Excimer Laser-Induced Removal of Particles from Silicon Surface and Effects of Photoacoustic Waves

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Introduction

The efficient removal of submicron particles from semiconductors surfaces is one of the most challenging tasks the microelectronics industry must face [1]. The laser cleaning technique demonstrates a high potential for this task, because of its high efficiency, simplicity, conformability to cluster tools, speed and low cost [2]. There are two laser cleaning methods. The first, called "steam" laser cleaning, has a high removal efficiency, made possible by the use of a thin liquid film. The second is dry laser cleaning which is simpler and has no intermediate medium [2].

We have made direct comparisons between the two variants in their capacities to remove submicron particles from silicon surface, using a KrF excimer laser emitting at 248 nm with a short pulse. A silicon surface is able to strongly absorb at this frequency, converting the laser energy to heat. In the dry process, this heat causes an instantaneous expansion of the surface by thermoelastic processes, capable of overcoming the adhesion force of the particles. Alternatively, this heat can be transferred to a layer of liquid deposited onto the surface, causing it to evaporate explosively. These processes excite photoacoustic waves (PAW) at the silicon surface. We have used a piezoelectric transducer to detect these PAW and analyze them by Fourier transform.

Experiment

The experimental setup is similar with that already described elsewhere [3]. The 100 mm <100> silicon wafer samples were made hydrophilic using the SC1 recipe [3], then contaminated by 0.2 μm Al_2O_3 or 0.1 μm SiO_2 particles using a particle generator (Particle Measuring System Inc.). The surface were then irradiated in ambient air with KrF excimer laser pulses (wavelength: 248 nm, pulse duration: 24 ns). To evaluate the cleaning efficiency, a laser scanning surface inspection system (Particle Measuring System Inc., SAS 3600) was used to classify particles on the wafer surface. A broadband piezoelectric transducer (Panametrics , V1091) contacted the backside of the wafer, with vacuum grease as the coupling medium. The PAW signal was displayed on a digitizing oscilloscope (HP 54201D), and the data were analyzed by computer.

Results and Discussion

The removal efficiency analysis was carried out in a 30 mm circle inside a 50×50 mm^2 cleaned square. In Fig.1, the particle densities of silica and alumina on the wafer surface are given, as a function of their size distribution, before and after four cycles of dry laser cleaning scans. The laser energy flux was 314 mJ/cm^2. After laser cleaning, the particle densities were not much reduced. The van der Waals force is one of the adhesion forces holding oxide particles on the substrate surface. In a humid ambient air environment, capillary forces and chemical bond (hydrogen bond) must be considered [4,5,6]. They are much larger than the van der Waals force for small particles [7]. The removal force, induced by a laser pulse whose flux was kept below the damage threshold of the silicon surface, is not strong enough to overcome the adhesion force, so most particles bound to the substrate surface cannot be removed.

For steam laser cleaning, the particles were covered by a thin film of water. Through electrostatic shielding, the van der Waals force is reduced, in our case, by about a factor of two [7]; the capillary forces are nullified and chemical bonding between particles and substrate are reduced. Therefore, the overall adhesion force is reduced by an order of magnitude or more. The steam laser cleaning results are shown in Fig.2. The laser flux was 180 mJ/cm^2, and four cycles of cleaning scans were used. In this case, most of the particles were removed. The remaining particles may come from several sources: recontamination by the ejected particles near the surface, a transfer from adjacent uncleaned areas; original particles having strong adhesion to the substrate surface.

The PAW signal detected during steam cleaning was about two times greater those during dry cleaning at a laser energy flux 180 mJ/cm^2. The Fourier transform spectra of the PAW during dry and steam cleaning are shown in Fig.3, where there is no evidence of stronger high frequency peaks during steam cleaning. It can be demonstrated that the superheated liquid induced by the laser pulse generates explosive bubble growth and collapse, which create larger removal forces for ejecting particles from the substrate surface [8,9]. Thus, steam cleaning has a much higher cleaning efficiency because the presence of a liquid film can greatly reduce adhesion forces and its explosive evaporation can generate larger removal forces.

References

[1] W. Kern, in *Handbook of Semiconductor Wafer Cleaning*, edited by W. Kern (Noyes Publications, Park Ridge, NJ 1993), p.3, 68 and 595.

[2] A. C. Tam, W. P. Leung, W. Zapka and W. Ziemlick, J. Appl. Phys. **71**, 3515 (1992).

[3] S. Boughaba, X. Wu, E. Sacher and M. Meunier, J. Adhesion **61**, 293 (1997).

[4] M. B. Ranade, Aerosol Sci. Technol. 7, 161 (1987).

[5] R. K. Iler, in *Surface and Colloid Science*, Vol. 6, edited by Egon Matijevic, (Wiley-Interscience, New York, 1973), p.3.

[6] S. R. Morrison, in *The Chemical Physics of Surfaces*, (Plenum Press, New York, 1977), p.133.

[7] R. A. Bowling, J. Electrochem. Soc. **132**, 2208 (1985).

[8] H. K. Park, D. Kim, C. P. Grigoropoulos and A. C. Tam, J. Appl. Phys. **80**, 4072 (1996).

[9] O. Yavas, A. Schilling, J. Bischof, J. Boneberg and P. Leiderer, Appl. Phys. **A 64**, 331 (1997).

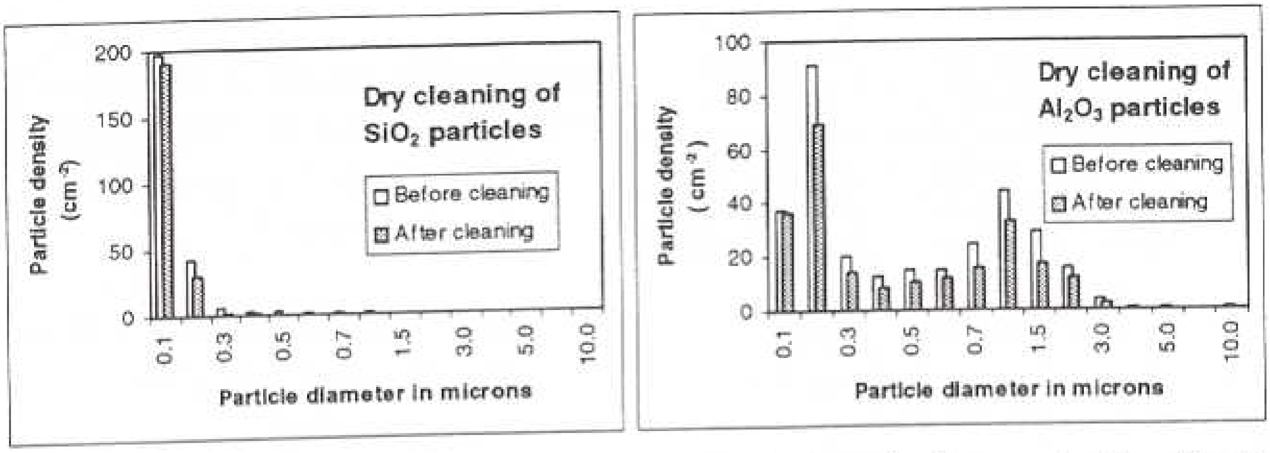

Fig.1 Particle densities of silica and alumina before and after dry laser cleaning, as a function of particle diameter. The laser energy flux was 314 mJ/cm^2 and four cleaning scans were used.

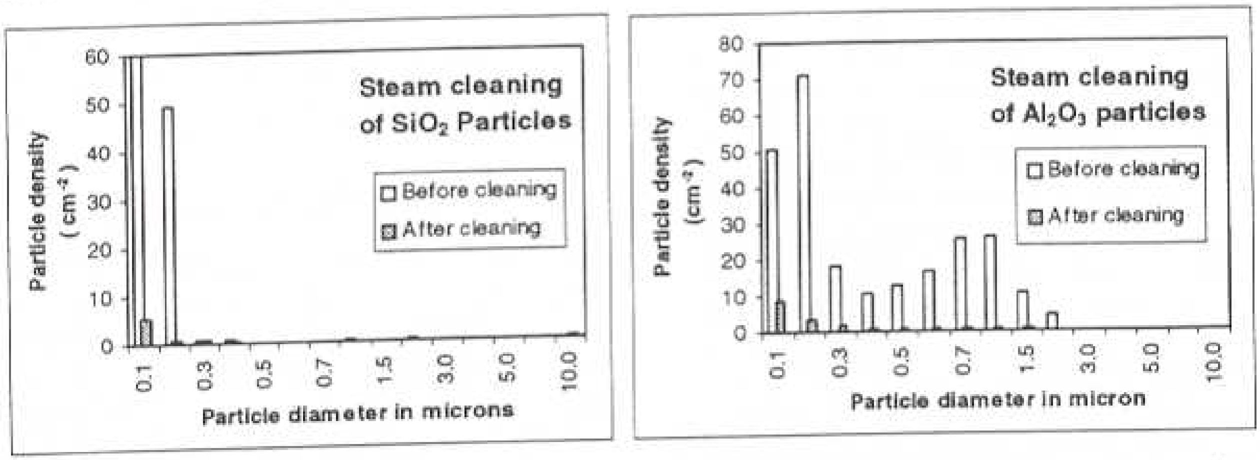

Fig.2 Particle densities of silica and alumina before and after steam laser cleaning, as a function of particle diameter. The laser energy flux was 180 mJ/cm^2 and four cleaning scans were used.

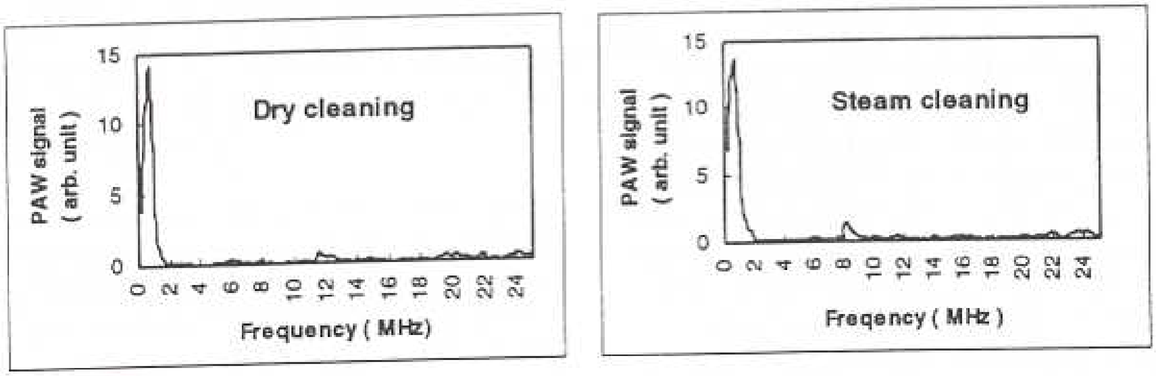

Fig.3 Normalized frequency spectra of the PAW signals for dry and steam laser cleaning. The laser energy flux was 348 mJ/cm^2.