A Study on Improving Polishing Process Effectiveness for Silicon Reclaim Wafer

Chia-Pao Chang, Wei-Ling Wang, and Yung-Ching Kuo

Abstract In this study we improve the capacity of the polishing process of silicon reclaim wafer by applying the six sigma approach and the five steps of DMAIC. Based on the Taguchi experiment approach, a four-factor three-level experiment is designed by experimental design method using the existing polishing parameters, in particular such processing conditions as the cylinder head down force of the main process section, the PP rpm, LP rpm, and the flow of polishing slurry. The four factors are as follows: cylinder head down force, PP rpm, LP rpm, and the slurry flow. By studying the correlation between various parameters in the polishing process and the polishing result, the polishing factors' effect on the material removal rate (MRR) and wafer's total thickness variation (TTV) after the polishing process is analyzed, to obtain the optimized parameters for the improvement of the quality of polishing process and enhancement of process yield rate.

Keywords Silicon reclaim wafer • Polishing process • Taguchi experiment method

1 Introduction

With the rapid development of semiconductor processing technology, that is, very-large-scale integration (VLSI) circuit, especially the continuous improvement of the processing technology of the 12-in. (300-mm diameter) silicon wafer, the quality of over 100 processes during the manufacturing process of the semiconductor IC has to be ensured, as any change in parameters of each process has great influence on the final yield rate of the wafer production. To make sure each process is strictly monitored, lower-cost testing wafers have to be used to ensure correctness of the process parameters and guarantee the yield rate of production.

C.-P. Chang (✉) • W.-L. Wang • Y.-C. Kuo
Department of Industrial Engineering and Management, National Chin-Yi University of Technology, Taichung 41170, Taiwan, R.O.C.

J. Juang and Y.-C. Huang (eds.), *Intelligent Technologies and Engineering Systems*, Lecture Notes in Electrical Engineering 234, DOI 10.1007/978-1-4614-6747-2_96,

Therefore, reclaim wafers made of recycled control wafers and dummy wafers are used. The most important polishing process among the silicon reclaim wafer processes (chemical mechanical polishing, CMP), or the planarizing technique of the chemical mechanical planarization process, is an anisotropic etching technique in the domain of mechanical function. The basic principle of the polishing process is mainly to pour the polishing slurry onto the PU pad of the polishing machine for polishing action on the wafers. The objective of the process is to remove the oxidized materials on the surface and planarize it to reduce the extent of defects and TTV of the wafer.

Nonetheless, as the size of wafers is becoming larger, it is a greater challenge to achieve the high-precision silicon wafer processing technique even in a single process of treating the large-size silicon wafer surface. Furthermore, the requirement to improve the wafer quality after the polishing process and enhance the yield rate is an even more important concern of the manufacturers of silicon wafer semiconductor. In order to ensure the precision of silicon wafer surface processing, two-step (rough polishing and refine polishing) or three-step (rough polishing, fine polishing, and final polishing) or four-step (rough polishing, fine polishing, refine polishing, and final polishing) processing will be carried out [1].

In the chemical mechanical planarization (polishing) of the wafer semiconductor processing, chemical mechanical polishing slurry in the form of acid or alkali fluid that contains suspended abrasive particles, oxidant, and active agent is poured between the rotary work bench carrying the silicon wafer on one side and the polishing pad on the other side, so that the polishing pad is rotating against the wafer, and hence global planarization is achieved through the alternative action of the chemical etching and the removal mechanism that grinds the two materials. Many defects on the surface of the wafer are removed in the polishing process, and thus it helps improve the product yield rate. However, some defects will be created during the process as well, such as scratches, residual slurry, particles, erosion, and dishing [2].

Preston equation has always been used to describe the relationship between polishing speed and pressure, as expressed below:

$$\text{R.R.} = K\text{p}(\text{PV}) \tag{1}$$

In the equation, R.R. means removal rate, Kp is a constant, P represents the down force on the polishing surface, and V is the sliding speed between the polishing surface and the polishing pad. Polishing rate will increase with the rise in pressure and rotational speed [3].

Chemical mechanical polishing slurry is composed of fine suspended colloidal silica that contains SiO_2 and NaOH (or KOH, NH_4OH, HNO_3) or other organic acid. The SiO_2 particle size, concentration, and pH value in the slurry are the major factors that affect the removal rate and quality of polishing. And the mechanical reaction mechanism means the removal of the oxidized layer with the mechanical friction between the polishing pad, colloidal silica, etc., and the wafer, and it also provides the kinetic source for corrosion oxidation [4].

2 Research Method

In this study, relevant literature of both domestic and overseas research was compiled, and a certain wafer manufacturer was taken as example, using the DMAIC steps and experimental design analysis. Results of the experiment were provided as a reference for improvement of the process.

2.1 *Defining the Question*

By observing the result of the daily monitored MRR of the polishing process by the 12-in. wafer polishing machine SpeedFam, it was found that the MRR had a declining trend. Controllable factors that affect the polishing process were analyzed, after eliminating the effect of other uncontrollable factors.

2.2 *Measurement*

Among the parameters of the rough polishing process, major processes that affect the polishing result are the cylinder head down force, PP rpm, LP rpm, and slurry flow. The process may be divided into six processing sections (by time). As a basic concept of polishing, the chemical mechanism and mechanical mechanism of polishing have the best result under high temperature (low slurry flow) and high pressure.

2.3 *Data Analysis*

Table 1 shows the experimental factors and levels. As the original pressure setting of the main processing section (the fourth section is defined as the main processing section due to the largest pressure and longest polishing time) was down force setting at 230 kg, the maximum down force was set at 250 kg considering the load of the machine. Maximum slurry flow was set at 8 L/min, and maximum PP rpm and LP rpm range at 60 rpm.

In this study the polishing pad model used in the experiment was SUBA-800 50″D PS, and the slurry model was BINDZIL 999. The thickness of test film collected was 760–780 um, and TTV was measured before and after polishing. The cylinder head with non-crystallized surface and relevant polishing consumables were replaced with new ones, and the slurry was also replaced with new slurry after completion of each production lot on a component ratio of 1:20 (slurry:DI). Polishing experiments were carried out according to the experimental configuration parameters in the L9 (3^4) orthogonal arrays, together with a brand-new rough

Table 1 Experimental factors and levels

Level factor	Controllable factor	Level 1	Level 2	Level 3
A	Down force (kg)	210	230	250
B	Slurry (L/min)	4	6	8
C	L.P. (rpm)	40	50	60
D	P.P. (rpm)	60	50	40

Then, the L9 (3^4) orthogonal arrays were used to configure the 9 sets of experimental parameters

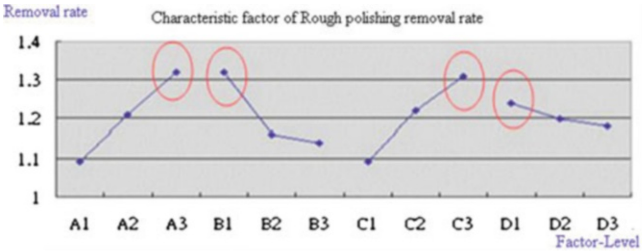

Fig. 1 Characteristic factor of rough polishing MRR

polishing pad. The central removal rate was largest when the processing down force was higher (250 kg), slurry flow was lower (4 L/min), LP rpm was faster (60 rpm), and PP rpm was faster (60 rpm). (1) When the slurry flow is higher, the change in central removal rate is not significant. (2) When the PP rpm becomes slower, the change in central removal rate is not significant. (3) Processing pressure and LP rpm are the controlled factors that have the most significant effect on the change of the central removal rate.

The effect of cross multiplication of various controlled factors on the TTV divergence was concluded: (1) Change in TTV is the smallest when the processing pressure is higher (210 kg), slurry flow is higher (6–8 L/min), LP rpm is slower (40 rpm), and PP rpm is slower (40 rpm). (2) Change in TTV is not significant when the processing pressure becomes higher. (3) Change in TTV is not significant when the slurry flow becomes higher. (4) LP rpm and PP rpm are the controlled factors that have the most significant effect on the change of TTV.

2.4 Improvement

The MRR and geometric accuracy difference (△TTV) of various factors and levels were calculated according to the above-mentioned nine sets of experimental parameters, and the resulting data were plotted on the cause and effect diagram like Figs. 3 and 4, for determination of various polishing factors' influence on the MR and TTV of rough polishing. Figure 1 shows the polishing factors' influence on the MRR of rough polishing: (1) Factor A: Large, processing temperature becomes relatively higher. (2) Factor B: High, greater removal mass, but the effect of greater slurry flow on the removal mass is not significant. (3) Factor C: The faster the LP rpm, the higher the processing temperature, and the greater the removal mass. (4) Factor D: Removal mass is largest when PP rpm is at 60 rpm, but its effect on the change of removal rate is not significant. Therefore, the combination of levels that meets the larger the better (LTB) criterion of MRR is A3B1C3D1 (down force, 250 kg; flow, 4 L/min; LP rpm, 60 rpm; PP rpm, 60 rpm).

The polishing factors' influence on the geometric accuracy (TTV) is described as follows: (1) Factor A: Change in TTV is smallest when the down force of the main process is at 210 kg, and the processing temperature is low. (2) Factor B: The smaller the slurry flow, the higher the processing temperature, and the bigger the TTV change, but the effect of greater slurry flow on TTV is not significant. (3) Factor C: The lower the processing temperature, the smaller the TTV change. (4) Factor D: Change in TTV is smallest when PP rpm is at 40 rpm, but the processing temperature is high. Therefore, the combination of levels that meets the smaller the better (STB) criterion of △TTV is A1B2C1D3 (down force, 210 kg; flow, 6 L/min; LP rpm, 40 rpm; PP rpm, 40 rpm).

2.5 Control

The above experimental results were introduced to the change in the processing parameters, and the process stability was monitored by the polishing statistical process control (SPC) approach. Moreover, polishing stability was observed and maintained through the inspection items of the machine for the polishing process, for example, PH value of slurry and processing temperature calibration at the machine. When the observed data have reached stable levels, these process parameters may be established as standardized operational processing criteria, to ensure the control of the parameters and the normal operation of mass production.

3 Results

After adopting the new parameters, the mean value of MRR increases from 0.96 to 1.15 (Fig. 2), and the trend of △TTV transforms from divergent to convergent (Fig. 3).

4 Conclusion

The DMAIC steps of the six sigma approach were used in this study for improvement of the polishing process parameters for silicon reclaim wafers. A four-factor three-level experiment was designed by means of experimental design method, and the effect on the removal rate and change in wafer thickness after the polishing process

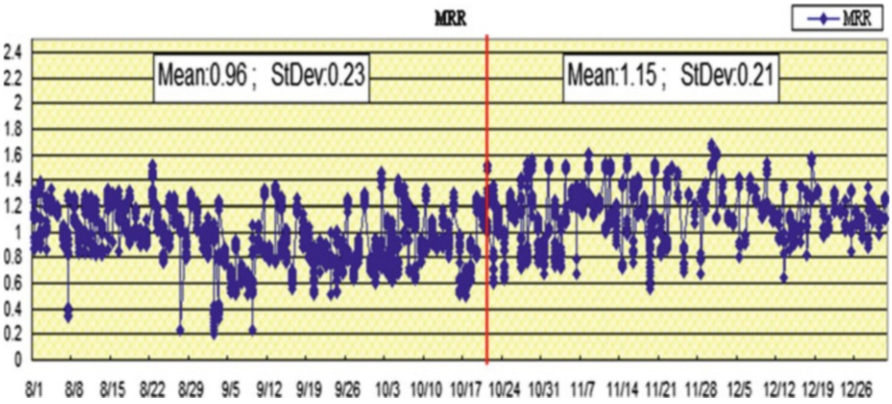

Fig. 2 MRR before and after changing processing parameters

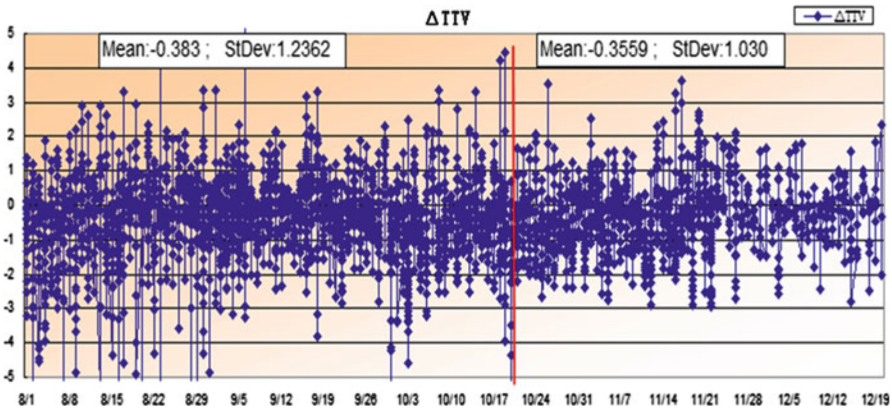

Fig. 3 TTV before and after changing processing parameters

was considered. It is known from the research results that the optimized parameters of the polishing process are down force setting at 230 kg, slurry flow at 5 L/min, LP rpm at 50 rpm, and PP rpm at 50 rpm during the polishing process stage, so that the MRR and TTV stability of the process may be improved.

References

1. Chang JC (2009) The manufacturing technology of silicon wafers. Chemistry Industry Publishing Ltd.
2. Hong X (2002) Introduction to semiconductor processing technology. Pearson Education
3. Chou SW (2005) A study of the dynamic and static mechanical properties of The CMP Pad. Master thesis. National Tsing Hua University, Hsinchu City

4. Chiu JB, Su AJ, Yu CC, Shen SH (2004) Planarization strategy of Cu chemical mechanical polishing: interaction between plated copper thickness and removal rate. J Electrochem Soc 151:G217–G222
5. Li MS (1999) Materials technology of silicon wafers. Chuan Hwa Publishing Ltd.
6. Singh RK, Bajaj R (2002) Advances in chemical-mechanical planarization. MRS Bull 27:743–747
7. Patrick WJ, Guthrie WL, Standley CL, Schiable PM (1991) Application of chemical mechanical polishing to the fabrication of VLSI circuit interconnections. J Electrochem Soc 138:1778–1784
8. Preston FW (1927) The theory and design of plate glass polishing machines. J Soc Glass Technol 11:214–256