Accelerating the next technology revolution

Challenges of cleaning of EUV masks below the sub-16 nm HP

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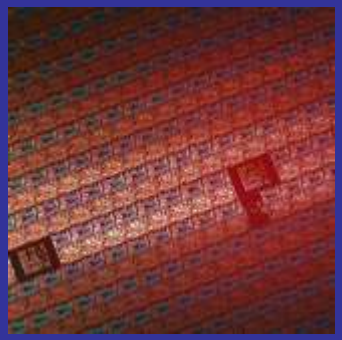
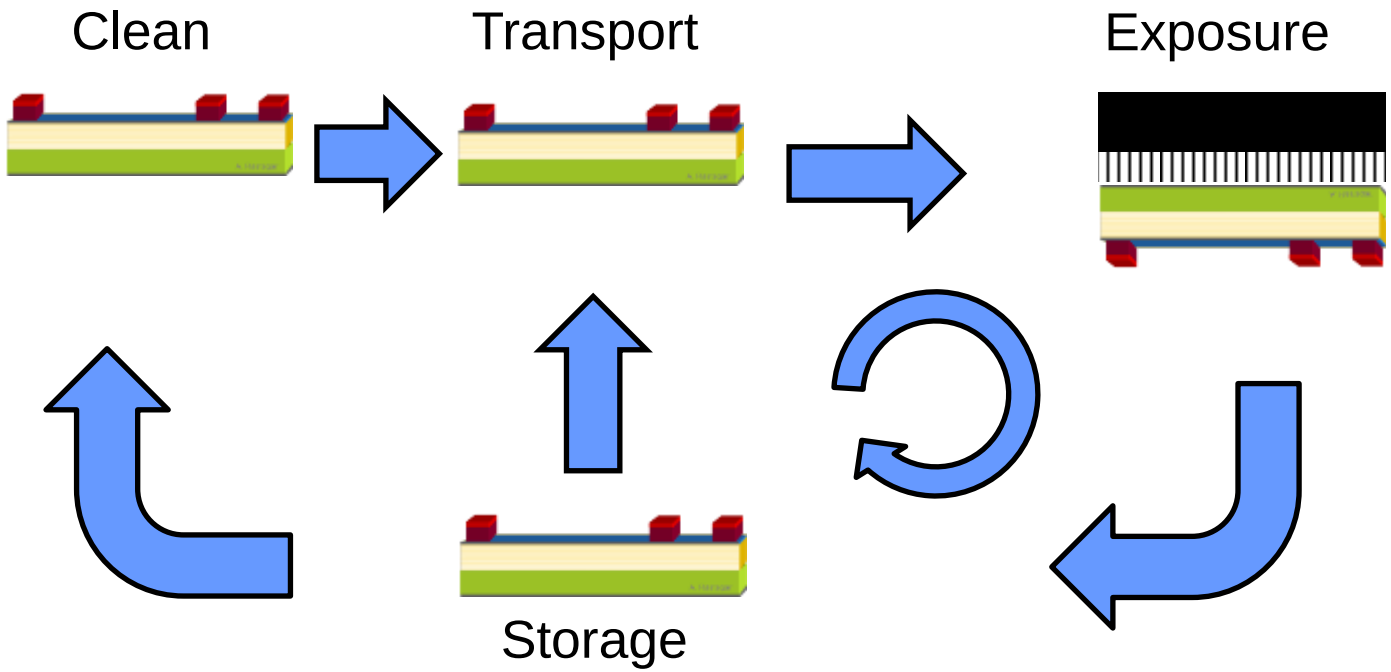


EUV masks for sub-16 nm HP

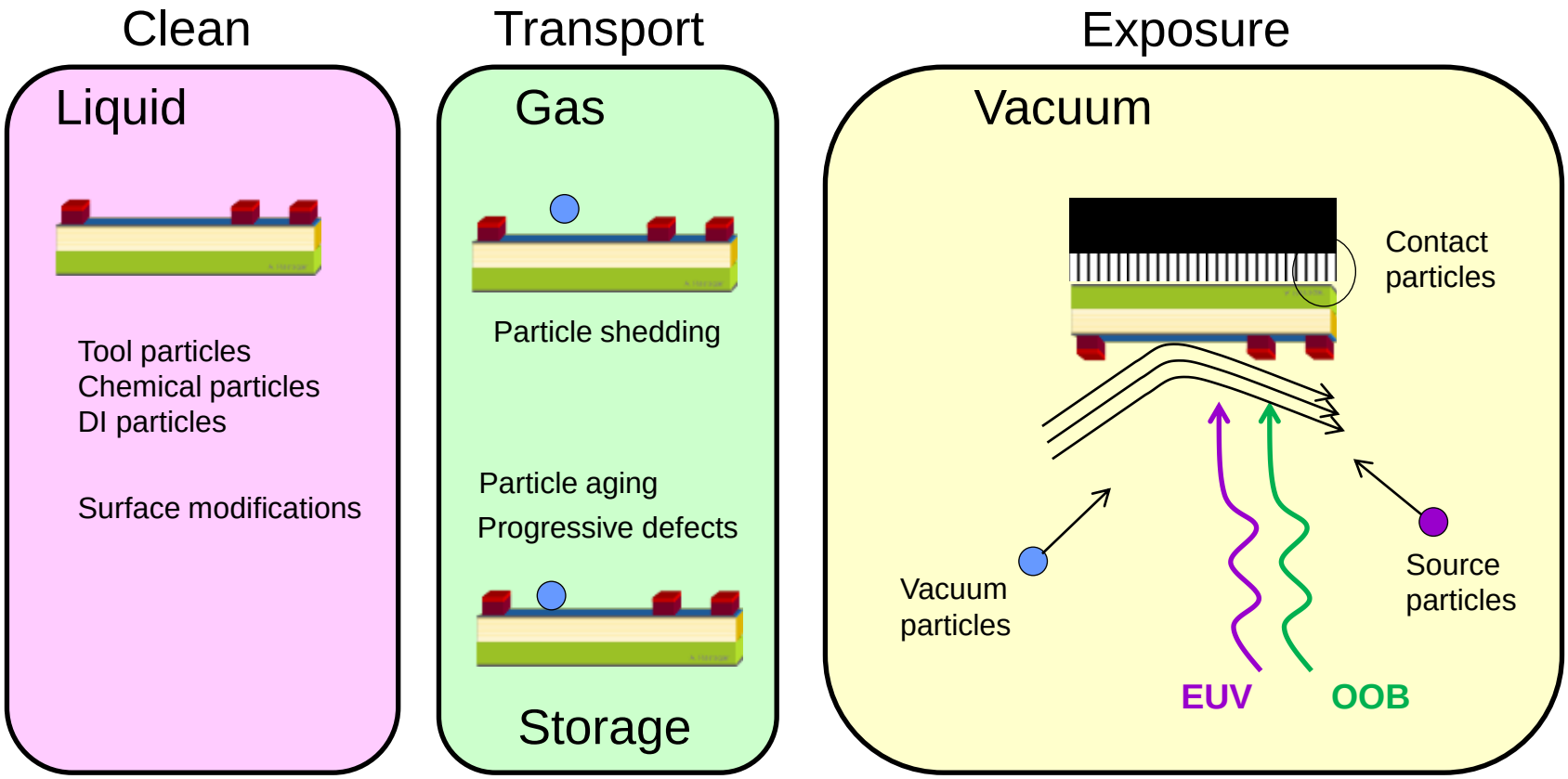
- Decision on EUV projection optics (NA >0.5) and magnification (>4X) impacts cleaning requirements for sub-16 nm HP nodes
  - NA >0.5 → CRO > 6° → Thinner absorber → New materials
  - New absorber materials such as Ni and Pt and their alloys should be investigated for chemical stability
  - Changing absorber gives an opportunity to replace Ru with other capping materials (e.g., V_2O_5 or TiO_2) (new absorber etch process)
  - NA<0.5 → magnification >X4 → mask feature size increases
    - Less stringent requirement on cleaning
- EUV source meets HVM requirements→ Higher radiation intensity
  - → Radiation effects on mask lifetime should be considered

EUV Mask Lifetime Cycle



- An EUV mask should be cleaned at least 100X
  - No EUV reflectivity change
  - No CD change

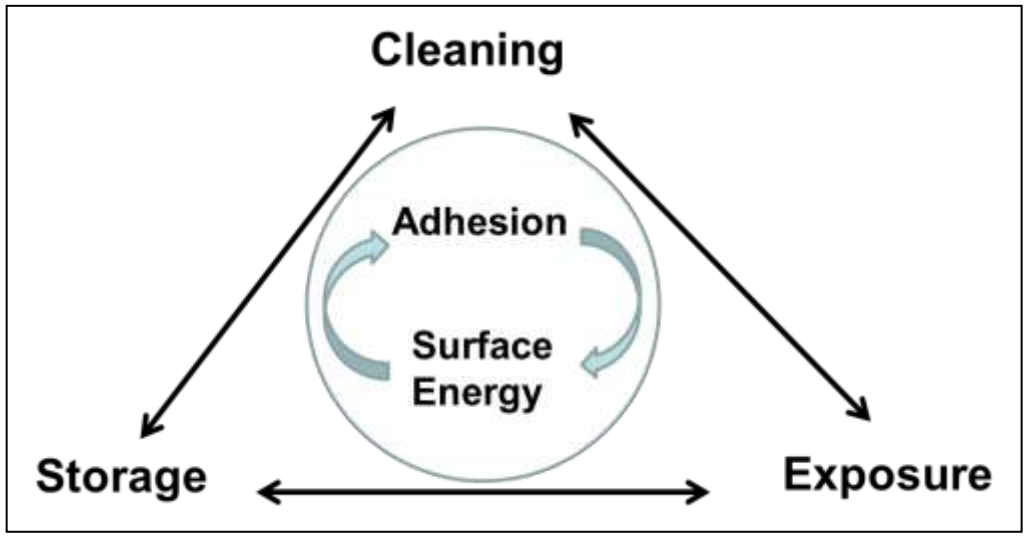
EUV Mask Lifetime Cycle-Defectivity Concerns



- Physics involved in particle adhesion, dynamic and formation is different in each case and depends on defect size
- Cleaning, exposure and storage are interdependent

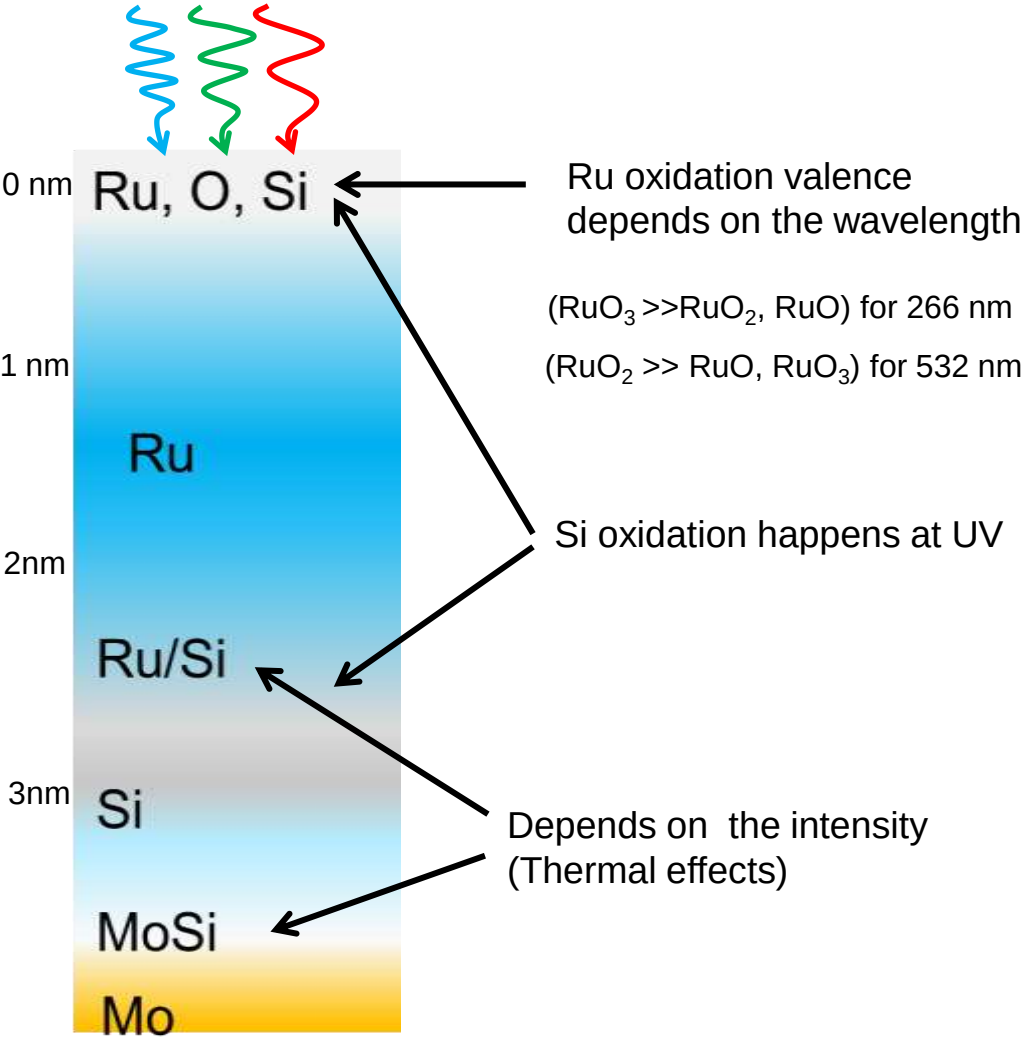
EUV Mask Cleaning Challenges

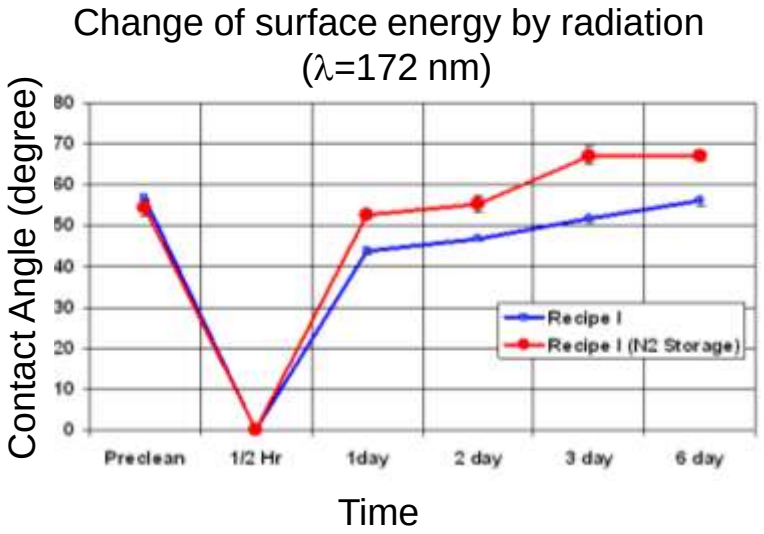
- Particle adhesion
  - Radiation effects
  - Aging
  - Progressive defects
- Particle adders
  - backside
  - frontside



- Pit adders
  - Role of oxygen in megasonic cleaning
- CD loss
  - TaN etch by SPM → New Chemistries→ Ruhai Tian

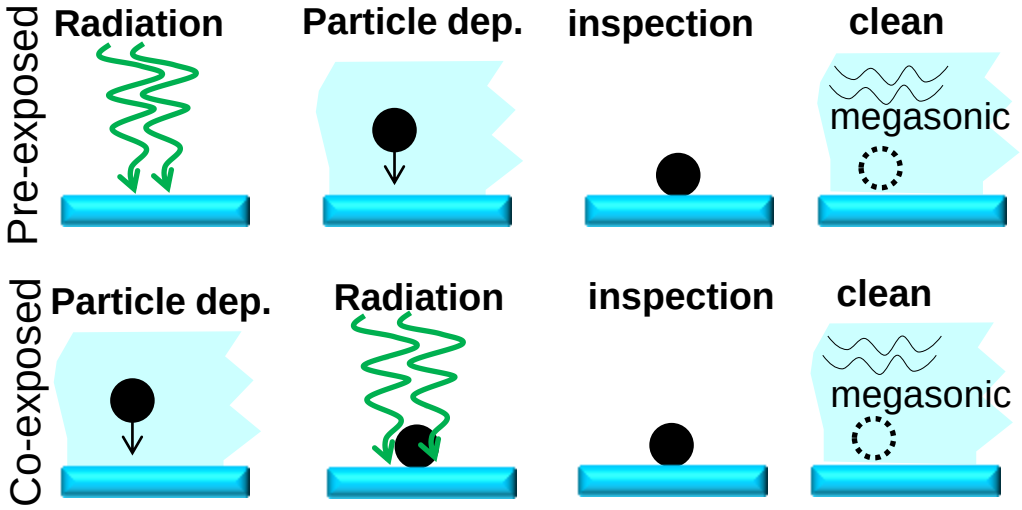
Radiation Effects on Ru Cap Surface

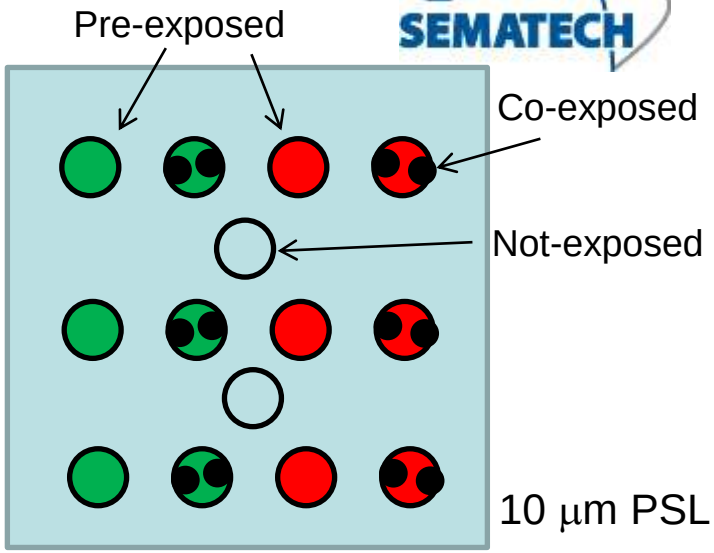


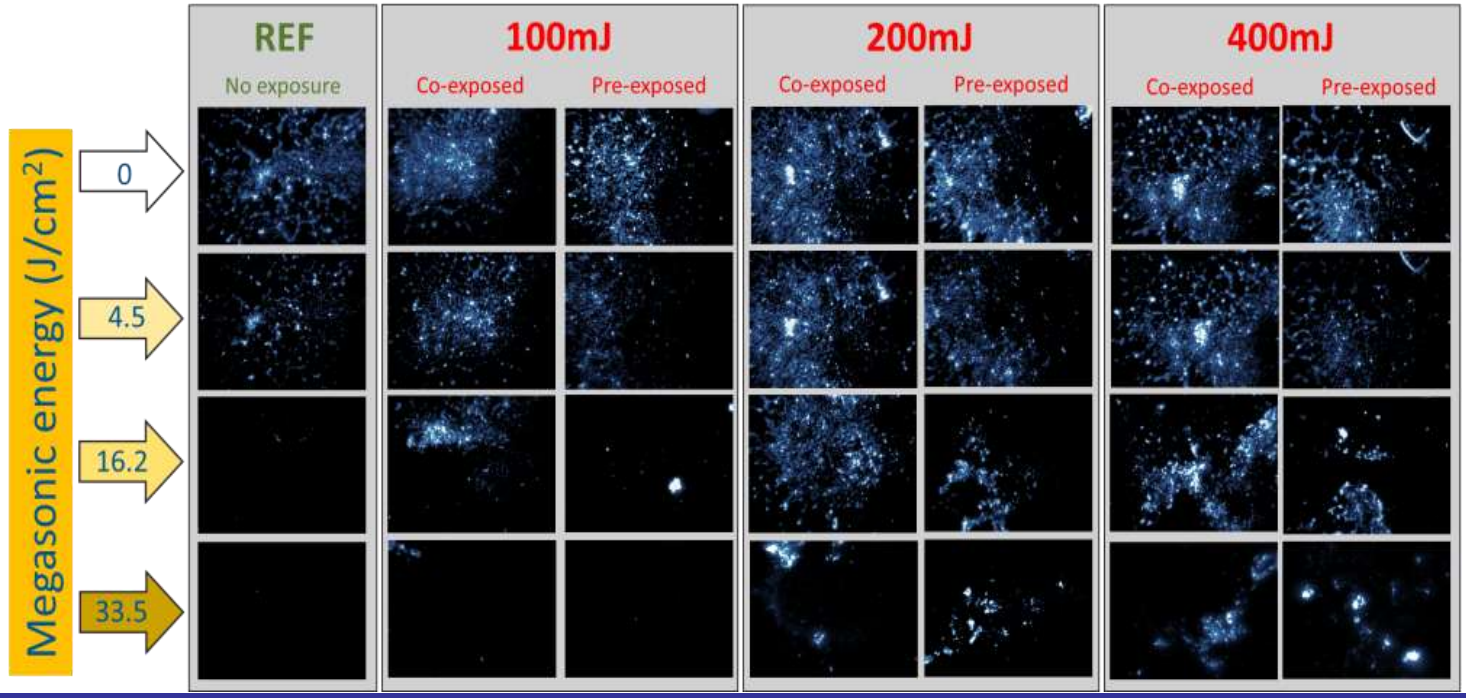


- Surface composition and energy of the Ru-capped ML changes under radiation

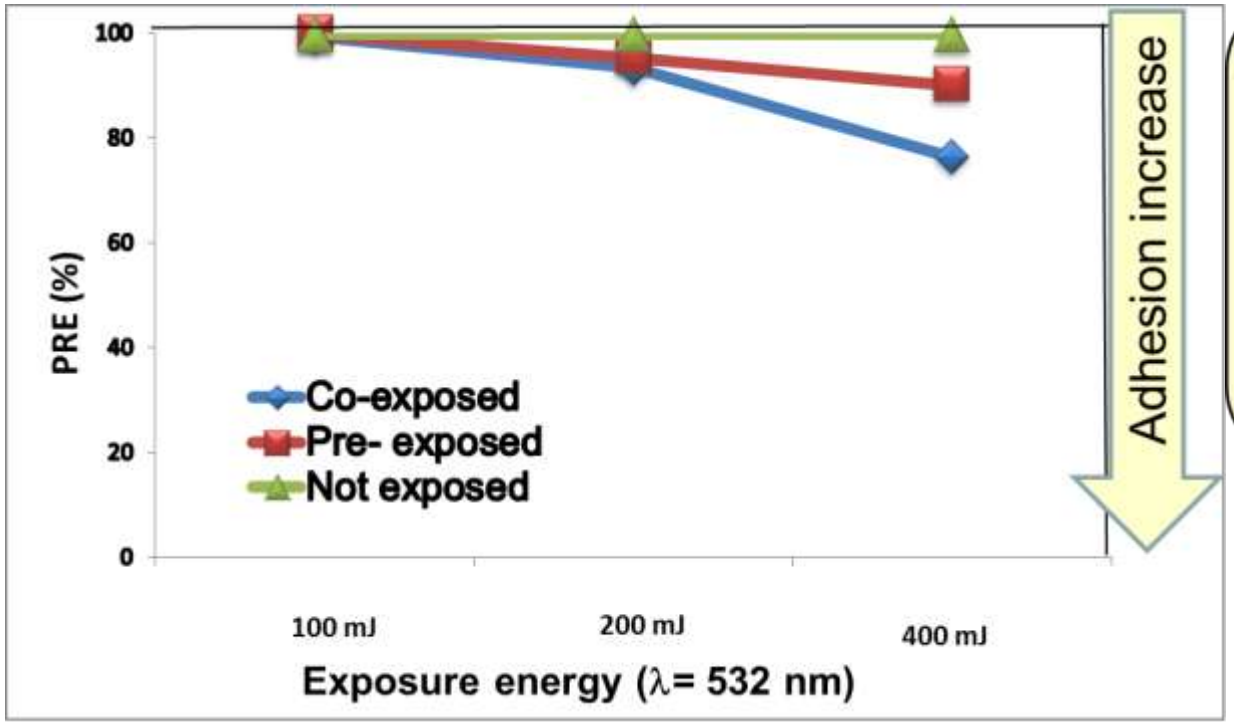
Radiation Effects on Particle Adhesion

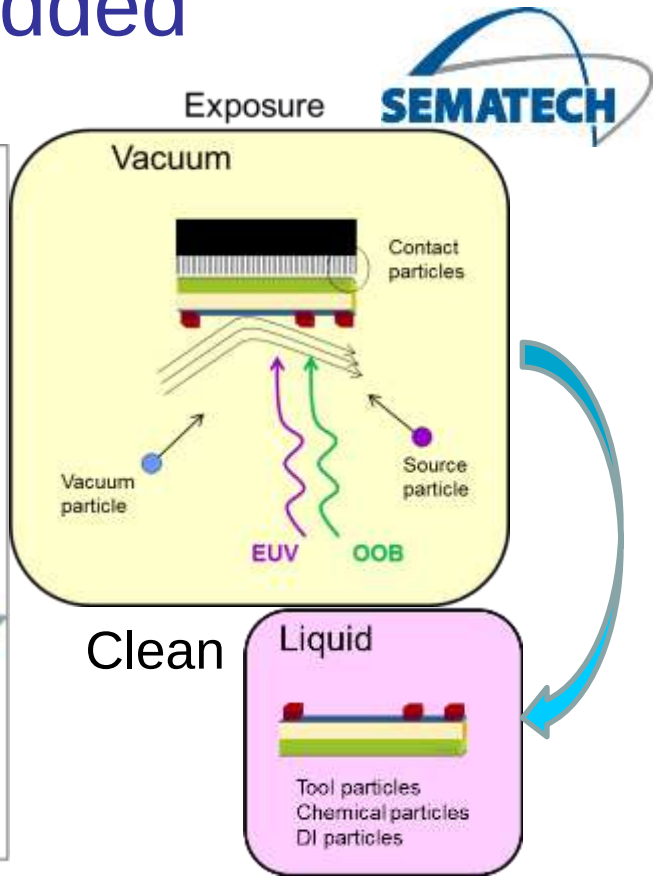






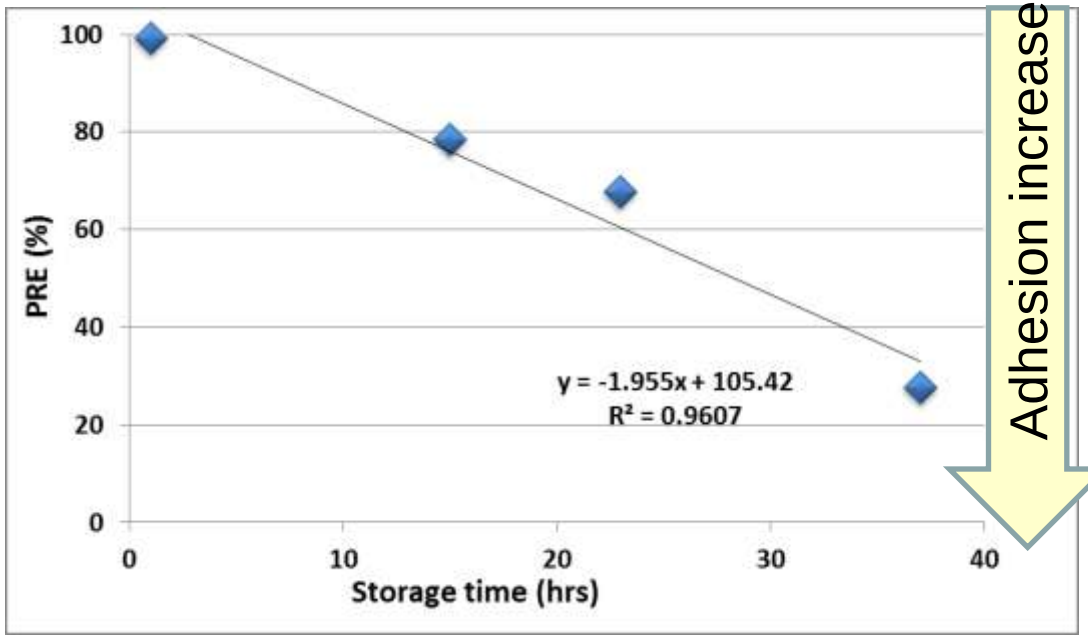
Radiation Effects on Cleaning-added Particles





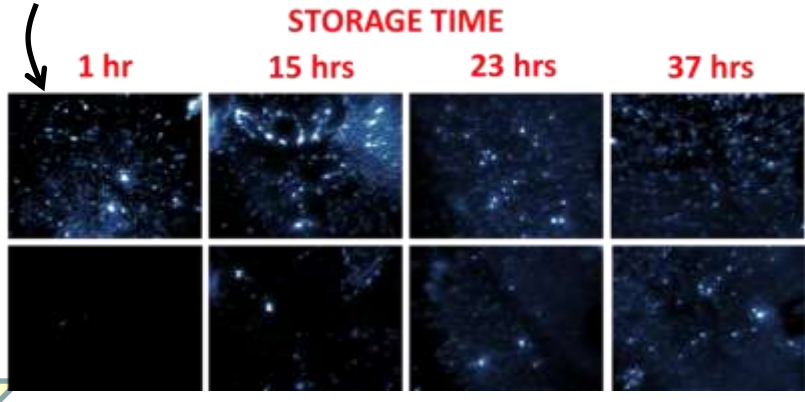
- Out-of-band (OOB) radiation increases particle adhesion
- Particles prefer to adhere to pre-exposed areas during cleaning
- When particles are on the mask during exposure, they become more difficult to remove

Storage Effect on Particle Adhesion



Adhesion increase

Before clean

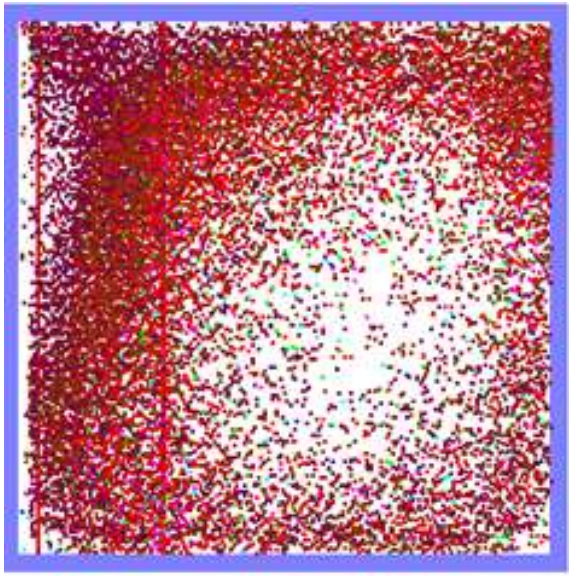


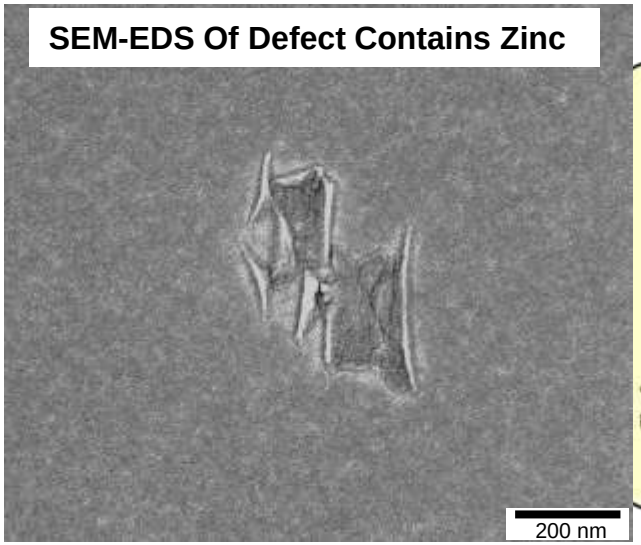
10 μm PSL

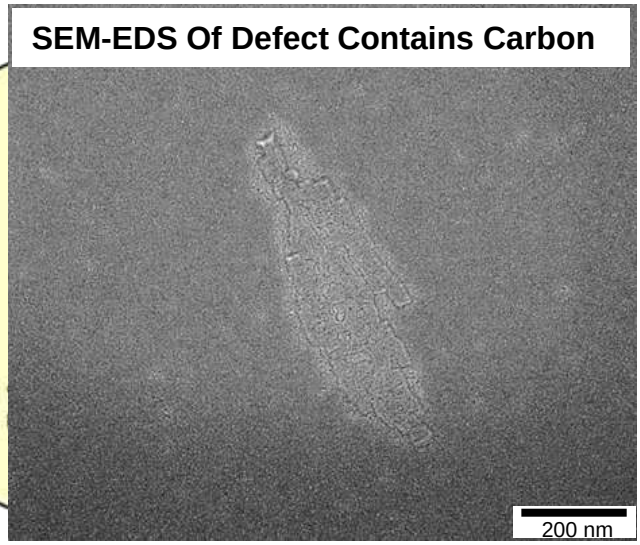
Post clean (DI –MS 33.5 J/cm^2)

- PSL particles were deposited, and the blank was stored in air in the cleanroom
- If particles remain on the surface for a long time, they cannot be removed

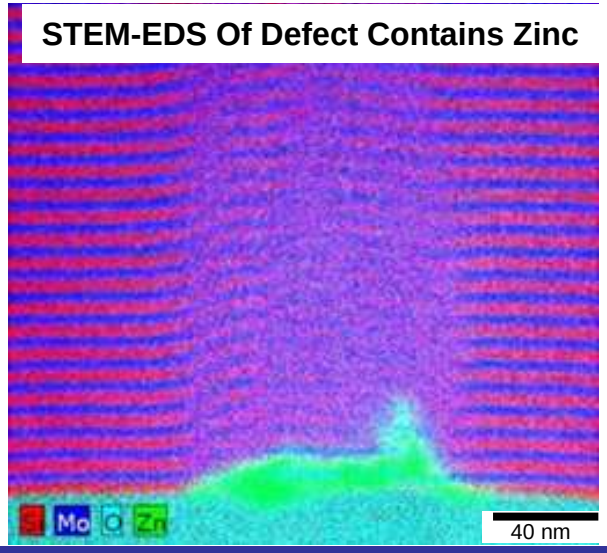
Progressive Defects

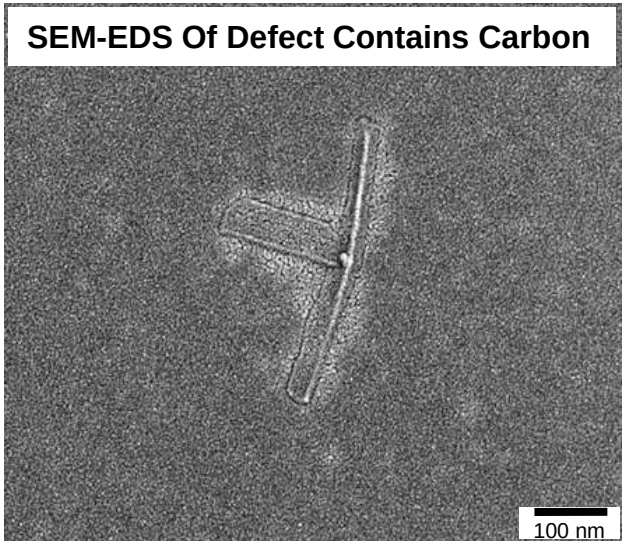




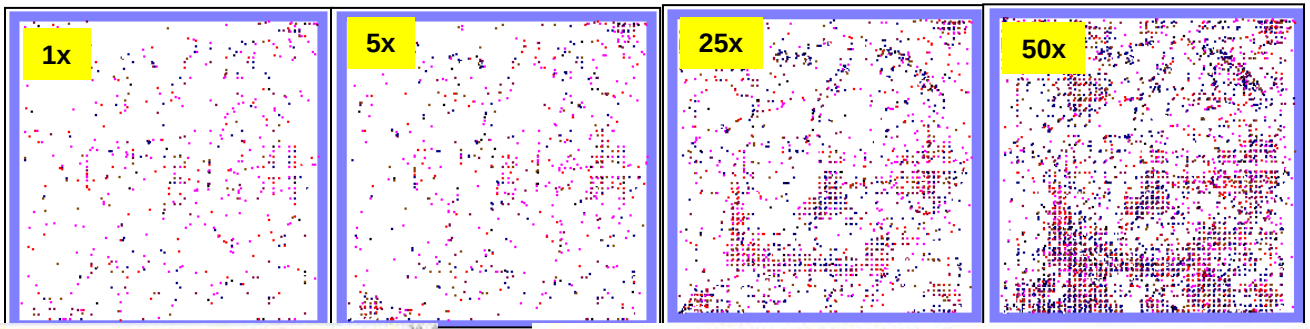


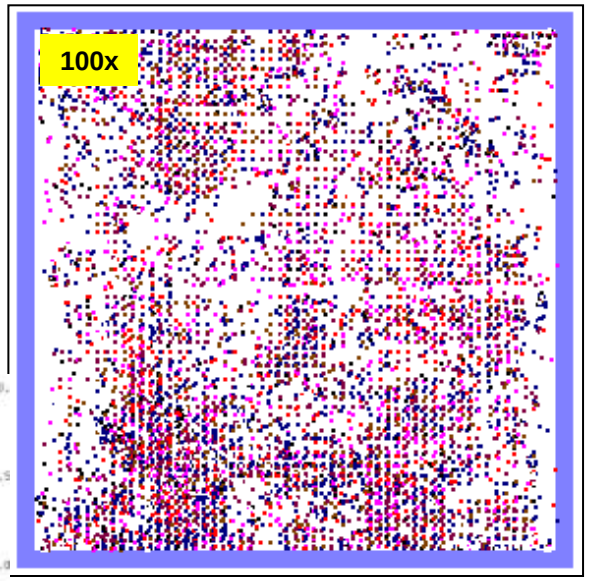
Chemical residues remaining on surface will grow into progressive defects

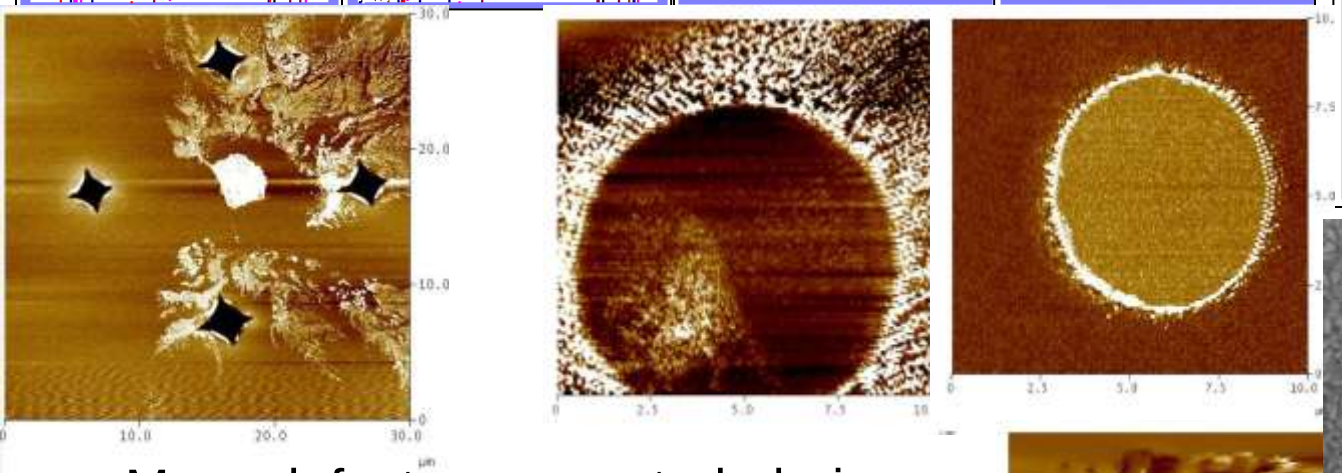


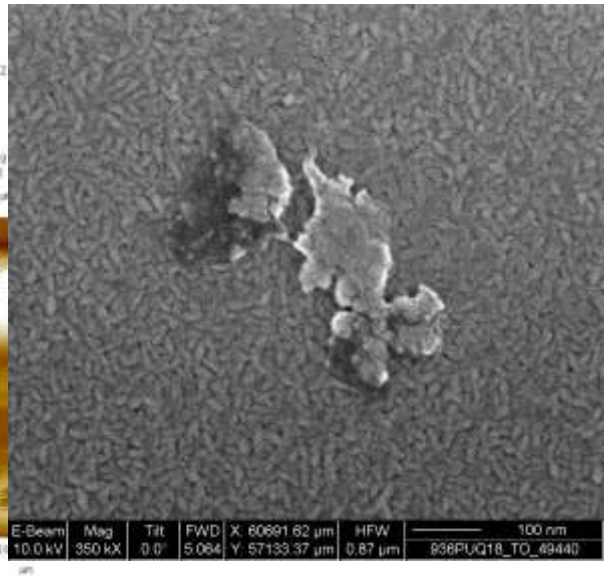


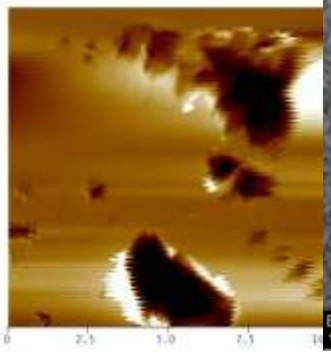
Electrostatic Chucks Create Particles







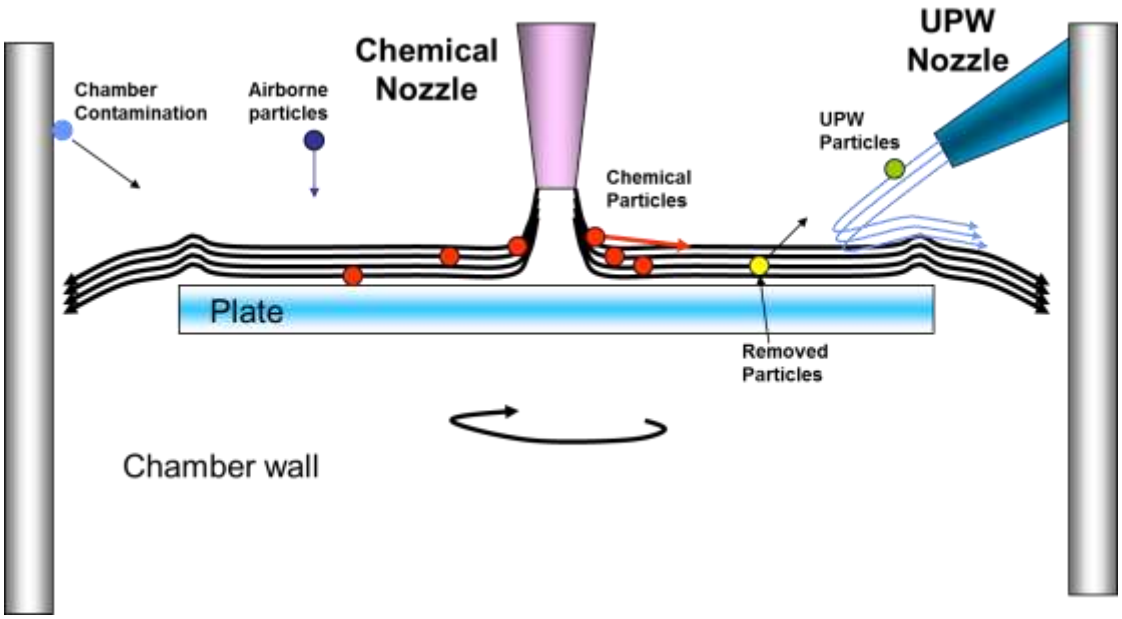


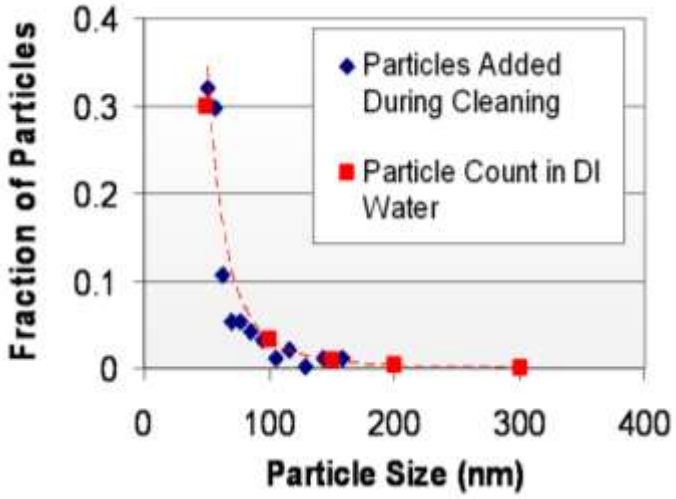


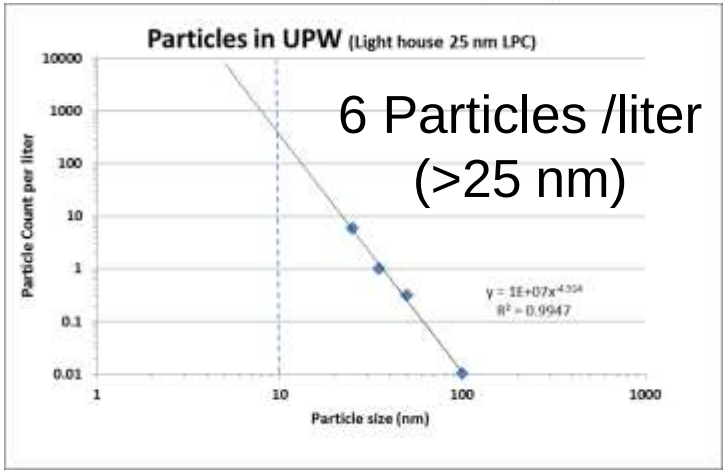
- Many defects are created during ESC chucking
- These defects are hard to remove
- Should be resolved for 16 HP tools

Particles Added During Cleaning

- Particles are added by
  - Chemicals, tool, process, UPW, airborne contaminants

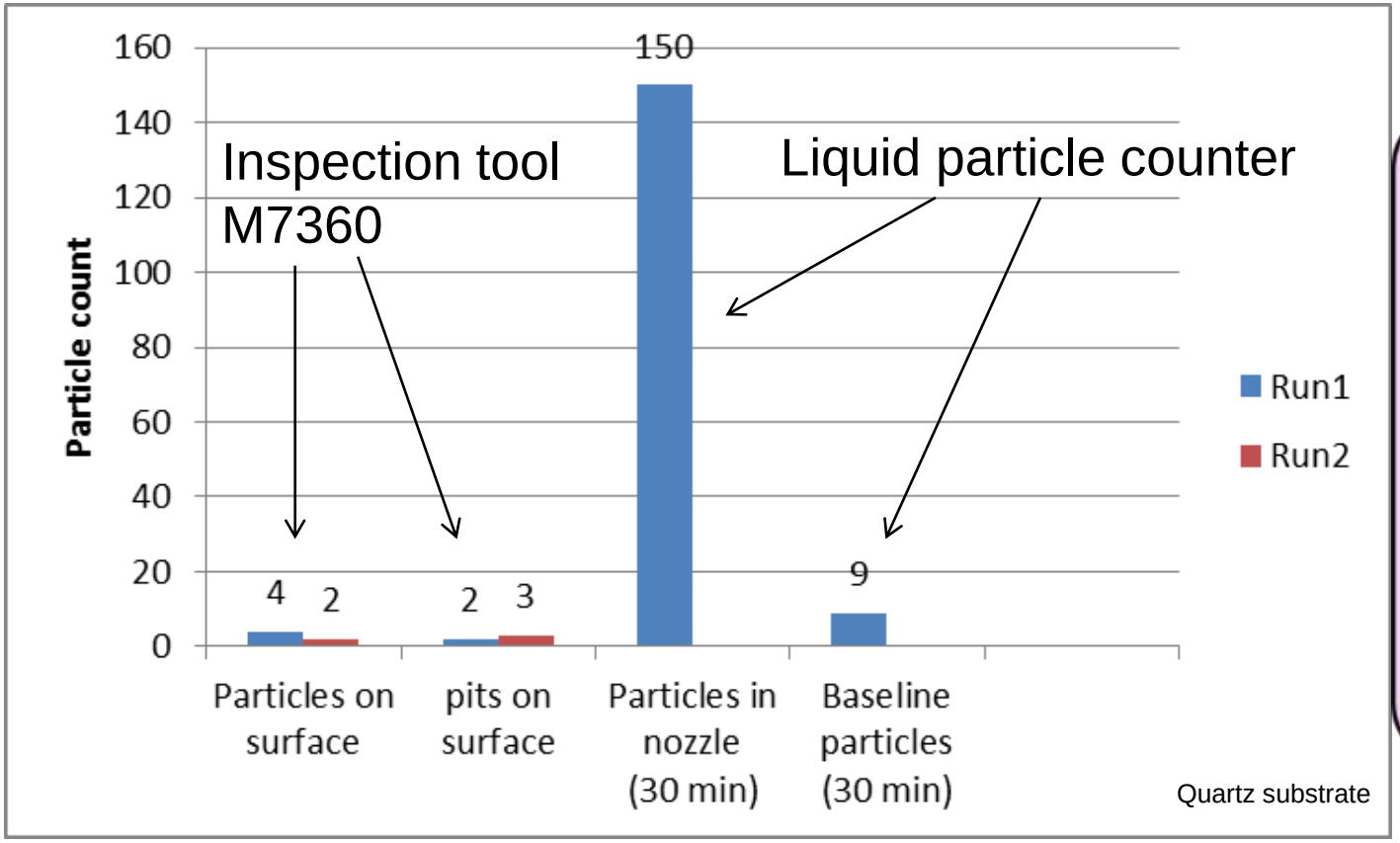


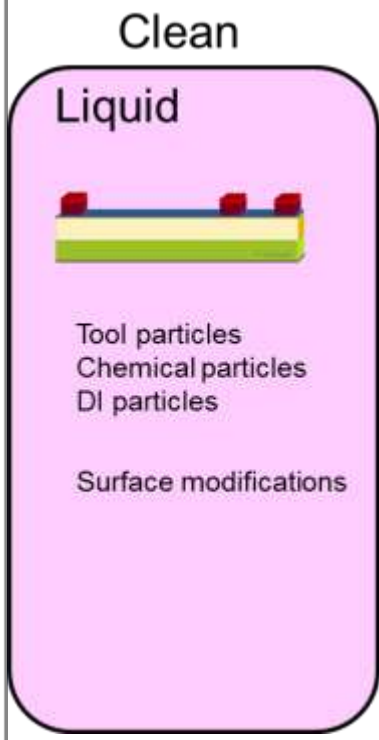




- Particles added during final rinse/dry most probably remain on the surface

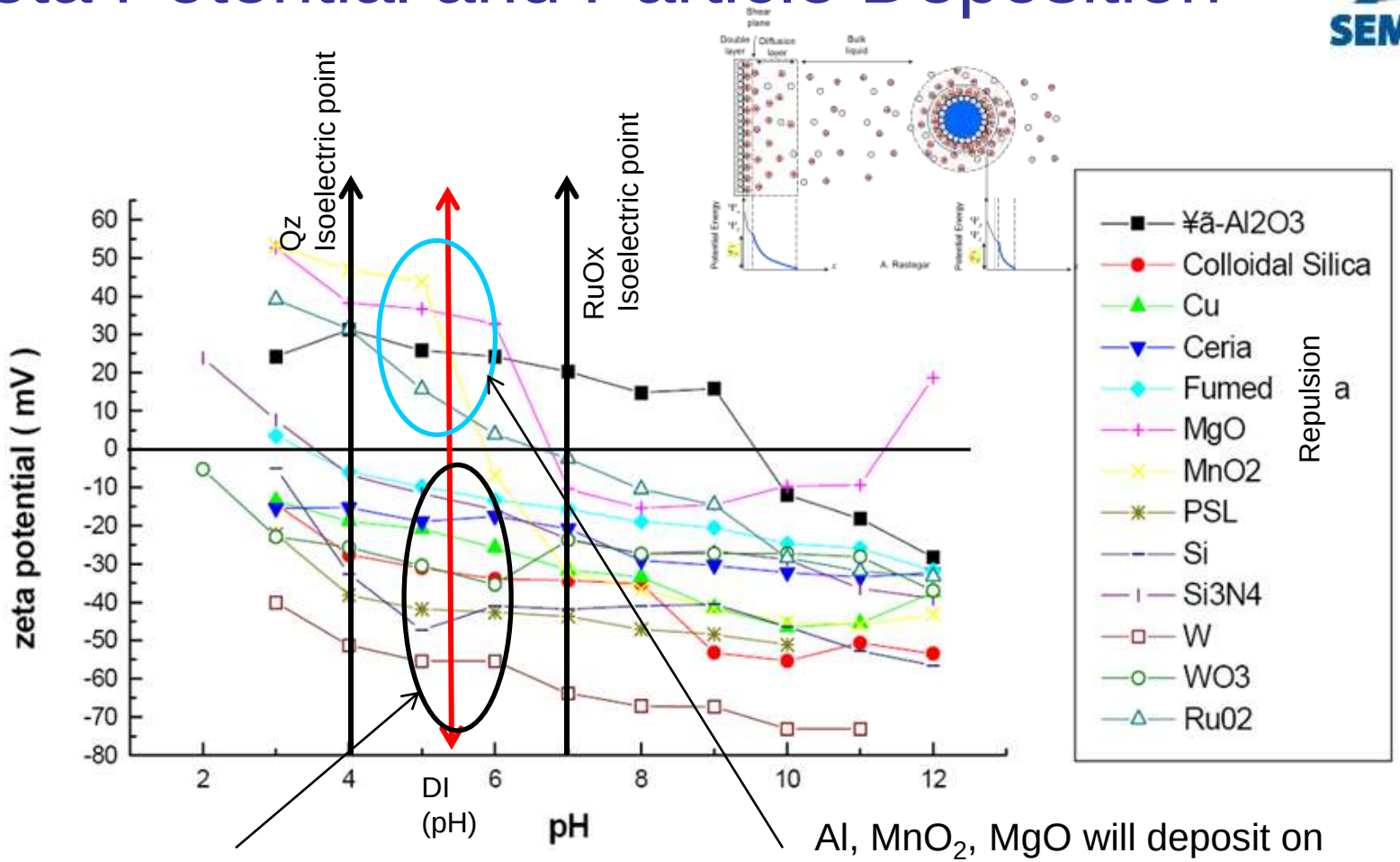
Are UPW Adders Remaining on The Surface?





- During 30 min rinse, quartz surface is exposed to 150 particles (>50 nm count by LPC)
- Inspection by M7360 (> 45 nm) shows only a few particles on the surface

Zeta Potential and Particle Deposition



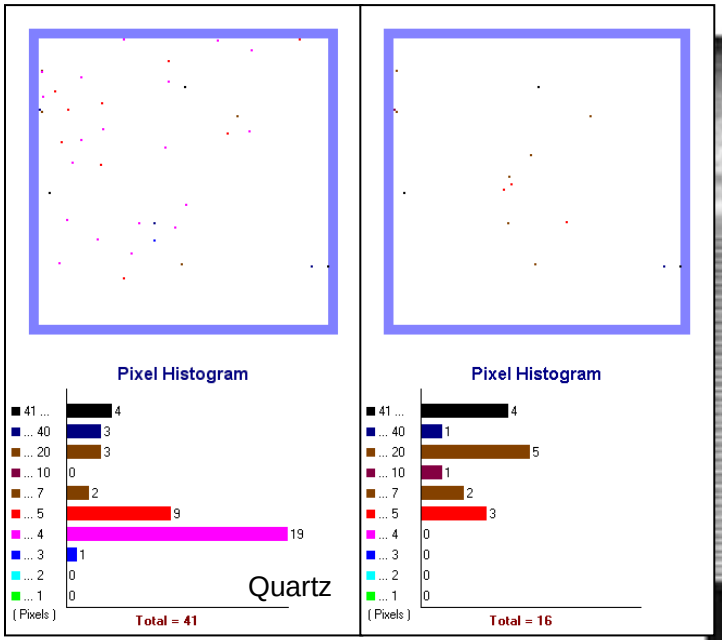
In DI water (pH=5.5),these particles will deposit on Ru but not on quartz/LTEM

Al, MnO_2, MgO will deposit on quartz/LTEM but not on Ru

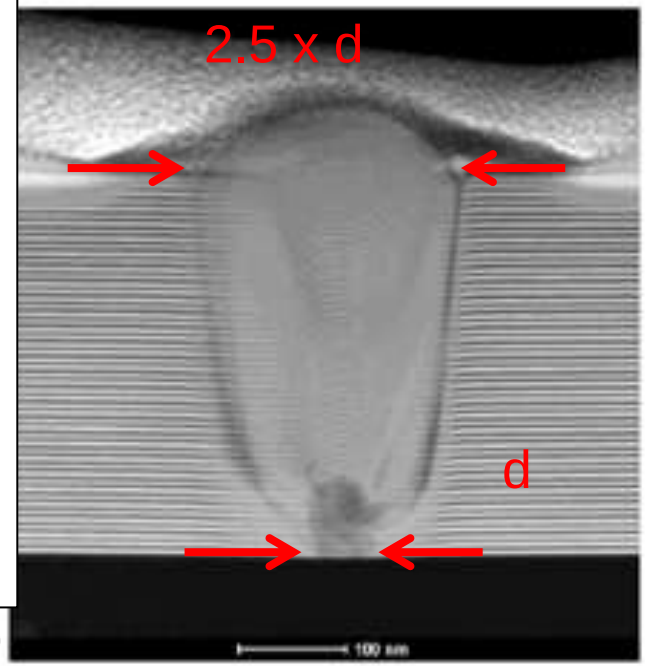
Many particles are deposited on Ru/oxide surfaces during the rinse process

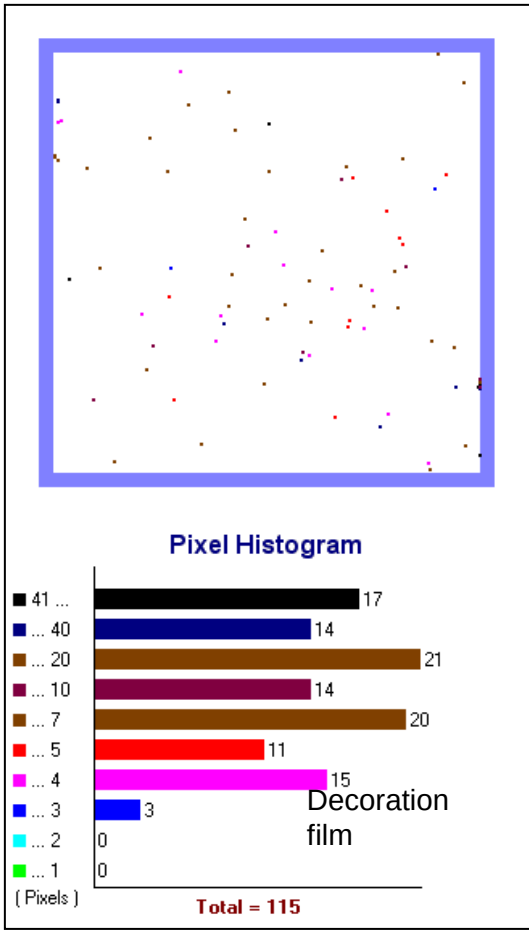
Zeta potentials: A. Busnaina, NEU

Detection Challenges
Sub-resolution Defects



Before rinse-M7360 After UV+rinse-M7360

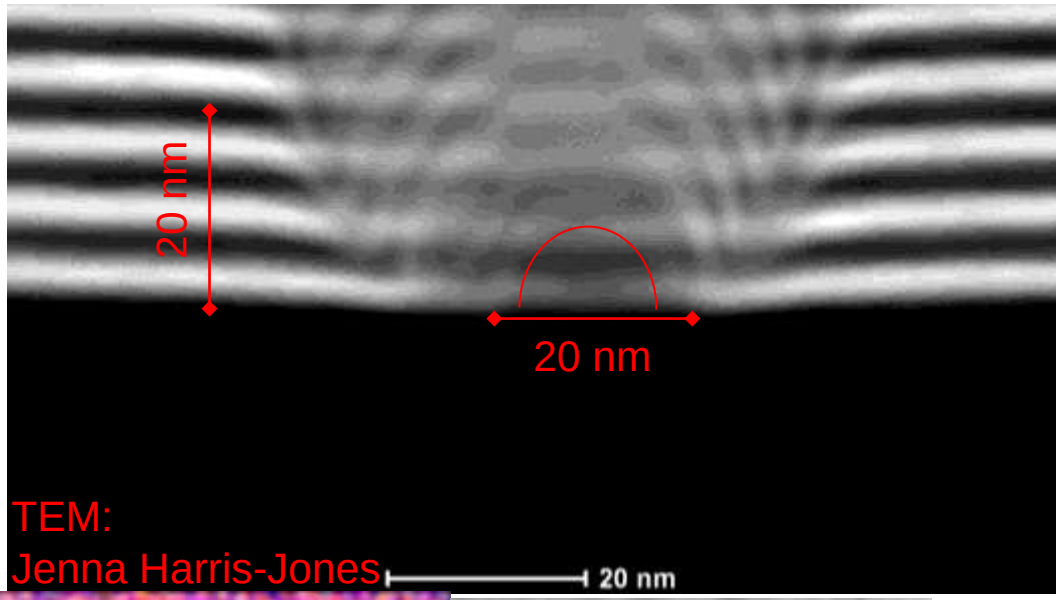


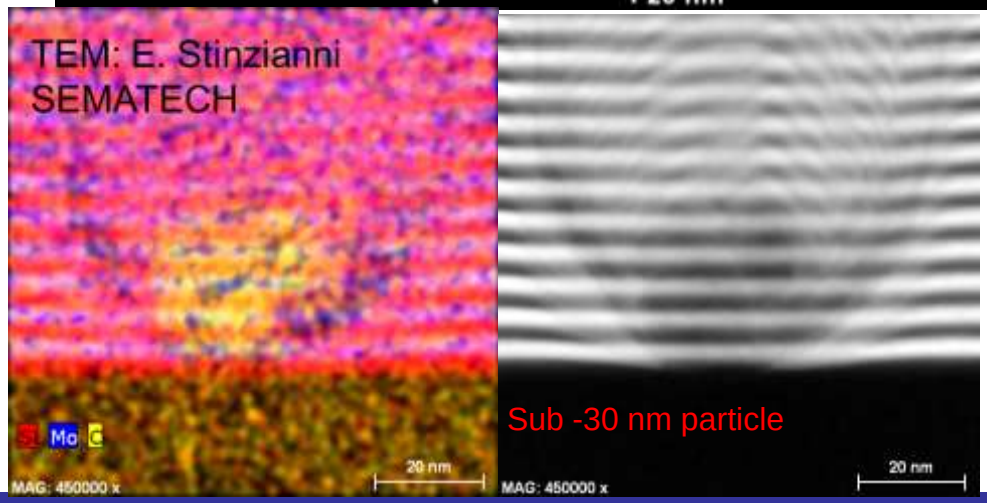


After decoration-M7360

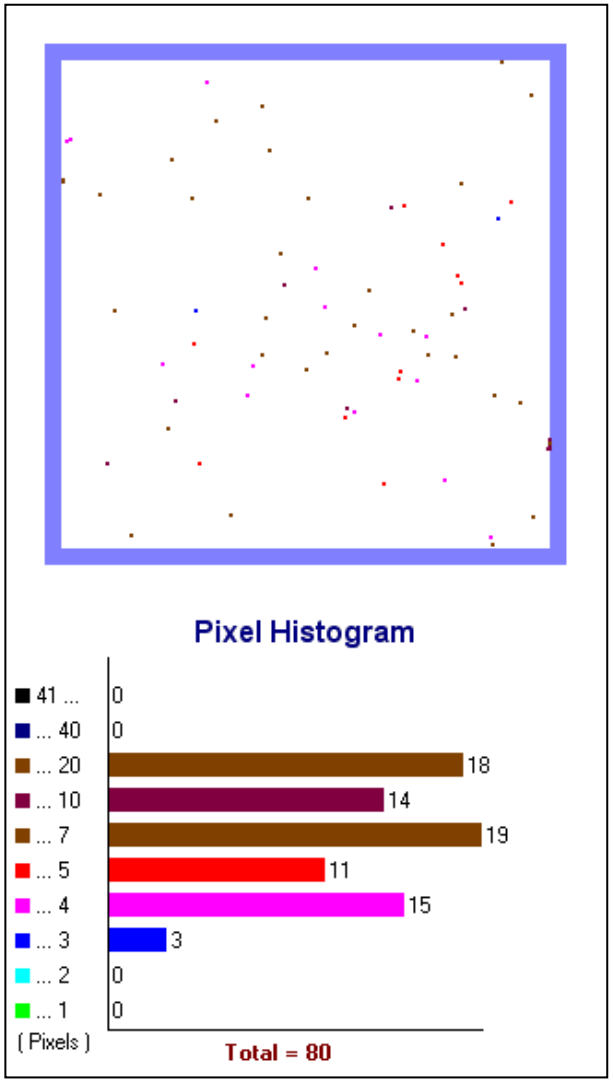
- SEMATECH's multilayer deposition team has developed defect decoration techniques to increase the lateral dimension of particles by 2.5 times
- 15 nm particles on a surface can be detected with a capture efficiency >90%

Detection of Sub-15nm Defects

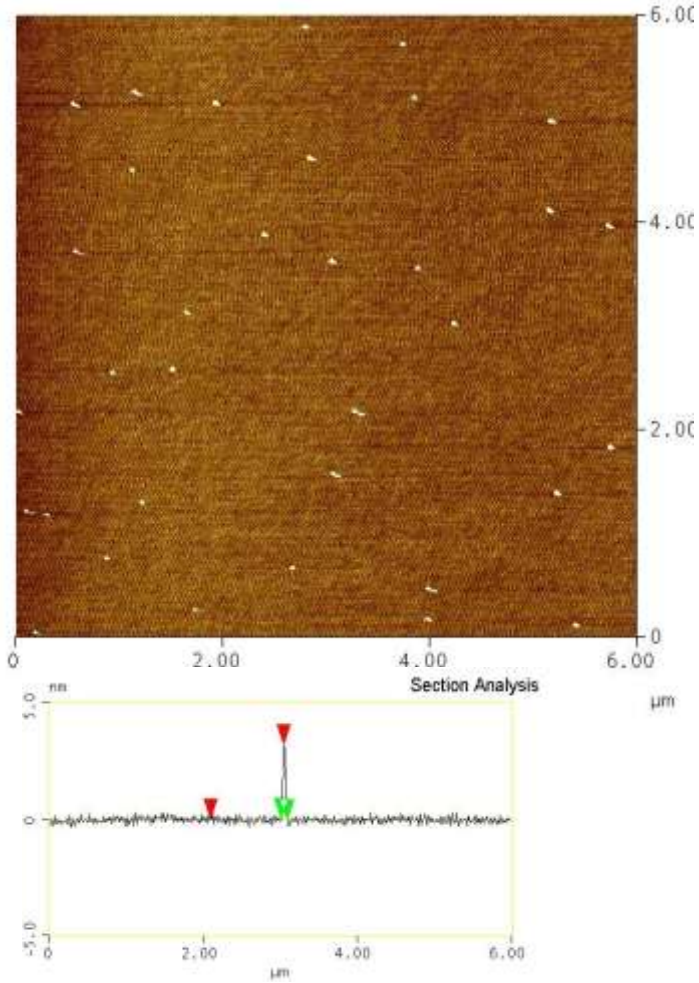


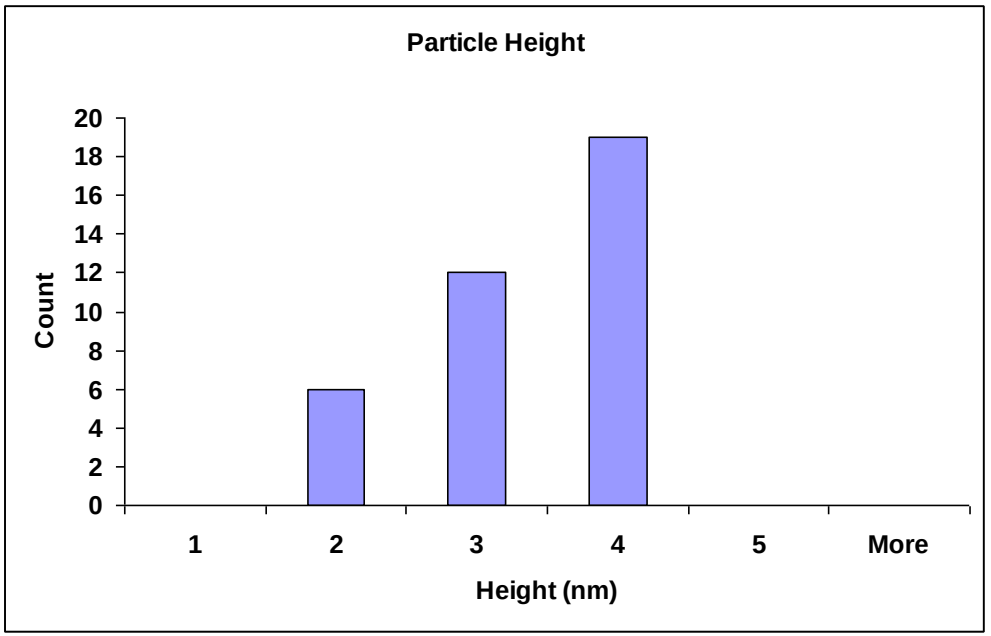


Sub -30 nm particle



Non-Detectable Particles

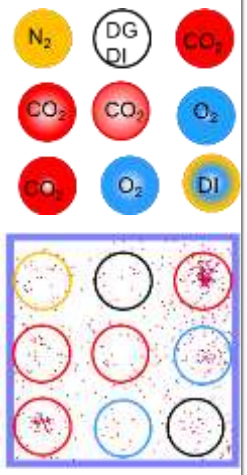


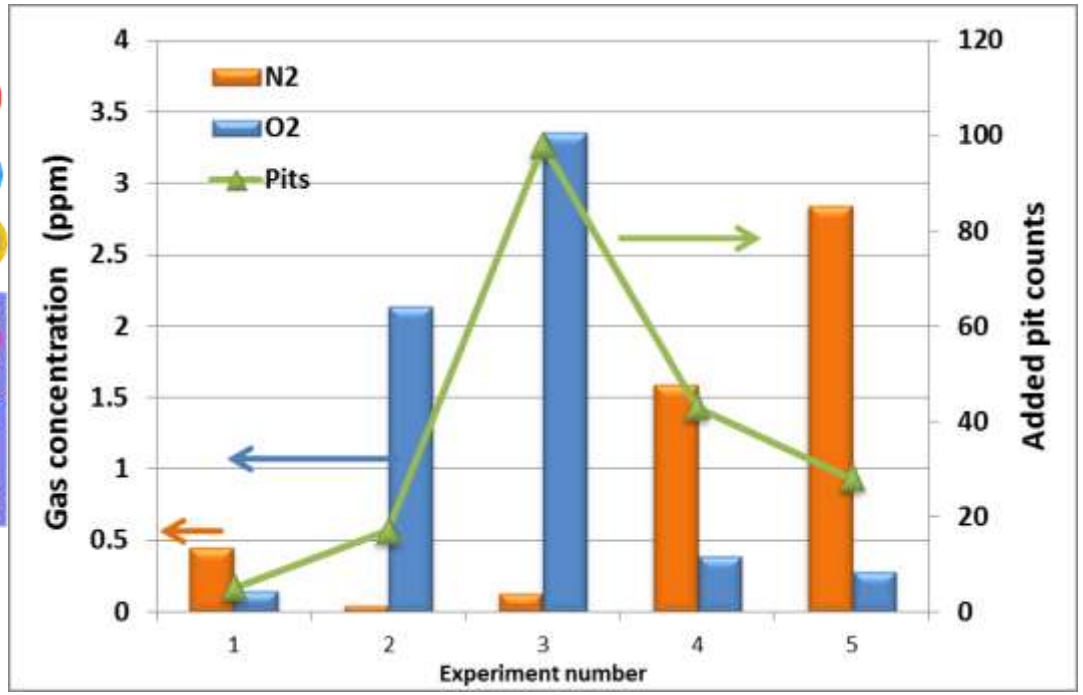


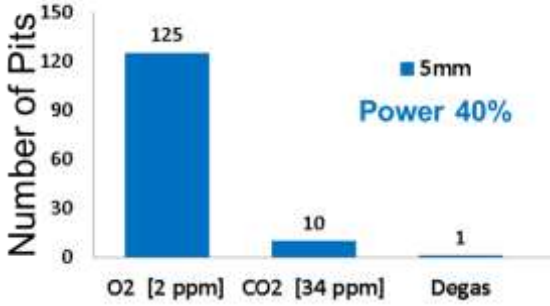
Surface distance	949.54 nm
Horiz distance(L)	949.22 nm
Vert distance	3.212 nm
Angle	0.194 °
Surface distance	82.425 nm
Horiz distance	82.031 nm
Vert distance	0.062 nm
Angle	0.043 °

- **Cleaning processes add very small particles (10 nm to 17 nm) SEVD that CANNOT be detected with existing defect inspection tools**

Ru Cap is Sensitive to Dissolved Oxygen







- Dissolved oxygen in DI will drastically increases the number of pits
- Polytropic index (γ = Cp/Cv) = 1.4 for both N_2 and O_2 resulting in the same level of sonoluminescence → the same level of cavitation
- EUV mask cleaning tools and processes may need to be oxygen free!

Conclusions

- EUV mask cleaning will depend on the choice of EUV projection optics schemes
- EUV mask cleaning remains a key player in EUV mask lifetime and will be affected by exposure and storage conditions
- The Ru cap remains a challenge in terms of contamination and cleaning
- An oxygen-free tool and processes may be required to reduce megasonic damage
- New chemistries are required to replace SPM

Thank You