Nanoscale Surface Cleaning of EUV Reticles

Category: Mask Poster # 40

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Introduction

The Objective of the work is:

- Evaluated several cleaning techniques for their potential as cleaning process candidate for the EUV reticle cleaning.
- Identify possible effective cleaning techniques for nano size particles and contamination without causing substrate damage especially on patterned films.
- The following cleaning techniques are currently the most promising candidates for cleaning sub-100nm particle removal and will be evaluated:
  - supercritical CO2 cleaning,
  - megasonic cleaning,
  - brush cleaning
  - laser shock cleaning.
- Each cleaning technique will be assessed for both the ability to remove nanoscale particles.

The Effect of Surfactants on Particle Removal

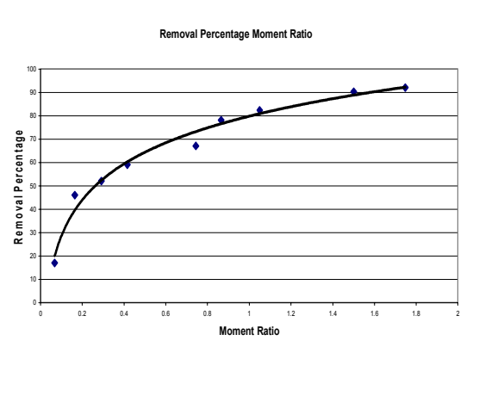
➢Surfactants, in addition to lowering the surface tension of liquids, are used to assist in particle removal by modifying the surface charge/zeta potential of particle and/or substrate surfaces.

➢There are several compilations on the solubility of commercial surfactants in liquid and supercritical CO2. These compilations show that there are anionic, cationic and nonionic surfactants which have significant solubilities.

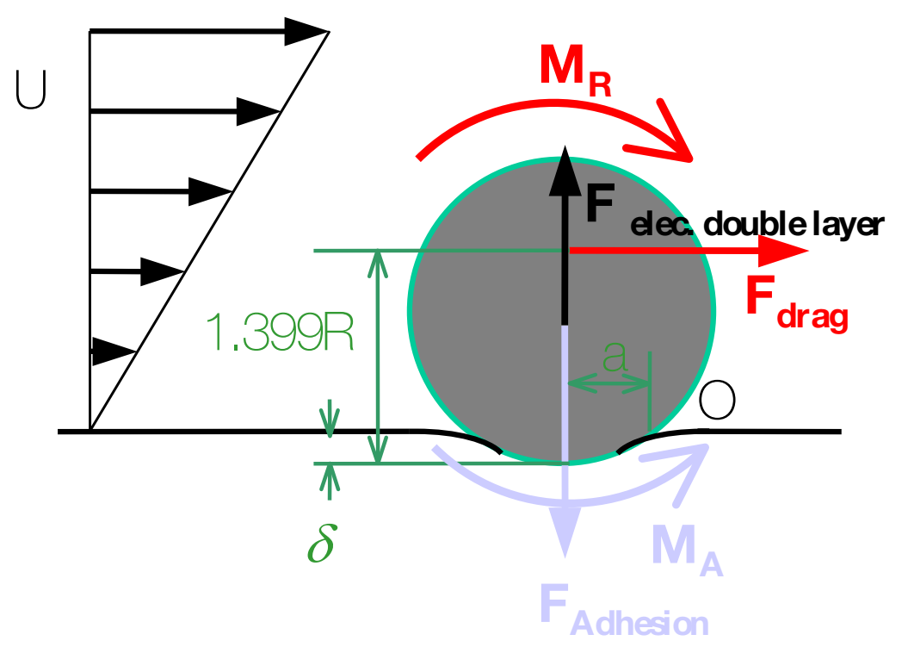
➢Advantages:

***Increase of wettability improves the cleaning of hydrophobic surfaces, trenches and vias.**
***Possible surface zeta potential modification by applying anionic, cationic and nonionic surfactant- make particle removal easier.**
***Etch rate reduction and control by passivation of surfaces.**

Particle Removal Mechanism



Removal Percentage vs. Moment Ratio (Silica Removal Experiment)
The figure shows when RM >1, 80 % of particles are removed.

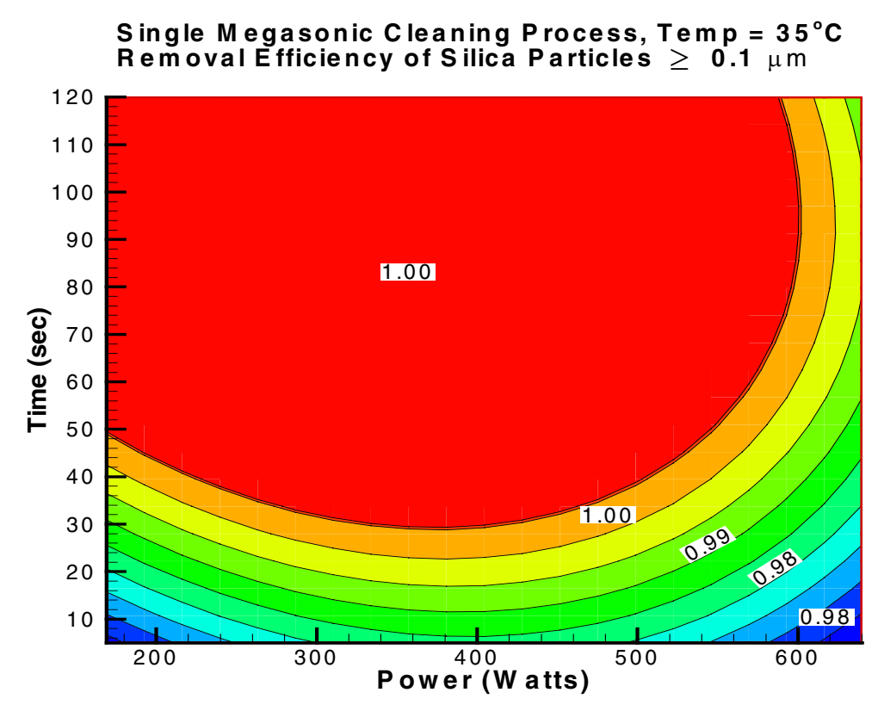


Rolling removal mechanism

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

$$RM = \frac{F_d(1.399R-\delta)+F_{dl}\cdot a}{F_a\cdot a}$$

Complete removal of silica or alumina particles down to 100nm is achievable by using a single wafer megasonic <u>cleaning with DI water only.</u>



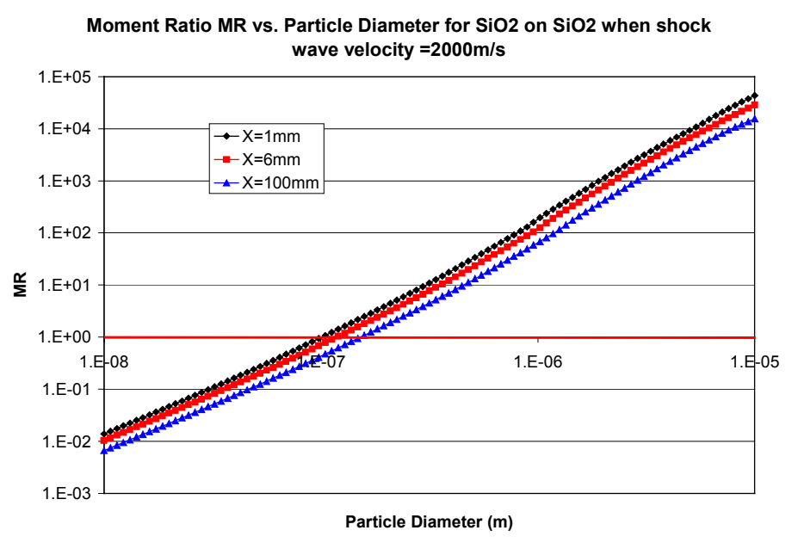
Brush Cleaning Pros and Cons

Pros:
Brush cleaning has been in fabs for decades. It has and still been used recently been exclusively used for BEOL cleaning. If used properly (right pressure, rotational speed and water flow rate) the technique is very effective in the removal of particles down to 100 nm and it could be used with DI water or a cleaning chemistry. The best cleaning conditions is high pressure, high speed, and short cleaning time (15-30 seconds).

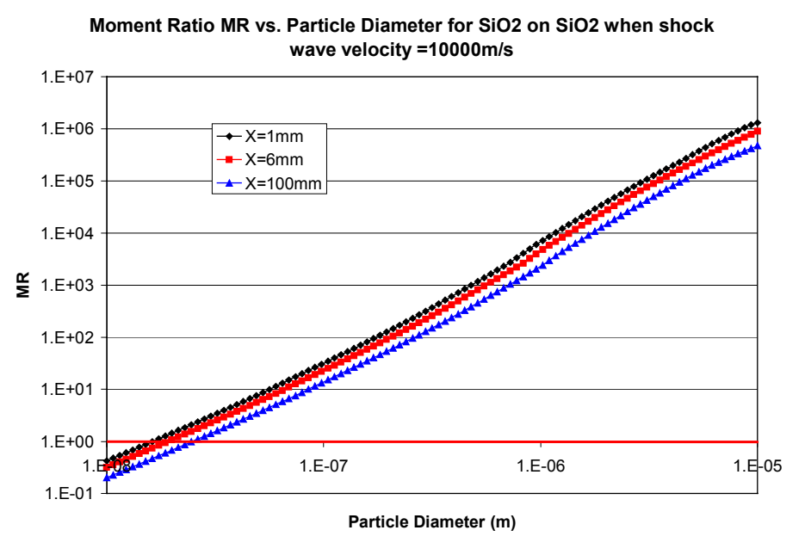
Cons:
This technique could cause scratching (surface damage) or particle re-deposition from a loaded brush if the water flow is low or the pressure is high (for a long cleaning time).

Laser Shock-wave Cleaning

Moment Ratio For Silica Particles on Bare Wafers



Shock wave velocity of 2,000 m/s



Shock wave velocity of 10,000 m/s

Particle Adhesion Force

The adhesion force includes van der Waals force and adhesion-induced deformation:

$$F_{adhesion} = F_{vdw} + F_{deformation} = \frac{AR}{6z_0^2}\left(1+\frac{a^2}{Rz_0}\right)$$

A is the Hamaker constant, R the particle radius, z0 the distance between particle and substrate. Usually it is assumed as 4Å.
a is the contact radius (obtained from elastic, JKR, or plastic model, MP). For silica, PSL particle on silicon substrate, the MP model is applicable.

$$a = \sqrt{\frac{2W_A R}{H}} \quad , \quad W_A = 2\sqrt{\gamma_1\gamma_2}$$

WA is work of adhesion between particles and surface.
1 and 2 are Surface free energy of two contact materials.
SiO2 = 70 mJ/m2, PSL=103.2mJ/m2.
H is the deformation part's hardness. HPSL =32.4 MPa, HSiO2 =750 MPa.

Particle Removal in Supercritical CO2

➢For liquid and supercritical CO2, the van der Waals adhesion forces are higher than the corresponding value for water.

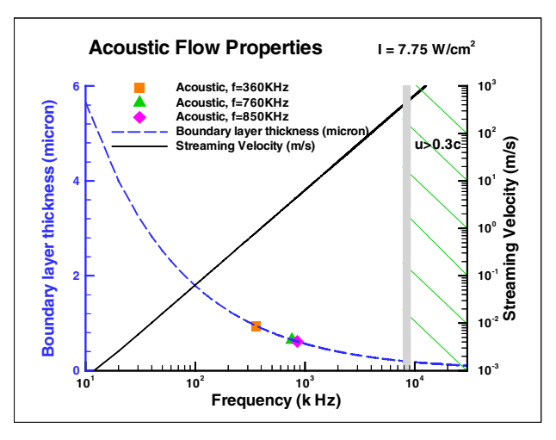
➢For the drag force a higher viscosity is preferred, which is not favorable for CO2. However, the boundary layer thickness is much thinner.

➢Additional removal forces must be generated if dense-phase CO2 is to achieve comparable removal forces obtainable with water-immersion.

Acoustic Flow Properties

➢ Acoustic boundary layer thickness:

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



➢ Acoustic streaming velocity (at center of tank):

$$u = \frac{8\pi^2}{3\rho c^4}\cdot If^2\left(\frac{h^2}{4}-z_1^2\right)$$
$$u \propto If^2$$

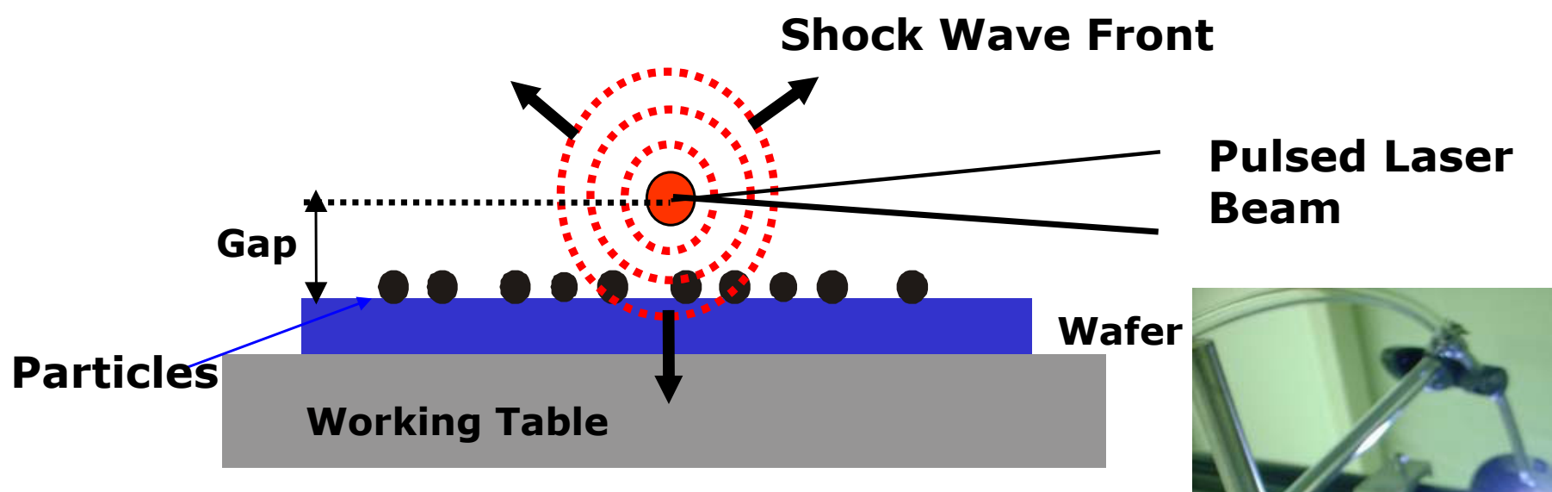
Megasonic Cleaning Pros and Cons

Pros:
Megasonic cleaning has been introduced in the mid seventies by Werner Kern and since then it has been used in every fab. It has and still been used exclusively for FEOL cleaning. It has been recently been used for the BEOL cleaning applications such post-CMP cleaning. It has been shown to effectively remove particles down to 100 nm. It could be used with different cleaning chemistry, surfactants or just DI water. The technique has also been shown to clean trenches and vias.

Cons:
The only reported disadvantage is possible damage on patterned wafers (such as polysilicon lines) as mentioned in section 7.4. No scientific experimental study has been performed on the damage to identify the mechanism and show possible cleaning without damage.

Laser Shock Cleaning Technique (LSC)

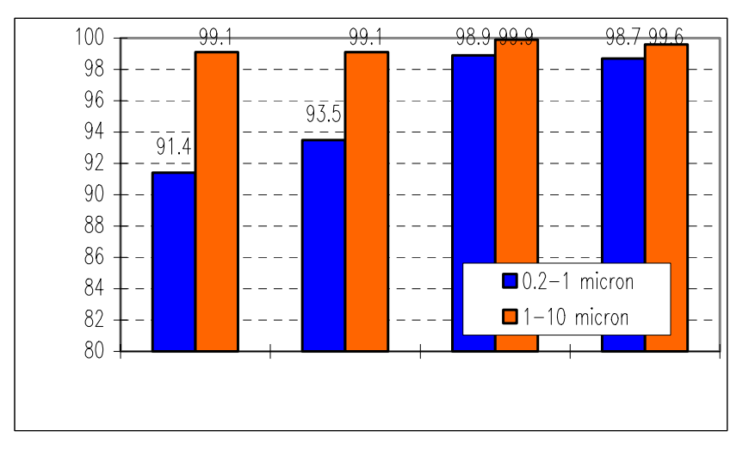
❖ **A technique to remove the contaminants on the surfaces using laser-induced plasma shock waves (multi-photon ionization)**

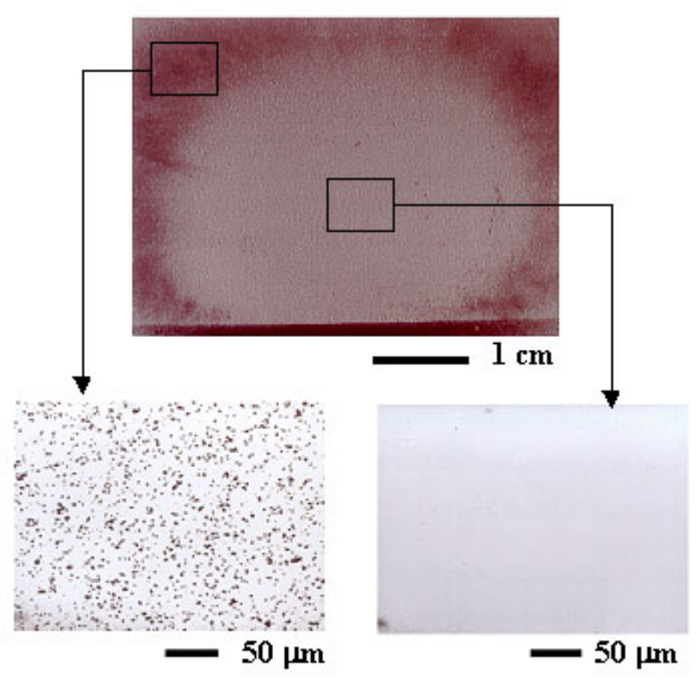


® **Cleaning condition:**
Shock wave force > Adhesion force

Removal of Particles from Si Wafers

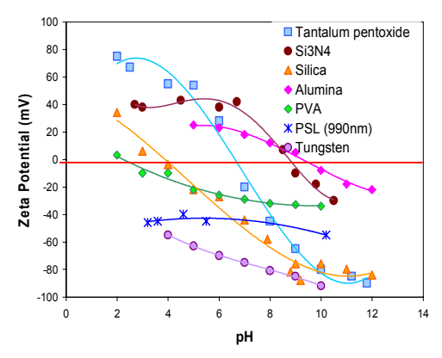
➢Alumina particle size: 0.05 m, 0.3 m, 1 m
➢Hybrid: UV irradiation + Laser shock wave application





➢Large cleaned area leads to high throughput
➢Process time is one minute per 8” wafer

Electrical Double Layer Force



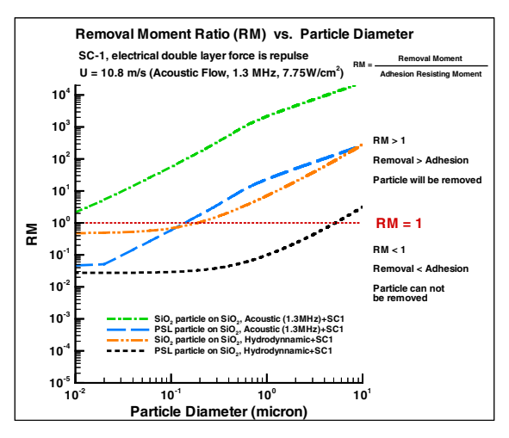
- **At the pH of water, silica, PSL, PVA, and W particles are all negatively charged.**
- **The high negative zeta potentials are measured at high pH solution for SiO2, Si3N4, Al2O3, tantalum pentoxide, tungsten, polyvinyl alcohol (PVA), and also for Si and PSL.**
- **Using a high pH cleaning solution, electrical double layer force occurs as a strong repulsion between the particle and the substrate.**

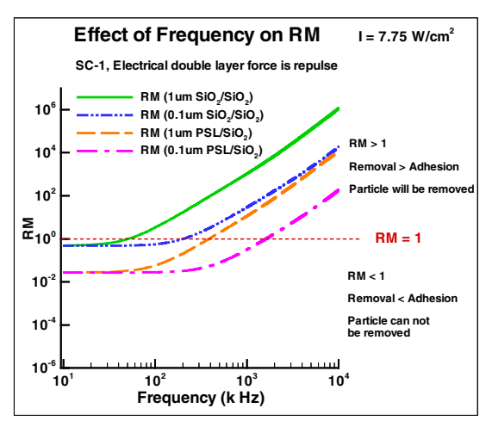
Particle Removal in Supercritical CO2

Pros:
Supercritical CO2 has many advantages:
1. The CO2 acts as a solvent for the removal of organic contaminants.
2. It could also be used use with co-solvents (that could be easily separated from CO2 after cleaning).
3. It also has a very low surface tension that allows the cleaning of nano and microscale trenches and vias. Fourth, it eliminates the need for a drying process since no liquids are used.

Cons:
Physical removal of contaminants such as particles, although likely, has yet to be demonstrated. The high cost of capital for the equipment because of high pressure (3000-6000 psi) and the high cost of high purity CO2 unless recycling is used.

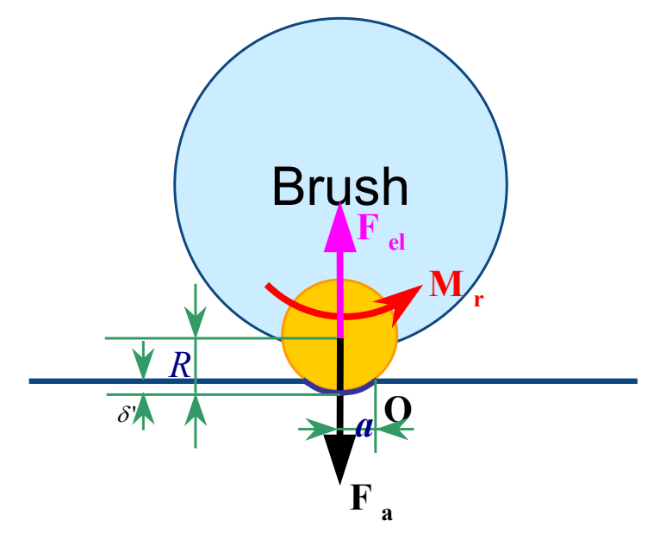
Removal/Adhesion Moment Ratio (RM)

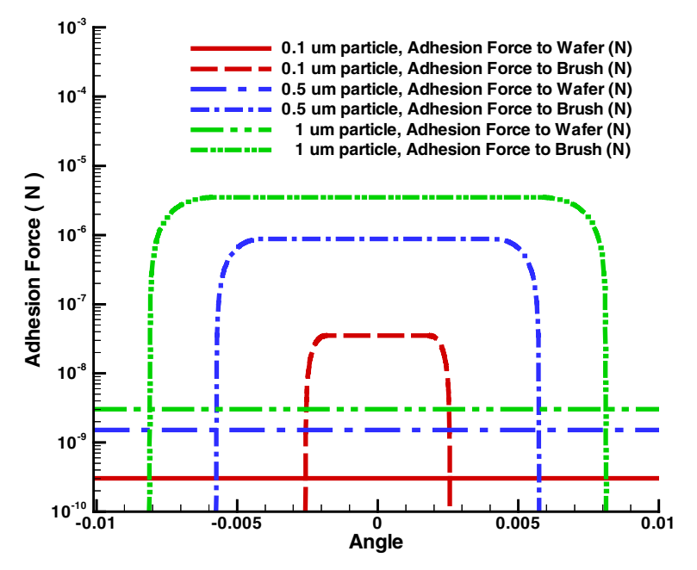




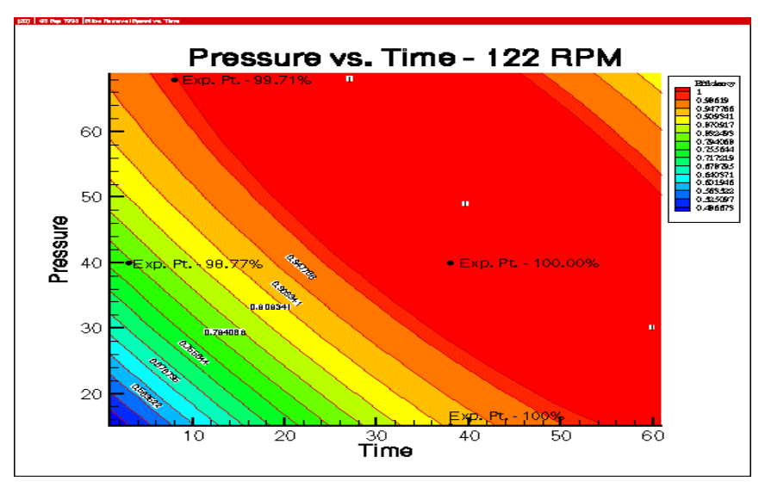
➢ **Using DI water only, the removal of nano-size particles (10-100 nm) can be best accomplished using acoustic streaming at frequencies larger than 1.3 MHz.**
➢ **The smaller the particles, the higher frequency acoustic flow is needed.**
➢ **Soft particles (PSL) are more difficult to remove.**

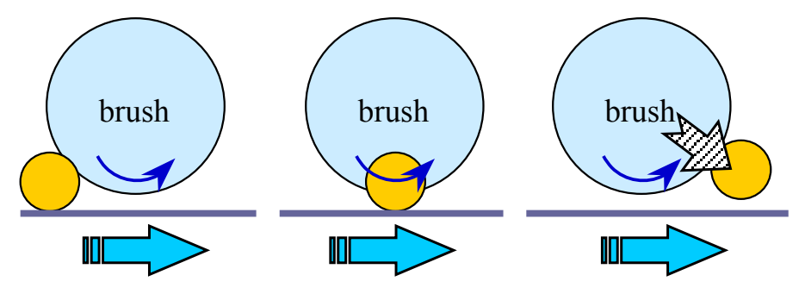
Contact Brush Cleaning Dynamics





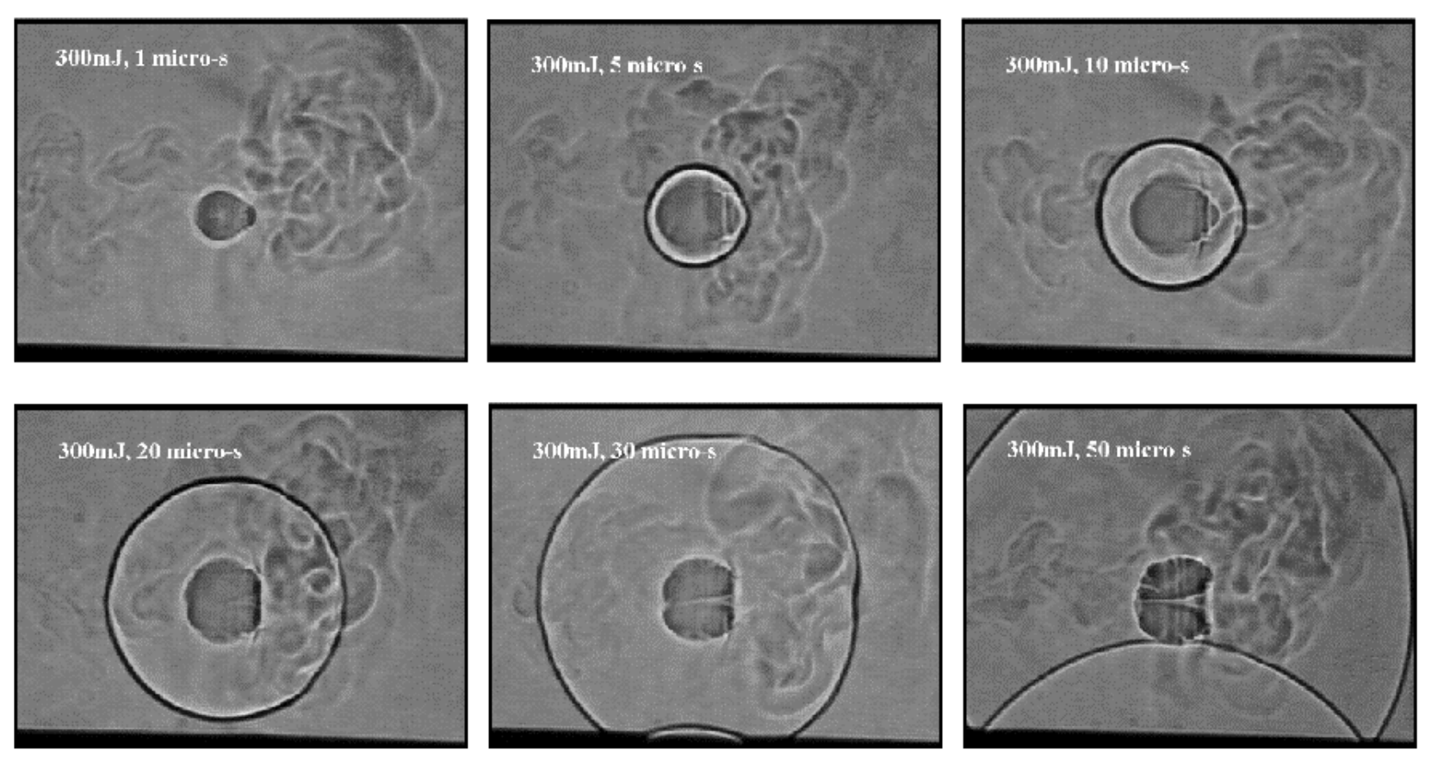
Adhesion Force During Particle Engulfment





Visualization of Shock Wave

Laser shadow-graphic photography
➢XeCl excimer laser used for back-light source



Parametric investigation of the shock wave: laser power, pulse width, wavelength, type of gas, gas pressure, particle behavior and shock propagation through the hole (patterned wafer)

Laser Shock Cleaning Pros and Cons

Pros:
Laser shock cleaning is a new techniques that for the first time allow the removal of submicron inorganic particles (down to 200 nm) using a completely dry process. The technique has been show to effectively remove silica and alumina particles without substrate damage. The process throughput is also high at 1 minute per 8” wafer due to the large cleaning are per pulse (a few square centimeters).

Cons:
This technique is not very effective in the removal of organic particles. However, it is has been shown to be effective when combined with a UV laser (hybrid laser). Damage is possible if the laser is too close to the wafer. However, no damage has been observed on patterned wafers down (down to a separation gap of 5 mm between the laser focus point and the laser).