Challenges of Removing 30nm Particles in EUV Mask Blank Cleaning

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Sean Eichenlaub

Cleaning Core Team
Mask Blank Development Center
Albany, New York
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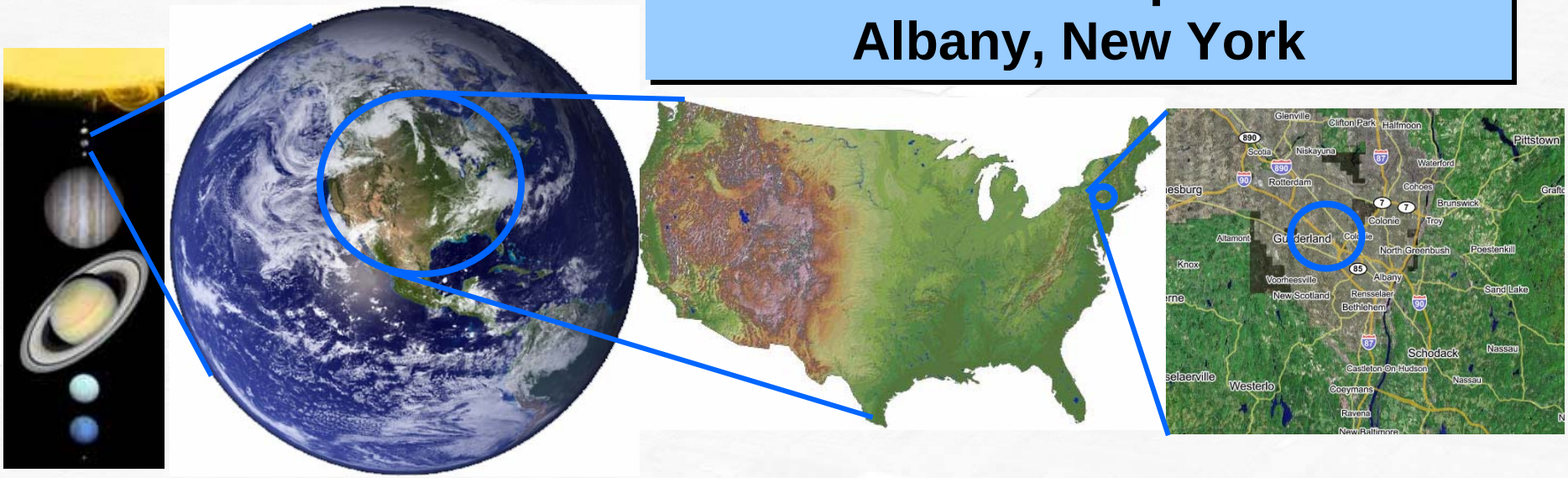
Where We Are

SEMATECH North
Mask Blank Development Center
Albany, New York



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SEMATECH MBDC Cleaning Core Team

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Mask Strategy Manager

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MBDC Manager

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Austin

Project Manager

Pat Marmillion
IBM Assignee

LITH 184
Albany

Technical Manager

Abbas Rastegar
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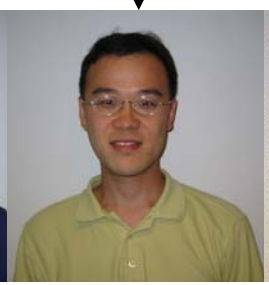
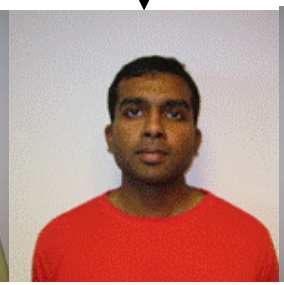
Matt House
HamaTech



Ssuwei Chen
HamaTech



Arun John
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Vivek Kapila
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Sean Eichenlaub
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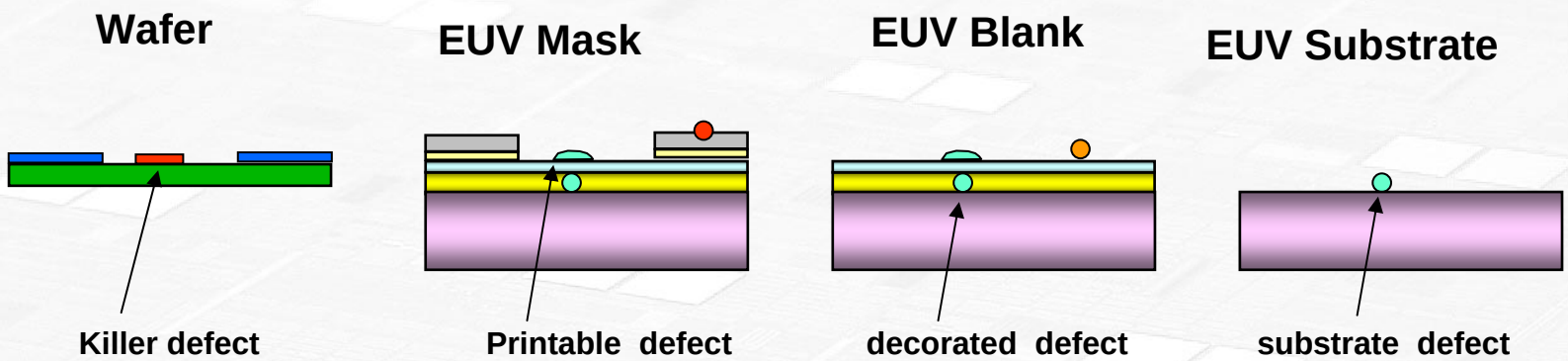
Outline

- EUV defects
  - Critical size
  - Shape
  - Detection
- 30 nm particle removal in SEMATECH's MBDC
  - Cleaning recipes based on SC1
    - Particle removal
    - Added defects
    - Defect morphology
    - Defect composition
- Comparison of different cleaning recipes
- Outlook

EUV Critical Defect Size



Critical Defect size d_k^W ↔ Printability Test ↔ d_P^M ↔ E. Gullikson Model ↔ d_p^B ↔ AFM imaging ↔ d_d^S

ITRS node	d_k^W	d_P^M	d_p^B	d_d^S
45 nm@2010	22.5 nm	36 nm	36 nm	35 nm
32 nm@2013	16 nm	26 nm	26 nm	30 nm
22 nm@2016	11.5 nm	18 nm	18 nm	25 nm

Substrate Defect Size *—the minimum diameter* ***spherical defect (in polystyrene latex sphere equivalent dimensions)*** *on the substrate beneath the multilayers that causes an unacceptable linewidth change in the printed image. Substrate defects might cause phase errors in the printed image and are the smallest mask blank defects that would unacceptably change the printed image.*

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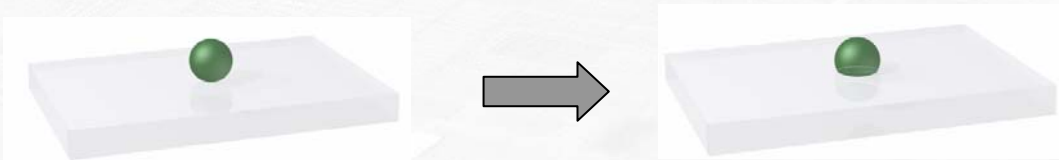
PSL Equivalent Size

- PSL Equivalent Size
  - Defect size is the diameter of the PSL that appears at the same bin as the defect in the inspection tool

- Advantage:
  - Narrow size distribution → precise sizing
  - NIST traceable → Comparison of different tools with a similar reference

- Disadvantage:
  - Unstable
    - Shrink by UV radiation
    - Deform by aging
  - Low contrast
    - Difficult to get contrast on glass



- SUB-50 nm defect inspection tools use UV lasers

PSL cannot be used for calibrating sub-50 nm Optical-based (UV) inspection tools

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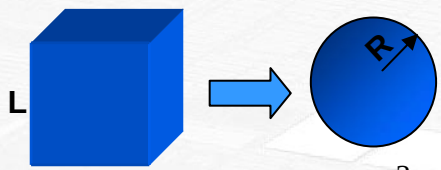
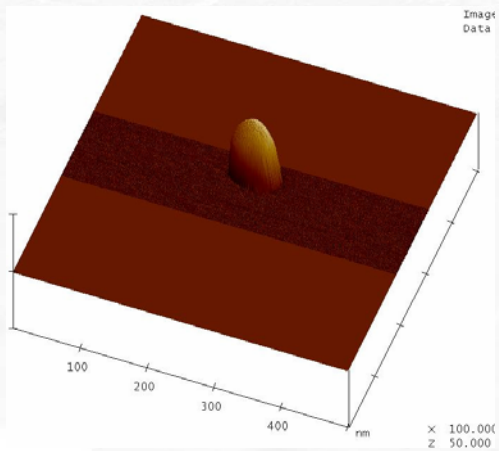
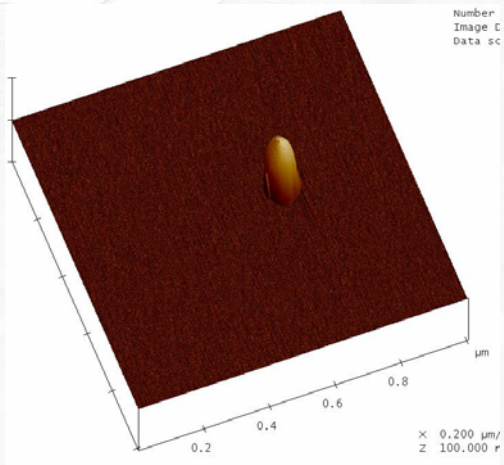
Sphere Equivalent Volume Diameter (SEVD)

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



$$L^3 = \frac{4\pi R^3}{3}$$

$$\boxed{\text{SEVD} = 2R}$$

50 nm PSL	100 nm PSL
	
Height = 49.6 nm SEVD = 54.2 nm FWHM = 52.7 nm	Height = 93.5 nm SEVD = 105.2 nm FWHM = 95.0 nm

50 nm PSL (± 3 nm) → 54.2 nm SEVD

100 nm PSL (± 5nm) → 105.2 nm SEVD

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

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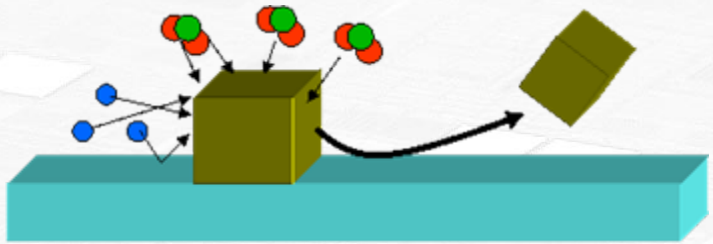
Cleaning Capability & Defect Shape

Chemical reaction
Oxidizing
dissolving,
……

Physical reaction
Hydrodynamic flow
Megasonic streaming
Shockwaves,
……

Physical forces→ transfer momentum,→ separate particle

Chemical forces→ dissolve particle → shrink the size

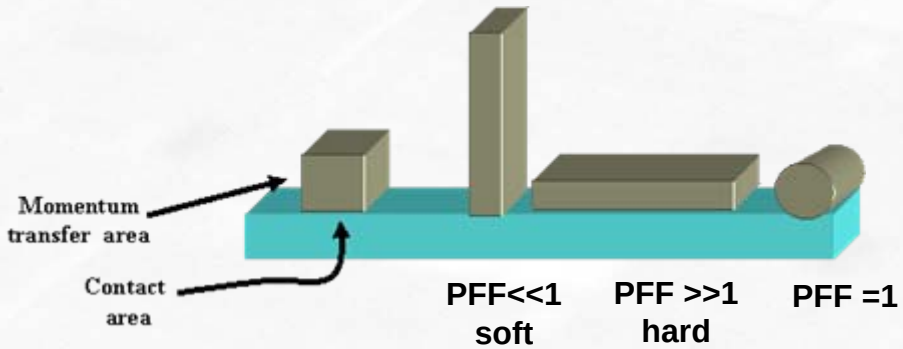


Defect Shape

The same volume → the same SEVD

Particle Form Factor

$$PFF = \left(\frac{\text{Contact Area}}{\text{M.T. effective cross section}} \right)$$



Critical dimension for the cleaning is the defect height

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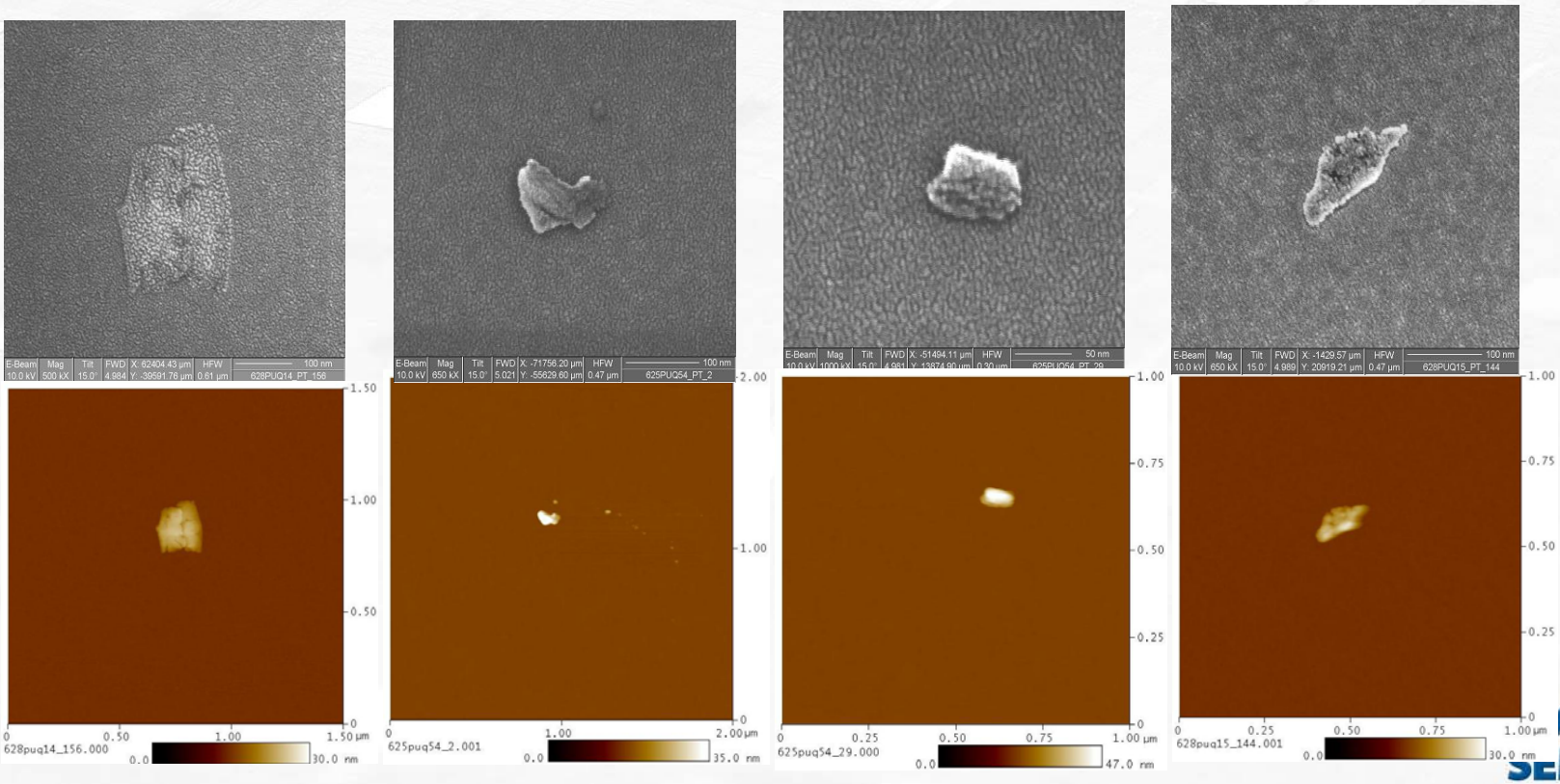
Typical Non-removable Particles

Height: 8 nm
Width: 205 nm
Length:234 nm
Volume:134116 nm^3
SEVD:63.5 nm
Bin:4~ 45-55 nm
EDS: Background
Clean: 5 X SC1

Height: 25 nm
Width: 111 nm
Length:160 nm
Volume:99905 nm^3
SEVD:57.6 nm
Bin:6~ 60-70 nm
EDS: Fe
Clean: 5X SC1

Height: 24 nm
Width: 62.5 nm
Length:113 nm
Volume:60190 nm^3
SEVD:48.6 nm
Bin:4~ 45-55 nm
EDS: Background
Clean: 5 X SC1

Height: 13 nm
Width: 89 nm
Length:183 nm
Volume:57708 nm^3
SEVD:48 nm
Bin:6~ 60-70 nm
EDS: Background
Clean: 10 X SC1



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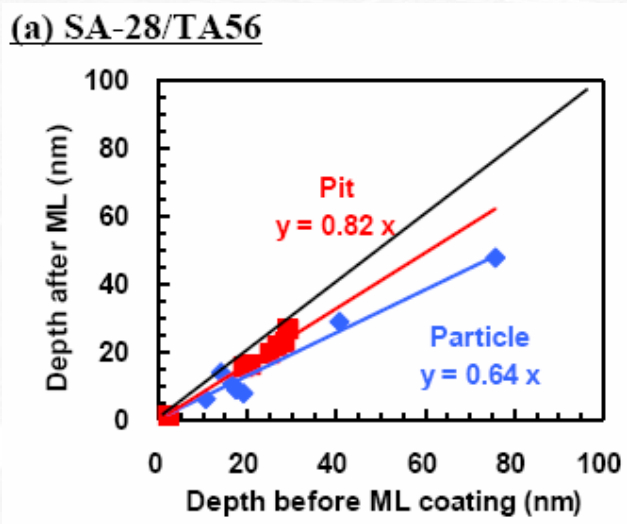
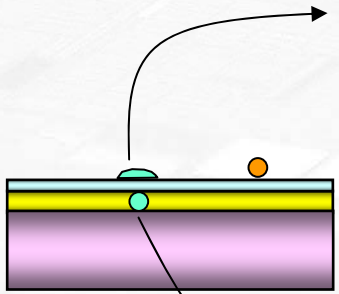
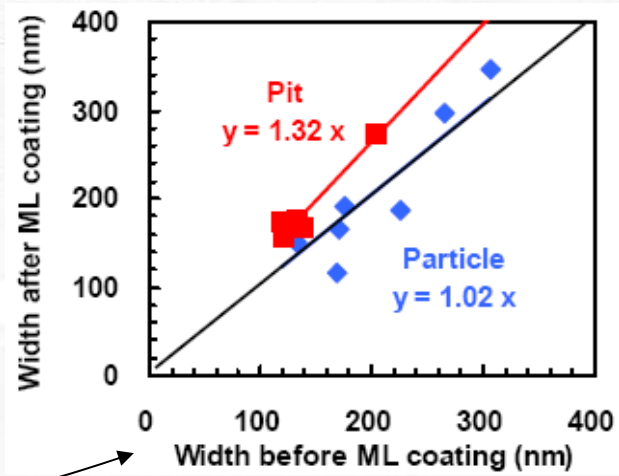
Critical substrate defect size

- **Detectable ML defects**
  - A particle with ~ 50 nm SEVD on quartz can be decorated. However, this particle has a **height of ~10 nm and width of 120 nm** on quartz







All particles with height of 10 nm and higher should be removed

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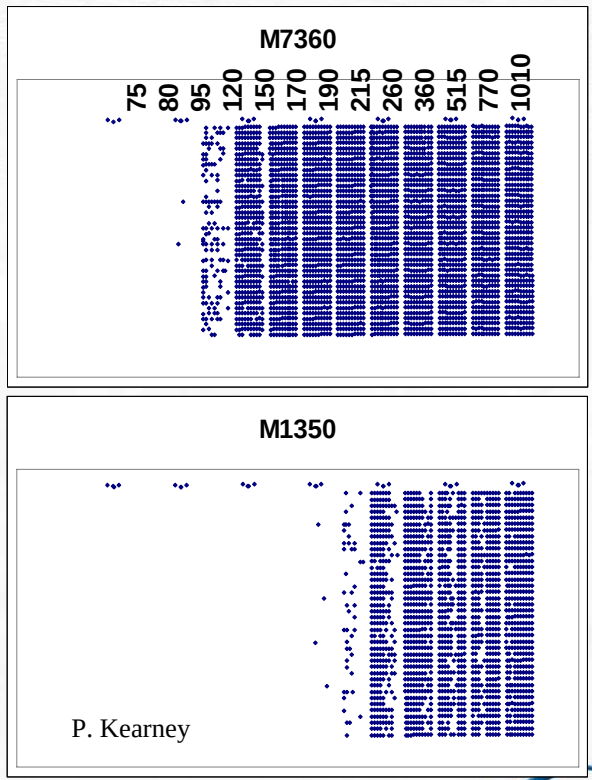
SEMATECH MBDC Defect Inspection

SEMATECH MBDC has demonstrated 20 nm SEVD native defect detection capability on quartz surface

- **All data presented here are based on SEVD size unless otherwise explicitly mentioned.**
- **This presentation will report all defects 30 nm and above when the tool has a capture efficiency of 99% or more.**



- For more information, see **Pat Kearney's** presentation from the SEMATECH MBDC in this symposium

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    - **Added defects**
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    - **Defect composition**
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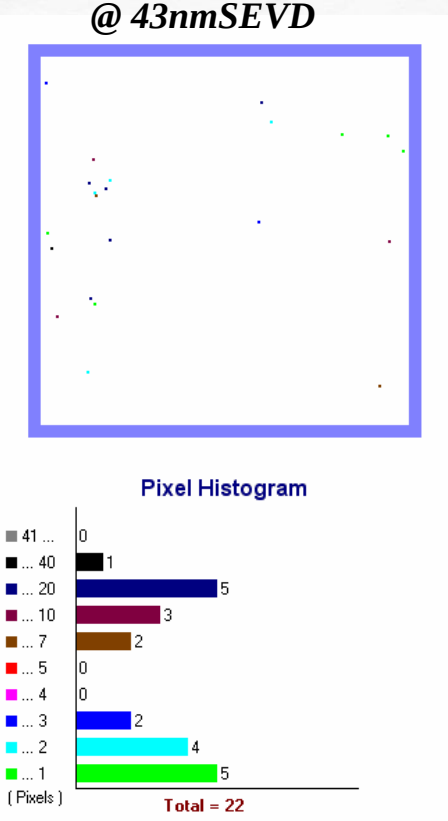
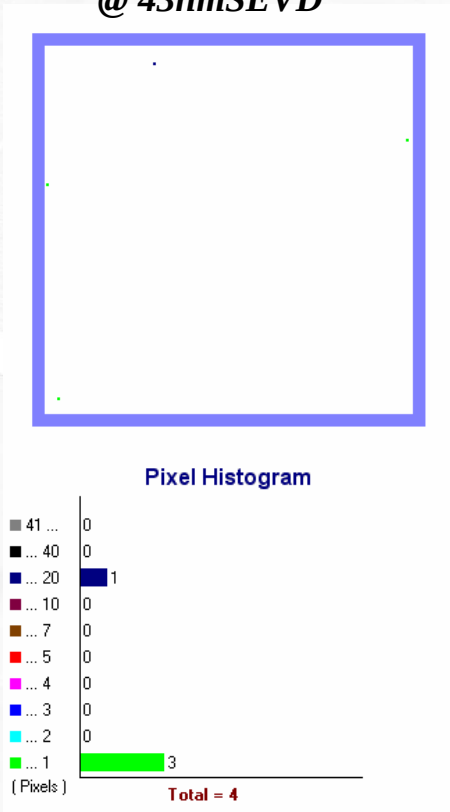
Cleaning Processes Based on SC1

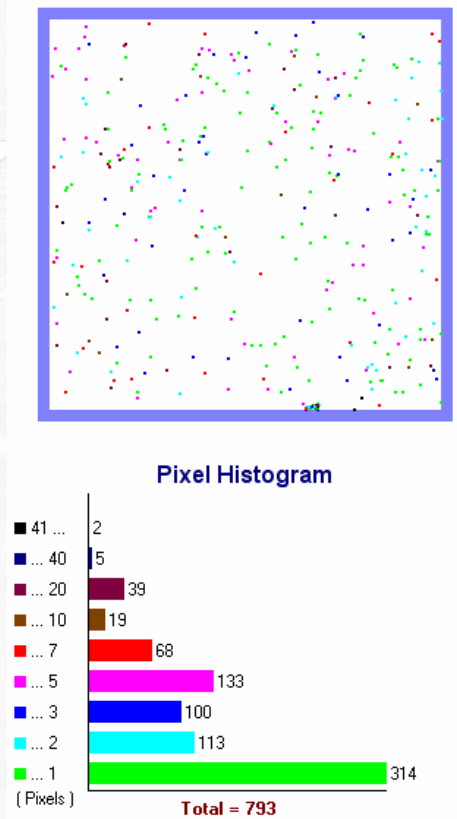
Before cleaning @ 43nmSEVD



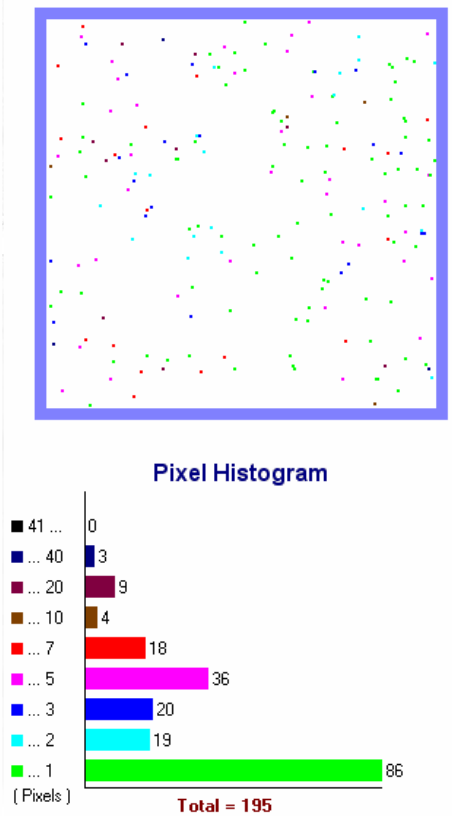
After cleaning @ 43nmSEVD



Before cleaning @ 20nmSEVD



After cleaning @ 20nmSEVD



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Defect density@ 30 nm SEVD=0.35 defects/cm^2

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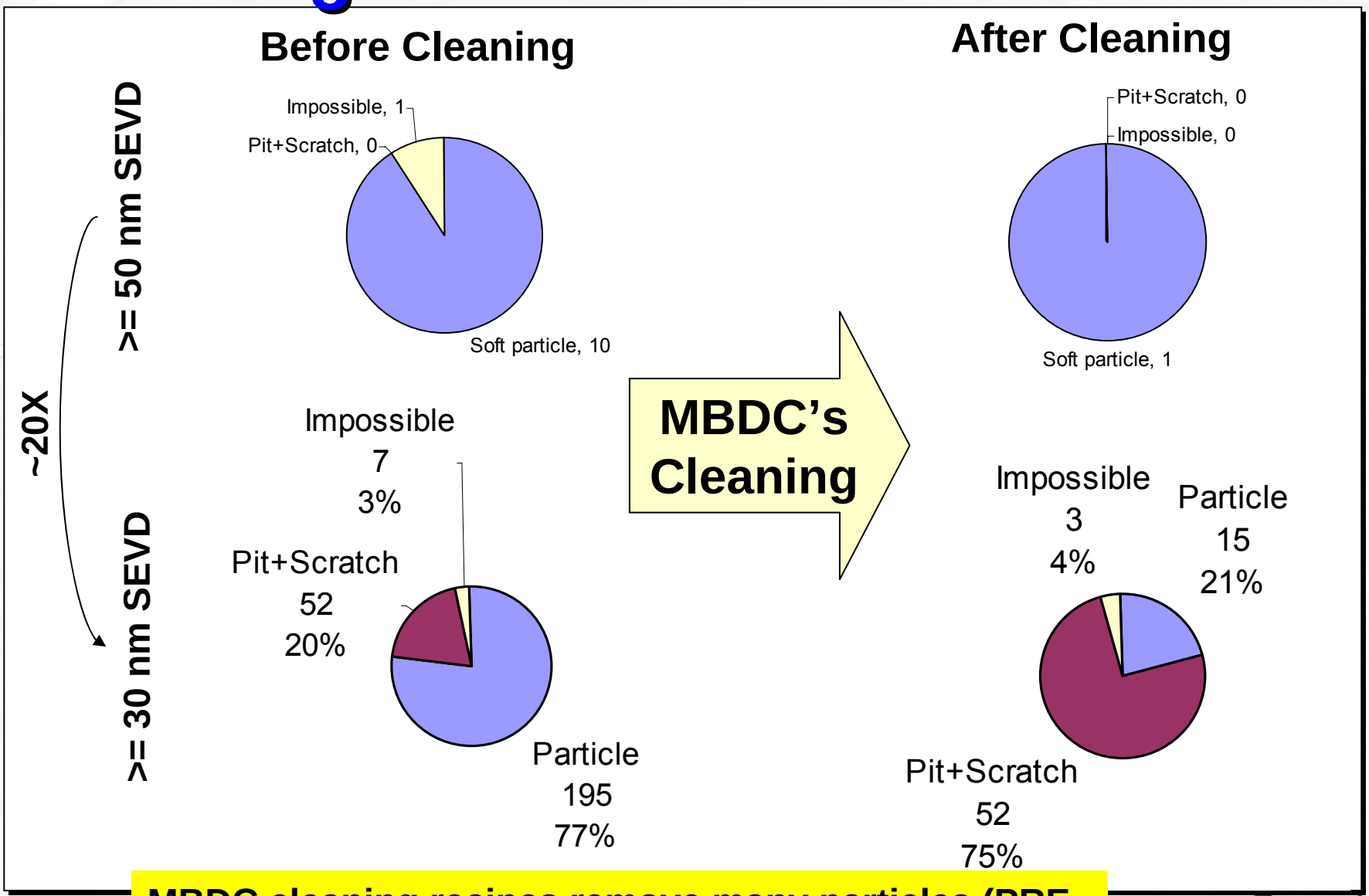
Cleaning Processes Based on SC1



MBDC cleaning recipes remove many particles (PRE~ 92%) between 30-50 nm SEVD

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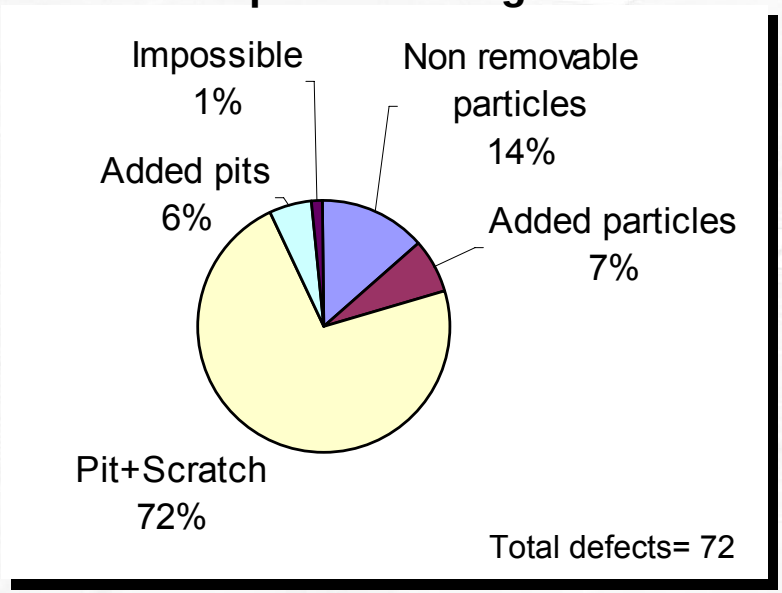
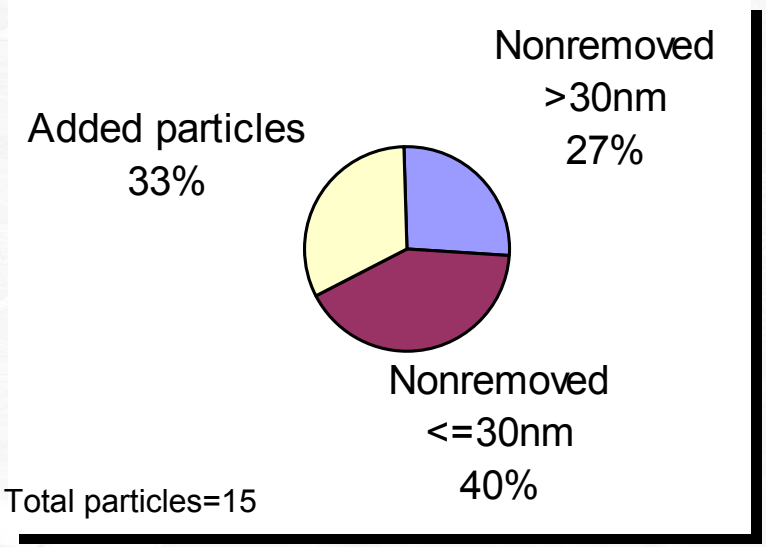
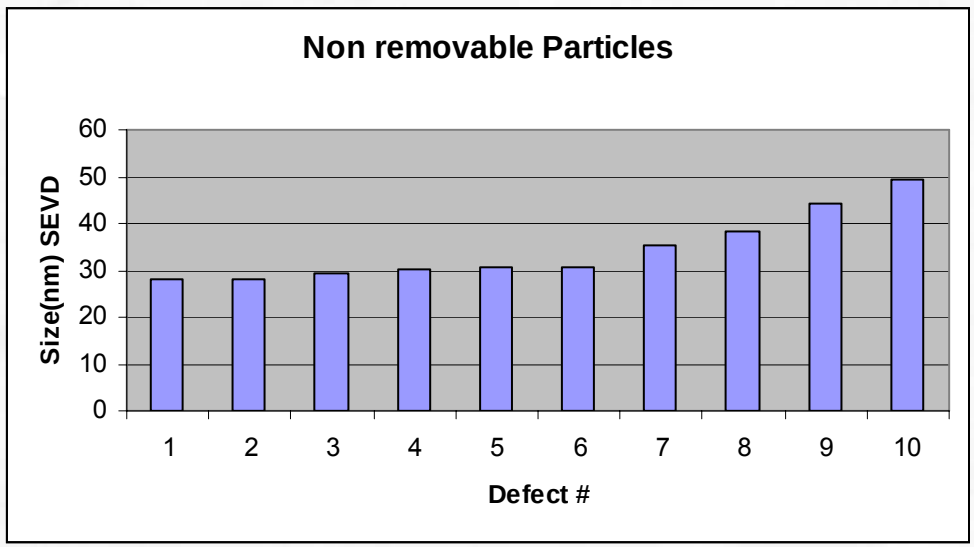
Post-cleaning Defects

Total post-cleaning defects



Total post-cleaning particles





MBDC cleaning recipes have good particle removal capability; however, both particles and pits were added by the cleaning process.

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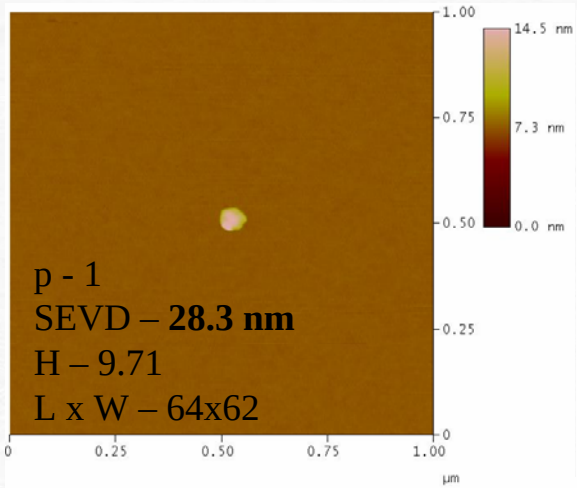
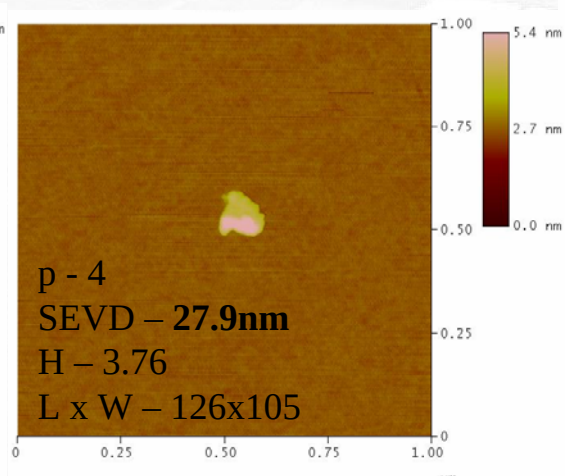
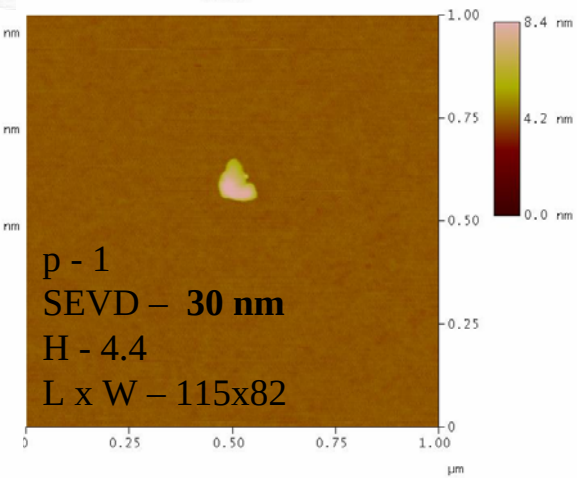
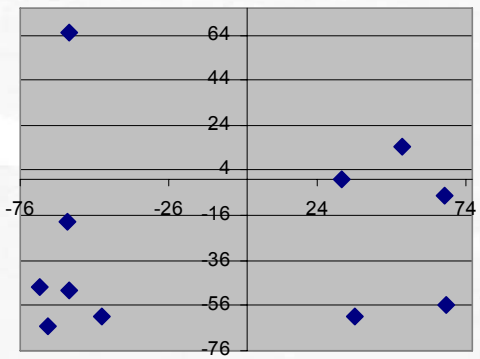
Topography of Non-removable Particles by AFM

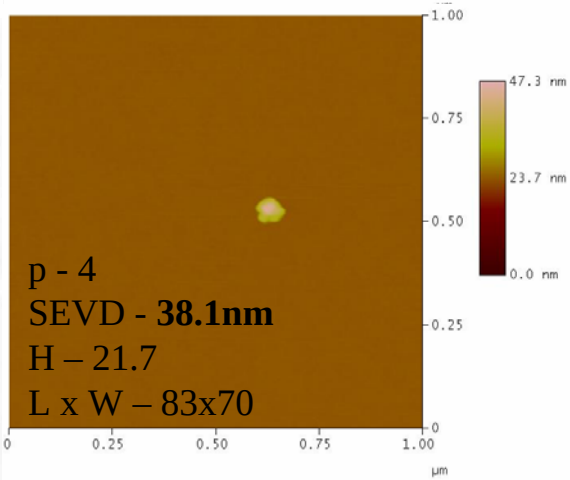


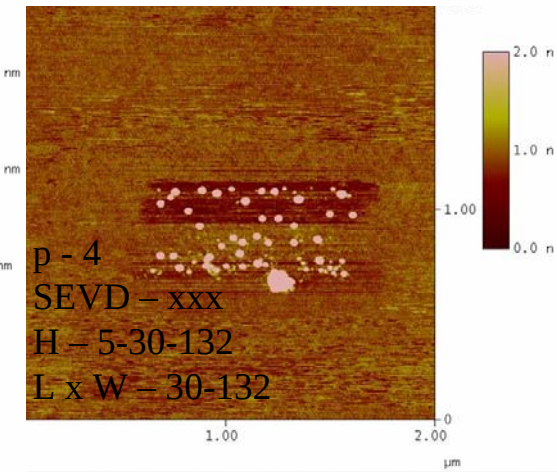






Defect location on the plate





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Non-removable particles have a large contact area and low height.

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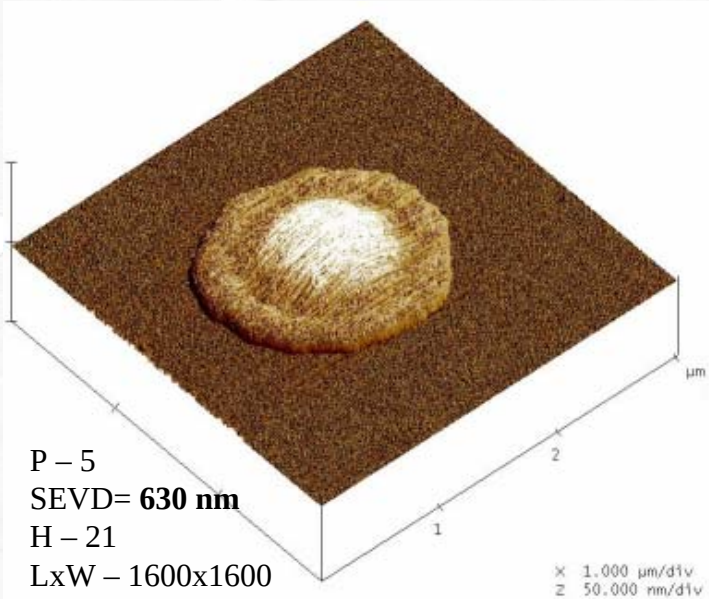
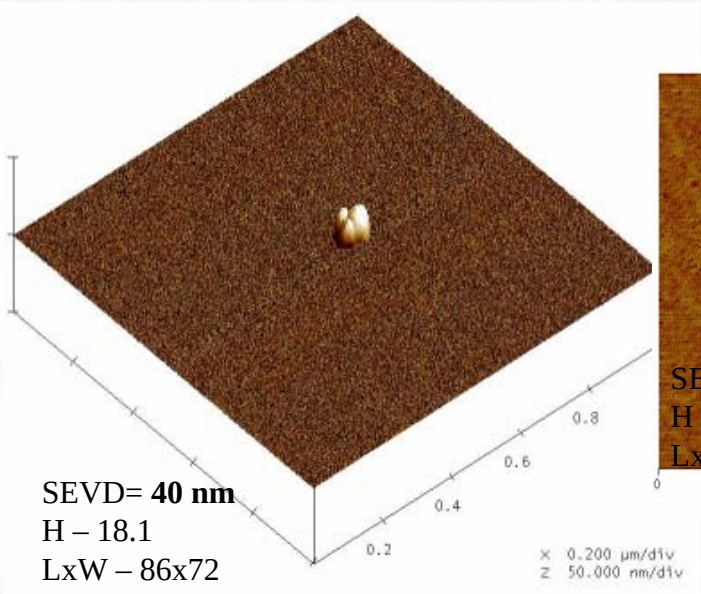
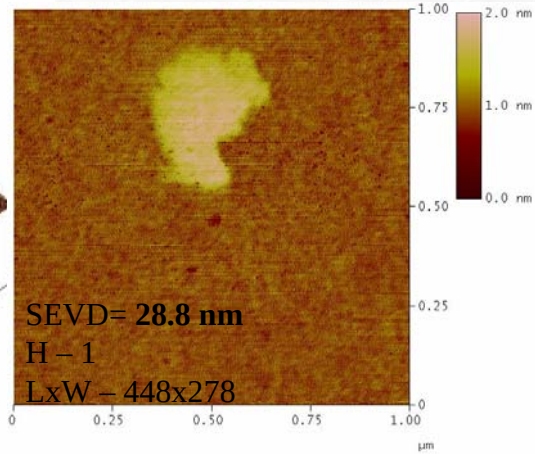
Topography of Added Particles by AFM



P – 5
SEVD= **630 nm**
H – 21
LxW – 1600x1600



SEVD= **40 nm**
H – 18.1
LxW – 86x72



SEVD= **28.8 nm**
H – 1
LxW – 448x278

Large particles are added by handling.
Some added particles are very short.

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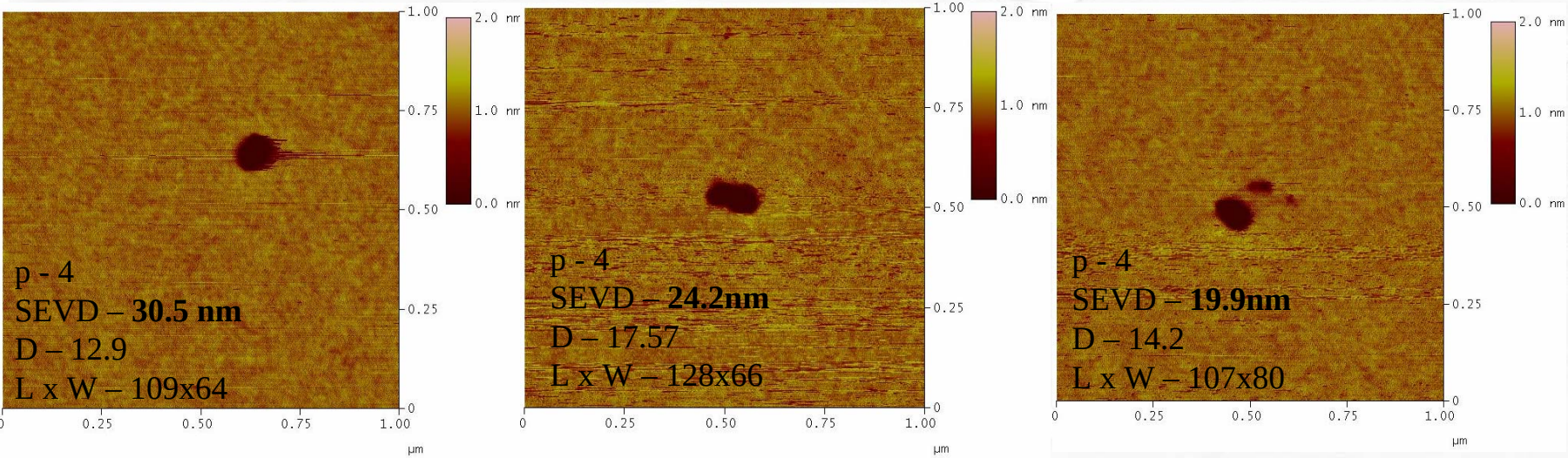
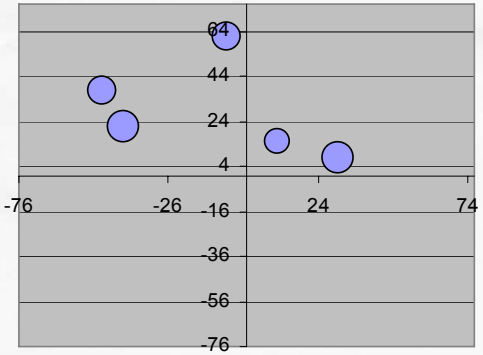
Topography of Potentially Added Pits by AFM





Defect location on the plate

Pits added by cleaning are similar to the pits existing on the substrate with a relatively higher depth.

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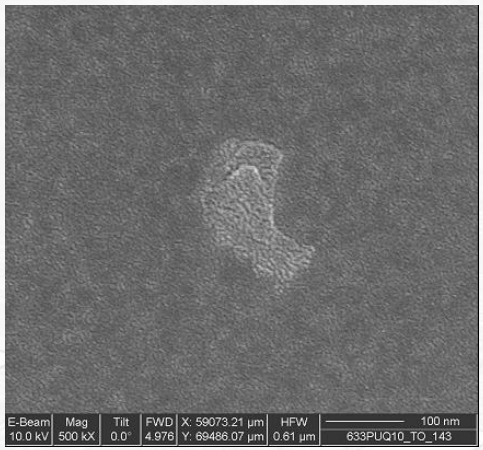
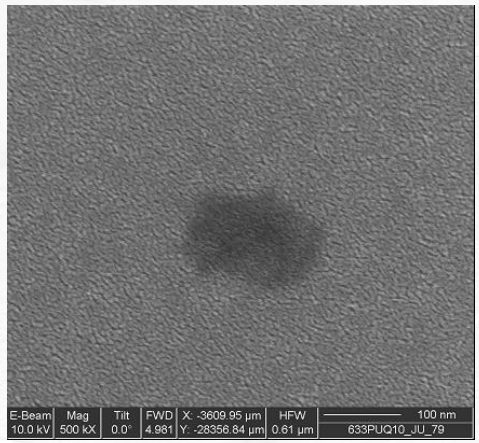
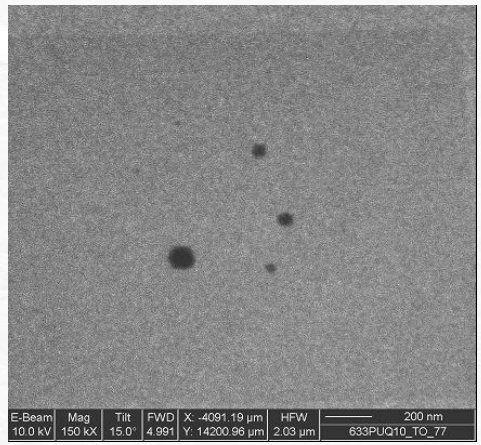
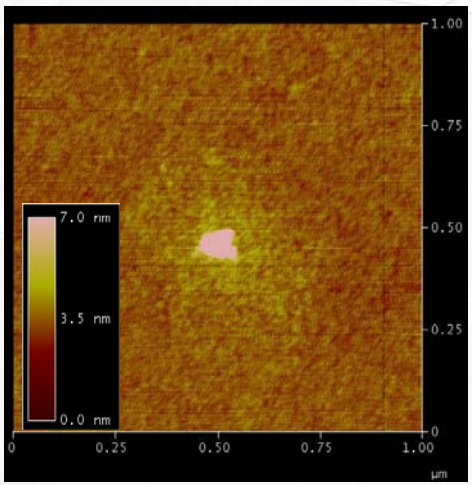
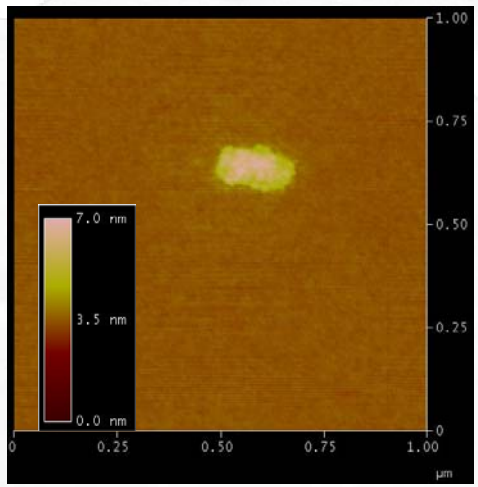
Typical Small Particles by SEM

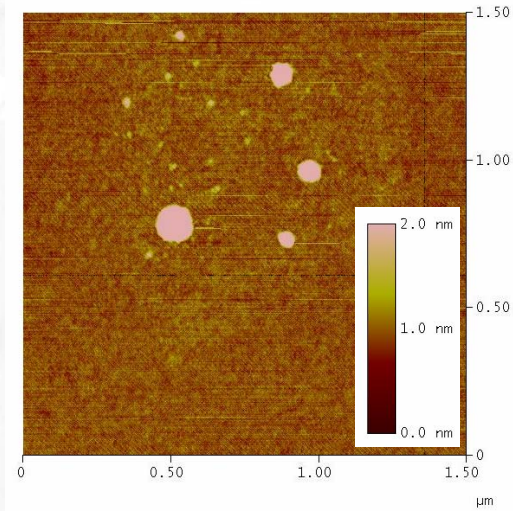












Particles are too small to obtain composition information by using EDS.

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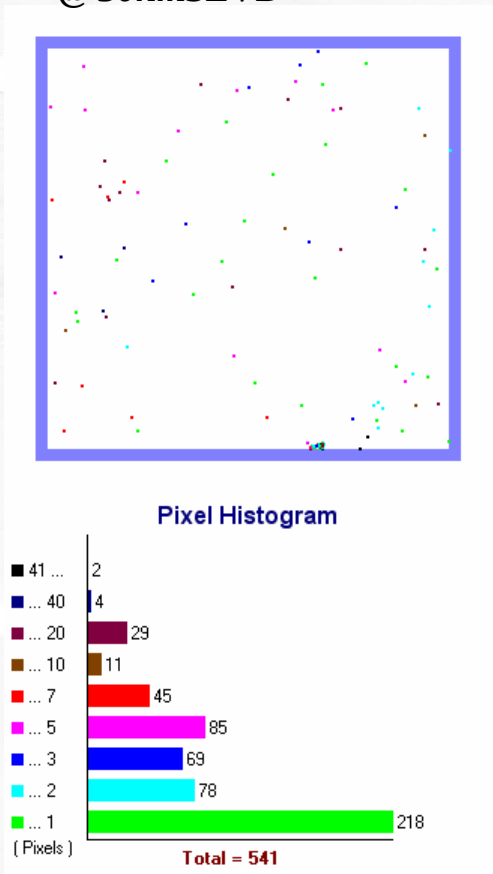
Cleaning processes based on SC1

Before cleaning
@ 30nmSEVD



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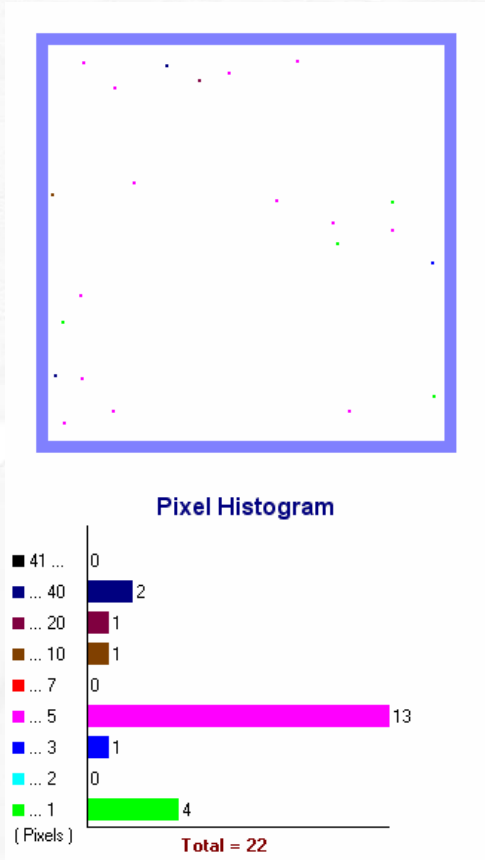
MBDC's Cleaning

Particles @ 30 nm SEVD

After cleaning
@ 30nmSEVD



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Defect density@ 30nm SEVD=0.075 particles/cm^2

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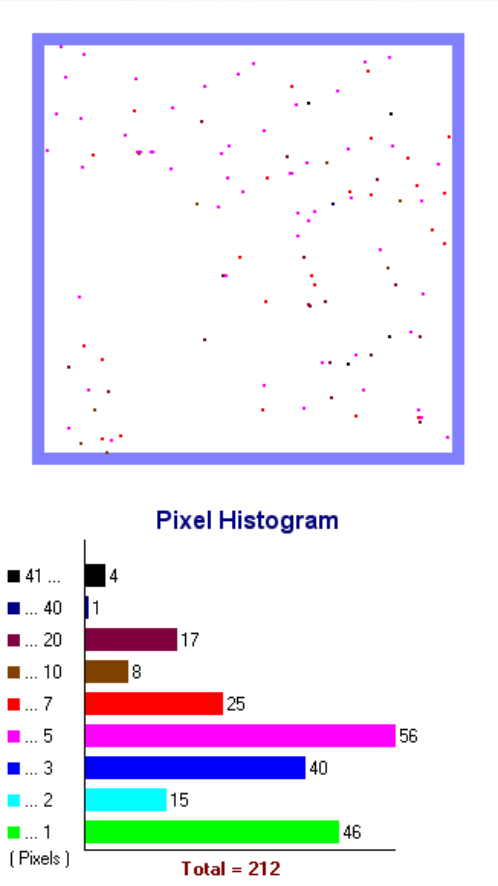
Cleaning processes based on SPM

Before cleaning
@ 30nmSEVD



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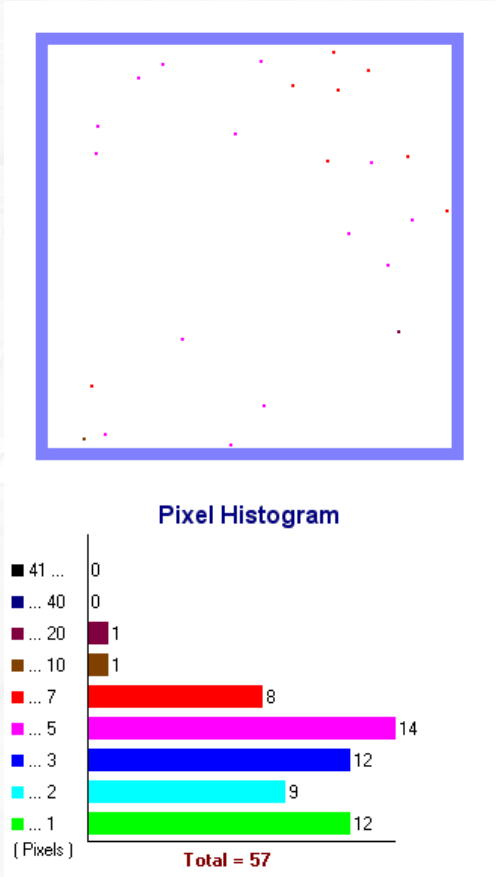
MBDC's Cleaning

After cleaning
@ 30nmSEVD



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Particles @ 30 nm SEVD

Defect density@ 30nm SEVD=0.119 particles/cm^2

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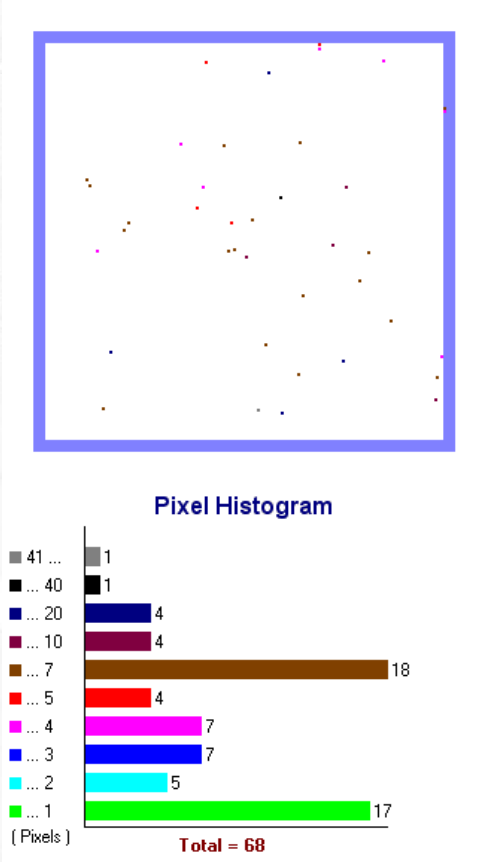
Cleaning processes based on O3-DI

Before cleaning @ 30nmSEVD



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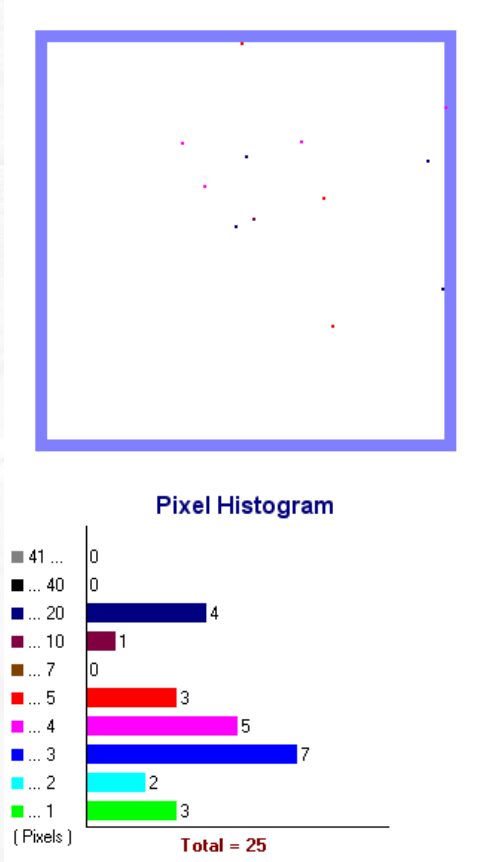
MBDC's Cleaning

Particles @ 30 nm SEVD

After cleaning @ 30nmSEVD



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Defect density@ 30nm SEVD=0.065 particles/cm^2

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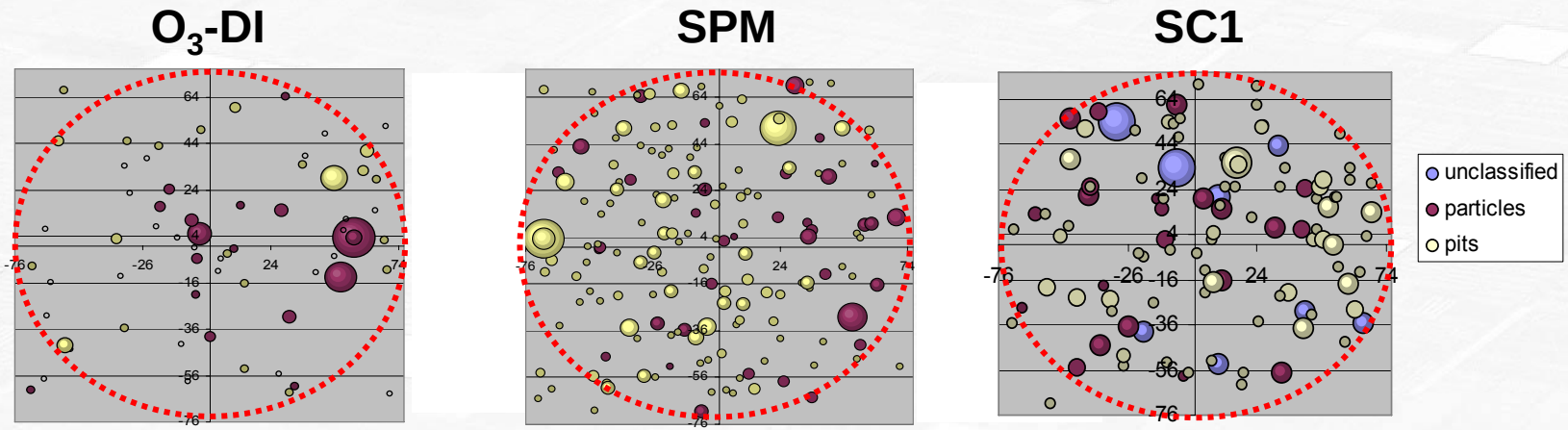
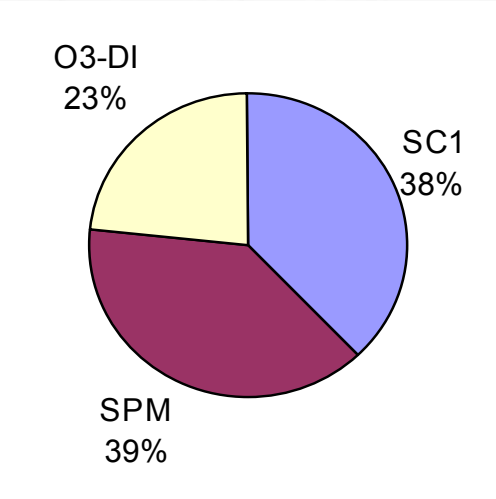
Added Defects by Different Cleaning Processes





Ozonated water processes seem to have fewer added defects.

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Summary & Conclusion

- **Blank substrate inspection capability exists up to ITRS 22 nm node(2016)**
- **High particle removal efficiency of 92% for >= 30 nm SEVD particles was demonstrated for the first time.**
- **Defect density of 0.065 particles/ cm^2 for particles on the quartz substrate was demonstrated for the first time.**
- **As far as substrate cleaning is concerned:**
  - The blank substrate defect density requirement for ITRS 45 nm node(2010) is feasible (5 particles →1 particle)
  - The blank substrate defect density requirement for ITRS 32 nm node(2013) is feasible (13 particles →1 particle)
  - The blank substrate defect density requirement for ITRS 22 nm node(2016) is feasible (18* particles →1 particle)

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EUV Mask Blank Cleaning Challenges

- **Total particle removal 10 → 0 is very challenging**
  - Requires new level of cleanness in UPW, Chemicals
  - Requires no generation of particles by tool
  - Requires effective control of particle redeposition by zeta potential management
  - Rinse process should be optimized for particle removal

- **Damage source should be identified and eliminated**
  - Megasonic is potential source of damage that should be properly tuned for this range of particle sizes
  - Etching by Ammonia or high spray jet flow are potential sources of roughness increase that should be controlled
  - These surface roughness is changing by the current cleaning recipes that limit us

- **Defect shape is important in sub 30 nm particles**
  - Different cleaning processes should be developed for particle removal or residue removal

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Enjoy Barcelona

The End

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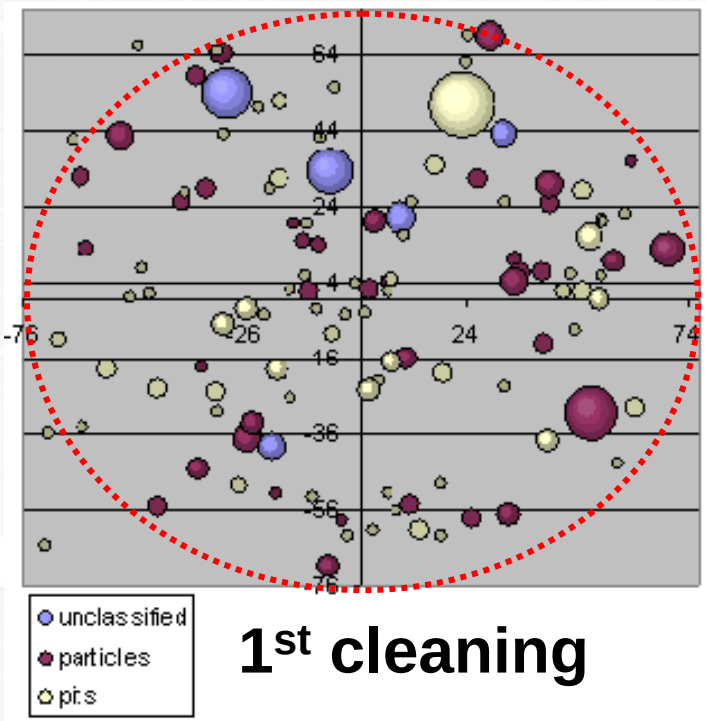
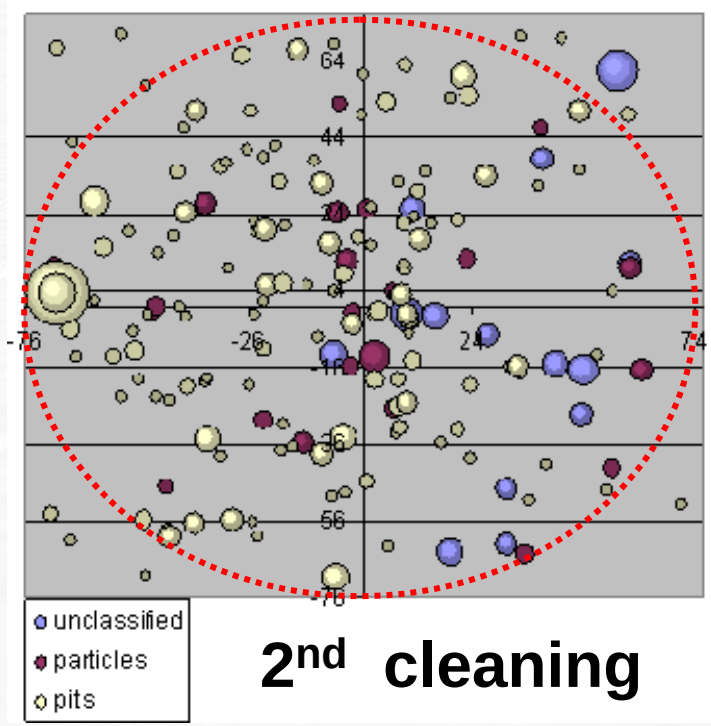
Origin of Added Defects



1st cleaning



2nd cleaning

- Many sub-50 nm SEVD defects are added by the cleaning process.
- Process development is needed to reduce added defects.

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