DEVELOPMENT AND PERFORMANCE DATA OF A NEW CVD DIAMOND CMP PAD CONDITIONER

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Abstract

Characteristics of a revolutionary new design—SiC with high integrity and consistency, non-contaminating CVD diamond CMP pad conditioner are discussed with performance data. This innovative design provides maximum abrasive flexibility, effectiveness and efficiency, extends pad and conditioner lifetime, eliminates diamond fall-out issues, and results in highly tunable pad conditioning performance, with a full range of pad cut-rates and surface roughness for polymeric and poromeric pad materials. Experimental data will be presented and discussed for metal extractables for new conditioning disks, pad cut-rate (PCR), and pad surface morphology (Ra, Sa and surface height pdf development). This study demonstrates the advancements and opportunities for lab scale evaluation of CMP pad conditioners.

Introduction

Chemical mechanical polishing (CMP) pad surface morphology plays a major role in wafer material removal rate (MRR) stability, non-uniformity, defectivity and device yield. Pad conditioning is the process of removing the glaze formed on the pad during the CMP process. With increasingly stringent process specifications for 22 nm and smaller nodes, CMP consumables must significantly improve to achieve low defectivity, higher yield and acceptable cost of ownership. According to Lawing's theory of pad conditioning, the pad surface structure or morphology is determined by the balancing act between the competing effects of pad glazing due to the pad-wafer contact, and pad surface restoration due to the pad conditioning.[1] The scratch formation phenomenon in the CMP process has been extensively investigated.[2–3] Pad debris formed during in-situ conditioning affects the scratch formation. Nature of the pad debris strongly depends on the pad material and conditioner abrasives characteristics. A well controlled abrasive disk can be fine-tuned to get lower and stable defectivity performance. This paper presents the design attributes and conditioning performance stability data of a novel, highly tunable CVD diamond disk.

Next-Generation CMP Pad Conditioning

Most conventional diamond pad conditioners use a diamond grit of ~35 micron to 250 micron size, randomly or structurally arrayed (brazed, electroplated or sintered in place) on a substrate. Such 4" disks typically have ~20,000–300,000 diamonds, with <20% active (Figure 1).

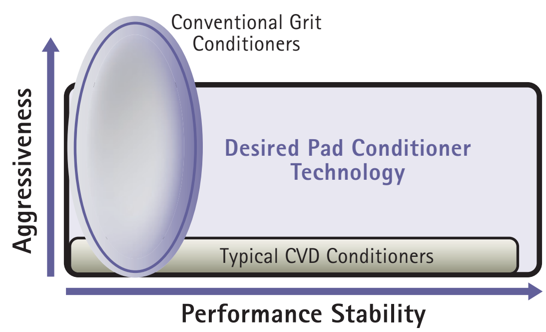


Figure 1. Next-gen "Desired Pad Conditioner Technology" performance attributes

Typical conventional diamond disks have limitations of: (i) diamond or abrasive quality and consistency, (ii) abrasive diamonds breaking/chipping or release during the break-in or usage, (iii) size, shape and height variability of abrasives, resulting in a wide PCR range and rapid performance variability[4] over the usage, (iv) material and chemical compatibility, and/or (v) shorter and variable lifetime. The CMP pad conditioners for the next-gen applications must have attributes of "tunability in design" and "stability in performance" (Figure 1). These new products should have much tighter control of the materials and dimensions to create consistent and much cleaner final products (ppt level extractables). Increasingly stringent abrasive feature size, shape, protrusion, aggressiveness, and distribution control in such disks should result in shorter pad break-in time, longer pad lifetime, and stable pad roughness (Ra). A new CVD diamond conditioner "Planargem®" (Figure 2) was developed to meet the above challenges.

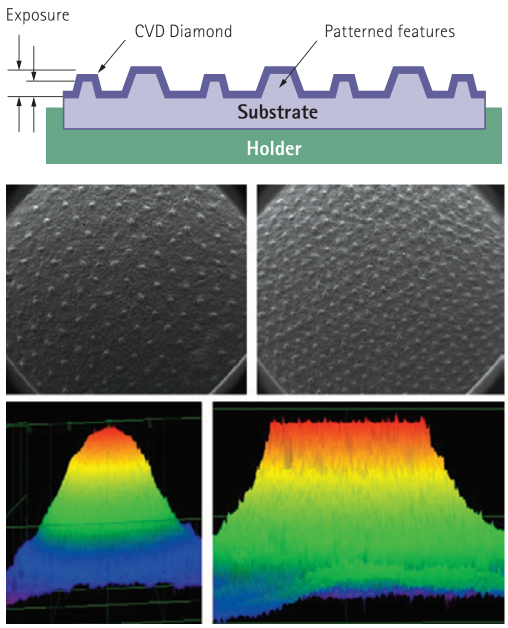


Figure 2. A novel, highly-tunable CVD diamond "Planargem" CMP pad conditioner

Planargem design, based on an innovative texturing approach provides full design flexibility (for all pad materials and types) due to the replacement of diamonds with well controlled topography created in substrate material, and fine-tuning of the CVD diamond coating properties, to achieve the desired level of performance consistency and lifetime in most demanding applications. This results in abrasive feature size, protrusion and density consistency, as well as chemical and mechanical stability in very acidic to strongly alkaline environments.

Pad Conditioner Characterization

During the conditioner lab scale evaluations, within-lot specific gravity (SG), and pad groove shape (and width) variations in hard commercial pads could result in PCR variations of up to ~30%, for the same disk. It is important to consider such variations in comparative data. Pad conditioners are typically evaluated using PCR, pad surface morphology (Ra, Sa, pad surface height pdf), and coefficient of friction (COF) data. The chemical (and particulate) cleanliness of conditioners can be analyzed by extraction tests of disks in acidic and alkaline solutions and CMP slurry blends. Typically 6 to 100 hour marathon tests are performed using 6", 12", or 30" (full size) CMP pads on the Center for Tribology (CETR; Bruker Nano) tribometer, Buehler® benchtop polisher, and 300 mm Araca APD-800 polisher and tribometer system, respectively, to generate comparative PCR, Ra, COF, pad surface height pdf and MRR data.

Results of Pad Conditioner Evaluations

This section presents results of 5 case studies related to characterization of pad conditioners.

Case Study 1

In this study, metal extractables were measured in pH3 HCl and Aluminum CMP slurry for a conventional diamond disk and Planargem segments and disks. The results are presented in Table 1. Results show much lower extractables level in Planargem extractions.

TABLE 1. ICP-MS METALS ANALYSIS DATA FOR DIFFERENT CMP PAD CONDITIONERS

Extraction 24-Hour Soak (µg/device)	Brazed Conditioner Submerged pH3 HCl	Planargem Segments Surface Extracted pH3 HCl	Planargem Conditioner Submerged pH3 HCl	Planargem Conditioner Submerged Aluminum Slurry
Na	0.162	0.169	0.199	0.470
Mg	0.078	0.041	0.129	0.315
Al	0.705	0.028	0.454	0.289
K	0.120	0.148	0.178	0.098
Ca	2.198	1.573	3.669	3.486
Ti	0.014	0.003	0.103	0.002
Cr	3.079	0.002	0.086	0.940
Mn	3.051	0.001	0.507	1.431
Fe	21.965	0.064	3.422	10.954
Ni	432.716	0.002	1.610	0.570
Co	0.103	0.000	0.030	0.053
Cu	0.007	0.441	0.748	2.244
Zn	20.171	0.028	0.711	1.842
Ag	0.000	0.000	0.030	0.047
Ba	0.021	0.002	0.032	0.015
Pb	0.016	0.000	0.030	0.011
Total	**484.407**	**2.502**	**11.937**	**22.767**

Case Study 2

In this test, two conventional diamond disks and three Planargem disks were tested for the PCR stability using IC1000™ pad, DI water, and 7 lbs disk downforce on a benchtop polisher. Results shown in Figure 3 demonstrate the stability of PCR data for three Planargem designs as well as the flexibility of this approach in designing the required aggressiveness disks. The two conventional disks show significant drop in PCR during the 10-hour tests. Similar results for conventional disks have been reported in another study.[4] According to this study, typical new conventional diamond disks overcondition the pads, and are used until the PCR falls to the minimum needed. Also, in a commercial process one disk was used for 50 hours and was replaced when the PCR or wafer non-uniformity became unacceptable. In a typical 50 hours test the average PCR of disk had dropped exponentially to 16% of the original PCR (~4 mils/hour) and the disk was replaced. The study suggested that if a new disk would have a PCR of ~25% of the original PCR for the entire 50 hours, much less of the expensive pad material would have been removed, and the process would have a comfortable safety margin over the absolute minimum rate. It was concluded that since the conditioners with fixed diamonds dull over time and it is not possible to re-dress disks, one cannot create a disk with a fixed PCR.[4] Planargem design is an effort to achieve this challenging task of creating conditioners with almost fixed PCR (Figure 3).

IC1000 Pad Cut-Rate Data for Three PGM and Two Conventional Diamond Pad Conditioners

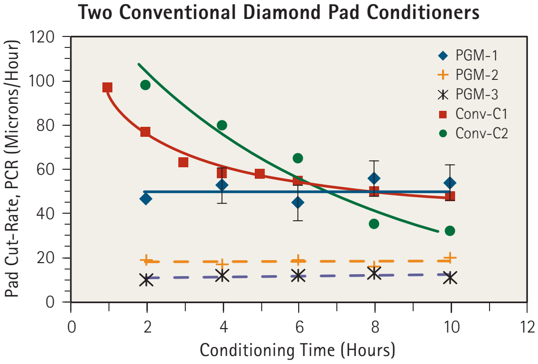


Figure 3. PCR data for three types of Planargem disks and two types of conventional diamond disks

Case Study 3

The main objective of this study was to develop a best known method for conditioning a new polymeric Pad-A. The Pad sample was tested on a benchtop polisher with selected disk for 17 hours, using a downforce of 7 lbs and DI water supplied with a Levitronix® pump. A stylus type roughness tester was used for the Ra data. An Olympus® laser confocal microscope (LCM) was used for pad surface morphology and Sa measurements. During this study, the pad Ra decreased from ~4.6 microns for a new Pad-A to ~3.3 microns in the first ½ hour of the test, and stayed the same, within experimental uncertainty, over the complete 17-hour duration of the study. This would suggest that a 30-minute time would be sufficient for a new Pad-A break-in process. LCM results of pad surface imaging and surface height pdfs are presented in Figures 4a and 4b.

NEW PAD-A: Ra = 4.6 MICRONS; Sa = 9.9 MICRONS

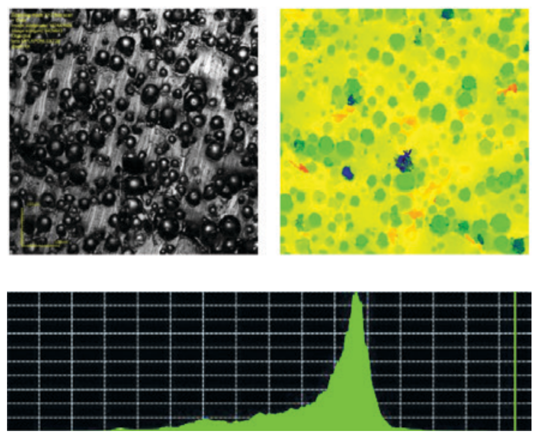


Figure 4a. Surface morphology and height probability density function (pdf) for new Pad-A

CONDITIONED PAD-A: PLANARGEM CONDITIONING FOR ½ HOUR: PCR = 52 MICRONS/HR; Ra = 3.3 MICRONS; Sa = 5.1 MICRONS (AFTER ½ HOUR PAD BREAK-IN PROCESS)

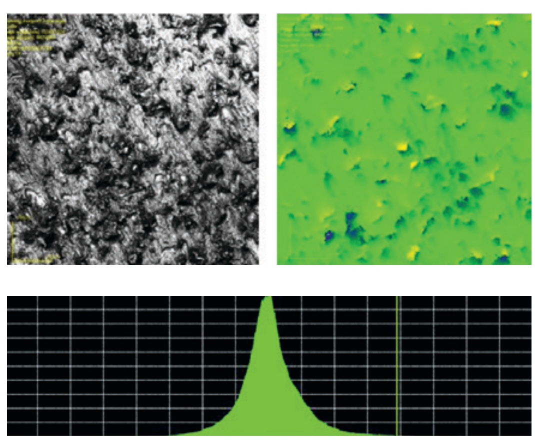


Figure 4b. Surface morphology and height pdf for Pad-A after ½ hour pad break-in process

Figure 5 shows PCR and Ra data (filled symbols). After 17-hour test the used Pad-A (Pad-1) was replaced with a new Pad-A (Pad-2). The conditioning test and measurements were continued for the next 3 hours (open symbols in Figure 5). The PCR values for Planargem disk at the start of 17-hour test (with IC1000 Pad on benchtop polisher) and at the start of 2nd Pad-A were very similar (~50 microns/hr), suggesting that the PCR drop for Pad-1 test in Figure 5 may be attributed to the changes in Pad-A material of different layers. It is very useful to remeasure the used disks performance on a new pad in such evaluations.

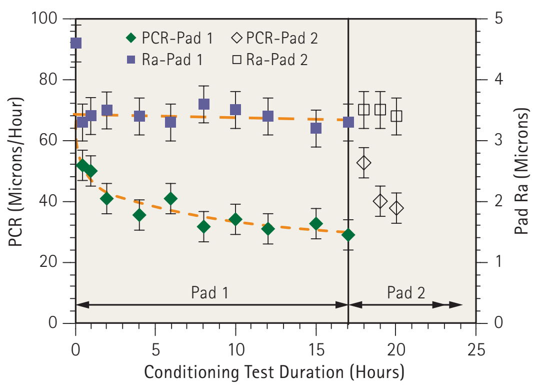


Figure 5. PCR and Ra variation during Planargem conditioning of Pad-A (17+3 hours)

Case Study 4

In this study, a Planargem disk was tested on APD-800 system for the PCR and pad Ra data for a new polymeric Pad-B, supplied with 250 mL/min DI water and using 3.6 lbs conditioner downforce. The pad and conditioner speeds were 113 and 93 rpm, respectively. Figure 6 shows PCR and Ra data. The LCM results of pad surface imaging and surface height pdfs are presented in Figures 7a, 7b and 7c. The conditioned Pad-B morphology shows the significant effect of pad conditioning (opening of the pore structure and smoothening of the pad surface) for the 50-hour conditioned pad.

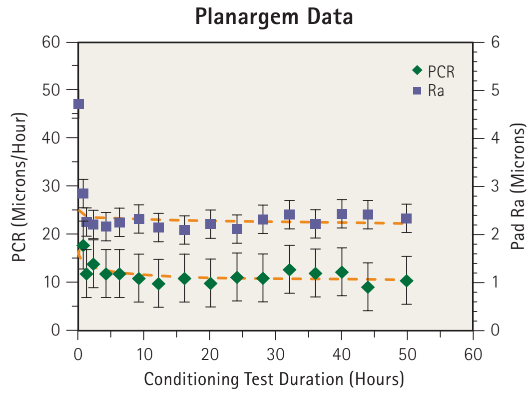


Figure 6: PCR and Ra variation during Planargem conditioning of Pad-B (50 hours)

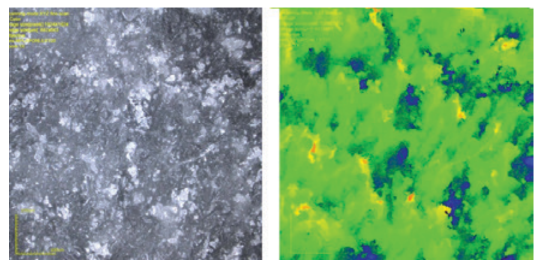


Figure 7a. Surface morphology images for the new polymeric Pad-B

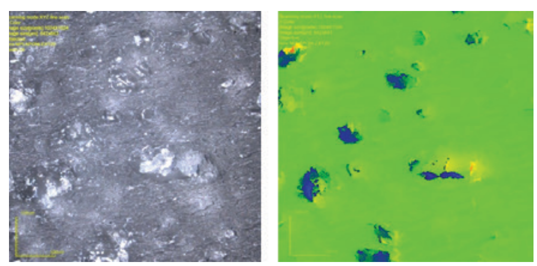
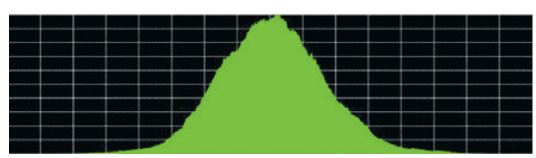


Figure 7b. Surface morphology images for Pad-B after 50 hours pad conditioning

NEW PAD



CONDITIONED PAD (AT THE END OF 50 HOUR STUDY)

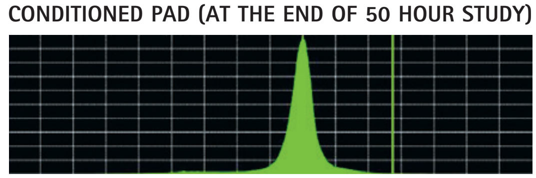


Figure 7c. Surface height pdf data for the new Pad-B and Planargem conditioned Pad-B

Case Study 5

In this evaluation, a Planargem disk was tested on an APD-800 polisher and tribometer system for the PCR and pad Ra data for a new 29" OD poromeric Pad-C, supplied with 250 mL/min DI water and using 2.2 lbs conditioner downforce. The pad and conditioner rotational speeds were 93 and 80 rpm, respectively. Results of this study in Figure 8 demonstrate the stability of PCR and Ra data over the 18-hour run. This study confirmed the suitability of Planargem designs for new Pad-C break-in and extended period conditioning. The LCM results of pad surface imaging and surface height pdfs for this study are presented in Figures 9a, 9b and 9c. The conditioned Pad-C morphology shows the significant effect of pad conditioning and opening of the pore structure.

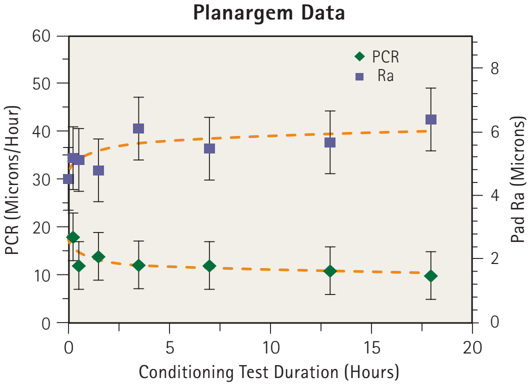


Figure 8. PCR and Ra variation during Planargem conditioning of Pad-C (18 hours)

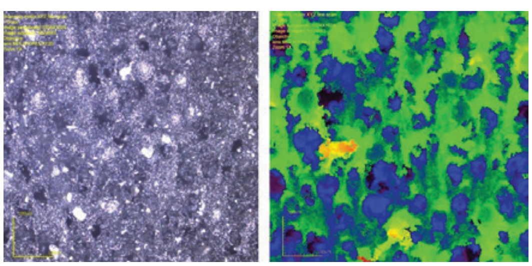


Figure 9a. Surface morphology images for the new poromeric Pad-C

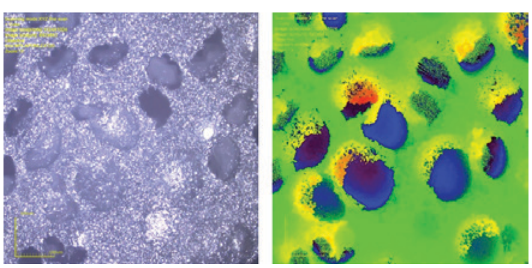
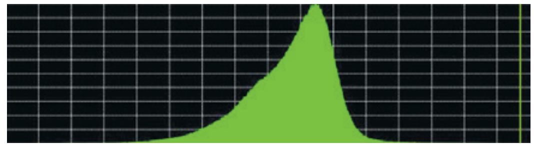


Figure 9b. Surface morphology images for Pad-B after 50 hours pad conditioning

NEW PAD



CONDITIONED PAD (AT THE END OF 50 HOUR STUDY)

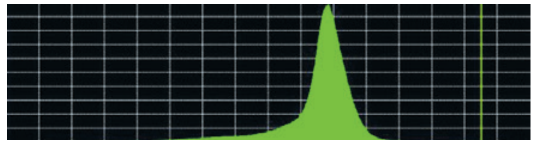


Figure 9c. Surface height pdf data for the new Pad-C and Planargem conditioned Pad-C

Conclusions

Design and performance characteristics of a new, highly tunable CVD diamond Planargem CMP pad conditioner are presented. This design, based on a novel texturing approach and replacement of diamond abrasives with well controlled size and shape topography (features) created in the substrate material provides full design flexibility, much higher level of cleanliness, performance consistency and extended lifetime in most demanding next-generation applications. The results of present study demonstrate the advancements and opportunities for the lab scale characterization of CMP pads and conditioners. Further evaluations are continuing to understand the effects and interactions of pad and conditioner materials, designs attributes and process parameters for different applications.

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