Evaluation of High Pressure Micro Jet Technology as an Alternative Pad Conditioning Method for Silicon Dioxide Chemical Mechanical Planarization

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Abstract

In CMP, currently diamond conditioning is widely used to condition the polishing pad to maintain the pad asperity during planarization. However, diamond disc conditioning can create non-uniform thinning of the pad, leading to non-uniform contact pressures and polishing rates across the wafer. In addition, embedded diamond can be abraded away from the disc during conditioning, causing catastrophic defects, such as scratches on the wafer. In this study, a high pressure micro jet (HPMJ) technology is used as a novel pad conditioning method for silicon dioxide CMP applications. During the conditioning process, HPMJ sprays KOH solution at the pressure of 10 MPa onto the polishing pads to clean the residual slurry off the pad surface, remove embedded slurry particles and re-establish acceptable pad asperity heights. Coefficient of friction (COF), removal rate and pad flattening ratio (PFR) are used to evaluate the efficacy of the HPMJ system. Results are compared among conventional diamond conditioning, HPMJ conditioning, combination of HPMJ with diamond disc conditioning and no conditioning. It is found that silicon dioxide removal rate, COF and PFR are closely correlated to one another. Results suggest that HMPJ conditioning has great potentials to become an alternative pad conditioning method in mainstream CMP processes.

Introduction

Chemical mechanical planarization (CMP) has been widely used in integrated circuits manufacturing industry to achieve local and global surface planarity through combined chemical and mechanical means. During polishing, the worn pad materials, abraded wafer materials and slurry residue are trapped in the surface pores, causing the rate of material removal to decrease [1,2]. Hence, pad conditioning is used to continually revive the surface of the pad, helping to maintain uniform and constant removal rates during polishing. Currently, diamond discs are widely used to condition CMP pads. Diamond disc conditioning can create non-uniform thinning of the pad, leading to non-uniform contact pressures and polishing rates across the wafer. In addition, embedded diamonds can be dislodged from the disc during conditioning, causing catastrophic defects, such as scratches on the wafer. Furthermore, significant pad abrasion occurs during diamond disc conditioning therefore reducing the pad life. In this study, a high pressure micro jet (HPMJ) is used as a novel pad conditioning technology for ILD CMP. During the conditioning process, HPMJ sprays KOH solution at the pressure of 10 MPa onto the polishing pads to clean the residual slurry off the pad surface, remove embedded slurry particles and re-establish pad asperities. Analyses on coefficient of friction (COF), removal rate and pad flattening ratio (PFR) are used to evaluate the efficacy of the HPMJ system.

Experimental Apparatus and Procedure

Figure 1 shows the CMP apparatus and the high pressure micro jet system used in this study. A scaled down version of a Speedfam-IPEC 472 polisher was used, and details of the polisher as well as its unique ability to acquire real-time shear force data critical for determining the coefficient of friction (*COF*) were described elsewhere [3-5]. The HPMJ conditioning system consisted of a water reservoir, a high pressure tank, a controller and a nozzle. The nozzle was specially designed to create discrete high-pressure miniature droplets, which are ejected onto the pad surface to remove slurry waste particles and abraded materials from the pores of the pad surface and the pad grooves. The nozzle was placed 5 mm above the pad. The HPMJ sprays KOH solution (pH 11.6) at the pressure of 10 MPa onto the polishing pads during conditioning. HPMJ droplet size distributions, average kinetic energy, and pressure distribution on the pad were illustrated in detail elsewhere [6,7]

Fig. 1 CMP apparatus (left) and HPMJ system

Rohm and Haas IC-1000™ perforated pads were used to polish 4-inch blanket silicon dioxide wafers in this study. Polishing pressure and pad-wafer sliding velocity were 3 PSI and 0.62 m/s, respectively. Prior to data collection, the pad was conditioned for 30 minutes with ultra-pure water by a 100-grit diamond disc at the pressure of 3.5 kPa (0.5 PSI). The diamond disc rotated at 30 RPM and oscillated at 0.33 Hz. During polishing, Fujimi PL-4217 slurry with 12.5 % fumed silica abrasives was used and the slurry flow rate was kept constant at 80 ml/min. Different conditioning methods and solutions were used for pad conditioning between each wafer polish and were listed in Table 1. Diamond conditioning was conducted for 30 seconds with Fujimi PL-4217 slurry or KOH solution (pH 11.6) at the pressure of 3.5 kPa (0.5 PSI) by the 100-grit diamond disc, which rotated at 30 RPM and oscillated at 0.33 Hz. Pad conditioning with HPMJ was performed for 10 seconds with KOH solution (pH 11.6). The KOH solution spray rate was 0.77 L/min. Fifty wafers were polished for each run to investigate the COF and removal rate decay under different conditioning methods and solutions.

The Pad Flattening Ratio (PFR) apparatus was used to analyze the surface of the pads in this study. The PRF apparatus is a non-destructive pad-surface monitoring tool and is shown in Fig. 2. A fiber-light guide is used to vertically introduce incidence light produced from the halogen light source to the polishing pad. When the incident light hits the pad, it is reflected and the degree of the vertical reflection relies on the flatness of the pad. The reflected vertical light is detected by the CCD camera. The CCD camera then sends the pad surface image to the machine vision controller where the image is digitalized. The PFR is calculated based on the digitalized image, indicating the percentage of the pad that are flattened or glazed. A square area of the pad underneath the wafer center (5 mm x 5 mm) was selected for PFR image after each polishing.

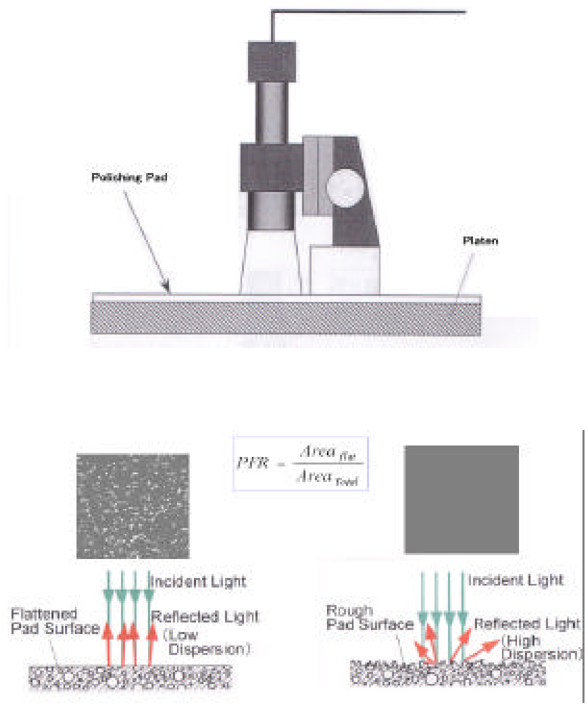

Fig. 2 Pad Flattening Ratio (PFR) apparatus

Table 1. Conditioning methods and solutions used for ILD polishing

Run	Conditioning Type	Time (s)	Conditioning Solution
I	Diamond conditioning	30	Fujimi PL-4217
II	No conditioning	-	-
III	HPMJ conditioning	10	KOH
IV	Diamond conditioning	30	KOH
V	Diamond + HPMJ conditioning	10 + 10	Fujimi PL-4217 + KOH

<u>Results and Discussion</u>

Figure 3 shows the removal rate results under different pad conditioning methods and solutions. For the diamond disc conditioning with Fujimi PL-4217 slurry (Run I), the removal rates decrease initially and stabilize after approximately 10 wafer polishing, with an average removal rate of 15 A/s. In comparison, the removal rates decrease significantly when there is no pad conditioning (Run II), and the stabilized removal rate is about 2 A/s. For HPMJ conditioning with KOH solution (Run III), the removal rates also experience an initial decrease and level off after approximately 25 wafer polishing, achieving an average value of 8 A/s. The removal rates of Run IV are significantly lower than those of Run I, indicating that the chemistry of the conditioning solution has a great effect during the diamond conditioning. The removal rates of Run V experience a large initial decrease and reach a steady value after 10 wafer polishing. The stabilized value is almost the same as that of Run III, suggesting that 10 seconds of diamond conditioning is not enough to fully revive the pad surface

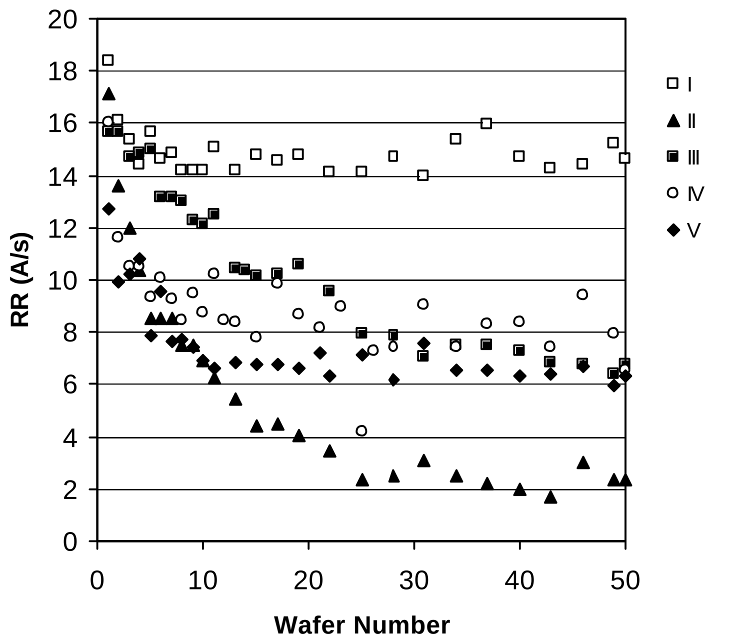

Fig. 3 Removal results under different pad conditioning

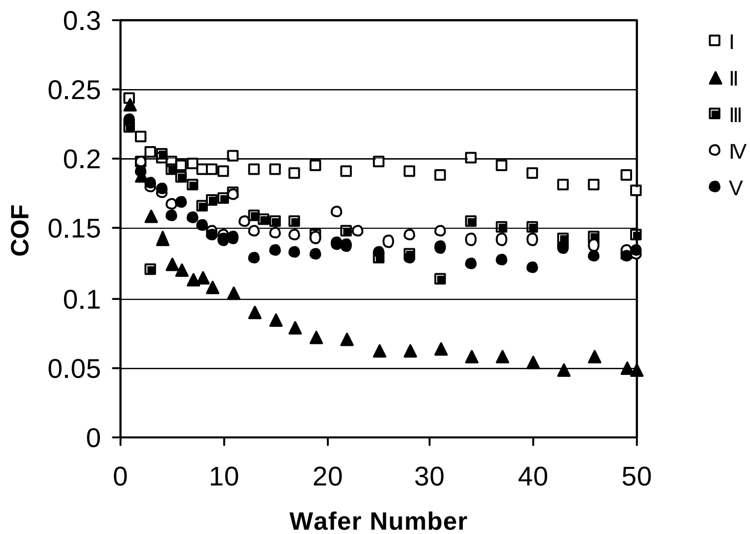

Fig. 4 COF results under different pad conditioning

Figure 4 shows the coefficient of friction (COF) obtained under different conditioning methods and solutions. The coefficient of friction (COF) is defined as the ratio of the shear force to normal force:

$$COF = F_{shear} / F_{normal}$$

The coefficients of friction follow almost the same pattern as the removal rates shown in Fig. 3 for different conditioning methods and solutions. Diamond disc conditioning (Run I) achieves the highest stable COF, while no conditioning (Run II) results in the lowest value. The COF of Run III, Run IV and V are close to each other and lie between the diamond conditioning and no conditioning. The relationship between the removal rates and COF is shown in Fig. 5. There is a linear correlation between the silicon dioxide removal rates and COF.

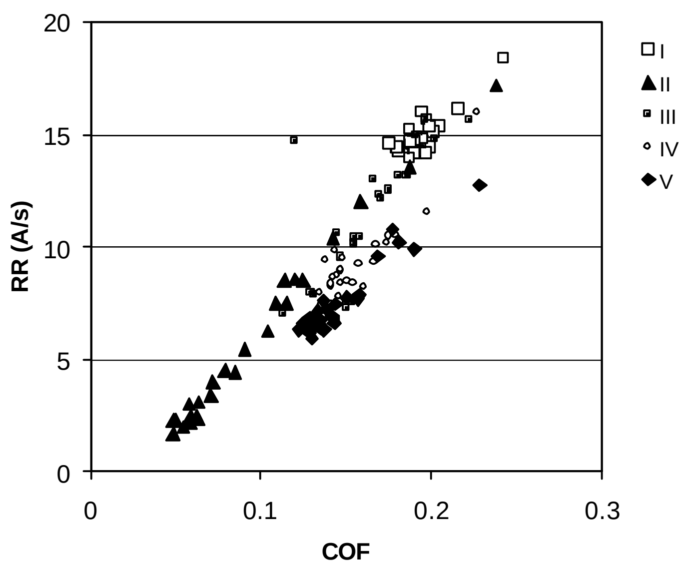

Fig. 5 Correlation between COF and silicon dioxide removal rate

The results of PFR analysis are shown in Figs. 6 (a) and (b). In Fig. 6 (a), regardless of the conditioning solutions used, diamond conditioning achieves the lowest PFR that is close to zero, indicating the pad surface is not flattened or glazed. When there is no conditioning (Run II), PRF values increase significantly with the polished wafer number and reach almost 100 %, suggesting the pad is completely flattened or glazed. The PFR value for the HPMJ conditioning increase gradually with the polished number to about 20 %, indicating most area of the pad is not flattened or glazed. Fig. 6 (b) shows an inverse relation between the PFR and removal rates. This is expected as flattened or glazed pad leads to reduced mechanical contacts between the wafer and the pad during polishing, resulting in a low removal rate.

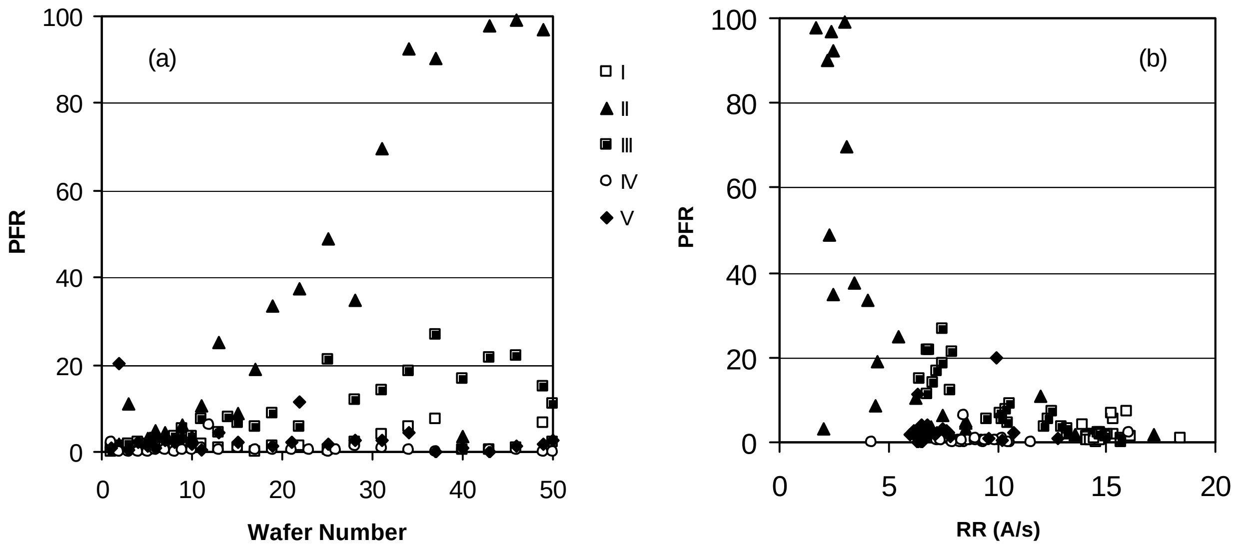

Fig. 6 PFR results under different pad conditioning and relation between PFR and removal rate
(a) PFR vs. Wafer Number, (b) PFR vs. RR

Conclusions.

In this study, a novel high pressure micro jet (HPMJ) technology is used as a pad conditioning method for silicon dioxide CMP applications. While the removal rates of the HPMJ conditioning are less than those of the conventional diamond disc conditioning, the HPMJ conditioning achieves lower coefficients of friction, suggesting a longer pad life. The conditioning solutions are found to have a significant effect on the removal rates for the diamond disc conditioning. PFR analysis indicates the HPMJ conditioning is effective in preventing the pad from being flattened and has great potentials to become an alternative pad conditioning method in mainstream CMP processes.

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