Recent advances in the cleaning of EUV substrates at SEMATECH

Abbas Rastegar

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Sean Eichenlaub,
Kurt Goncher,
Helmut Popp,
Pat Marmillion

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EUVL Symposium – November 7, 2005

Where We Are

SEMATECH North
Mask Blank Development Center
Albany -New York

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SEMATECH MBDC Cleaning Core Team

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Helmut Popp
Schott Lithotec

Kurt Goncher
Steag HamaTech

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Outline

- **EUV Mask Cleaning**
  - EUV Blank Defects
  - EUV Substrate Defects
  - Soft Defects and Sources of Added Particles
- **Cleaning of Clean Quartz Substrates**
  - Quality of Quartz Substrates
  - Achieved Results
- **Single Defect Tracing in MBDC**
  - Particle Removal Mechanism and Damage
- **Sub-50 nm Particle Removal**
  - Definition of Sphere Equivalent Volume size
  - Achieved Results
- **Modeling of Particle Deposition and Removal**
  - Will be presented as a poster

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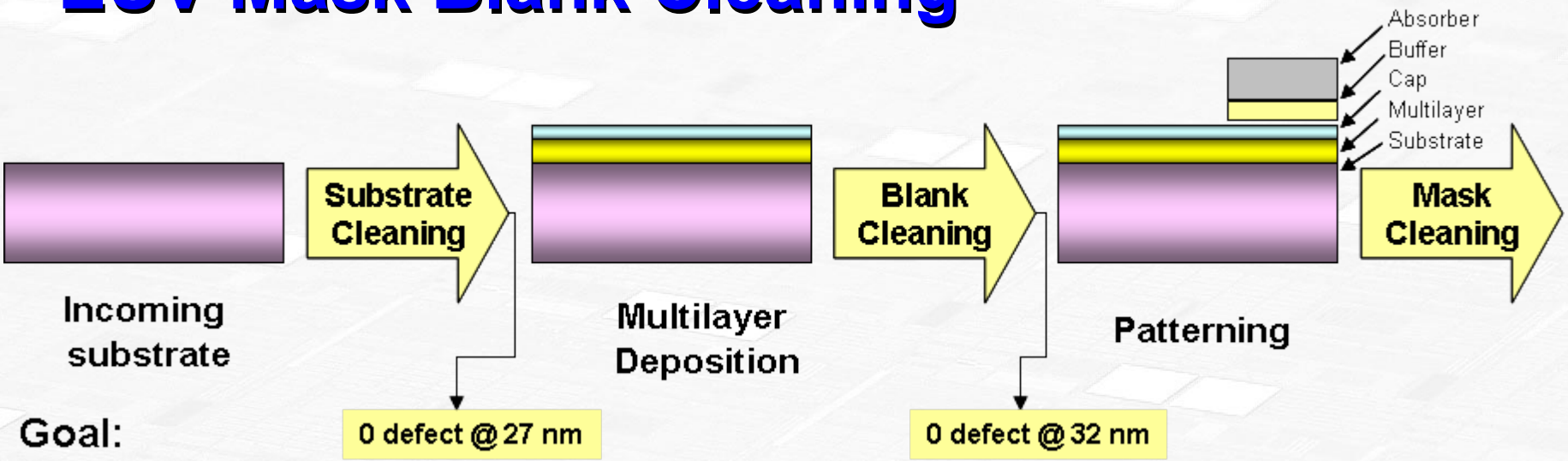
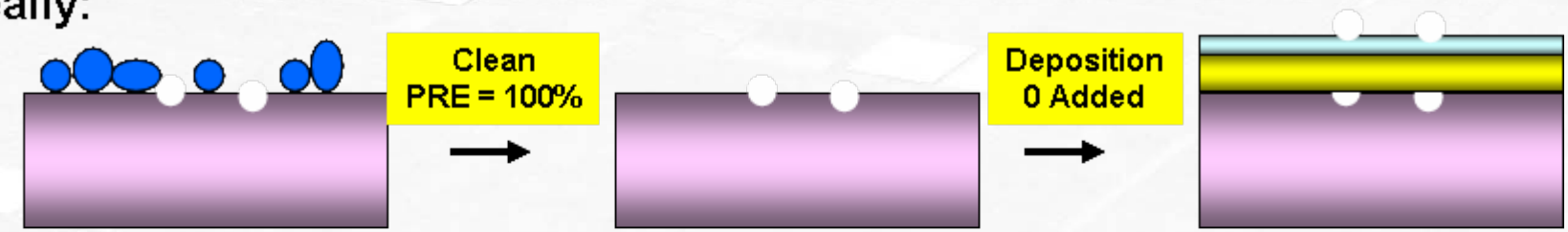
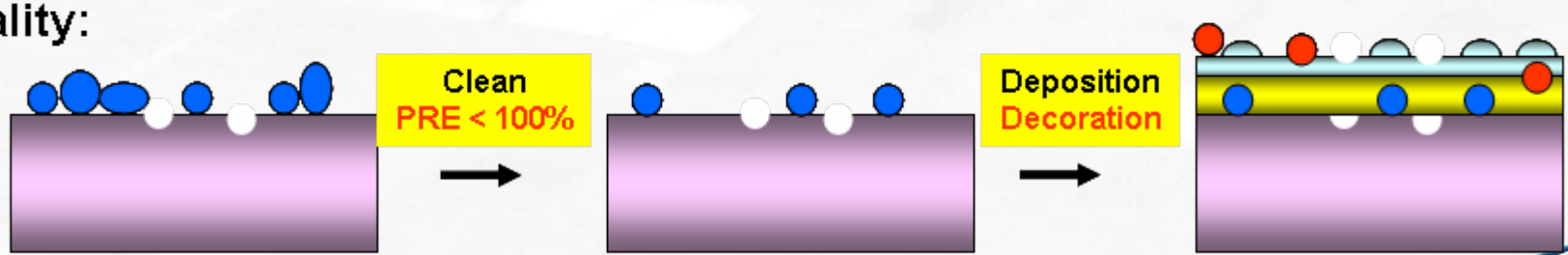
EUV Mask Blank Cleaning



Ideally:



Reality:



* PRE=Particle Removal Efficiency

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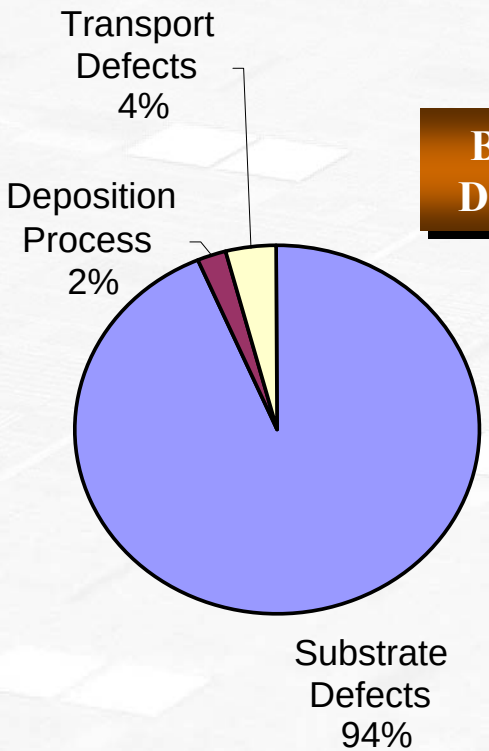
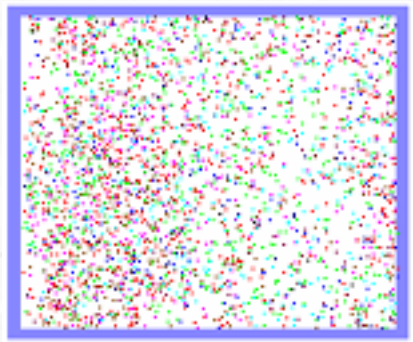
Mask Blank Defects

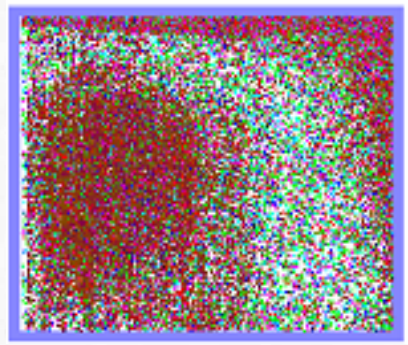


Blank Defects = **Substrate Defects** + **Deposition Defects** + **Transport Defects**

Before ML deposition



After ML deposition



Defect Decoration

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Substrate has the highest contribution to the blank defects

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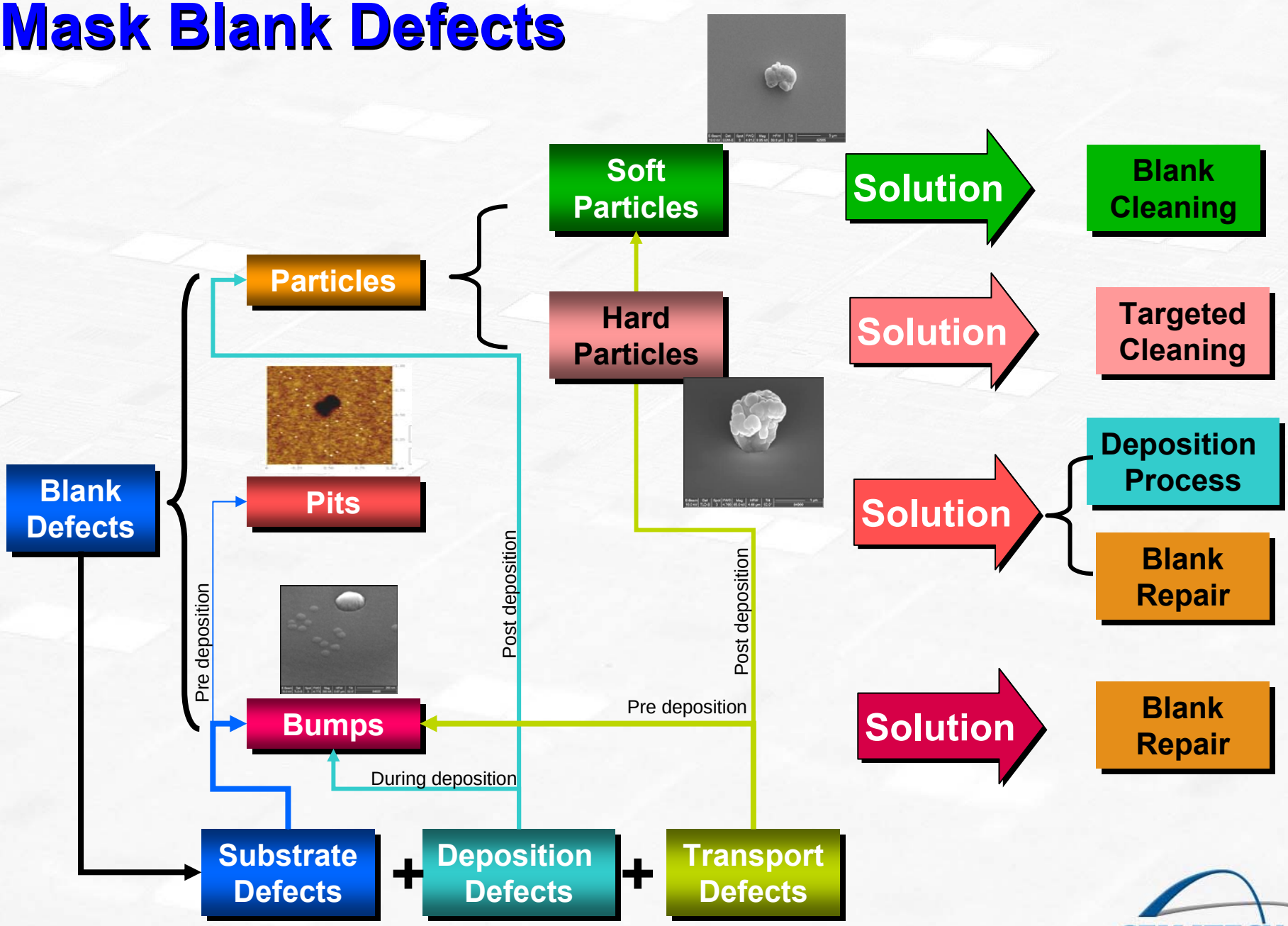
Mask Blank Defects



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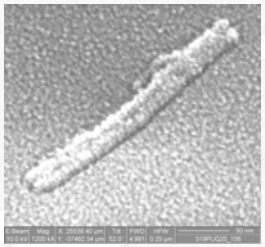
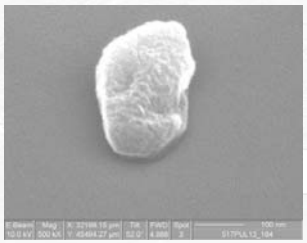
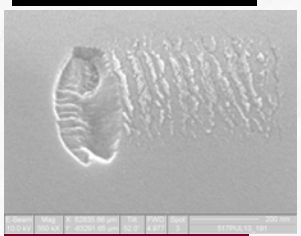
EUV Substrate Defects







Substrate Defects

- **Hard Particles** — 30% → **Solution** → **Targeted Cleaning**
  - Local Laser Removal
  - AFM-based Repair
  - Novel Ideas
- **Soft Particles** — 60% → **Solution** → **Substrate Cleaning**
  - Process Development
  - Fundamental Understanding
- **Pits** — 10% → **Solution**
  - Deposition Process
  - Substrate Repair

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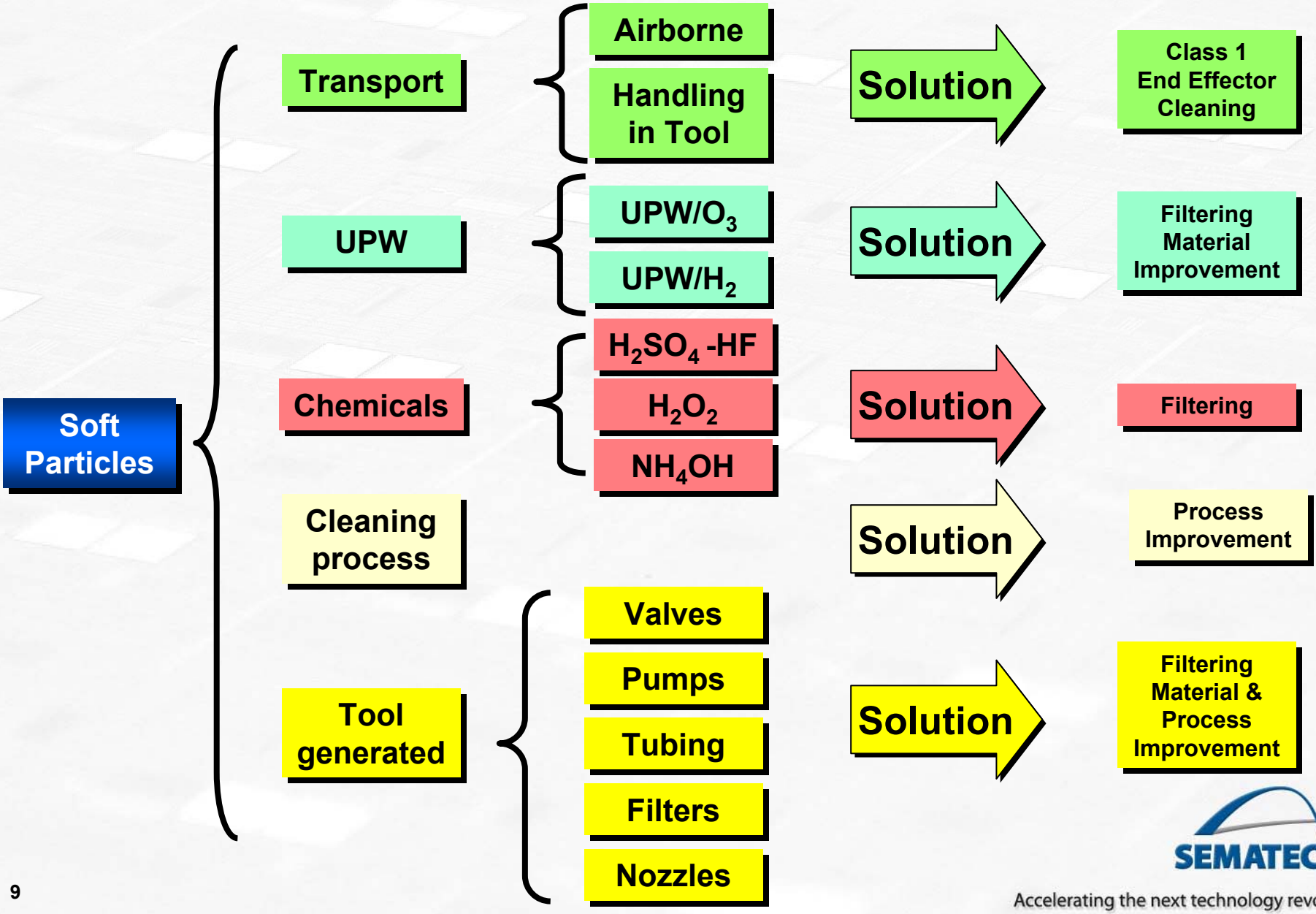
Particle (Re)/Deposition by Cleaning Tool



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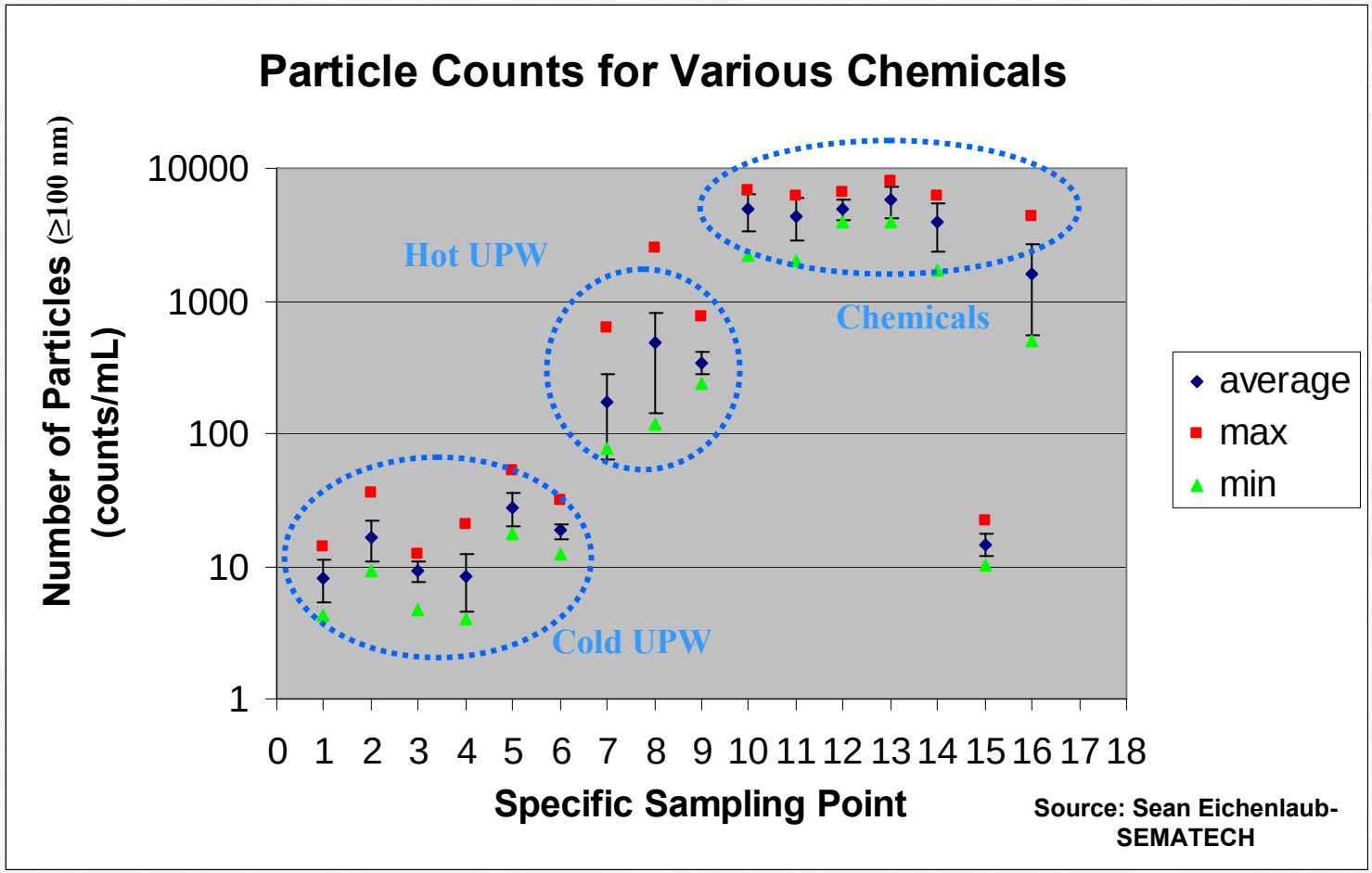
Particles in UPW and Chemicals



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Most chemicals have many particles !

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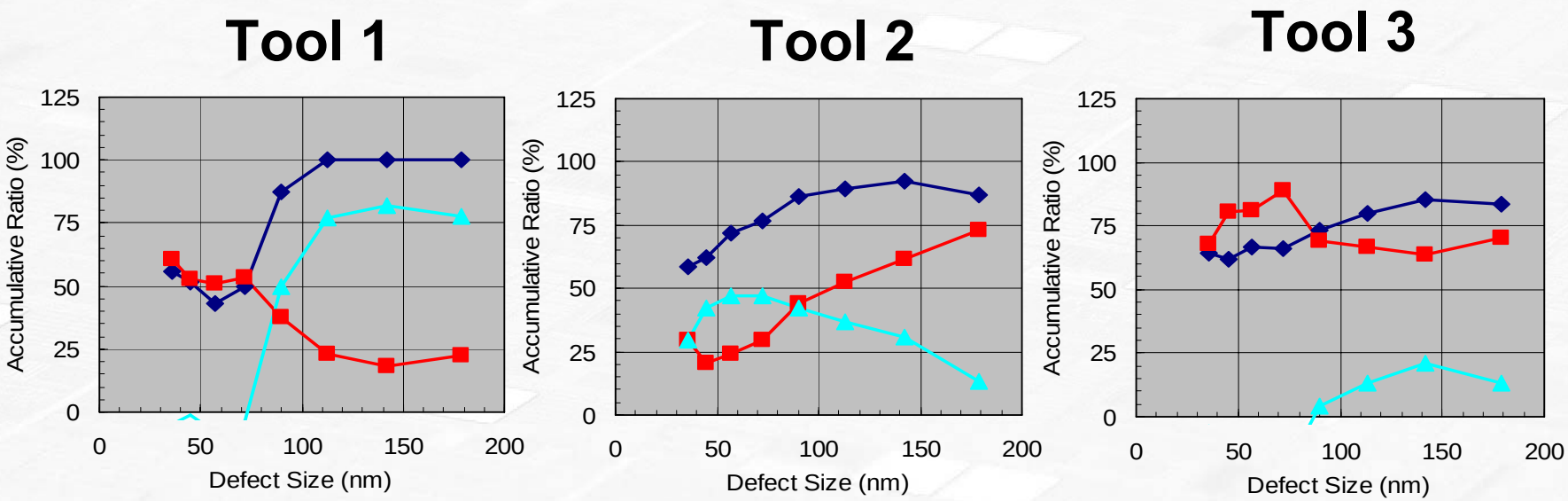
Particles in Cleaning Tools



Cleaning Efficiency

(Deposited + Redeposited)/Pre

Removed/Pre

Most clean tools add more particles than the ones they remove

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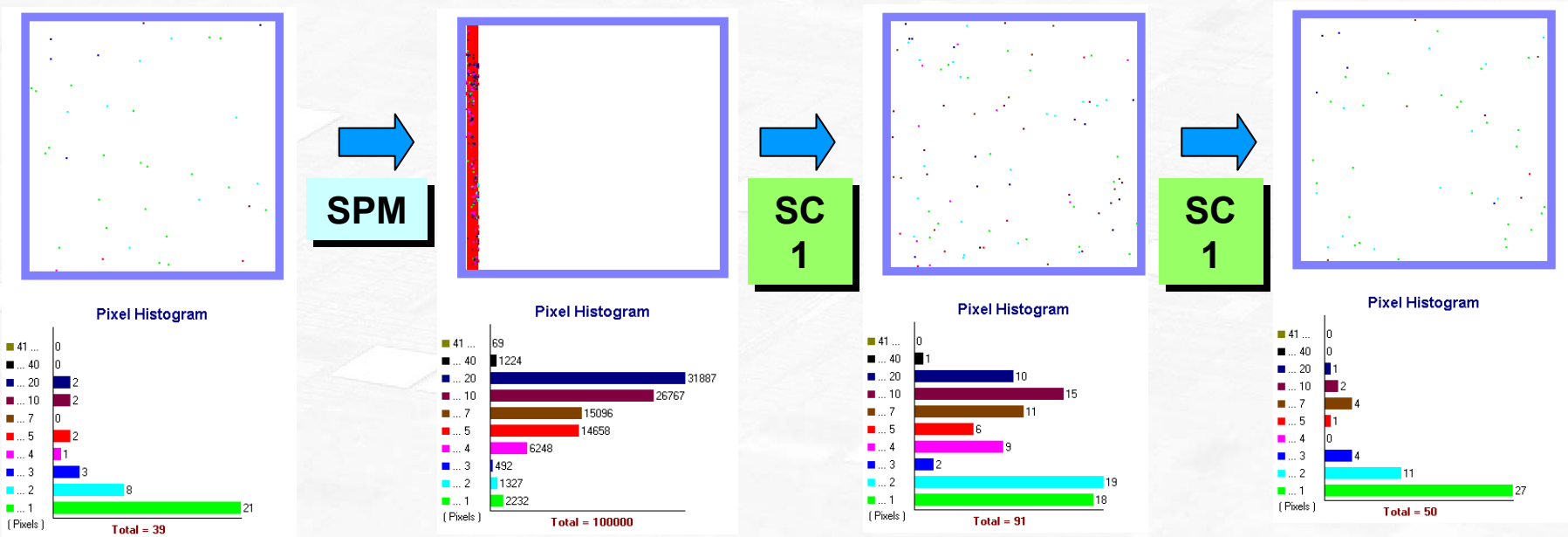
Process Added Particles



7	~1 000 000	52	8

Number of defects
Larger than 53 nm

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SPM= H_2SO_4+H_2O_2

SC1= NH_4OH+H_2O_2

Different steps of a cleaning process can add many particles

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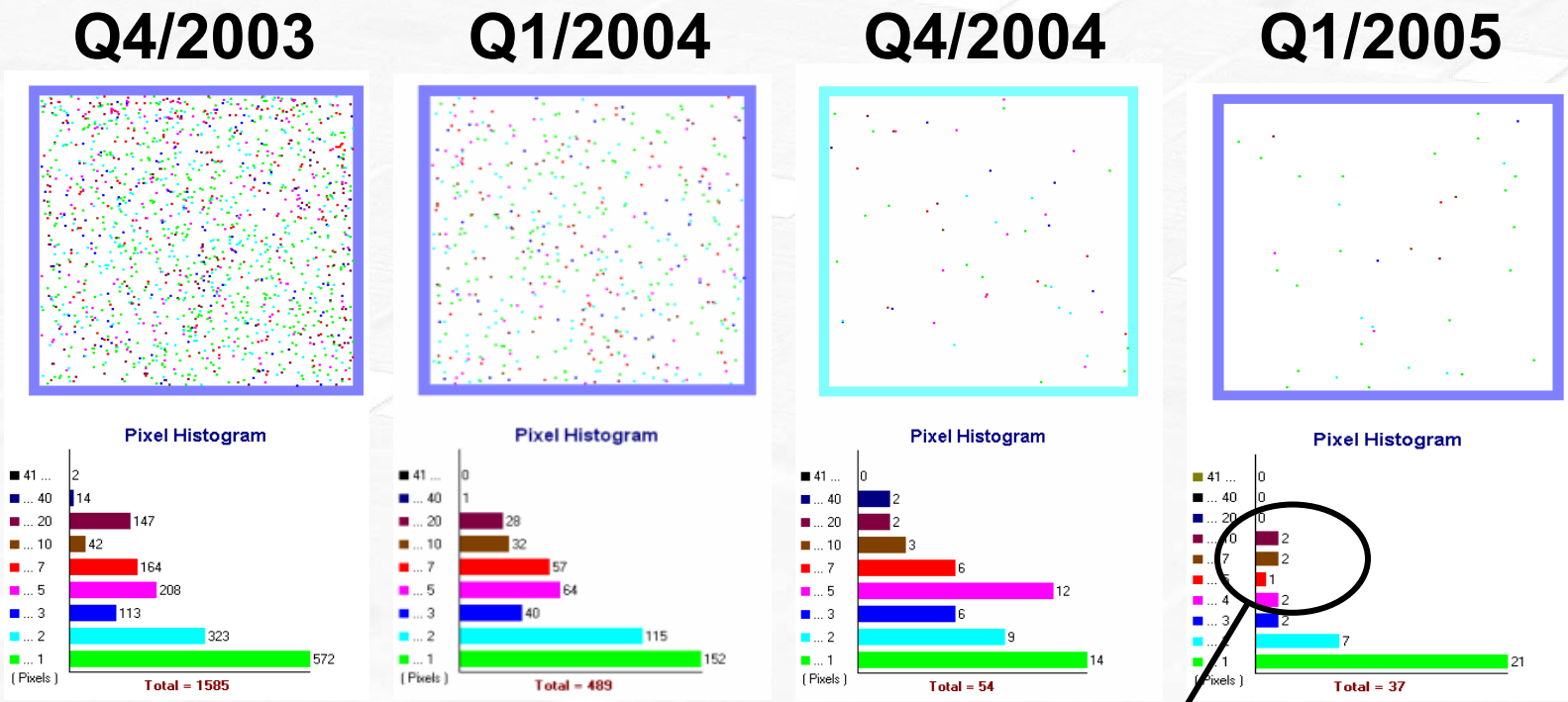
Glass Suppliers (progress)

- Improved defect performance of blank substrates



Only 7 defects larger than 53 nm on whole area of (142 x 142 mm^2)!

Cleaning tool cleanliness is the biggest challenge

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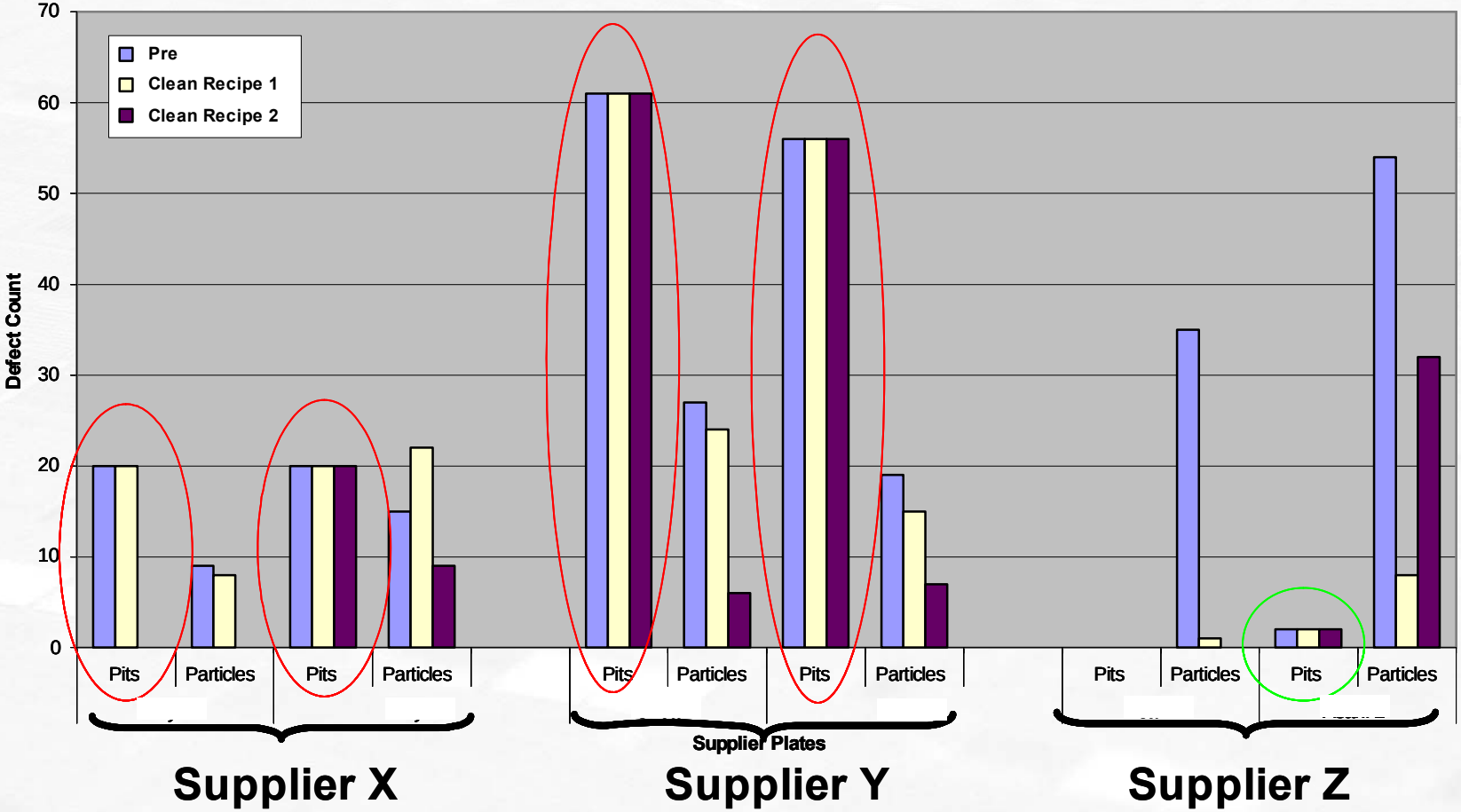
Glass Suppliers (issues)

- Improving surface roughness creates pits



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Pits are the major issue for glass suppliers

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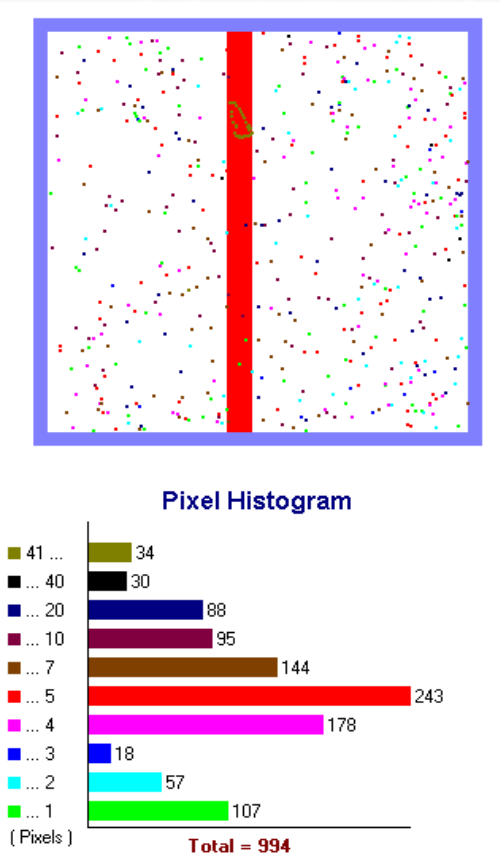
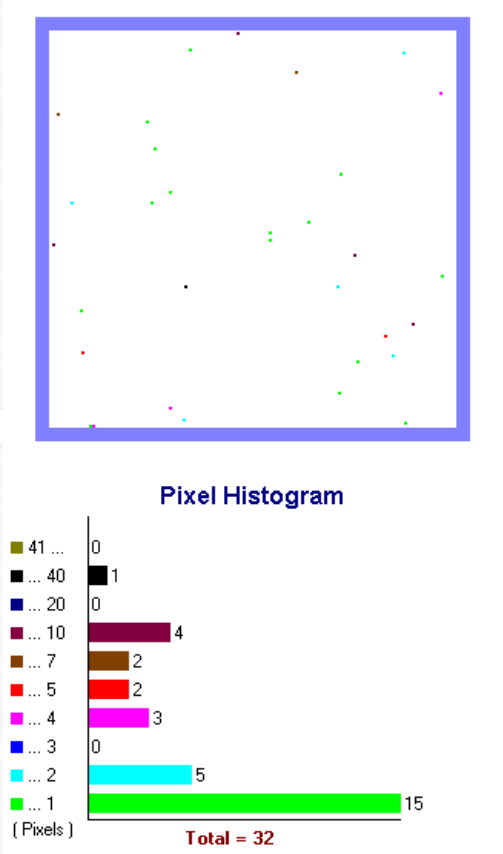
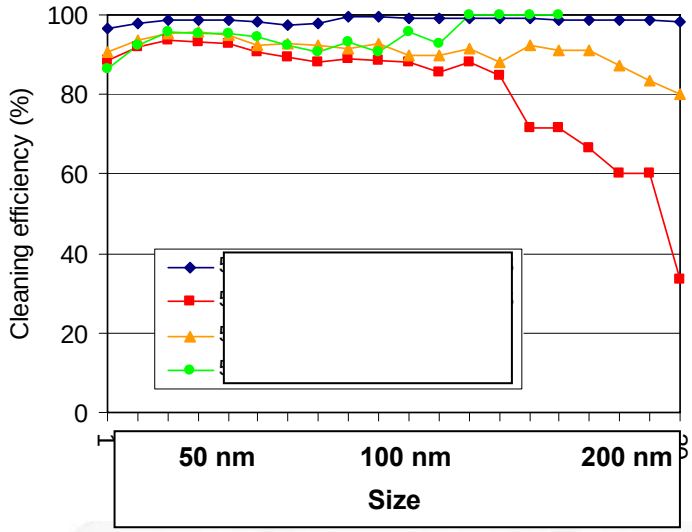
Cleaning Capability (artificially added particles)



832 defects ≥ 53 nm



12 defect ≥ 53 nm



Most particles can be removed easily with HIGH cleaning efficiency BUT NOT ALL of them !

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Artificially added particles are not a good measure for evaluating the cleaning capability of a tool

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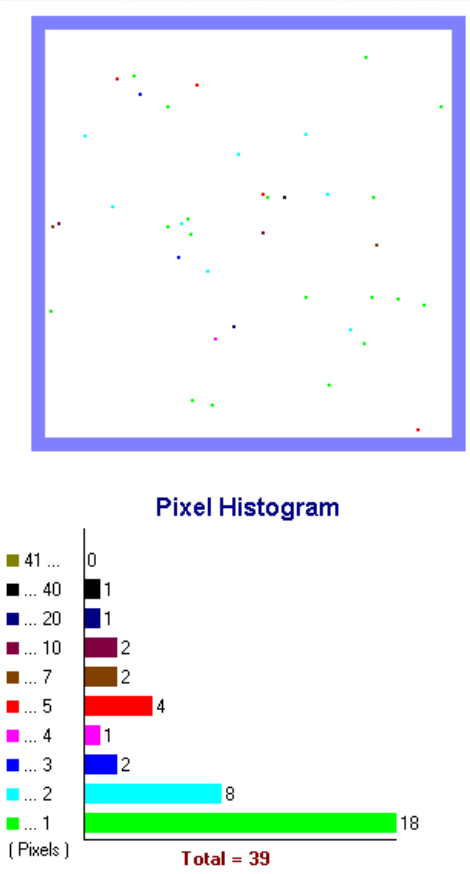
Cleaning Capability (native defects)

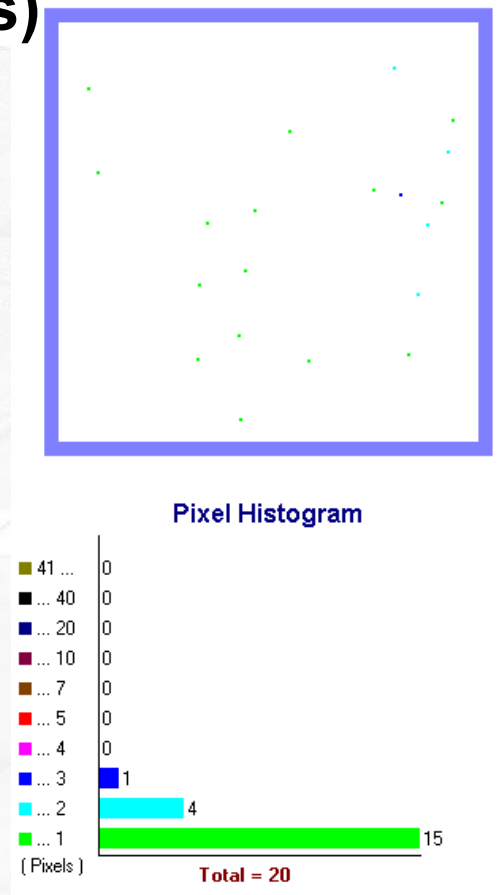
- Achieved 0 defects/cm² @ ≥ 53 nm on quartz (conventional cleaning process)



11 defects ≥ 53 nm

0.055 defect/cm²

MBDC's Cleaning



0 defect ≥ 53 nm

0.000 defect/cm²

Big Challenge
11 → 0

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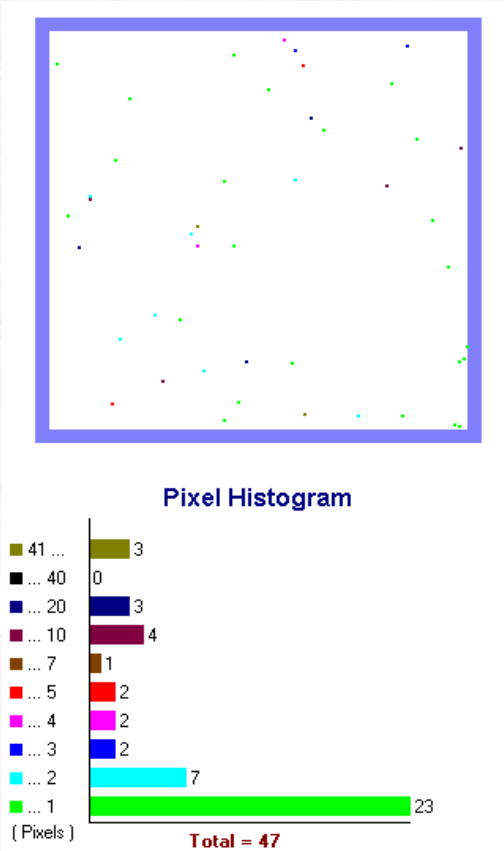
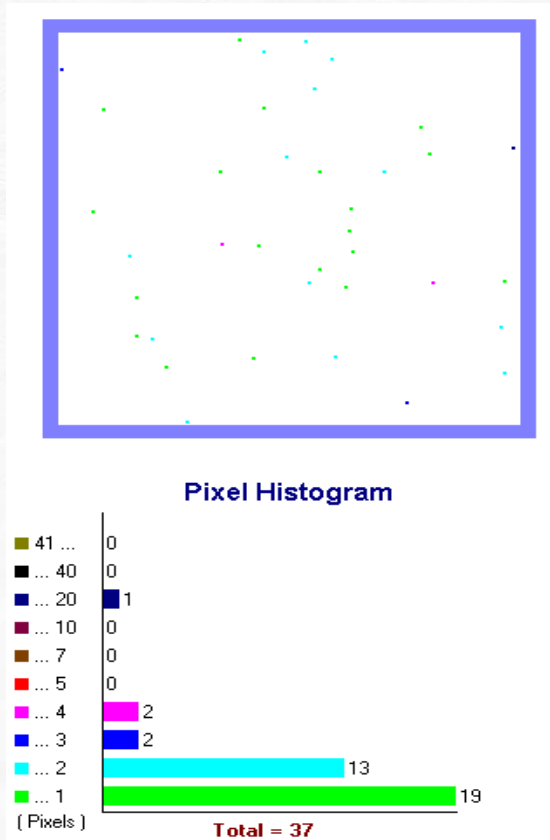
Quartz (backside Cr) Native Defects

- Achieved 0.015 defects/cm^2 @ ≥ 53 nm on quartz (acid-free process)



15 defects ≥ 53 nm

MBDC's Cleaning



3 defects ≥ 53 nm

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High O_3 Concentration Process

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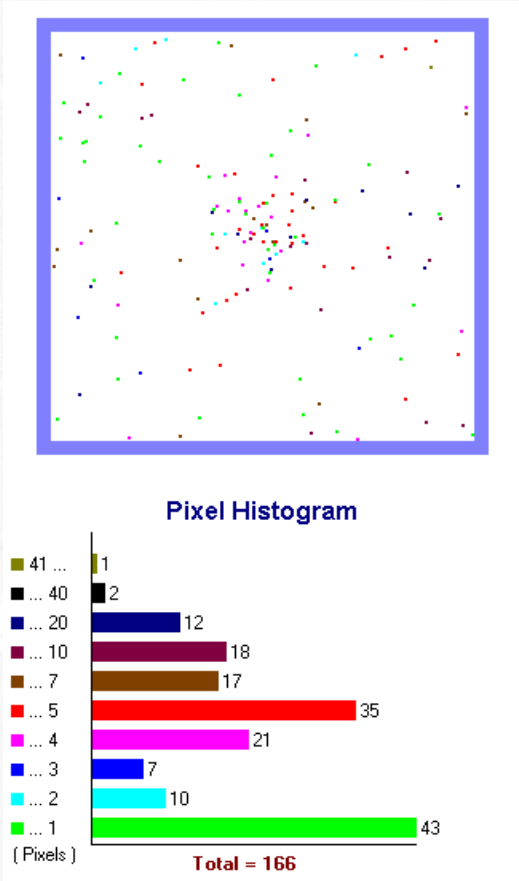
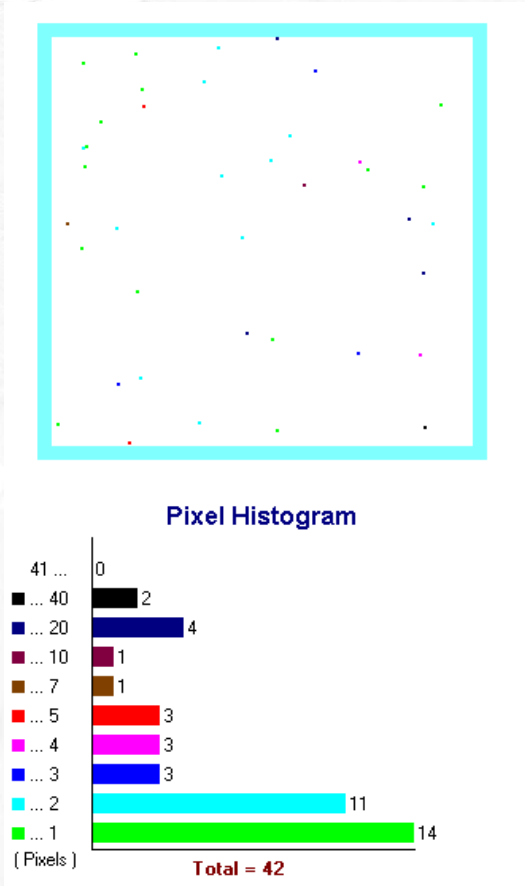
LTEM (backside Cr) cleaning in MBDC

- Achieved 0.07 defects/cm^2 @ >= 53nm on LTEM



MBDC's Cleaning



106 defects ≥53 nm

0.527 defect/cm^2

14 defect ≥53 nm

0.07 defect/cm^2

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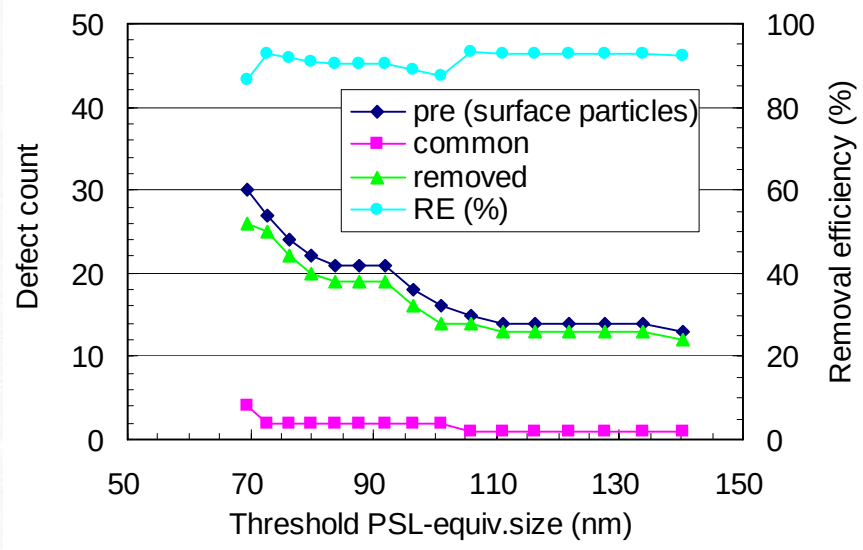
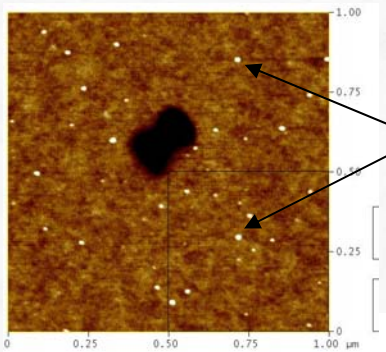
Mask Blank (ML) cleaning

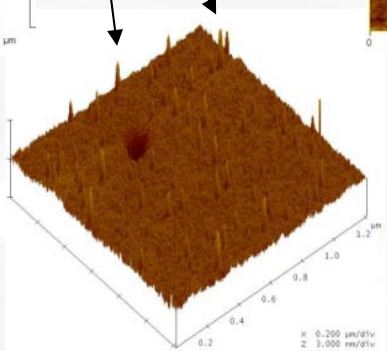
- **Very small cleaning efficiency on deposition added defects**
- **High cleaning efficiency on handling added particles**
- **Remove nano bump defects** (usually are present on ML with Si caps)
- **No change in optical properties**

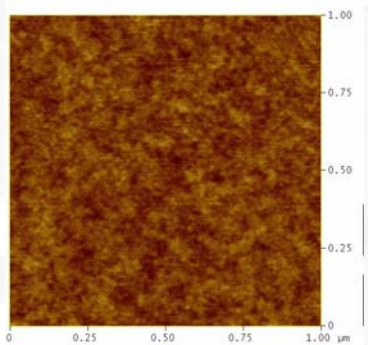




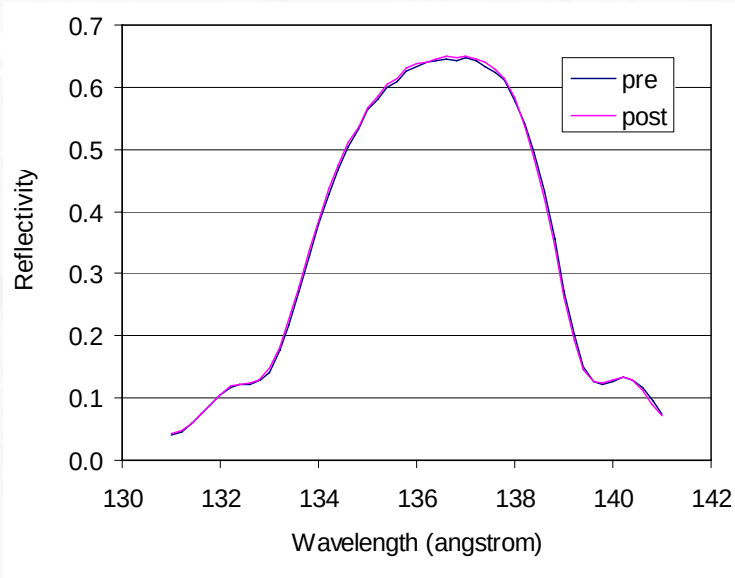
Before cleaning

Nano bump defects





After cleaning



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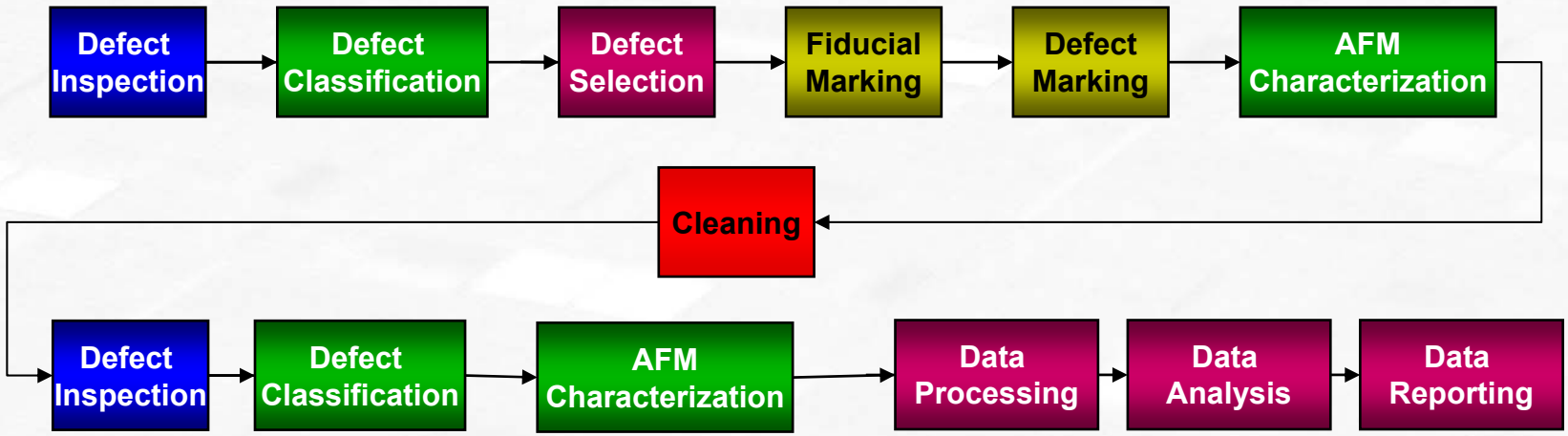
Single Defect Tracing in MBDC

- MBDC has the unique ability to trace every single detectable defect down to 40 nm (tools, techniques, expertise)
- MBDC has developed a method based on locating the defect before cleaning and tracing it after cleaning



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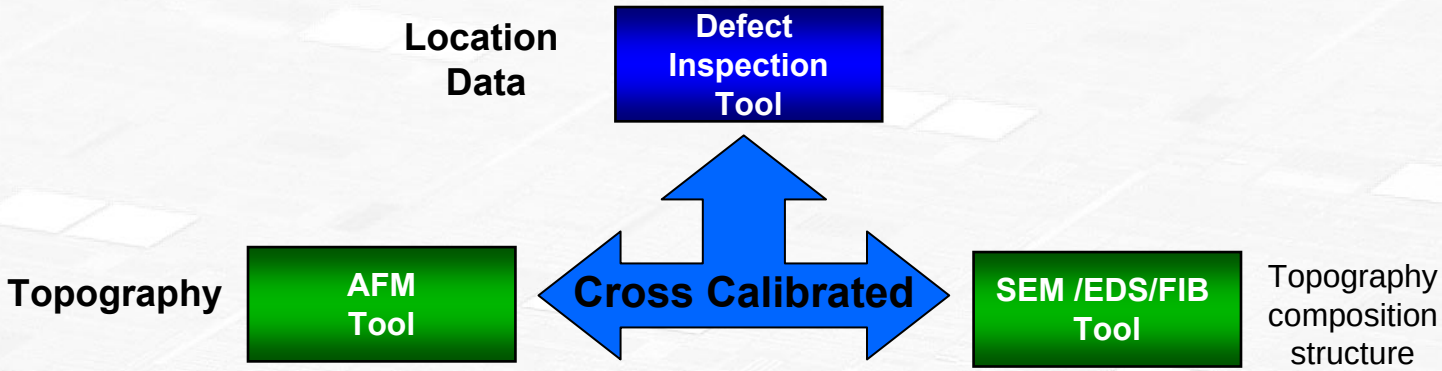
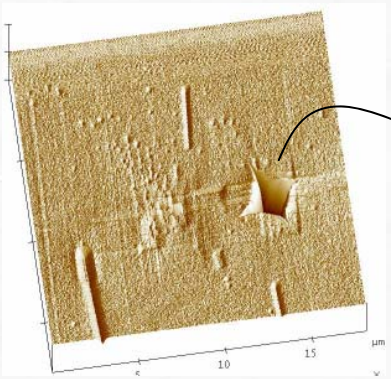
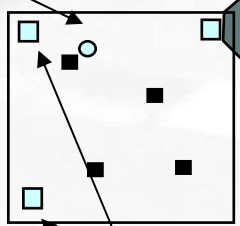
Single Defect Tracing in MBDC

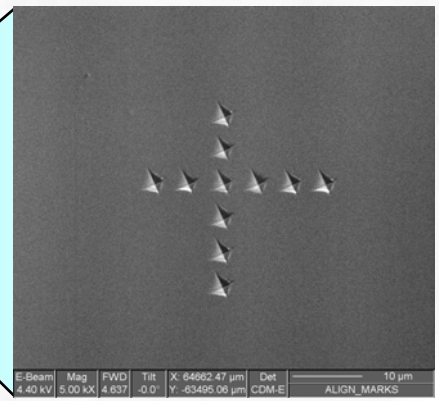


All tools handle full-size 6” mask

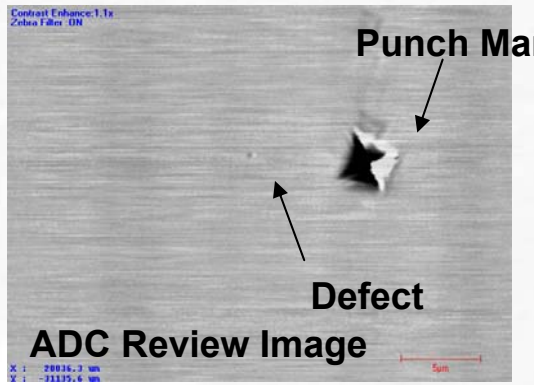


AFM of Punch Mark and Defect





SEM of Fiducial



Inspection Review Image

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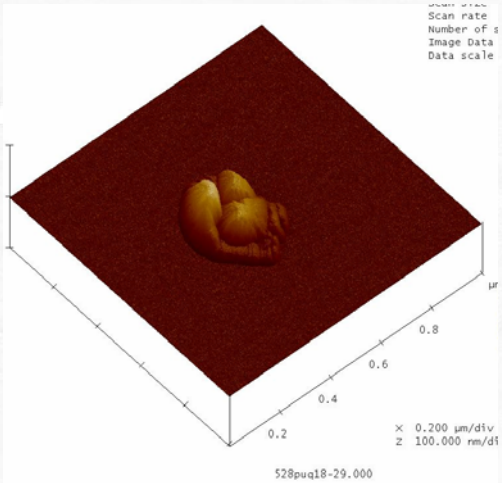
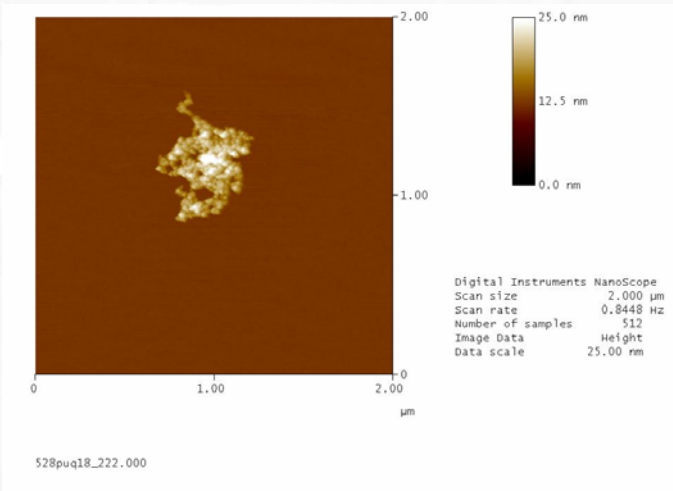
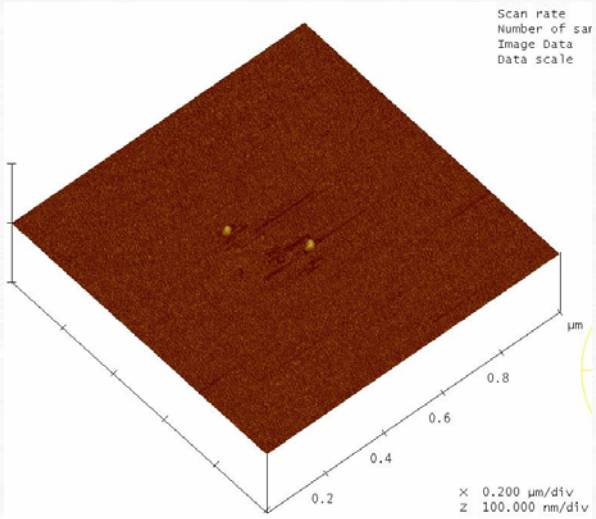
Particle Removal Mechanism (sub-100 nm)

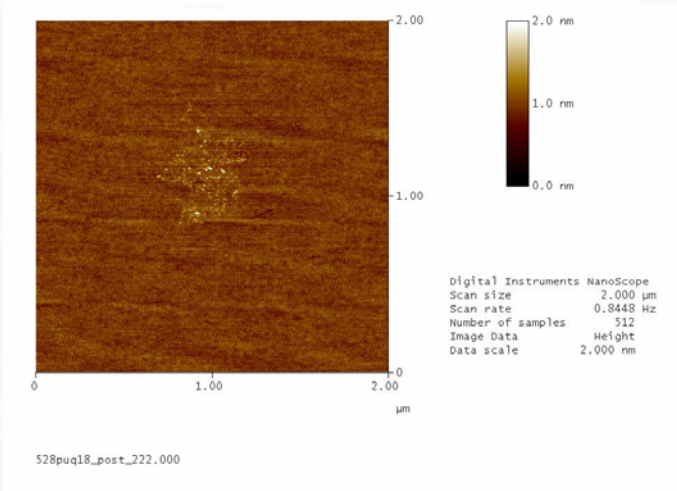
Before Clean





After Clean





Some particles leave residues

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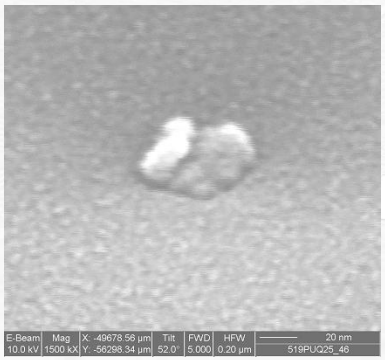
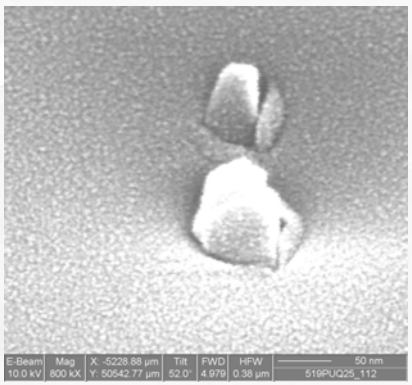
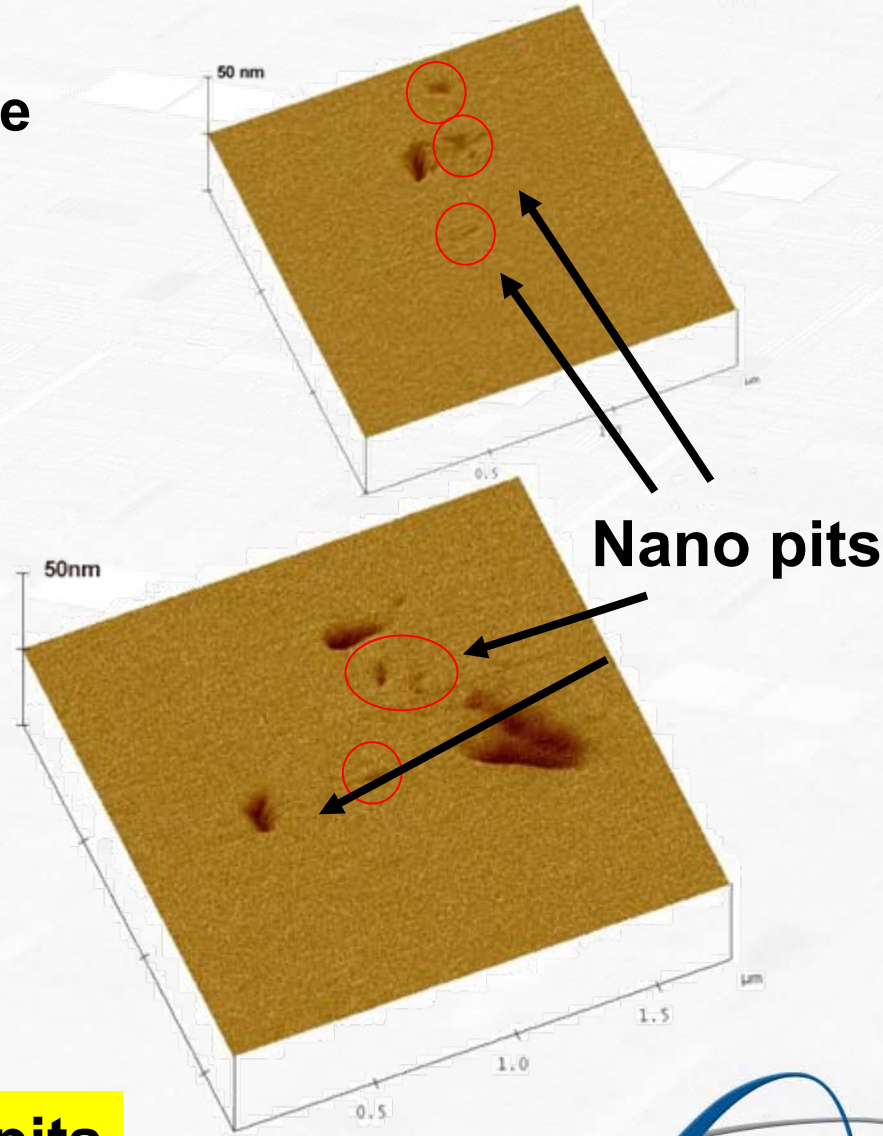
Particle Removal Mechanism (sub-100 nm)

Some particles embedded on a substrate lead to sub-detectable pits when removed by cleaning







Some particles leave pits

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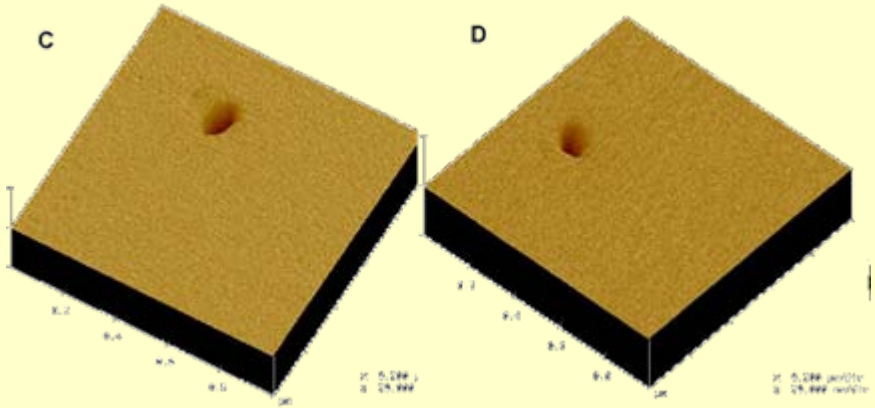
Does Cleaning Process Damage the Surface?

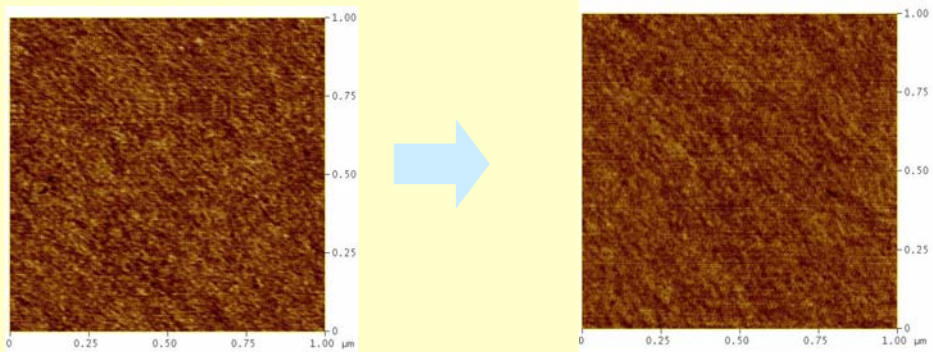
Pit Dimension

Before Clean | After Clean



Surface Roughness

Before Clean | After 5X Clean



Roughness increase per cleaning cycle = (0.02/5) = 0.004 Å !!

Roughness change is negligible
Pit size does not change by cleaning

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  - Particle Removal Mechanism and Damage
- Sub-50 nm Particle Removal
  - Definition of Sphere Equivalent Volume size
  - Achieved Results

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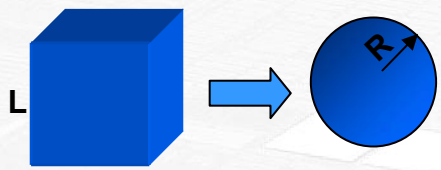
Definition of Sphere Equivalent Volume Diameter (SEVD)

- Sphere equivalent volume diameter is the diameter of a sphere with the same volume of defect
- Defect volume is calculated by using AFM software

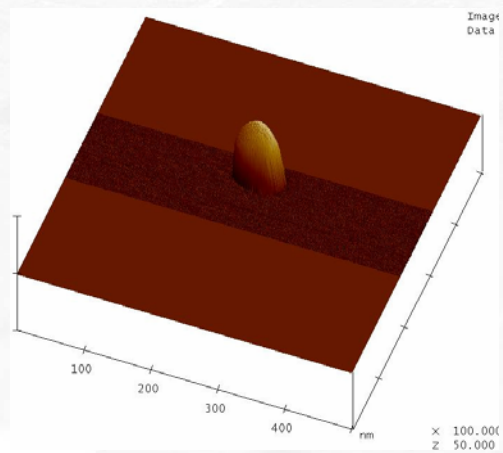


$$L^3 = \frac{4pR^3}{3}$$

50 nm PSL (± 3 nm) → 54.2 nm SEVD

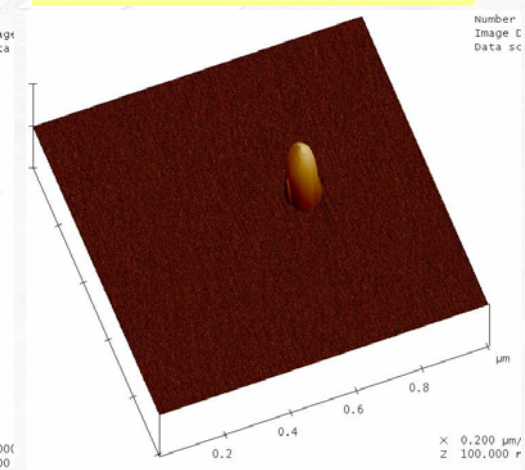
100 nm PSL (± 5nm) → 105.2 nm SEVD

50 nm PSL



Height = 49.6 nm
SEVD = 54.2 nm
FWHM = 52.7 nm

100 nm PSL



Height = 93.5 nm
SEVD = 105.2 nm
FWHM = 95.0 nm

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Sphere equivalent volume diameter is slightly bigger than PSL diameter due to AFM artifacts

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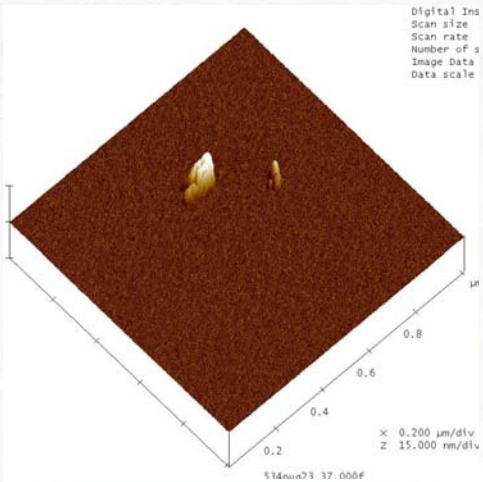
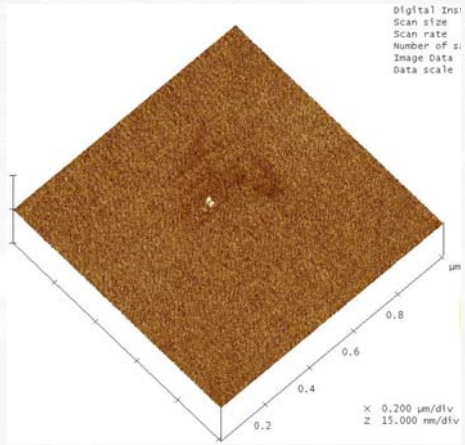
Sub-50 nm Particle Removal

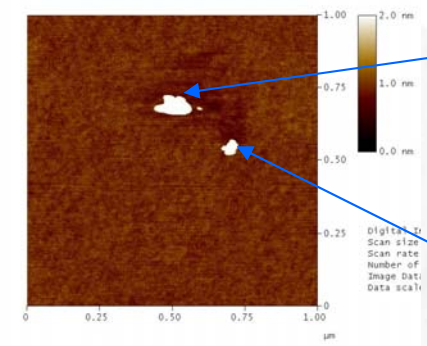
- **Demonstrated sub-50 nm (SEVD) defect removal**
  - Larger particles shrank in size
  - Smaller particles were removed

Before Cleaning
37.3 nm

After Cleaning
8.7 nm

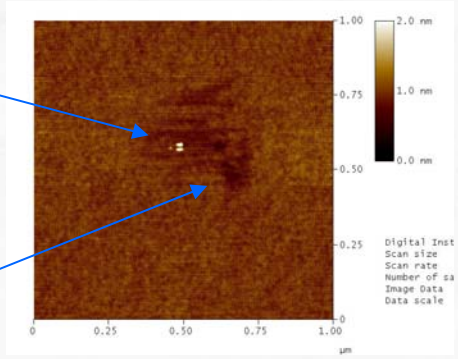






Shrank

REMOVED



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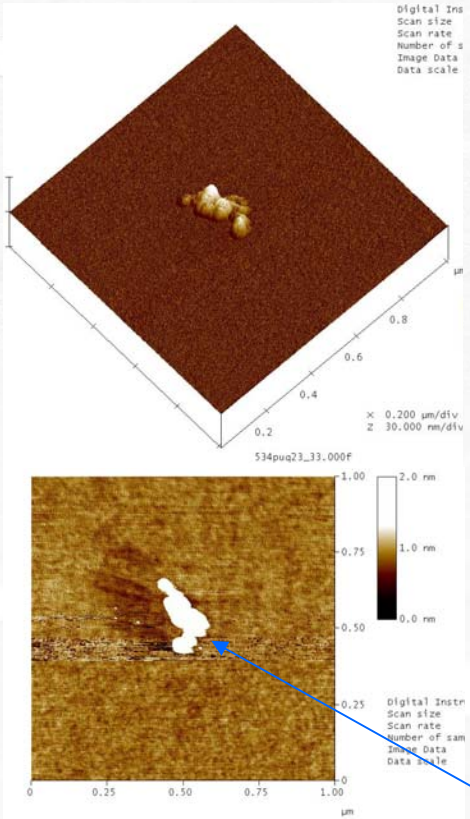
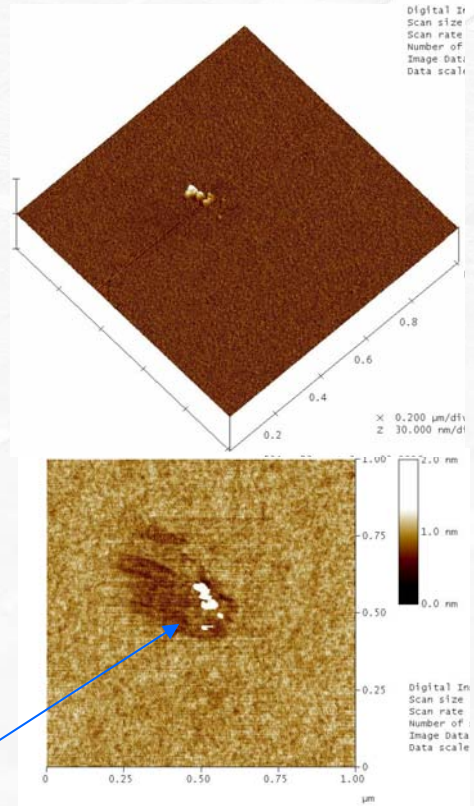
Sub-50 nm Particle Removal

Before Cleaning
50.3 nm



After Cleaning
23.2 nm



SHRANK

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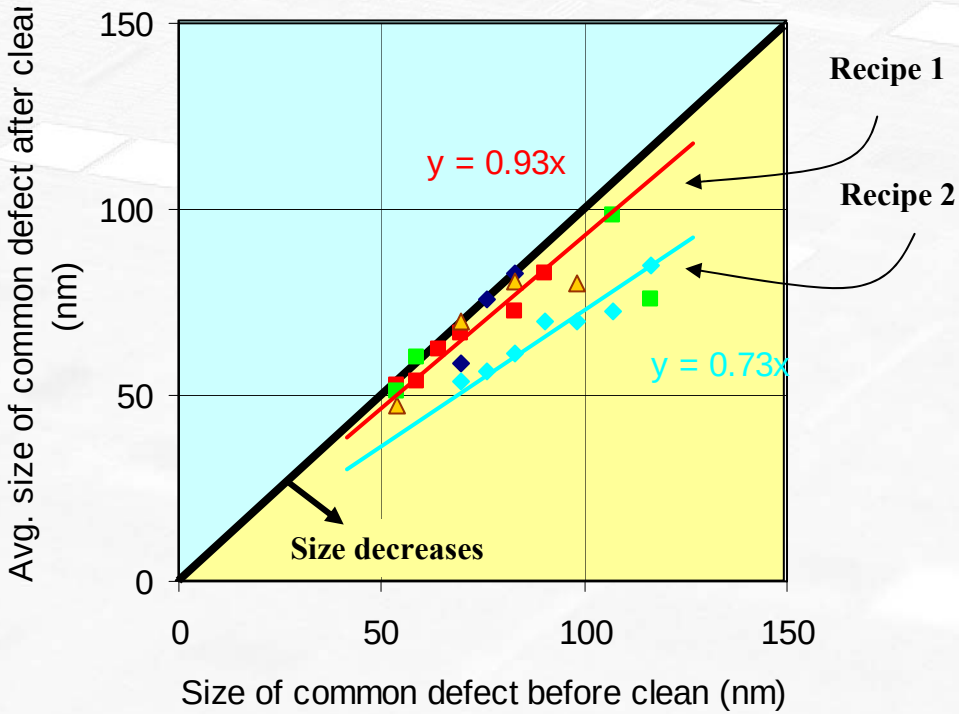
Sub-50 nm Particle Removal

- Developed recipes that significantly reduce particle size without damaging substrate
- Recipe 2 reduces the sizes of particles by 20%



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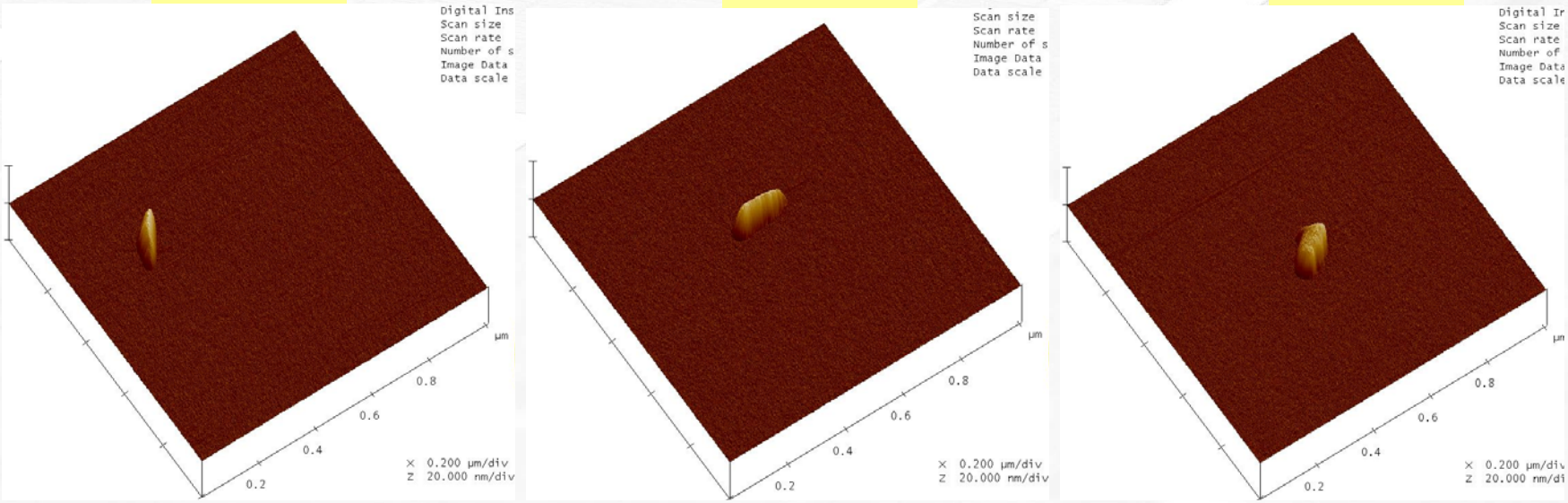
Sub-50 nm Particle Removal

- **Demonstrated sub-50 nm (SEVD) defect removal**
  - Actual particle size is smaller than calculated size

Particle Size Before Cleaning

42.5 nm **49.3 nm** **53.0 nm**



Sub-50 nm (SEVD) particles were removed by cleaning

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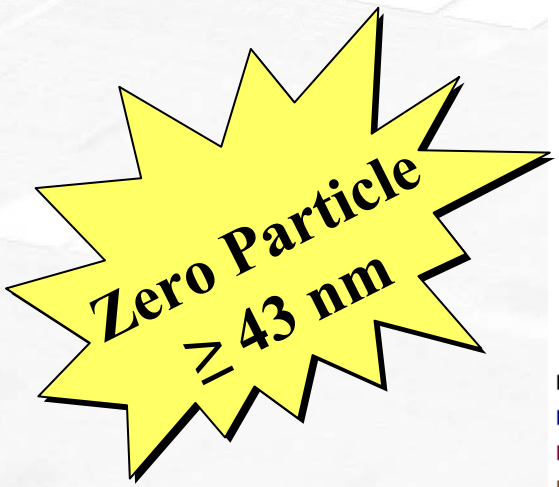
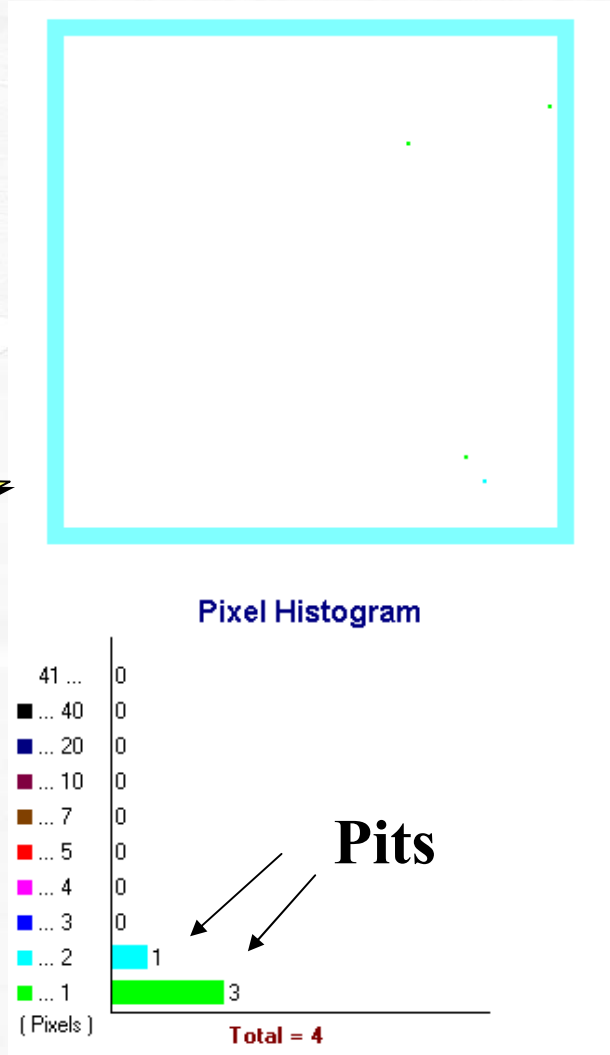
Demonstrated total particle removal down to 43 nm

- Achieved 0 particles ≥ 43 nm on backside Cr coated quartz





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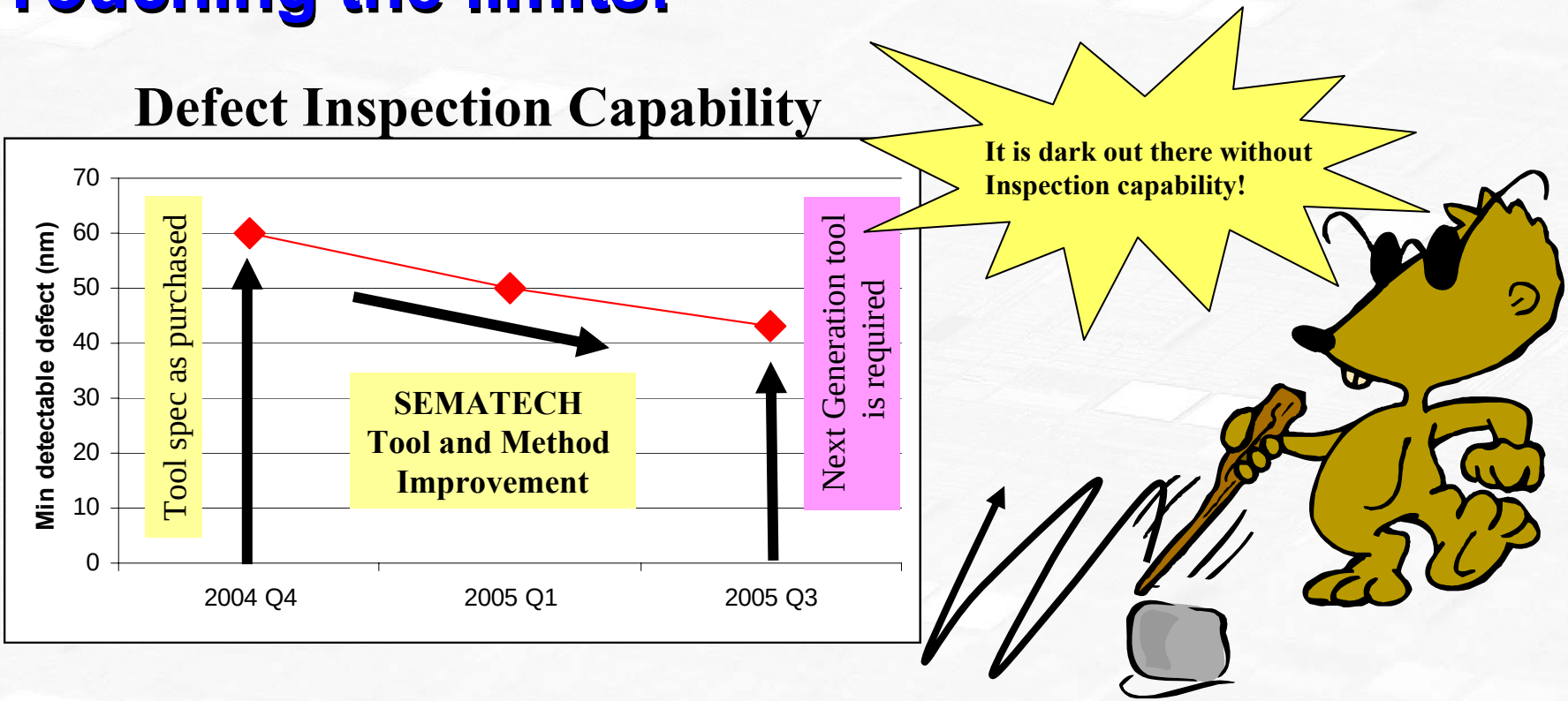
Touching the limits!



- **SEMATECH approach**
  - Sematech is developing methods in which sub threshold defects are enlarged and therefore become detectable
  - Technique ensures continuous progress till we receive the next generation defect inspection tool.

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Summary

- **Substrate defects are the main source of the EUV blank defects**
  - Glass suppliers should take care of pits whereas particles can be addressed by cleaning
- **Soft defects are the main contributor to the substrate defects**
  - Originate the from tool, process, chemicals, UPW
- **Results: SEMATECH**
  - Achieved 0 defects/cm^2 larger than 43 nm on quartz surface by using optimized conventional cleaning processes
  - Achieved 0.07defects/cm^2 larger than 53 nm on LTEM surface by using optimized conventional cleaning processes
  - Achieved 0.015 defects/cm^2 larger than 53 nm on quartz surface by using high concentration ozone cleaning processes
- **Sub-50 nm defect removal**
  - SEMATECH has developed single defect tracing method
  - Demonstrated ***sub-50 nm defect removal***
  - Developed recipes to reduce particle size by 20% without damaging surface

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Acknowledgement

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  - Dan Bader
  - Toshiyuki Uno
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  - Nancy Lethbridge

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Backup

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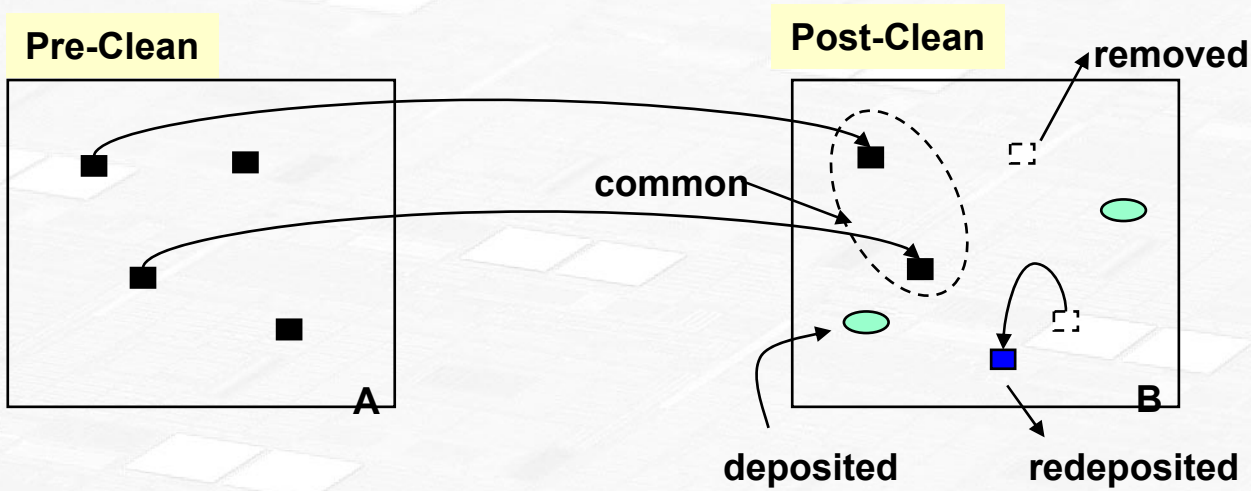
Defect Inspection – Definitions



n_{com} = Defects common to pre- and post-inspection

n_{rem} = Defects removed from substrate

n_{dep} = Defects deposited on the substrate

n_{redep} = Defects removed but redeposited on substrate

$$n_{com} = A \cap B$$

$$n_{rem} = A - (A \cap B)$$

$$n_{dep} + n_{redep} = B - (A \cap B)$$

Cleaning Efficiency

$$CE_{\geq 50nm} = \left(1 - \frac{\sum_{j=4}^{j=41} \left(n_{post}^{insp} \right)_j}{\sum_{j=4}^{j=41} \left(n_{pre}^{insp} \right)_j} \right)$$

Removal Efficiency

$$RE_{\geq 50nm} = \left(1 - \frac{\sum_{j=4}^{j=41} \left(n_{com}^{insp} \right)_j}{\sum_{j=4}^{j=41} \left(n_{pre}^{insp} \right)_j} \right)$$

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