Proposal # 7: Nano and Microscale Particle Removal

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Goals and Objectives

The objective of the proposed work is to

- Develop an effective nanoscale particle removal technique using acoustic streaming.
- Provide a fundamental understanding of the removal mechanism that will be experimentally verified.
- Experimentally measure particle removal of particles in the size range of 10-100 nm from semiconductor wafers.
- Evaluate effect of streaming flow frequency, velocity amplitude and particle size and particle/substrate composition on the removal efficiency experimentally and numerically.

Problem Description:

With the International Technology Roadmap for Semiconductors decreasing particle removal requirements from 125 nm and a surface concentration 0.3-0.75 per cm^2 in 1997 to 25 nm and a surface concentration of 0.01 - 0.15 per cm^2 in 2011, the most challenging cleaning application requirements in semiconductor manufacturing is upon us. 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-µm DRAM process flow has 60 to 70 cleaning steps. In 0.18µm CMOS technology about 80 of 400 process steps will be cleaning[1]. Particles larger than about ¼ of the minimum line-width may cause fatal device defects. As semiconductor device geometry continue to shrink, (currently at about 0.18µm, will shrink to 70nm by the year 2008[2]) 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. Surfaces prepared for nanoscale applications such as deposition of monolayers or self-assembly of nanoparticles need to be completely free of any particulate contamination equal or smaller than a nanometer depending on the process tolerance. A physical, substrate independent, cleaning process is highly desirable since it does 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.). Thus innovative cleaning processes are needed to specifically target removal of strongly adherent, nano-scale particles.

Approach:

In order for current cleaning processes to meet the International Technology Roadmap for Semiconductors requirements, there is a need to understand the particle removal mechanisms and their limitations. The decreasing particle size down to the nano-scale level and its limiting effect on present surface cleaning techniques is the most dominant effect. Theoretically, it can be shown that the removal of nano-size particles (10-100 nm) can be accomplished using acoustic streaming at frequencies larger than 1 MHz (typically referred to as high frequency megasonics). One of the most important aspects of using acoustic streaming is the effect of the frequency on the boundary layer. As the frequency increases, the acoustic boundary layer thickness decreases and the streaming velocity increases. Both effects tremendously increase the drag force and consequently the particle removal moment. When the applied removal moment overcomes the adhesion moment, removal will take place. Experimental results show that complete removal down to 100 nm is possible using frequencies lower than 1 MHz[3-7]. However, physical noncontact substrate and particle independent removal of nanoscale particles is not well understood and no commercial techniques exist in the industry today for the removal of nanoscale particles.

The Removal of nanoscale particles is proposed to be studied experimentally as well as using physical modeling. Experimental studies will include the use of fluorescent polystyrene spheres to quantify particle removal as well as the use of scanning Auger methods and electron microscopy to image particles. The fluid flow field and particle transport will be modeled using a finite difference solution of the governing momentum conservation, acoustic streaming equations with associated boundary conditions and particle adhesion and removal models. Particle removal from substrates will be simulated using oscillating flow at high frequency.

A direct outcome of this research will be a rigorous relation of nanoparticle removal to the flow frequency, velocity and pressure amplitude (intensity). Understanding the fundamental mechanisms underlying nanoscale particle removal will determine the effectiveness and limitations of the proposed approach. Another one of our goals is to create an easy to use a physical model that will indicate the frequency and intensity required for different particles and substrates at the end of this research.

References:

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