

Development of a Pad Conditioning Method for ILD CMP using a High Pressure Micro Jet System

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The goal of this study is to determine if High Pressure Micro Jet (HPMJ) conditioning can be used as a substitute for, or in conjunction with, conventional diamond pad conditioning. Five conditioning methods were studied during which 50 ILD wafers were polished successively in a 100-mm scaled polisher and removal rate (RR), coefficient of friction (COF), pad flattening ratio (PFR) and scanning electron microscopy (SEM) measurements were obtained. Results indicated that PFR increased rapidly, and COF and removal rate decreased significantly, when conditioning was not employed. With diamond conditioning, both removal rate and COF were stable from wafer to wafer, and low PFR values were observed. SEM images indicated that clean grooves could be achieved by HPMJ pad conditioning, suggesting that HPMJ may have the potential to reduce micro scratches and defects caused by slurry abrasive particle residues inside grooves. Regardless of different pad conditioning methods, a linear correlation was observed between temperature, COF and removal rate, while an inverse relationship was seen between COF and PFR.

Keywords : High pressure micro jet(HPMJ), Chemical mechanical planarization(CMP), Pad flattening ratio(PFR), Pad conditioning

1. INTRODUCTION

Presently, polyurethane pads are widely used in Chemical Mechanical Planarization (CMP)[1]. However the performance of these pads becomes limited when pores on the surface are filled with slurry and other polishing by-products[1-3]. To revive the pad surface, diamond conditioning has traditionally been implemented during polish. This method, however, has several limitations including reduced pad life (due to wear by the diamond) and the dislodging of diamonds and diamond fragments from the conditioning disc, which can scratch semiconductor devices. In addition, slurry residues and polish by-products can coagulate in the pores and grooves during polishing, and if not removed by diamond conditioning, can cause defects. These issues all serve to decrease throughput and increase cost of ownership (COO). To possibly eliminate these issues, a High Pressure Micro Jet (HPMJ) pad conditioning method has been investigated as an

alternative to diamond disc conditioning. During conditioning, the HPMJ system sprays high-pressure (up to 20 MPa) water droplets onto the pad to slowly wear and refresh the pad while simultaneously cleaning the surface of slurry residues and other embedded particles [4,5]. This study evaluates various conditioning techniques through 50-wafer ILD CMP marathon tests. Processes are evaluated in terms of pad flattening ratio (PFR), silicon dioxide removal rate, coefficient of friction (COF), and scanning electron microscopy (SEM) images.

2. INTEGRATED HIGH PRESSURE MICRO JET (HPMJ) PAD CONDITIONING SYSTEM

The HPMJ system can pressurize UPW, or other solutions such as KOH, from 3 to 20 MPa. The pressurized fluid is then sent to an accumulator to absorb any fluctuation, and moved to a high-pressure filter that

Table 1. Details of various conditioning methods tested.

Conditioning Method	Description
I	<i>Ex-situ</i> diamond with slurry for 30 seconds after each polish
II	<i>Ex-situ</i> HPMJ with KOH for 30 seconds after each polish
III	No conditioning
IV	<i>In-situ</i> diamond with slurry
V	Combined <i>in-situ</i> diamond with slurry and <i>ex-situ</i> HPMJ with KOH for 10 seconds after each polish

removes particles before sending the fluid to the nozzle through an automatic valve. The nozzle is positioned on a traverse arm above the pad that allows the nozzle to move over the surface of the pad such that the entire pad surface can be treated. The nozzle is specially designed to create high-pressure miniature droplets, which are ejected onto pad surface to remove slurry residue and to condition the pad. Details regarding droplet size distribution, average kinetic energy and pressure distribution at the pad level can be found elsewhere[4]. An important feature of these studies is the real-time acquisition of COF (ratio of shear force to normal force). Details of how COF was acquired during these types of conditioning experiments may be found elsewhere[6,7].

3. EXPERIMENTAL PROCEDURE

Experiments were performed on a scaled polisher[6,7]. IC1000 K-groove pads were used to polish 100-mm, 6,000 angstrom thermally grown silicon dioxide on silicon wafers. For each experiment, 50 silicon dioxide wafers were polished for 2 minutes each at a constant pressure of 3 PSI and a sliding velocity of 0.64 m/s. Fujimi PL-4217 fumed silica slurry (12.5 percent by weight) was used at a flow rate of 80 cc/min.

Details of various conditioning methods are described in Table 1. *Ex-situ* diamond conditioning was performed with working slurry for 30 seconds. For diamond conditioning, a 2-inch diameter, 100-grit diamond disc was used at a disc pressure of 0.5 PSI, a rotation rate of 30 RPM and a sweep frequency of 0.33 Hz. *Ex-situ* HPMJ conditioning was performed for 10 seconds using KOH solution, with a pH of approximately 11.6 (formulated to be identical to the pH of the PL-4217 slurry). A fluid pressure of 10 MPa, a fan angle of 25 °, flow rate of 770 cc/min, an actuator angle of 90 ° (i.e. normal to the pad surface) and a nozzle-to-pad distance of 10 mm were used.

During polishing process, the frequency of shear force acquisition was 1,000 Hz. The resulting 120,000 data points for each run were averaged to calculate the average coefficient of friction (COF). ILD removal rates

were obtained by optical measurements of the oxide films using a reflectometer before and after polishing at 49 locations on the wafer. Pad flattening ratio (PFR) was determined using a novel apparatus that measured the fraction of light incident on an unloaded pad sample that was reflected directly back to the light source. As such, PFR values should be low when the surface is rough and high when asperities have been substantially flattened by wafer-induced processes. Physically, one may interpret the PFR as being proportional to the mean asperity tip radius of curvature. Details of the PFR apparatus and analysis methods can be found elsewhere[8]. After each marathon run, a 5 × 5 mm pad sample was analyzed using a scanning electron microscope.

4. RESULTS AND DISCUSSION

4.1 PFR analysis

The results of PFR under different pad conditioning methods are shown in Fig. 1. Without pad conditioning, PFR values increase significantly from about 4 % after 10 polishes to 27 % after 19 polishes, and they continue to increase to about 40 % at the end of the 50-wafer marathon. This indicates the pad surface becomes glazed rapidly when pad conditioning is not used. With *ex-situ* diamond conditioning, PFR values remain almost unchanged for the first 30 or so polishes, after which they increase gradually. Using *in-situ* diamond conditioning, as well as a combination of *in-situ* diamond and *ex-situ* HPMJ conditioning, result in the lowest PFR values, suggesting that a relatively rough and stable pad surface is maintained during polishing. For *ex-situ* HPMJ pad conditioning, PFR values increase gradually and stabilize at about 23 %, indicating that the pad surface is partially flattened or glazed at the end of the 50-wafer marathon. Also, these results suggest that pad asperities can be partially re-established by HPMJ pad conditioning. However, the energy generated by HPMJ conditioning system is not enough to abrade the surface of the pad compared to diamond conditioning method.

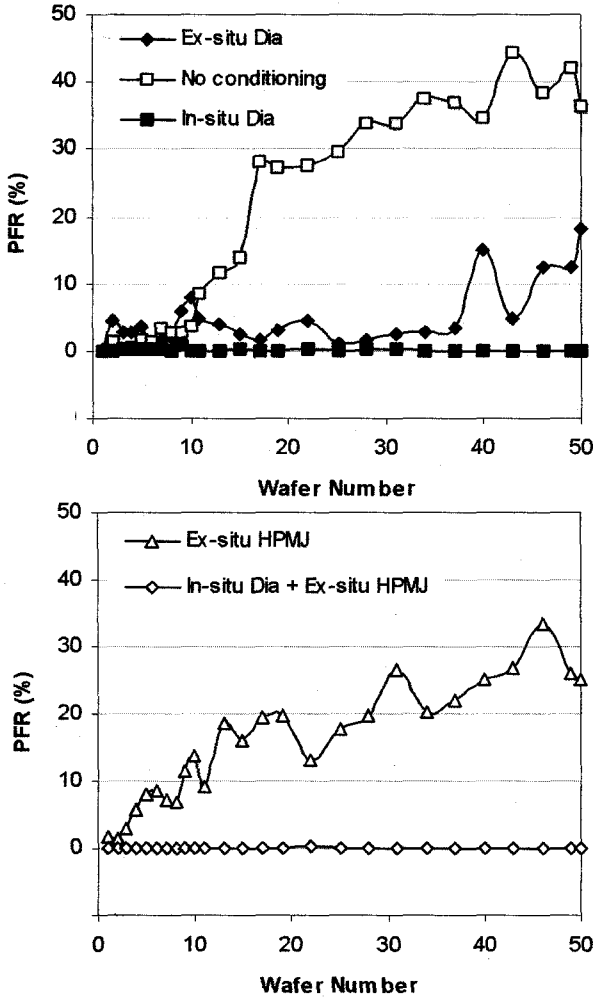


Fig. 1. PFR results as a function of wafer number.

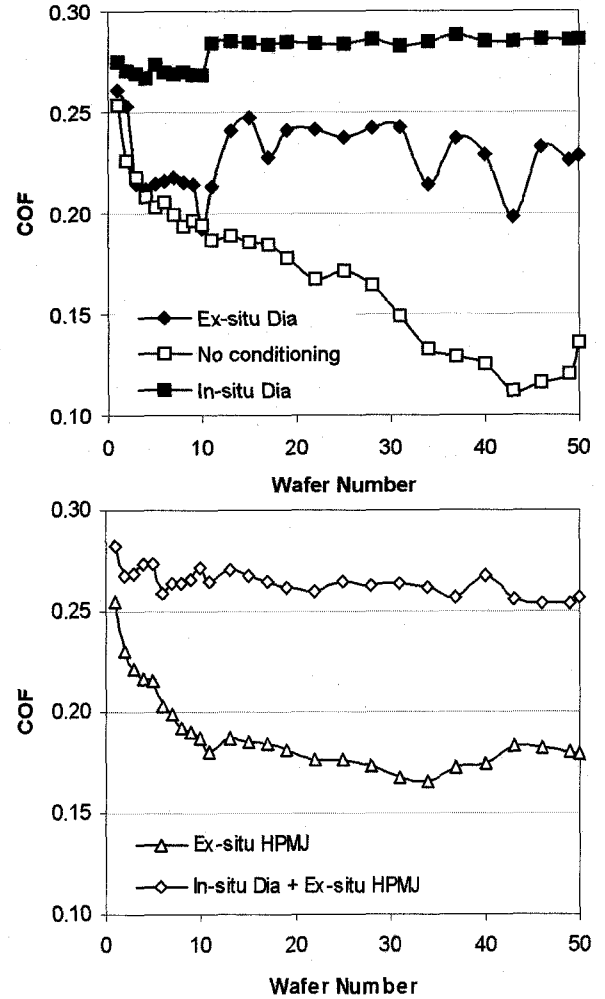


Fig. 2. COF results as a function of wafer number.

4.2 COF and removal rates

COF results as a function of wafer number for different conditioning methods are shown in Fig. 2. Results indicate that COF significantly decreases with cumulative wafer number and reaches a low steady-state value using when conditioning is not performed. This shows that without pad conditioning, pad asperities collapse rapidly and the pores in the pad surface are quickly clogged by slurry residues. With ex-situ diamond conditioning, a slight decrease in COF is initially observed, followed by rapid stabilization of COF. With ex-situ HPMJ conditioning, COF decreases continuously from 0.25 to 0.17 and then is stabilized, suggesting that pad asperities can be partially restored by HPMJ conditioning. PFR results indicate that the values of PFR with HPMJ conditioning are lower than those of PFR without conditioning, and higher than those of PFR with diamond conditioning. Relatively constant values of COF are achieved by in-situ diamond conditioning, as well as combination of in-situ diamond and ex-situ HPMJ

conditioning, suggesting that diamond conditioning can effectively restore collapsed pad asperities and break up the glazed area during polishing. In comparison between these two conditioning methods, low COF is observed using combination of in-situ diamond and ex-situ HPMJ conditioning without any different removal rate (see the results of removal rate) compared to in-situ diamond conditioning, suggesting that low COF may increase pad life.

Figure 3 shows removal rate as a function of wafer number for different conditioning methods. Removal rate behaves similarly to coefficient of friction shown in Fig. 2. Without conditioning, removal rate significantly drops off with cumulative wafer number and stabilizes at a low steady-state value. Under ex-situ diamond conditioning, removal rate slightly decreases and stabilizes quickly. Using in-situ diamond conditioning, as well as a combination of in-situ diamond and ex-situ HPMJ conditioning, result in obtaining the relatively constant removal rates, indicating that rough surface is

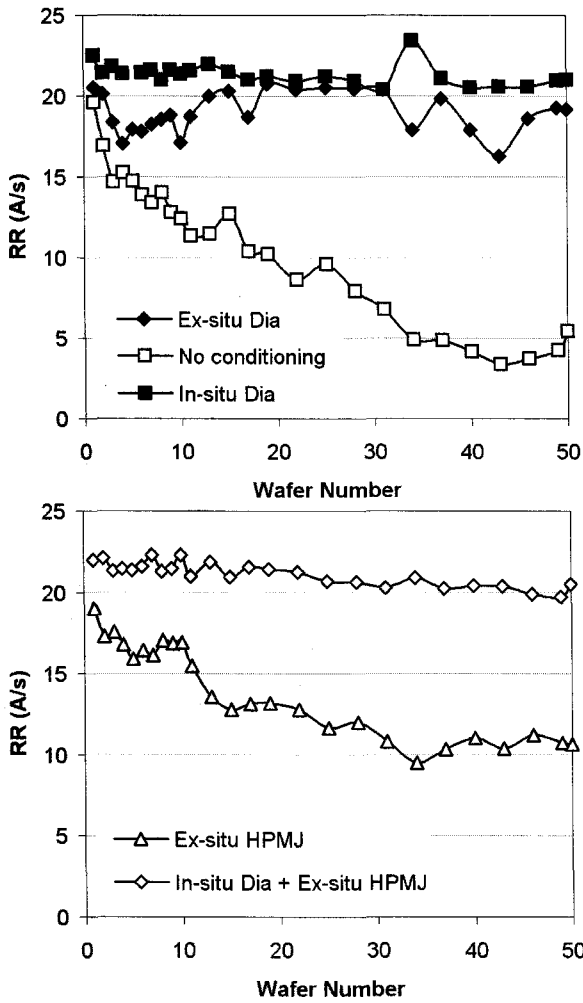


Fig. 3. Removal rate results as a function of wafer number.

maintained during polishing. These results are consistent with the previous reports that showed a logarithmic decay of removal rate without pad conditioning and a stabilized removal rate with diamond disc pad conditioning[1-3]. With ex-situ HPMJ conditioning, continuous early decrease in removal rate is observed and stabilized removal rate is achieved later. Removal rate obtained by HPMJ conditioning lies between that of ‘no conditioning’ and ‘diamond conditioning’. Based on results of COF and removal rates, HPMJ pad conditioning may have much lower pad wear rates in order to explain the observed COF and removal rate trends compared to diamond conditioning.

4.3 Correlation between COF, removal rate and PFR

Figure 4 shows the correlation between removal rate and COF under different conditioning methods during the 50-wafer marathon. Results indicate that the silicon dioxide removal rate is strongly dependent on COF in the

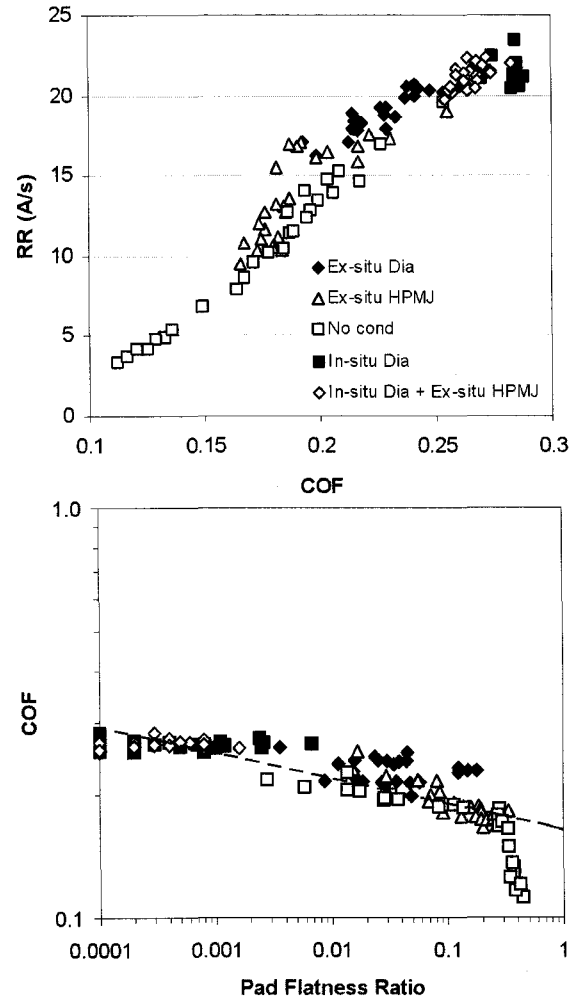


Fig. 4. Correlation between COF and removal rate (upper), and COF and PFR (bottom).

range of parameters considered in this paper. The existence of a correlation between COF and removal rate has been reported previously[7-9]. The basis of such a relationship has been described experimentally and theoretically in detail in a recent publication[10]. Based on this result, COF is quite a useful parameter to analyze since it can be measured in real-time via a strain gauge set-up thus allowing the prediction of removal rate during polishing without having to independently measure removal rate.

The correlation between COF and PFR under different conditioning methods during the 50-wafer polishing marathon is shown in Fig. 4. Results indicate that the extent of pad flatness and glazing has a significant effect on COF during the polishing process. As the pad surface is flattened or glazed, the number of pad asperities making mechanical contact with the wafer decreases significantly, resulting in a low shear force and COF. In a recent publication[11], it is shown that for a given pad

under constant sliding velocity and slurry viscosity, the viscous shear contribution to COF is proportional to the mean asperity tip radius of curvature (which in this study we assume to be proportional to PFR) to the -0.19 power. The reason for the log-log plot of PFR vs. COF in Fig. 4 is to demonstrate that, regardless of the conditioning method employed, the data are consistent with the theoretical treatment in reference 11 as the best fit to the data indicates a -0.20 power.

4.4 SEM images of the groove

Figure 5 shows SEM images of pad grooves after 50 polishes under different conditioning methods. SEM images show that clean grooves are achieved by conditioning methods using HPMJ conditioning. This is due to the fact that HPMJ pad conditioning has a unique cleaning feature since the small droplets (mean droplet diameter of $45\ \mu\text{m}$ and average velocity of $18\ \text{m/s}$)[4,5] can get inside pad grooves and eliminate the build-up of slurry residues. However, slurry residues in groove are observed using conditioning method adopted with only diamond conditioning. This is partially due to that diamonds (which in most cases protrude no more than 60 micrometers beyond the disc substrate's reference plane) do not reach the bottom of the grooves (which are typically 500 micrometers or greater in depth) and are quite ineffective in cleaning the entrained slurry residues or polish by-products. During polishing, such residues can harden, and occasionally dislodge from the grooves, thus causing micro-scratches on the devices

5. CONCLUSION

A series of 50-wafer marathon runs were performed to investigate whether HPMJ pad conditioning could be used as an alternative to, or in conjunction with, conventional diamond conditioning for ILD CMP. Results indicated that diamond conditioning alone effectively resulted in stable removal rate and COF during extended runs due to its ability to re-establish pad asperities. However, SEM images showed slurry residues in pad grooves with diamond conditioning. On the other hand, HPMJ conditioning was able to effectively clean the entire pad surface, yet it did not provide enough energy to abrade the surface of the pad and maintain constant removal rate and COF during extended polishing. A new pad conditioning method, which combined diamond and HPMJ conditioning, allowed for stable polish results in terms of removal rate and COF compared to in-situ diamond conditioning during extended marathon runs. This hybrid method also yielded substantially residue-free surfaces which could potentially cause an increase in pad life and a reduction in wafer-level defects.

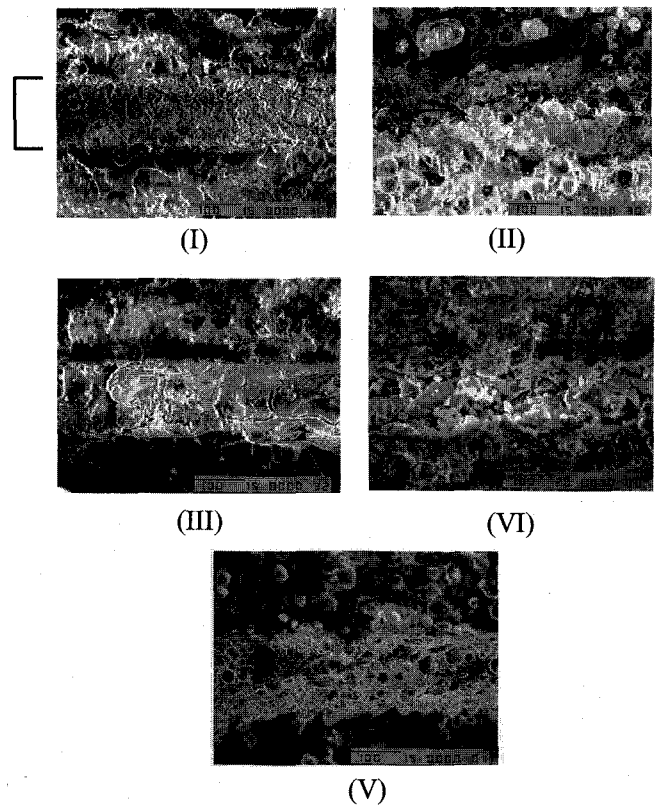


Fig. 5. SEM images of pad grooves after 50 polishes using (I) ex-situ diamond, (II) ex-situ HPMJ, (III) no conditioning, (IV) in-situ diamond, and (V) combination of in-situ diamond and ex-situ HPMJ conditioning; 100 micron scale bar refers to all images; Bracket to the left of Figure I represents the location of the pad groove.

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