Wafer [Mask] Inspection for Sub-20nm Patterning

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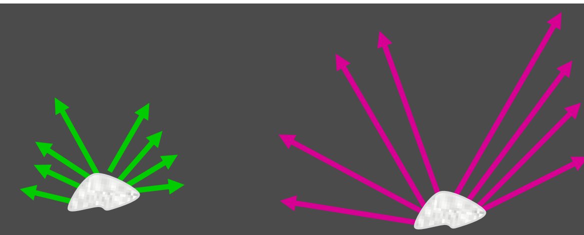
Outline

- Current State of the Art Wafer Inspection
- E-Beam Inspection
- EUV Mask/Wafer Qualification
- Special Requirements
- Summary
- ML2 [time permitting]

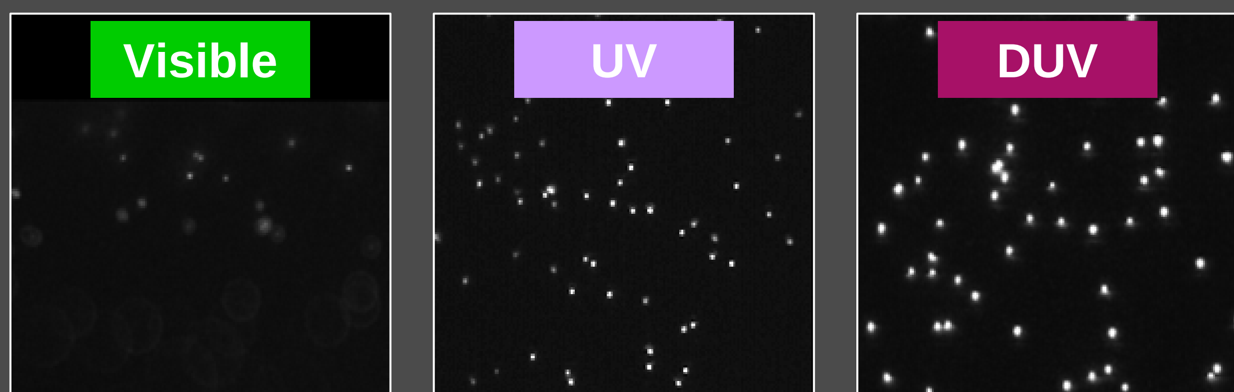
Why DUV?

Light Scattering ~ $1/\lambda^4$

Higher light scattering with shorter wavelength

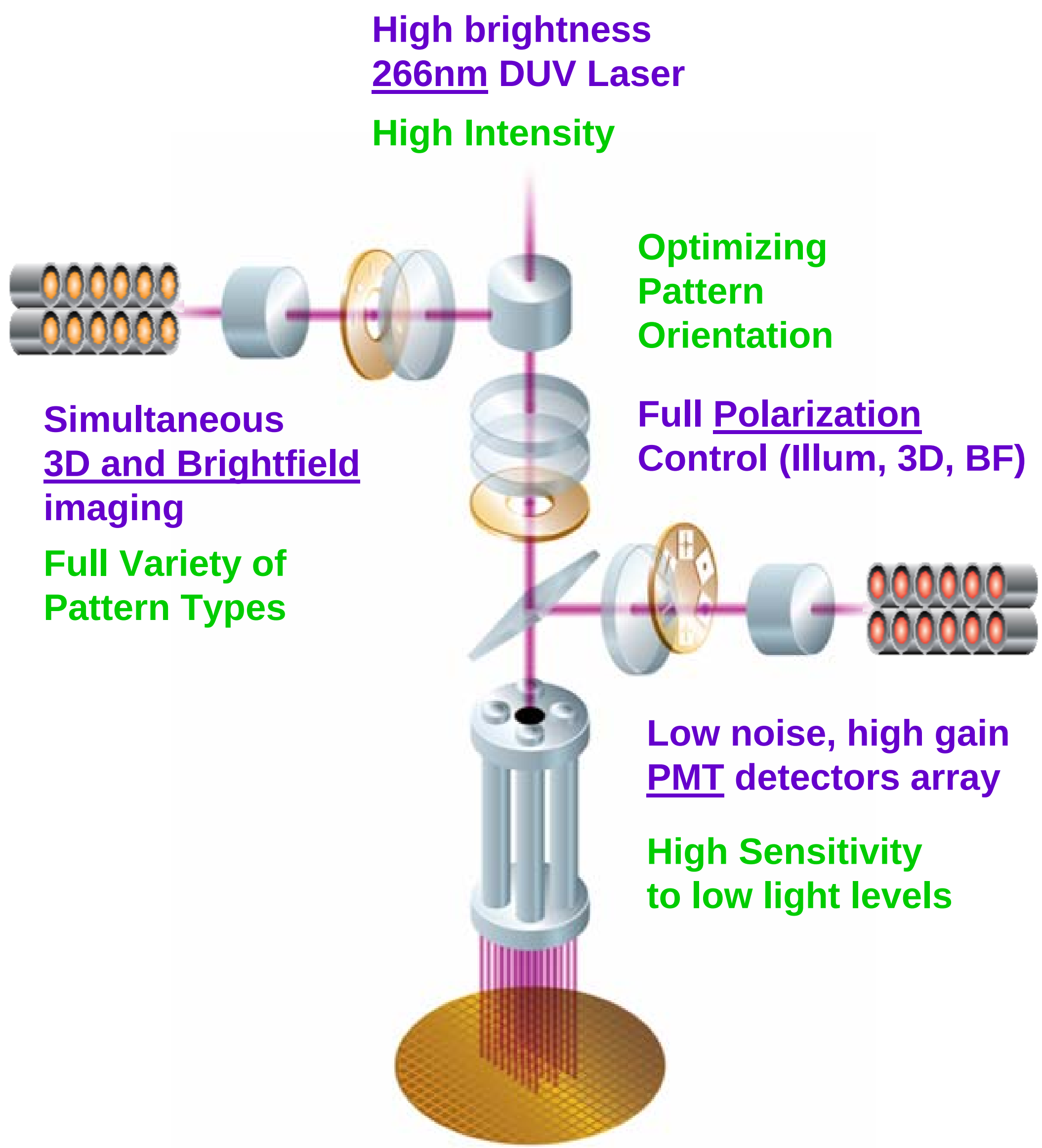


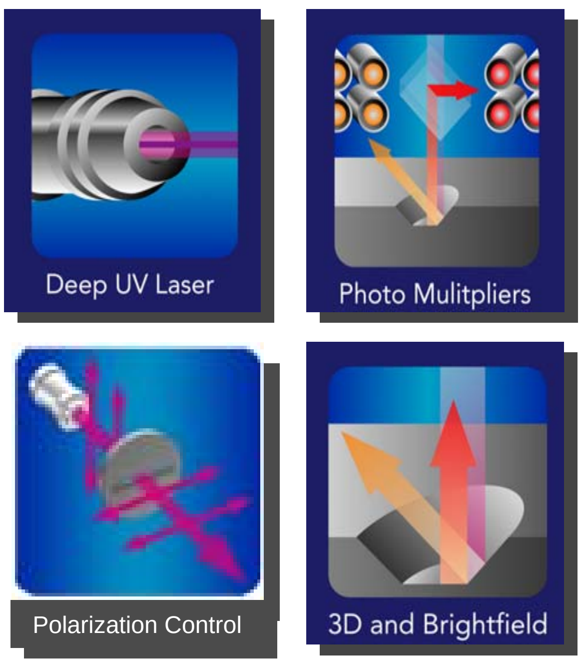
40nm PSL on bare Si:



SNR increases at shorter wavelength

State of the Art Wafer Inspection Concept

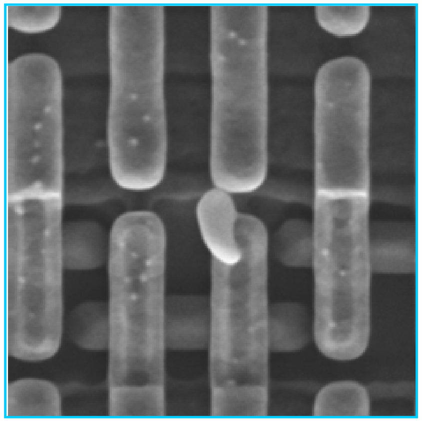




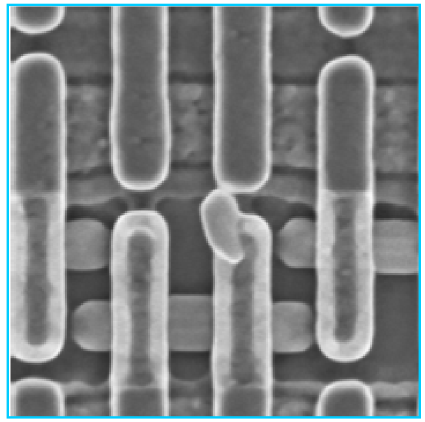
APPLIED MATERIALS.

Still: Defect Review is done by SEM = EB

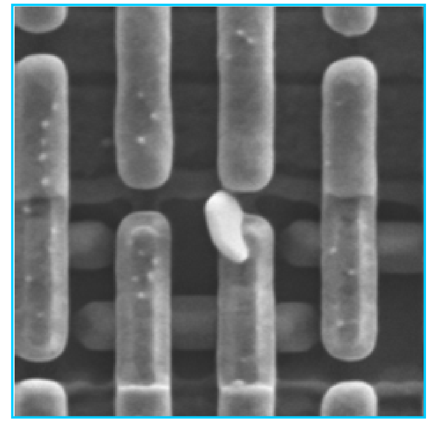
5 Detector Imaging



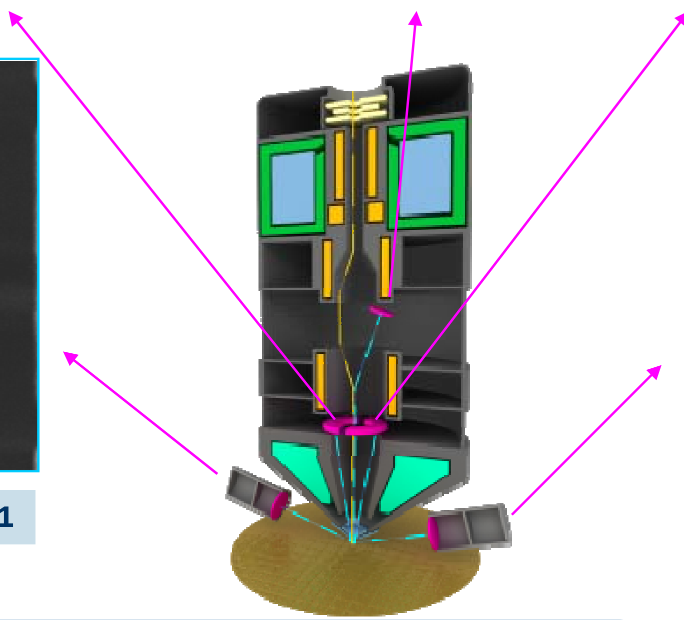
Internal Topography 1

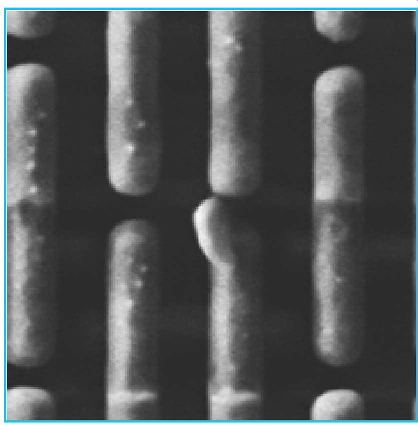


Material Contrast- FOV0.5

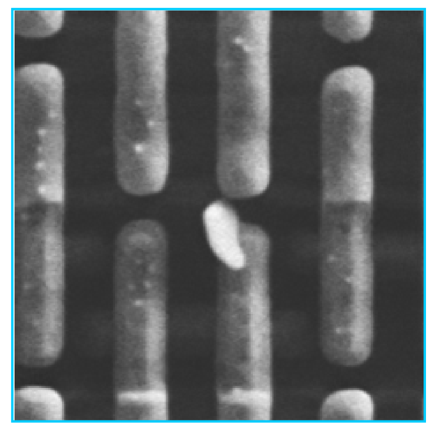


Internal Topography 2



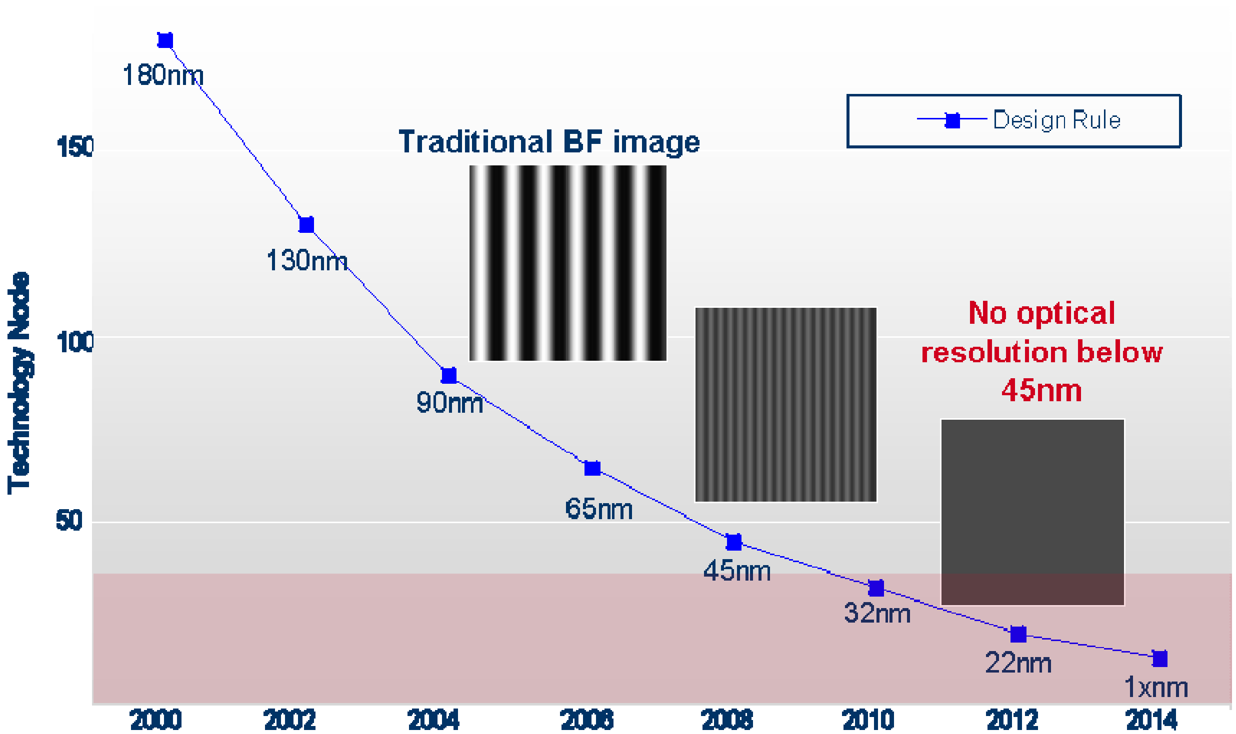


External Topography 1



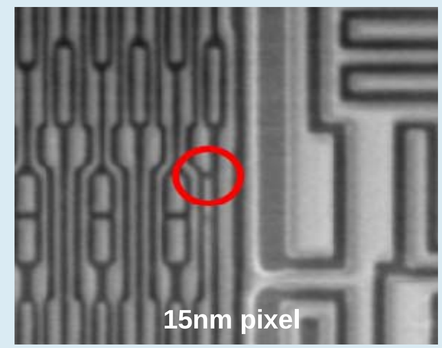
External Topography 2

Optical Inspection – Resolution Limitation



e-Beam is the most promising technology for small physical defect detection.

Available solutions have limited throughput.



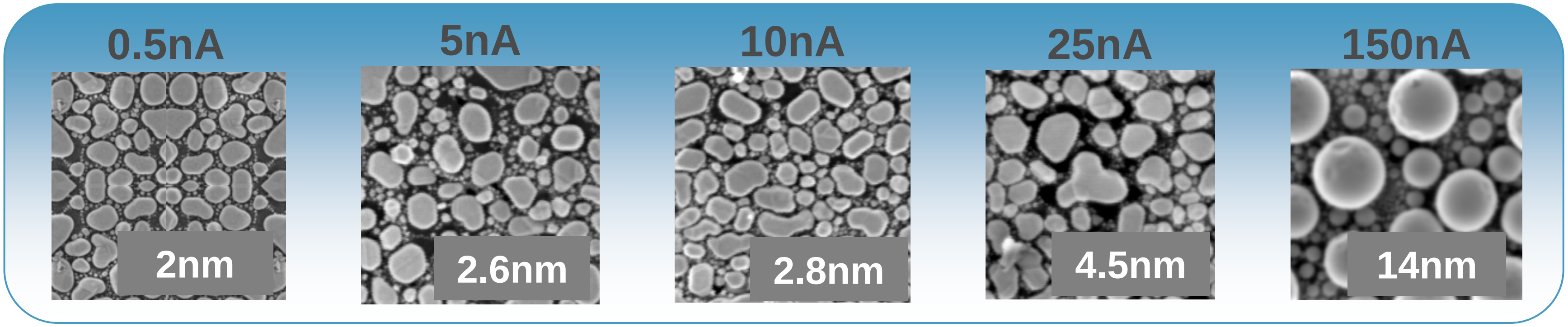
WLP [mW/Spot]	PSL Diameter [nm]					
	λ = 193nm			λ = 266nm		
	Cu	Ox	Poly	Cu	Ox	Poly
1	24	30	21	34	44	30
10	16	21	15	25	32	22
50	14	16	14	21	26	20

Detection limits of BF inspection

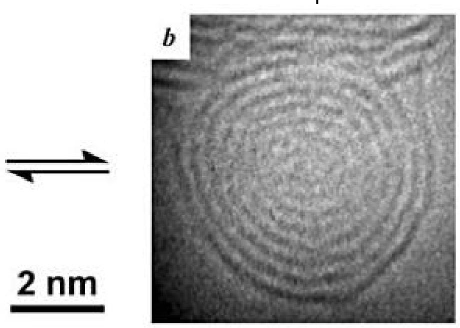
- 266nm provides the most cost-effective solution
- Even 193nm does not meet the 10nm defect detection requirement

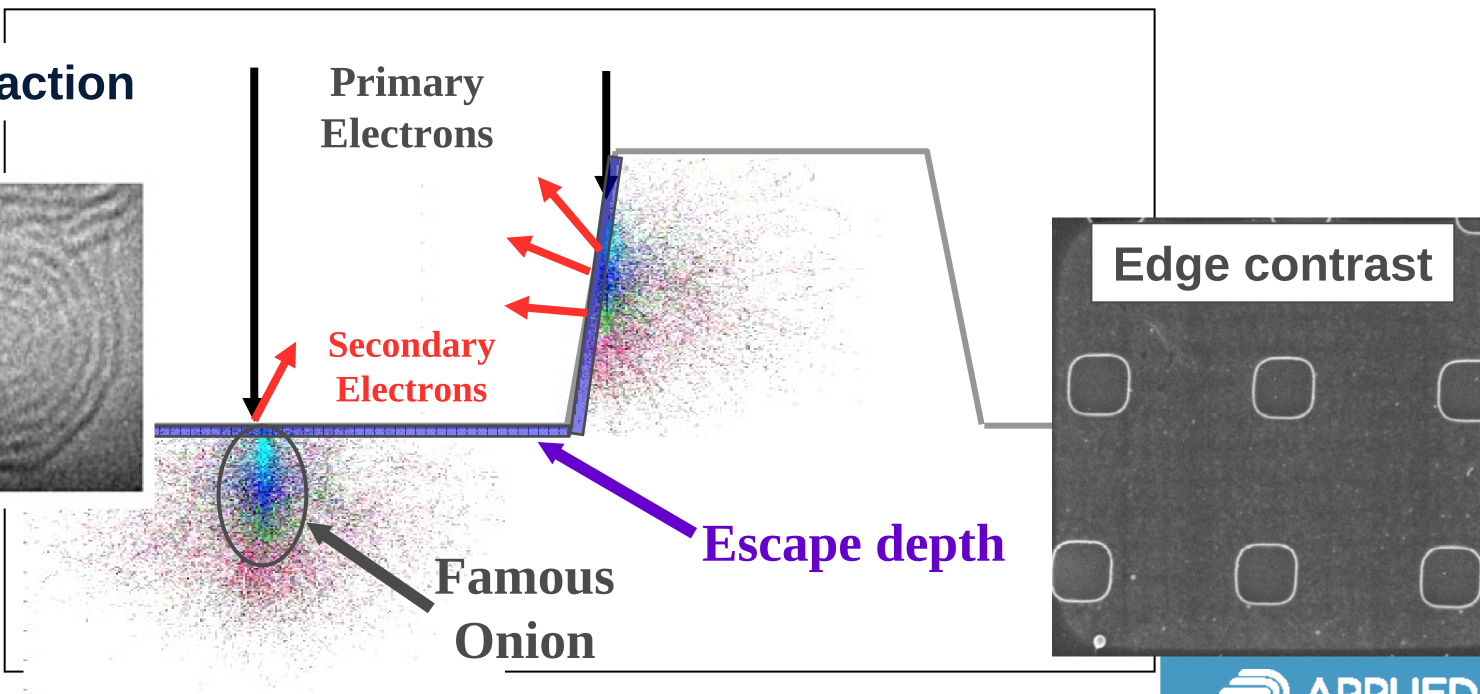
E-Beam resolution is nearly unlimited

- Careful column design enables large dynamic range of resolution with the same column



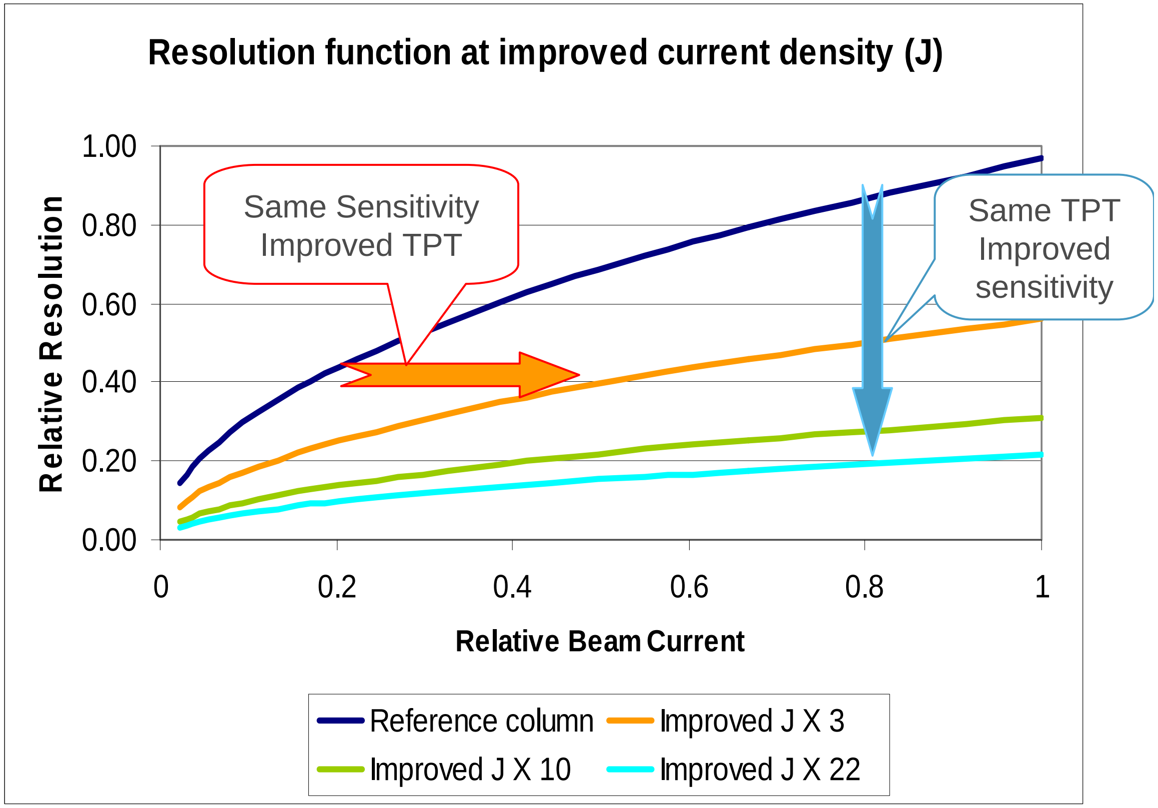
E-Beam interaction





E Beam inspection throughput - solutions

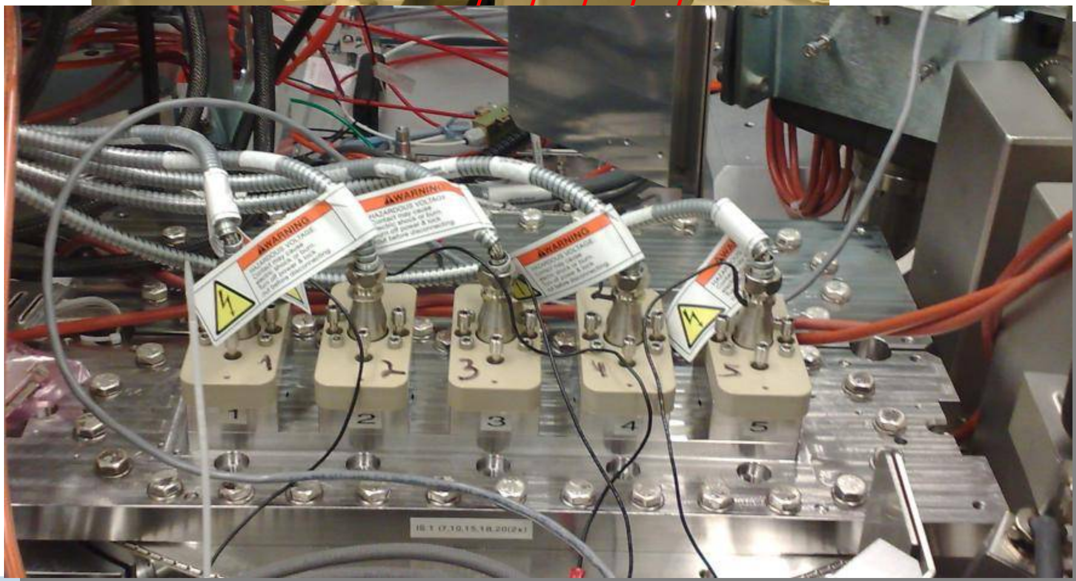
- **Multi Column EBWI can reach the TPT and Sensitivity goals [trade-off]**
- Improved column design
  - Increase J [current density] by factor of 10-20
- Inspection area thinning
  - Wafer area sampling



EBI – Multi-Column E-Beam Wafer Inspection

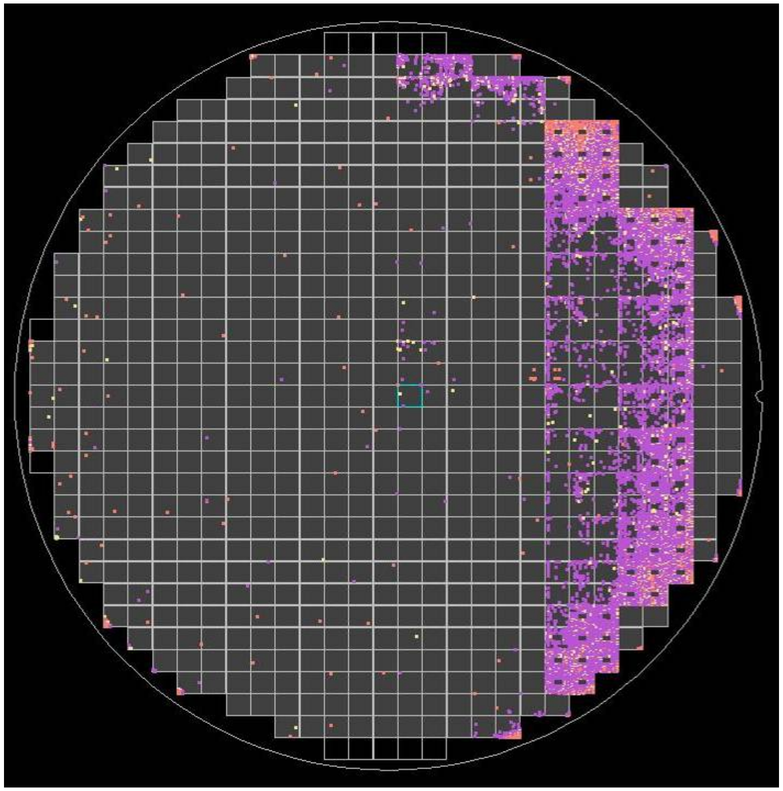
- **Core technology**
  - E-beam resolution
  - Revolutionary multi-column technology
  - High data rate columns

- **Benefits**
  - High TPT
  - Leap jump in resolution

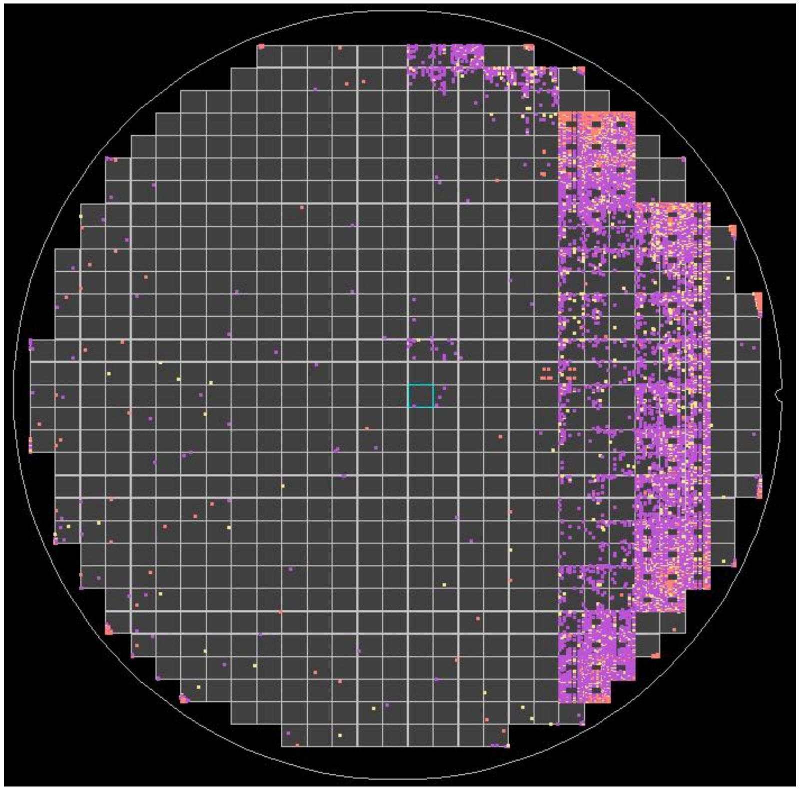


Full wafer scan: SCM vs MC5

Single-column scan: 183 min



Multi-column scan: 47 min



TPT = 40 cm^2/hr

Same conditions:

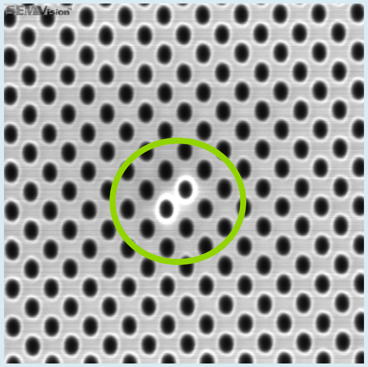
- Thinning 1/6 (17%)

TPT = 160 cm^2/hr

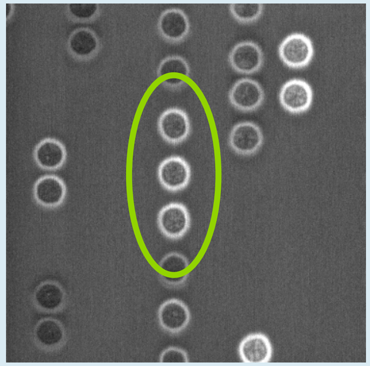
APPLIED MATERIALS.

E-Beam Inspection Applications

VC: Electrical Defects



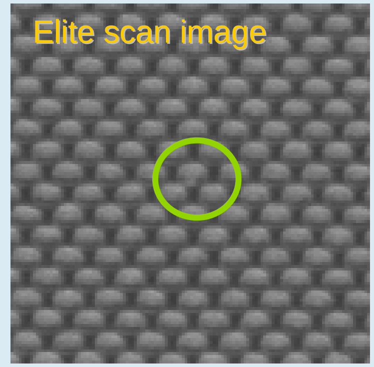
Capacitor Etch
Bottom residue



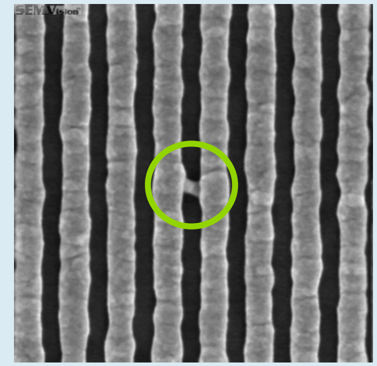
WCMP
Blocked contacts

- Cause charge variations that are only detectable by e-beam
- Have a high kill ratio
- High contrast enables high TPT
- The predominant application in production today

PD: Small Physical Defects



Deep Trench
Residue



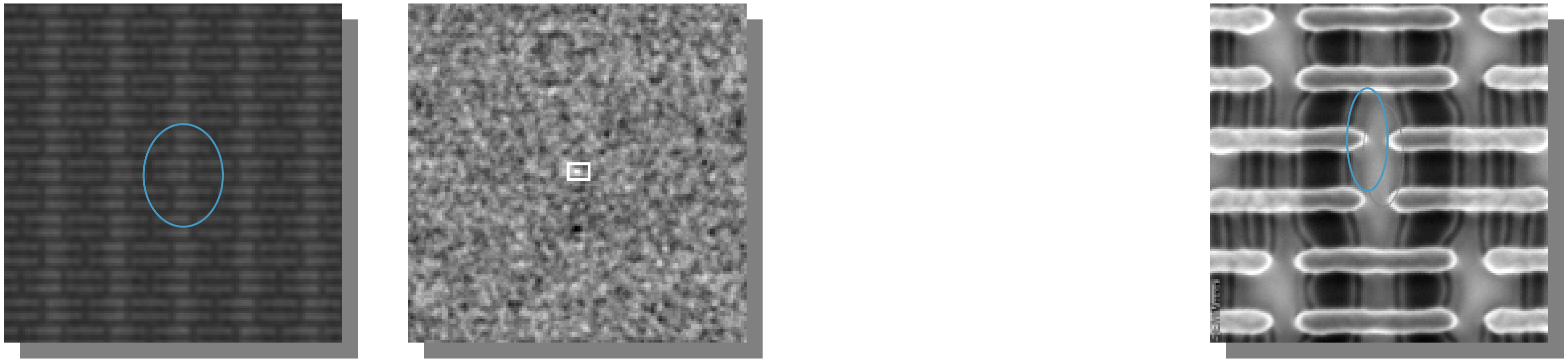
Gate
Bottom Bridge

- Very small defects beyond optical detection capability
- Signal generated by material and edge contrast
- Detected by high resolution SEM imaging
- Mostly used in R&D today

APPLIED MATERIALS.

Line extension

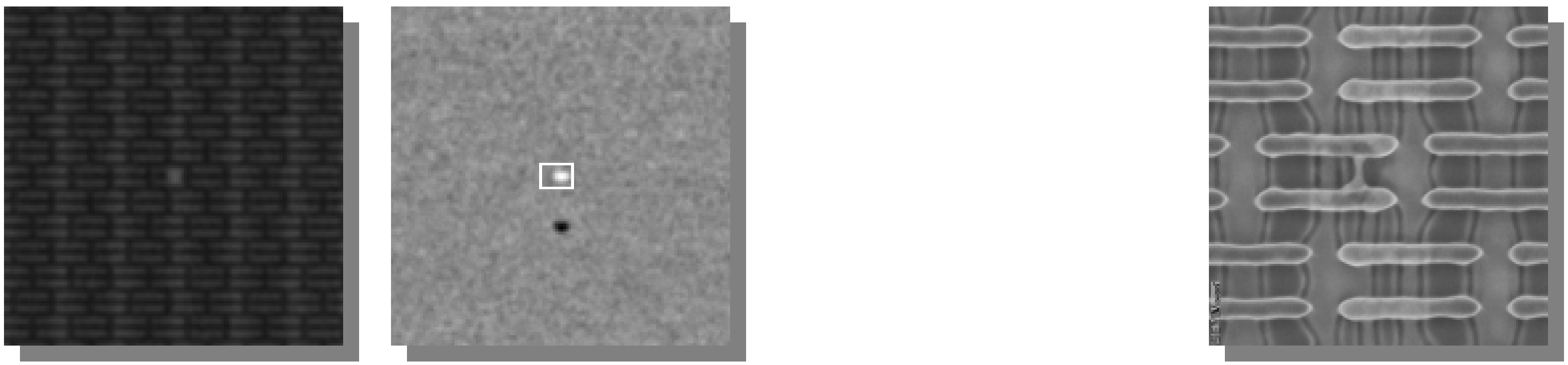
SEM review



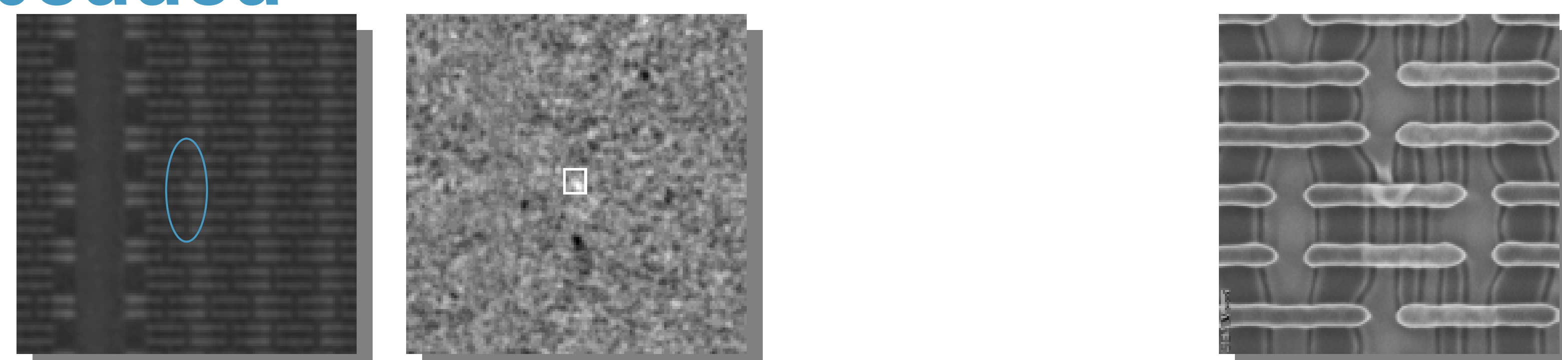
Bridge

OTF

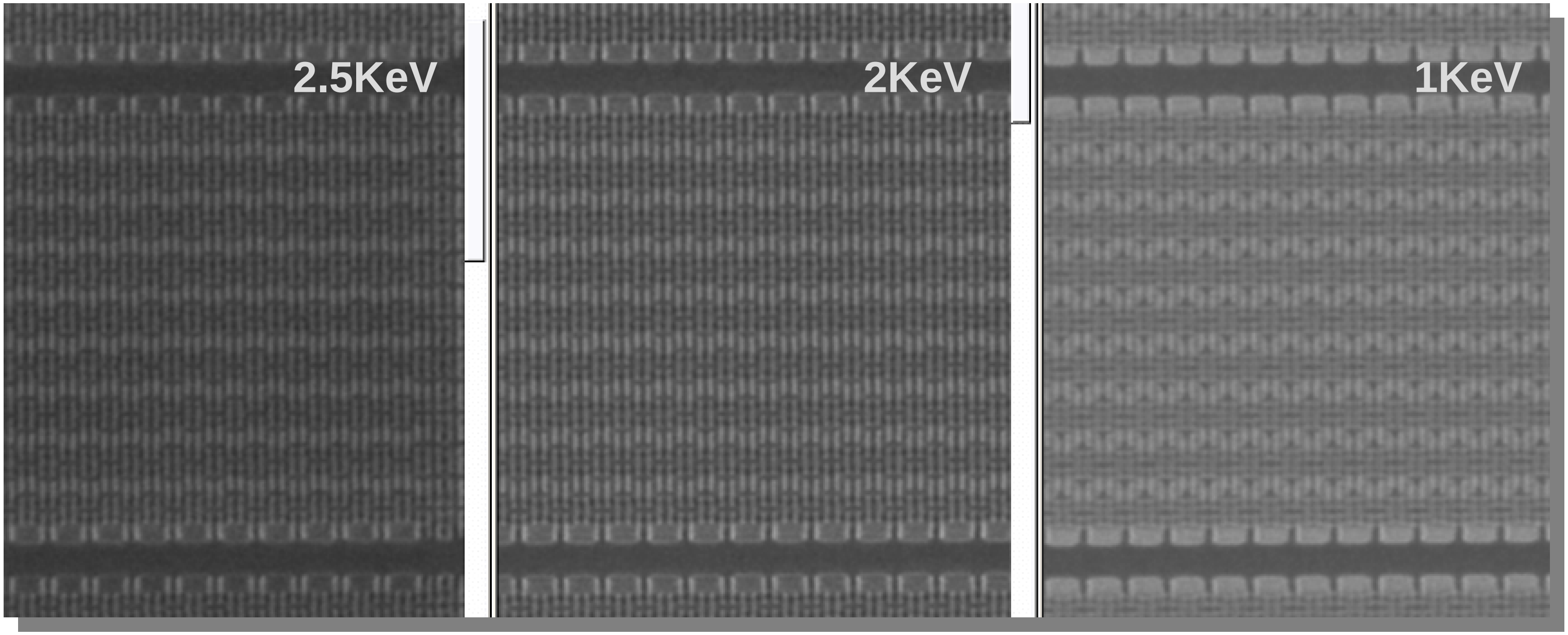
OTF Diff



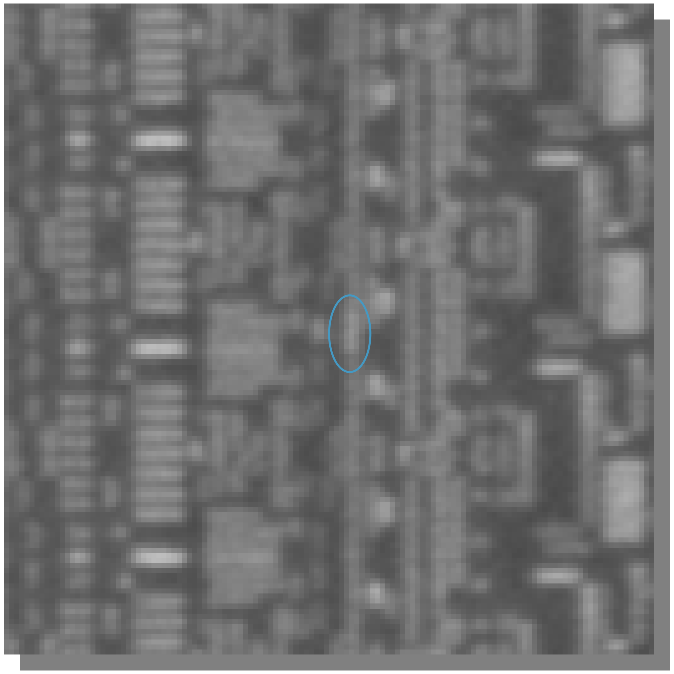
Embedded



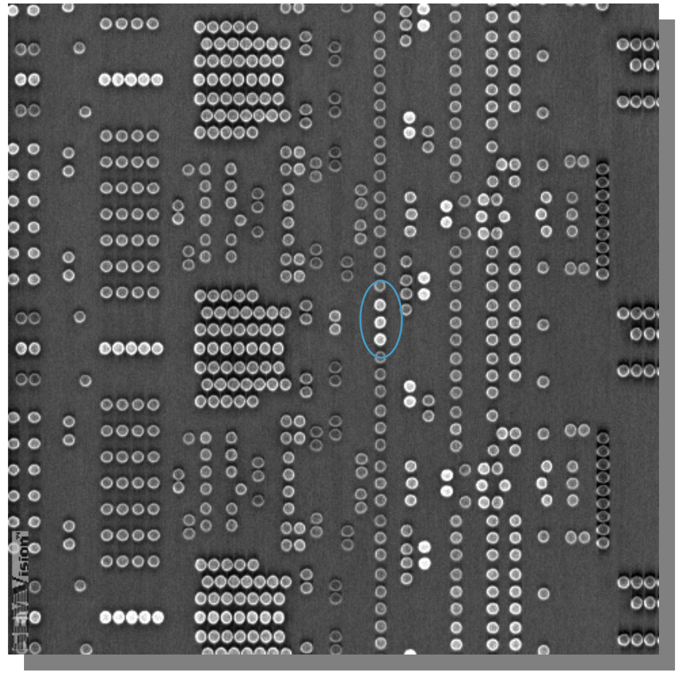
LE comparison



Defect A

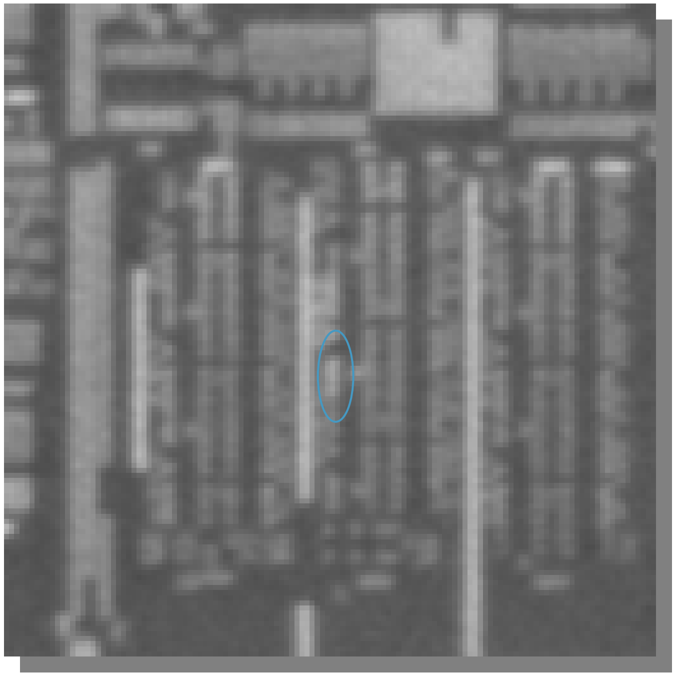


Scan

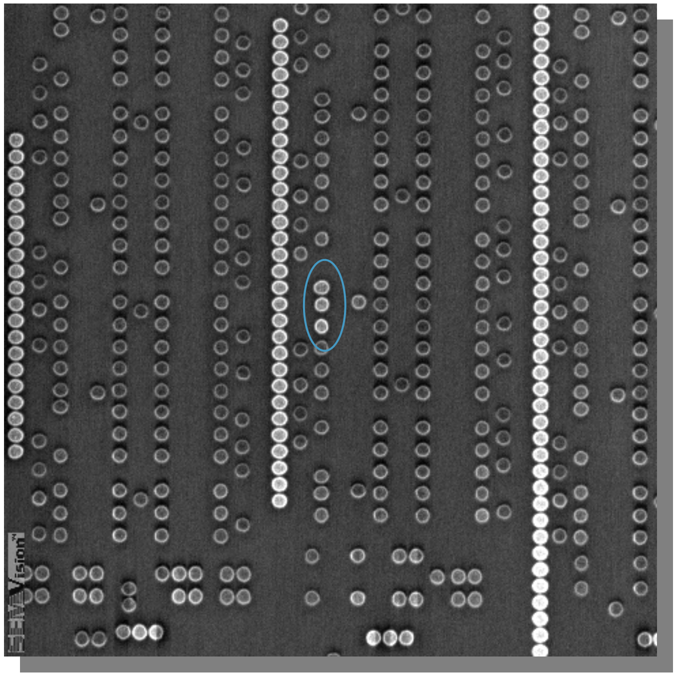


Review

Defect B

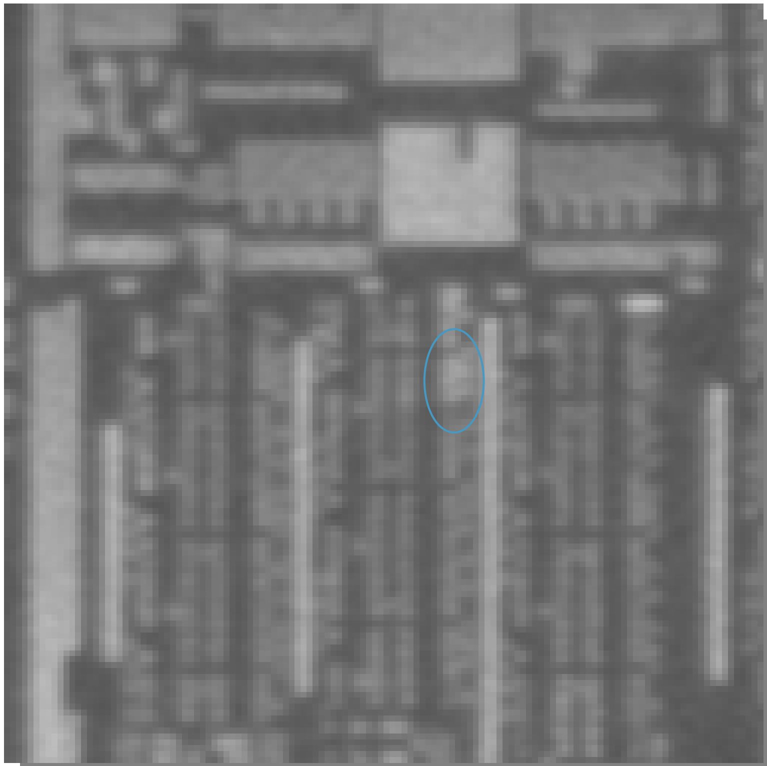


Scan

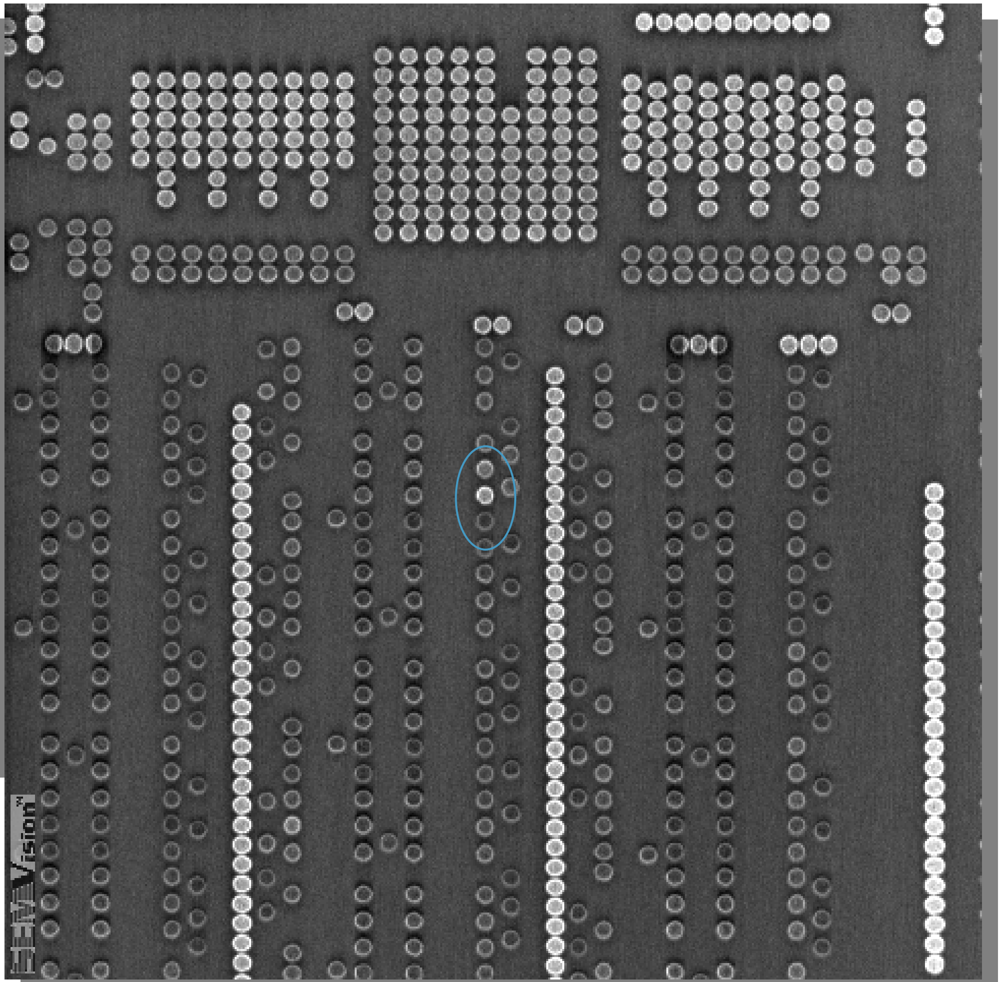


Review

Defect C

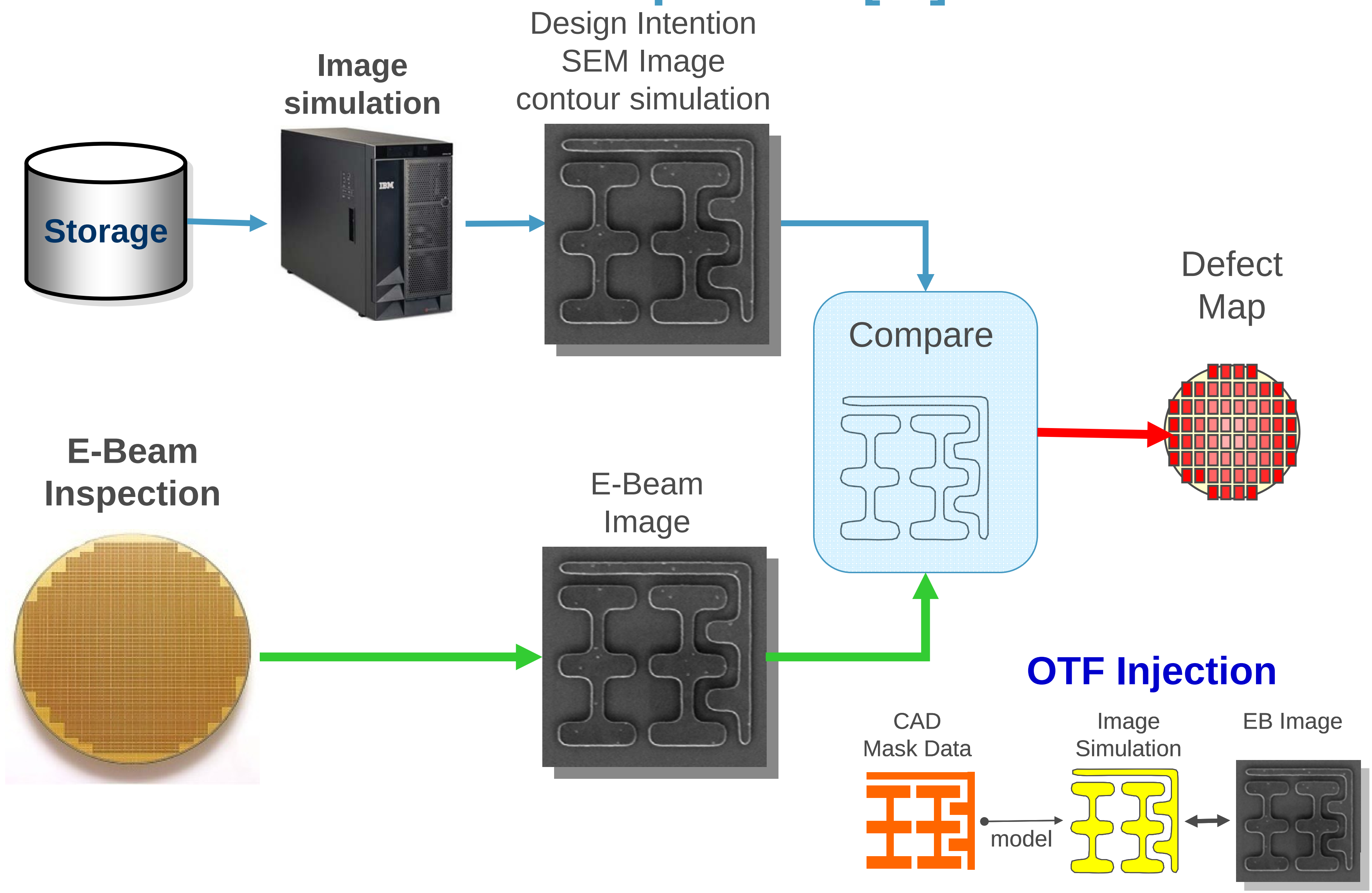


Scan



Review

Die to EB-Model – Inspection [at] Runtime



Mask Inspection Driven by Litho Roadmap

KrF / ArF
- Binary masks

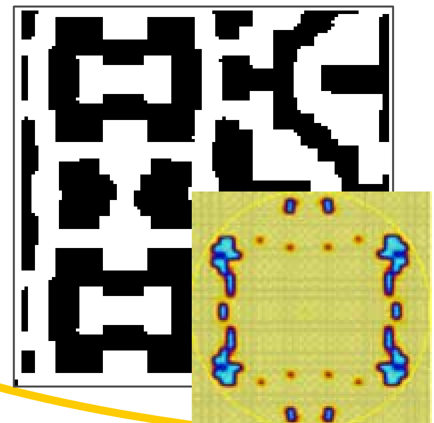
90+

ArF
- OPC
- Phase masks

65/45

DUV 2nd

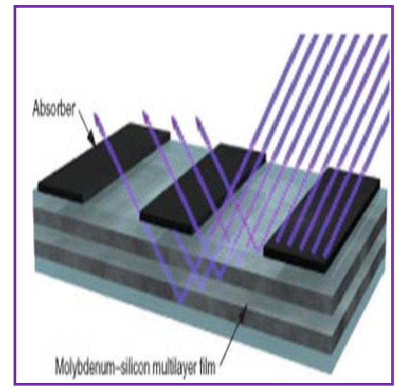
ArF
- OPC
- Phase masks
- Double patterning
- SMO



DUV 3rd

32/22

EUV



22/16

DUV 4th

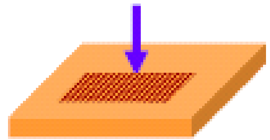
- Challenges:
  - **Double patterning**: Sensitivity for smaller defect detection
  - **SMO/FlexRay**: Main pattern vs SRAF can not be distinguished at Mask level
  - **EUV:** Mask technology inflection point

Blank & Pattern Inspection seen as Highest Risk

Blanks

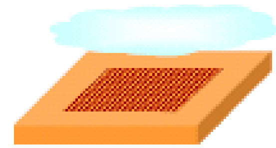
Risk	Phase defect
Solution	Defect position management based on actinic inspection

EB Exposure



Risk	Pattern distortion
Solution	Compensation of distortion based on flatness estimation

Etching

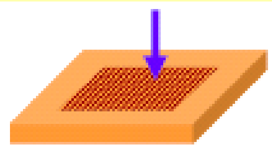


Risk	Formation of shading frame
Solution	Frame formation by removing multilayer

Inspection

Risk	Sensitivity
Solution	hp2Xnm: Inspection by UV hp1Xnm: Inspection by EB

Defect Repair



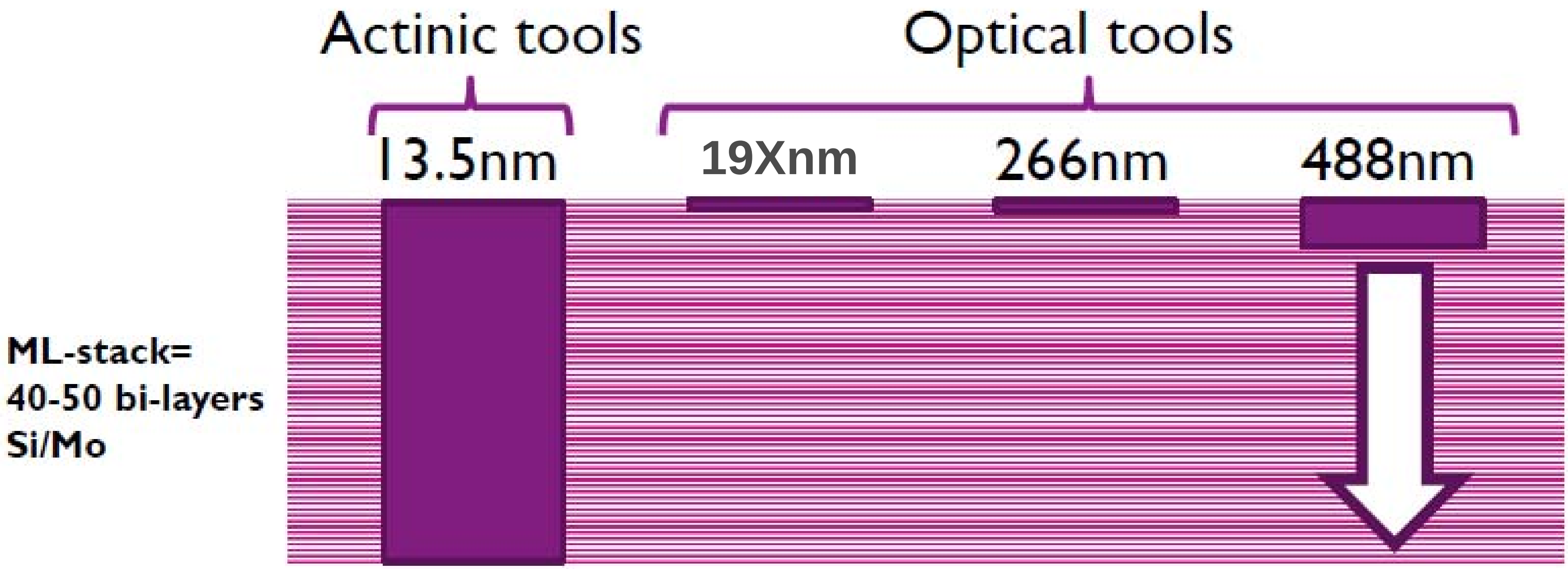
Risk	Guarantee method
Solution	Lithography simulation using mask 3D image to EUV-AIMS

Shipping

Risk	Pellicle less
Solution	Dual Pod

Source: Watanabe, Toshiba

BLANK INSPECTION TECHNIQUES PENETRATION DEPTH



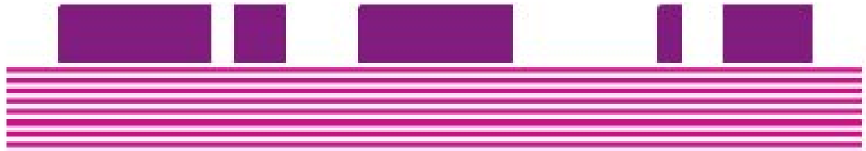
Ref. "Printability and inspectability of programmed and real defects on the masks in EUV lithography", Sungmin Huh et al, 2010 EUVL International Symposium

Evidence of printing ML-defects missed

Source: imec = D. vd Heuvel

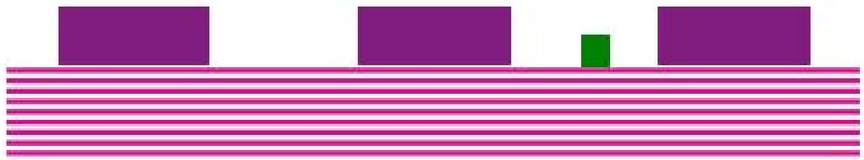
4 TYPES OF EUV MASK DEFECTS

Absorber defect



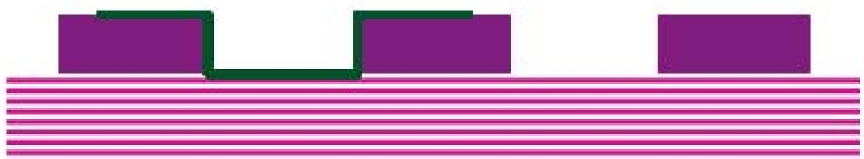
Mitigation: mask inspection + repair at mask shop

Particle



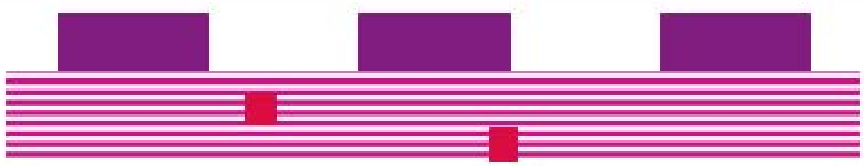
Mitigation: Avoid(handling/shipping); clean+verify at wafer fab

(Local) *cap deterioration*



Mitigation: clean (+ avoid) at wafer fab

Multilayer (ML-) defect



Need to be found by blank inspection (BI) by blank vendor + avoid printing

Source: imec = M. Lamantia

Absorber defect

Mitigation: mask inspection + repair at mask shop

Absorber Defect Detection

Patterned Mask Inspection (best case) succeeded in finding all absorber related defects for 32nm node.

Evolutionary

Source: imec = M. Lamantia

APPLIED MATERIALS.

EBMI Mask Inspection – 1st Gen. Prototype (HV1)

imec ADT Printed 32nm L/S, full mask [Bacus 2010]

- EUV **full mask** - 32nm L/S – with 9 PDMs of programmed absorber defects –
- Full mask area was inspected, compared to baseline **natural printing** defects
- EBMI sensitivity was tuned to maximize throughput while meeting print line
- Demonstrated inspection at throughput was 15hrs/Col/Mask at “Fast” mode

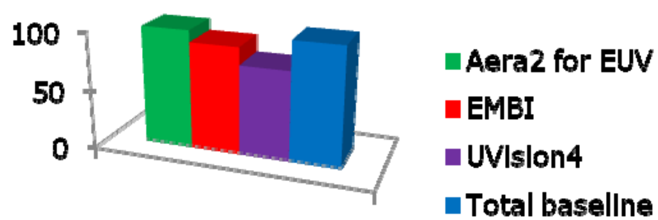
		8	10	12	14	16	18	20	22	24	26	28	30	32
Pinspot 1X:1Y	imec wafer data*													
	eBeam MI - Fast													
Pinspot 2X:1Y	imec wafer data*													
	eBeam MI - Fast													
Pinspot 1X:2Y	imec wafer data*													
	eBeam MI - Fast													
Extension 1X:1Y	imec wafer data*													
	eBeam MI - Fast													
Extension 2X:1Y	imec wafer data*													
	eBeam MI - Fast													
Extension 1X:2Y	imec wafer data*													
	eBeam MI - Fast													

<<Nominal Defect size 1x

Inspection Capture Rate	
	66-100% Detected
	33-66% Detected
	1-33% Detected
	Not Detected
	Did not print

Wafer Print line

Printing Natural Absorber defects:



Capture Rate

Mask and wafers: courtesy of imec

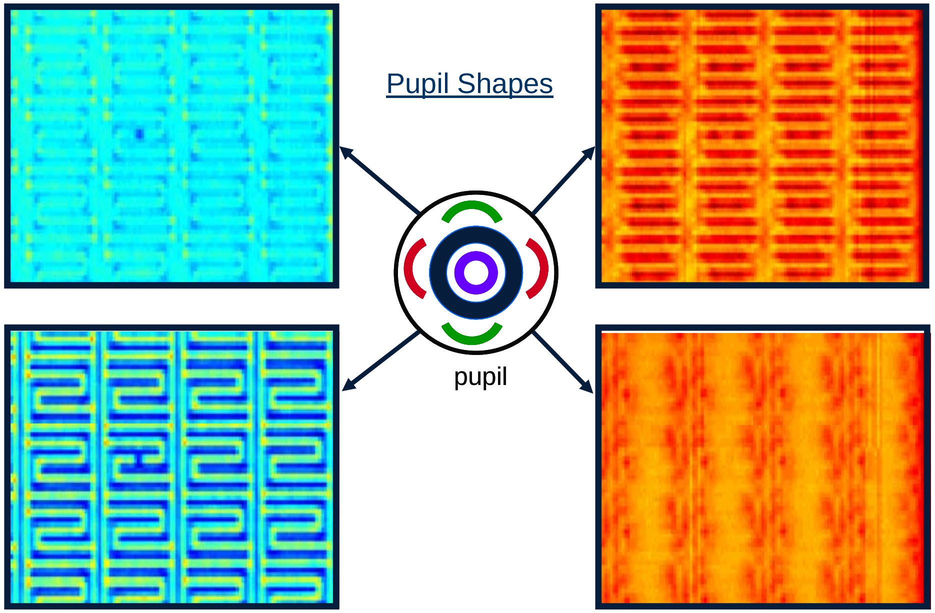
EBMI meets 32nm printability line

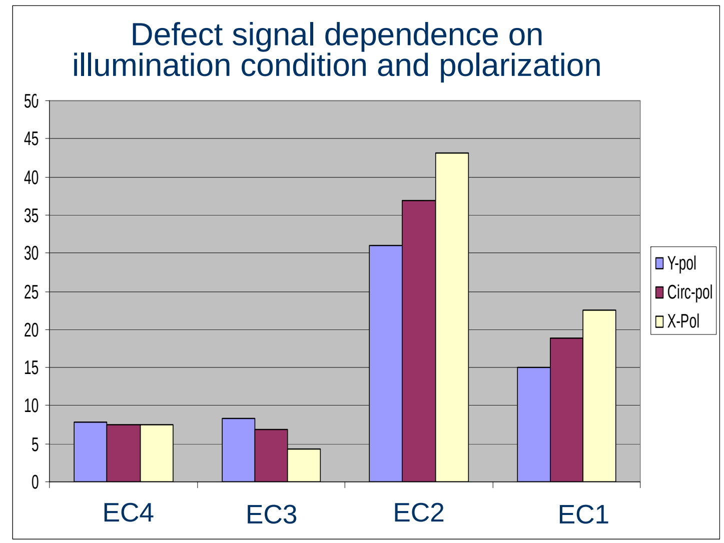
Potential Throughput on multi-beam: 6Hrs

*Imec data taken from: R. Jonckheere et al @EUVL Symposium, Prague 2009, O_RI1-04

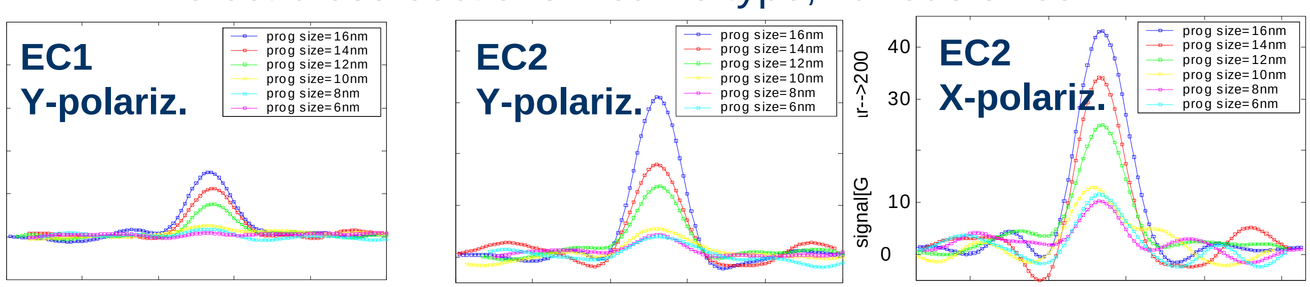
Using DUV RET Illumination Modes for Detection

L/S 1:1 128nm CD





Defect cross-sections – same type, various sizes



Optimizing illumination pupil and polarization can enhance defect signal

Absorber defect

Mitigation: mask inspection + repair at mask shop

Absorber Defect Detection

Patterned Mask Inspection (best case) succeeded in finding all absorber related defects for 32nm node.

Evolutionary

But:

Multi-layer Defect Detection

Combination of blank inspection and wafer prints are required to identify multi-layer defect.

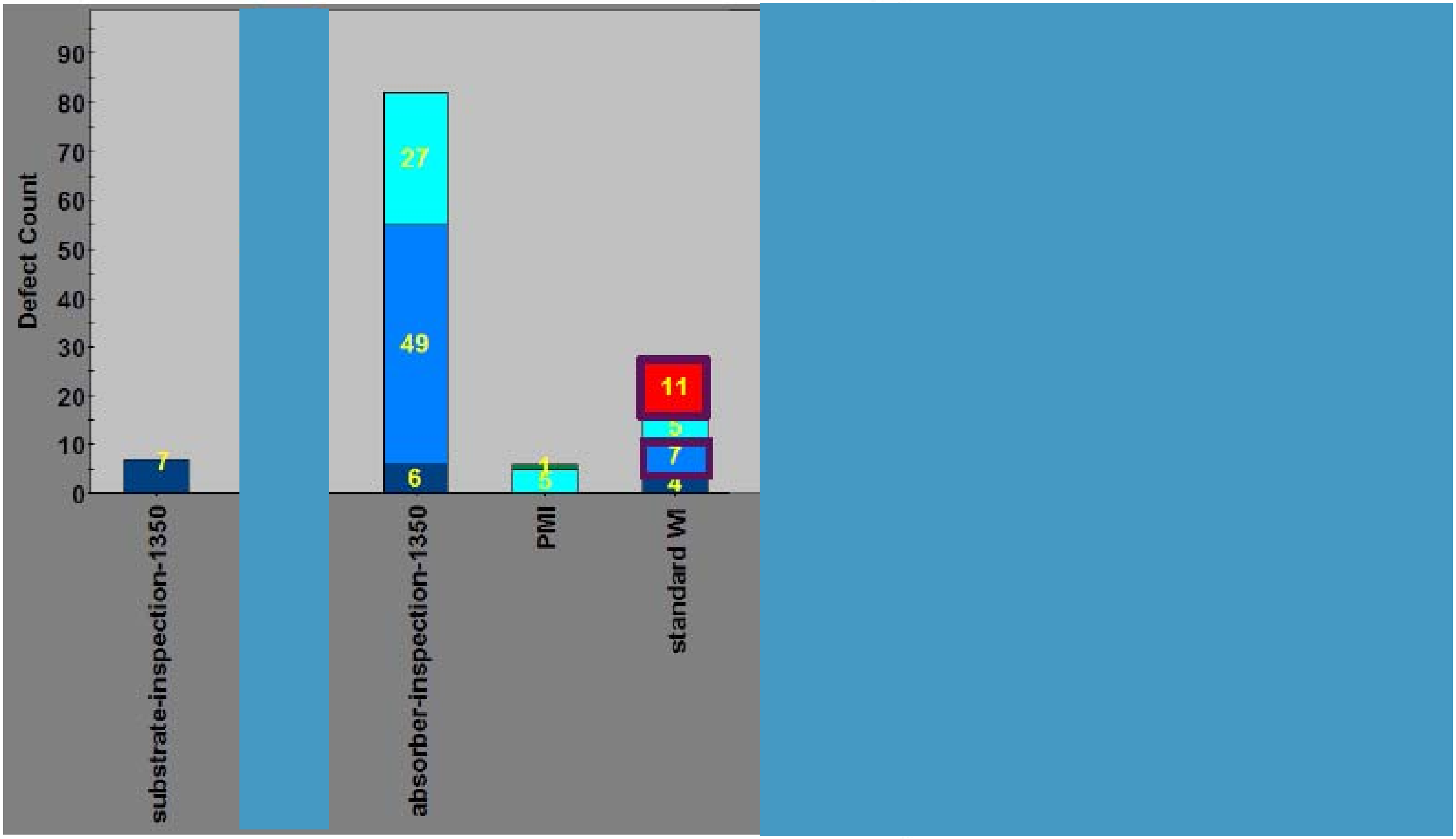
Revolutionary

Multilayer (ML-) defect

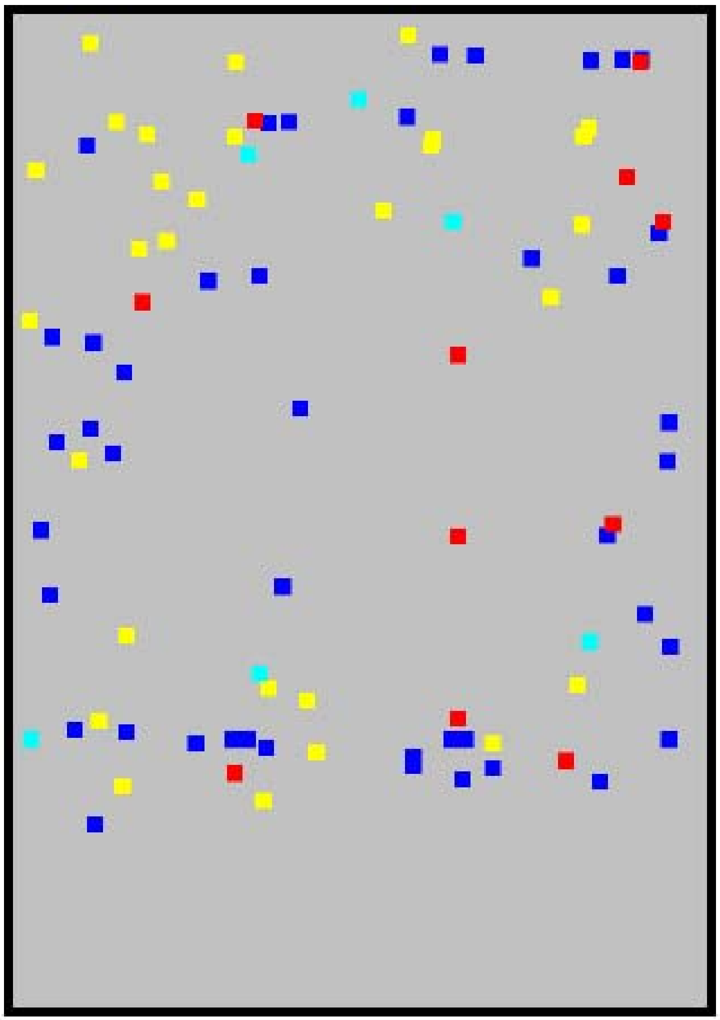
Need to be found by blank inspection (BI) by blank vendor + avoid printing

Source: imec = M. Lamantia

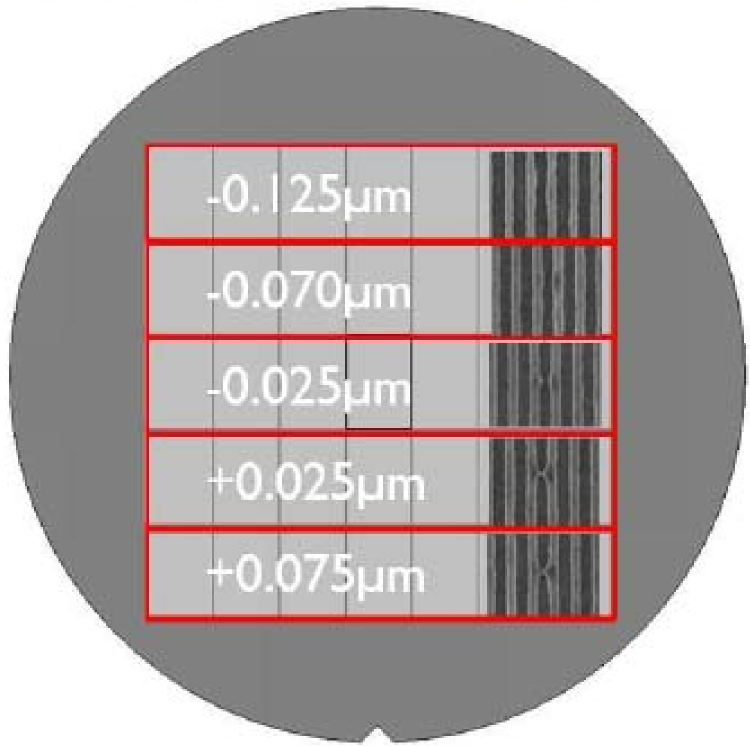
DEFECT40FF-B:
DSA WITH OPTIMIZED WI



IMPROVEMENT OF WAFER INSPECTION TECHNIQUE



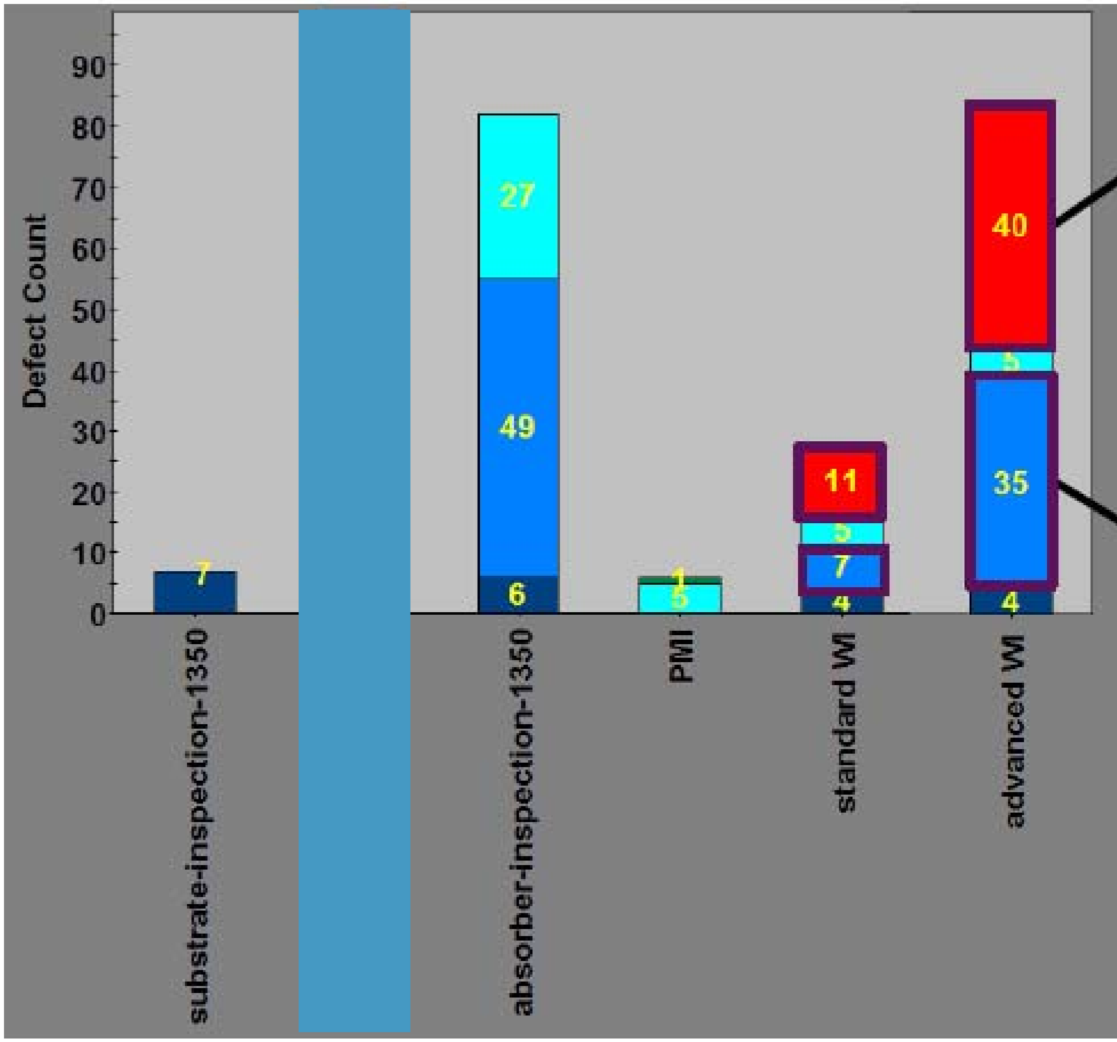
Existing WI tools onsite



Advanced WI in BF

Advanced WI on focus-skew wafers

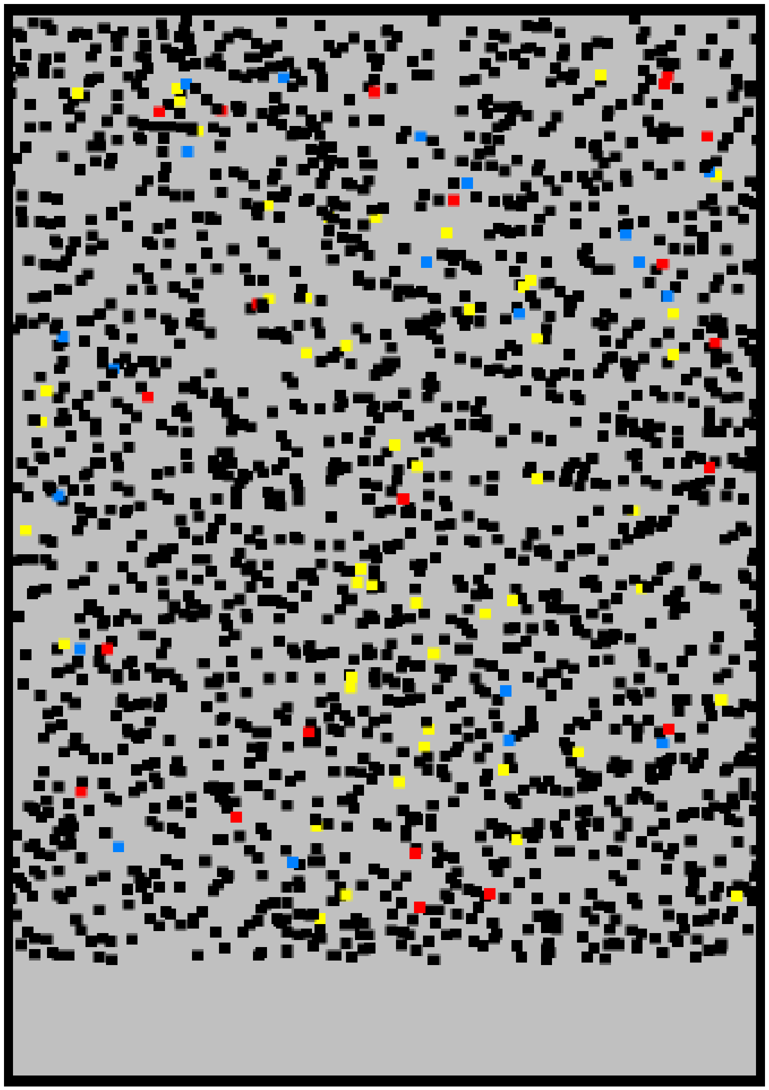
DEFECT40FF-B: DSA WITH OPTIMIZED WI



Nr. of defects only found by WI also increases significantly

Number of defects correlating with BI increases significantly

WHAT ABOUT MORE ADVANCED BLANK INSPECTION (M7360)?



1. **Did M7360 detect these 21 defects?**

   ☺ All 21 defects were detected (red dots)

2. **Reticle review revealed not 21, but in total 41 defects that were related to ML (no focus effect).**
   Did M7360 find all these defects?

   ☺ All 41 defects were detected (red + blue dots)

3. **Review of additional detections by M7360 on wafer => how many print?**

   ☺ An additional 50 printing defects were detected (yellow dots)

4. **Review of additional detections by M7360 on wafers => how many don't print?**

   ☹ The amount of detections of non-printing defects (black dots) is unacceptable
   Note: locations were only reviewed in BF

5. **Important remark: state-of-the-art wafer inspection tools might reveal smaller, even more-challenging ML-defects that might have been missed by M7360-inspection (future work)**

Blank & Pattern Inspection seen as Highest Risk

Blanks

Risk	Phase defect
Solution	Defect position management based on actinic inspection

EB Exposure

Risk	Pattern distortion
Solution	Compensation of distortion based on flatness estimation

Etching

Risk	Formation of shading frame
Solution	Frame formation by removing multilayer

Inspection

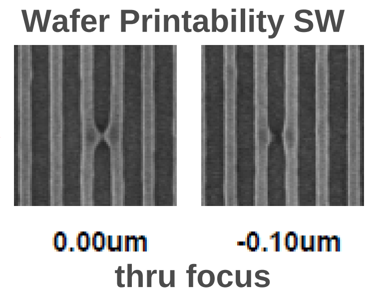
Risk	Sensitivity
Solution	hp2Xnm: Inspection by UV hp1Xnm: Inspection by EB

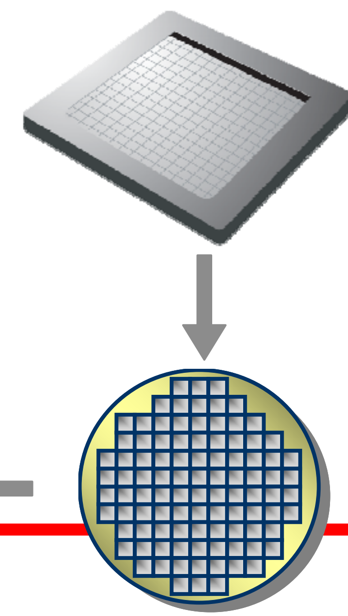
Defect Repair

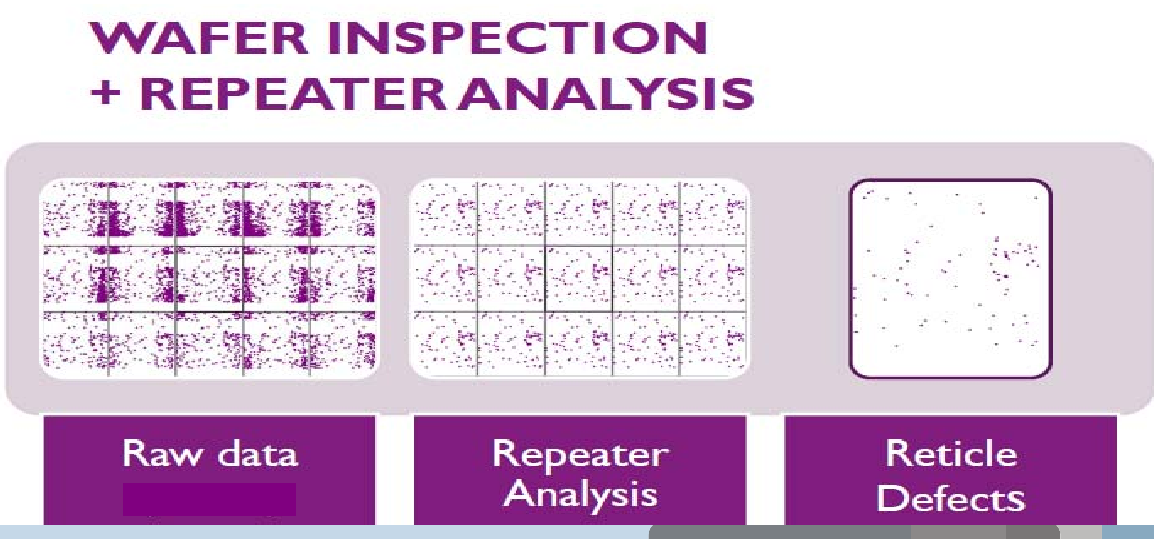
Risk	Guarantee method
Solution	Lithography simulation using mask 3D image to EUV-AIMS

Shipping

Risk	Pellicle less
Solution	Dual Pod







APPLIED MATERIALS.

Portability / Interchangeability in EUV Regime

- Pursuing EBI for both Wafer and EUV Mask makes sense [$]
  - Leverage same basic Technology
  - Leverage Platform Development
  - Leverage HW Front-End
  - Leverage SW Development
    - Job Set-Up, ADR, Expert Systems, Statistics, etc pp
- Special Requirements for EUV Mask + Wafer Print [synergistic to ML2]
  - D2EBM
  - Needs similar SW FE to existing DUV Mask Inspection System
    - Some elements exist [OPC Check]
- EUV Mask Inspection [and ML2] need close Customer Interaction
  - Steep Learning Curve
- ML2 only requirement
  - Sampling Plan
    - Mix and Interaction of DUV and EB

Summary

- EBI Strategy
  - EBI is the inspection technology for detection of <30nm defects
  - We are developing EBI technology to address future inflections in both Wafer Inspection and EUV Mask Inspection

- Current Performance
  - Very stable system – good image quality during the scan, focus is stable, no charging related instabilities encountered
  - Easy to set up a recipe – layout , following WI tool SW

- Next steps
  - Continued SW development > Data Front End
  - Continued HW development - Next generation e-beam
    - Higher beam current
    - Resolution / Speed
    - Higher data rate

Outlook

- DUV and E-Beam are the technologies for Optical Roadmap Extension
  - both: Wafer and Mask
  - For Mask: DUV will cut out at <20nm
  - EB will be ready to take over
- Wafer Technology is currently taking the lead
  - Development Roadmap based on WI
  - Switch = higher priority on Masks – would require roadmap acceleration
- EB is known risk
  - EB Technology and EB Inspection has been around for a decades
  - Challenge is COMPACTION = <u>Multi Column Technology</u>
  - Challenge is <u>Transfer Rate</u> = Speed [gpps]

- Many parallels in development between Wafer and Mask Systems
  - One feeds off the other

Questions ?

EBMI Damage tests Result on EUV Mask
No reflectivity loss was found

The experiment

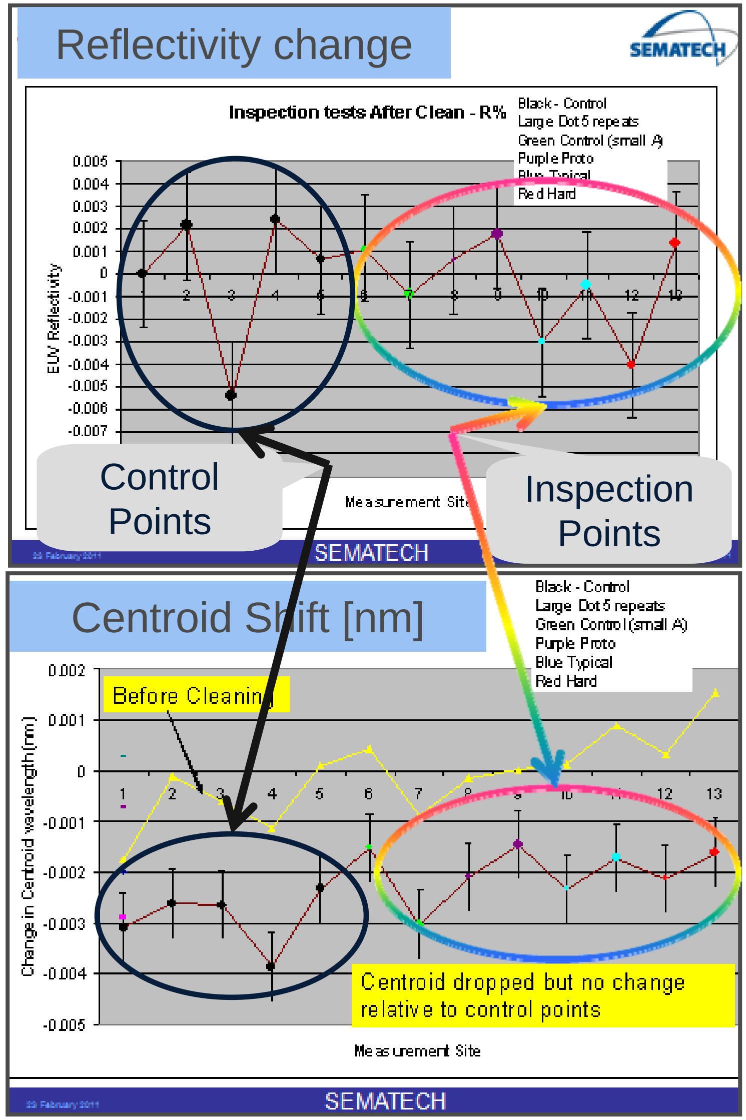
- Performed on a 2nd gen EBI platform ("HV2")
  - EBI chamber was open from top
  - Mask adapter was mounted
  - EUV mask manually inserted into chamber
  - Chamber was closed and pumped
- Mask used: Ru cap, ML Blank
- Tested several inspection conditions and repeats
- Reflectivity change and centroid shift measured at Sematech*

Results relative to control points:

- No reflectivity loss was identified
- No Centroid shift

Conclusion

- No mask damage is identified



* Thanks to Greg Hughes and C.C. Lin from Sematech, Albany

- KLA-Tencor eS35
  - Die-to-die
  - Image contrast inspection
  - Pixel size: 15, 20, 25nm
  - Landing energy 1750V
  - Data rate 50mpps
- Hermes Microvision eScan 315
  - Die-to-die
  - Image contrast inspection
  - Pixel size: 10, 15nm
  - Landing energy: 2000V
  - Data rate 100mpps
- NGR 2100
  - Die-to-database
  - Fast CD inspection
  - Pixel size: 3nm
  - Landing energy 2600V
  - Data rate 50mpps

Molecular Imprints

Questions ?