Corrective Planarization Method Using Chemical Mechanical Polishing Assisted by Laser Particle Trapping

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1. Introduction

The improvement in the integration of VLSI has resulted in the increment in the number of interconnect layers, and thus high planarity has been required. According to the 2001 ITRS Roadmap1), the site flatness of 100 nm is required for the generation of DRAM 1/2 pitch at 100nm in the year of 2003, while the generation at 70nm in the year 2006 will demand the site flatness of 70nm. However, since it is difficult to achieve these goals with the current process of the CMP technology, developments in new planarization technologies are in need.

The requirements on CMP process in the VLSI's planarization process are as follows:

(1), To gain excellent images with exposure of patterns when creating interconnect layers by making planarization on interconnect layers, and reducing step height of silicon wafer surface smaller than the depth of focus of wafer stepper's projection lens;

(2) To build up the required structure of interconnect layers, by removing accumulated, unnecessary portions for metal interconnect layers such as Copper.

This research aims to realize the planarization with the chemical mechanical polishing where the aggregated marks of fine particles in slurry are created with the optical radiation pressure by irradiated laser beam, and to process selective material removal intentionally in small projected areas on the VLSI's circuit pattern.

In the previous report2), the polishing property of material removal at the aggregated marks located on the surface of silicon wafer was investigated.

In this report, at first, the considerations to create the aggregated marks by laser beam irradiation onto the surface of silicon wafer were investigated. Furthermore, new planarization method, which fills up the dimples with laser aggregated marks and polish the area as one surface, was proposed and attempted to obtain high planarity on trench-shaped uneven surface which was processed by FIB(Focused Ion Beam) machining on the silicon wafer surface.

2. Conditions to Planarization

As the common idea of the planarization process, the planarity can be made by removing selected projections on uneven surfaces of silicon wafers. Generally, it is considered that material removals are achieved with the stress distribution, caused by the elastic contact between polishing pad and projections on silicon wafer surface. It is, however, not necessarily true that polishing pads contact with projected areas. Since polishing pads have large pores in size of 20 to 40µm and fluffy surfaces with fibers made by dressing, as shown in Fig.1, the polishing pads contact evenly with entire surface of silicon wafer in many occasions, though it is likely that they touch with projected areas. As a result, only material removals are progressed,

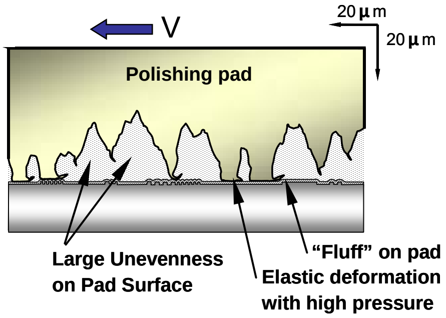


Fig. 1 Contact between polishing pad and surface of silicon wafer

while step height reductions do not show any changes despite a long-time polishing. This attributes to the fact that the whole surface of silicon wafer is evenly polished, although the step height reduction is slow.

This result shows us the necessity of “the Conditions to Planarization”, which are listed as follows:

[A] ***Selective removal of projected areas on silicon wafer surfaces;***
[B] ***Simultaneous controls on removal of recessed areas.***

3. Laser Trapping by Optical Radiation Pressure

“Laser Trapping”[3)] is a well-known phenomenon that captures dielectric particles with optical radiation pressures, which are larger in size than the wavelength of light. It is considered that changes in momentum of laser beam at reflection and refraction, provide the generation of forces, when the laser beam irradiates into particles.

On the other hand, with particles smaller than the wavelength, the scattering of light results in a different phenomenon than when considering light as rays. Therefore, it cannot be treated as the generation of optical radiation pressure by the change in momentum of rays, but it is possible to consider as Maxwell’s stress is in effect.

Sugiura[4)] attempted to calculate the fine particles’ electric field with Mie’s theory, and to obtain the force of optical radiation pressure with Maxwell’s stress. It was clarified by the result that fine particles receive optical radiation pressure in a direction of light propagation, and the optical radiation pressure is amplified with the size of fine particles. Takaya, et al.[5)] concluded, as shown in Fig. 2, that fine particles receive a thrust force to the focal point of laser beam, in parallel to the light propagation, and form aggregated marks on the focal point.

Generally, in colloidal solution, fine particles can keep stable state of dispersion with balanced forces between repelling forces caused by surface potential and van der Waals forces. At around the focal point, the forces by the optical radiation pressure are applied additionally. Fine particles are condensed and gathered on silicon wafer to form aggregated marks due to the effect of heat.

The experiment to form the aggregated marks was attempted with the experimental apparatus as illustrated in Fig.3. Laser beam is irradiated from the light source, Ar+ laser (λ=488m), and radiate into the test piece through objective lens (40x, NA=0.55). The test piece is diced silicon wafer (10x10mm) and was put on slide glass and filled with slurry. The piece was set on the piezo XYZ stage, and positioning, focusing, and laser beam scanning motion were carried out by the XYZ stage.

Fig.4 shows the aggregated marks which were created with the experimental apparatus. The width of aggregated marks is approx. 2-3μm, almost the same size as diameter of laser beam.

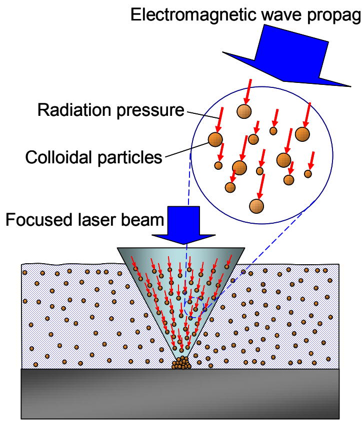


Fig. 2 Optical radiation pressure on fine particles

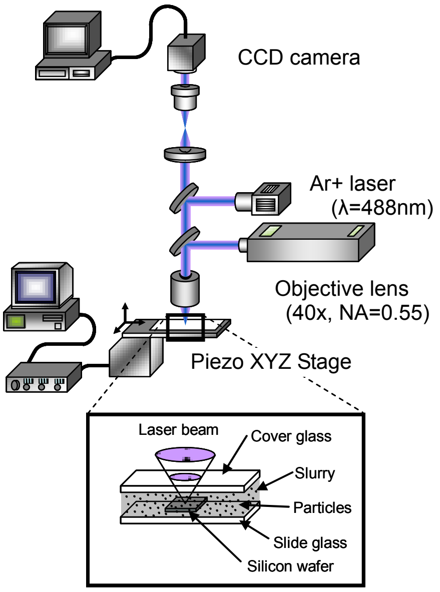


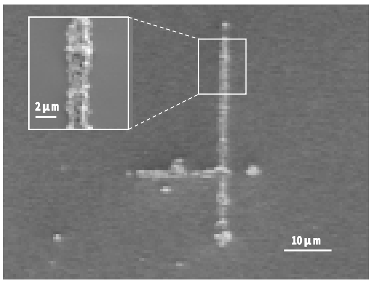
Fig. 3 The experimental apparatus for laser irradiation

4. Basic Concept of LAFP Method

In order to make planarization on irregular surface of silicon wafer, the removal of projected areas and the prevention to the removal of the bottom of the recessed parts are required simultaneously. Fig.5 shows the concept of the LAFP (Laser Aggregation, Filling-up & Polishing) method that enables to fulfill these conditions.

Firstly, dimples on uneven silicon wafer surfaces are irradiated by laser beams for the generation of aggregated marks, made of fine particles in slurry. In the next step, polishing is applied to that particular area. This series of processes makes dimples on uneven silicon wafer surfaces be filled by aggregated marks of fine particles. Then, the surface is polished.

As a result of these processes, the bottom of surfaces of recessed areas are masked with aggregated particles, and no material removal at recessed areas takes place during the polishing. Furthermore, the bottom of surfaces of recessed areas is polished only when polished surface of projection reaches down to the initial height of bottom of trenches. This result shows us a potential for polished surface with the higher level of planarity.



(a) SEM photograph

(b) AFM observation

Fig.4 Aggregated marks on silicon wafer

5. Polishing with LAFP method

Based on the LAFP concept, polishing experiments were implemented. Fig.6 illustrates polishing unit for the experiments. The polishing unit has φ20mm polishing pad and can control rotation speed and down force of polishing pad. Moreover, four trenches were shaped on the surface of test pieces of diced silicon wafer by FIB (Focused Ion Beam) machining. One test piece was for polishing experiment, and the other was polished after aggregated marks were formed at the bottom of two trenches.

Fig.7 shows the test piece with formed four trenches. The width of trenches is approx. 2μm, and the depth is approx. 57nm. Fig.8 shows the change in its cross-section during polishing. At T=9 min, the entire area of trenches was removed in concaved shape, and at T= 12min, the recessed geometry is remained after unevenness of trenches were disappeared.

Fig.9 shows the test piece which has two aggregated marks at two trenches of 120nm depth, and the height of the aggregated mark is approx. 520nm.

The cross-section of the trenches is illustrated in Fig.10. The aggregated areas are possible to control material removal as with masks, and whole area of aggregated marks created was slightly in convex shape at T= 12min. At T= 24min, surface where trenches were formed is planarized as a smooth plane with surface roughness. This result shows that the formation of aggregated marks with laser irradiation is useful for planarization on uneven surface of silicon wafer.

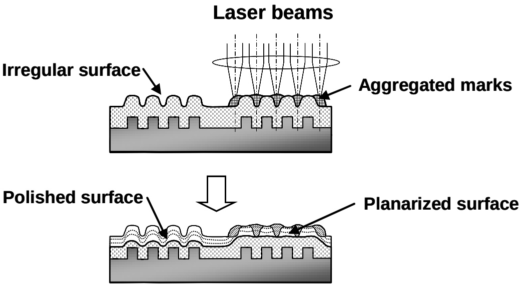


Fig. 5 Concept of LAFP method

Fig. 6 Polishing unit for experiments

6. Conclusion

The new planarization method is proposed and attempted by experiments. This method indicates two unique points as follows:

(1) The aggregated marks are forms with laser irradiation on surface of silicon wafer. The aggregated marks are made of fine particles in slurry.

(2) After aggregated marks are formed and filled up at the recessed areas of surface of silicon wafer, polishing is carried out. This process is possible to realize high planarity on silicon wafer.

As a final result, the smooth surface with surface roughness is obtained with the LAFP (Laser Aggregation, Filling-up & Polishing) method, and the method has a high potential for planarization.

References

1) ITRS Roadmap, Front End Process 2001 Edition (2002)
2) K. Kimura et al.: Proc. of ASPE 2001 (2001) 537
3) A. Ashkin et al:Physical Review Letter, 24 (1970) 156
4) T. Sugiura : Osaka University Doctoral Thesis (1993)
5) Y. Takaya, K. Kimura et al : Proc. JUSFA (2002)

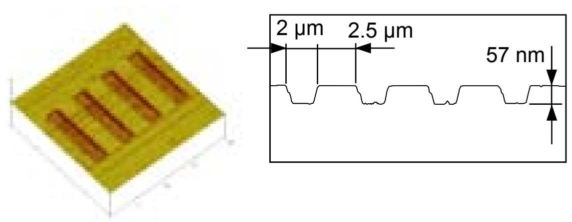


Fig. 7 Trenches formed on siliconw wafer by FIB machine.

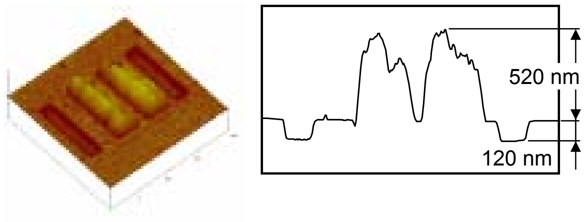


Fig. 9 Aggregated marks on the bottom of trenches

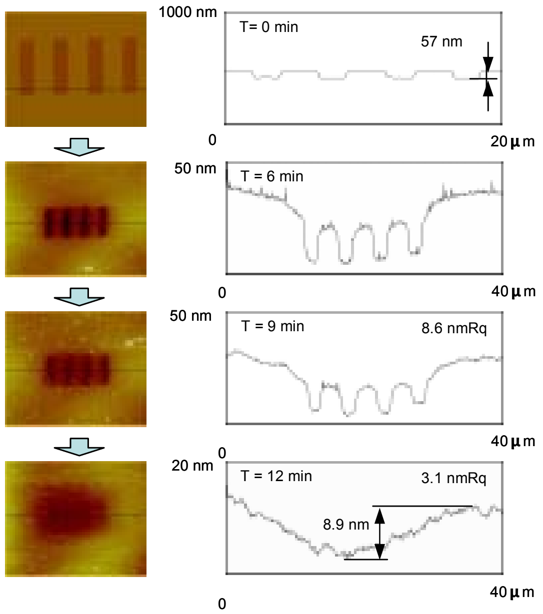


Fig. 8 Cross section of trenches during polishing

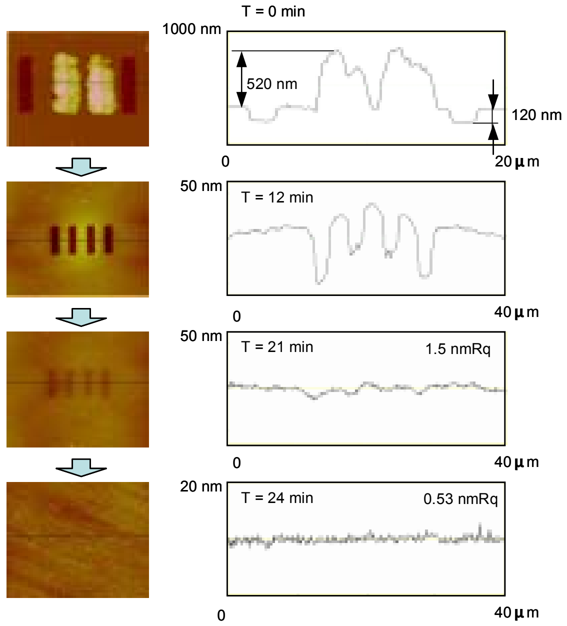


Fig. 10 Cross section of trenches and aggregated marks