Solid State Phenomena Vol. 195 (2013) pp 185-190

doi:10.4028/www.scientific.net/SSP.195.185

Removal of Fine Particle using SAPS Technology and Functional Water

David H. Wang[1, a], Yue Ma[1], Fuping Chen[1], Liangzhi Xie[1], Xi Wang[1], Xiaoyan Zhang[1], Juyoung Lee[2], Dongjoo Kim[2], Jeongyun Lee[2], Pyo Leem[2], and Geunmin Choi[2]

[1] ACM Research (Shanghai), Inc.

[2] Hynix Semiconductor

[a] Email: dwang@acmrcsh.com

Keywords: Particle removal, Functional water, SAPS megasonic technology

Introduction

Space alternated phase shift (SAPS) megasonic technology incorporating with functional water, with dissolving gases H_2 or N_2, was applied to remove fine particle in wet cleaning processes of semiconductor manufacturing in this study. The performances of particle removal were investigated quantitatively by varying the parameters of functional water and megasonic energy. The optimized cleaning performance was further proved with significant yield improvement of mass production by comparison with other main cleaning technology.

In semiconductor manufacturing, in order to removal impurities such as small particles, residual chemicals, and contaminations in trench and via, a wet cleaning step is necessary. Especially, when device manufacture node migrating to very integrated devices, it is important to use dilute chemicals or de-ionized water only to reduce or eliminate the material loss. However, the dilute chemical or de-ionized water usually is not efficient to remove fine particle from the surfaces.

Functional water was used for wet cleaning process in semiconductor manufacturing instead of RCA cleaning due to its advantage of reduction in cost and environment pollution in recent years. It refers to those solutions dissolving specific gases, such as the hydrogen, oxygen, nitrogen or ozone, into water containing a small amount of chemicals such as ammonia [1]. The radicals for impurity removal are generated in those solutions, and the radical generation is promoted by water excitation under megasonic irradiation [2]. Furthermore, the mechanical force of bubble cavitations generated by megasonic also improves the particle removal capability during the cleaning process. In addition, the functional water can be used in cleaning process for metal film, such as tungsten, preventing the material loss resulted from the addition of H_2O_2 in traditional SC1 solution.

In this paper, the method of space alternated phase shift (SAPS) megasonic technology incorporating with functional water is applied for fine particle cleaning process. The SAPS technology provides uniformly sonic energy on each point of entire wafer by alternating phase of megasonic wave in the gap between a megasonic device and the wafer. Two types of dissolving gases, H_2 or N_2, are under investigation. The influence of the process parameters, including dissolving gas concentration, dilute chemical concentration and megasonic energy, was studied and optimized. The results show that this technology has a high efficiency in fine particle removal, especially particle diameter less than 65nm, while with the minimal damage to the structures.

Key Process Parameters Influence on Particle Removal Capability

The influence of the key process parameters on the Particle Removal Capability is important. The main parameters of the cleaning process are concentrations of functional water's dissolving gases, dilute chemicals and megasonic energy. A series of DOE tests (design of experiment) are done to analyze the parameters and further to optimize them.

Table Ⅰ shows the parameters used in the DOE for a specific application of SAPS technology and function water. Here, the function water contains dissolving N_2 gas and very dilute NH_4OH. The megasonic intensity increases from P_1 to P_2, standing for the nominal power of megasonic, and $P_1<P_2$. The DOE is based on the cleaning process on the bare wafer with particle number less than 30. The particle size under the inspection is in the range of above 44nm.

Table I: Parameters Used in DOE

Parameters	Range
Dissolving N_2 concentration	3-14 ppm
Dilute NH_4OH concentration	5-30 ppm
Megasonic power	P_1-P_2

Figure 1 shows the impact intensity of the key parameters on particle removal capability, which is estimated by DOE model. The top three impact factors are N_2 amount, NH_4OH amount & Mega Power interaction and N_2 & NH_4OH amount interaction under the range of investigation. The effect of these parameters is complicated, and the interaction between them works significantly. The OH radicals can be generated by dissolving N_2 and dilute NH_4OH, and this generation is maximized at a certain range of N_2 concentration. The generation of the OH radicals from the water excited by megasonic irradiation is strongly affected by the dissolving gases species [2]. In addition, as the solution's pH increases with the small amount of ammonia addition, the zeta potentials of the surface move to a more negative value. The repulsive electrostatic force between particle and surface helps the particle escaping from the wafer [3]. And the mechanical force of bubble cavitations generated by megasonic and dissolving N_2 also assists in particle removal.

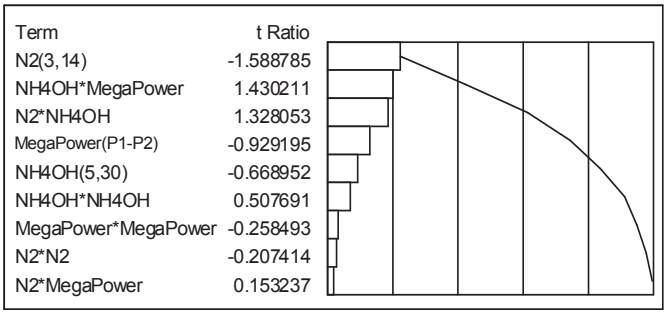


Figure 1: Impact Intensity of Key Parameters on Particle Removal Capability

In this study, the SAPS megasonic and functional water with dissolving H_2 gases is also investigated and optimized by the parallel DOE tests. It has better particle removal efficiency than that with dissolving N_2 gases. During the process, megasonic irradiation generates both OH radials and H radials from ultra pure water, and these OH radials further react with the dissolving H_2 gases to generate more H radials. In this instance, the H radials are the active species contributing to the particle removal. They achieve higher particle removal efficiency due to their feature smaller than OH radicals [4]. A specific case to compare the particle removal efficiency with these two species of dissolving gases, N_2 and H_2, is described in the following text.

Further Tests to Confirm the Feasibility of SAPS technology and Functional Water process

Some further tests are done to confirm the feasibility of the optimized SAPS technology and functional water process.

To find the safe window of this process, a series of test are done on the wafers with pre conditions the same as above DOE test. Figure 2 shows the number of removed particles under the optimized dissolving gas and dilute chemical concentration while the megasonic power varying from 0 to P. It indicates three periods with different removal mechanism: chemical domination and megasonic

assistant removal when megasonic power increasing from 0 to P_a; megasonic domination and chemical & gas assistant removal when megasonic power increasing from P_a to P_b; megasonic domination removal when megasonic power above P_b. Here the P_a, P_b are nominal power of megasonic, and $0<P_a<P_b<P$. The middle period with the megasonic power from Pa to P_b shows a good cleaning performance. This window is wide enough to be feasibly controlled and adjusted during the production.

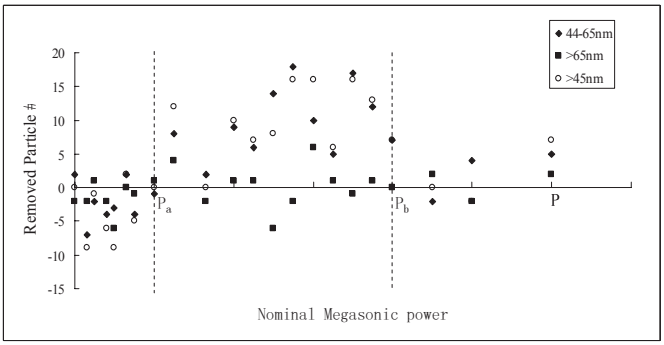


Figure 2: Megasonic Power Windows

The etch rate test of the optimized SAPS technology and functional water condition is done on thermal oxide (TOX) wafer with 1000Å thick and CVD tungsten wafer with 70Å thick respectively, and the functional water process time is 48sec. The result shows no obvious etch rate for TOX wafer and CVD tungsten wafer. The etch rate for TOX wafer is less than 0.4 Å/min, which meets the target for dilute cleaning chemical for TOX. The etch rate is less than 5 Å/min for CVD tungsten wafer, which is very slight comparing to traditional SC1 solution.

Comparison of Particle Removal Efficiency between SAPS Technology Incorporating with Functional Water and Other Main Cleaning Technologies

The comparison between the SAPS technology incorporating with functional water and other mainstream cleaning technology is carried out by Particle Removal Efficiency (PRE) test with wafers pre deposited with thousands of Si_3N_4 particles, ageing several days.

Table Ⅱ shows the different applications of SAPS megasonic technology coupled with functional water cleaning. The dissolving gas is selectively used as H_2 or N_2. The dilute NH_4OH is added or not. The megasonic power is applied at comparatively low level or medium level.

Table II: SAPS Technology and Functional Water Applications

Application	N_2	H_2	NH_4OH	Low Mega	Medium Mega
1		X	X	X	
2		X	X		X
3		X		X	
4	X			X	
5				X	

Figure 3a and 3b shows the results of the comparison. The best application of them, Application-2 with dissolving gas H_2, dilute NH_4OH and medium megasonic power, obtains 96% PRE for particle size>65nm and 89% PRE for particle size>44nm. It also shows a significant enhancement for the removal efficiency of fine particles below 65nm.

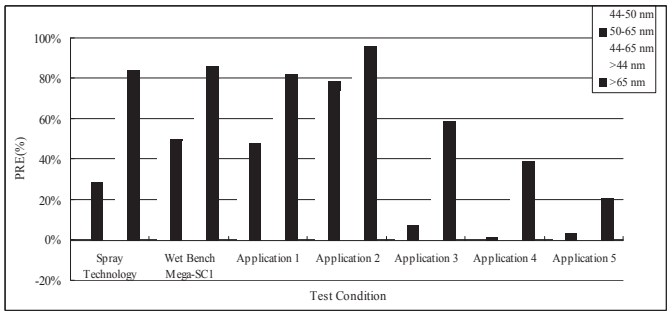
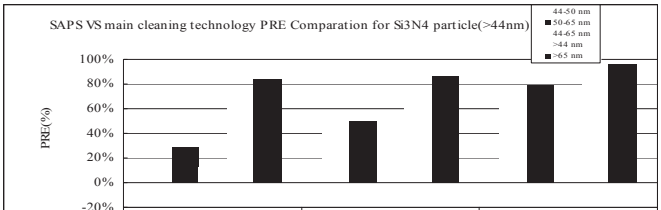


Figure 3a: Comparison of Particle Removal Efficiency between SAPS Technology Incorporating with Functional Water and Other Main Cleaning Technologies



	Spray Technology	Wet Bench Mega-SC1	Application 2
44-50 nm	-3%	46%	63%
50-65 nm	29%	50%	79%
44-65 nm	13%	49%	74%
>44 nm	62%	73%	89%
>65 nm	84%	86%	96%

Figure 3b: Comparison of Particle Removal Efficiency between SAPS Technology Incorporating with Functional Water and Other Main Cleaning Technologies

Yield data Validation

To validate the SAPS technology with functional water in the production, the split tests are done to compare it with the base cleaning methods in different steps, such as pre mask, pre metal deposition, post CMP, post nitrite deposition, post TEOS deposition etc.. The yield data are obtained based on a certain number of production lots for the statistical accuracy.

Table III shows the yield improvement in the split lots using SAPS megasonic technology incorporating with functional water instead of the corresponding base process for the specific steps. The results indicate the obvious yield improvements in the split lots with SAPS technology and functional water application.

Table III: Yield Improvement When Using SAPS Technology and Functional Water

Step	Base Cleaning Technology	Yield Improvement of Functional Water + SAPS Megasonic
A	Spray Technology 1	0.7%
B	No Cleaning	1.3%
C	Spray Technology 2	0.3%
D	Spray Technology 3	0.6%
E	Spray Technology 4	1.2%
F	Wet bench 1	0.5%
G	Wet bench 2	1.3%
H	Wet bench 3	1.0%

Figure 4 shows the defect inspection map of the wafer samples for a specific cleaning step post CMP. It illustrates that the split group using SAPS technology and functional water achieves higher particle removal efficiency, above 15% enhancement, than the base group using normal spray process.

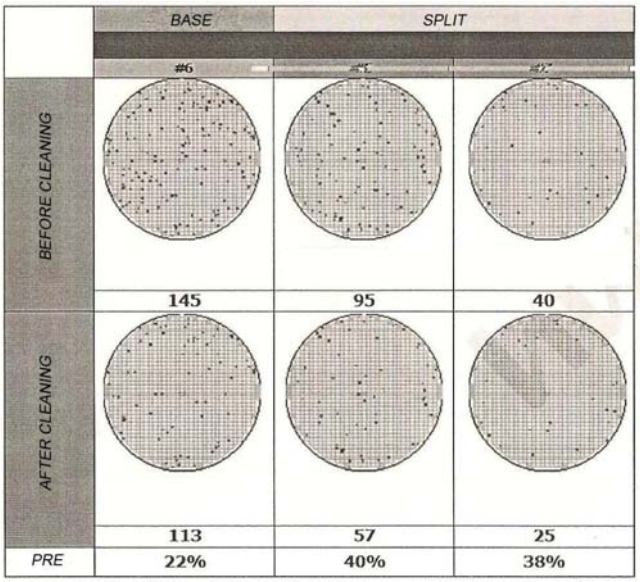


Figure 4: Inspection Map

Figure 5 shows the defect review image of the wafer samples in figure 4. The surface particles are completely removed in the split group after the SAPS technology and functional water cleaning, while some particles still can be found on wafer surface after the normal spray process. It further proves the great advantage of the SAPS technology incorporating with functional water in particle removal efficiency.

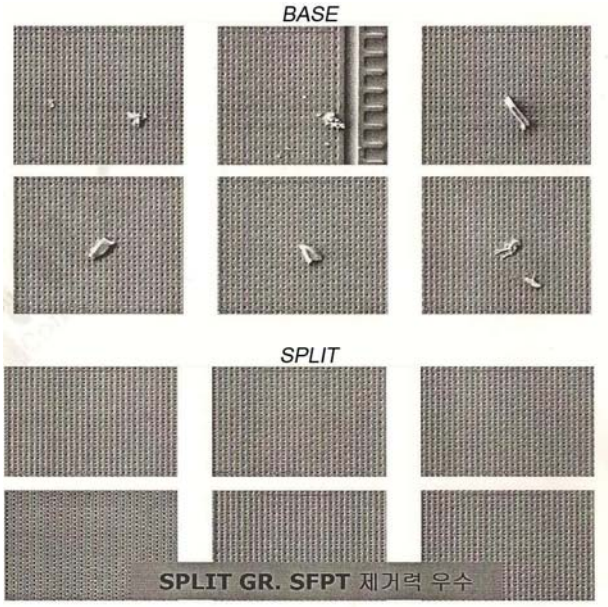


Figure 5. Defect Review

Conclusions

The SAPS megasonic technology coupled with functional water has a significant capability for fine particle removal and can be applied in the cleaning process of semiconductor manufacturing.

The mechanism of the SAPS megasonic technology coupled with functional water cleaning is explained by the radical generation. And the key parameters of this cleaning process, such as concentrations of functional water's dissolving gas, dilute chemicals and megasonic energy, exert great impacts on the particle removal efficiency. The interaction between dilute chemical amount and Megasonic Power and that between dissolving gases and dilute chemical amount also have important effects.

The window of megasonic power is wide. The etch rate of the process, less than 0.4 Å/min, meets the target of dilute chemical for TOX. The etch rate is less than 5 Å/min for CVD tungsten wafer, which is very slight comparing to traditional SC1 solution.
In the comparison with other main cleaning technologies, the best application of the SAPS technology and functional water process shows a great advantage in fine particle removal.
The technology of SAPS megasonic and functional water is validated in real production. It shows an obvious yield enhancement comparing with the base cleaning technology for many cleaning steps. The defect inspection map and review image of the wafer sampled from the production further proves the good performance of this technology in particle removal efficiency.

Acknowledgments

Thanks to the support from Hanwool Scientific Co., Ltd. to this study.

References

[1] Hiroshi Kurobe and Hiroshi Morita, Environmentally conscius design and inverse manufacturing, Dec. 590-591(2005)

[2] Masayuki Toda and Seijiu Uryuu, Cleaning technology in semiconductor device manufacturing VIII , Volume 26, 1-12(2003)

[3] Hiroshi Morita and Tochihiro Ii, Cleaning technology in semiconductor device manufacturing VI, Volume 36, 45-48(1999)

[4] Hiroshi Morita, Semiconductor Manufaturering, Dec. (2006)