# Damage Free and Dry Removal of Nano-size Inorganic and Organic Particles from EUV Mask Layers by Laser Induced Shockwaves

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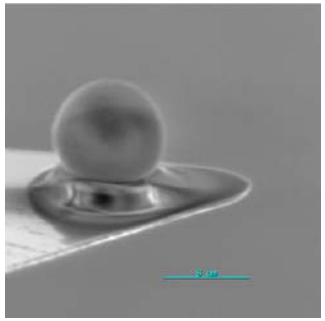
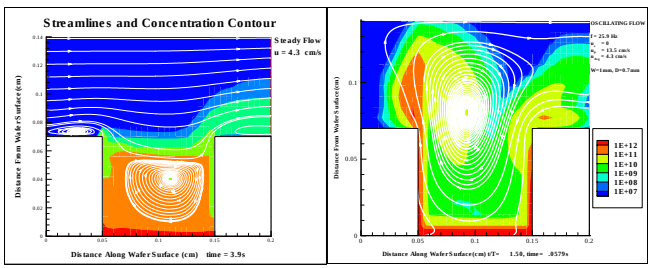
# Outline

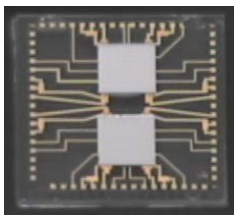
- Introduction
- Laser cleaning technique overview
- Advantages & disadvantages
- Conventional laser wafer cleaning
- Laser shock cleaning
- Experimental test and results
- Overall comparisons of CLC & LSC
- Conclusions

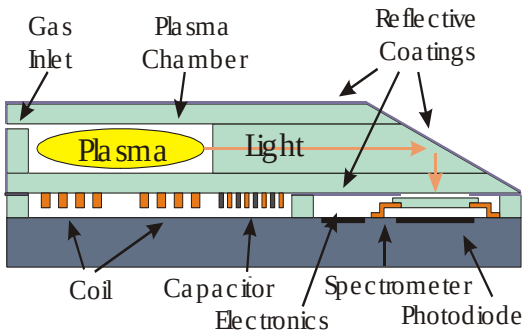
# Research Focus at the NSF Center for Micro and Nanoscale Contamination Control

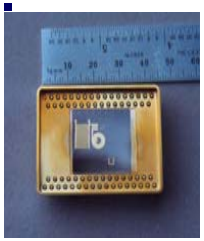


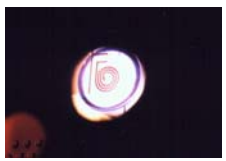
- Fundamentals of surface cleaning and preparation.
- Particle adhesion and removal mechanisms.
- Development and fabrication of in situ micro sensors technology (MEMs based micro gas analyzer).
- Particle generation, transport, and deposition during wafer processing and handling.
- Contamination in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







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# Introduction

- EUV lithography needs to operate without a pellicle.
- The reticle may be subject to particulate and chemical contamination, in the absence of a pellicle.
- There is a need to develop a cleaning process that would remove all contaminants according to EUV cleaning requirements.
- EUV cleaning requirements are:
  - Removal of all particles larger than 30nm
  - Removal of organic contamination
  - Cleaning should not change the ARC reflectivity by more than 1%,
  - The process should be damage free and should adhere to the environmental safety standards.

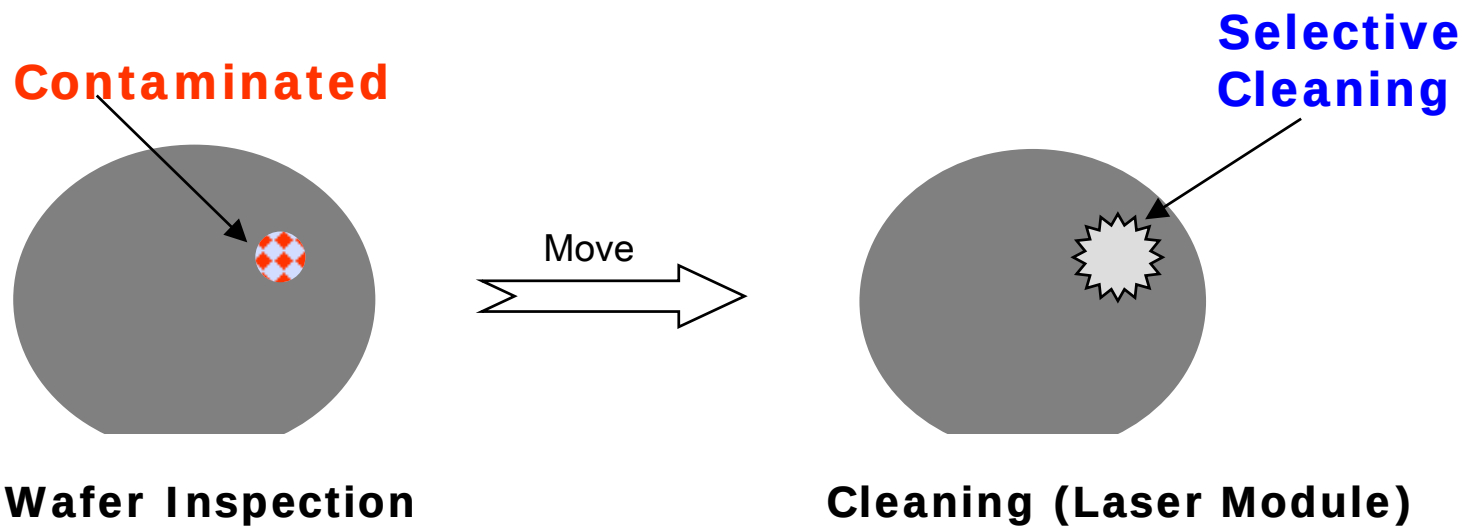
# Introduction

- Laser Shock Cleaning (LSC) is a room temperature physical cleaning process that has been shown to be effective in the removal of particles down to 200 nm from silicon wafers.
- It has been shown to work in post CMP applications and on patterned wafers without damage.
- Laser shock cleaning is a very promising technique for reticle cleaning because of the similarity of the substrates (Silicon, quartz, etc.) and physical nature of the LSC technique.
- Experiments are underway to use LSC to remove nanoparticles from EUV reticles.

# Local/Selective Area Cleaning

- **For 300mm wafers, DUV and EUV reticles**

  **Localized contamination may require local/selective cleaning with in-line inspection and laser cleaning**

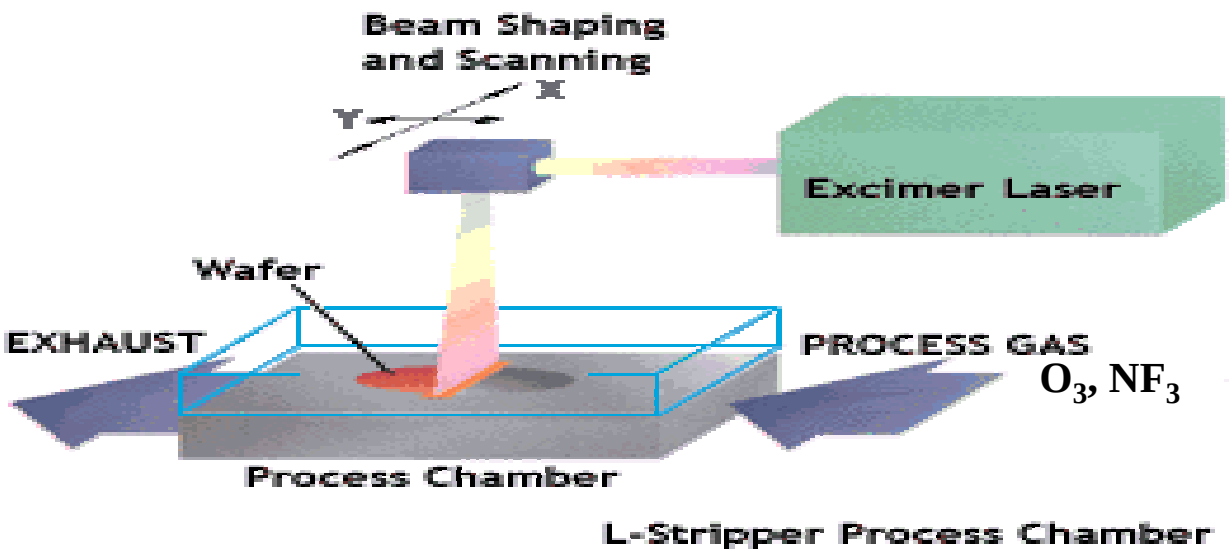



**Possible Solution**

**>> In-line inspection and laser cleaning**

# Conventional Laser Wafer Cleaning

- Mostly UV Excimer laser (KrF) used
- Effective for the removal of organic contaminants by photo-chemical interactions



# Disadvantages of Conventional LC

- **Slow speed of cleaning**

  Small laser spot size => Slow process and significant

- **High probability of substrate damage**

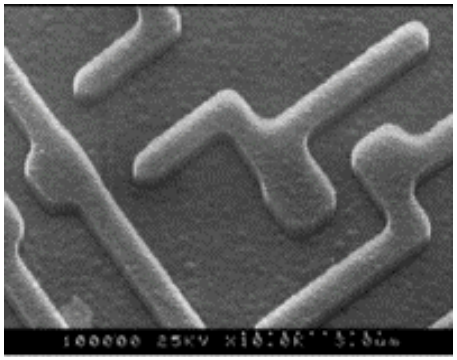
  Focusing the laser beam on the surface => possible damage

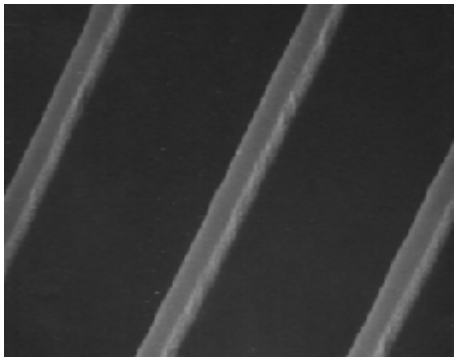
- **Poor cleaning performance for inorganic particles**

  Inorganic submicron particles are not removed in a dry process

# Oramir Laser Cleaning

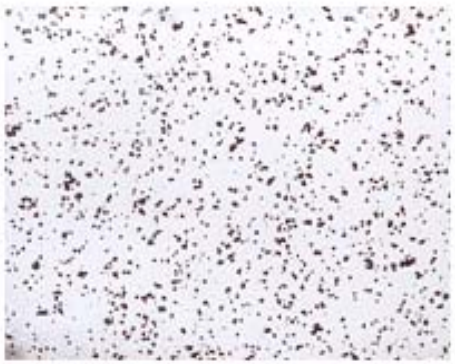
- **PR residue removal after poly-Si RIE process (at Motorola)**





> **Effective for organic**

- **Problem: W particle removal**



**before cleaning** **after cleaning at 0.28 J/cm$^2$**

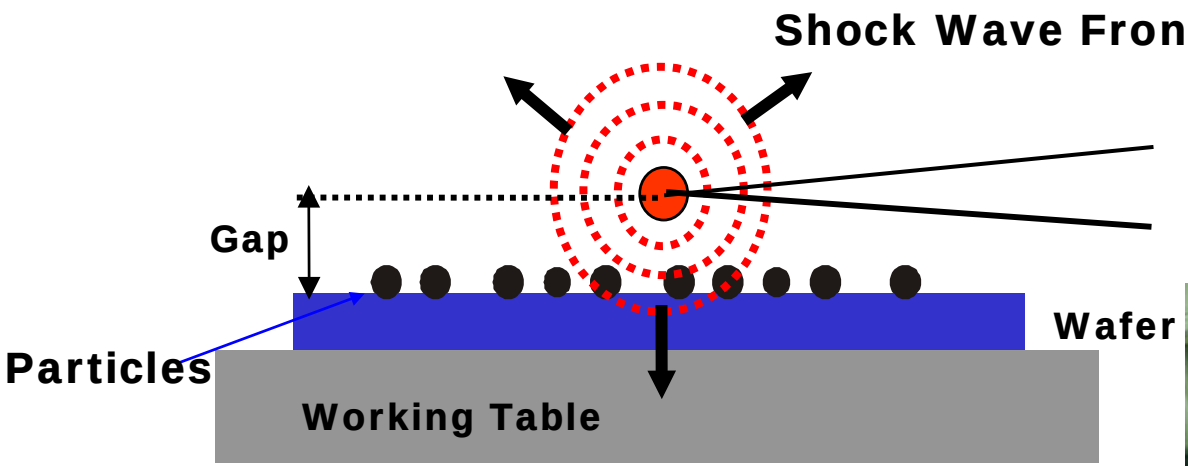
**Si substrate damage threshold = 0.3 J/cm$^2$**

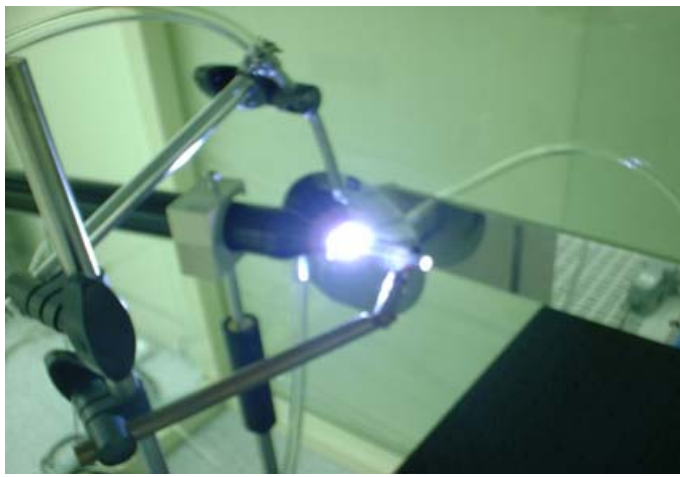
**→ Not feasible for inorganic**

**→ Inorganic particle shows critical killer effect: more than 85% of device failure**

# Laser Shock Cleaning Technique (LSC)

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



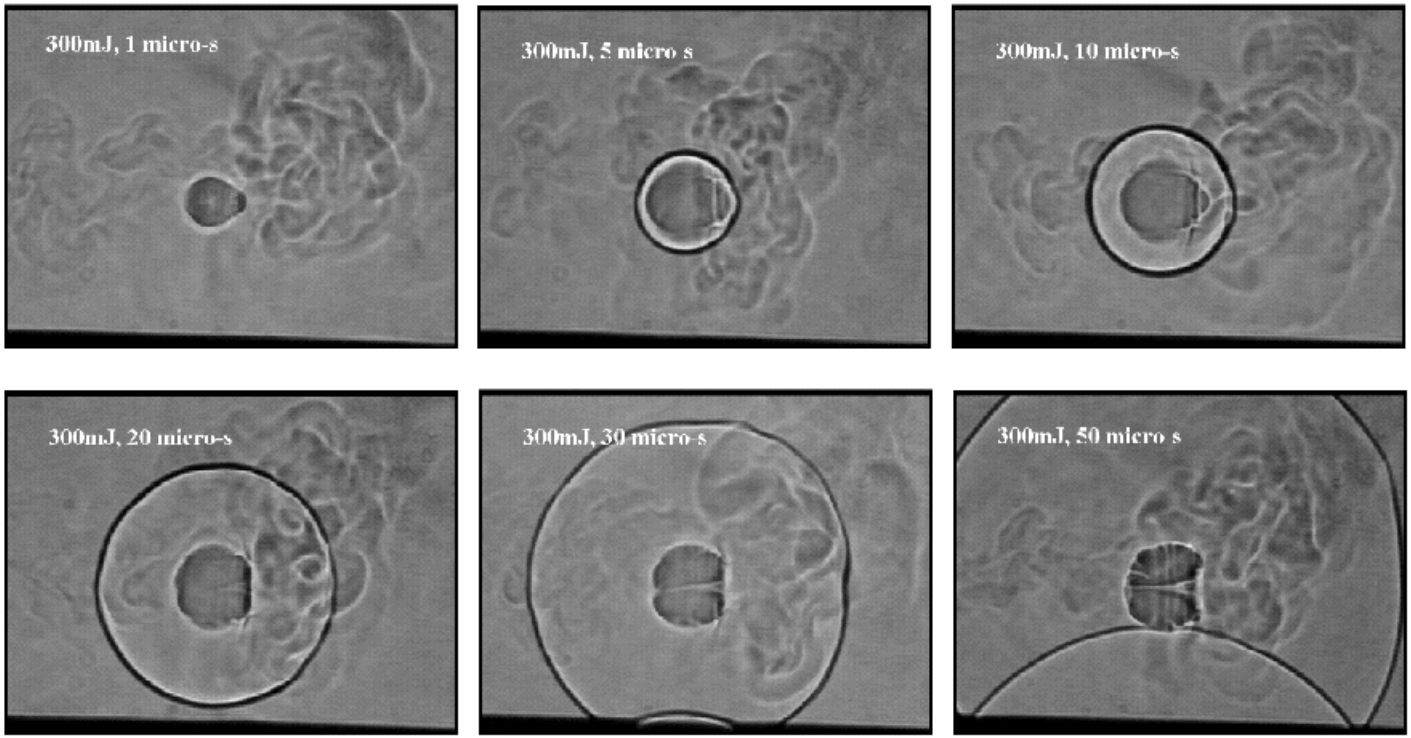
→ **Cleaning condition:**

**Shock wave force > Adhesion force**

# Visualization of Shock Wave

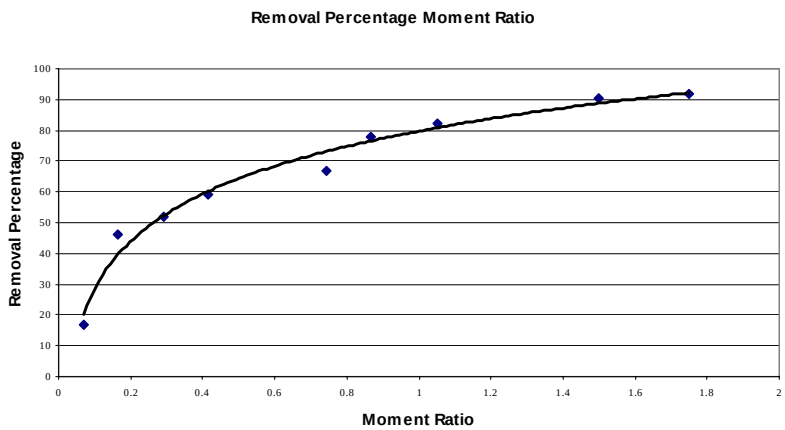
**Laser shadow-graphic photography**

- XeCl excimer laser used for back-light source



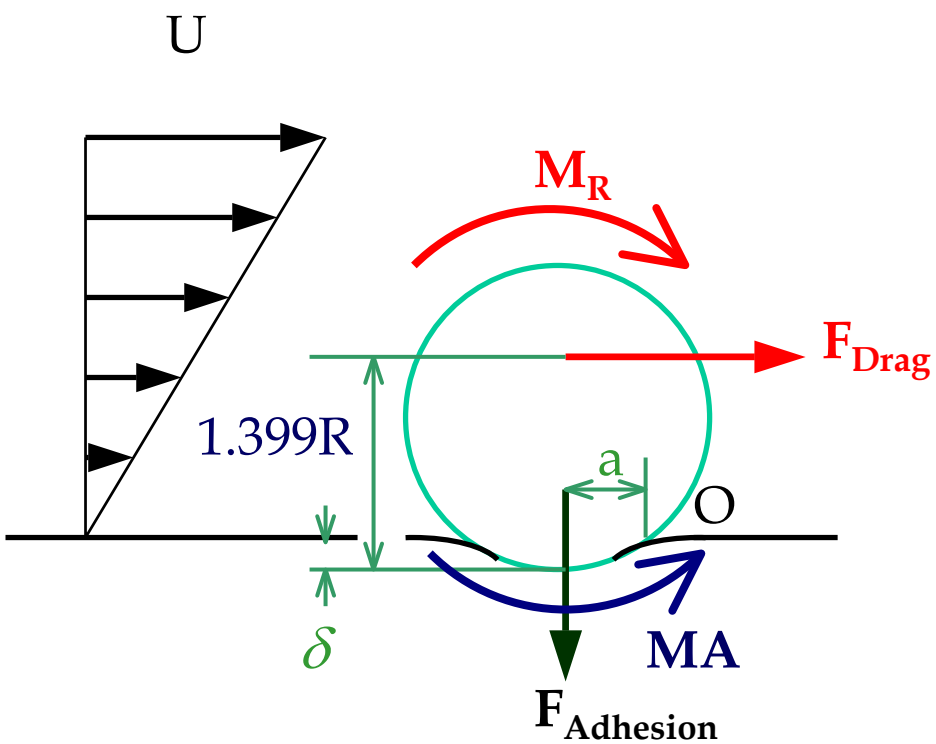
# Removal/Adhesion Moment Ratio (RM)

**Removal Efficiency vs. Moment Ratio (MR) Colloidal Silica (0.3-0.7micron) Removal Experiments**




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

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




**Rolling removal mechanism**

**When MR >1, most particles are removed.**

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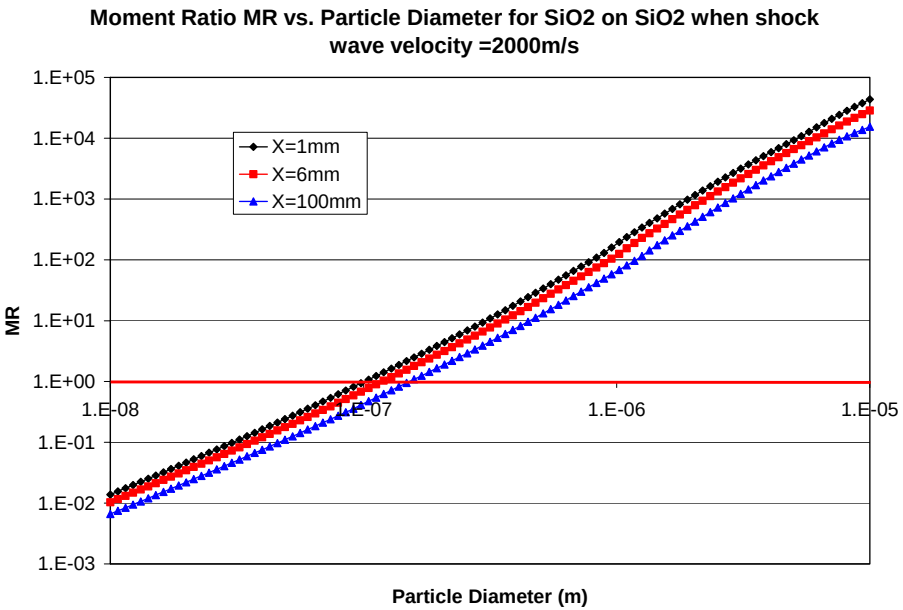
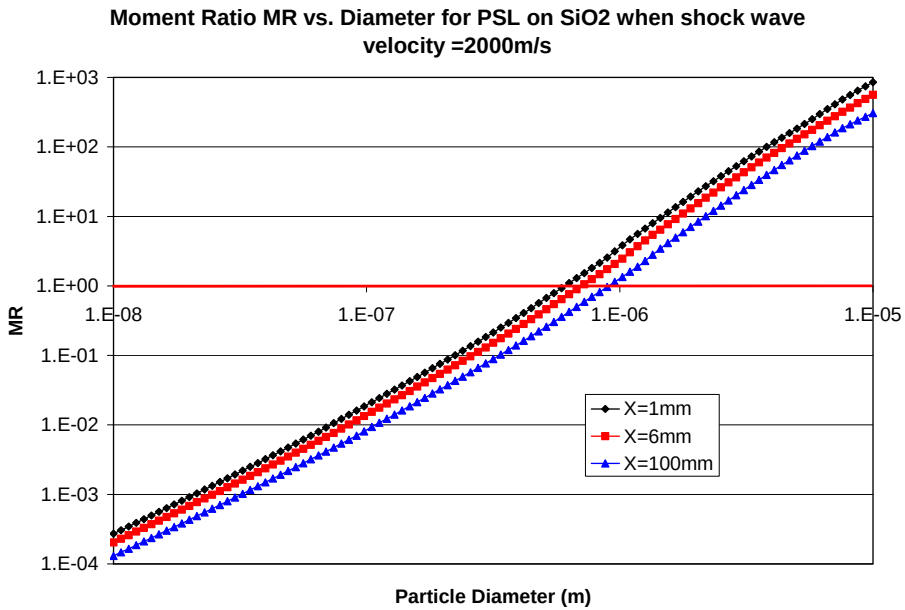
# Modeling of Laser Shock Cleaning

- **Moment Ratio at a shock wave velocity of 2,000 m/s**




**Silica particles on $SiO_2$**

**PSL particles on $SiO_2$**

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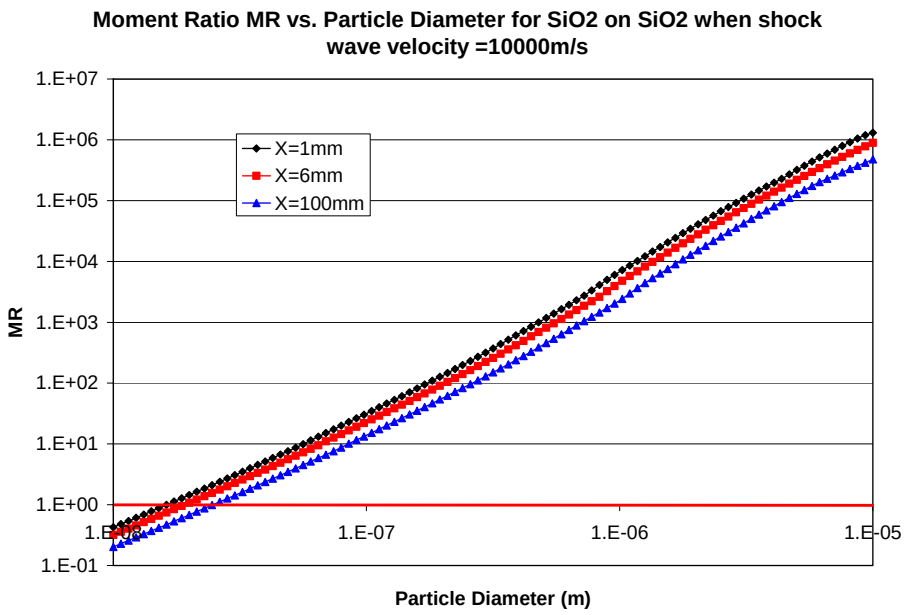
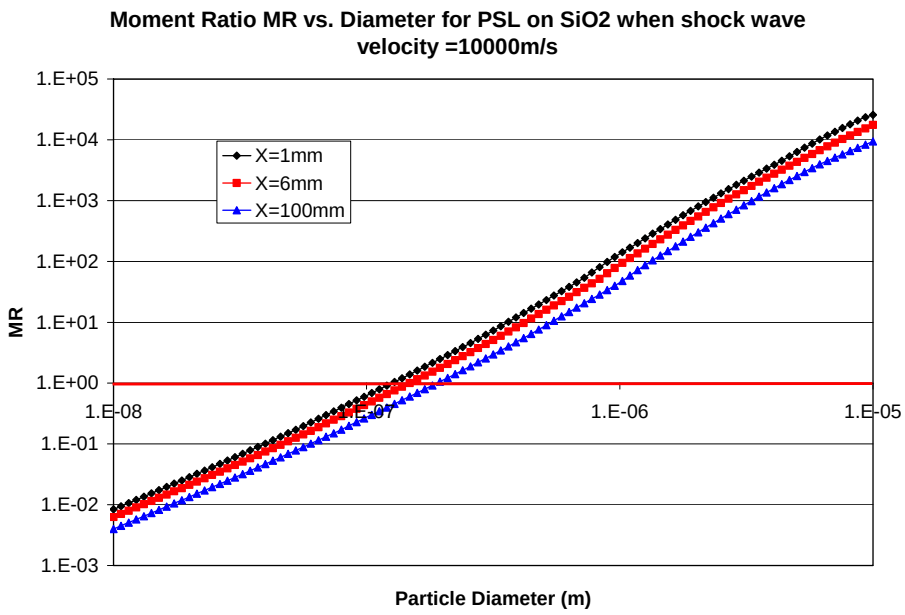
# Modeling of Laser Shock Cleaning

- **Moment Ratio at a shock wave velocity of 10,000 m/s**




**Silica particles on $SiO_2$** **PSL particles on $SiO_2$**

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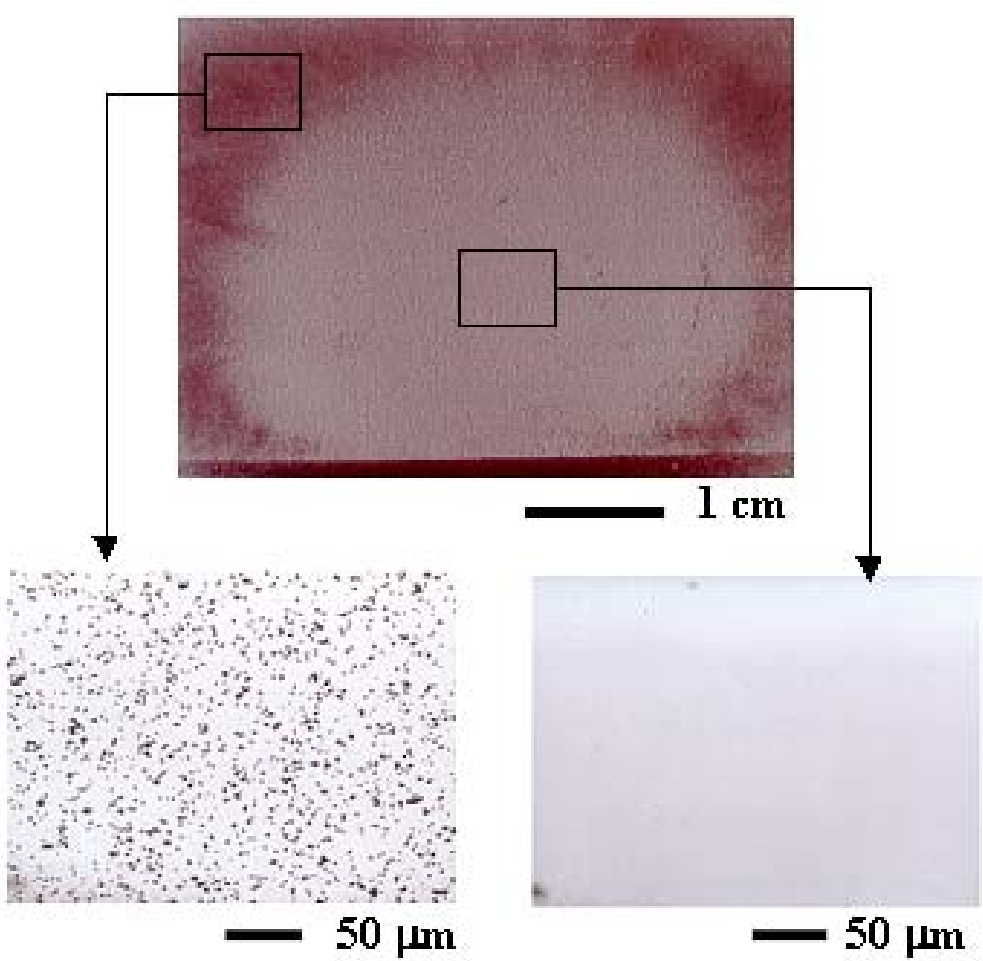
# Removal of W Particles




- Just 2 laser pulses irradiated
- Very effective for inorganic particles
- Huge cleaned area → high cleaning speed → high throughput

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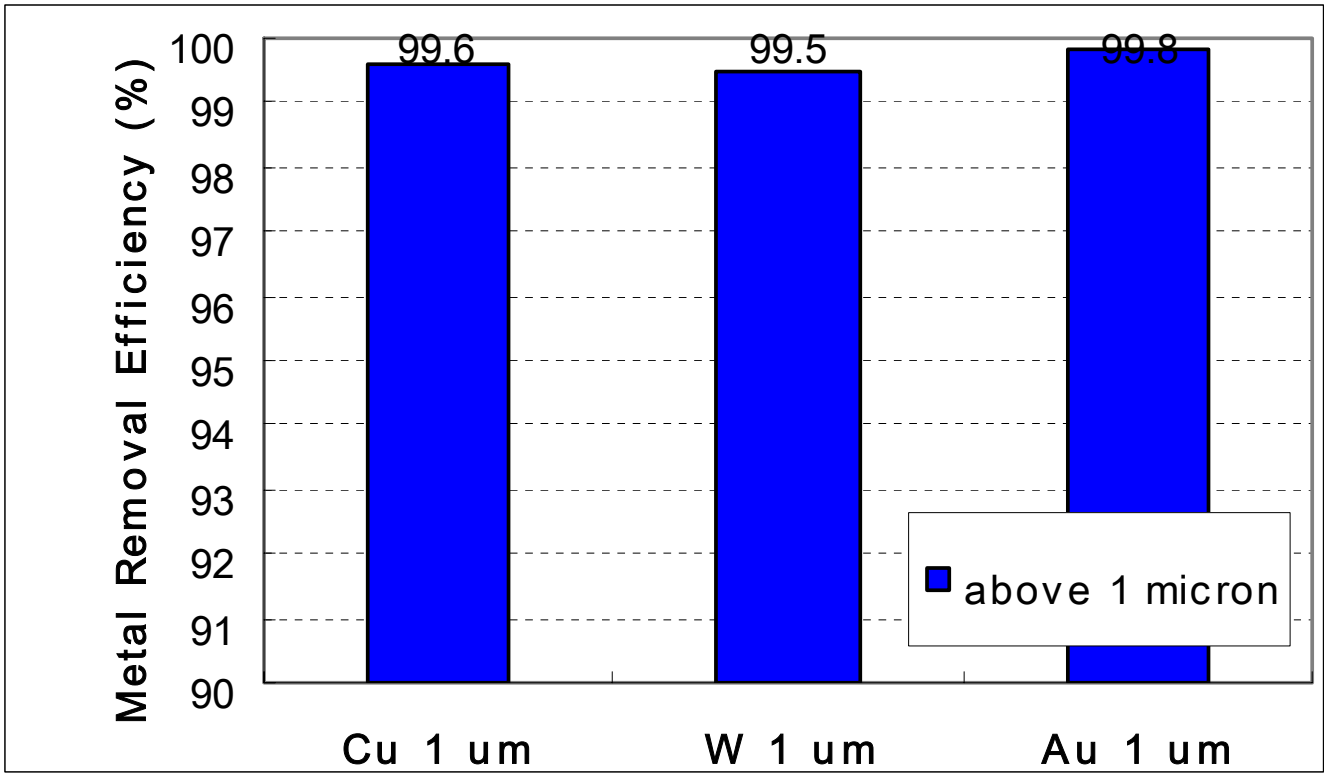
# Metal Particles on Silicon Wafers

- **Particle species: Cu, W, Au**
- **Particle size: 1 μm**

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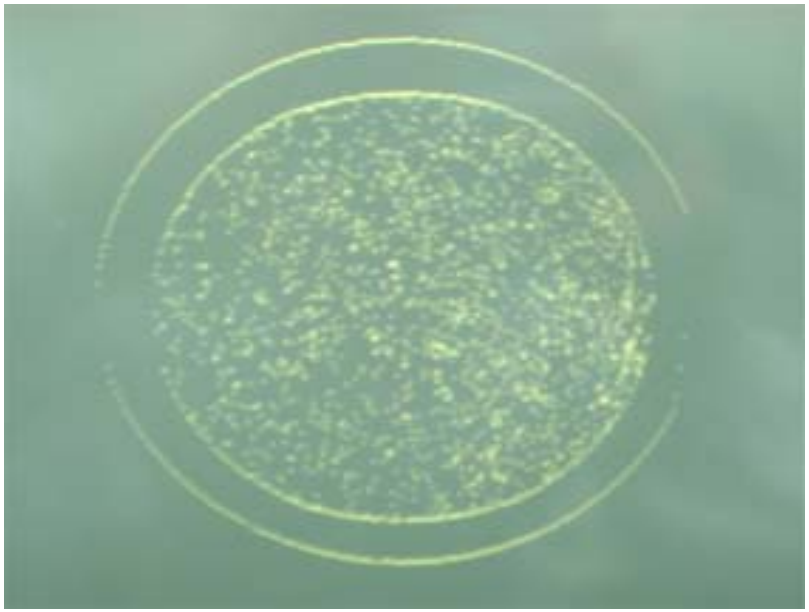
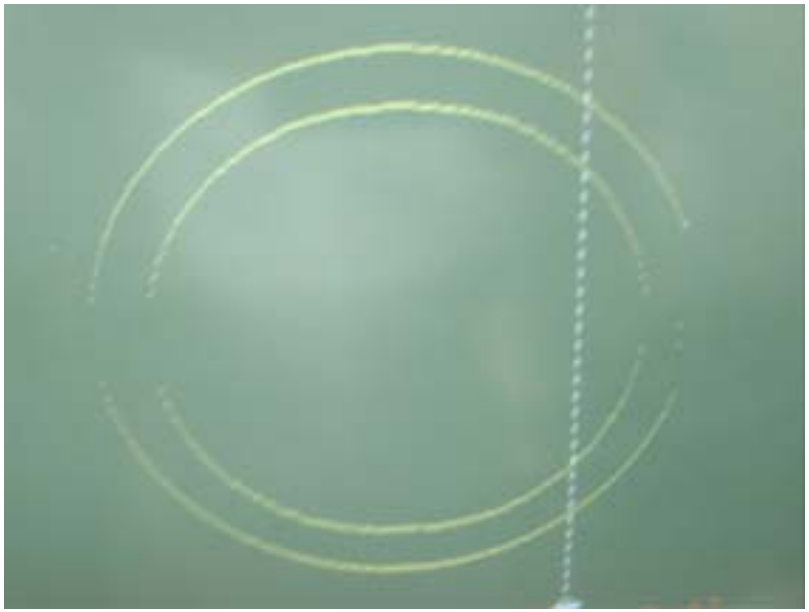
# Particle Removal by LSC

- Scanned surfaces: KLA-Tencor Surfscan 5500
- Silica particles on Si wafers



Before Cleaning



After Cleaning

> Total number of particles before cleaning: 4,000 – 10,000

> A successful removal of the particles was carried out by LSC.

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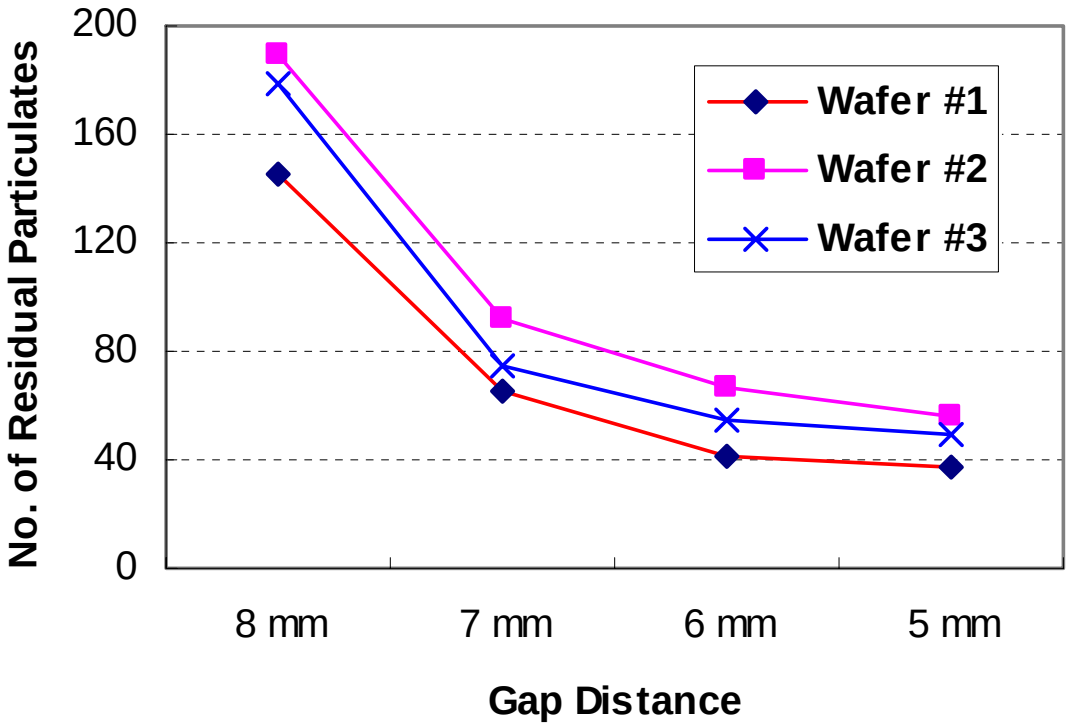
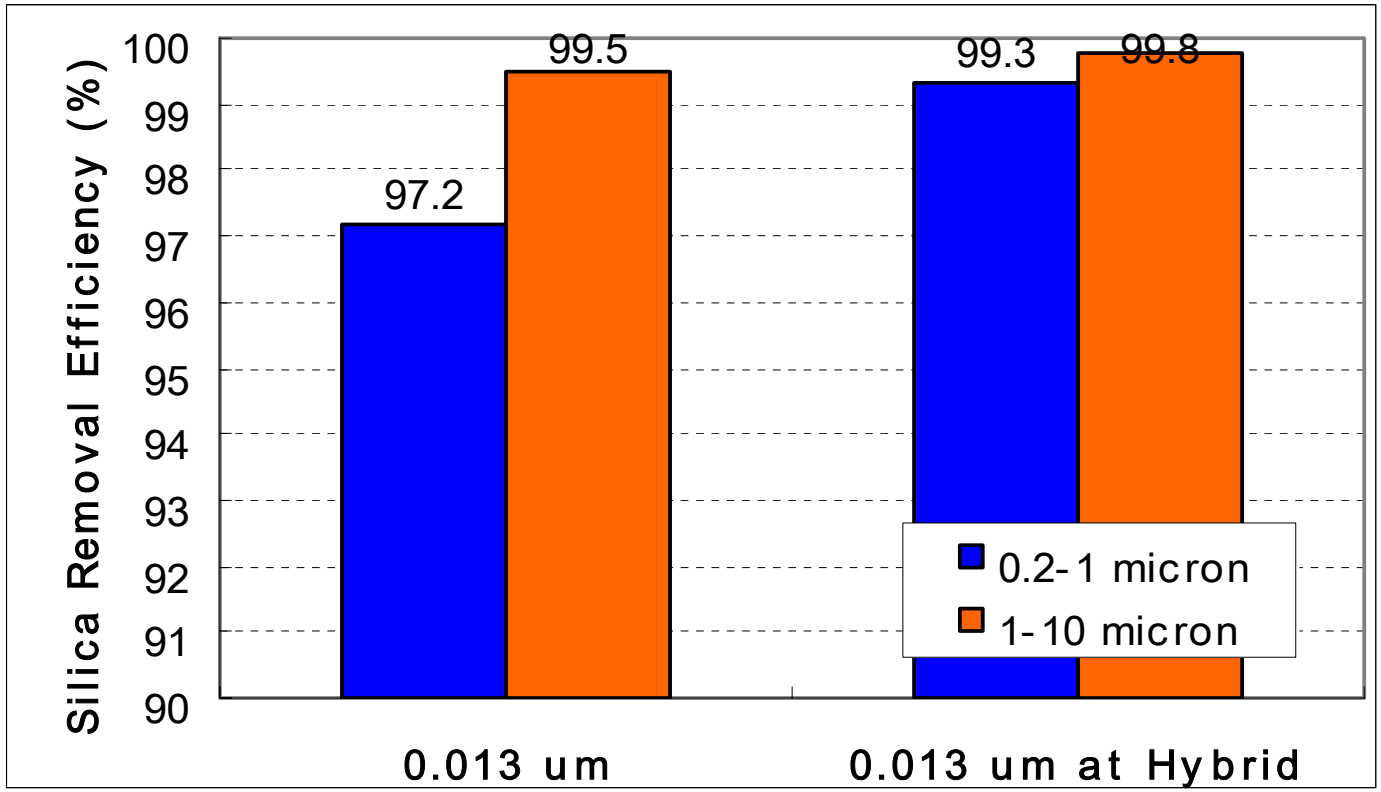
# Effect of Gap Distance on Cleaning

- Significant increase of the residual particles with increasing the gap distance
- Which is due to the attenuation of the shock wave with distance i.e $I \sim I_0 \exp(-ax)$
- Gap distance => strong cleaning factor



# Silica Particles on Silicon Wafers

- **Particle size: 0.013 μm**
- **Hybrid: UV irradiation + Laser shock wave application**




**LSC Only** **UV + LSC**

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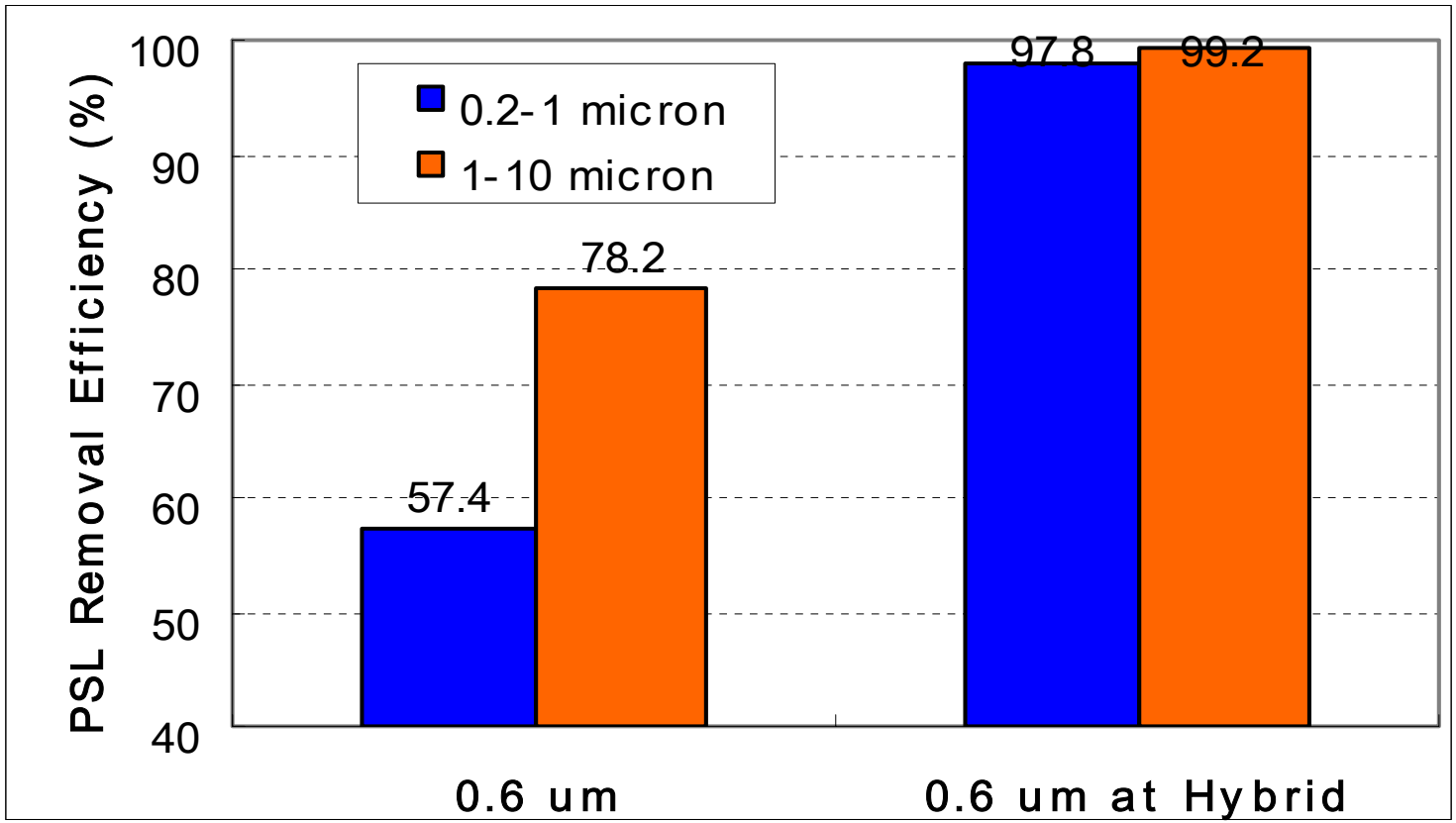
# PSL Particles on Silicon Wafers

- **Particle size: 0.6 μm**
- **Hybrid: UV irradiation + Laser shock**




**LSC Only** **UV + LSC**

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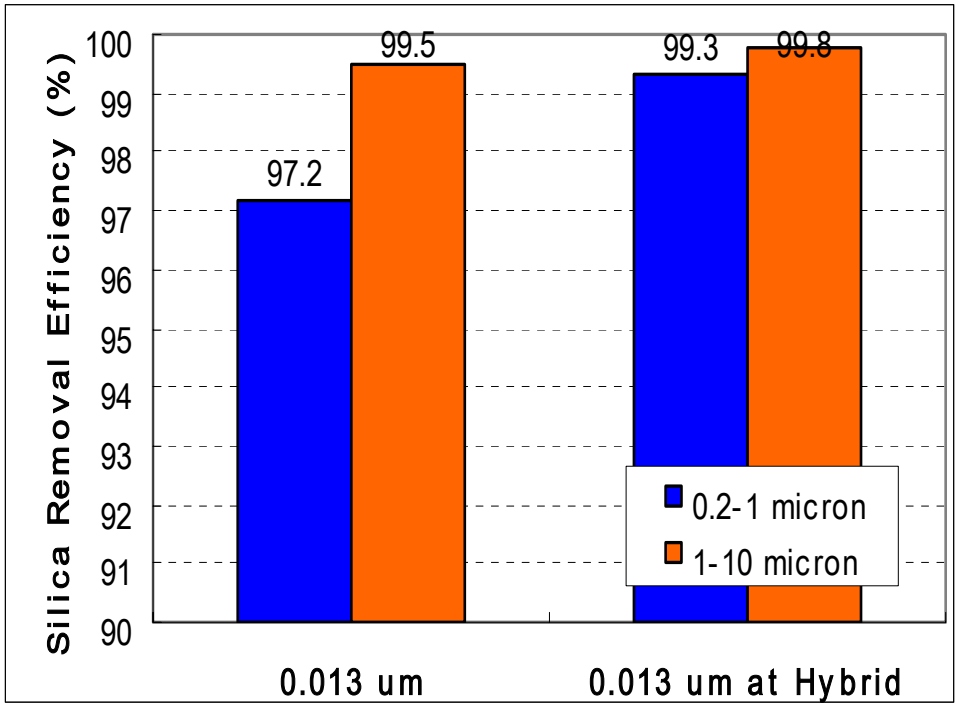
# Silica Particles on TEOS Wafer

- **Particle size: 0.013 μm**
- **Hybrid: UV irradiation + Laser shock wave application**




**LSC Only** **UV + LSC**

***Before cleaning***

***After cleaning***

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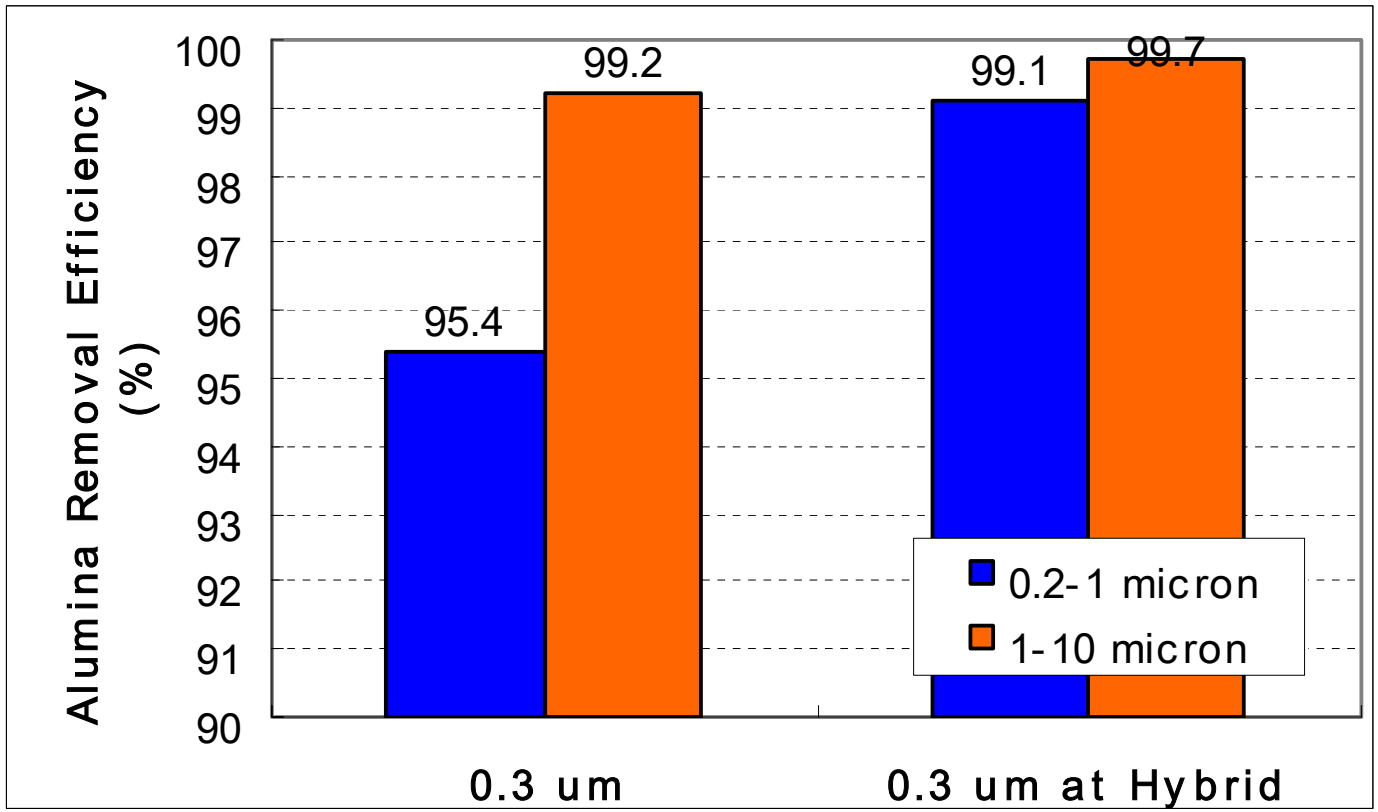
# Alumina Particles on TEOS Wafers

- **Particle size: 0.3 μm**
- **Hybrid: UV irradiation + Laser shock wave application**




**LSC Only** **UV + LSC**

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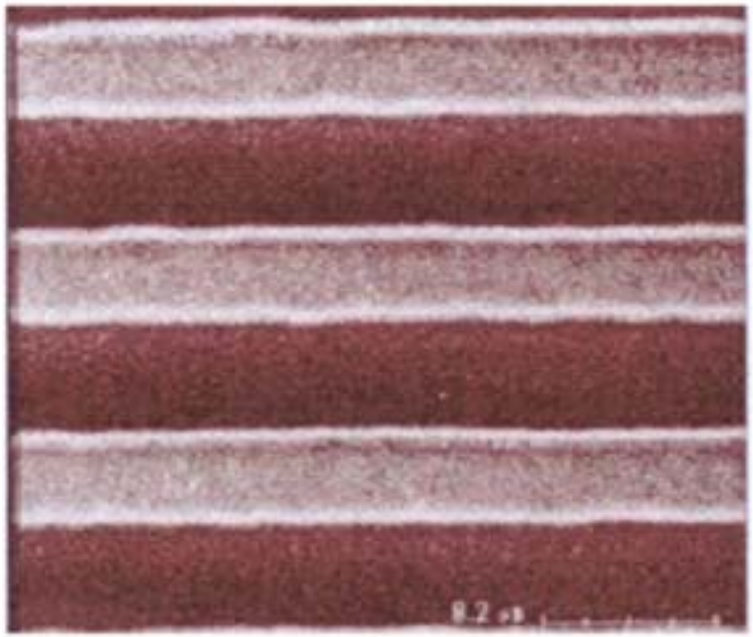
# Pattern Damage Issue

→ **Target: Gate patterned wafers**

**(DR = 0.12 μm feature, Aspect Ratio = 3)**

0.12 μm



**After LSC treatment**
**(No pattern damage)**

- **No pattern damage was found which is superior to some megasonic based wet cleaning processes.**

# Overall Comparisons

## ❑ Conventional LC vs LSC

| | Conventional UV Laser Cleaning | Laser Shock Cleaning |
|---|---|---|
| System Cost | Expensive (Excimer laser) | Economical (Nd:YAG laser) |
| Cleaned Area | < 0.25 $cm^2$ => slow speed (Oramir: 6 min / 8”wafer) | > 3 $cm^2$ => high speed (IMT: < 1 min / 8” wafer) |
| Required No. of Laser Pulses | > 10 laser pulses | < 5 laser pulses (dependent on particle size) |
| Substrate Damage | Potential due to direct interaction | Damage free due to iMT LSC technology |
| Cleaning Performance for Organic Particles | Excellent | Poor |
| Cleaning Performance for Inorganic Particles | Poor | Excellent |
| Process Control | Difficult | Easy |
| Recontamination Probability | High (Blowing gas system) | Low due to anti-static current effect (FFU enough) |

# Conclusions

- Laser Shock Cleaning represents a new paradigm in wafer cleaning technology.
- The Laser induced shock wave has a velocity of 2-10 km/s that provides a very large removal force.
- Modeling shows that the removal of nano-size silica particles (10 nm for 10 km/s velocity and 100 nm for 2km/s) can be accomplished.
- Silica, metallic and alumina particles were successfully removed from silicon and oxide wafers
- The Combination of UV and LSC (Hybrid LSC) enhances the removal of organic contamination.
- LSC represents a very promising technology for EUV reticle cleaning.