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The Removal of Micro and Nanoscale Particulate Defects

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Northeastern UNIVERSITY

BOSTON, MA

NEU Enrollments: 22,599 students
Undergraduate enrollment: 18,949
Graduate enrollment: 3,650
Faculty: 1105

The First International Surface Cleaning Workshop

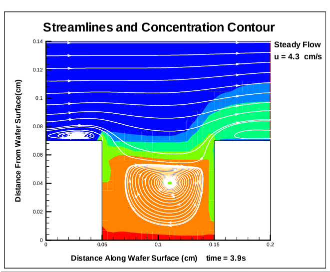
Hosted by the NSF Center for Nano and Microcontamination Control at Northeastern University and the University of Arizona Announces

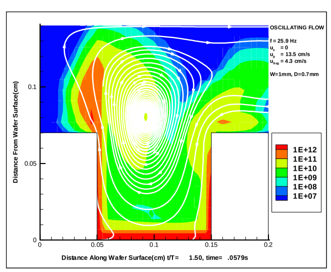
25 Presentations, 2 Panels and 2 Tutorials

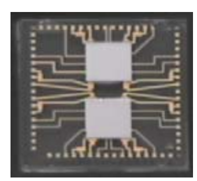
Location: Northeastern University Boston Campus, November 12-13, 2002
Website: http://www.cmc.neu.edu/surfacecleaning.html

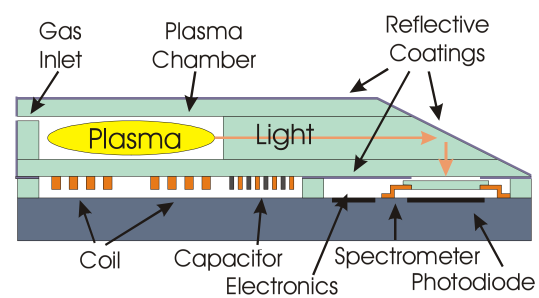
Research Focus at the NSF IUCRC Center for Micro and Nanoscale Contamination Control

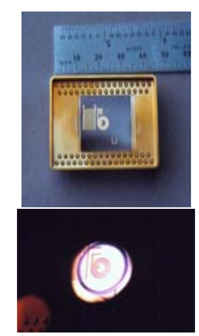
- **Fundamentals of surface cleaning and preparation.**
- **Particle adhesion and removal mechanisms (backside wafer contamination).**
- **Development and fabrication of in situ micro sensors technology (MEMs based micro gas analyzer).**
- **Particle generation, transport, and deposition during wafer processing and handling.**
- **Contamination in thin film deposition processes (LPCVD, Sputtering, ion implant, etc.)**
- **Reduction of chemical use through the use cryogenic aerosols, supercritical fluids, ozone or dilute chemistries.**
- **Reduction of water use through increased cleaning and rinse efficiency.**









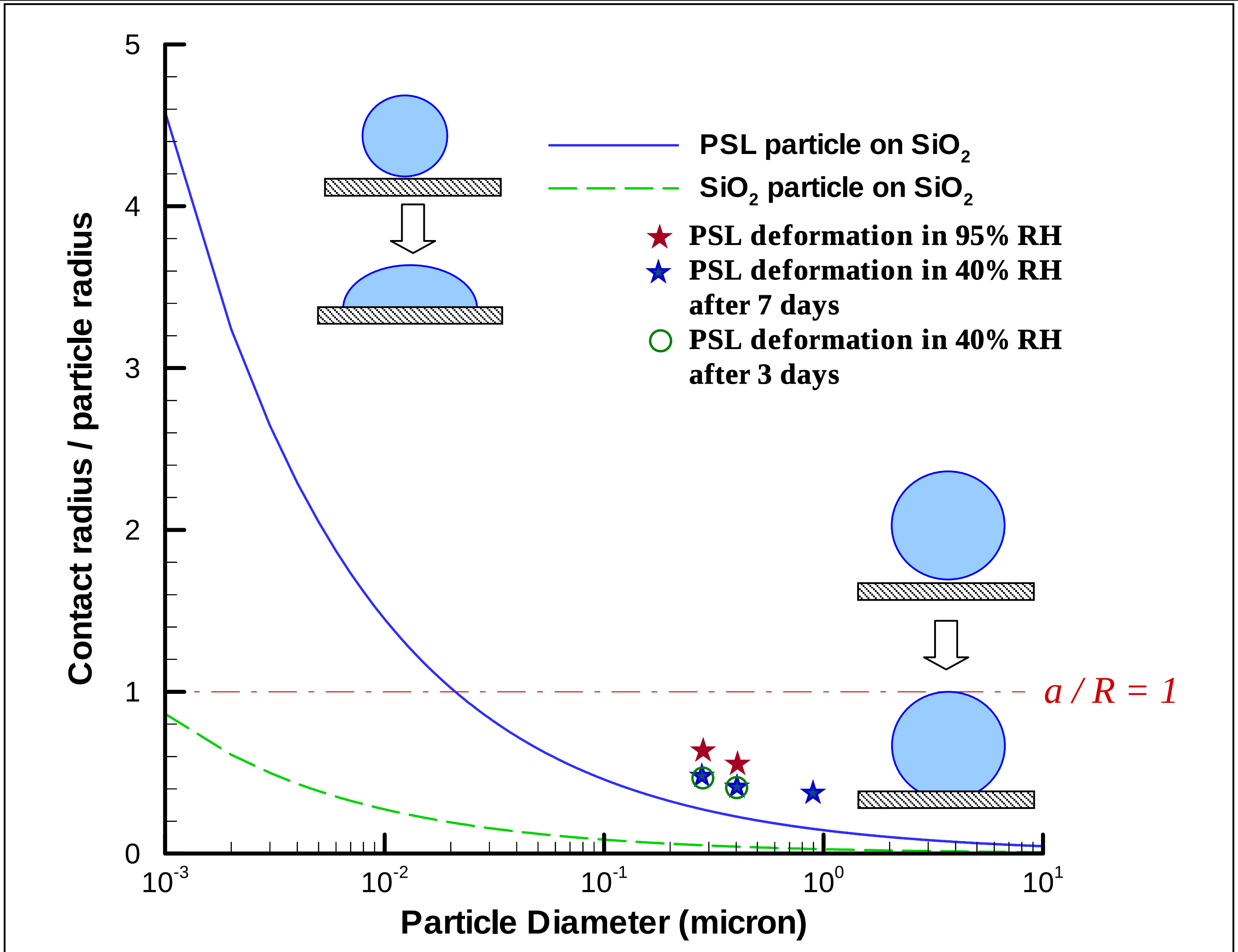


OUTLINE

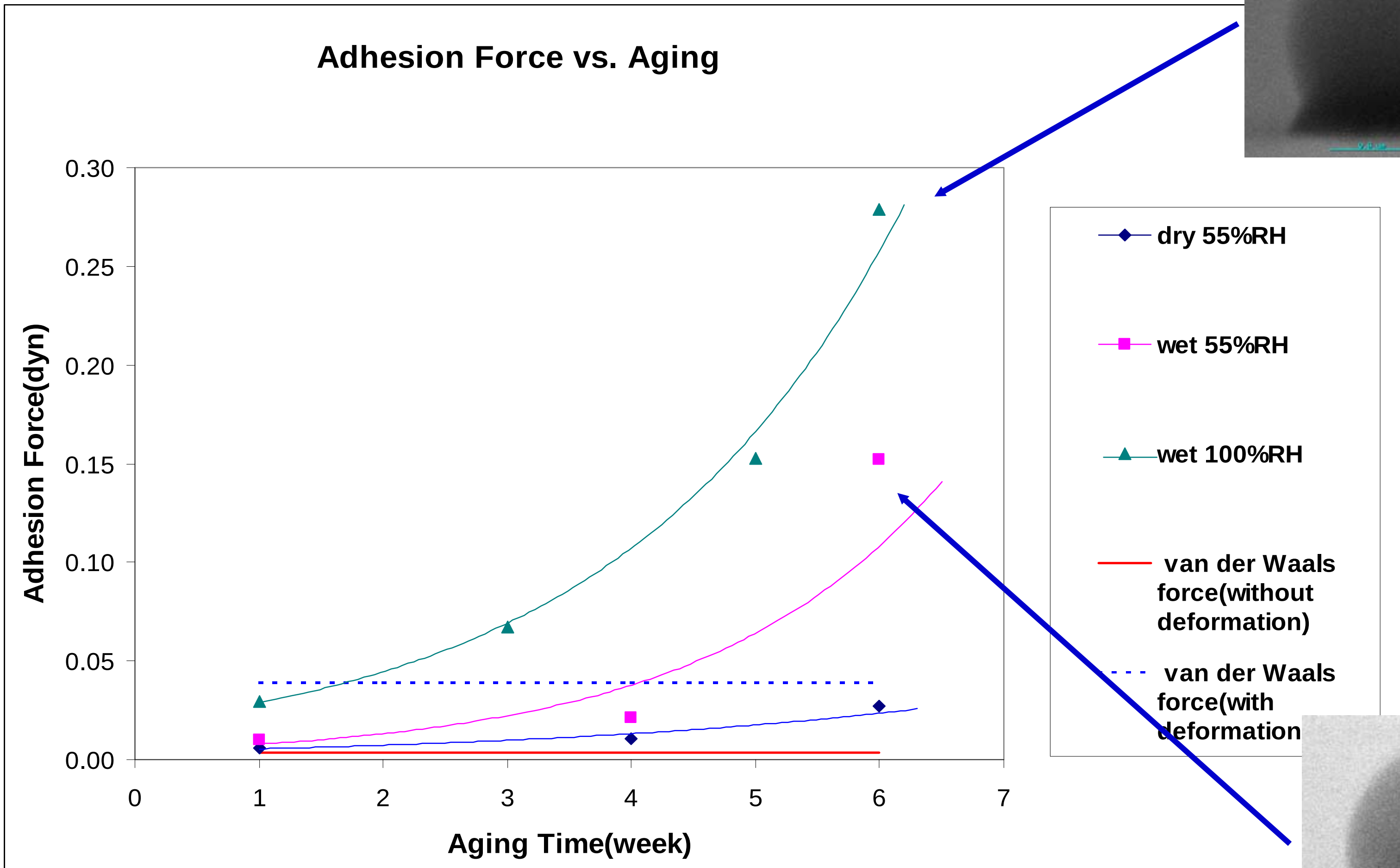
- Particle Adhesion
- Hydrodynamic and Brush Cleaning
- Removal Of Nano and Microscale Particles Using Megasonics

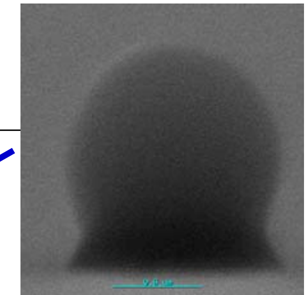
Particle Contact Area

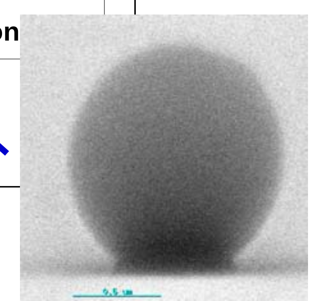
Based on the Maugis-Pollok, plastic deformation model



RESULTS

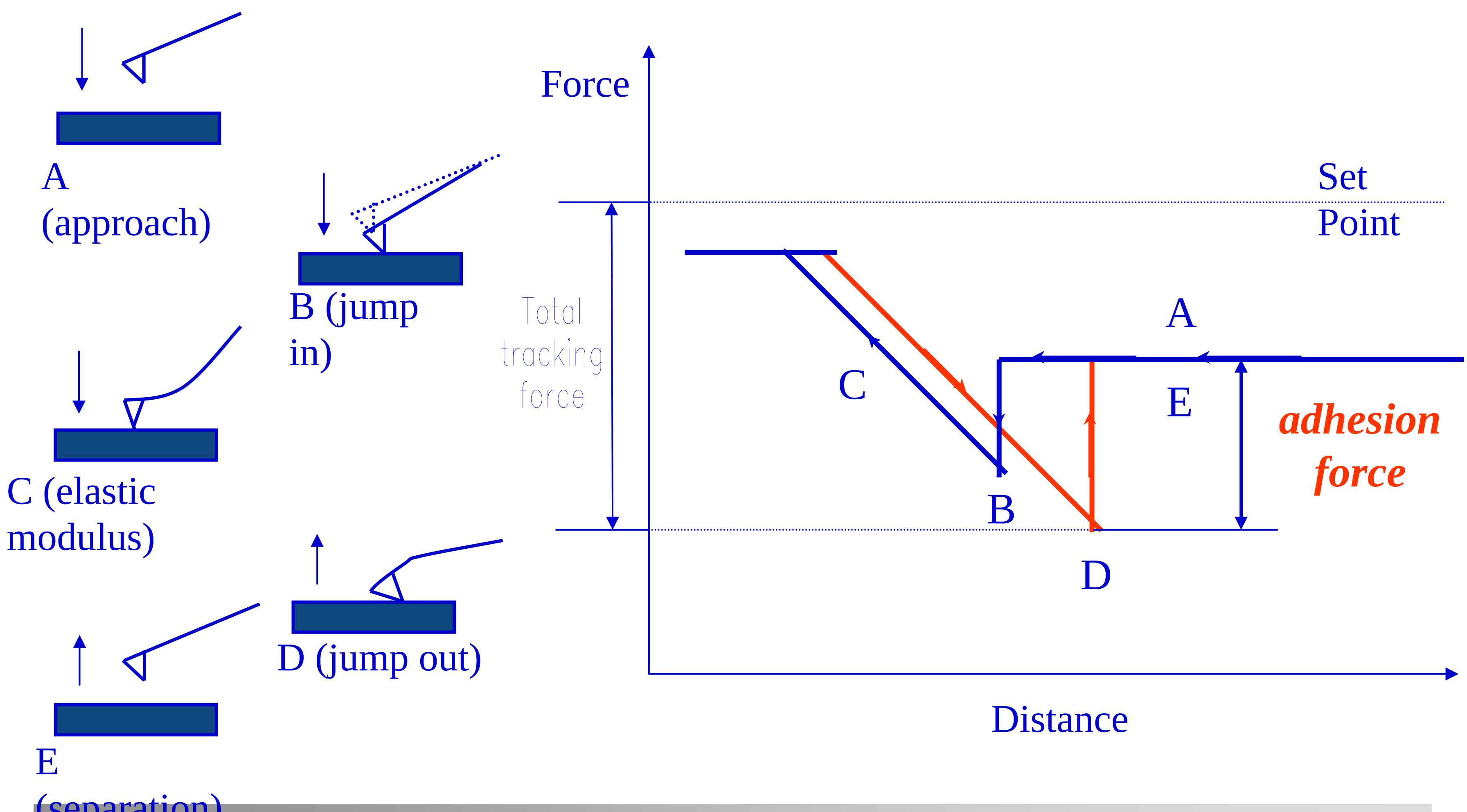




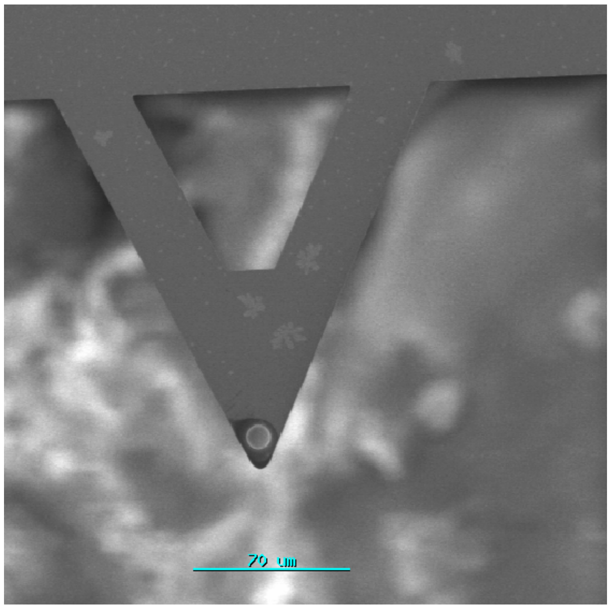


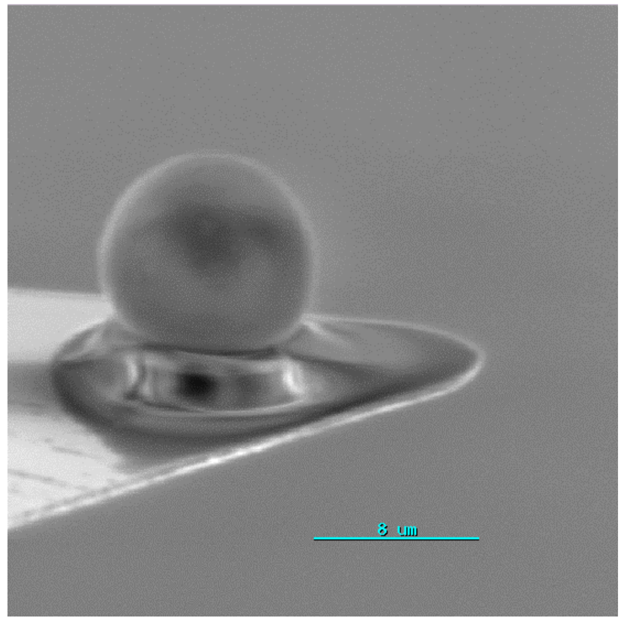
Feng, J.W., and Busnaina, A., *Proceedings*, AVS, 47TH Int'l Symposium: Vacuum, Thin Films, Surfaces/Interfaces, and Processing, Boston, MA, October 2-6, 2000.

Measurements of Adhesion Forces



Silica Particle on AFM Tip



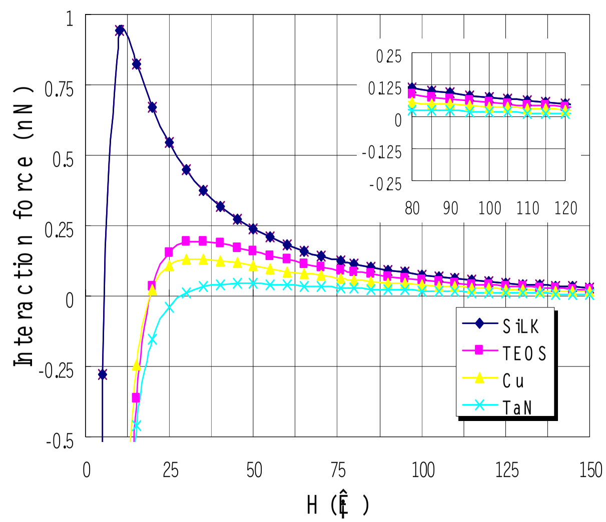


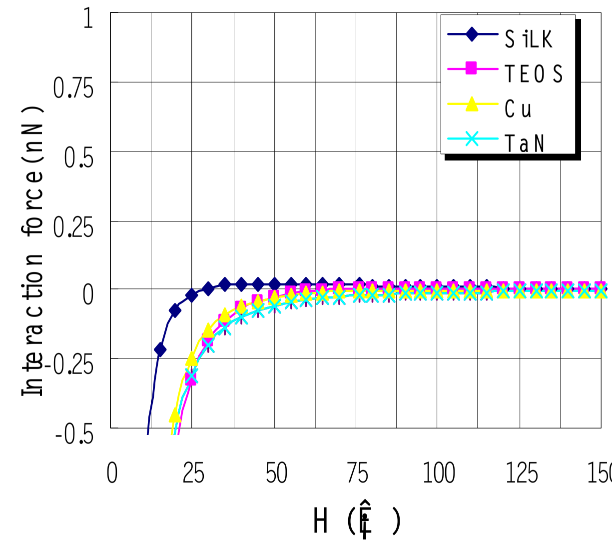
8 micron Silica Particle on an AFM cantilever

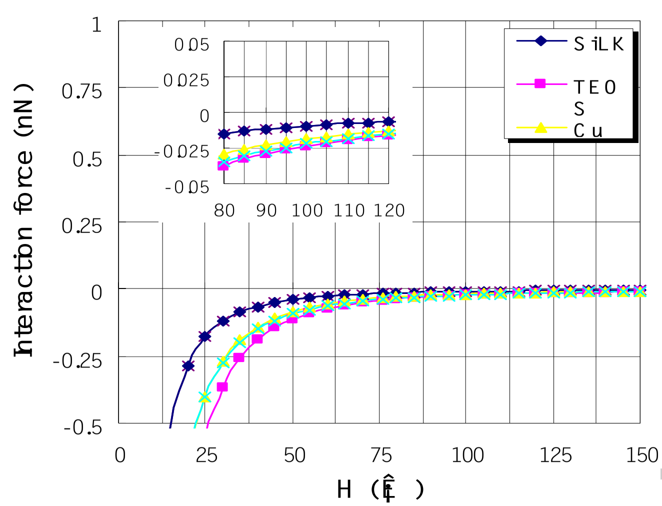
Silica Particle on cantilever (x 500)

Moumen, N., Piboontum, C. and Busnaina, A. A., *Proceedings,* Adhesion Society, 23rd Annual Meeting, Myrtle Beach, SC, February 20-23, 2000.

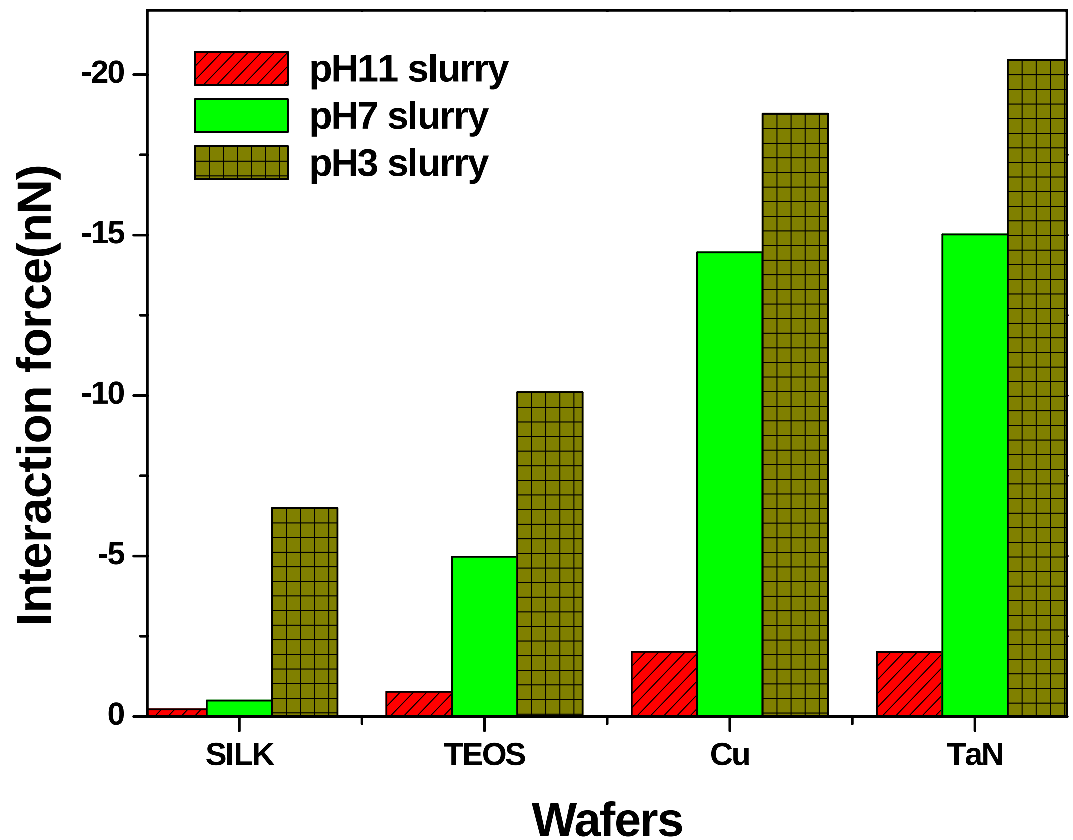
DLVO Interaction Force Between Particle and Various Wafers



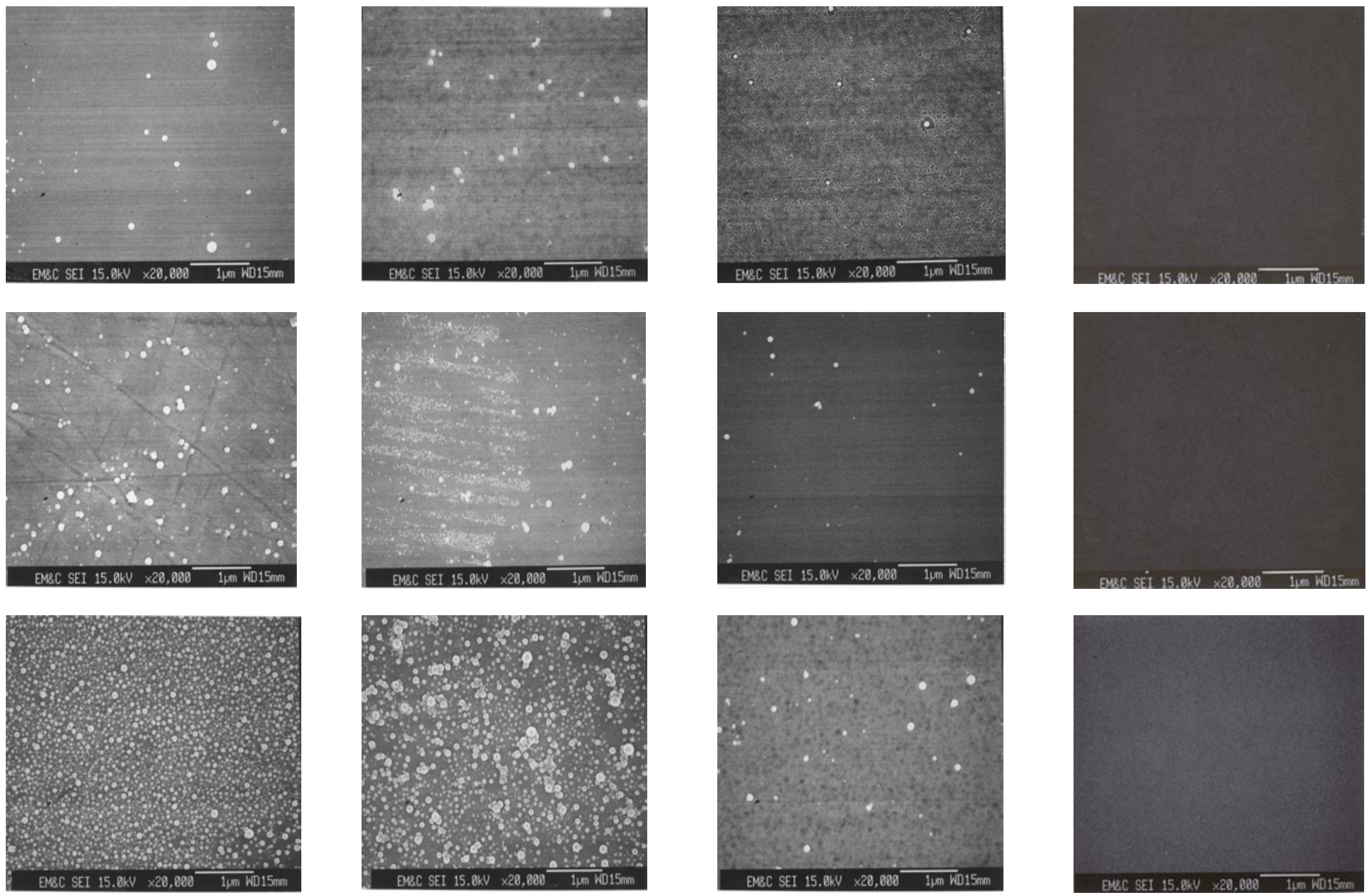




Measured Interaction Force Using AFM Between Particle and Various Wafers



Particle Contamination on Various Wafers After Polishing

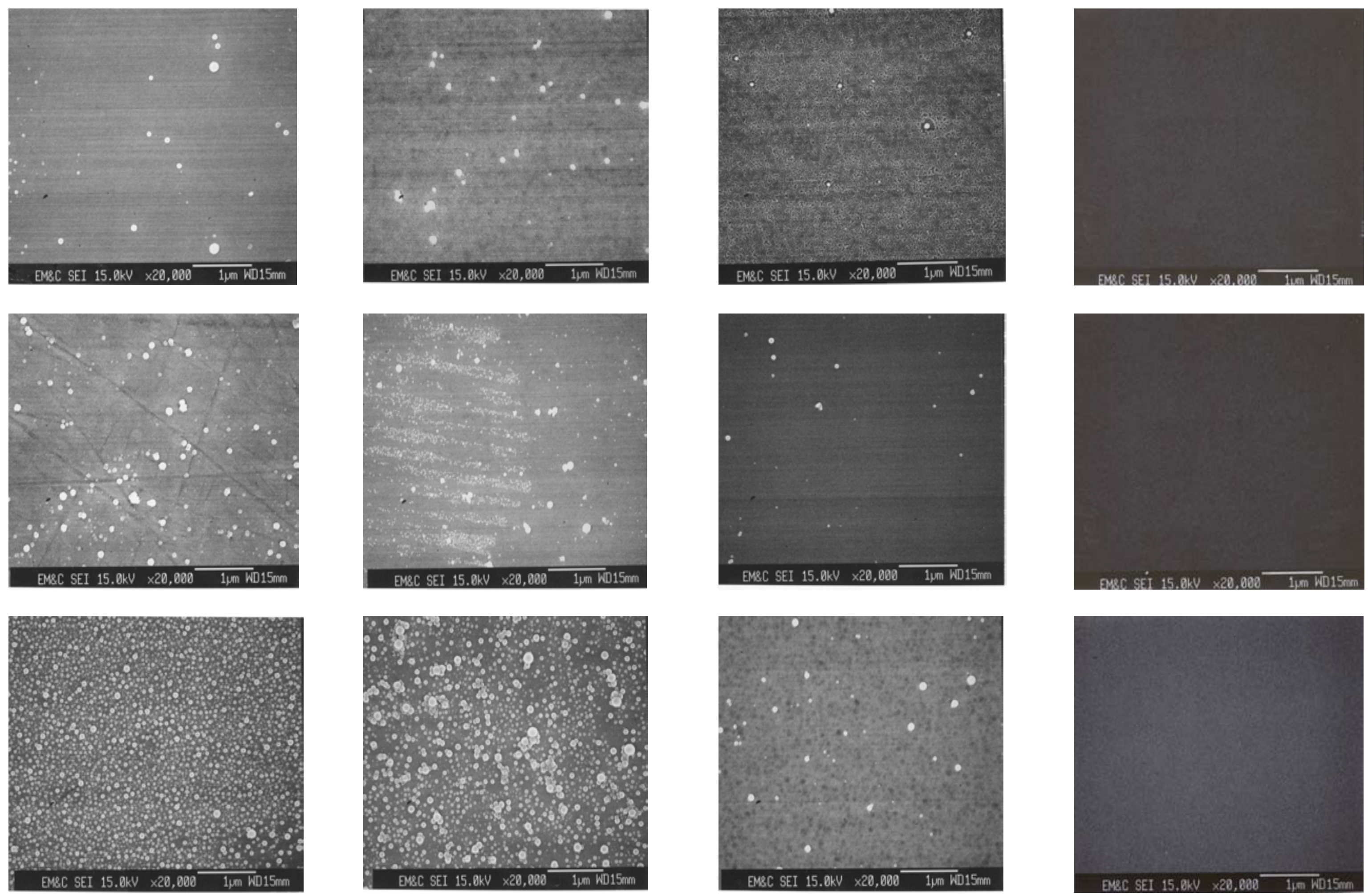


Particle Contamination on Various Wafers After Polishing

pH 11

pH 7

pH 3



Cu TaN TEOS SiLK

Removal/Adhesion Moment Ratio (RM)

Rolling

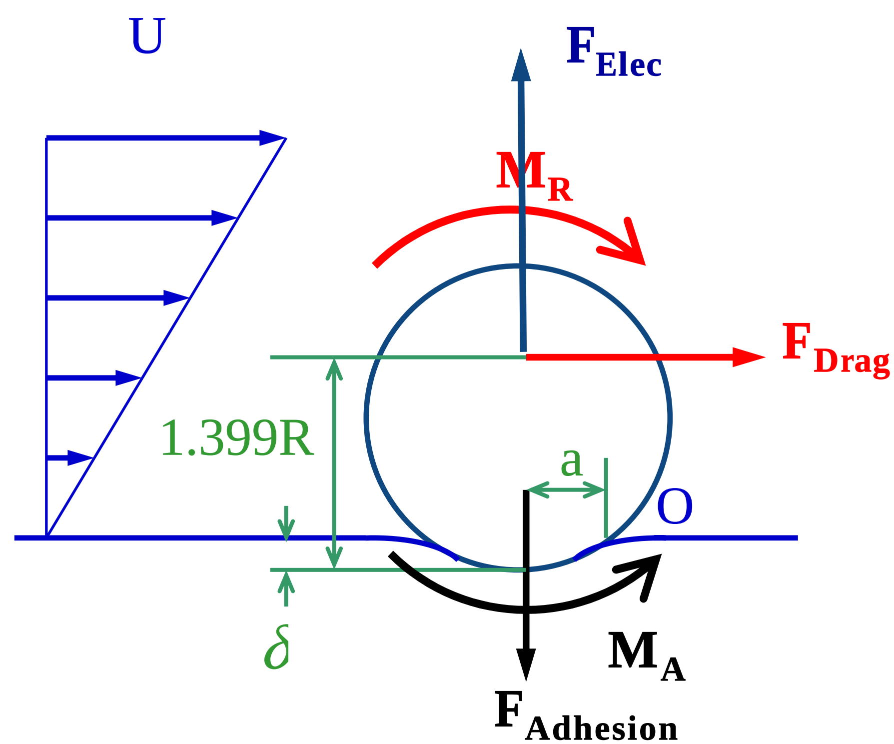
Hubbe evaluated the torque balance on a spherical particle in contact with the surface. When large deformation (a/R>0.1) is considered, the torque balance equation can be described as:

$$(F_{ad}-F_L)\, a = (1.4\, R-\alpha)\, F_D$$

$$RM = \frac{Removal \quad moment}{Adhesion \quad resisting \quad moment}$$

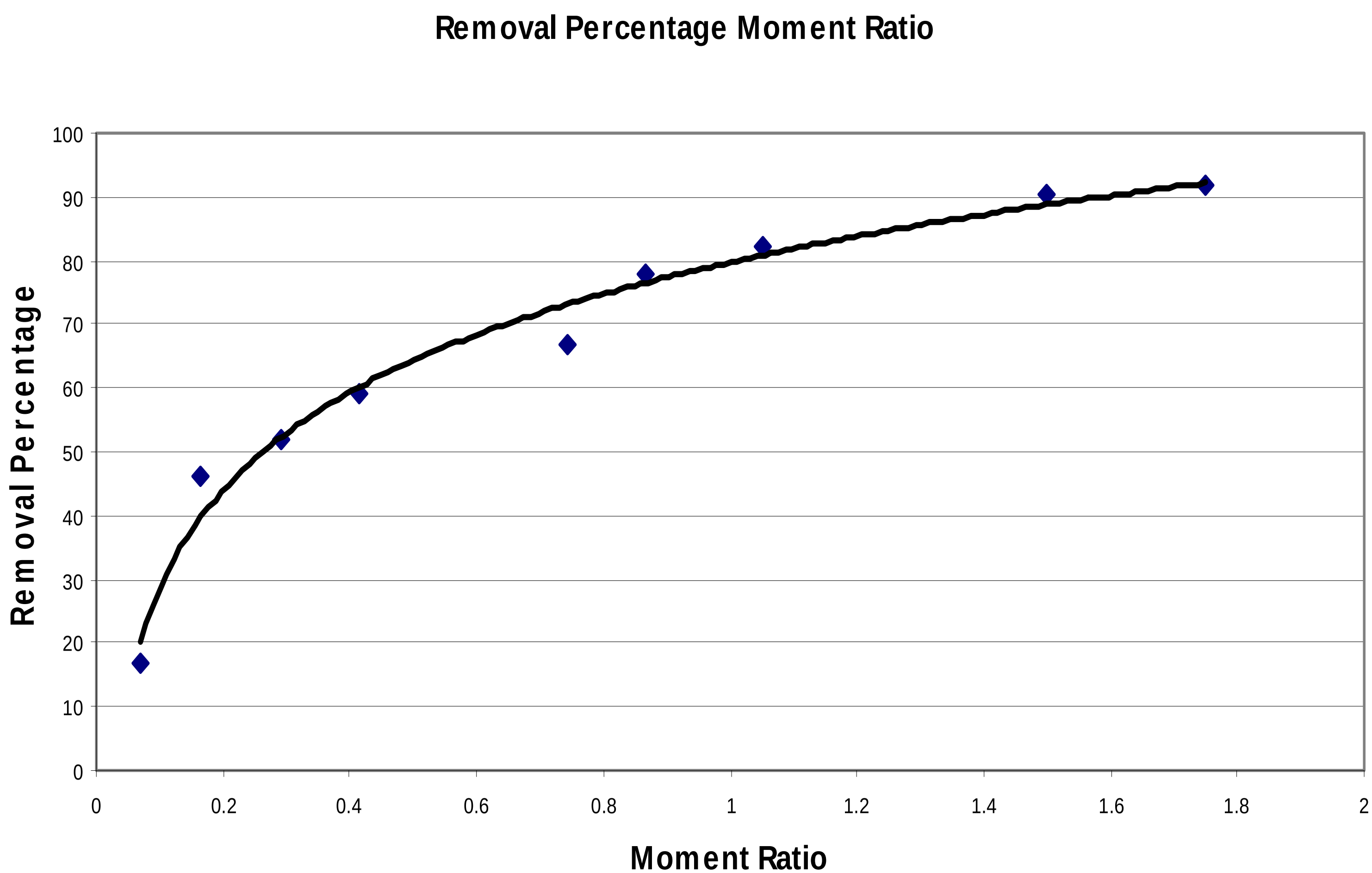
$$RM = \frac{F_D(1.399R-\delta)}{F_a \cdot a}$$

When RM >1, most particles are removed.

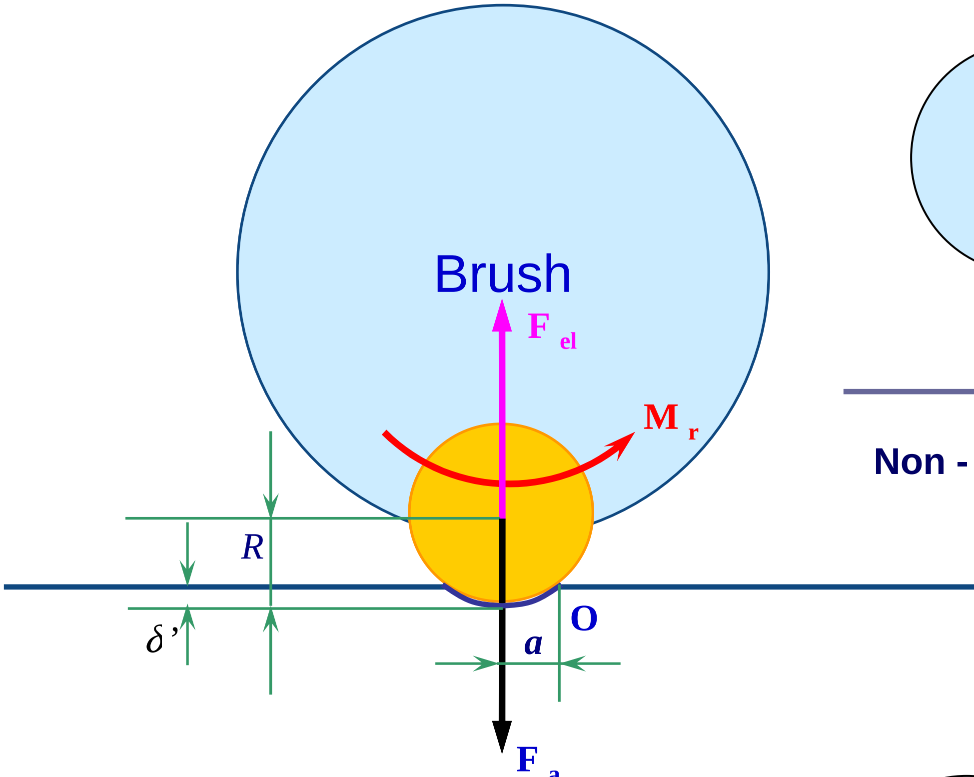


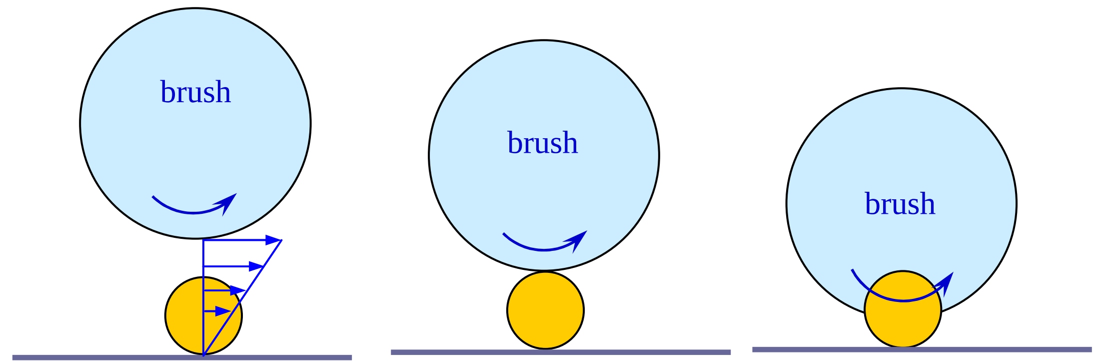
Rolling removal mechanism

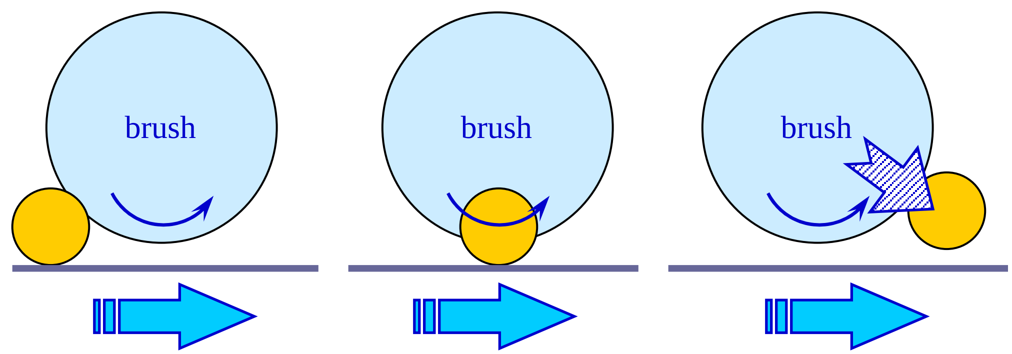
Removal Percentage vs. Moment Ratio
Colloidal Silica (0.3-0.7micron) Removal Experiments



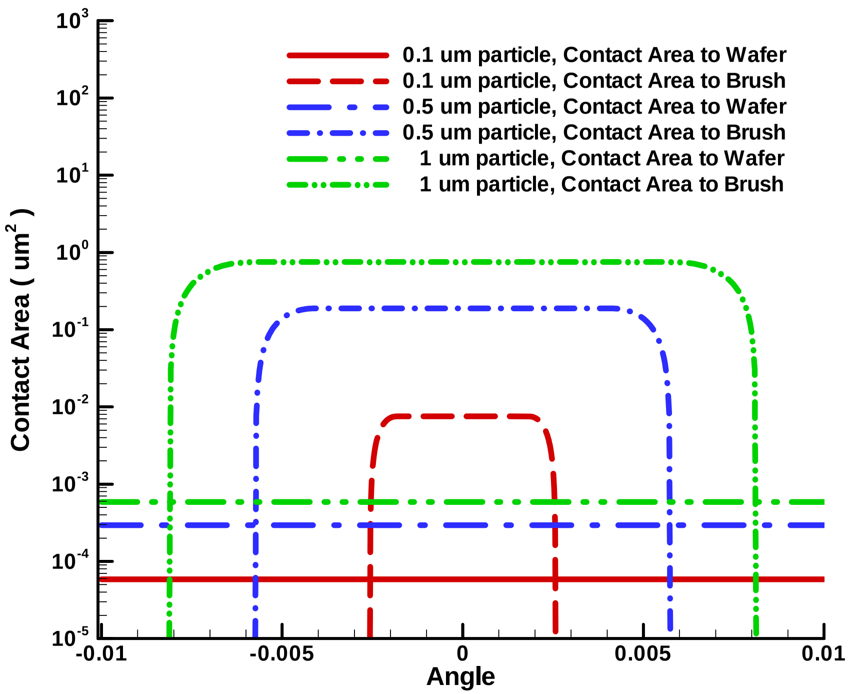
Contact Brush Cleaning Dynamics

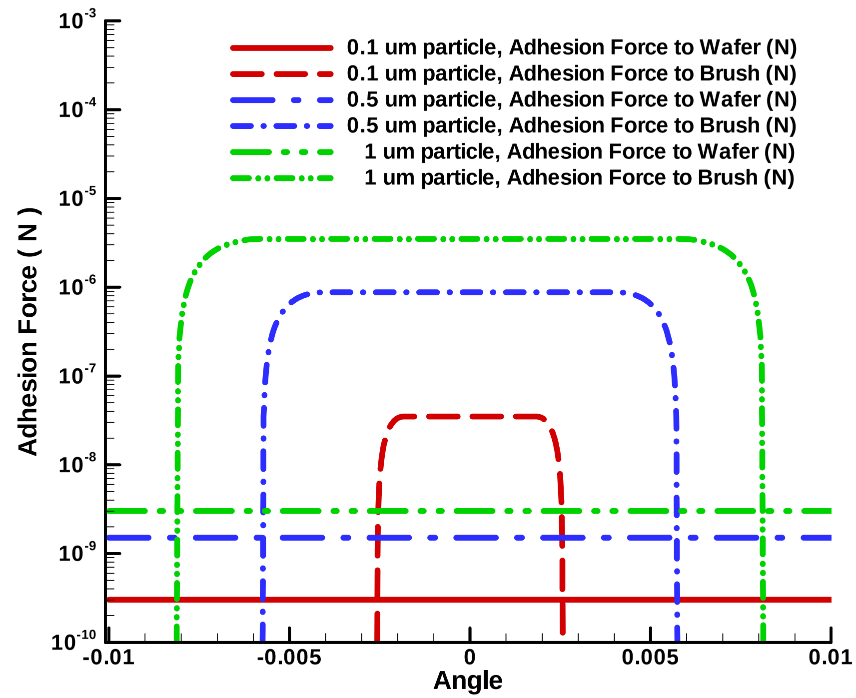






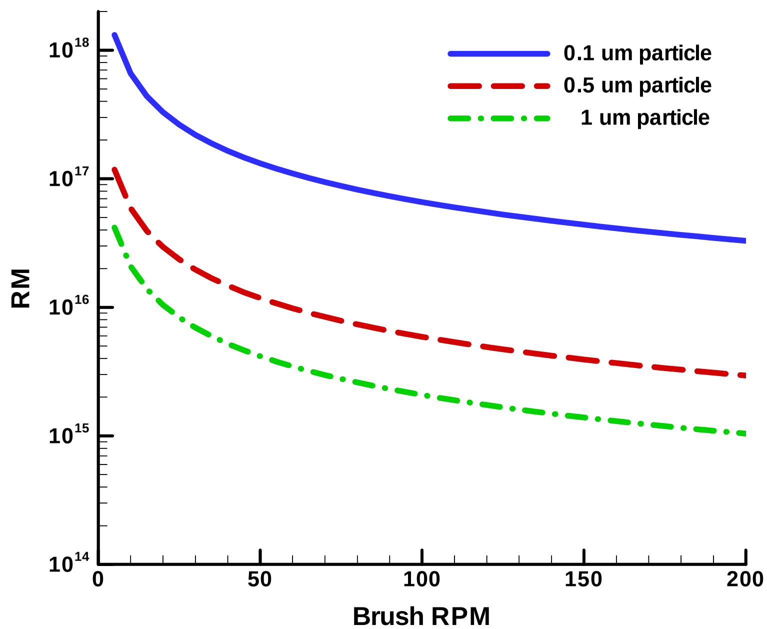
Contact Area and Adhesion Force during the Particle Engulfment



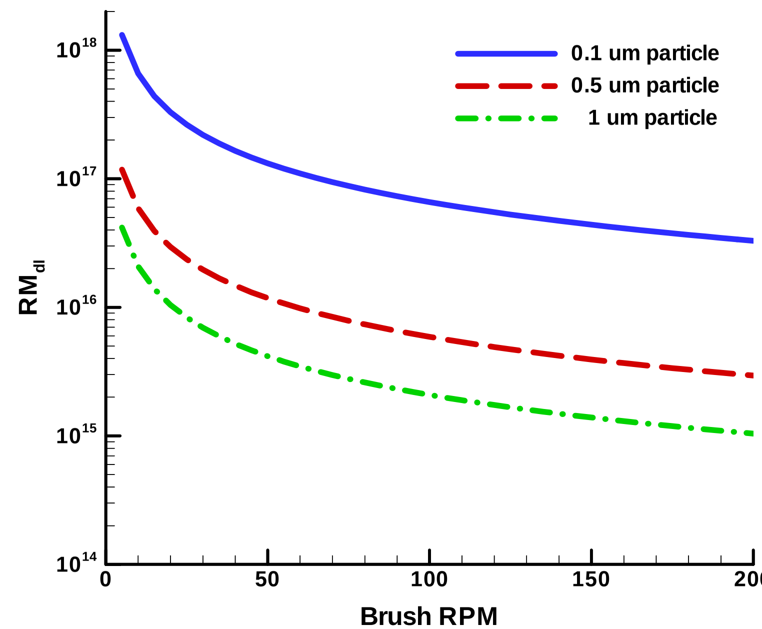


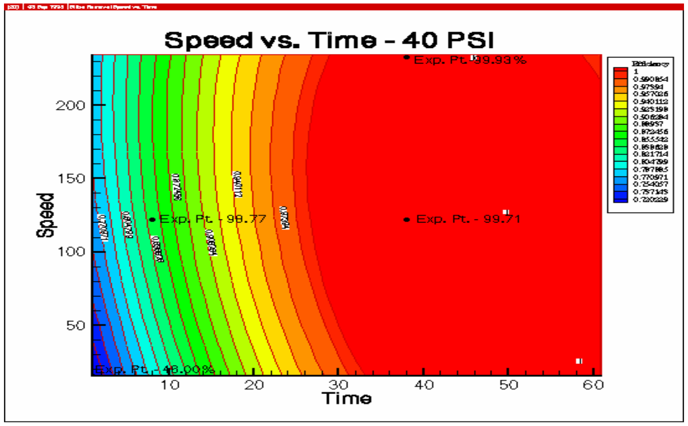
RM in Contact Brush Cleaning

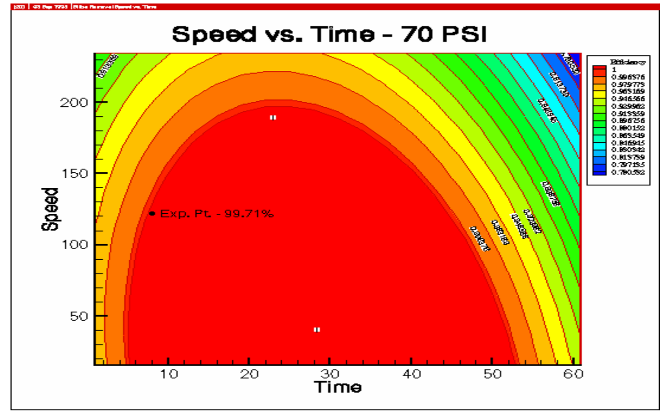
without double layer force

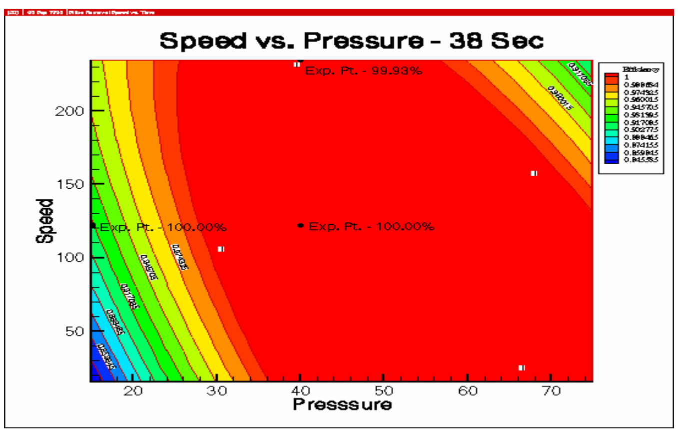


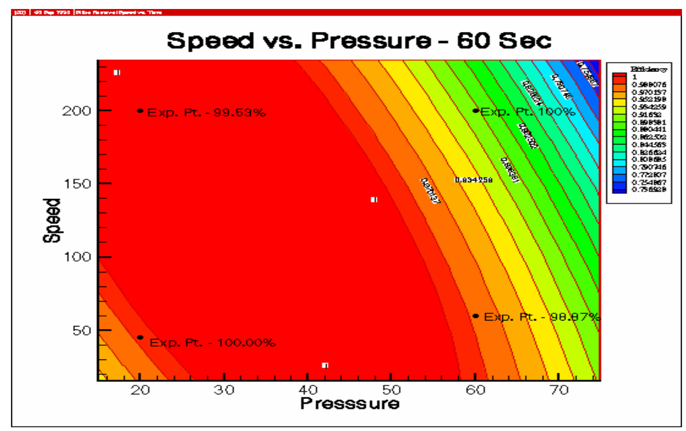
with double layer force











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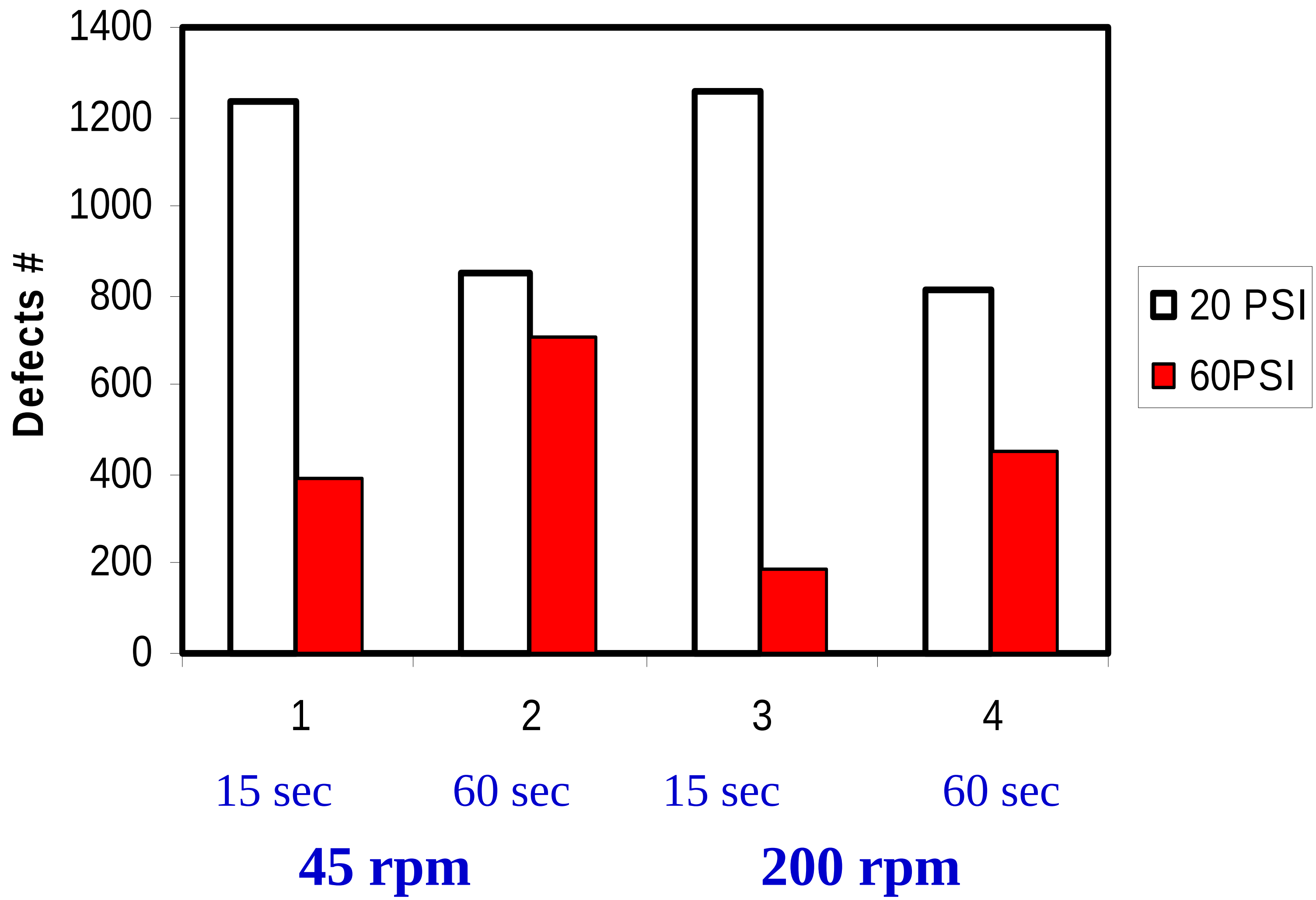
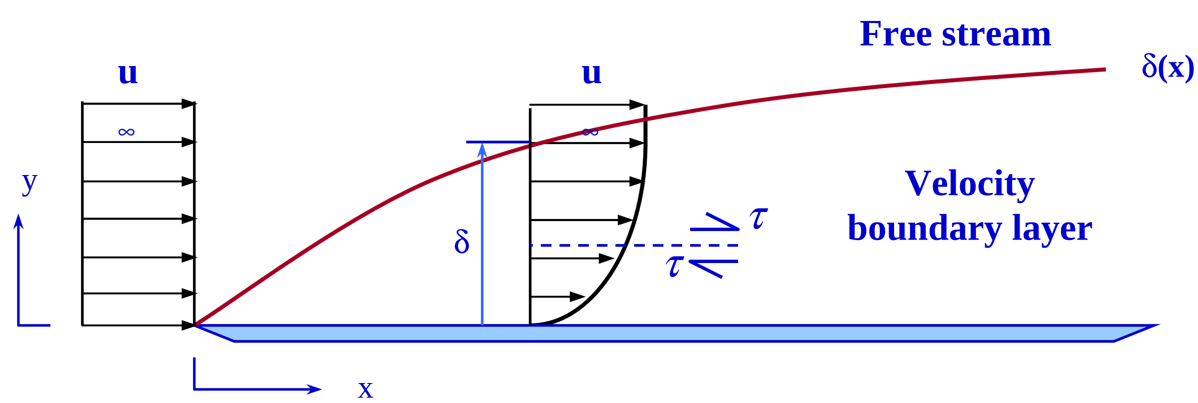
Contact Cleaning of Polished TOX Wafers



Acoustic Boundary Layer Thickness



Velocity boundary layer on a flat plate

- **Acoustic boundary layer thickness**:

$$\delta_{ac} = \left(\frac{2\nu}{\omega}\right)^{\frac{1}{2}}$$

in water, f=850KHz, δ_{ac}=0.61µm
f=760KHz, δ_{ac}=0.65µm
f=360KHz, δ_{ac}=0.94µm

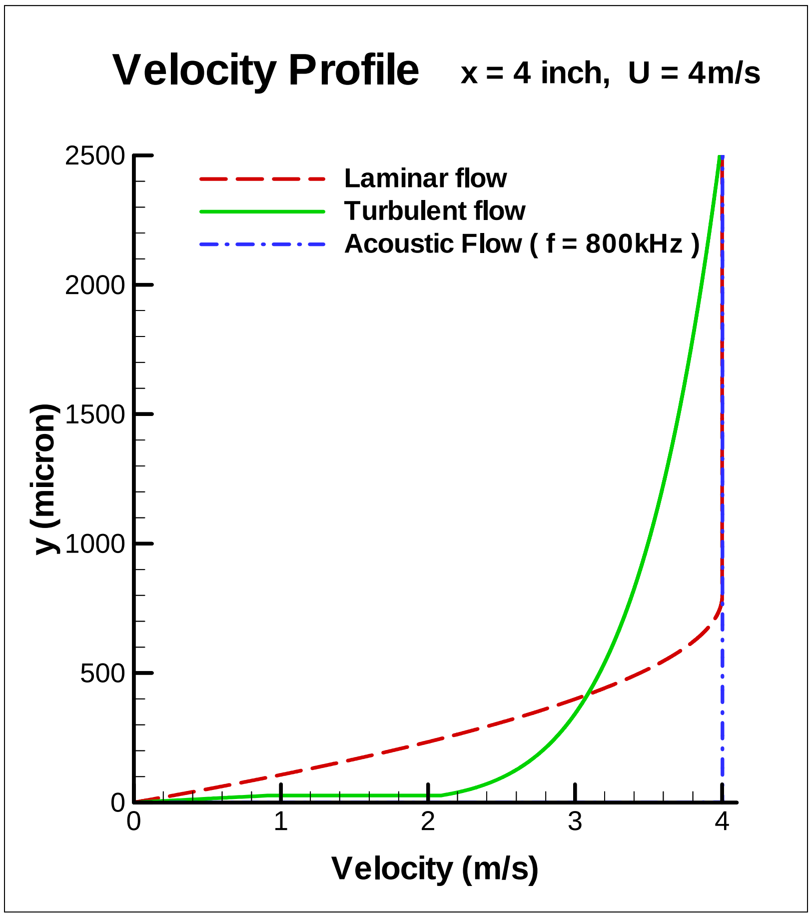
- **The hydrodynamic boundary layer thickness**:

$$\delta_H = 0.16\left(\frac{\nu}{Ux}\right)^{\frac{1}{7}} \cdot x$$

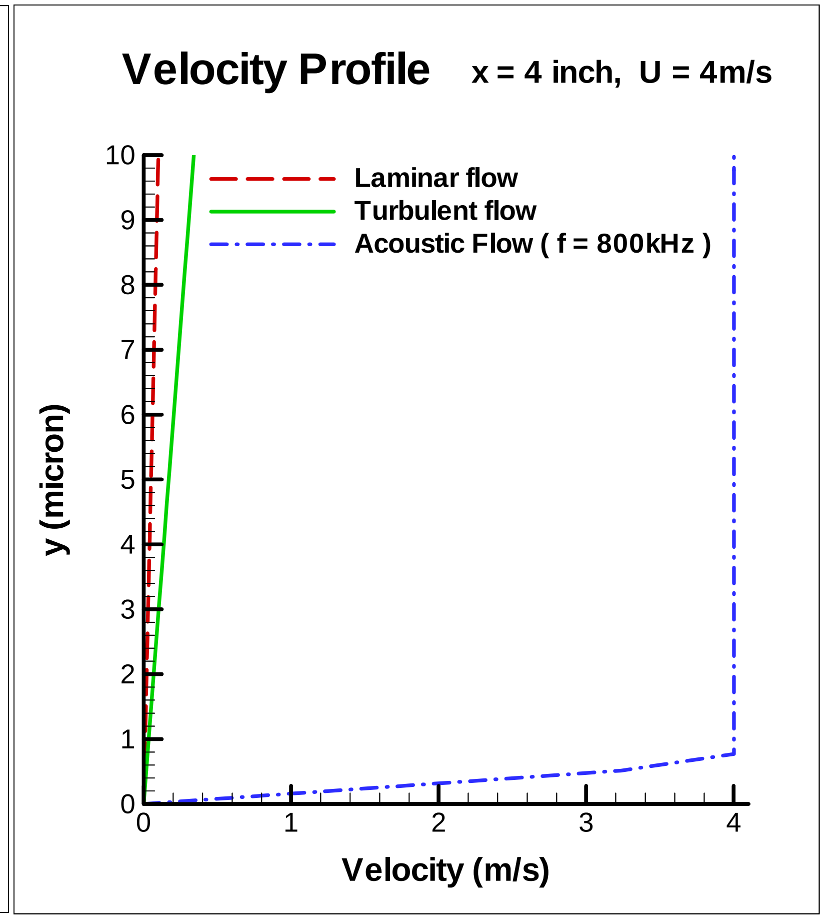
in water, u=4m/s, at center of an 8" wafer, δ_H=2570 µm

Velocity Profile in a Boundary Layer

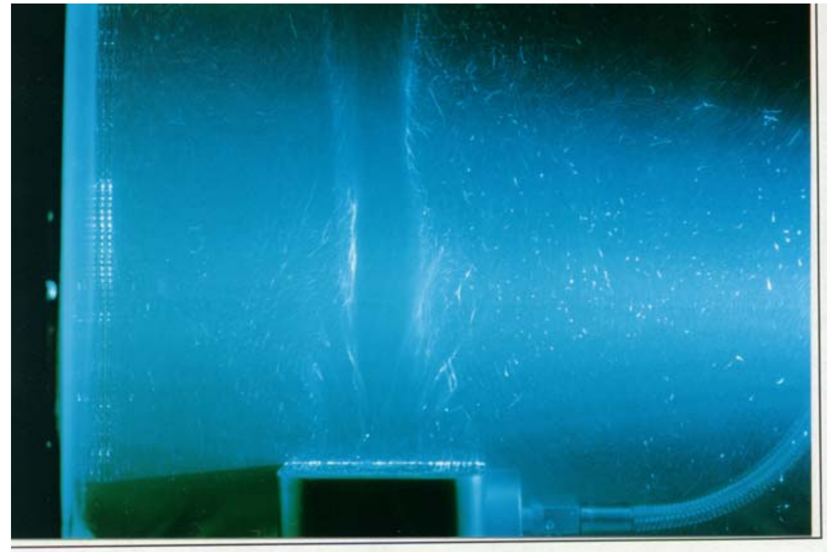
y = 0~2500 micron

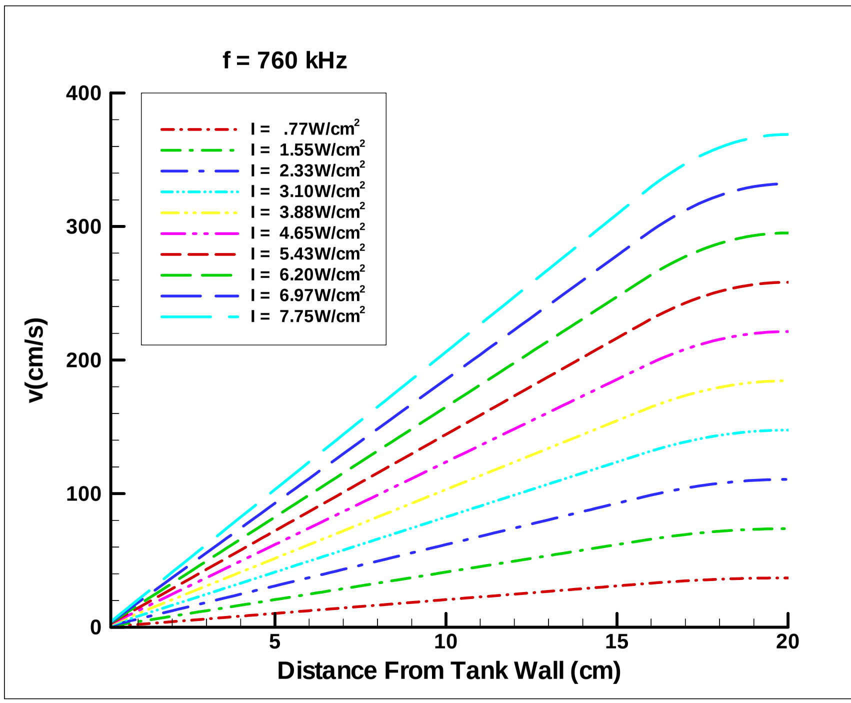


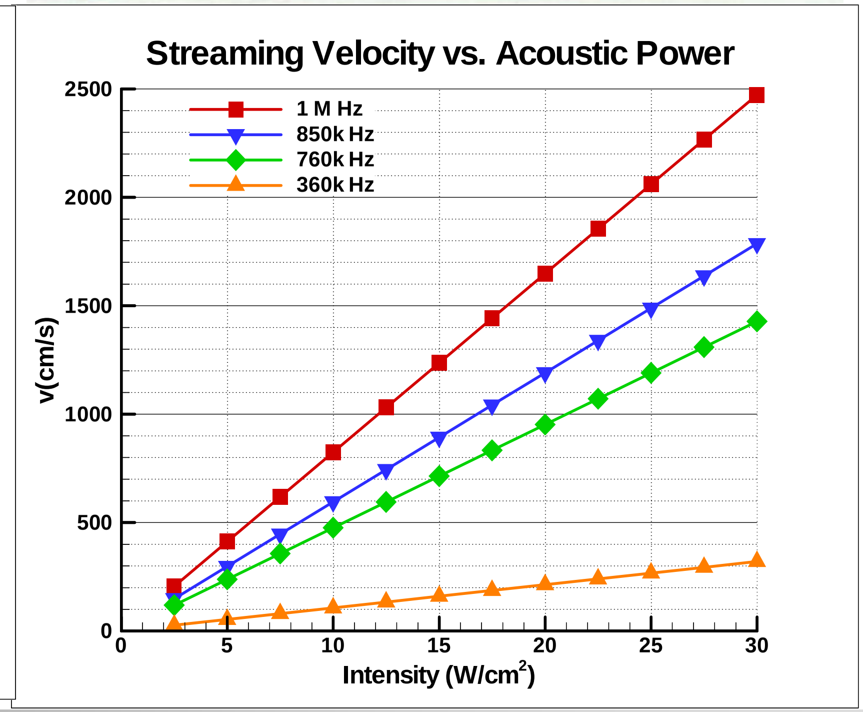
y = 0~10 micron



ACOUSTIC STREAMING







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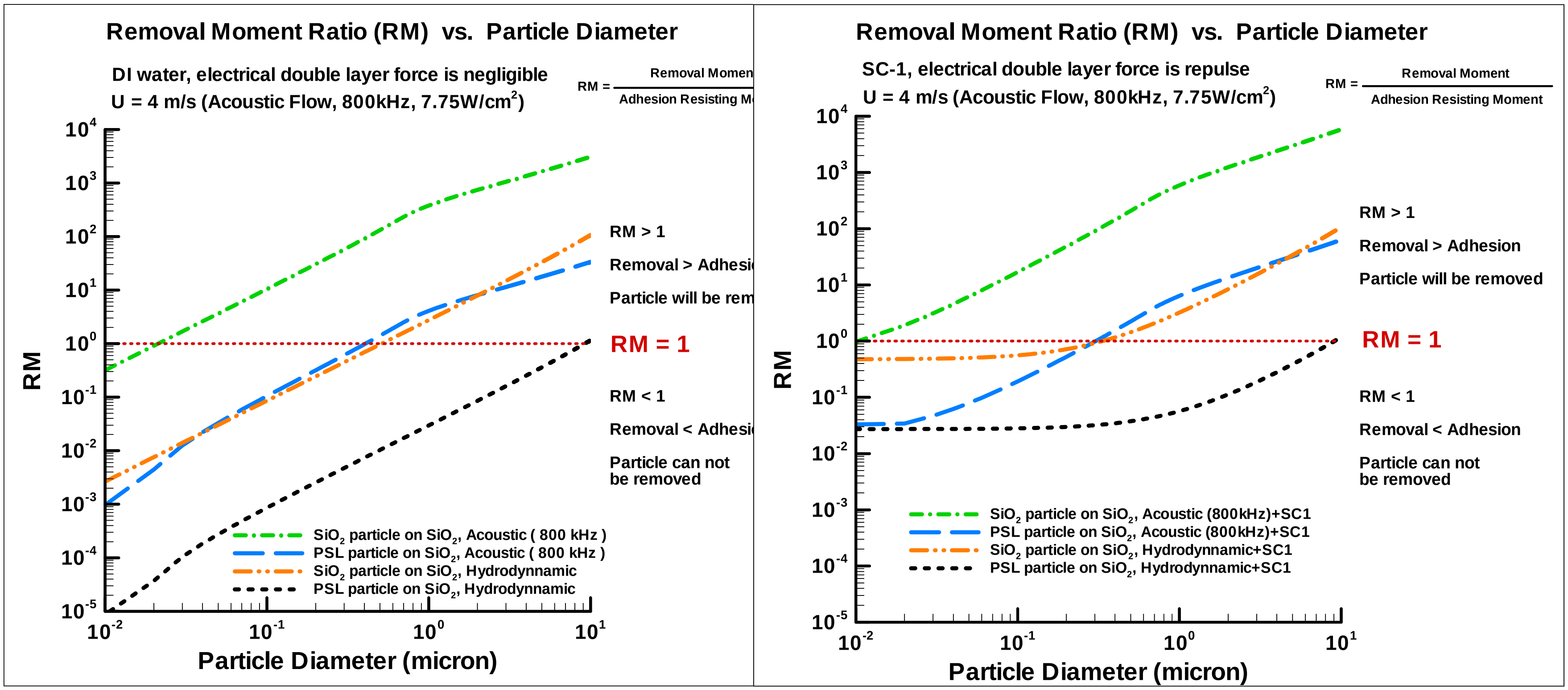
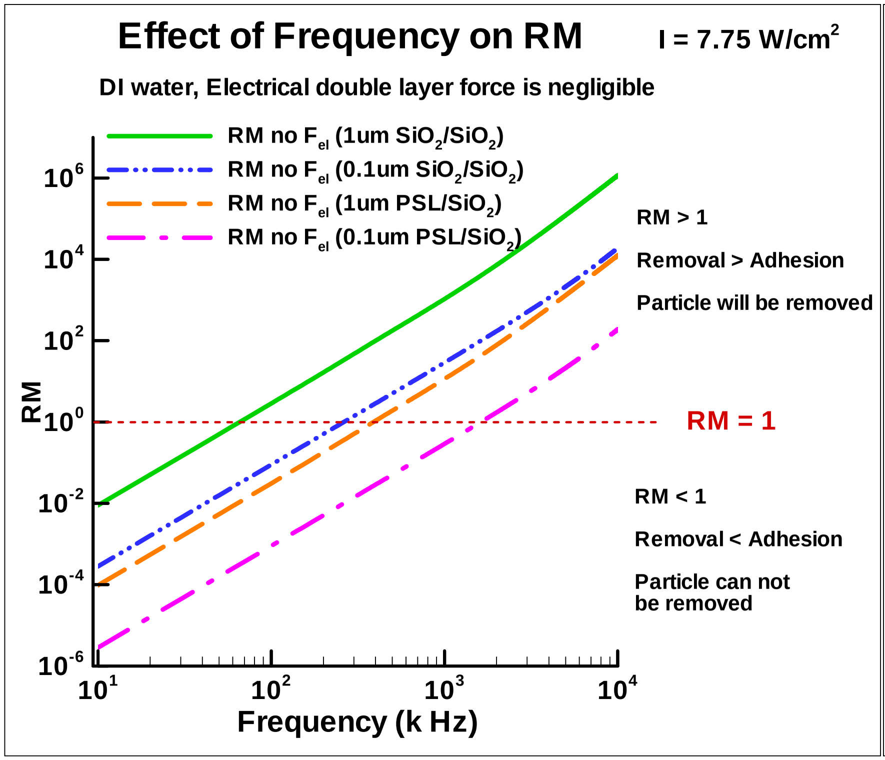
Removal/Adhesion Moment Ratio (RM) vs. D

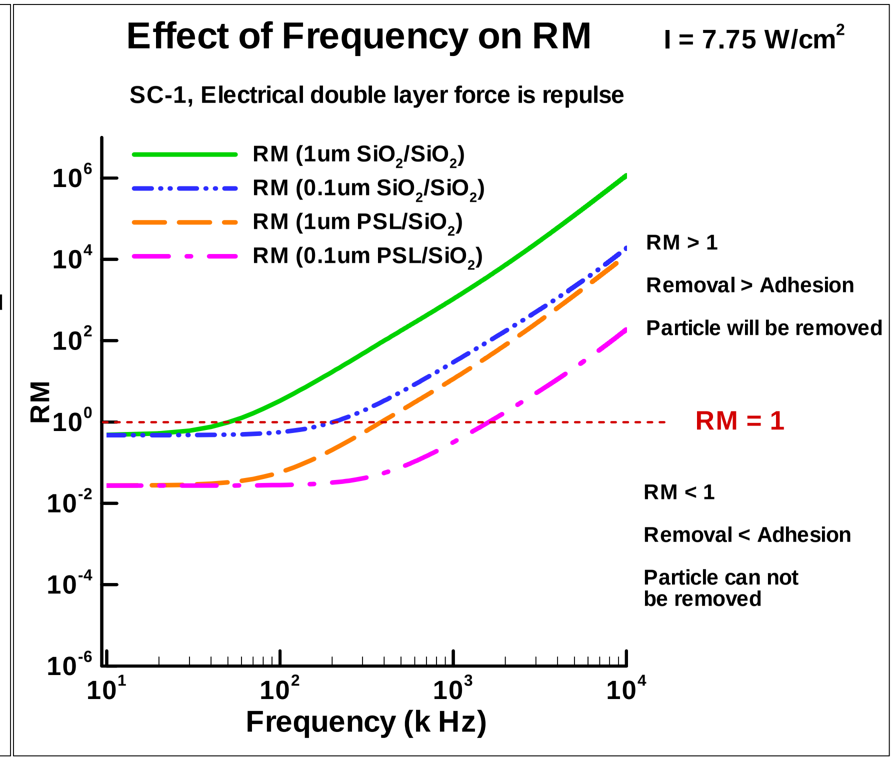


- Hard particles (silica) are easier to remove than soft particles (PSL).
- Particles larger than 20nm can be removed, but when electrical double layer force is considered, removal of 10 nm silica particle is possible.
- Hydrodynamic flow (at 4m/s) did not remove PSL particles smaller than 10 um.

Effects of Frequency on RM

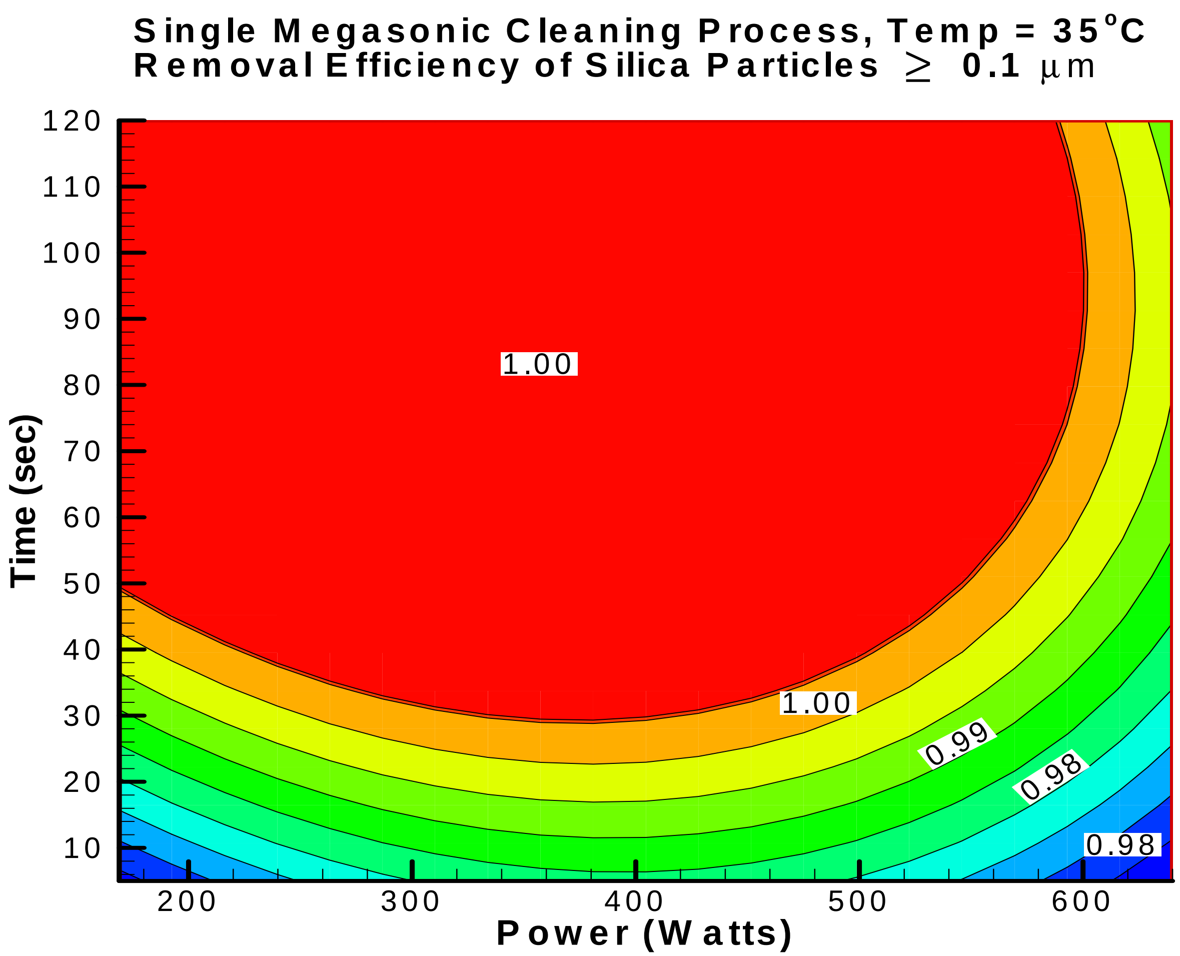
DI water, Electrical double layer force is negligible	SC-1, Electrical double layer force is repulsive force



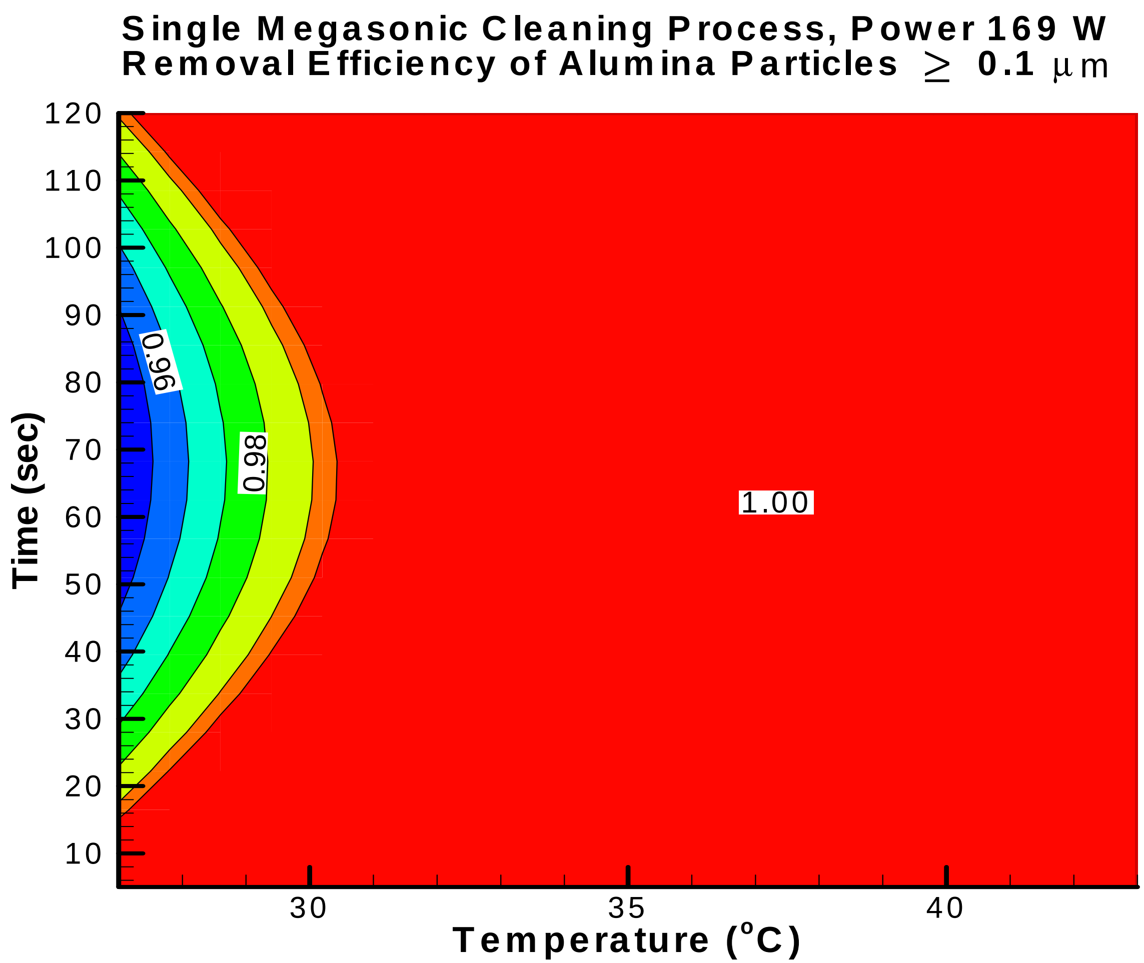


- The smaller the particles, the higher frequency acoustic flow is needed.
- Soft particles (PSL) are more difficult to remove than hard particle (silica), needing almost an order of magnitude higher frequency.

Complete removal of silica particles down to 100nm is achievable by using a single wafer megasonic cleaning with DI water only



Complete removal of alumina particles down to 100nm is achievable by using a single wafer megasonic cleaning with DI water only



Summary

- Adhesion-induced deformation can dramatically increase the total adhesion force.
- The removal efficiency of particles is strongly influenced by particle deformation.
- magnitude of the force of adhesion between a particle and a substrate depends on the contract area.
- Hydrogen bonds and covalent bonds play an important role in adhesion force especially in the presence of moisture.
- In brush cleaning, contact between the particle and the brush is essential to the removal of submicron particles.
- In full contact mode, RM>>1 for a 0.1-micron particle is found for typical brush rotating speeds investigated.
- 100% removal using The brush Scrubber with DI water is achieved using wafer dipped in silica slurry.
- Intermediate brush pressure, speed and time gave the best overall particle removal efficiency.

Summary

- **Because of the thin acoustic boundary layer, high frequency acoustic streaming is essential to the removal of submicron and nano-size particles.**
- **The acoustic boundary layer thickness decreases and the streaming velocity increases with increasing frequency thereby increasing the removal (drag) force.**
- **The removal of nano-size particles (10-100 nm) can be accomplished using acoustic streaming at frequencies larger than 1.3 MHz.**
- **If a repulsive electrical double layer force is utilized, removal of 10nm silica particles can be accomplished using frequencies above 800 kHz.**
- **Removal forces (for the range of frequencies used),**
  - d>100nm, the acoustic flow drag force is dominant;
  - 30nm<d<100nm, drag force and electrical double layer force are equivalent;
  - d<30nm, electrical double layer force is dominant;
- **Soft particles (such as Polystyrene Latex PSL) are more difficult to remove than hard particle (silica), because of adhesion-induced deformation, needing almost an order of magnitude higher frequency.**