MINIMIZING OXIDE LOSS IN IMMERSION SC1 PROCESS

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Particle removal efficiency is studied as a function of several different SC1/megasonics parameters while trying to maintain oxide loss at less than 1Å. It is found that high particle removal efficiency can be maintained down to oxide loss levels of 3Å in a spray acid tool. Below this level of oxide loss particle removal efficiency is greatly reduced for both spray and immersion tools. There is also a dependence on dissolved gas where high and low levels of dissolved gas cause a reduction of particle removal, while an intermediate level, corresponding to about 450 ppb of dissolved oxygen gives optimal particle removal. With tank modifications, megasonics energy can be used to remove particles with an oxide loss of 1Å and without damaging 60nm wide polysilicon lines with an aspect ratio of over 3.0.

INTRODUCTION

In current integrated circuit manufacturing processes, the gate electrode and surrounding surfaces are subject to increasing cycles of implant mask ashing and cleaning. This is being driven by the desire to have transistors with several different threshold voltages on the same chip. Since each different type of transistor needs several different implants, there can be up to 15 implant masks, each with subsequent ashing and cleaning, after the gate electrode has been formed. With the simultaneous decrease of the gate electrode width, this is posing a challenge for post-ash cleaning, which is targeted at removing ashing residues as well as particle contaminants. Traditional megasonics is not currently used at this stage in device manufacturing because it causes damage to gate structures narrower than 100nm. Consequently, increased material removal (etching) is required in order to achieve sufficient particle removal efficiency. However, the increasing number of cleaning steps is forcing a reduction in the allowable amount of material removed. The sequence of ashing and cleaning also causes the silicon surface to be oxidized and then etched away. These issues are illustrated in Figure 1, which shows the cross-section of a 90nm node transistor indicating areas of concern for material loss. The challenge for cleaning devices currently in production is to achieve sufficient particle removal efficiency while controlling the amount of material loss and avoiding damage to the gate electrode. Current manufacturing processes are requiring less than 1Å of thermal oxide loss per cleaning cycle with less than 0.5Å being specified in just a few years.

The ammonium hydroxide / hydrogen peroxide / water solution, also known as SC1, is the predominant chemistry for achieving particle removal in front end cleaning. When sensitive structures are not present, megasonics energy is applied to assist in particle removal. Without megasonics energy, surface etching is required to detach particles. There have been many studies of the SC1 chemistry over the 30 years since it was first introduced by Kern and Poutinen [1]. Some studies have focused on the surface effects of SC1, measuring the etching rate of silicon and silicon dioxide as well as surface roughening [2-5]. Other studies have focused on particle removal as a function of SC1 parameters [6-7] without studying the influence of material loss. Meuris and co-workers found that a minimum removal of 20Å of oxide was required to achieve more than 95% particle removal at >0.2 microns while immersing wafers in dilute HF without megasonics energy [8]. Christenson and co-workers found that removal of 15-20Å of oxide was required to achieve 99% particle removal at >0.15 microns while spray wafers with SC1 solution in a spray acid tool [9-10]. More recent studies by Meuris et al. [11] and Vos et al. [12] have also proposed that a minimum removal of 30Å of oxide is required to achieve sufficient particle removal. This level of oxide removal is clearly not acceptable for post-ash cleaning with integrated circuits now in production.

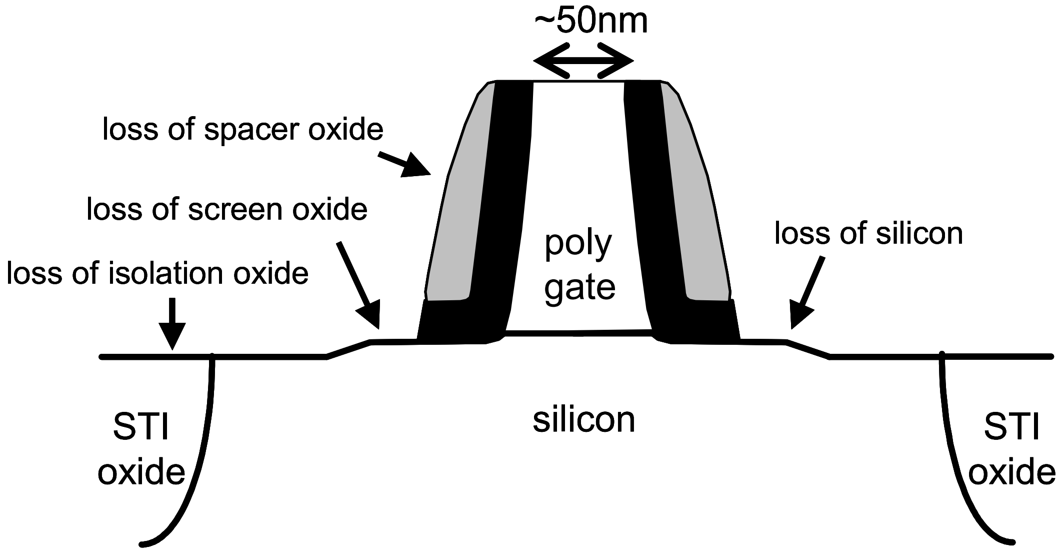

Figure 1. Typical 90nm technology node transistor structure indicating areas of material loss during cleaning processes.

The focus of this study is to investigate the effect of SC1 and megasonics tank parameters on particle removal efficiency while maintaining very low oxide removal. The goal is to achieve high particle removal efficiency while avoiding damage to the gate electrode.

EXPERIMENTAL

A four-variable, three-level Box-Behnken experimental design was used for the main study. Megasonics power (400W, 1200W, 2000W), SC1 temperature (25ºC, 40ºC, 55ºC), SC1 dilution (1:1:50, 1:1:125, 1:1:200), and solution degassing (0, 10, 20 inches Hg vacuum) were the controlled variables. Particle removal efficiency was measured for silicon nitride particles which were wet deposited on bare-300mm wafers (with SC1 chemical oxide present), allowed to "age" for 24 hours, and analyzed using a KLA-Tencor SP1 for nominal sizes greater then 90nm. For the particle removal tests, the challenge wafers were processed in full, 52-wafer batches, and were run for 2 minutes for each of the experimental design conditions. For each condition, the SC1 step was followed by 2 cycles of quick dump rinsing and a final surface tension gradient dry. Oxide loss was measured separately on thermal oxide wafers for each combination of SC1 temperature and dilution in the experimental design. A flat-bottom quartz tank was used with a 4-quadrant megasonics transducer attached to the bottom. Preliminary data was also collected without megasonics energy and also with SC1 solutions dispensed in a spray acid tool to gain a better understanding of the etching effect, alone. Also, a final test of tank modifications was run to demonstrate elimination of megasonics damage to sensitive polysilicon structures.

RESULTS AND DISCUSSION

The preliminary results without megasonics and also with a spray acid tool are shown in Figure 2. For the spray acid tool, particle removal efficiency stayed high for oxide losses down to 3Å. Below 3Å of oxide loss in the spray tool, particle removal efficiency drops of significantly, down to about 30% for a 1Å oxide loss. For the immersion tank without megasonics, removal efficiency falls off at a higher oxide loss level. At 3Å oxide loss, the removal efficiency in the immersion tank without megasonics is only 60%. This difference between the spray tool and the immersion tank without megasonics indicates the influence of flow dynamics on particle removal. In the spray tool, centrifugal forces are used to propel chemical and water off the wafer surface at high velocity reducing the distance which particles much diffuse away from the surface and enhancing their removal. Also, it should be noted that the fall off in particle removal efficiency for these 90nm particle tests occurs at a much lower oxide loss than that indicated by previous studies which measured removal efficiency at >200nm [8] and at >150nm [9-10]. One possible explanation for this difference is that smaller particles might be more easily undercut, requiring less oxide removal, than larger particles.

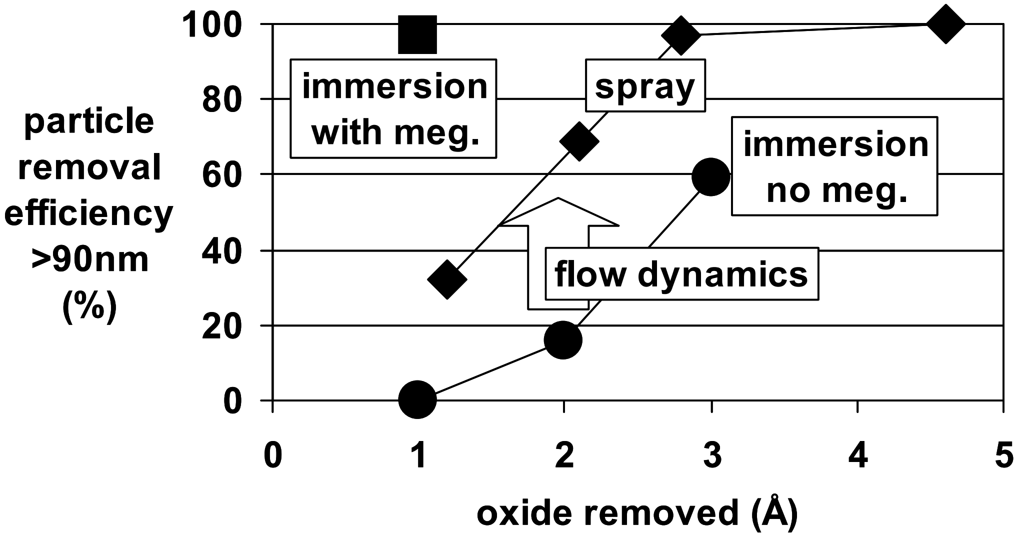

Figure 2. Preliminary studies of particle removal as a function of oxide loss in SC1 solutions in a spray tool (◆) and in an immersion tank without megasonics (●). For comparison, particle removal in an immersion tank with full megasonics power is also shown (■).

The results of the designed experiment indicate that particle removal efficiency is a strong function of megasonics power and of SC1 solution temperature, increasing with both parameters, and only a weak function of SC1 dilution. The dependence on megasonics power is as expected. The dependence on temperature is most likely linked to the increase in oxide loss with the increase in temperature. Figure 3 shows the thermal oxide loss dependence on both temperature and SC1 dilution. It is evident that SC1 dilution over this range has a very weak effect on oxide loss and thus on particle removal.

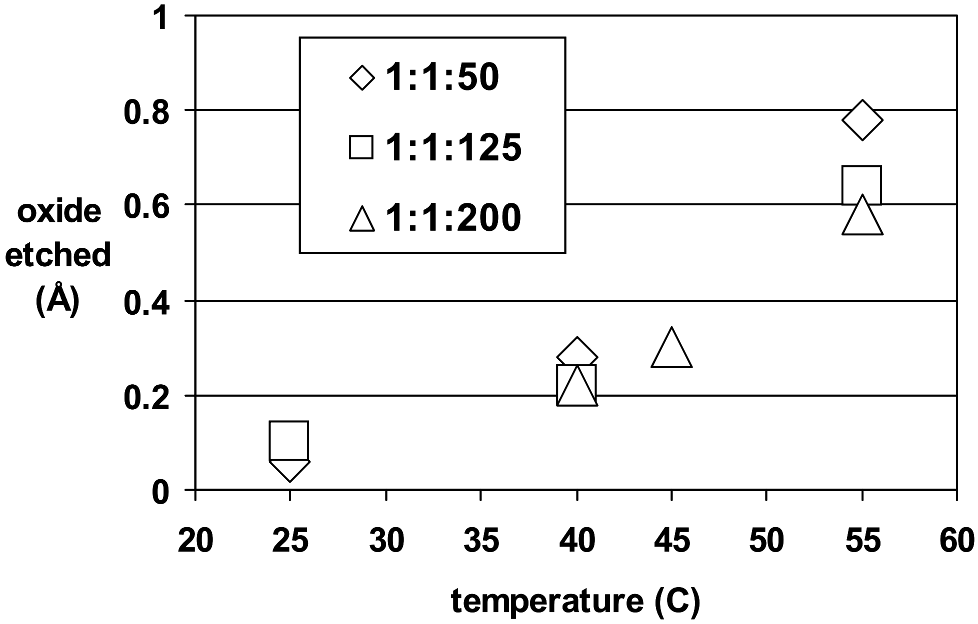

Figure 3. The dependence of oxide loss on SC1 temperature and SC1 dilution. It is evident that oxide loss is only a weak function of SC1 dilution, but a strong function of temperature in this range of parameters.

The dependence of particle removal efficiency on dissolved gas is very interesting. As the dilution water is degassed, the particle removal efficiency initially rises as shown in Figure 4. However, at a certain point, corresponding to a dissolved oxygen level of about 450 ppb, the particle removal efficiency falls sharply with further decreases in dissolved gas level. One possible explanation is that at high dissolved gas levels, most of the megasonics energy is used to create bubbles that collapse near the bottom of the tank. As the dissolved gas levels are reduced more energy is transmitted to the top of the tank and the entire surface of the wafer is cleaned. However, if the dissolved gas levels are reduced too much, cavitation bubbles will no longer form and the megasonics energy will be simply transmitted to the top of the tank without dislodging any particles.

Figure 5 shows the dependence of particle removal efficiency on oxide loss at 1200W and at two different dissolved gas levels. The particle removal efficiency decreases with lower oxide loss even with megasonics energy applied to the wafer.

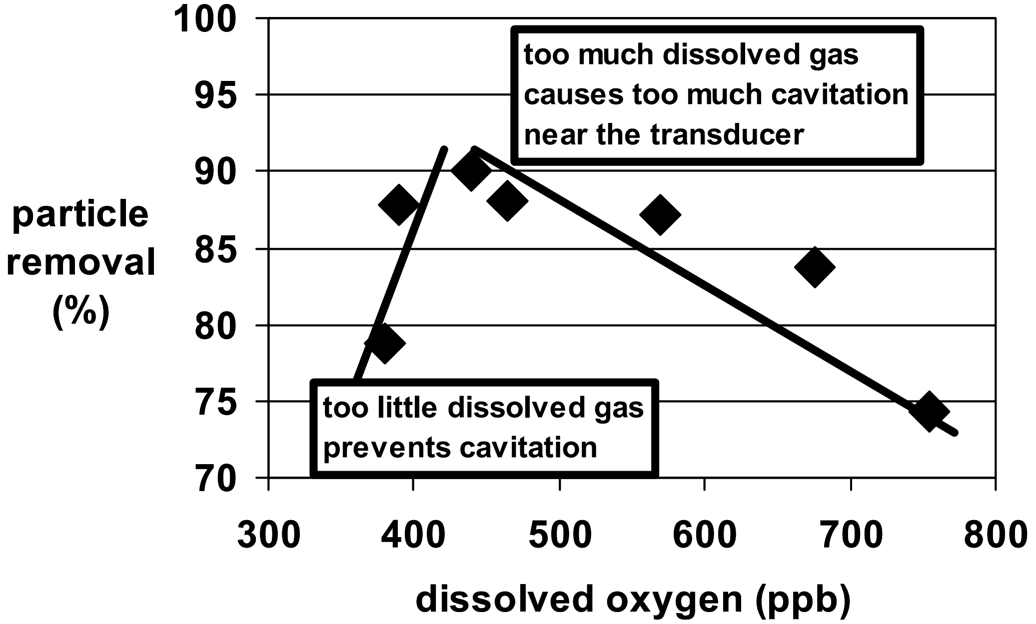

Figure 4. The dependence of particle removal efficiency on dissolved gas content.

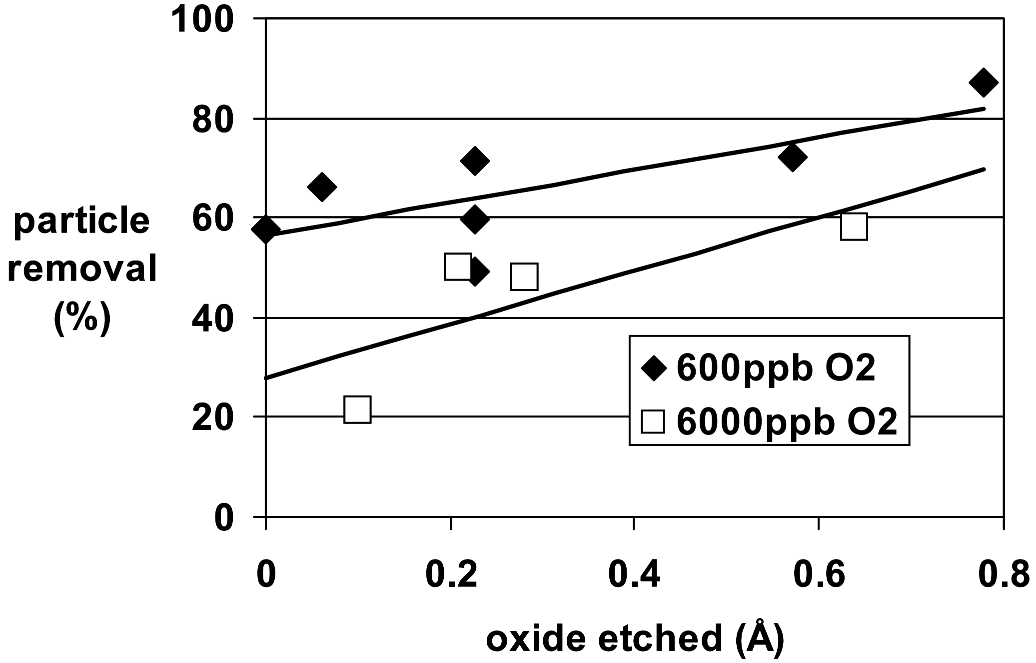

Figure 5. The dependence of particle removal efficiency on oxide loss with 1200W megasonics energy and at two different dissolved gas levels.

The final question is whether megasonics can be applied at these conditions to achieve particle removal without damaging sensitive structures. Tests were carried out using dense arrays of polysilicon lines which were 60nm in width and 220nm in height. While a traditional megasonics configuration caused significant damage to these lines, a modified megasonics configuration that was able to achieve 80% removal of 90nm silicon nitride particles with a 1Å oxide loss, did not cause any observable polysilicon line damage. Additional work is required to demonstrate efficient, non-damaging particle removal on actual production integrated circuits with oxide removal of 0.5Å.

CONCLUSIONS

Several aspects of particle removal in low oxide etching SC1 solutions were studied. By comparing the removal efficiency in a spray tool with that of an immersion tank without megasonics, the importance of fluid dynamics becomes evident. It was also shown that with oxide loss of less than 3Å megasonics energy is required to efficiently remove particles. Finally, particle removal can be achieved with low oxide etch and without damage to sensitive structures through optimization of multiple parameters including megasonics energy distribution and dissolved gas content.

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KEY WORDS

Page 1 : particle removal, SC1
Page 2 : megasonics, material loss
Page 3 : oxide loss, spray, immersion
Page 4 : dissolved gas, cavitation
Page 5 : particle removal, oxide loss
Page 6 : damage, polysilicon line