Experiments on removing nano particles on a substrate using a supersonic particle beam

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ABSTRACT

Cryogenic particle beam can be an effective means of removing nano-sized contaminant particles from a substrate surface. In order to generate a particle beam of high intensity and controlled size and temperature, Argon gas was expanded through two different types of supersonic nozzle, simple orifice and contoured Laval nozzle. A variety of particle size and velocity was obtained by controlling the stagnation pressure and temperature, the back pressure, and the use of nozzles with differing throat size and expansion angle. The two different types of nozzles showed different characteristics of particle generation. Increased stagnation pressure resulted in an increased particle size with the contoured nozzle, but a decreased size with the simple orifice. The generated particle beam was found to be almost perfect in removing micron and submicron particles, and also quite effective for nano-sized particle. Experiments on the cleaning efficiency with both types of nozzles clearly showed that there exists an optimum bullet particle size corresponding to each contaminant particle size.

Keywords: nano particle cleaning, cryogenic, supersonic nozzle

1 INTRODUCTION

It is clearly predicted that the critical size in particle contamination control will go down rapidly with the continued advancement in nano technology. But the removal of particles in the nanometer size range is very difficult, and the existing cleaning techniques developed for micron-sized particles may become ineffective for particles smaller than 100 nm due to the relative importance of the adhesion surface force over the mass or inertia force. One of potential cleaning methods effective for dislodging nano-size particles adhered onto a surface is to use impulsive, not continuous or periodic, force.[1] In this study nano particles adhered on a flat substrate was removed using Argon particle beam which was generated by homogeneous nucleation and growth during supersonic expansion through a sharp orifice or a Laval nozzle. Fundamental characteristics of cleaning and the existence of the optimum size for the beam particles were investigated.

2. EXPERIMENT

The experimental system is schematically shown in Figure 1. Argon gas is pre-cooled down close to the triple point, and then expanded through a simple orifice nozzle or a contoured Laval nozzle in vacuum environment. During the supersonic expansion small condensation nuclei are formed and grown, and the final size of the nano particles are controlled by the stagnation pressure and temperature, back pressure of the vacuum chamber, and the shape of the nozzle. Wafers coated with monodisperse Polystyrene Latex (PSL) particles of various sizes are bombarded by the Argon particle beam, and cleaning efficiency is calculated by the ratio of the particles remaining on the wafer before and after the cleaning. MD(molecular dynamic) simulation predicted the existence of an optimum size of bullet particles depending on the contaminant particle size [2], so it is another objective of this study to confirm the existence of the optimum cleaning particle size.

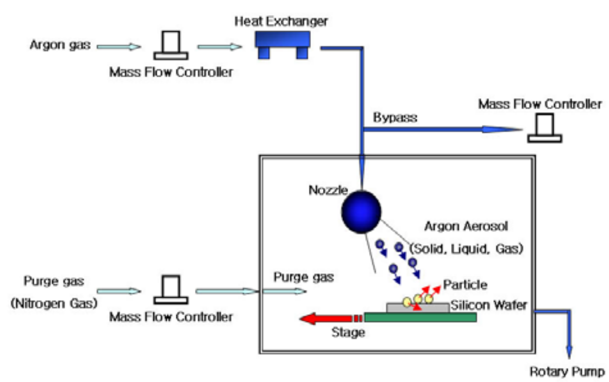

Figure 1 : Schematic of experimental set up

3. RESULTS

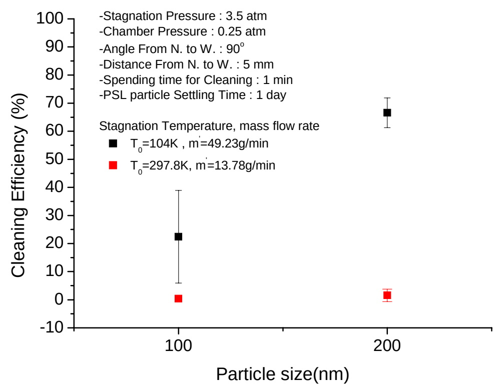

Figure 2 : Cleaning by Argon Gas Jet and Particle Beam

Before particle beam cleaning was tried, the effectiveness of supersonic gas jet was tested for wafer cleaning. Supersonic gas jet was generated by controlling the stagnation pressure and temperature so that no nucleation or growth occurred in the nozzle expansion, and was ejected over a wafer coated with PSL particles. The supersonic gas jet removed only 1-2% of the PSL particles on the wafer, both for 100 nm and 200nm size. (Figure2) It is confirmed through this experiment that the cleaning efficiency of a supersonic gas jet is close to zero for particles of 100nm size. This result reconfirms the previous work of Gutfinger that the cleaning efficiency of an air jet was less than 50% for 300nm particles.[4] For particles of 100 nm size range, a continuous gas jet is not an effective means of removal. For smaller sizes the effectiveness will become much smaller.

Removal efficiency of particle beam generated through a simple orifice nozzle is shown in Figure3 for two different contaminant particle sizes, 100nm and 50nm. First of all, it is observed that for 100 nm particles the cleaning efficiency monotonically decreases with increased stagnation pressure but for 50nm particles the efficiency shows a peak at a particular pressure. The change in cleaning efficiency for different stagnation pressures is thought to result from different particle size in the beam. When a simple orifice is used for supersonic expansion, the supersonic flow field and particle formation are formed downstream of the orifice. As the stagnation pressure is increased, the jet pressure at the orifice is increased and the jet boundary which is formed by the balance between the jet pressure and back pressure comes to have a large expansion angle. Since the jet boundary formed downstream of a simple orifice works the function of a supersonic nozzle, supersonic flow velocity is higher in a nozzle with a larger expansion angle, and the high flow velocity, in turn, results in a reduced growth time. So particles generated through a simple orifice at a higher stagnation pressure are smaller.

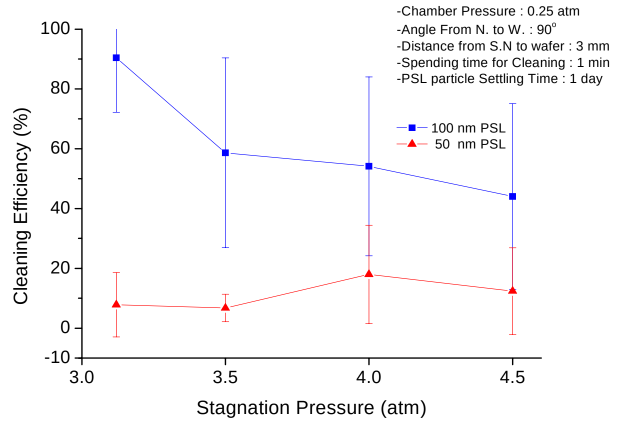

Figure 3 : Effect of Stagnation Pressure on Cleaning Efficiency with the Simple Orifice Nozzle

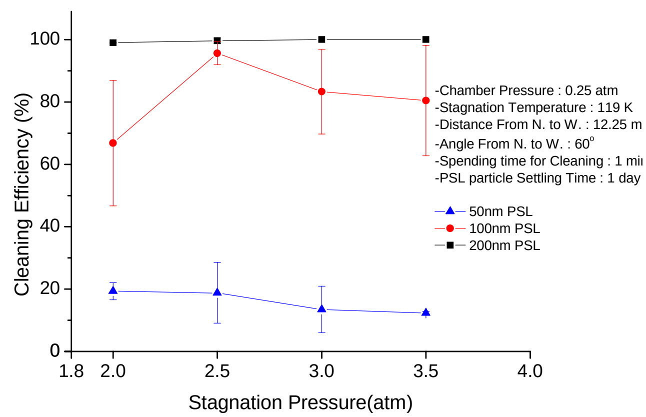

Figure 4 : Effect of Stagnation Pressure on Cleaning Efficiency with the Contoured Laval Nozzle: L = 12.1mm

The cleaning efficiency for 50nm particles shown in Figure 3 clearly shows the existence of an optimum size for the bullet particles. Cleaning efficiency for 100nm particles does not show the peak for the pressure range studied, but the larger beam particles obtained with lower stagnation pressures gave higher cleaning efficiency. Considering the fact that the optimum bullet size for 100nm particles is expected to be larger than that for 50nm particle, it is expected to get a peak at a smaller stagnation pressure..[3] Cleaning efficiency of particle beam generated through a Laval nozzle at various stagnation pressures is shown in Figure 4. What is noticed in the figure is that unlike with a simple orifice, the cleaning efficiency shows a peak for 100nm particle but a monotonic decrease for 50nm particle. Beam particles generated through a Laval nozzle with a given profile are larger when generated at a higher stagnation pressure. As was mentioned previously, the optimum bullet size for 50nm particle should be smaller than that for 100nm particle. It is expected that a peak can be obtained at a lower stagnation pressure. Low overall efficiency can be improved through an increased beam velocity and intensity, which can be obtained through a balanced control of the nozzle profile and stagnation pressure and temperature.

4. CONCLUSIONS

Nano particles on a flat wafer surface are cleaned by bombardment with supersonic Argon particle beams. Particle beams were generated by a supersonic expansion through a simple orifice or a Laval nozzle, and the particle size was varied by controlling the stagnation pressure and temperature, and the chamber vacuum pressure. Cleaning characteristics are summarized as follows.

- The continuous gas jet is not effective means of removing contaminant particles of 100nm or smaller on a substrate. Removal efficiency expected at supersonic speed is in the order of 1%.

- Size of the beam particles generated through a simple orifice is increased when the stagnation pressure is lowered or the chamber pressure is raised. When a Laval nozzle is used, the beam particle size is increased by raising the stagnation pressure, but is almost independent of the back pressure.

- Cleaning efficiency shows a maximum at particular bullet particle sizes, which is larger for larger contaminant particles.

REFERENCES

[1] N. Narayanswami, “ Teoretical analysis of wafer cleaning using a cryogenic aerosol”, Journal of the Electrochemical Society, 146(2), 767, 1995

[2] M.Y. Yi and J.W. Lee, “ Molecular Dynamic Simulation on the Collision of a Nano-sized Particle onto another Nano-sized Particle on a Flat Substrate”, J. Aerosol Science, 36(12), 1427-1443, 2005

[3] S.K. Cho, 2005, “ Experimental Study on Nano Particle Removal Using a Supersonic Particle Beam ”, M.S. Thesis, POSTECH

[4] C. Gutfinger, and G. Zisking, “ Particle resuspension by air jets-application to clean rooms ”, J. Aerosol Science, 30(Suppl. 1), S537. ,1999