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Principle and Experiment of Ultrasonic Subtle Atomization in CMP

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Abstract. The method of chemical mechanical polishing (CMP) using slurry which was ultrasonic subtle atomized was researched, and the system of Ultrasonic Subtle Atomization—Chemical Mechanical Polishing was established. The effects of polish parameters on polishing were also investigated. The results show that the experimental system can fully realize the expected function of polishing, the use of slurry is about one-tenth of the amount of traditional CMP, material removal rate can reach 113.734nm/min and the surface roughness is similar to the surface roughness in the traditional way.

Introduction

Wafer planarization by chemical mechanical polishing (CMP) usually obtains super-smooth surface without damaging. In today's semiconductor industry, it requires a higher level silicon manufacturing technology with the increasing of wafer size, the getting smaller of the groove width, and the more and more high degree of integration [1]. When IC feature size is smaller than 22nm, this traditional method will be no longer applicable in theory. It needs to find cyber-shot technologies of other principles, some of which originate from the traditional CMP technology such as abrasive-free CMP (AF-CMP), fixed abrasives (FA-CMP), electrochemical mechanical deposition (ECMD), plasma assisted chemical etching (PACE), stress-free polishing(SFP), etc[2-4]. The development of AF-CMP is based on the traditional CMP by removing the abrasive from slurry, and there are almost no scratches and other defects on silicon surface because no abrasive. FA-CMP condense abrasives into small abrasive blocks with specific three-dimensional structure by using resin binder and forming a polish pad with composite structure by pasting or inlaying the blocks on the surface of base material with thin organic film according to certain rules. Slurry is demonized water or aqueous solution only containing basic chemical composition. Effect of the initial application of this technology has raised concerns [5].The research results show that the cost of slurry accounts for 40% ~ 60% in traditional CMP process [6-7] and the utilization rate of slurry is low, resulting in poor economic and social benefit.

In this study, the slurry which is ultrasonic subtle atomized is used in polishing, so it could improve the utilization rate of slurry and reduce the emission of waste and harmful chemicals. The method of Ultrasonic Subtle Atomization polish uses specific frequency ultrasonic to atomize special slurry and get uniform micron-sized droplets whose diameters are 5~15μm. The droplets are imported to polished/polishing interface by negative pressure and converted to a uniform film of low shear strength on the surface after chemical reaction. The surface is super-smooth in nano-scale without damaging after the film is removed by mechanical action.

Technical principles and equipment

In this system, high-frequency ultrasonic atomizer is used to atomize slurry by controlled frequency, and micron-sized droplets which obtain uniform chemical composition are produced. Then the droplets are imported to polishing interface to join chemical reaction by negative pressure. The scratches on polished surface made by a large number of abrasive particles’ reunion can be avoided both in theory and in practice because of the ultrasonic vibration effect. Slurry can be dispersed well-proportioned. Micron-sized slurry that is atomized has high specific surface area, so it can be adsorbed rapidly in the polished interface. Formation of super-smooth surface without damaging lies on the uniform chemistry on the interface and the mechanical effect of abrasive and polish pad with the reaction film. The polish experimental system is shown in Fig. 1. Wafer is nipped by the clamp and rotates around its axis. The pressure depends on the pressure parts which are added to the clamp. Clamp swings around the swing arm. The droplets are imported to polishing interface by negative pressure. They are adsorbed on the surface of polish pad and demonized water film, then join the polishing reaction, and start polishing the wafer.

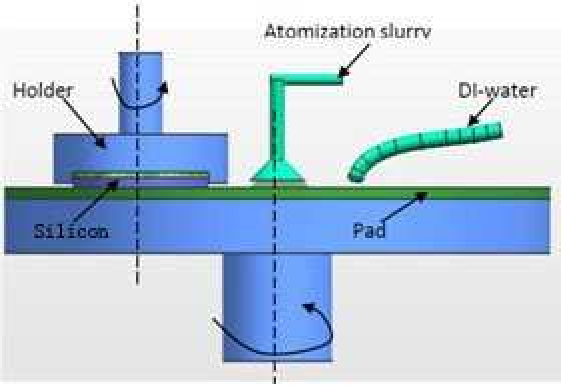

Fig. 1: Ultrasonic subtle atomization polishing system

Experiment

Pressure, nozzle angle and radius which between polish pad center and nozzle center were analyzed respectively. Pressure, nozzle height, nozzle angle and radius were orthogonal experimented under the same condition. Experimental conditions were as follows: ambient temperature was 25°C, and polishing time was 5minute. Deionized water was used to polish for 1minute after polishing was finished, and then the silicon was washed with deionized water[8]. The speed of swing arm was 9 times/min. Deionized water flow was 100ml/min. Polish pad speed was 40r/min. The size of silicon wafer was 20mm×20mm×0.6mm. The polish pad was made of polyurethane (Φ381mm). Slurry was made of silica suspension, the size was 50nm and the concentration was 15%. The wafer was weighted (n=3) by Mettler-Toledo XS205-DU precision electronic balance (accuracy: 0.01mg). Surface roughness was measured by CSPM5000s Atomic Force Microscope System.

Experimental results and analysis

Fig. 2 shows the silicon surface morphology after conventional CMP. Fig. 3 shows the silicon surface morphology after ultrasonic subtle atomization CMP. The surface roughness of silicon wafer is 5nm after conventional CMP while 9nm after ultrasonic subtle atomization CMP, and it can reach the same magnitude as conventional CMP, but the amount of slurry in ultrasonic subtle atomization CMP is only about 1/10 compared to traditional CMP.

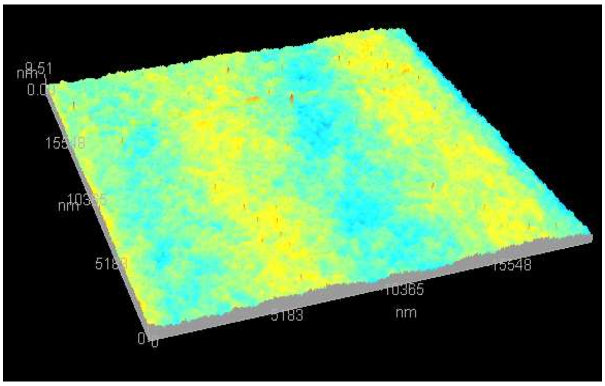

Fig. 2: Surface topography after traditional polish

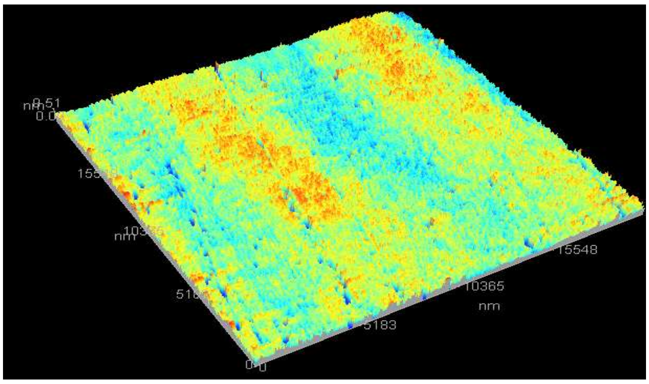

Fig. 3: Surface topography after ultrasonic polish

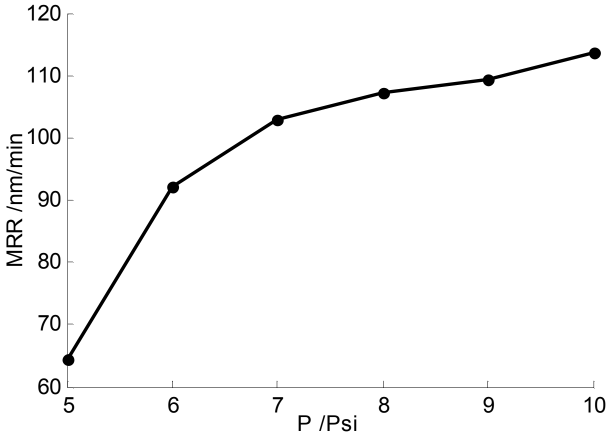

Fig. 4: MMR's change with pressure

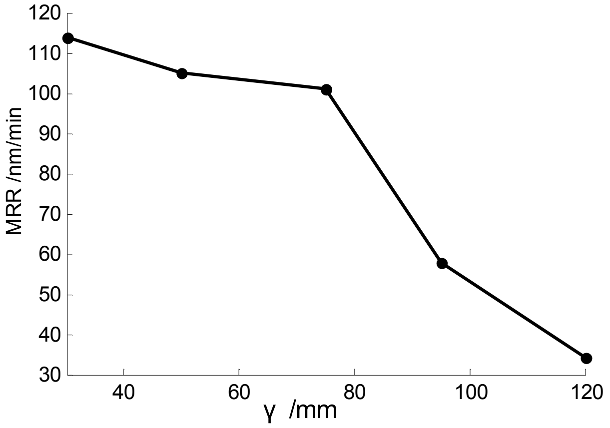

Fig. 5: MMR's change with radius

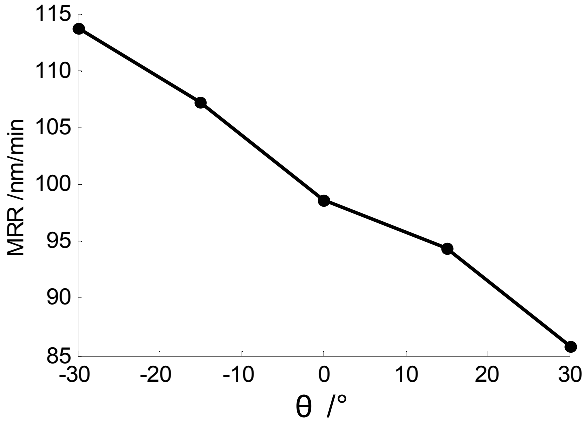

Fig. 6: MMR's change with nozzle angle

As the pressure increased, MMR of silicon wafer increased (shown in Fig. 4). When the pressure increased to a certain level, the change trend of MMR slowed down. And high pressure would lead to defects such as the accelerated loss of polishing pad, too high temperature on polishing interface and prone to debris and scratches and so on. It can be seen from Fig. 5 that as the radius increased, the MMR decreased. And when the radius increased to a certain level, the decrease trend of MMR increased sharply. As the angle increased, MMR decreased (shown in Fig. 5). And there was almost an inversely proportional relationship between MMR and angle.

Radius was the most important parameter among the four parameters from this orthogonal experiment. The optimal parameter combination in this experiment were: pressure 10Psi, nozzle height 5mm, radius 30mm and nozzle angle -30°. The experiment results also proved that MMR of this optimal parameter combination was 113.734nm/min, and it was the maximum.

Abrasives are dispersed because of the ultrasonic vibration, so it can avoid making the scratches on polished surface by a large number of abrasive particles' reunion. Meanwhile, micro-sized slurry can absorb fast and put up chemical reactions for high-activity because of its' high specific surface area.

This character makes the strength and speed of reaction much higher than that of traditional CMP, and it can alleviate or even solve the conflicts in surface roughness, surface scratches and MMR. Ultrasonic subtle atomization polish improves the utilization rate of slurry and reduces the amount of slurry. Thereby, it can reduce the initiate and expense of cracks from surface /subsurface with the mechanical action and improve the surface roughness. Reduction in the amount of slurry reduces the number of abrasive which remains on the surface of polish pad and reduces the surface scratches made by the remained abrasives, so it can improve the surface roughness.

Conclusions

(1) The ultrasonic subtle atomization experiment system can realize to ultrasonic subtle atomize slurry and can get ideal surface roughness.
(2) Amount of slurry in ultrasonic subtle atomization CMP was only about 1/10 compared to traditional CMP. Therefore, this system can be used to research ultrasonic subtle atomization CMP.
(3) MMR increased with pressure and decreased while nozzle angle and radius increased. In this experiment the maximum of MMR was 113.734nm/min while pressure was 10Psi, nozzle height was 5mm, the distance between polish pad center and nozzle center was 30mm and nozzle angle was -30°. The distance between polish pad center and nozzle center has the most significant effect to MMR among the four selected parameters.

Acknowledgements

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