New Pad Conditioning Disk Design Delivers Excellent Process Performance While Increasing CMP Productivity

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Abstract

As the market for dielectric chemical mechanical planarization (CMP) matures, semiconductor manufacturers continue to seek increased yields and lower cost of ownership. Optimized pad conditioning is fundamental to oxide CMP process performance which includes high and stable removal rate, WIWNU, WTWNU, and excellent defect performance. Pad life and conditioning disk life can also have a significant impact on the cost of ownership of an oxide process.

Through a joint development effort between Applied Materials, Inc. and 3M, a new diamond conditioning disk has been developed that delivers excellent process performance, while increasing pad life. The disks are manufactured using 3M's patented sintering technology that provides for control of diamond placement, diamond exposure height, and disk front-side flatness.

This paper presents process and productivity results for a new diamond disk pad conditioner. Oxide removal rate, uniformity, and defectivity data are provided as a function of pad life.

Introduction

Consumables play an important role in dielectric CMP. Controlling consumable properties is fundamental to optimizing CMP process performance and minimizing variability. The benefits of pad conditioning for oxide CMP have been well documented (1-4). Pad conditioning is required to obtain and maintain an acceptable oxide removal rate and stable process performance. While alternative conditioning methods have been proposed (5), diamond pad conditioning disks are the most widely utilized form of pad conditioning in production fabs today. Diamond pad conditioning disks refresh (or wear) the pad surface during CMP wafer processing to maintain a uniform pad surface (6,7). Pad conditioning helps maintain optimal pad surface roughness and porosity ensuring slurry transport to the wafer surface and the removal of CMP residuals. Without conditioning, the pad surface will “glaze” and oxide removal rates will rapidly decline (8,9).

Pad conditioning can also have a significant impact on Cost of Consumables (CoC) and overall CMP system Cost of Ownership (CoO) (10). Pad and conditioning disk costs can contribute up to half of total CMP consumables costs. Therefore, changes in pad life and disk life can have a significant impact on overall CoC. In addition, longer pad life results in increased tool availability and more wafers out per week as less time is spent changing pads and requalifying the tool (11). The higher effective throughput (wafers out per week) reduces overall CMP system CoO. Diamond pad conditioning disk design is driven by the desire for excellent and stable process results while also obtaining maximum pad and conditioning disk life.

The objective of the joint effort between Applied Materials and 3M was to design a new pad conditioning disk for the Mirra® CMP system that maintains or improves current oxide process performance while lowering CoO. In this context, lower CoO can be achieved by increasing pad life, increasing disk life, reducing disk break-in time and/or increasing system availability.

3M manufactured all of the disk designs evaluated over the course of the program. The 3M™ Diamond Pad Conditioning Disk utilizes proprietary processes that allow for the controlled placement and spacing of diamonds in a specially formulated metal matrix. The proprietary nickel alloy metal matrix is designed to resist corrosion and maximize diamond adhesion. The sintering process results in a strong substrate-diamond bond that minimizes diamond loss due to bond failure. The controlled diamond placement, resulting in a clearly visible diamond grid, can be seen in the photographs of the 3M™ Pad Conditioning Disk shown in Figure 1.

All of the process work was conducted by Applied Materials on the Mirra® CMP system. In this paper we will present the results of the collaboration between Applied Materials and 3M during the development of a new diamond pad conditioning disk.

Experimental Design

The final 3M disk design was developed based on data collected using a variety of test disk designs. Test disks were evaluated in a series of DOE experiments and evaluated based on screening criteria including removal rate, WIWNU, and defect performance. Conditioning disk prototypes, which passed DOE screening tests, were evaluated by conducting extended runs measuring process performance over the entire pad life.

A number of disk design parameters can impact CMP process results and pad life. Typically, diamond size, shape, density, and exposure will determine the polishing characteristics in oxide CMP. Table 1 below summarizes disk parameters evaluated during the DOE screening tests. Diamond size, shape, density, and exposure height were varied. Diamond sizes evaluated ranged from 100µm to 425µm. Both natural and synthetic diamonds were tested. Diamond exposure was varied from near zero to approximately 60 percent. Other considerations, including disk front-side flatness, presence of macro-scale topography, size of the diamond exclusion zone at the edge of the disk, and several 3M proprietary disk manufacturing methods were also evaluated. Macro-scale topography, which effectively reduces diamond density, was tested as plateaus and valleys. In total, over 60 diamond conditioning disk designs were evaluated and over 70,000 wafers polished during the course of the development program.

Table 1. Disk Design Parameters and Considerations

	Description
Key Parameters:	Diamond Size
	Diamond Shape
	Diamond Density
	Diamond Exposure
Other Considerations:	Disk Front-side Flatness
	Presence of Macro-scale Topography
	Diamond Edge Exclusion Zone Size
	Several 3M Proprietary Manufacturing Methods

Disk designs with the best performance in the DOEs were evaluated during extended runs over pad life. Disks were evaluated for removal rate, WIWNU, WTWNU, defect performance, pad wear rate, pad life, disk break-in time, and disk life. Removal rate and within-wafer non-uniformity performance was measured using blanket thermal oxide films and defect performance was measured using blanket PETEOS films.

All testing was conducted using the Applied Materials Mirra CMP system S12 in Santa Clara, CA. Cabot SS12 slurry was used for all of the data presented in this paper. Wafers were polished on platens 1 and 2 using Rodel IC1010 pads and rinsed on platen 3 using a Rodel Politex pad and de-ionized water. Total polish time for the extended runs was 110 seconds. Pad conditioning was conducted for 75% of the total polish time using pad conditioner downforce and conditioner sweep profiles optimized specifically for the 3M conditioning disk.

Results and Discussion:

Data from four process marathons conducted using the final 3M™ Conditioning Disk design are presented in Table 2. The first two marathons were conducted using a 4.5 psi pressure behind the wafer pressure. The last two marathons were conducted using a 5.0 psi pressure behind the wafer pressure. The average thermal oxide removal rate at 5mm EE for the four extended runs was 3345 Å/minute. The difference in behind the wafer pressure was the primary contributor to the average removal rate range shown in the extended run summary. The average WIWNU at 5mm EE for the four extended runs was 2.2% and the average WIWNU at 3mm EE was 3.8%. Oblique and normal incidence defect adders averaged less than 25.

Removal Rate, WIWNU, and defectivity over pad life are presented in Figures 2-4 for the first extended run. Average removal rate and WIWNU at 5mm EE through 2300 wafers was 3283 Å/minute and 1.9% respectively. WIWNU was stable throughout pad life. Defect performance was excellent throughout pad life and averaged less than 25 adders. Pad life was also excellent with more than 2300 wafers processed on two Rodel IC1010 pads (1150 wafers per pad). No disk break-in was conducted prior to this extended run.

Disk flatness irregularities can result in non-uniform pad wear, which in turn affects relative removal rates on the wafer. This is especially true at the edge of the wafer. Non-uniform pad wear can be a significant contributor to WIWNU drift over pad life.

Table 2. Four Extended Run Summary

Metric	Average	Range
Avg. 5mm Removal Rate	3345 Å/min.	3587 - 3022 Å/min.
Avg. 5mm WIWNU%	2.2%	1.9 - 2.5%
Avg. 3mm WIWNU%	3.8%	3.1 - 4.7%
Normal Incidence Average Adders	23 adders	20 – 25 adders
UCL	44 adders	36 – 57 adders
Oblique Incidence Average Adders	23 adders	20 – 27 adders
UCL	46 adders	37 – 67 adders
Wafers / Pad Set	2350 wfs/pad set	1600 – 3000 wfs/pad set

One of the reasons for the long pad life observed during the extended runs is the even pad wear resulting from excellent front side flatness designed into the 3M™ Pad Conditioning Disk. Figure 5 presents the pad wear profiles for platens 1 and 2 for the first extended run as measured using a linear variable differential transformer (LVDT). Two measurements were made across each pad at a 90-degree angle to each other at the beginning and end of pad life. The first set of measurements were taken after processing 16 wafers and the second after processing 2298 wafers. Figure 5 presents the difference between these two pad thickness measurements and represents the final pad profile as well as the amount of pad wear. The total pad wear that occurred over the course of the extended run was approximately 23 mils. Even after wearing 23 mils of pad, the pad profile remains flat. Average pad wear rates for platen 1 and platen 2 were 0.87 mil/hr and 0.88 mil/hr respectively. The uniform pad wear contributed to the excellent process performance and pad life seen in the extended runs.

Removal rate and WIWNU results from extended run 2 are presented in Figure 6. This extended run utilized the same two conditioning disks from the first extended run with a new IC1010 pad set. A 4.5 psi pressure behind the wafer pressure was also used for this process marathon. Average removal rate and WIWNU at 5mm EE through 3000 wafers was 3022 Å/minute and 2.5% respectively. After the second extended run, this set of 3M™ Conditioning Disks had over 60 hours of conditioning time per disk and processed over 5300 wafers.

Lower cost of ownership was realized through longer pad life, longer disk life, and higher system availability. Pad life averaged nearly 1200 wafers per pad (2400 wafers per pad set) for the four extended runs. The 1.5 to 2 X longer pad life observed with 3M™ Pad Conditioning Disk significantly lowers consumables costs. As presented in Figure 7, total CoC per wafer for the Mirra® CMP system Oxide BKM can be reduced up to 22% with 3M™ Pad Conditioning Disks.

The total CoC includes slurry, pad, retaining ring, membrane, and conditioning disk costs. In addition, reducing pad change and tool requalification downtime increases system availability and further lowers CoO.

Summary and Conclusions

A new diamond pad conditioning disk has been developed for the Mirra® CMP system. The Mirra® Oxide BKM with the newly designed 3M™ Pad Conditioning Disk has been shown to deliver excellent oxide CMP process performance including high and stable removal rate, excellent uniformity, and low defectivity. Data from multiple process marathons confirms these results. Tight control of 3M™ Pad Conditioning Disk front-side flatness resulted in even pad wear and contributed to excellent WIWNU stability over pad life. Defect performance was excellent and stable over pad life and disk life with defect adders averaging less than 25. Up to a 22 percent reduction in CoC was also demonstrated with longer pad and conditioning disk life.

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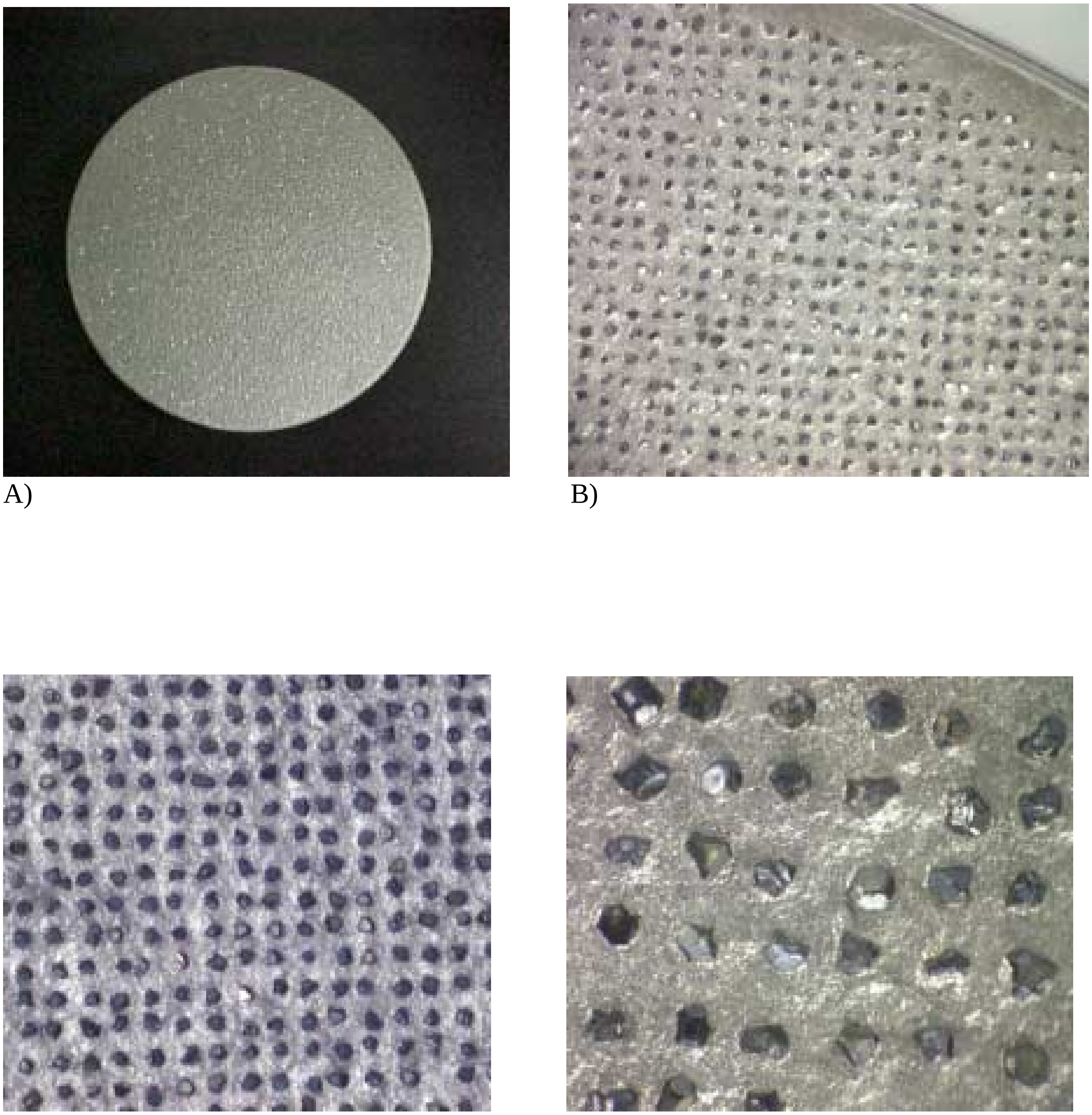

A) B) C) D)

Figure 1 (A-D): 3M™ Diamond Pad Conditioning Disk

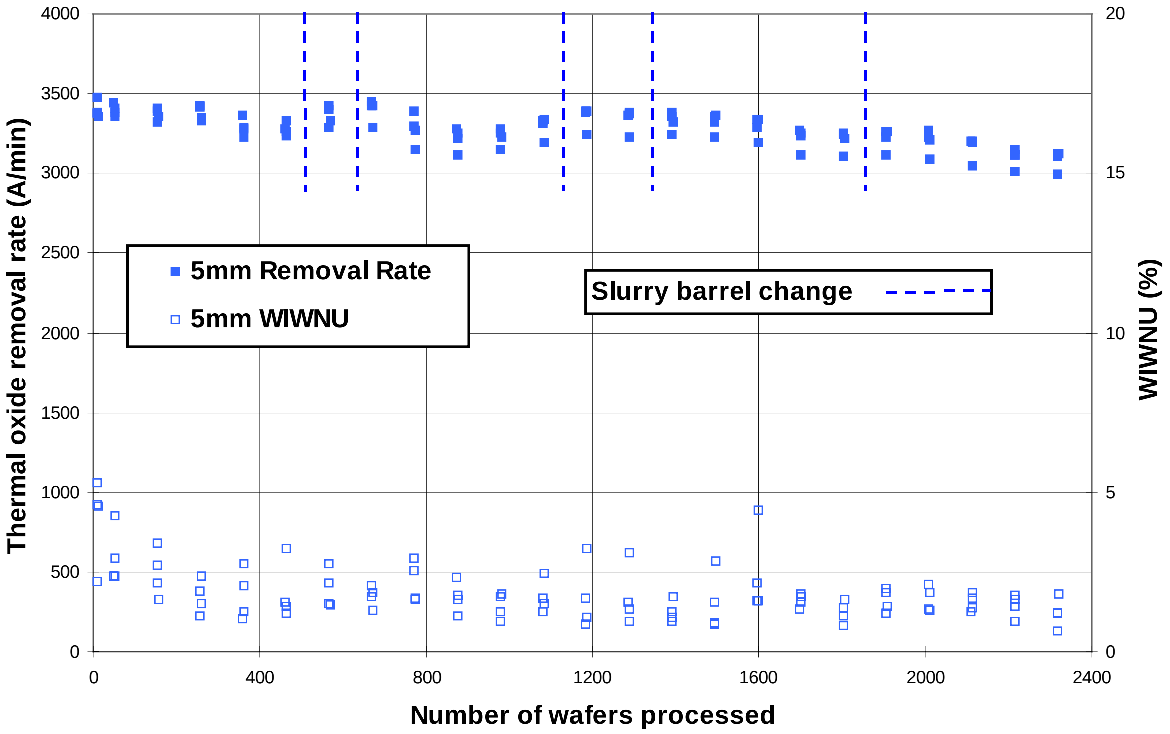

Figure 2: Extended Run #1 Removal Rate and WIWNU% at 5mm EE

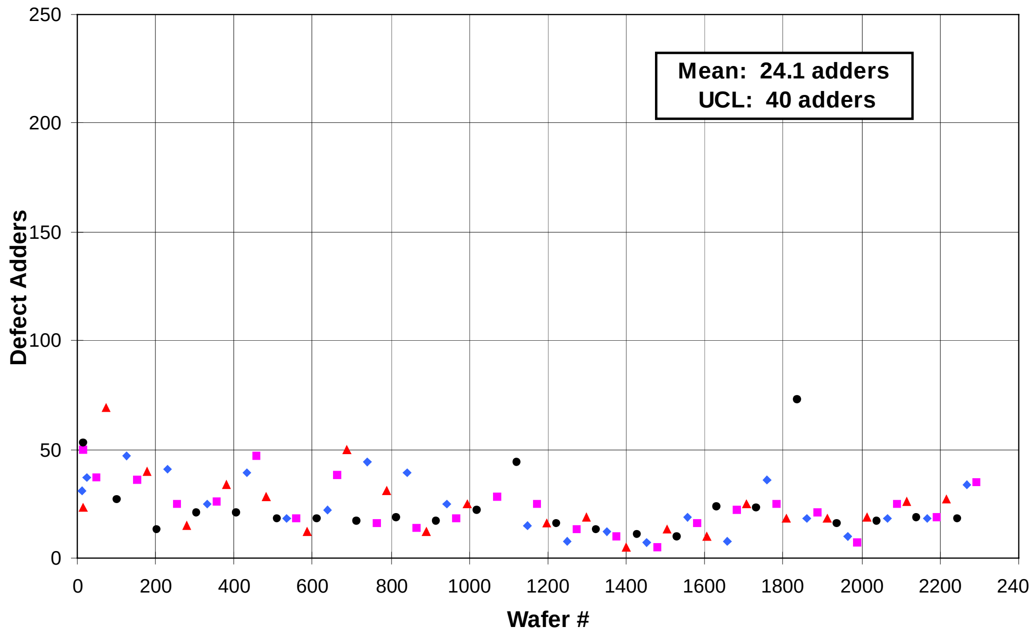

Figure 3: Extended Run #1 Normal Incident Defect Adders at 0.25µm Threshold

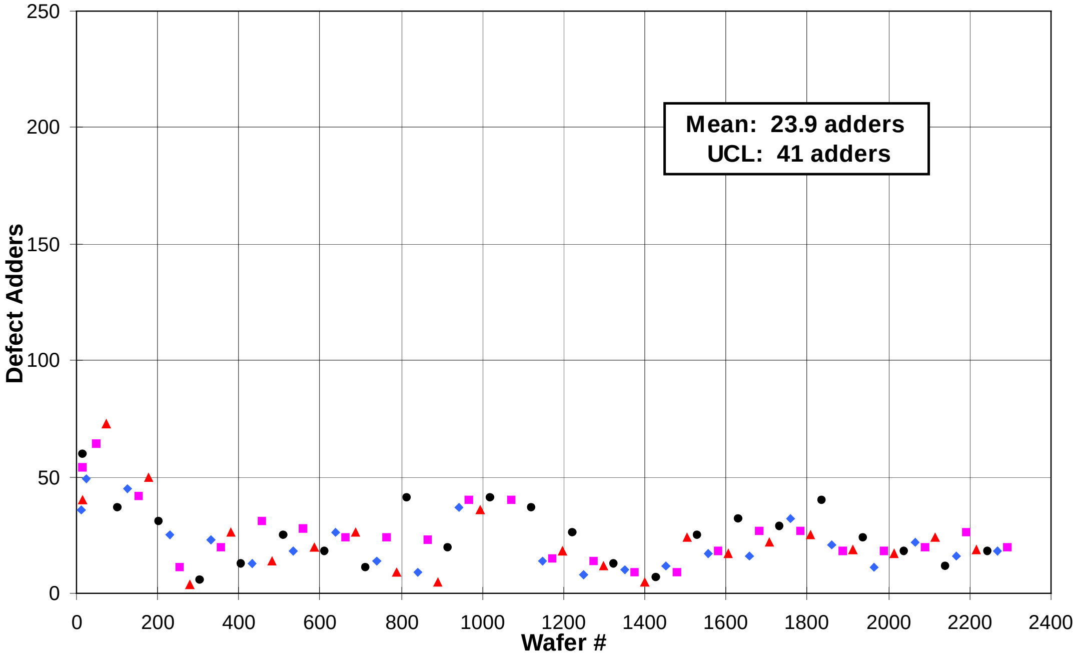

Figure 4: Extended Run #1 Oblique Incident Defect Adders at 0.20µm Threshold

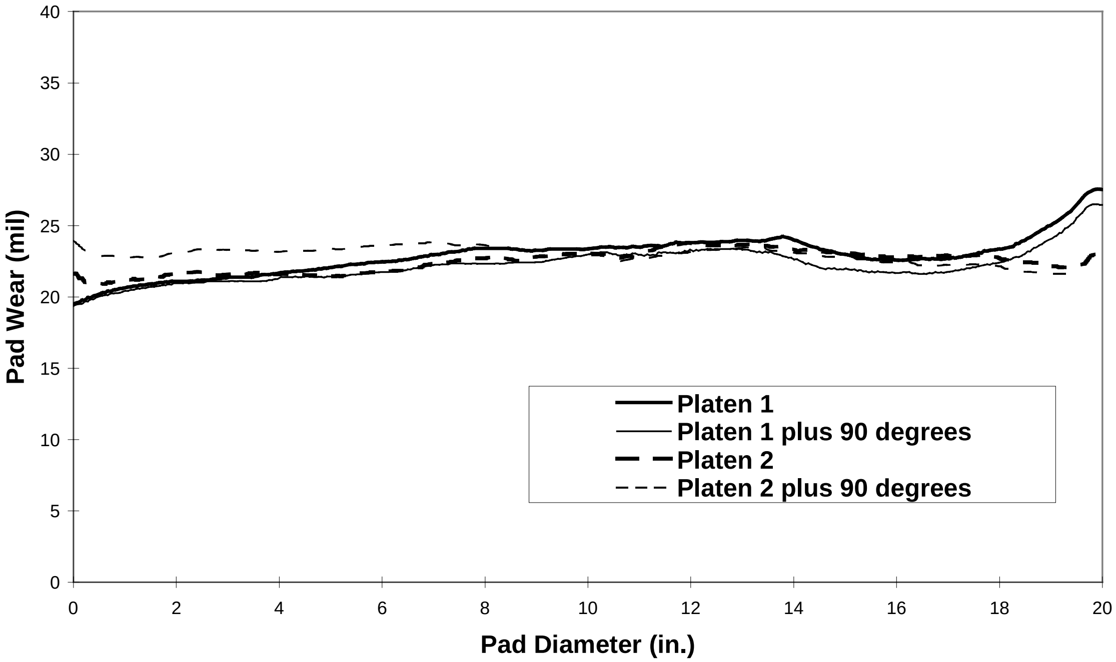

Figure 5: Extended Run #1 Pad Wear Profiles

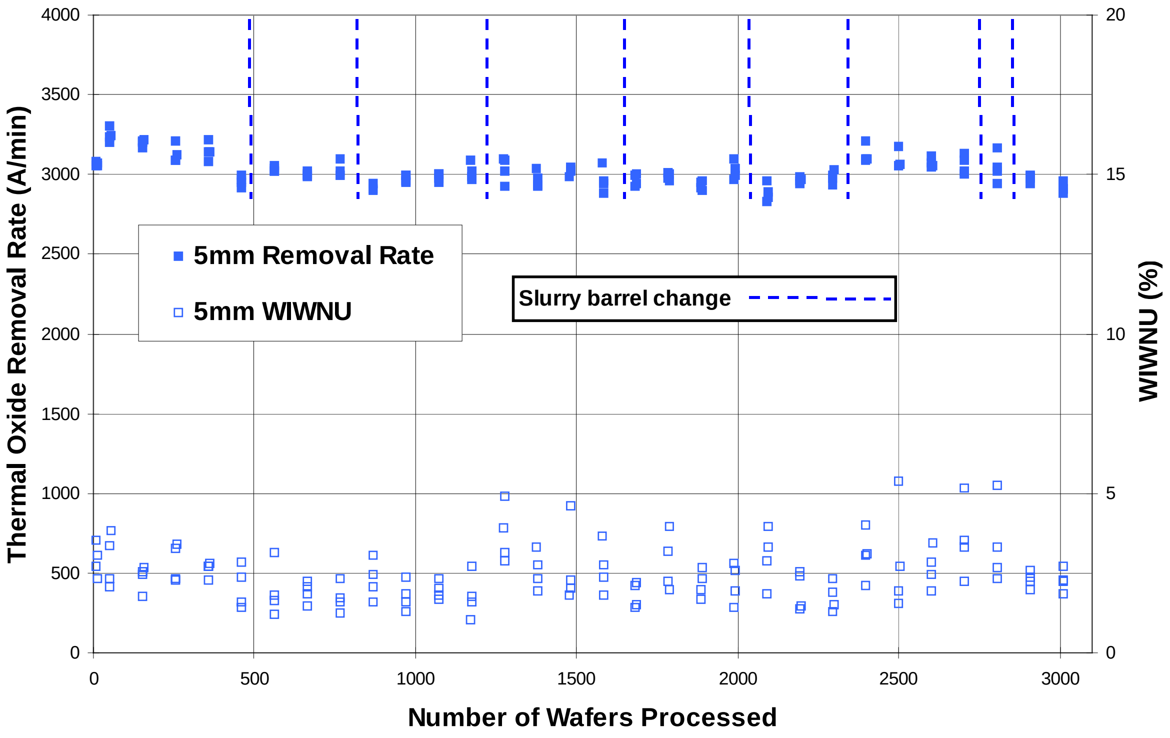

Figure 6: Extended Run #2 Removal Rate and WIWNU% at 5mm EE

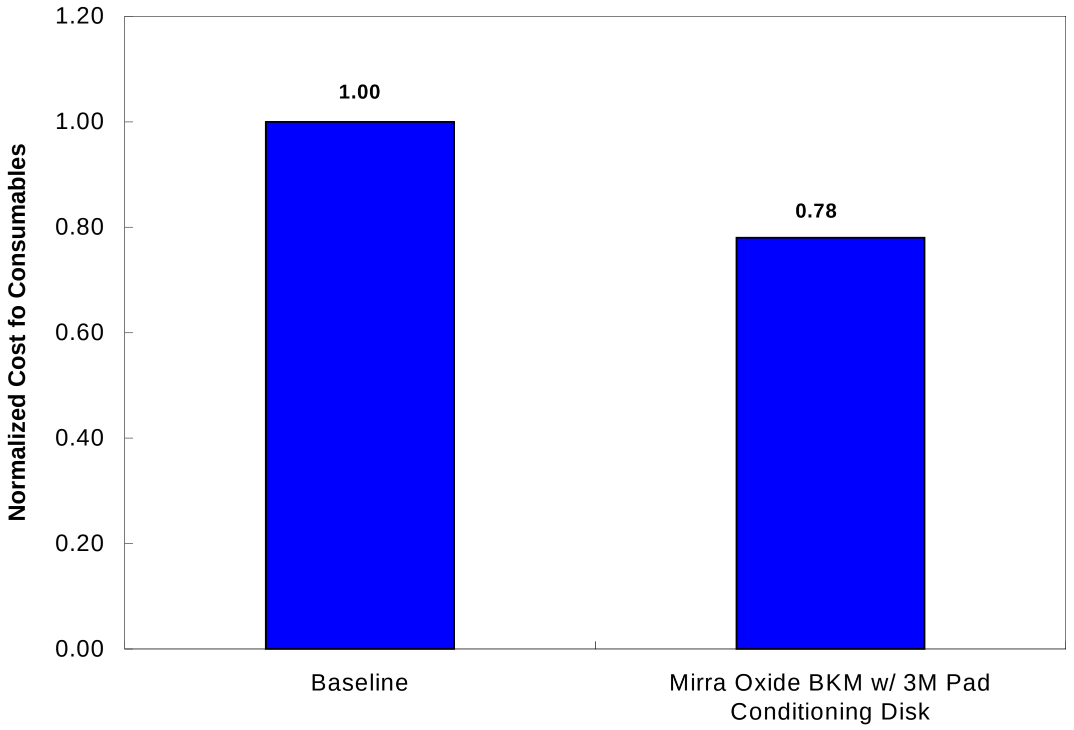

Figure 7: Mirra® Oxide CMP Cost of Consumables Comparison