LASER ASSISTED CHEMICAL MECHANICAL POLISHING FOR PLANARIZATION

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1. Introduction
As the Moore’s Law predicted, VLSI's scaling down of design rules has been developing steadily. The increase in the number of interconnection layers requires high planarity on individual surface of layers because the irregularities of the layers must be less than the DOF (Depth of Focus) of the projection lens of the Wafer Stepper. Moreover, the applications of the Cu interconnects, Low-k materials and the Dual Damascene processes have been started to the VLSI structure for achieving higher calculation speed and for preventing the increase in resistance and capacity of interconnect layers. At the Dual Damascene process, CMP is a key process that is required for removing accumulated copper to the designed level and for forming wire lines. Thus, CMP technology has developed along with the progress of VLSI's materials and processes. However, the principle of material removal was not changed from the conventional method, where wafers were polished with rotated polishing pad with pressure load and slurry feed. The essential factors for the evaluation of CMP processes are a) uniformity within wafers, b) global planarity within die, c) throughput. Although the higher level of uniformity can be achieved with material removal simulation technique 1), it is difficult to improve the planarity within a die with the conventional polishing method. Thus, the material removal technology that removes off the intended small portions of the material in the arbitrary small area on the surface of wafer, is required. The goal of this research is the development of microscopic material removal method by means of chemical mechanical polishing technology.

2. Concept of the Laser Assisted CMP process
2-1 Planarization process on the Interlayer dielectric film
Cook 2) suggested the polishing mechanism of glass, and it seems that CMP process for ILD (Interlayer Dielectric) follows the material removal mechanism. The material removal processes consist of the following two processes, working alternatively:
(1) Formation of chemical reactive layer;
(2) Mechanical removal of chemical reactive layer.
Therefore, the planarity can be realized after removing the top of bumps as controlling these processes. In general, to fulfill these requirements, hard and small elastic deformable polishing pads has been widely used. However, the surface of polishing pad is rough and fluffy, therefore it cannot be controlled for contact positions and pressure appropriately.
As a conclusion of these considerations, the conventional polishing method stated above, is not capable of controlling the material removals at the specific position on wafer surface.

2-2 Basic concept of Laser Assisted CMP
The basic concept of the material removal and planarization in this research is the followings:
(1) Increasing the polishing speed locally with formation of chemical reactive layer
(2) Restricting polishing area with aggregated marks formed by Laser irradiation
Fig. 1 illustrates the schematic diagram of these two mechanisms. By Laser irradiation, chemical reacted layer is generated rapidly, and thus, the increase of material removal speed of polishing is
expected. In the case that aggregated marks are located above the bumps, the increase in material removal speed on local points is expected after disappearance of aggregated marks. Moreover, in the case where aggregated marks are located at side of bumps, the improvement of planarity is expected because aggregated marks and top of bumps are polished simultaneously as aggregated marks work as masks for prevention of polishing.

The target of Laser assisted CMP process is that control of material removal speed at the microscopic area using phenomena of fine particle aggregations generated on the surface of ILD film on silicon wafer.

3. Experiments on Laser assisted CMP
3-1 Laser irradiation experiments

“Laser Trapping” 3) is known as the phenomena that laser beam captures a fine dielectric particle which is larger than 1 micro meter in diameter, and its principle has already solved. In the case where the laser beam irradiates into the colloidal solution which contains 10nm to 400nm in diameter fine particles, the phenomena that occurs, where these fine particles aggregate into the laser beam, is reported by Sawaki et al. 4). According to their report, the cause of the aggregation is not laser beam's optical radiation pressure, but the shrinkage of the distance between particles with water evaporation by the heat of laser beam.

On the other hand, Shimizu et al.5) reported that fine particles aggregate and accumulate by laser beam irradiation on the surface of ILD layer of silicon wafer in slurry, which contains fine particles of Silica(SiO2).

Fig. 2 illustrates the experimental setup of Laser irradiation. Ar+ Laser (wave length=488nm) is used as the light source, and Laser beam irradiates to the test piece through Objective lens (x 40, NA=0.55). The test piece is silicon wafer, which is deposited with the thermal oxide layer of 1000nm thickness and cut into 10mmx10mm. The 0.1mm thickness slurry film is formed on the surface. The test piece is fixed on the XY-stage, and focusing and beam scanning are possible. Lighting and monitoring optical systems are installed as on the same optical axis.

Fig. 3 shows the SEM photograph of aggregated mark formed by the above process. The aggregated marks appear along the locus of Laser beam scanning. The aggregated marks are consisted of SiO2. They attach tightly onto the silicon wafer, thus they cannot be removed by cleaning process.

![Fig. 1 Basic concept of Laser Assisted CMP](image)

![Fig. 2 Experimental set up for Laser irradiation](image)

![Fig. 3 SEM photo of aggregated mark](image)
3-2 Polishing Experiments

The polishing unit used in the experiment is shown in Fig.4. The tested piece is fixed on the XY-stage with the vacuum chuck, and is movable on the horizontal plane. The polishing pad is applied to rotating motion and down force with air cylinder.

The experimental condition is shown in Table 1. After aggregated marks are created, their heights are shortened as polishing process continues.

There are two typical patterns for the geometry change around the aggregated marks as follows:

[1] Material removal around the aggregated marks
As polishing progresses, the height of aggregated marks decreased. The peripheral areas of the aggregated marks are polished and removed, and thus recessed surface is formed. Fig. 5 shows the measured data of geometry change with AFM. At the beginning, approx. 347nm height of aggregated mark reduces its height to 189nm after 3 minutes polishing. At the same time, recessed areas with the width of 2-7 micro meter and the depth of 10-40nm are formed. This is the evidence where material removal works not only to the aggregated marks, but also to their peripheral area.

[2] Material removal beneath the aggregated marks
When polishing at the aggregated marks is tried, the the aggregated marks and their peripheral areas are polished. As further polishing carries on, the polished surface as Fig. 6 is obtained. It can be observed that the recessed area expand to the position where the aggregated marks and their peripheral area were. This is the evidence that the area beneath the the aggregated marks is polished and removed rapidly after the the aggregated marks disappeared.

Fig. 7 illustrates the transformation of cross sectional shape of the aggregated marks as polished. Initially, the the aggregated mark has the height of 209.3nm, though, the height shortens gradually as polishing continues. By the end of the entire process, the position of the aggregated mark is recessed to -25nm. As a result of these observations, the geometry of the aggregated marks and of peripheral area, transforms as follows:

(1) When polishing starts, the material removal also starts from the top of the aggregated marks, and the height decreases gradually;
(2) As the height of the aggregated marks become lower, the material removal at their peripheral areas is begun, decreasing their heights.
(3) After that, the the aggregated marks disappear, and recessed areas were generated on both sides of the aggregated marks.
(4) The position of the the aggregated marks is removed rapidly, connecting both sides of hollowed area, and extended hollowed area is created.

Consequently, it is confirmed that the microscopic area polishing at the position of the aggregated marks, is possible by irradiating Laser beam onto the specific position of SiO₂ film formed on silicon wafer.
4. Conclusion

The new attempt of Chemical Mechanical Polishing method is carried out. By Laser beam irradiation onto the ILD film at the specific position of silicon wafer surface, the aggregated marks are created, which are polished at microscopic area. As a conclusion, it is confirmed that the new CMP method has a potential for polishing at specific microscopic areas on silicon wafer.

[ References ]