REMOVAL OF NANO-PARTICLES BY USING MEGASONIC CLEANING

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ABSTRACT

Megasonic cleaning is a well-established technique for particle removal in the semiconductor industry. As the critical dimensions of the devices scale down, new targets for cleaning should be set in order to obtain high yield. One of them is the removal of particles down to 50nm. Tests were performed to evaluate the impact of parameters as gas concentration and chemical composition of the megasonic medium. The experimental results confirm the need for the presence of gas, to obtain removal in general. We can also confirm that particles down to 30nm can be removed on some areas.

INTRODUCTION

In the semiconductor manufacturing, the removal of different contaminants, classified as trace metals, organic matter and particles [1] is important to obtain a high process-yield and reliable circuits. As the critical dimensions of the devices scale continuously down, new targets for cleaning should be set. Consequently smaller particles should be removed. So is the critical particle size defined as half the technology node; at 100nm design rules (to be introduced in 2003), cleaning should be tuned for nano-particles with a diameter down to 50nm [2].

The first systematically developed silicon wafer cleaning process is the RCA-clean, introduced in 1965 [3]. This process is based on a 2-step wet-oxidation and complexing treatment in aqueous alkaline (H_2O_2-NH_4OH) and acidic (H_2O_2-HCl) mixtures at 75-80ºC. In a later stage 'ultrasonic energy' which uses high frequencies (0.8-1MHz, hence the term Megasonics) was added to a standard chemical solution, allowing higher dilution and lower heating [4]. Since then, the reduction of the number of process steps and of costs is under continuous investigation [5,6]. Research is also continuing to get a deeper insight in the mechanisms behind particle removal in a megasonic energy field.
In general it is believed that the particle removal is a 2-step process:

1. To overcome the van der Waals-forces (to detach from the surface)
2. To transport them away from the surface and to prevent redeposition.

Different research groups propose different mechanisms for each step [7-9], they will be discussed in the experimental part of this paper. The purpose of this paper is to discuss experimental data for nano-particle removal under different conditions in a megasonic energy field.

EXPERIMENTAL

Experimental studies on the particle removal efficiency are performed on 200mm Si wafers (p-type, <100>, Cz) in a batch type Megasonic Quartz tank. Eight flat array piezo-electric transducers are present at the bottom of the tank. They are fired two by two over 300s and produce a pressure wave fixed at 726 kHz with adjustable power (0-7W/cm^2). The particle measurements on the unpatterned wafers are performed using a KLA-Tencor SP1^{DLS} light scattering inspection tool. The signal from the scattered light reveals information about the haze (low frequency signal) and defect events (Light Point Defects). By optimizing both signals, particles from 30nm and larger can be detected [10]. Wafers were intentionally contaminated with SiO_2 slurry particles of different diameters: 30nm, 80nm, 140nm and 300nm, all considered to be challenging particles for the next generation of cleaning processes.

The controlled contamination in combination with the light scattering inspection tool, allows us to evaluate the particle removal efficiency for a wide range of conditions. The megasonic tank is installed in combination with a degassification system (Hoechst Liquicel membrane contactors), in order to remove dissolved gasses from the ultra pure water. Downstream the degassification unit, a gassification unit is installed, to add different gasses (O_2 in this case) and a spiking unit, to add different chemicals (NH_4OH, Tetra-Methyl-Ammonium-Hydroxide (TMAH), H_2O_2…) as shown in figure 1. All experiments are performed in a cleanroom class 1000. The system is supplied with Ultra Pure Water (UPW) and all chemicals are available in highest purity.

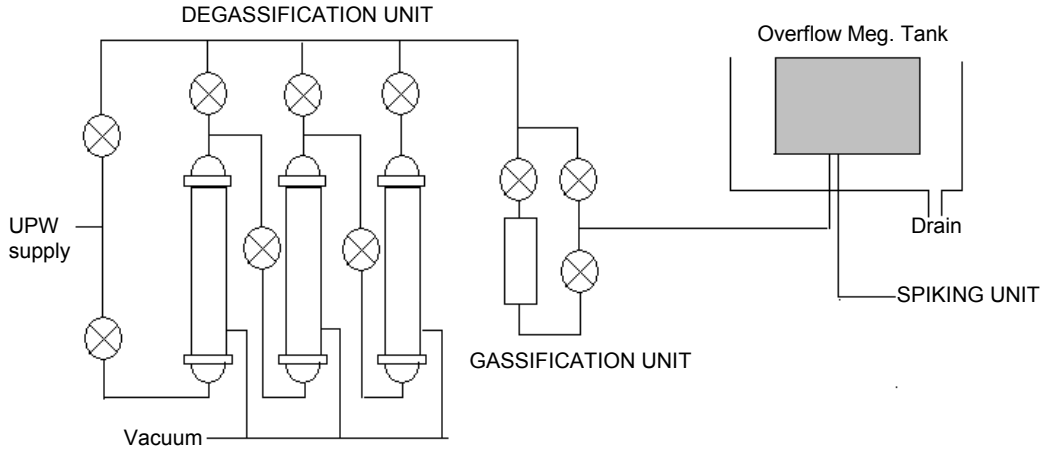

Fig. 1: Experimental set-up for megasonic tests.

RESULTS AND DISCUSSION

The combination of the experimental megasonic set-up, where a degassification unit is present, and the evaluation technique for particle removal made it possible (as shown in figure 2) to evaluate the role of dissolved gasses. Experiments with different particles (30-300nm), in either degassed

(<500ppb O_2) or oxygenated (20ppm) UPW show clearly that the presence of gas is a must to remove particles. This means that cavitation, understood as the formation and activity of bubbles in a liquid [11], plays a major role in the megasonic cleaning process. Theoretically D. Zhang [12] showed already that the comparison of the adhesion forces (van der Waals forces) with the drag forces generated by large scale acoustic streaming are not indicating any cleaning performance unless cavitation is considered.

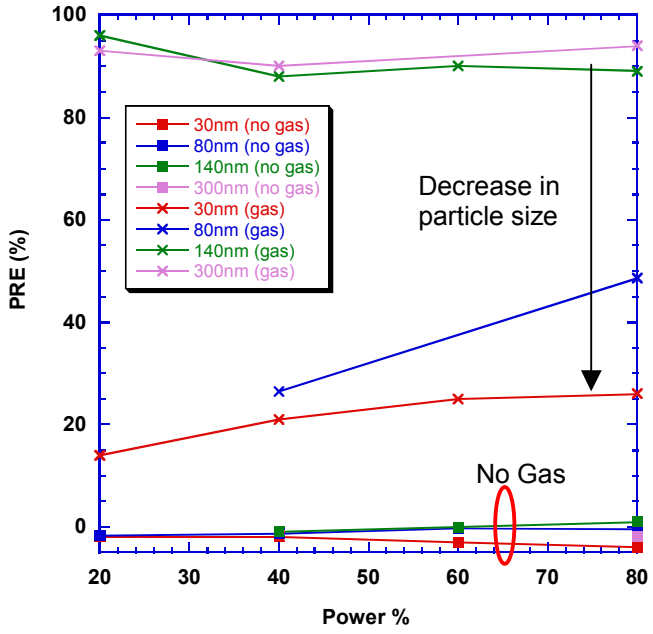

Fig. 2: Particle Removal Efficiency (%) for different SiO_2 particles (diameters: 30-300nm) in degassed or oxygenated UPW. Megasonic power set at 80%.

Results also show that the removal of particles becomes more difficult as the particle size decreases. A similar trend was found earlier for particles >0.3µm and is now confirmed for smaller particles [13]. It is shown in figure 3 that the lower particle removal efficiency is due to insufficiently cleaned regions. Regions of complete particle removal are alternating with regions of no particle removal. This is shown in fig. 3 A for 140nm particles (LPD map $SP1^{DLS}$) and in B for 30nm particles (haze map $SP1^{DLS}$). The regions of minimal particle removal are found to be close to the transducers (near field region), where the intensity of the megasonic energy is minimal and unstable, as shown in figure 4. Observed is also the non-linearity of the power variation.

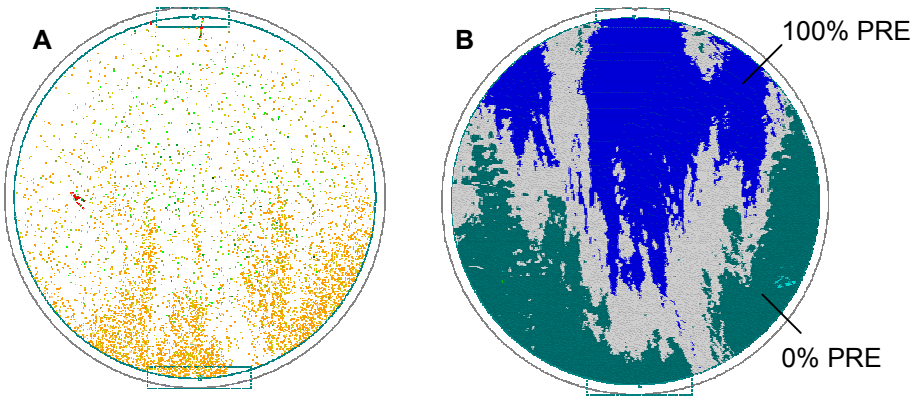

Fig. 3: Light scattering wafermaps after Megasonic batch clean for LPDs: 140nm (A) and haze: 30nm (B) in oxygenated UPW.

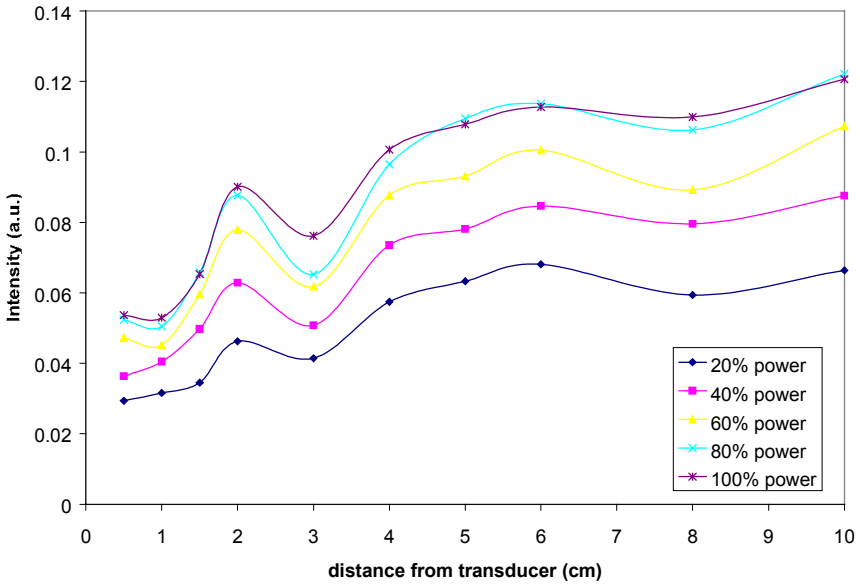

Fig. 4: Intensity of main frequency (1st Harmonic) in the tank, measured with a hydrophone, related to the distance from the transducer.

Improved particle removal uniformity can be obtained when the surface is better accessible. This can be achieved by a single wafer approach, where the wafer is spun under a megasonic source, as shown in figure 5, where system A represents a single wafer tool and B a tank tool. The tests were done in a diluted aerated SC1 mixture (1:1:50). Shown is that a good removal is obtained, also for smaller particles, spread over the entire wafer, for the single wafer cleaning system.

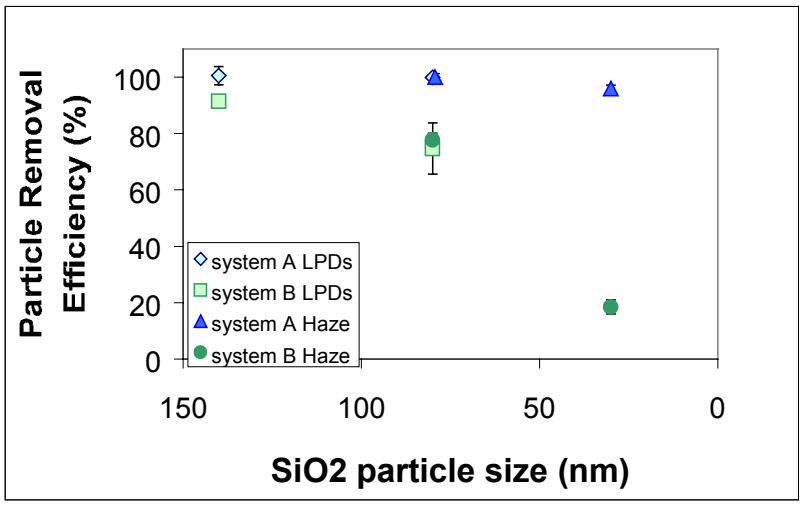

Fig. 5: Comparison between single wafer (system A) and batch system (system B) for Particle Removal Efficiency (%) in SC1 (1:1:50 @20ºC), followed by rinse and Marangoni dry.

The traditional way to overcome the van der Waals forces is the under-etch of the particles [7]. Most of the megasonic cleaning processes are performed in diluted aqueous alkaline solutions. Knowing that the OH^--concentration plays a major role in the etch mechanism, some tests were done to evaluate the particle removal efficiency of different diluted mixtures (NH_4OH - H_2O and TMAH - H_2O). They were combined with megasonics in a degassed or O_2 (20ppm) ambient. Shown in figure 6 is that from pH 9 and beyond, the under-etch is playing a role in the particle removal mechanism (for 5min processes). Etching is not the purpose of megasonic cleaning, since this will also cause roughening of the substrate. The goal of adding chemicals is to obtain electrostatic repulsion, this means equal charges on the particle and the substrate. The presence of NH_4OH without gases has no influence for the removal of SiO_2-particles. TMAH can play a role, by etching SiO_2-particles from the surface. Again, it is shown that cavitation is the main mechanism to remove particles from the substrate. We can conclude that we can work in very diluted chemistries

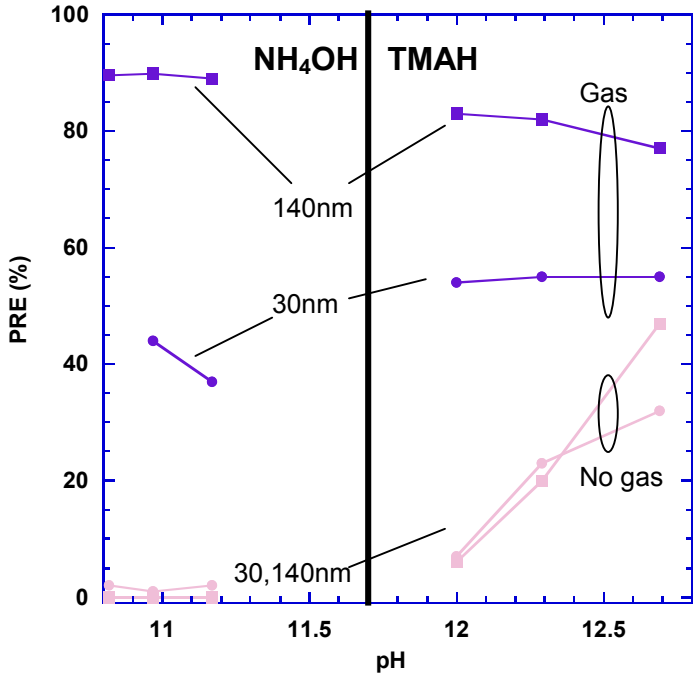

Fig. 6: Role of OH^- in the particle removal process for NH_4OH and TMAH for degassed and oxygenated UPW. For 30nm and 140nm particles.

CONCLUSIONS

The dominating effect in the particle removal process by using megasonics, is cavitation due to the presence of dissolved gasses in the liquid. Experimental data show also a decrease in cleaning efficiency for smaller particles in tank systems. Certain regions, closer to the transducer, are difficult to clean. This can be related to the lower intensity of the megasonic energy in the near-field area. Working in diluted alkaline chemistries gives promising results for particle removal.

REFERENCES

[1] W. Kern, 'Handbook of Semiconductor Wafer Cleaning technology', Noyes Publications, New Jersey (1993).
[2] See The International Roadmap for Semiconductors, Semiconductor Industry Association; see also http://public.itrs.net/ for the most recent updates (2001).
[3] W. Kern *et al.*, RCA Review, 31, 187 (1970).
[4] A. Mayer *et al.*, Journal of Electronic Materials, 8 (6), 855-864 (1979).
[5] M. Meuris *et al.*, 3rd Int. Symp. Cleaning Technol. In Semic. Dev. Manuf., 184th ECS Symposium (1993).
[6] T. Ohmi, 5th International SCP Symp. (1998).
[7] M. Meuris *et al.*, Jpn. J. Appl. Phys., 31 (1992).
[8] A. A. Busnaina *et al.*,Proceedings Third International Symposium on Ultra Clean Processing of Silicon Surfaces, Antwerp, Belgium (1996).
[9] T. Kujime *et al.*, Proceedings Third International Symposium on Ultra Clean Processing of Silicon Surfaces, Antwerp, Belgium (1996).
[10] K. Xu *et al.*, Proceedings Sixth International Symposium on Ultra Clean Processing of Silicon Surfaces, Oostende, Belgium (2002).
[11] L.D. Rozenberg,`High Intensity Ultrasonic Field`, Plenum Press, New York-Londen (1971).
[12] D. Zhang, ´Fundamental Study of Megasonic Cleaning´, Ph.D. Dissertation, University of Minnesota (1993).
[13] G.W. Gale *et al.*,Particulate science and Technology, 13, 197-211 (1995).