Advanced Pad Conditioner Design for Oxide/Metal CMP

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Advanced CMP conditioner design requires investigations of key conditioner manufacturing parameters and their effects on pad surface and then wafer performance. In the present investigation, diamond shape, concentration, distribution, and other key manufacturing parameters are considered to improve CMP process stability and conditioner life. Self avoiding random distribution (SARD^{TM}) of diamond abrasives has been developed and both numerical simulation and experimental results show very stable and reliable polishing performance.

Keywords : CMP, Conditioner, Oxide, Metal, Cu

1. INTRODUCTION

Fundamental understanding of conditioning effects on wafer performance in CMP requires an investigation of interaction mechanisms between conditioner, pad, and the wafer[1-3]. Statistical models have been developed to capture the relationship between the conditioning process and the pad surface morphology[3,4]. However detailed conditioner specifications and conditioning parameters have not been reported due to their proprietary nature. In Copper CMP compared to Oxide CMP, Cu removal mainly occurs by strong chemical reactions under low polishing pressure, subtle changes of pad surface by conditioning result in significant changes on relatively softer Cu surfaces[5]. Inappropriate selection of conditioner and conditioning process parameters could lead to higher wafer defect, unstable CMP process, higher pad cut rate, and shorter conditioner life. Therefore optimization of conditioner design and conditioning process parameters are crucial for achieving cost-effective and stable oxide and metal CMP processes.

The present research was undertaken to understand effect of key CMP conditioner manufacturing parameters and thereby develop advanced conditioners for metal and oxide CMP applications.

2. CMP CONDITIONER DESIGN – KEY MANUFACTURING PARAMETERS

In this section, important conditioner manufacturing parameters are considered to explain interaction between the diamond abrasives and the polyurethane CMP pad in terms of mainly pad wear rate. The following section will focus on polishing performance.

2.1 Diamond shape

In the majority of CMP applications, synthetic diamonds produced under high pressure and high temperature are utilized. The morphology of the synthesized crystals is dependent upon the particular growth conditions[6]. The crystal shape influences many diamond attributes such as crystal toughness and sharpness. Desirable pad wear rate can be obtained by proper selection of diamond shapes and their relative composition. Pad wear rate was measured with three different conditioners (Fig. 1) designated as “very sharp”, “sharp” and “dull”, respectively. Each conditioner was made with specific diamond shapes at the same diamond concentration. As can be seen in this figure, diamond shape or sharpness has a dramatic effect on pad wear rate. Changing from dull to very sharp diamond increases the wear rate by almost an order of magnitude.

Another way to quantify the effect of diamond sharpness is to measure conditioning forces, normal and tangential components, while diamond tips are conditioning or cutting the pad. In order to measure these forces, a proprietary tool set-up was internally developed by incorporating a dynamometer, computer data acquisition system, and fixture. Similar trend of higher conditioning force per grit with very sharp diamond is observed in Fig. 2.

2.2 Diamond exposure

Diamond exposure, the height of the diamond protrusion above the bonding material, is a very important factor and strongly affects pad wear rate and conditioner life.

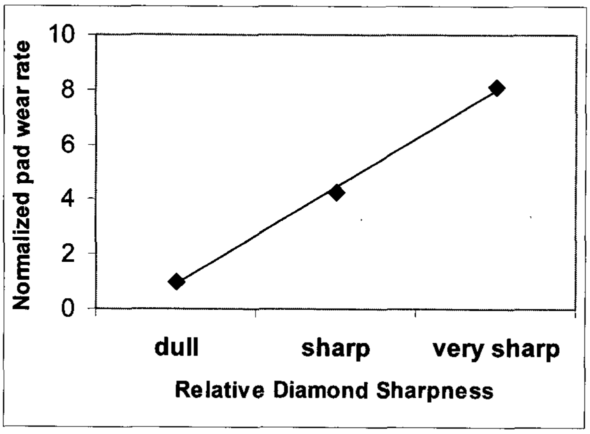


Fig. 1. Effect of diamond sharpness on pad wear rate.

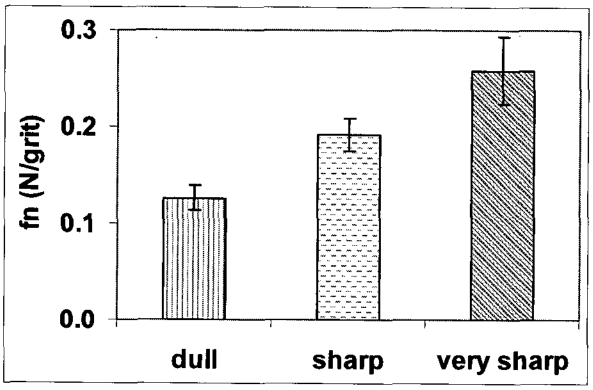


Fig. 2. Effect of diamond sharpness on normal conditioning force.

Micrographs of two typical examples of poorly exposed diamonds in Fig. 3(a) and well-exposed diamonds in Fig. 3(b) clearly reveal diamond exposure differences above bonding material. Figure 3(a) shows significant wicking of the bonding material over the cutting edges of the abrasive grains, which could lead to inefficient conditioning and therefore shortened conditioner life. The pad wear rate of poorly exposed diamond is reduced to 35 % compared to the pad wear rate of well-exposed diamond.

2.3 Diamond concentration

Abrasive grain concentration is the main concern for conditioner manufacturers. Ranges of diamond concentration or diamond separation distance can be varied depending on diamond size and manufacturing methods. The effect of diamond concentration on pad wear rate was evaluated with 1x, 2x, and 3x concentrations. For this work, the same grade diamonds carefully selected from a tight size distribution were used to manufacture conditioners. The pad wear rate, Fig. 4, linearly increases with diamond concentration within the tested diamond concentration range. Two conditioners with low and high diamond concentrations, respectively, were also tested at production environment for more than 20 hours to further investigate time dependent behavior of pad wear rate. The pad wear rates with both conditioners, Fig. 5, steadily decrease with conditioning time while the slope of the lower concentration conditioner is somewhat steeper. To better explain pad wear rate decrease with conditioning time, it is necessary to identify diamond wear at the active conditioning tips and corresponding wear mechanisms. Investigations of diamond wear mechanisms under especially metal CMP environments and technologies to increase conditioner life will be reported in a separate paper.

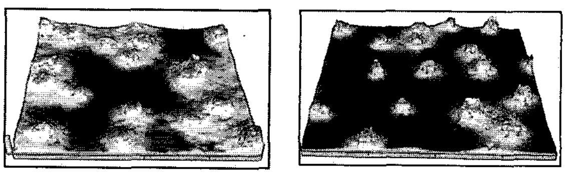

(a) (b)

Fig. 3 Micrographs of conditioner surface, (a) poorly exposed diamonds, (b) well –exposed diamonds.

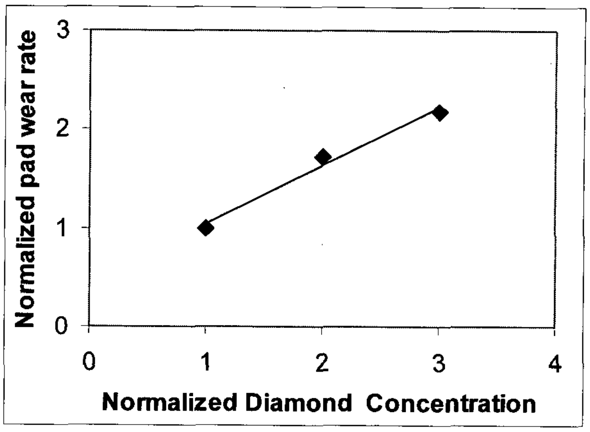


Fig. 4. Diamond concentration effect on pad wear rate.

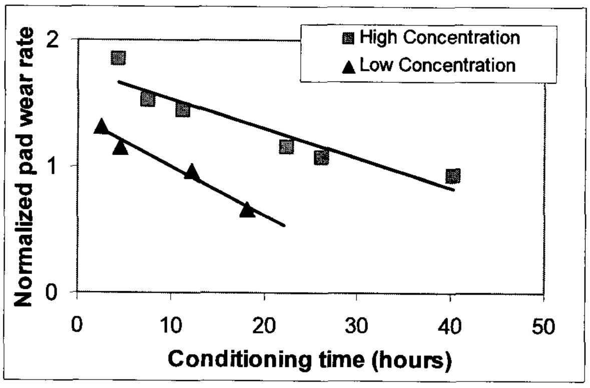


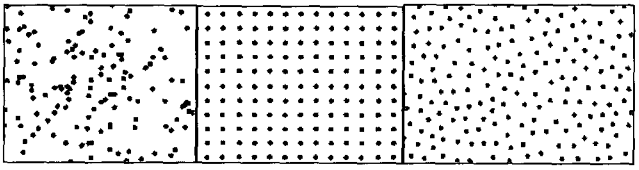
Fig. 5. Pad wear rate variation for two diamond concentrations.

Another important parameter we should consider related to diamond concentration is active diamond density, which can be defined as number of diamonds per unit area interacting with the pad surface during conditioning. Higher diamond concentration does not necessarily guarantee higher active diamond density. Active diamond density depends on conditioner flatness, diamond size distributions, conditioning load, bonding technologies, and etc. For most of CMP applications it is not easy to differentiate between active diamonds and inactive diamonds because dulling of active cutting edges is very minimal and hardly noticeable even with higher SEM magnification. One simple way to estimate active diamond density is first to measure diamond protrusion heights on the conditioner surface, for example which can be obtained from the optical micrographs as shown in Fig. 3, and use statistical diamond height distribution functions[7]. Much more efforts are needed in this area to accurately estimate active diamond grains.

2.4. Diamond distribution

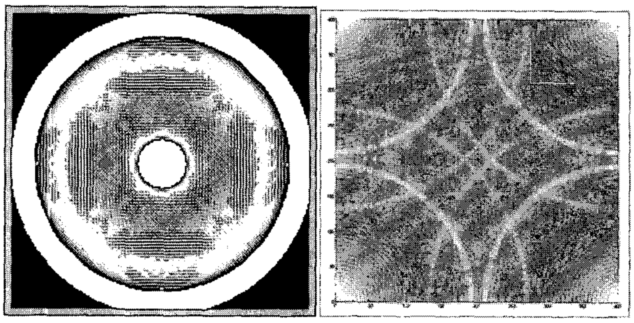
Diamond grains can generally be placed on the conditioner surface in random distribution or patterned distribution in Fig. 6(a), (b). A randomly distributed conditioner may have repeatability and reproducibility problems due to its inherent lack of manufacturing consistency. A conditioner with patterned array has inherent periodicity of diamond in Cartesian coordinates which may imprint undesirable regularity on the pad. Self-avoiding random distribution (SARD^{TM}) was developed to overcome both shortcomings. The SARD has regular diamond distribution, but no repeated pattern as seen on patterned array and no diamond free zone on random array (see Fig. 6(c)). Furthermore, each SARD conditioner is fabricated with exact duplication of each diamond position and has superior polishing performance in terms of process stability, lot to lot consistency, and wafer uniformity. Some polishing data will be presented in later section.

Numerical simulation model has been developed to understand diamond distribution effect on pad surface topography. Three distributions, random, patterned, and SARD were tested using computer simulation software. By accounting for each diamond trajectory on the virtual pad, we are able to calculate footprint on the pad. Both patterned and SARD distributions showed better pad uniformity over the random. However, by careful examination of the footprints between the SARD and the pattern (see Fig. 7), some periodicity is observed on the footprint with patterned array in Fig. 7(a). It is quite interesting that Discrete Fourier Transform (DFT) analysis on the patterned foot print in Fig. 7(a) shows the periodicity on the pad is exactly same as the periodicity of the diamond on the patterned conditioner. However the result with SARD in Fig. 7(b) shows very uniform and no repeated regularity.

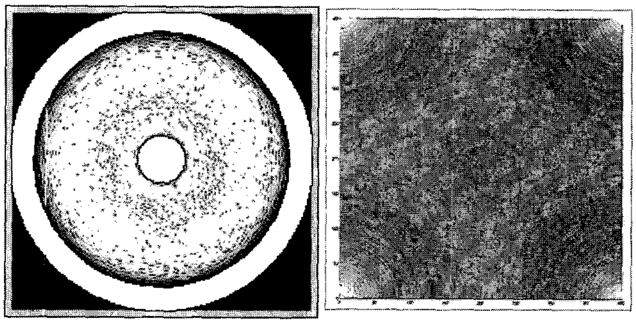


(a) Random (b) Patterned (c) SARD

Fig. 6. Diamond distribution on the conditioner surface.



(a) Patterned diamond distribution
(Left – simulated footprint, Right - DFT of the left)



(b) SARD diamond distribution
(Left – simulated footprint, Right - DFT of the left)

Fig. 7. Numerical simulation of patterned and SARD distributions.

3. EXPERIMENTAL VALIDATION AND DISCUSSION

Two types of machines were used with in-situ conditioning mode on IPEC polisher and ex-situ conditioning on Ebara polisher. During polishing, commercial Cu/

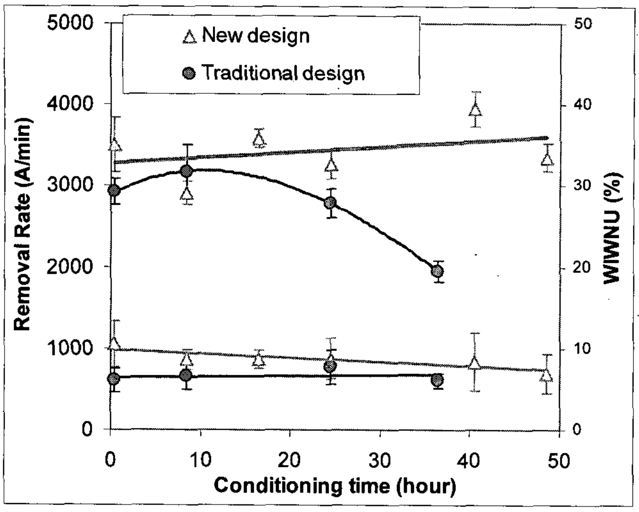


Fig. 8. Material removal rate and WIWNU versus conditioning time for two designs.

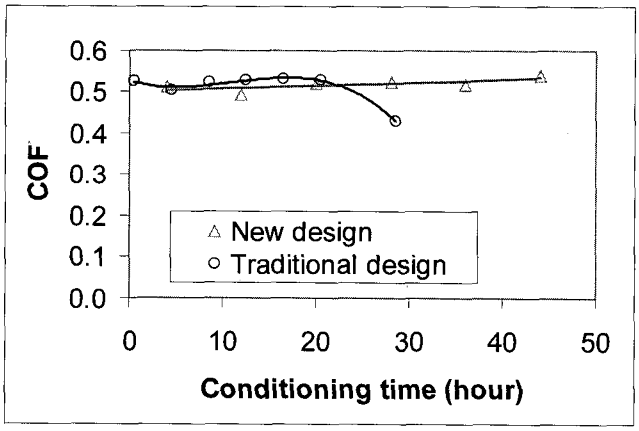


Fig. 9. Coefficient of friction between the wafer and the pad during polishing.

Oxide slurries and IC1400 K -grooved pad (Rohm and Haas) were used with slurry flow between 100 ml/min to 150 ml/min. The conditioning load applied was 14 to 22 Newton for in-situ conditioning and 200 Newton for ex-situ conditioning. Several different types of conditioners were manufactured by varying diamond sizes, shapes, concentrations, and bonding methods. Measurements of pad wear rate and diamond conditioning forces were made on a separate system equipped with linear variable differential transformer (LVDT), computer data acquisition system, force dynamometer to monitor the conditioning process.

Two conditioners, designated as traditional design and new design, were tested on the IPEC polisher equipped with an APP 1000 conditioner arm with in-situ conditioning. Copper removal rate and WIWNU measured during the testing were plotted versus accumulated conditioning time, Fig. 8. The copper removal rate of the traditionally designed conditioner initially increased up to about 10 hours and then decreased. Another similar type traditional conditioner was repeated and the removal behavior was similar to the first. The copper removal rate of the advanced conditioner increased with conditioning time and showed no removal rate decay after more than 50 hours of conditioning. The trend of wafer non uniformity of both designs showed no significant changes over conditioning time. Coefficient of friction (COF) between the pad and the wafer measured during polishing is presented in Fig. 9. A sudden drop off of COF for traditional conditioner after 20 hours of conditioning time may indicate near the end of conditioner life when the corresponding cu removal starts to decay.

Table 1. Conditioner performance comparison.

		Competitor	Saint-Gobain
Oxide	MRR (A/min)	2253	2564
	WIWNU(%)	6.1	3.0
	Defect	41	20
Tungsten	MRR (A/min)	4000	4757
	WIWNU(%)	7.0	2.6
	Defect	60	69

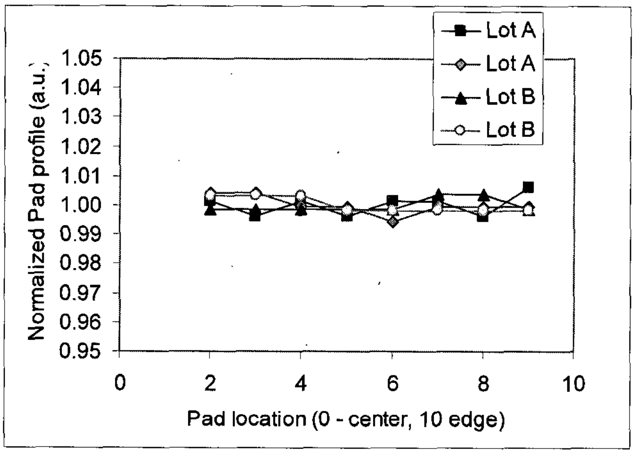


Fig. 10. Normalized global pad profiles after about 2000 wafers polished with Saint-Gobain conditioners.

Advanced Saint-Gobain conditioners were evaluated for oxide and tungsten CMP processes at external fabs. Table 1 compares removal rate, uniformity, defect of a competitor and Saint-Gobain conditioner. The Saint-

Gobain conditioner showed higher removal rate, lower uniformity and comparable defect, and comparable or longer conditioner life compared to competitor conditioner. One of advantages mentioned earlier is superior repeatability and reproducibility that are essential to maintaining process stability in production environments. Figure 10 shows used pad profiles after about 2000 wafers polished with SARD conditioners. All four used pad profiles were very uniform and reproducible, and wafer uniformity at near the end of pad life was very close to the wafer uniformity on fresh pad.

4. CONCLUSION

A novel CMP conditioner has been developed by proper selection of diamond shape, size, distribution, diamond exposure, and manufacturing technologies. Experimental results conducted internally and at fabs demonstrate that advanced Saint-Gobain conditioner provides very stable CMP performance, better wafer uniformity, higher polish rate. It has been also demonstrated that SARD diamond distribution yields superior repeatability and reproducibility to improve the stability of CMP process.

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