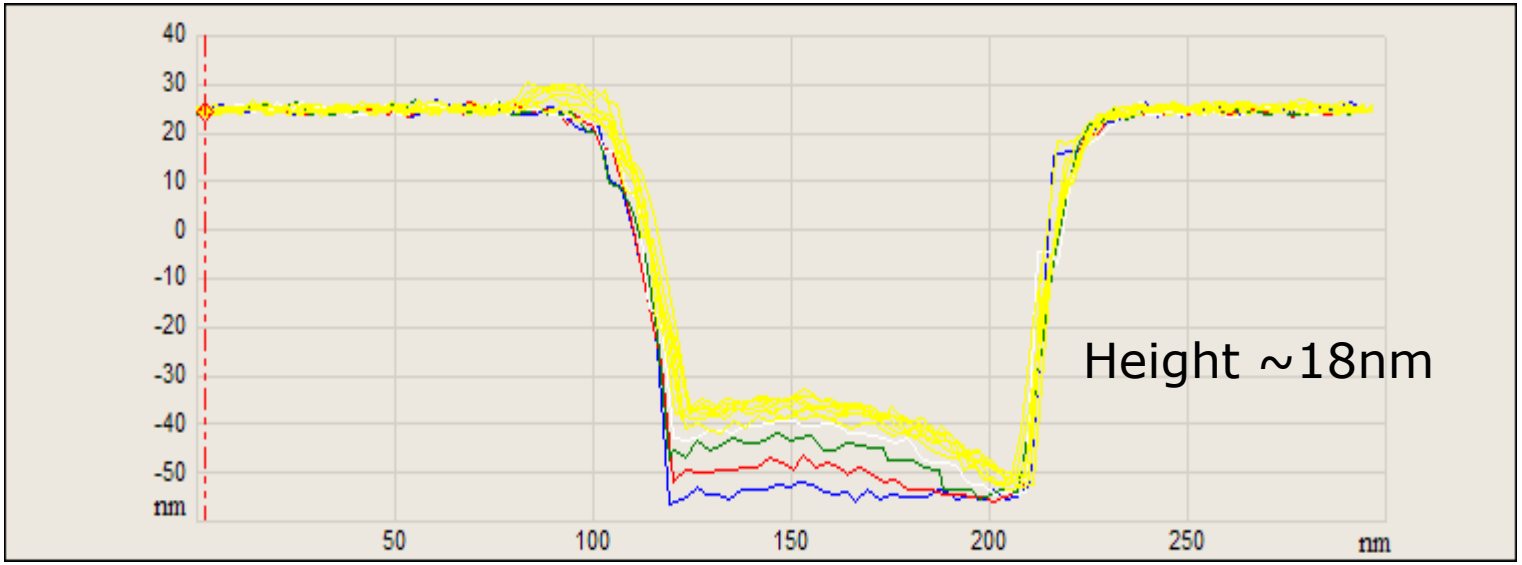
Reticle review
Wafer review

Example of printing natural defect
(ML and/or buffer)

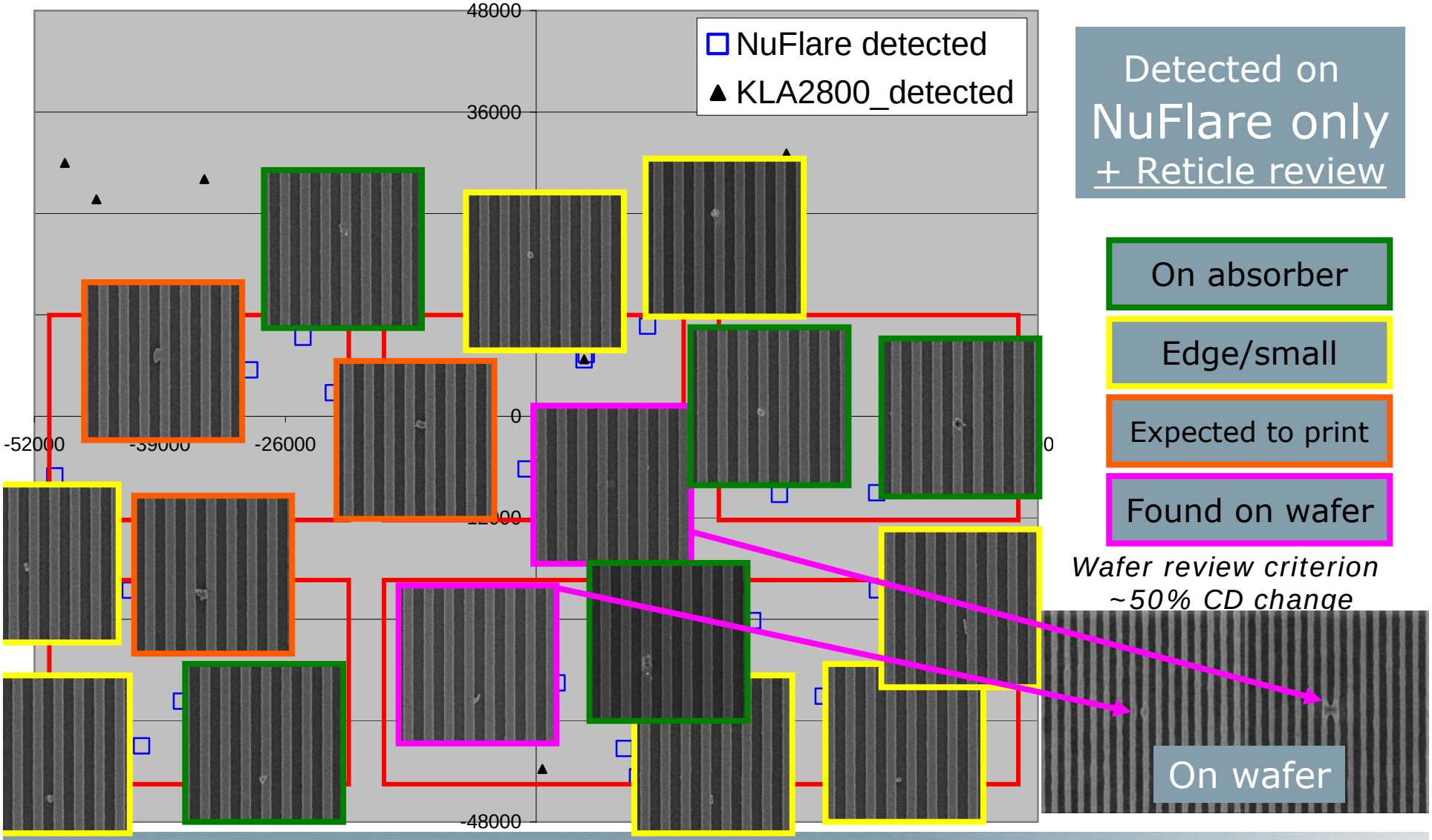




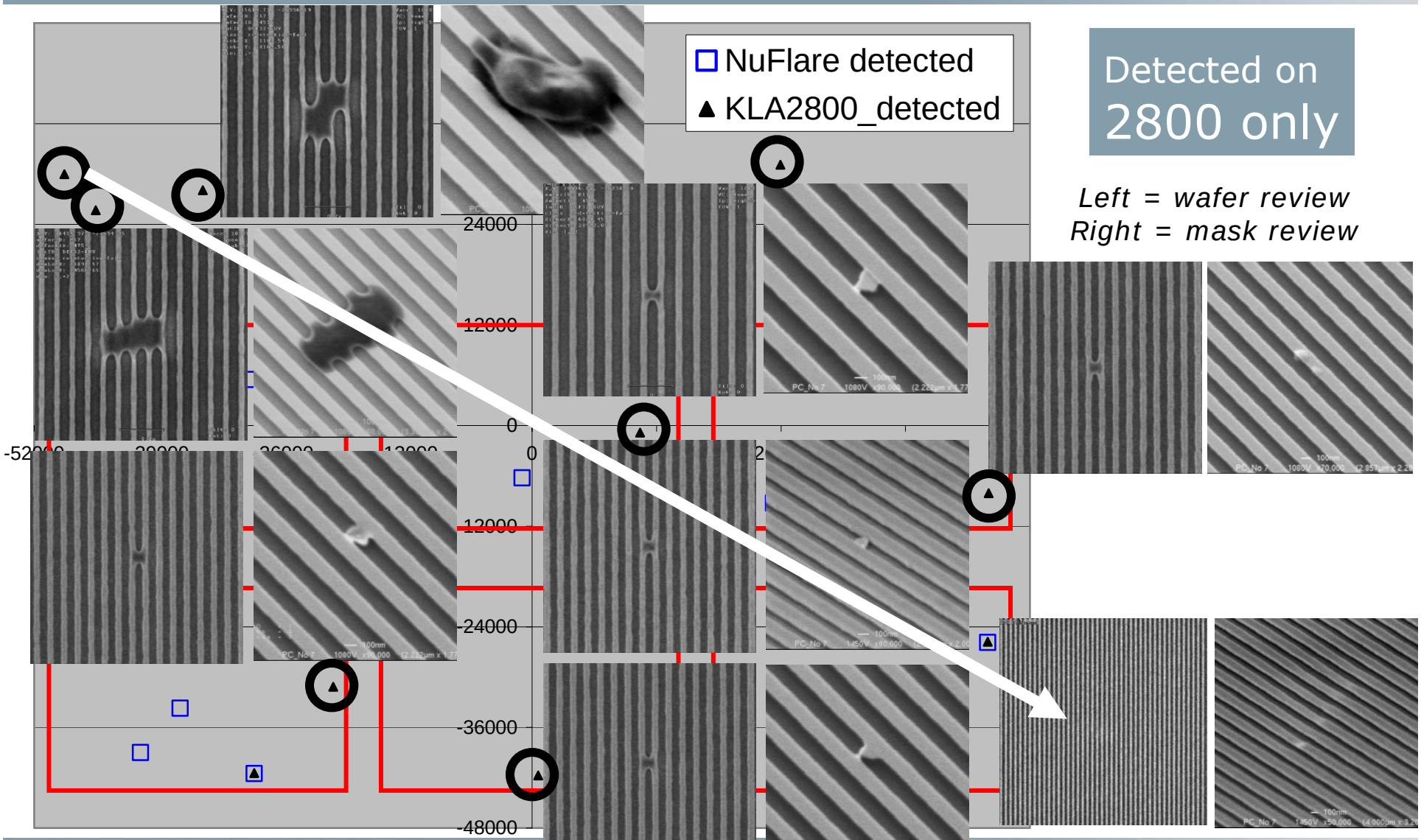




Wafer inspection (KLA2800) vs mask inspection (NuFlare NPI5000plus)



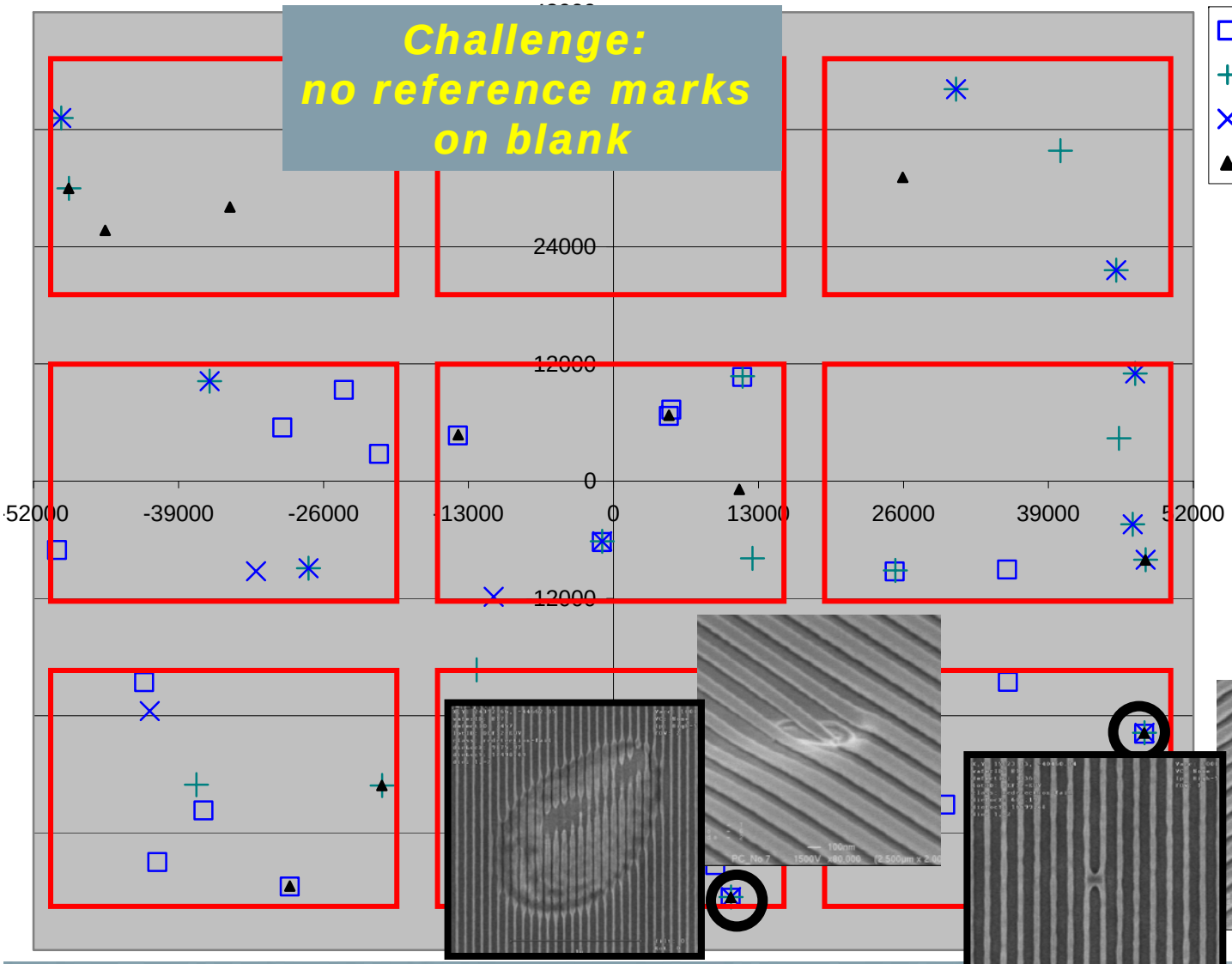
Wafer inspection (KLA2800) vs mask inspection (NuFlare NPI5000plus)



Detected on 2800 only

Left = wafer review
Right = mask review

Comparison wafer inspection, mask inspection and blank inspection

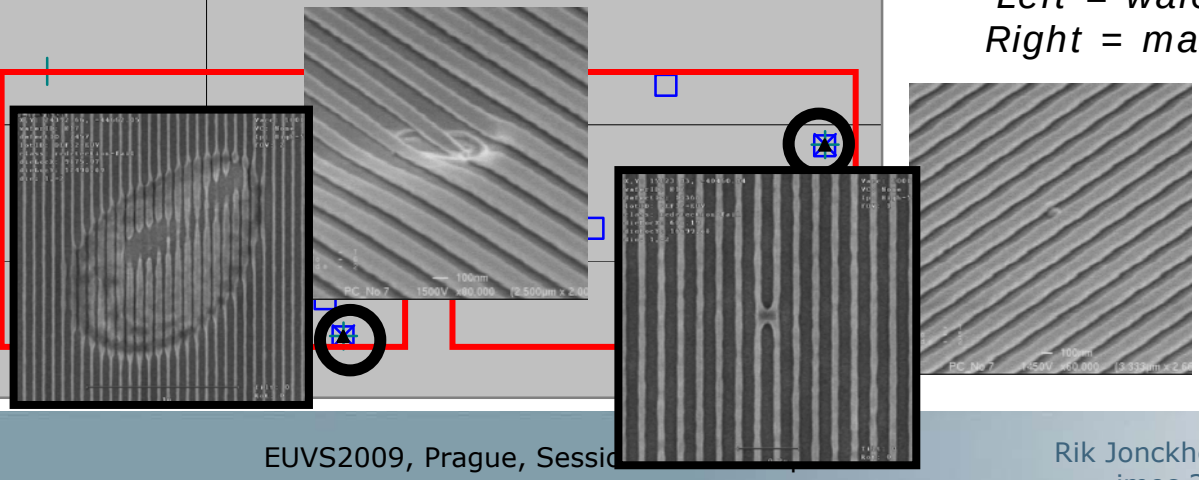


Challenge: no reference marks on blank

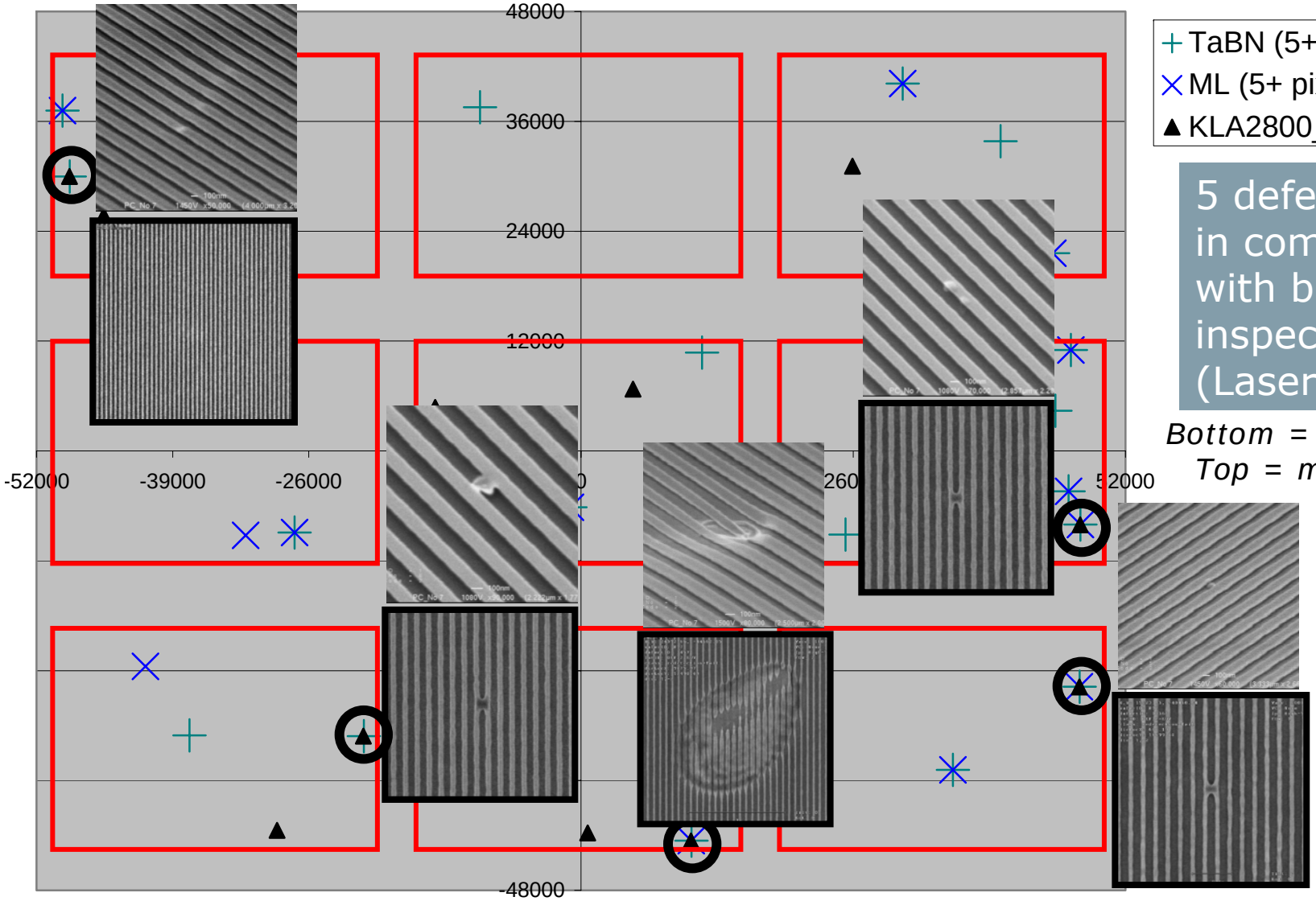
- Nuflare_detected
- TaBN (>6 pixels)
- ML (>6 pixels)
- KLA2800_detected

2 defects in common between all 4 techniques

Left = wafer review
Right = mask review



Wafer inspection (KLA2800) vs blank inspection (Lasertec)

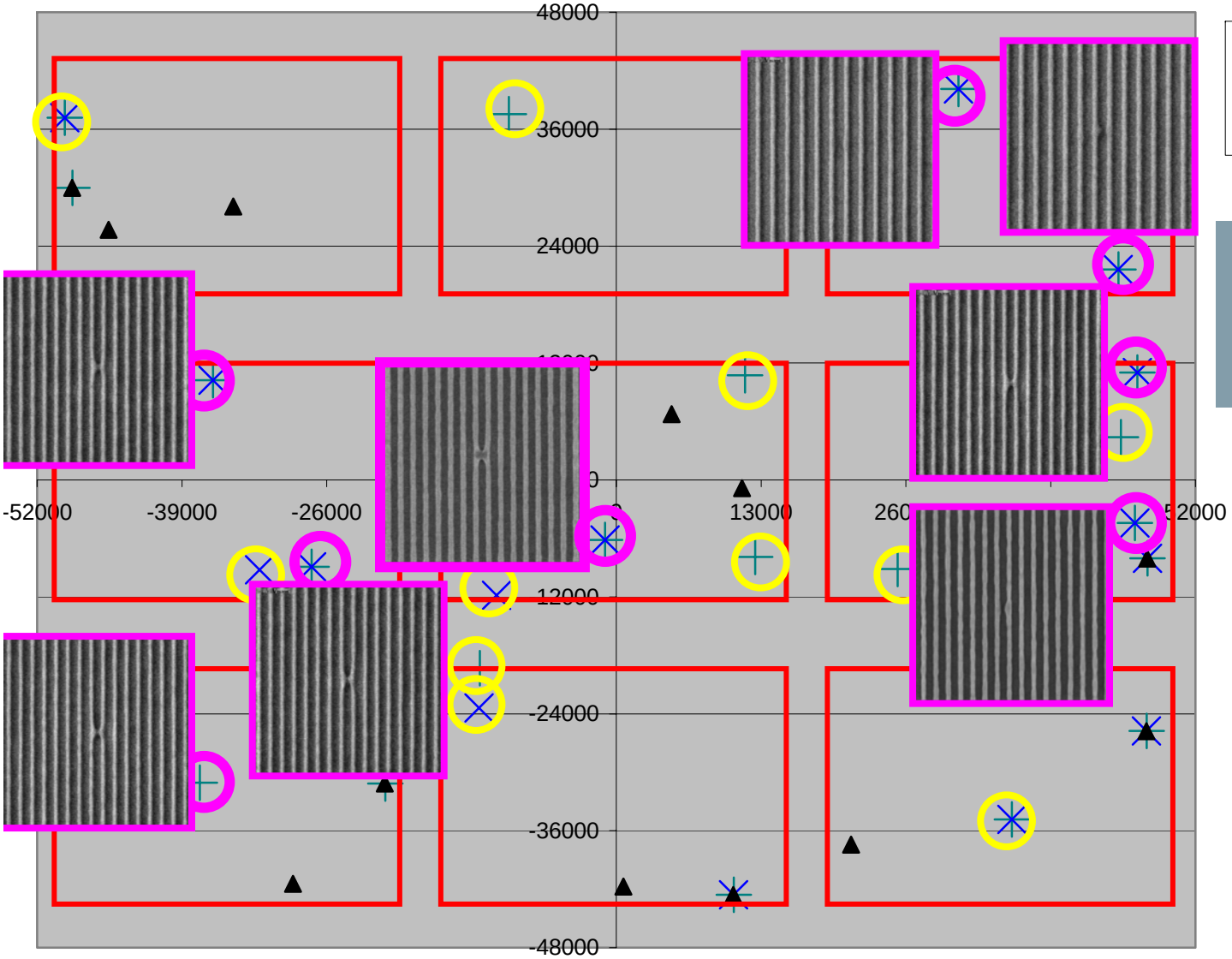


+ TaBN (5+ pixels)
× ML (5+ pixels)
▲ KLA2800_detected

5 defects in common with blank inspection (Lasertec)

Bottom = wafer review
Top = mask review

Wafer inspection (KLA2800) vs blank inspection (Lasertec)



+ TaBN (5+ pixels)
× ML (5+ pixels)
▲ KLA2800_detected

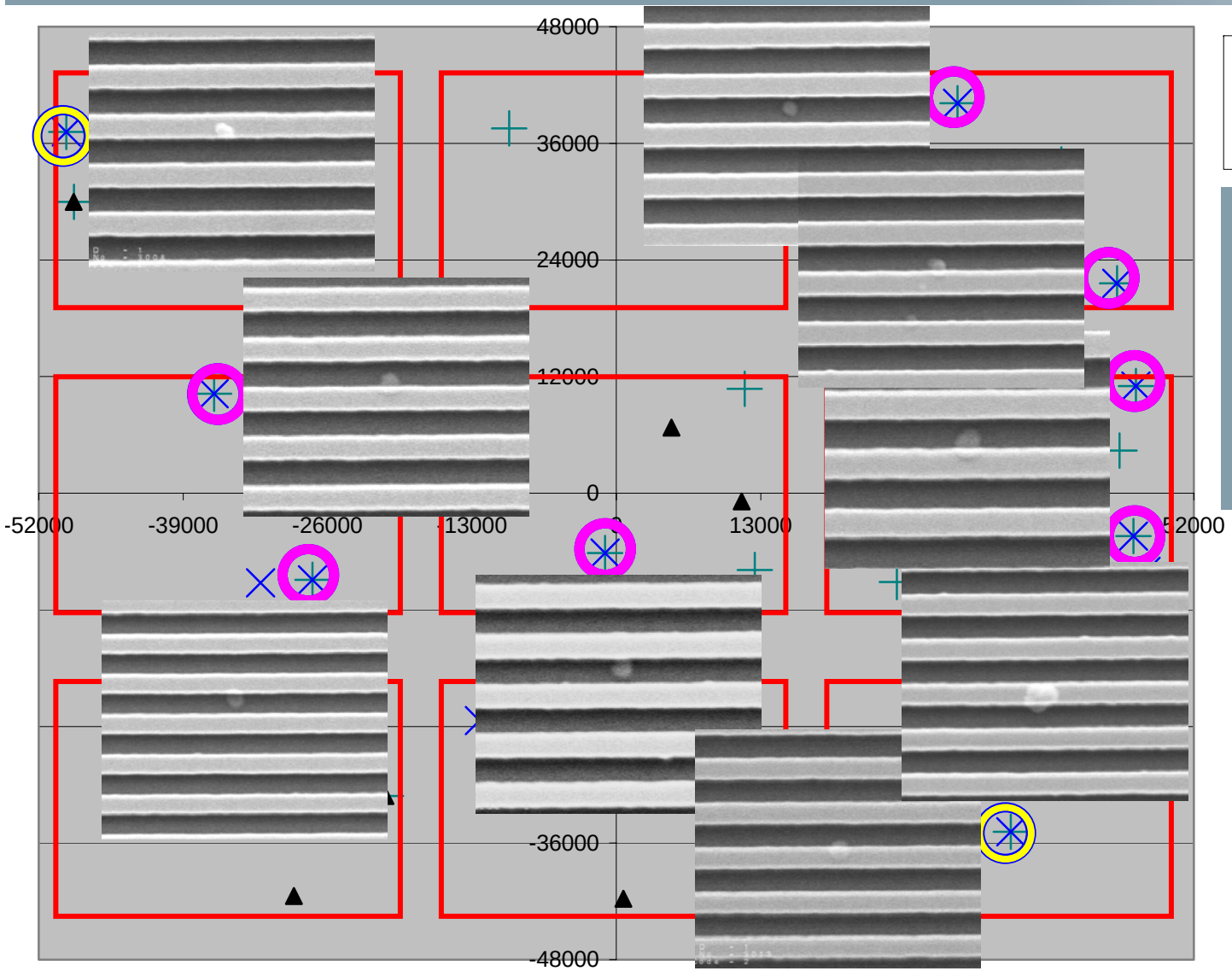
Detected on
Lasertec only
+ Wafer review

Not printing

Wafer review criterion ~50% CD change

Printing

Wafer inspection (KLA2800) vs blank inspection (Lasertec)



+ TaBN (5+ pixels)
× ML (5+ pixels)
▲ KLA2800_detected

Detected on
Lasertec only:
+ Reticle review
As example
Seen twice
ML + Absorber

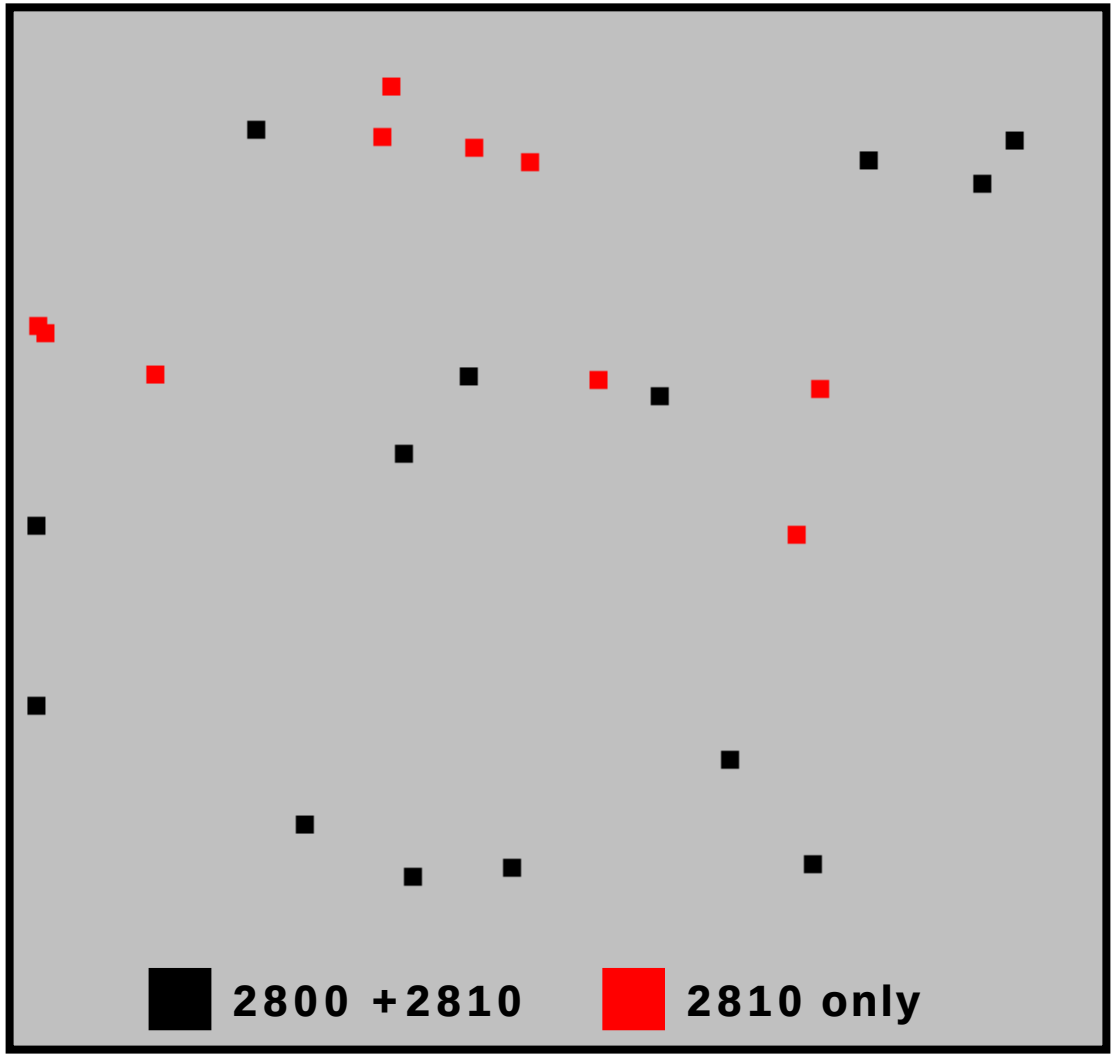
Need further AFM analysis

Wafer review criterion ~50% CD change because LER limited

Not printing

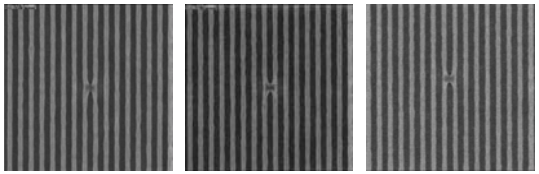
Printing

DEFECT32
Inspection on **KLA281X**: natural repeaters

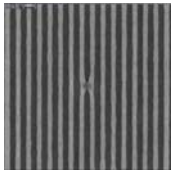


10 new natural repeaters detected:

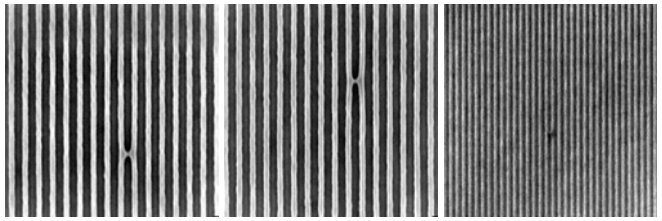
- 3 locations also detected on blank inspections



- 1 location also detected on reticle inspection



- 7 defects totally new



DEFECT32: Inspection KLA281X
Programmed **absorber** defects

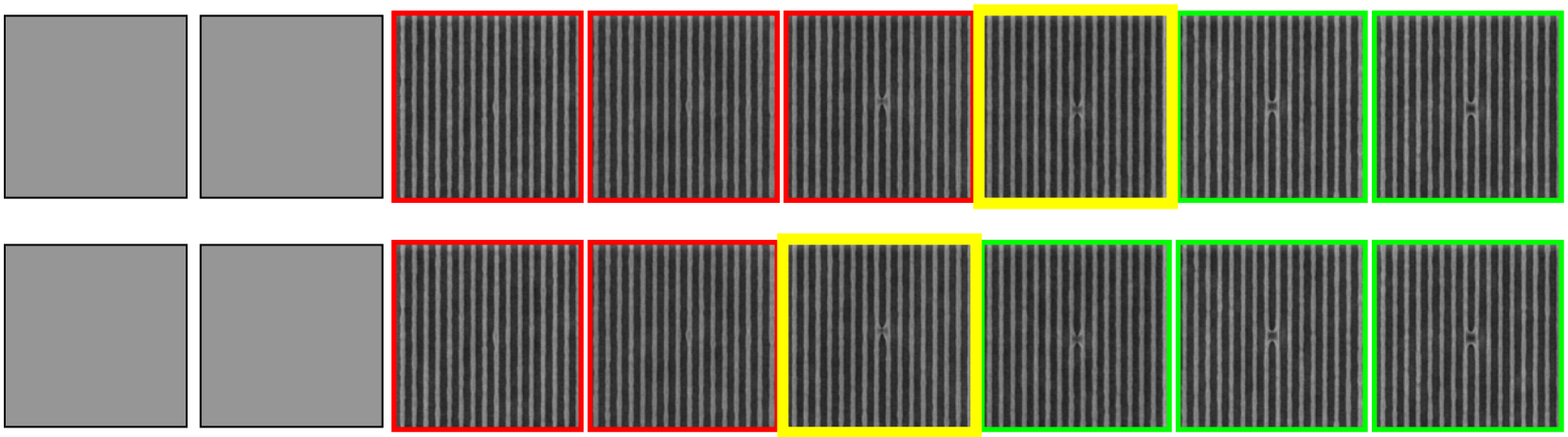
KLA2810 sensitivity

	8	10	12	14	16	18	20	22	24	26	28	30	32
pinspot 1X;1Y													
pinspot 2X;1Y													
pinspot 1X;2Y													
extension 1X;1Y													
extension 2X;1Y													
extension 1X;2Y													

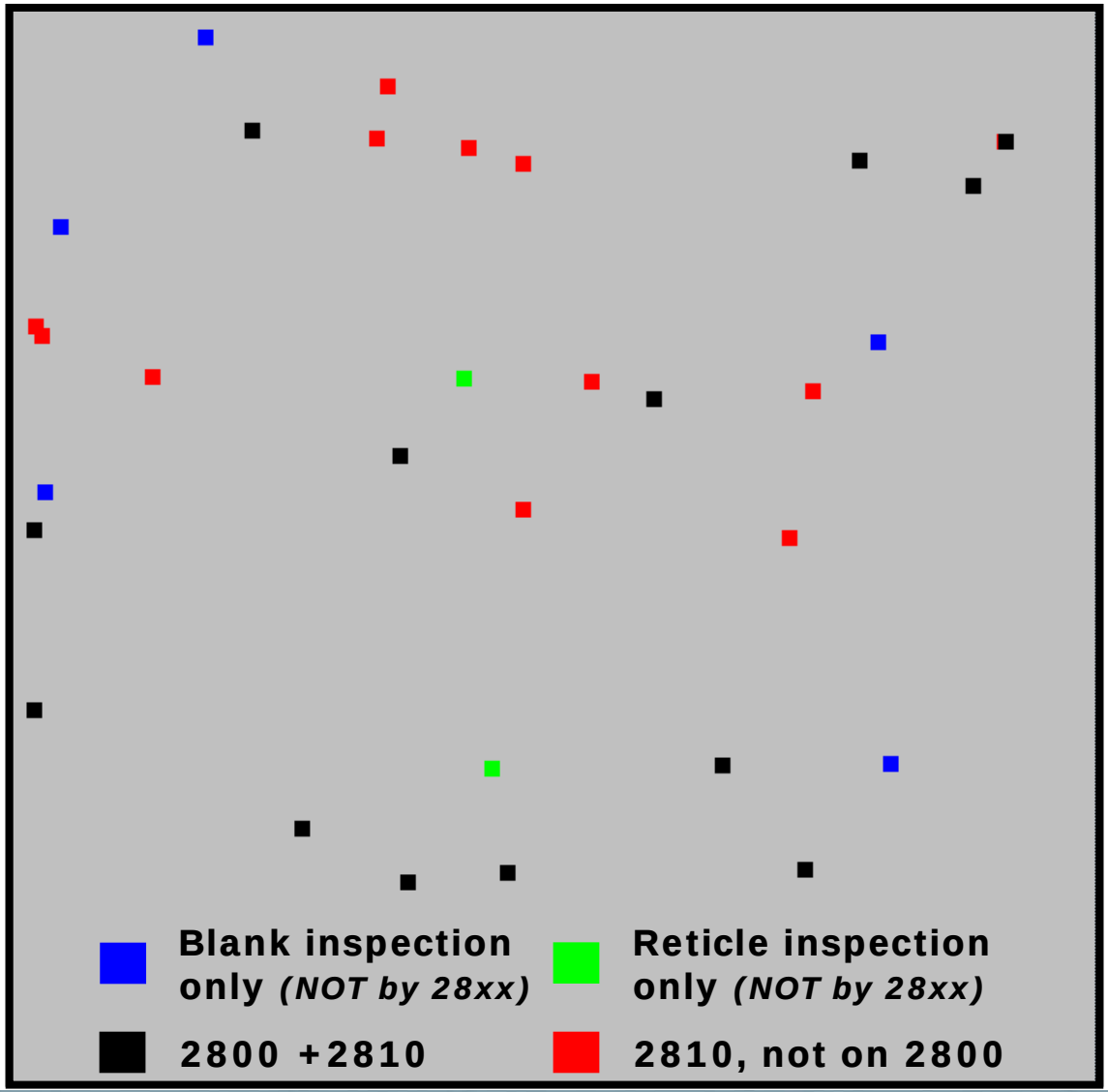
- Capture rate is above 66 %
- Capture rate is 33 % - 66 %
- Capture rate is 1 % - 33 %
- Not detected at all
- Doesn't print

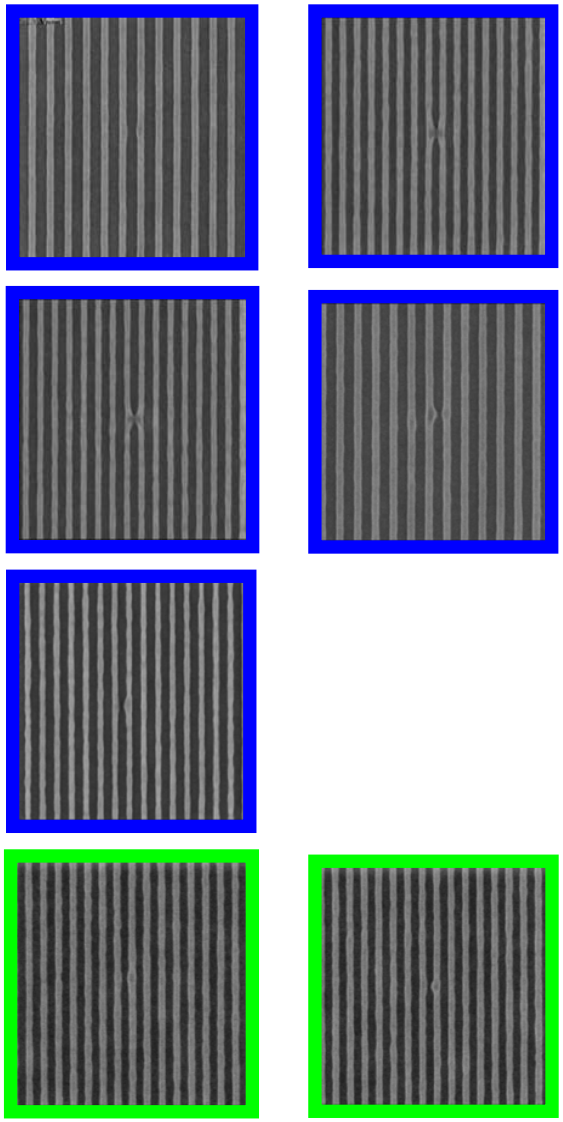
KLA2800

KLA2810

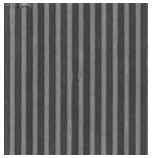


Printing defects on DEFECT32 (confirmed by wafer **review**): HOW detected ?

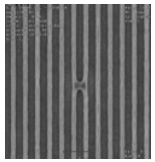




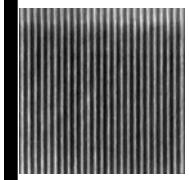
Picture 1:
• PRE



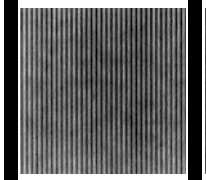
Picture 2:
• DEMO 2810
• 2800



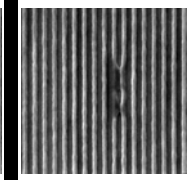
Picture 3:
• DEMO 2810



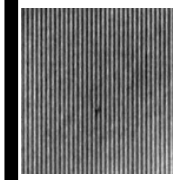
Picture 4:
• DEMO 2810



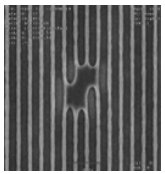
Picture 5:
• DEMO 2810



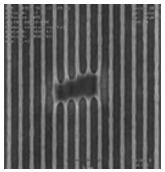
Picture 6:
• DEMO 2810



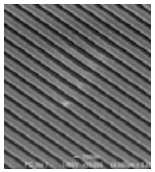
Picture 7:
• DEMO 2810
• 2800



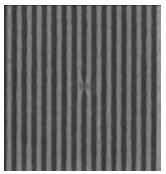
Picture 8:
• DEMO 2810
• 2800



Picture 9:
• PRE
• DEMO 2810
• 2800

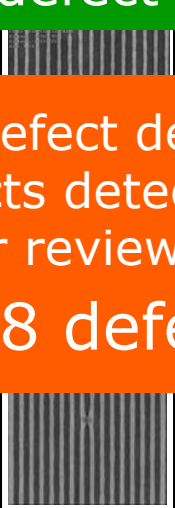


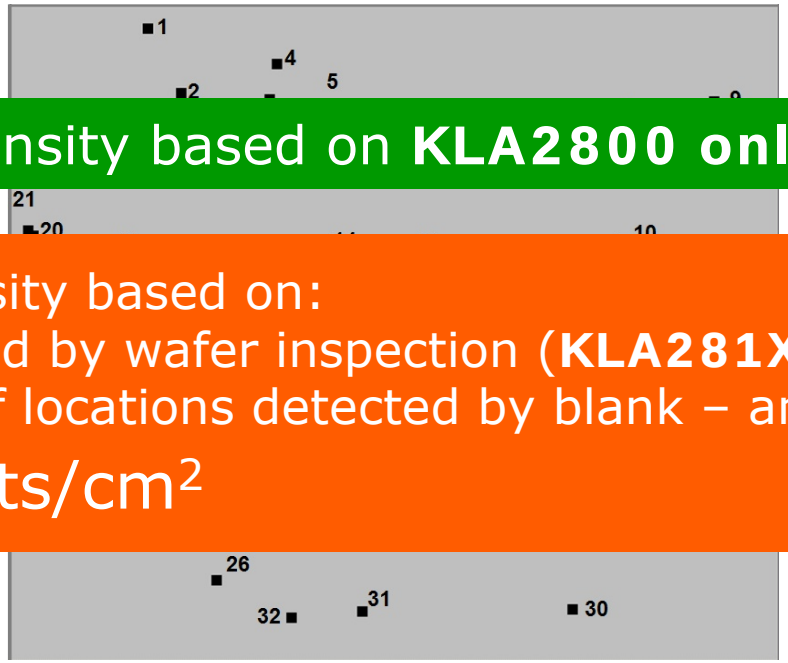
Picture 10:
• PRE



Picture 11:
• DEMO 2810

Picture 12:
• DEMO 2810





Picture 13:
• DEMO 2810

Picture 14:
• PRE

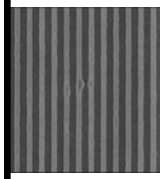
Picture 15:
• DEMO 2810

Mask defect density based on **KLA2800 only** was 0.21 defects/cm^2

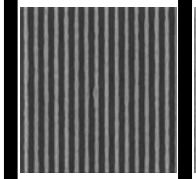
Mask defect density based on:
- defects detected by wafer inspection (**KLA281X**)
- wafer review of locations detected by blank – and reticle inspection (**PRE**)

is 0.48 defects/cm^2

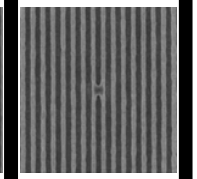
Picture 22:
• PRE



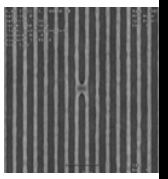
Picture 23:
• PRE



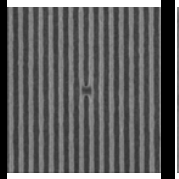
Picture 24:
• PRE
• DEMO 2810
• 2800



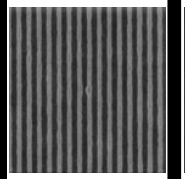
Picture 25:
• PRE
• DEMO 2810
• 2800



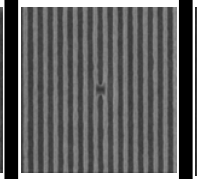
Picture 26:
• PRE
• DEMO 2810
• 2800



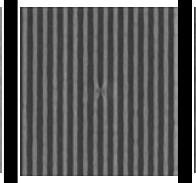
Picture 27:
• PRE



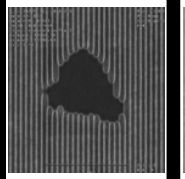
Picture 28:
• PRE
• DEMO 2810
• 2800



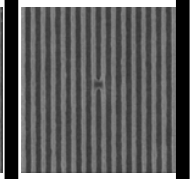
Picture 29:
• PRE



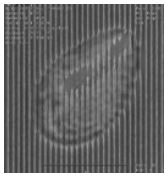
Picture 30:
• PRE
• DEMO 2810
• 2800



Picture 31:
• DEMO 2810
• 2800



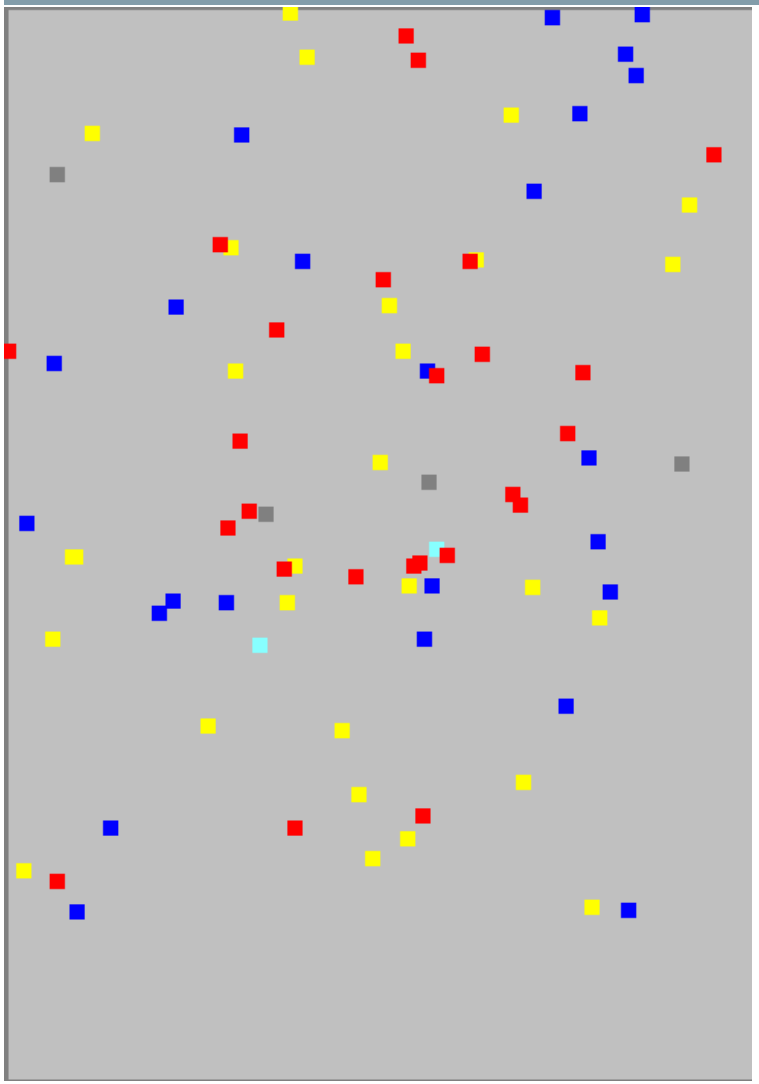
Picture 32:
• PRE
• DEMO 2810
• 2800



Outline

- Introduction
- First correlation of printed image to blank inspection AND patterned mask inspection
- Defect Source Analysis
- Conclusions

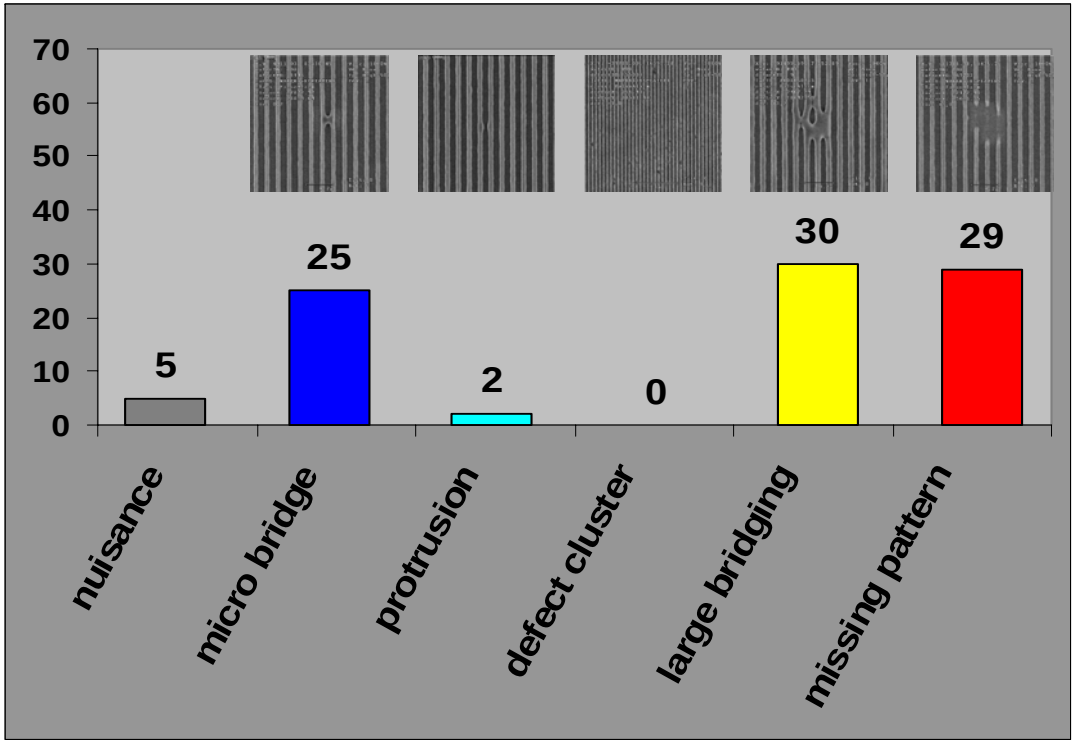
Defect40FF reticle A
Detections by KLA2800



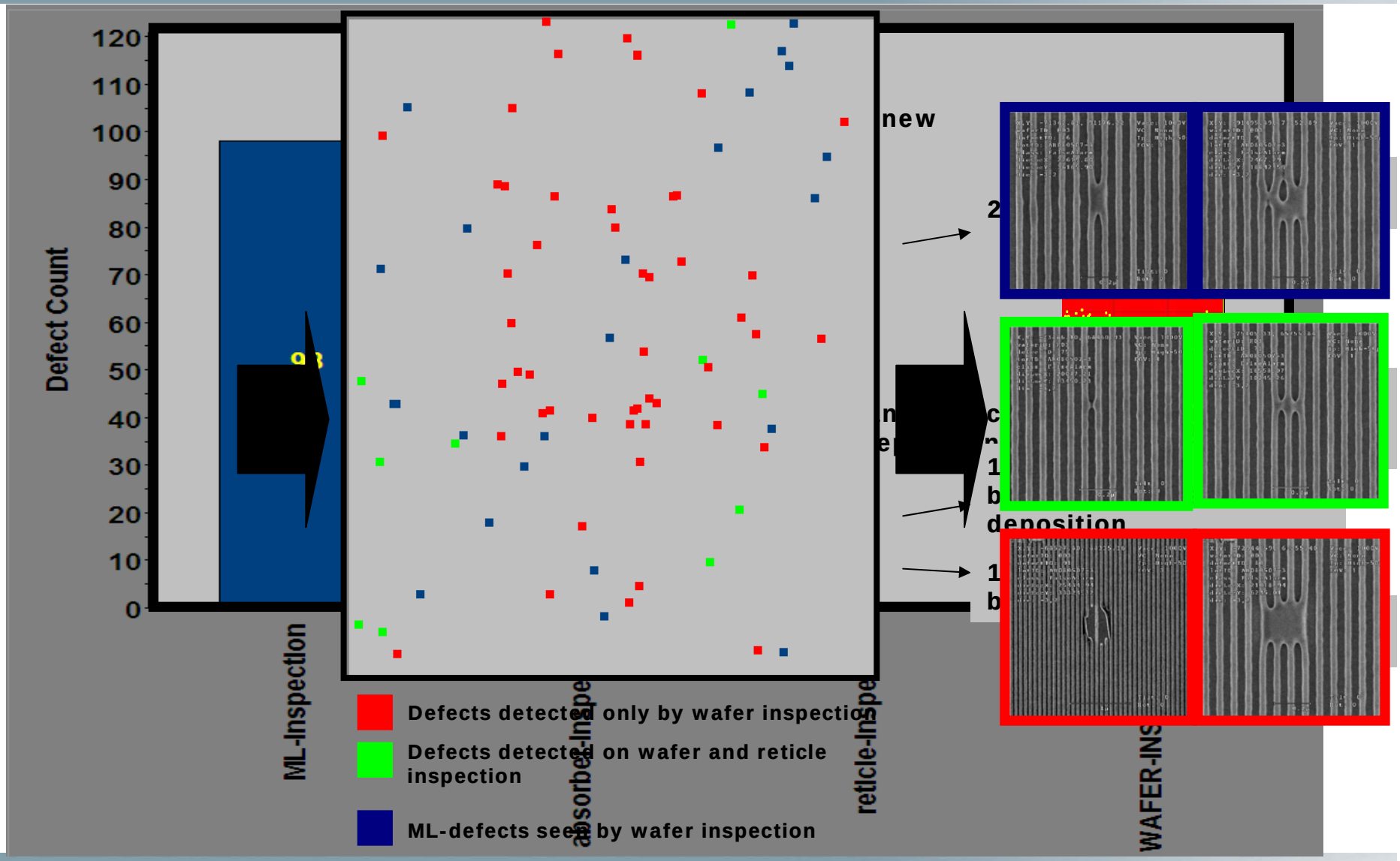
Total random repeaters = 91 defects:

- no defect in SEM (noise)
- micro bridges
- line protrusions
- defect cluster
- large bridging defects
- missing pattern

Classification by wafer review



Defect Source Analysis (DSA)
Defect40 Reticle A



Conclusions / final thoughts

- Wafer inspection reveals defects **not detected before**
  - **WHY ?**
    Present optical based **blank inspection** may not be sensitive enough for ≤3nm high/deep defects
    - → **strongest need for actinic**, or even aerial image based (AIMS-like) !!
    - **Yet present optical blank inspection detects defects that do not print**
  - **WHY ?**
    257nm/19xnm based **patterned mask inspection** unlikely to capture ML defects (inspection signal dynamic range determined by absorber pattern)
    - Not needed to be actinic if blank inspection is successful
    - **Will require improved resolution** (@16nm hp ?)
      → **may switch to EUV,** e-beam also considered
    - **Present optical mask inspection detects defects that do not print**
- Also our **wafer inspection** approach is **not** yet **sensitive enough**
  - Presently >~80nm, but the need is ~30nm

  => Each defect inspection technique has a gap
- ../..

Conclusions / final thoughts

- **Combination** of the **3 inspection techniques + wafer review** of prior detections is our **current best technique** to qualify defect density.
  - **Defect density of our champion reticle is still (>)13x higher than the "target" of ~0.036 defects/cm²**
  - And **detecting defects by printing is too late**

- **ML defects must be tackled at the source**
  - **AVOID the need for ML-defect repair** (see yesterday)
  - **Actinic blank inspection**
    - See above
    - Will give **evidence of a new range of defects**, that, as next step, **will first need to be solved** by the blank vendors
  - **Major need** on **substrate inspection**:
    - Presently little activity
    - Also needs capability for ≤ 3nm high/deep defects

Outlook

- Continue the learning from **analysis of natural defects** (found by combination of 3 inspection techniques)
  - AFM analysis of blank detections on DEFECT32
  - DEFECT40FF: Analysis of detections made during blank – and patterned mask inspections
    - Mask review (SEM + AFM)
    - Wafer review (for those not seen during wafer inspection)
- Further improve **wafer inspection** sensitivity
- Round robin of patterned **mask inspection** tools
- Refine insights in **blank inspection**
- Continue to **benchmark defect density** on **more** state-of-the-art EUV reticles

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  - Toppan
  - …
- All partners in IMEC's Advanced Lithography Program

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