Analysis of defects on extreme ultraviolet mask blanks and substrates

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Outline

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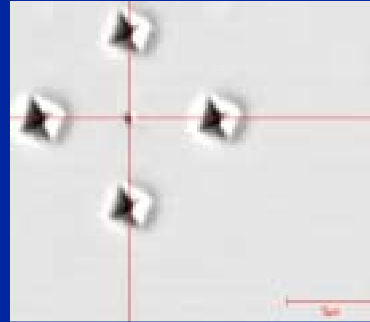
- Overview of defect analysis
- The blank inspection system
  - Defect pixel count is the critical output
- Surface analysis techniques
  - Auger Electron Spectroscopy (AES)
  - Integrated defect analysis
- Result and discussion
  - Classification of defect types
  - Identify process variation from inspection pixel count and AES data
- Conclusions

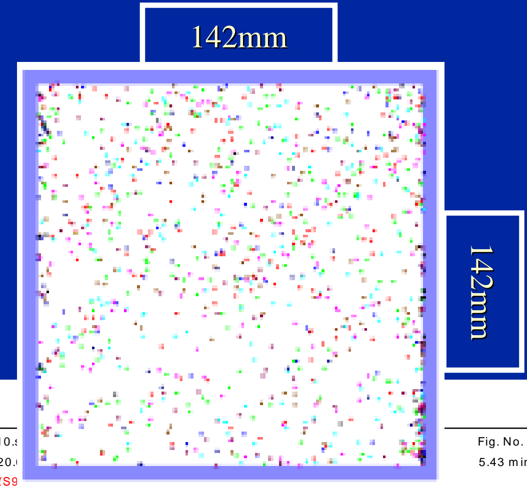
Introduction

- **Delivery of "defect-free" masks is a top priority**
  - Current defect level is orders of magnitude too high
- **Need to develop capability to detect, review, and characterize sub-100nm defects for root cause analysis and defect reduction**
  - Defect generated from complex integrated process: substrate finish, ML deposition, reticle handling, etc.
- **We applied a variety of surface science techniques following a highly sensitive inspection system to classify and characterize small defects on blanks**
  - Confocal microscope inspection tool maps and marks defects
  - Surface techniques - AES, EDX, AFM, SEM, FIB – analyze composition, sizes, height, shapes

Defect-analysis procedure

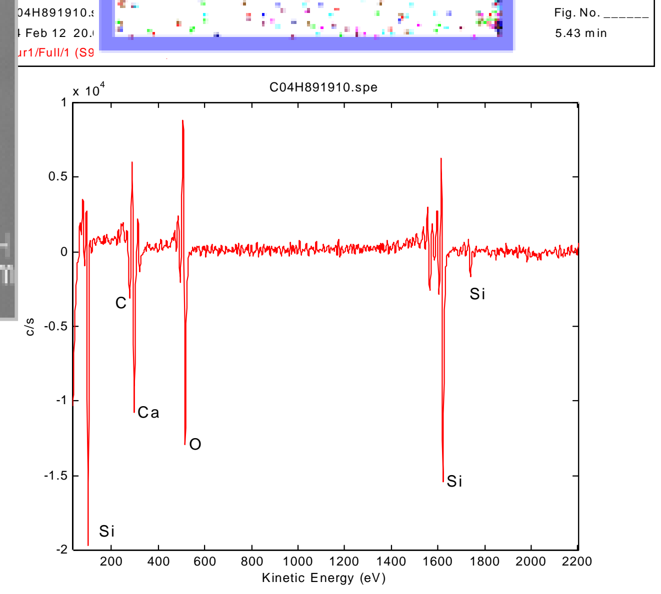
Defect inspection
1) map and mark defects 2) create fiducial marks for coarse & fine alignment





Align marks
Find defects
obtain defect image

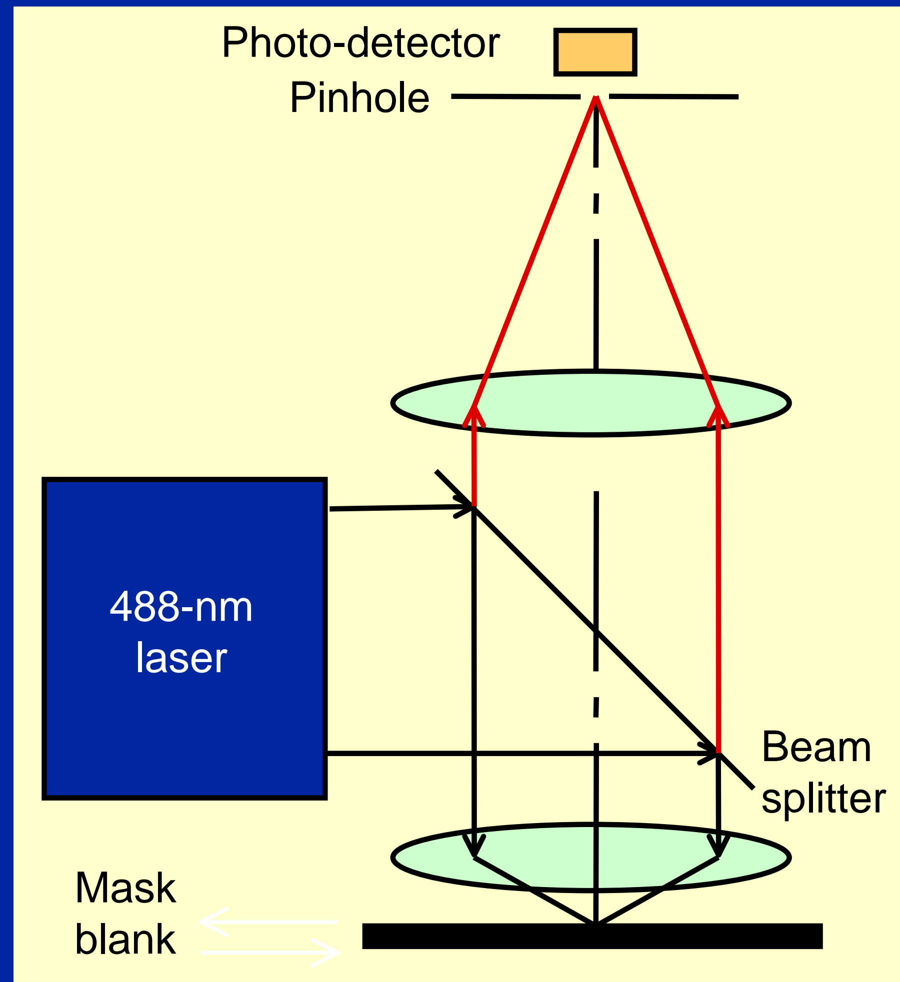
Defect Spectra and signal analysis
1) AEX or 2) EDX or 3) AFM or 4) SEM or 5) FIB



Defect classification, root causes, a

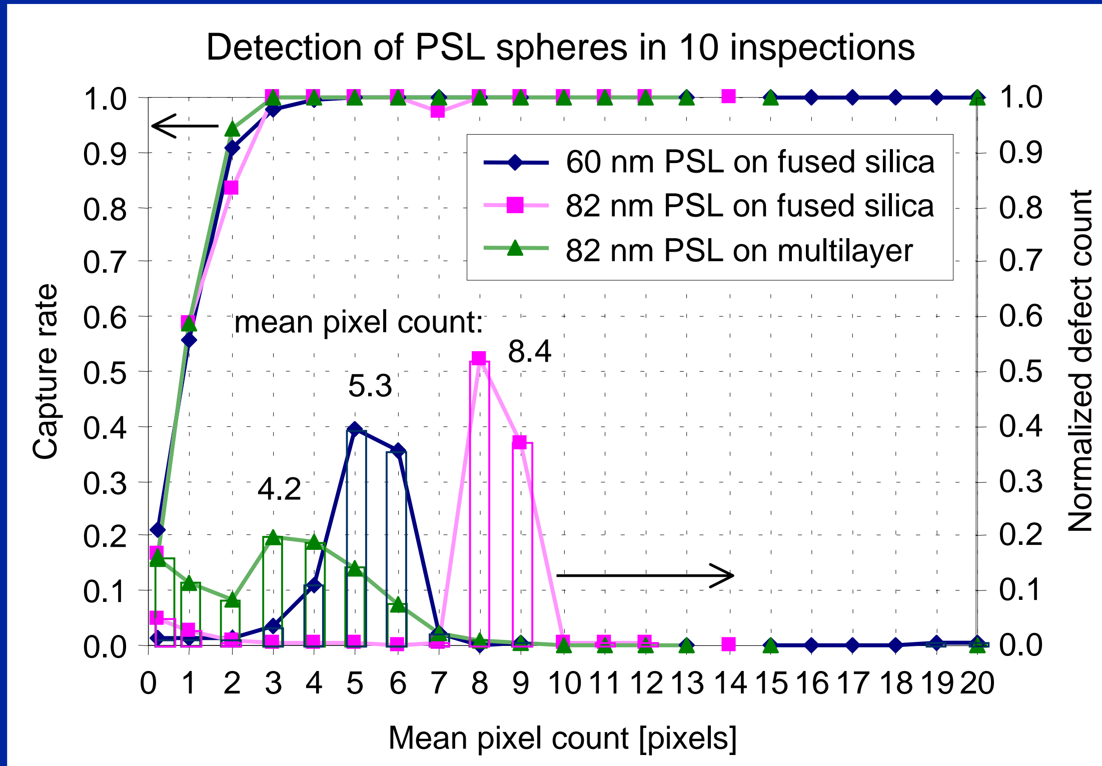
Mask Blank Inspection System

- High-NA scanning confocal microscope operating at 488 nm
- 33 parallel beams used for high throughput
- Optical contrast enhancement mode used to improve sensitivity
  - simple confocal mode also available
- Samples with different reflectivities can be measured
  - fused silica (3.5%)
  - Ru-capped Mo/Si multilayer (56%)



References:
A. R. Stivers et al., *Proceedings of the SPIE*, vol. **4889**, pp. 408-417, 2002
J.-P. Urbach et al., *Proceedings of the SPIE*, vol. **5256**, pp. 556-65, 2003

Inspection System Characterization



- Capture rate and mean pixel count
  - defect with mean pixel count of 1: capture rate >55%
  - defect with mean pixel count of 2: capture rate >80%
  - defect with mean pixel count of 3: capture rate >95%

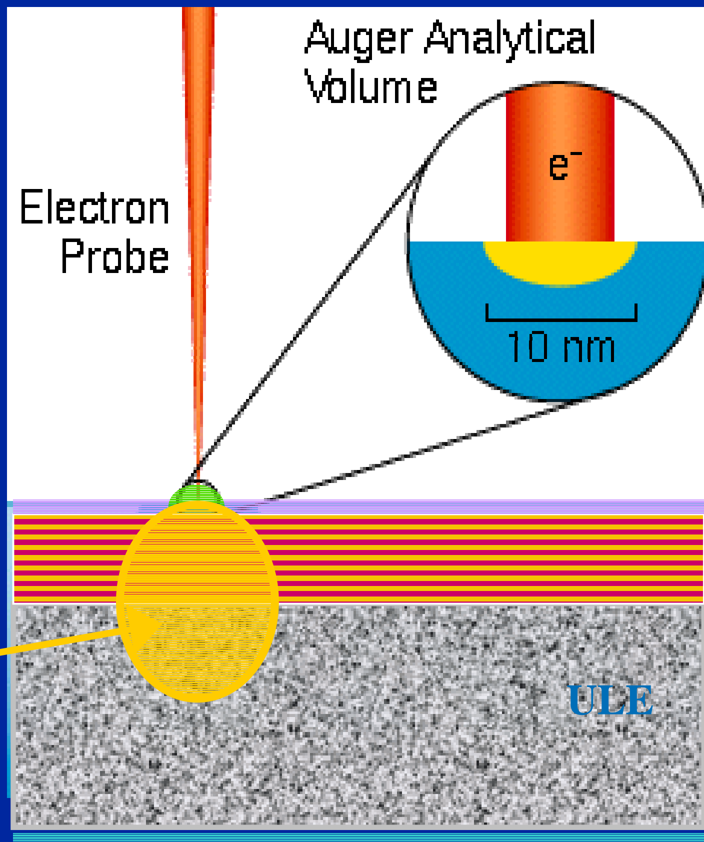
- For defects made of the similar material as the blank surface, 60-nm sensitivity corresponds to approximately to mean pixel count of 5.3
- Sensitivity for PSL spheres on fused silica is significantly better than for PSL spheres on Mo/Si multilayer owing to difference in image contrast

Overview of defect-analysis tools

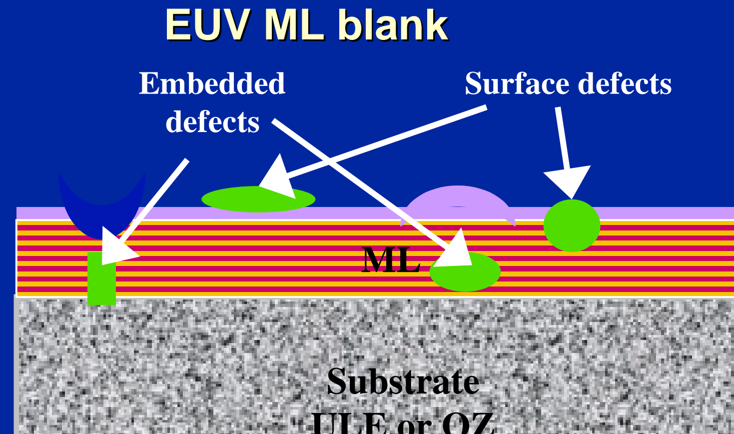
Techniques	Lateral resolution	Depth resolution	Advantages	Disadvantages
AES Auger electron spectroscopy	**70 nm** Demo'd	**2 nm**	**-High lateral resolution** **-Surface specific** **-Elemental info** -Semi-automated	**-Charging on glass**
EDX Energy dispersive X-ray spectroscopy	**250 nm**	**1500 nm**	**-Elemental info** **-Fast composition scan** -Semi-automated	**-Lateral resolution >250nm** **-Not surface specific** **-Can not tell embedded defect from surface**
SEM Scanning electron microscopy	**25-70 nm**	**NA**	**-High lateral resolution** **-Excellent morphology**	-No composition data
AFM Atomic force microscopy	**5 nm**	**0.1 nm**	**-Excellent height info**	**-Slow and small area** -No composition data
TOF-SIMS Time-of-flight SIMS	**500 nm**	**1 nm**	-Organic composition -Surface specific	Low lateral resolution

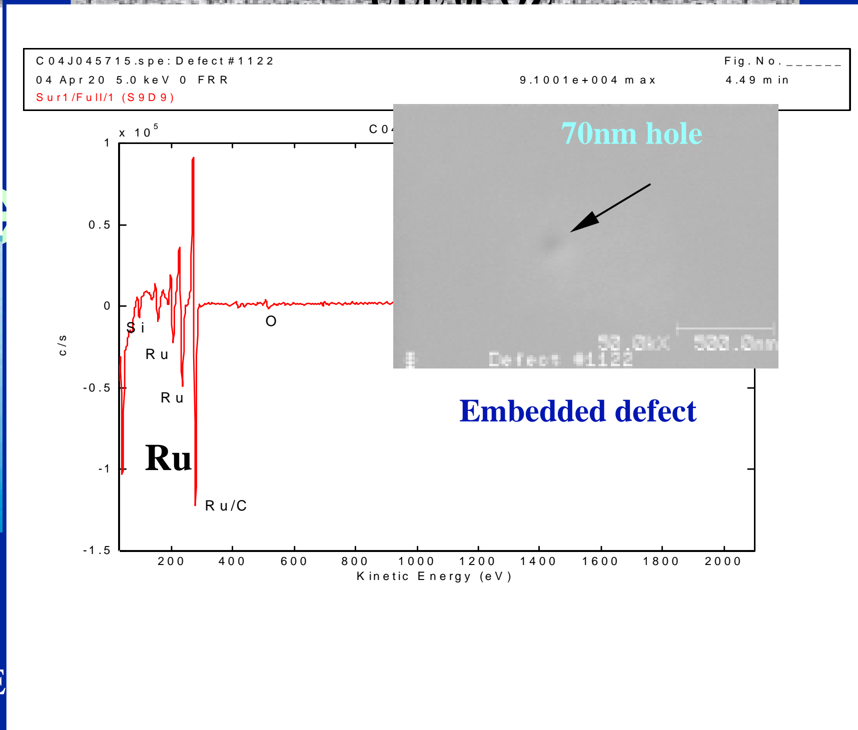
AES demonstrated surface-specific and sub-100nm lateral resolution

Auger electron spectroscopy:

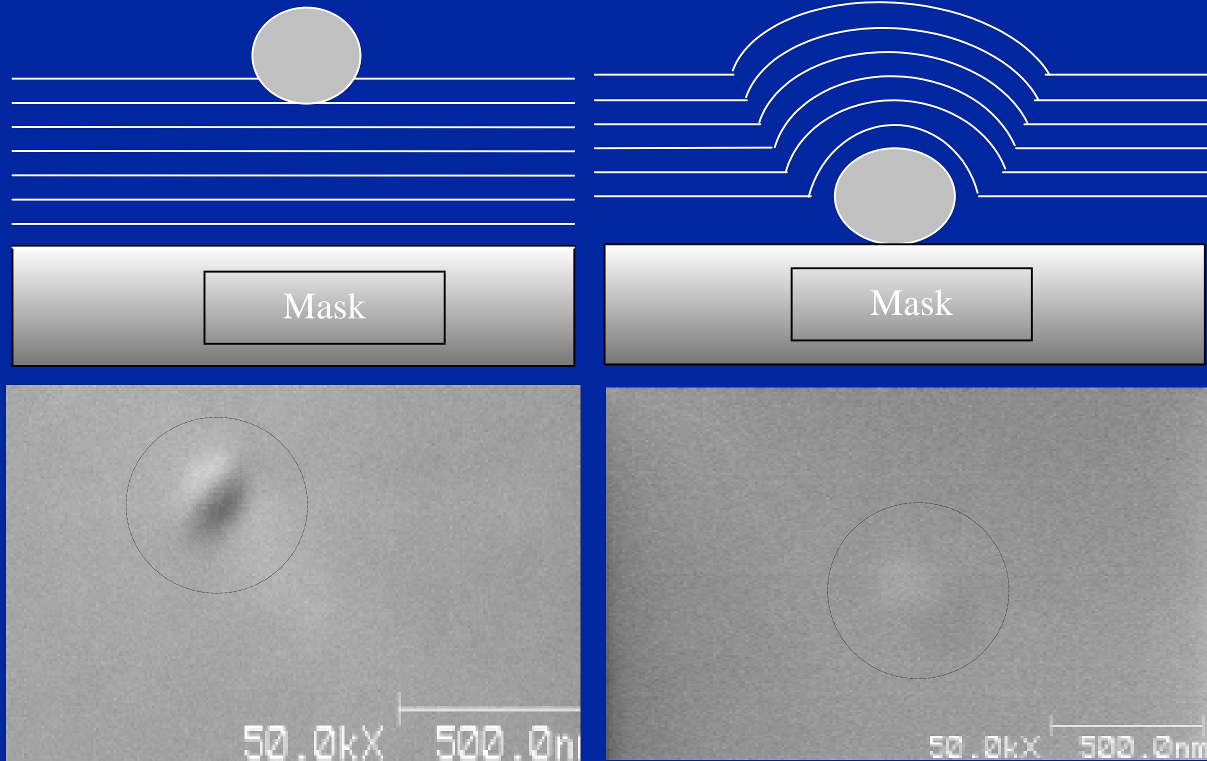


EUV ML blank

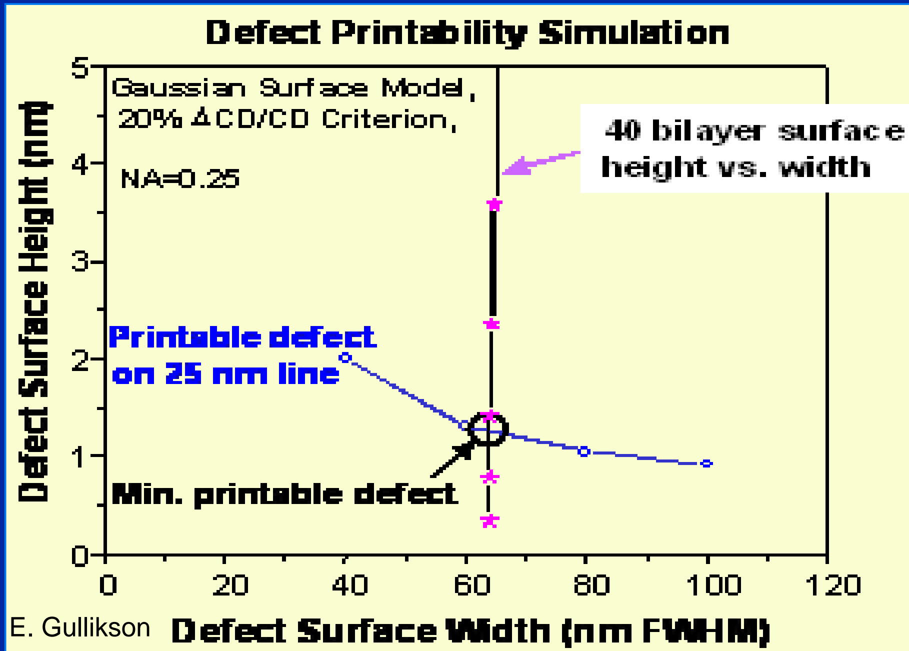


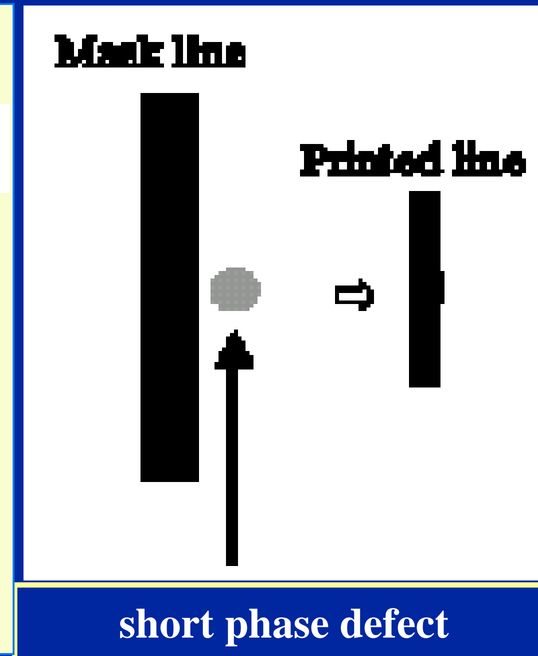


Defects on multilayer blanks can have very low contrast (in SEM)



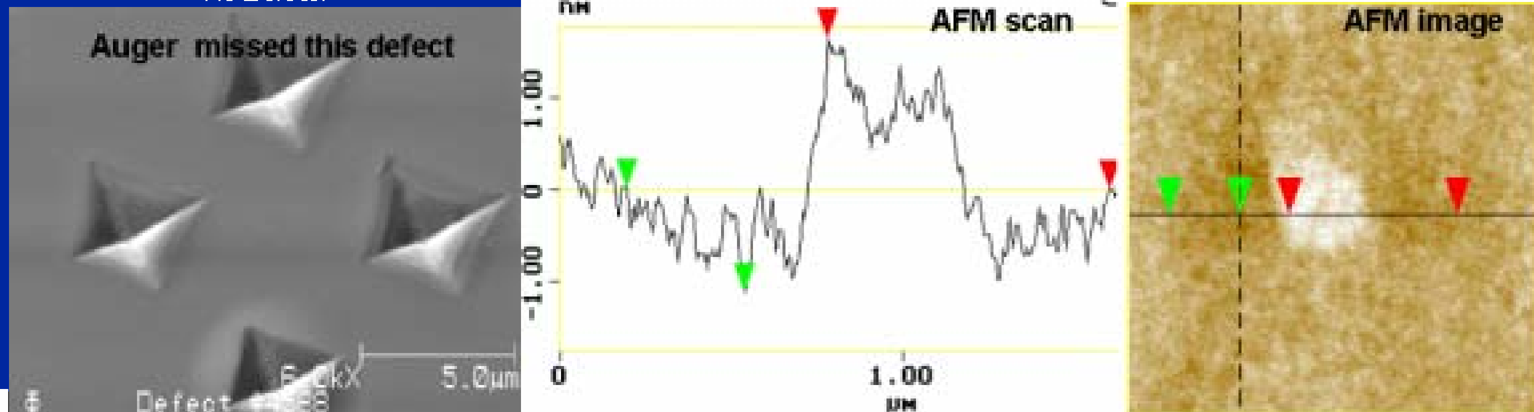
Need to detect "short" and wide defect



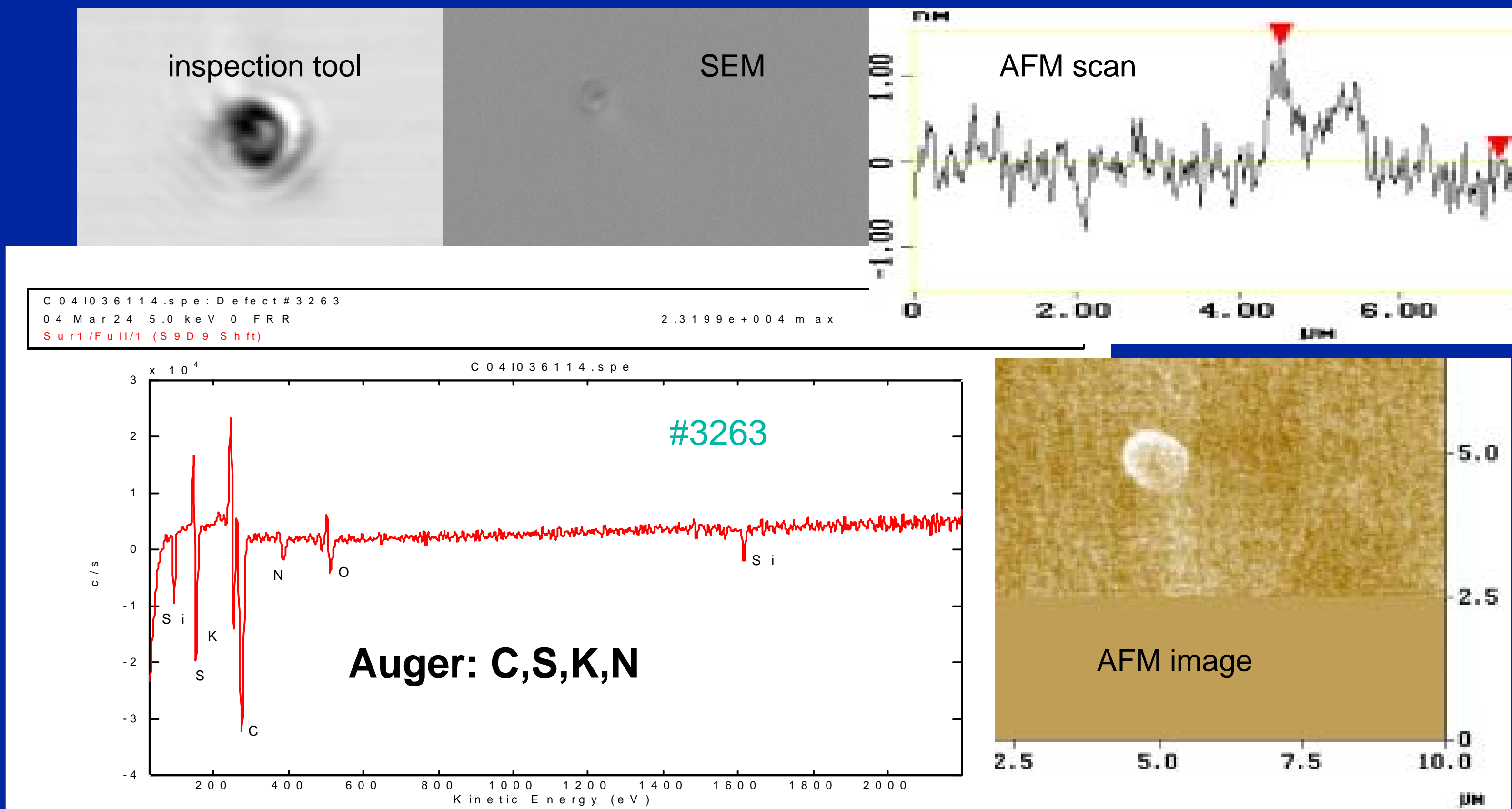


short phase defect

AFM found 1nm-high bump but SEM and AES missed it

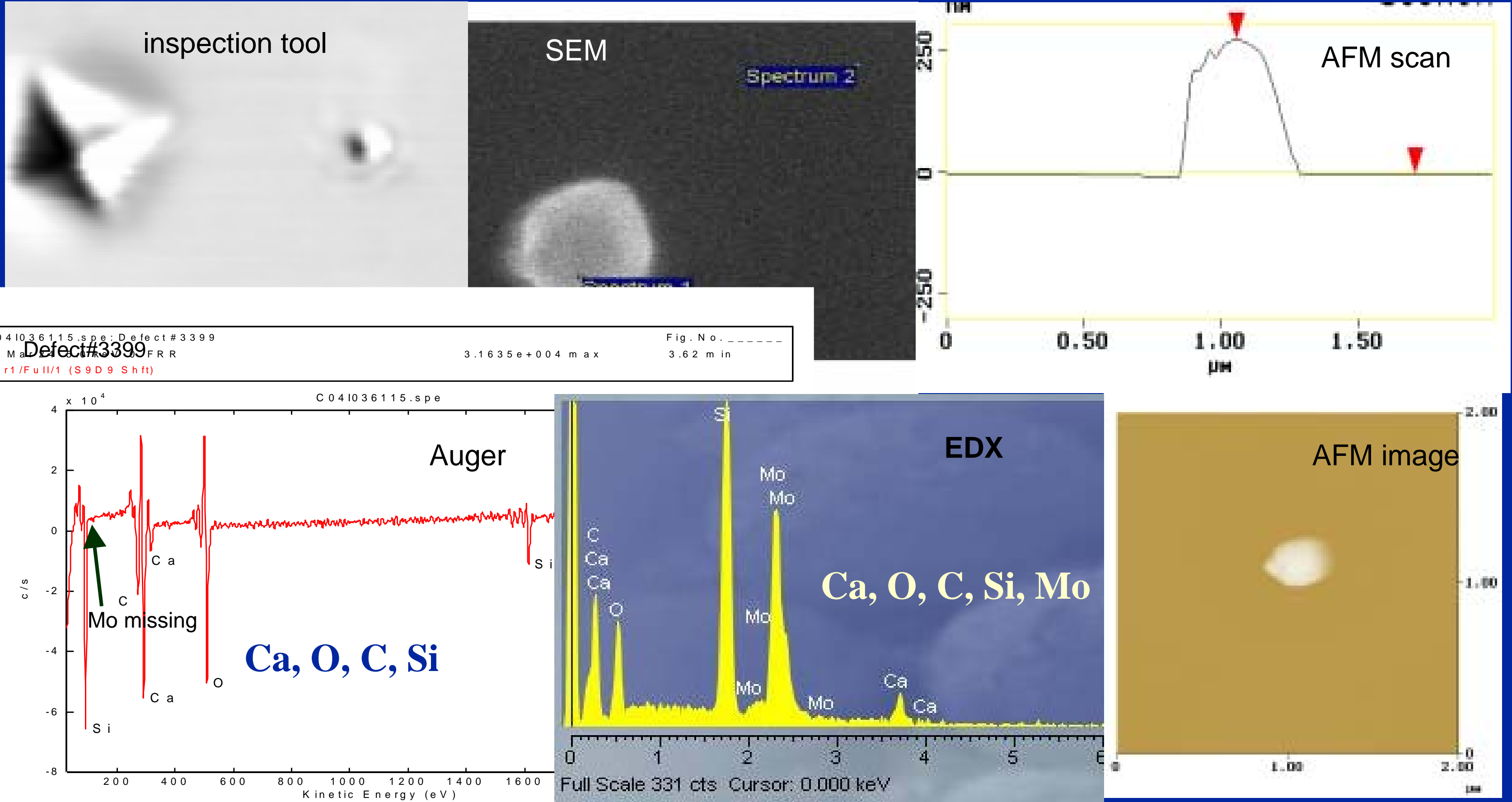


Using a suite of tools on "short" defect



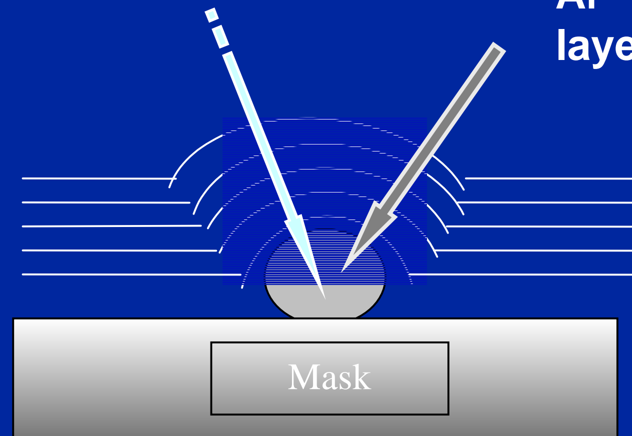
This is a 150nm wide, 0.6nm short bump containing C,S,K,N

Using a suite of tools on "tall" defect



This is a 350nm wide, 250nm tall particle containing Ca, O, C

AES profiling can cross section embedded defects inside ML stack



Ion milling + AES → depth resolution

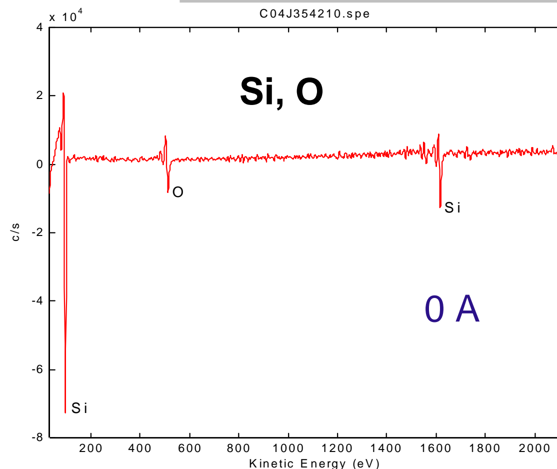
Depth-resolved image and composition of an embedded defect

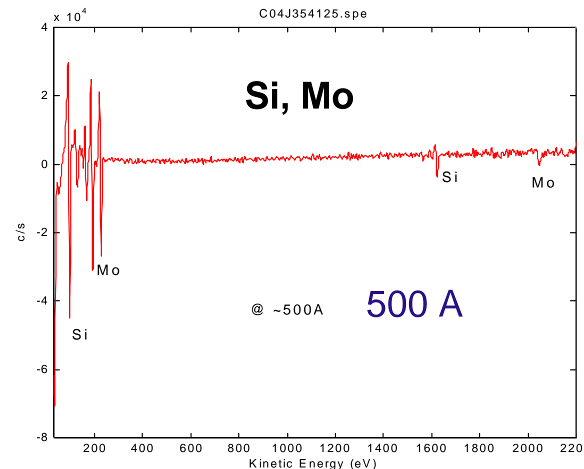
ML surface

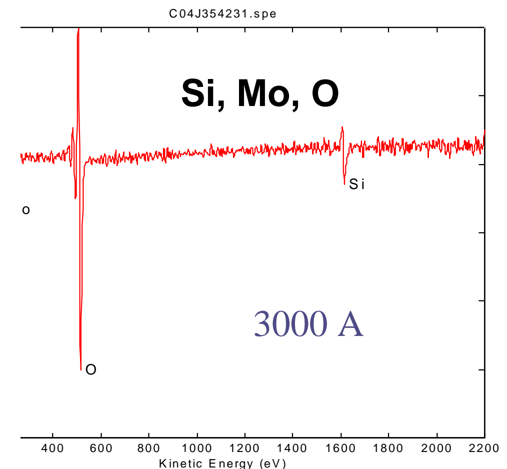
"as-received"

at ~3000A

Substrate surface

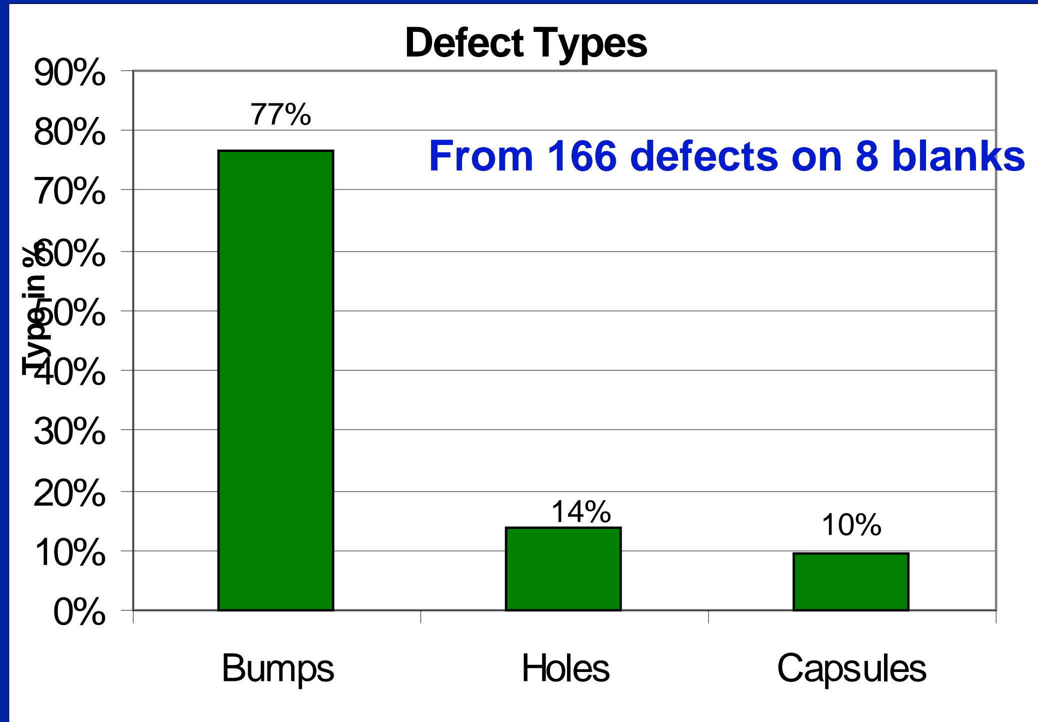


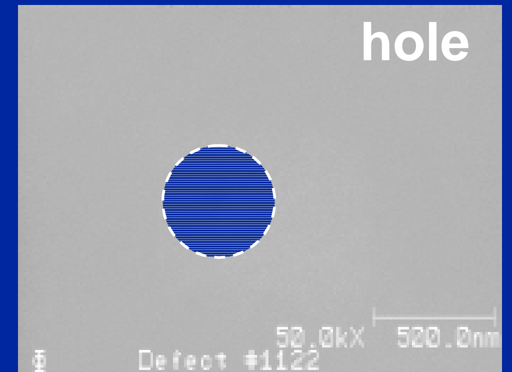


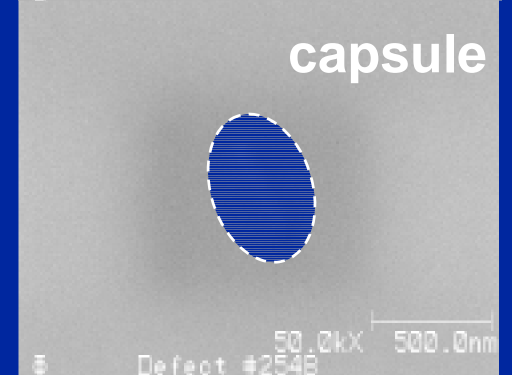


This defect originated on substrate surface

Defects are bumps, holes, capsules



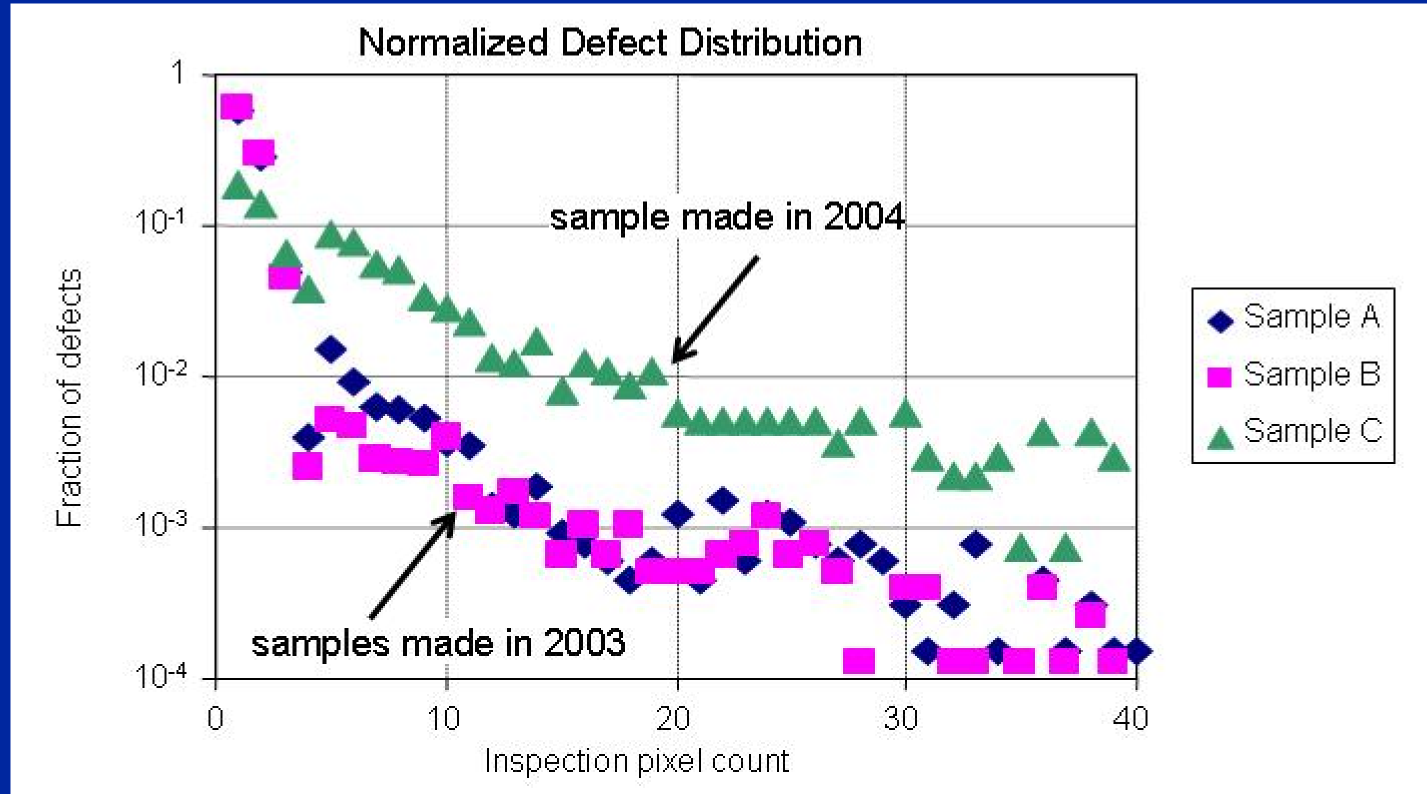




Among the analyzed 166 blank defects from 8 blanks, 127 are bumps, 23 are holes, 16 are “capsules”

Defect Distribution Reported by Inspection Tool

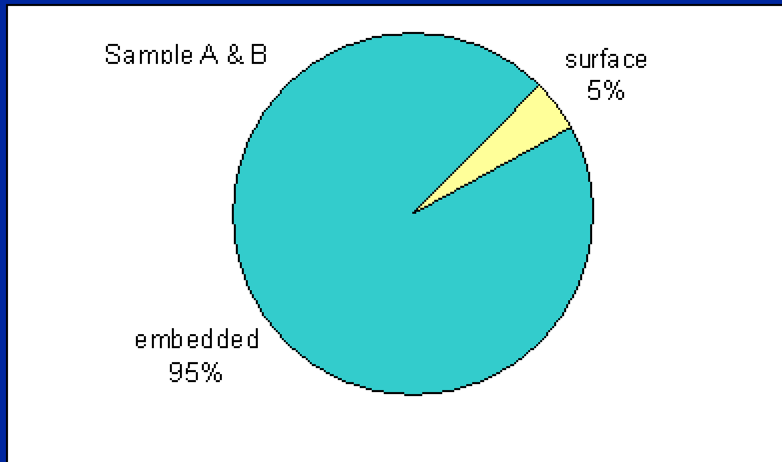
- Data from 3 samples (2.5nm Ru + Mo/Si multilayer on quartz)

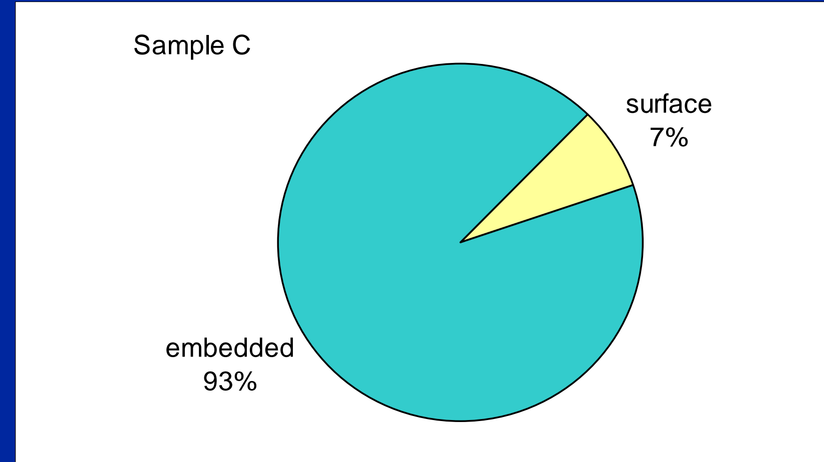


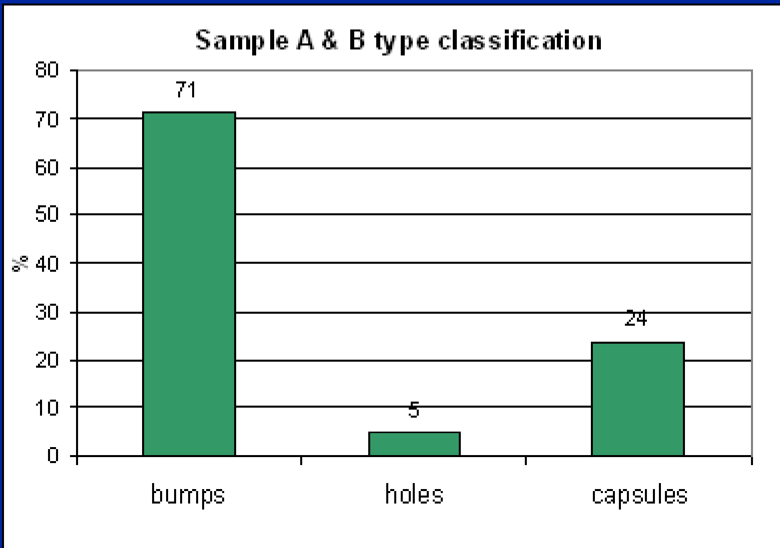
- Defect pixel count distribution depends on the fabrication process
- Same period samples have similar defect distributions

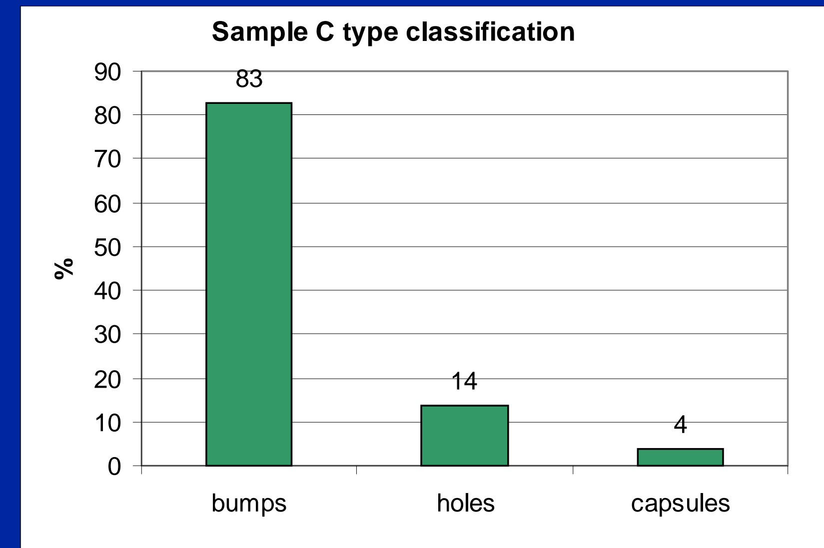
Compare Ru-blanks made Q4'03 (A&B) and Q2'04 (C)

- similarity: embedded bump defects
- difference: new samples have less capsules









Conclusions

- Successfully integrated blank inspection and defect metrology for sub-100nm defect analysis on EUV masks
- Applied data from inspection and surface analysis to classify defects and identify process variations
- Found >90% defects embedded in ML stacks
- Future plan is to work with suppliers to improve fabrication process and deliver "defect-free masks"!

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