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# **The Removal of Submicron Particles Using CO<sub>2</sub> Aerosol with emphasis on post-CMP Applications**

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## **Introduction**

An era of the most challenging cleaning applications in nanofabrication techniques and semiconductor manufacturing is upon us. With the International Technology Roadmap for Semiconductors decreasing particle removal requirements from 125 nm and a surface concentration 0.3-0.75 per cm<sup>2</sup> in 1997 to 25 nm and a surface concentration of 0.01 - 0.15 per cm<sup>2</sup> in 2011, the most challenging cleaning application requirements in semiconductor manufacturing is upon us.

The field of particle removal and surface cleaning in general extends far beyond the semiconductor industry. Many applications in biological, medical (implants and equipment), aerospace, imaging, automotive, pharmaceutical, etc. extensively use surface cleaning as a preparation step for post or pre processing. The need for scrupulously clean wafers in the fabrication of microelectronic devices has been well recognized since the dawn of solid-state device technology. Clean substrate surfaces are critical in ULSI fabrication for obtaining maximum device performance, long-term reliability, and high yields. For instance, a 64-Mb 0.25- $\mu\text{m}$  DRAM process flow has 60 to 70 cleaning steps. In 0.18 $\mu\text{m}$  CMOS technology about 80 of 400 process steps will be cleaning<sup>[1]</sup>. Particles larger than about  $\frac{1}{4}$  of the minimum line-width may cause fatal device defects. As semiconductor device geometry continue to shrink, (currently at about 0.18 $\mu\text{m}$ , will shrink to 70nm by the year 2008 <sup>[2]</sup>) and wafer sizes increase, the limitations of existing cleaning methods on devices yield will become more critical as the size of “killer” particles also shrinks. In nanoscale manufacturing that need is increased by more than one order of magnitude. A physical, substrate independent, cleaning process is highly desirable since it does not have to be modified for different substrates (as in a chemical based cleaning process) and it does not have a potential for modifying the surface (such as etching, roughening, etc.).

Traditionally there are several particle removal techniques used in semiconductor fabrication and other industries affected by surface contamination. They include ultrasonics, megasonics, brush scrubbing, dry Argon ice cleaning, plasma etching, or wet etching, etc. Effective dry cleaning techniques have been sought after methods in the industry for the past decade. One dry cleaning techniques that is film independent is aerosol jets (seeded gas) cleaning has been shown to have a good potential for dry removal of submicron particles. Aerosol jet cleaning has used solid water particles (Ohmori et al), solid CO<sub>2</sub> particles (Whitlock et al) or solid argon particles (McDermott, Wu, et al). Aerosol cleaning involves using the momentum of solid particles in a high velocity gas stream to remove contaminants. Particles in the gas stream can be formed by the solidification of liquid droplets or the gaseous medium during rapid cooling. When the solid particle collides with the particle, the collision energy may overcome the adhesion force and remove the particle from the surface.

### **CO<sub>2</sub> Snow Formation**

Snow is formed by the partial expansion of CO<sub>2</sub> within an orifice in the first stage (at constant enthalpy) and a complete expansion in the Teflon nozzle. The pressure drops from 800 psi to 80-psi (using either gaseous or liquid CO<sub>2</sub>) leads to a mixture of liquid and gaseous phases within the nozzle. The final expansion (below 80 psi) all the remaining liquid converts to solid dry ice. A gaseous CO<sub>2</sub> source will yield 8% dry ice where a liquid CO<sub>2</sub> source will yield 45% dry ice. The percentage of dry ice formed depends on the source temperature, pressure, nozzle and orifice design.

### **CO<sub>2</sub> Particle Removal Mechanism**

CO<sub>2</sub> dry ice particles are introduced into the gas stream and the collisions between the impinging dry ice particles and surface particulates give rise to momentum transfer and particle removal. The removed particles are then carried away by the gas flow

### **Hydrocarbon Film Removal**

The organic removal mechanism involves the presence of liquid CO<sub>2</sub> (an excellent solvent for hydrocarbons and other nonpolar substances). During the short impact time, high stresses exist at the snow - surface interface and the pressure can easily exceed the dry ice yield stress and triple point pressure. The dry ice particle liquefies and acts as a solvent while in contact with the surface. When the particle starts to rebound off the surface, the interfacial pressures decrease and the dry ice particle re-solidifies, removing the contamination. Sherman and Whitlock quantitatively demonstrated the effectiveness of carbon dioxide snow cleaning in removing organic residues from surfaces. Surface analysis was used to investigate the surface chemistry of the cleaned wafers.

### **Recontamination**

Whitlock performed a series of tests in a cleanroom by counting particles on new wafers before and after exposure to a carbon dioxide snow. The initial particle count increased from an average of 16 particles before cleaning to over 80 particles afterwards. The carbon dioxide source was the best available at the time of work, with roughly less than 100 ppm heavy hydrocarbons. EDS failed to identify an element heavier than sodium suggesting that these added particles are hydrocarbon-based. High temperature baking in air and also standard wafer cleaning methods eliminated these particles. Similar tests on commercial grades (industrial) led to extensive recontamination.

### **Static Charge**

There is a potential for build up of static charge on surfaces during cleaning. This is caused by the ionization from the flowing CO<sub>2</sub> gas. This static charge buildup is not a problem for metal samples. If the sample is grounded, static charge is not a problem. Charging is usually worse for glass samples or for electrically isolated parts on complex structures.

### **Moisture Condensation**

The cold CO<sub>2</sub> snow stream lowers the surface temperature and moisture can condense. Generally, moisture condensation does not interfere with cleaning in many applications, unless the moisture "freezes" or stays on the surface too long. Cleaning setups usually have a method to minimize moisture condensation such as a hot plate as part of the sample support. Usual set point for the hot plate set about 30-35C, but higher temperature may be necessary in some cases. For samples with poor thermal conductivity, such as thick glass, an overhead hot air gun or lamp can be used. In critical cleaning situations such submicron particle removal from wafers or optics, moisture

condensation must not occur. Cleaning must be done in dry controlled clean environmental chambers.

## **Objectives and Tasks**

### **Objectives**

The objective of the proposed work is to identify and establish an effective submicron particle removal technique using CO<sub>2</sub> aerosol cleaning for semiconductor wafers. The study will provide an understanding of the basic removal mechanism that will be verified by experimental measurements and develop an effective process based on this fundamental understanding to meet future semiconductor processing challenges. The effect of aerosol particle size, stream velocity, and mixing gas and particle size and particle/substrate composition on the removal efficiency will also be determined. The direction of the snow stream with respect to the surface will also be studied. The extent of recontamination problems identified by previous researchers will also be studied as a function of static charge, and moisture condensation.

### **Tasks**

1. Analytical modeling will be used to study the submicron particle removal process using CO<sub>2</sub> Aerosol.
2. Study the removal of particles (silica, alumina, PSL) from thermal oxide wafers using CO<sub>2</sub> aerosol.
3. Determine the effect of aerosol particle size, gas flow velocity, and particle size and particle/substrate composition on removal.
4. Study the effect of the flow direction with respect to the substrate orientation.
5. Study the removal of particles (silica and alumina) in post-CMP applications.
6. Assess the extent of recontamination problems as a function of static charge, and moisture condensation.