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Characterizing CMP Pad Conditioner Wear with Optical Profilers

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INTRODUCTION

Faster computer processors require smaller features for integrated circuits (IC), which in turn require smoother substrate surfaces. Chemical mechanical polishing (CMP) has become one of the most critical semiconductor fabrication technologies because it offers a superior means of removing unwanted topography in interlevel dielectric layers and achieving sufficient planarity for the creation of IC. The planarization performance of CMP is significantly influenced by polishing pad characteristics. Therefore, much research has been done in the development and choice of CMP pad type and conditioning.

With its noncontact, three-dimensional surface metrology capabilities, optical profiling provides an ideal method for analyzing pad wear and conditioning effects. Wyko® NT Series optical profilers from Veeco have been instrumental in a wide variety of such CMP process improvement studies, including investigating asperity behavior of the fluid layer under the wafer during CMP and the effects of polishing and conditioning on pads, among many others.[1, 2] This application note describes optical interferometry analyses of the wear rate of conditioning pads that have led to a repeatable method for quantifying extended wear to evaluate novel conditioner designs.

COPPER CMP

When the semiconductor industry transitioned from aluminum to copper conductors, different fabrication techniques were adopted, including the use of metal barrier layers and different methods for patterning the metal. In this process, the underlying insulating layer is patterned with open trenches where the conductor should be. A thick coating of copper that significantly overfills the trenches is deposited on the insulator, and CMP is used to level the copper to the top of the insulating layer. Copper within the trenches of the insulating layer is left to become the patterned conductor.

Since diffusion of copper into surrounding materials degrades their properties, a barrier metal layer must completely surround all interconnections. With successive layers of insulator and copper, a multilayer structure is created. Without the ability to remove the copper coating in a uniform fashion, and to stop repeatably at the copper-insulator interface, CMP technology would not be successful.

In CMP, the silicon wafer surface is pressed against a polishing pad that is rotated at different rates and angles. A slurry consisting of abrasives and oxidizing chemicals helps remove material and ensures a planar topography for circuit formation. The CMP pad transmits mechanical energy to the substrate as well as transports the slurry for polishing. Though the principles behind this process are relatively simple, there are many factors affecting removal rate that make the development of production models very difficult, particularly as feature sizes continue to dramatically shrink. Factors such as the relative motion of polishing head and wafer surface, slurry composition, polishing pad surface characteristics, and changes in wear rate over time can hinder the reliability and throughput of fab production.

CONDITIONING THE CMP PAD

CMP pad surface characteristics are particularly important because they affect the real area of contact, friction, wear, and lubrication in the polishing process. The pad is usually constructed of a urethane polymer, and many types exist that either change the surface rigidity or the pad's ability to hold the slurry. Pad surface conditioning with a diamond grit conditioner is performed both before and during CMP. Most commonly, a rotating diamond disc is moved against the polishing pad surface at a constant load. The diamonds on the disc slowly cut the pad surface, maintaining it against abrasive wear, plastic deformation, polishing debris accumulation, and other degrading factors. This conditioning opens up closed cells, improves slurry transport, and provides a consistent polishing surface and removal rate over time, regenerating the peaks and valleys on the pad.[3]

Simultaneously, slurry abrasive particles slowly wear the diamonds that contact the pad surface. When surfaces are brought together, the initial contact will occur on the tallest asperities of the surfaces. As the force on the surfaces is increased or continued, these asperities deform and shorter asperities start to contact each other. The established relationship between reduced asperity height on the pad due to continued polishing and the consequent decrease in reliability and removal rate on the wafer is well documented.[4] A less than optimum conditioning process results in a relatively rapid degradation of the removal rate. Too aggressive conditioning decreases pad life. Over time the conditioner itself will wear and jeopardize the polishing process. Factors like diamond crystal size, diamond crystal morphology, and crystal surface density have all been investigated in an effort to develop the ideal conditioning process.[3-5]

OPTICAL PROFILING FOR CMP

Optical profiling's ability to perform three-dimensional, noncontact, high-resolution surface texture mapping on the microscopic scale makes it an ideal metrology technique for characterizing conditioner wear and other aspects of the CMP process. Also known as white light interferometry, optical profiling passes white light through a beam splitter, which directs the light to the sample surface and a reference mirror. When the light reflected from these two surfaces recombines, a pattern of interference "fringes" forms that reveal the sample surface, similar to the way topographic lines show elevation on a map. The X, Y range of the contour map is determined by the size of the microscope objective used, and the Z range (height) is determined by mechanical movement of the sample stage. This technology can measure feature surface heights, planarity, bow, and pad roughness from 0.1 nm to several millimeters.

Researchers from Araca Inc. (Tucson, AZ), the University of Arizona (Tucson, AZ), Freescale Semiconductor, Inc. (Tempe, AZ), and Mitsubishi Materials Corp. (Saitama, Japan), in conjunction with Veeco application engineers, have performed a series of experiments investigating diamond conditioner wear on a conditioning tool by comparing interferometry images before and after extended wear testing.[6, 7] Utilizing a variety of analysis functions on the interferometric data, they identified peaks in the height distributions that corresponded to specific diamonds or groups of diamonds. Shifts in these identified peaks after wear testing allowed them to quantify wear on the conditioning pad. Figure 1 shows a three-dimensional analysis of the same diamond group before and after wear testing. This method was then used to evaluate novel conditioner designs for more efficient and longer lasting CMP pad conditioning.

A METHOD FOR CHARACTERIZING DIAMOND CONDITIONER MICROWEAR

Initial experiments were performed with a 100-millimeter-diameter Mitsubishi Materials Corp. conditioner, consisting of a flat metal substrate to which diamonds are attached using a metal binder. The diamond exposure was about 60 microns and the density was 34 diamonds per square millimeter, except in select diamond-free areas. Two areas were selected near the center and edge for imaging using a Wyko NT optical profiler.

The imaged areas were moderately large, up to 4.3 x 6.5 millimeters, and were imaged using stitched scans at a resolution of 3.24 microns. Following initial imaging, accelerated conditioner wear was induced by replacing the 4-inch polishing head of a scaled experimental polisher with the conditioner, and then cutting a series of polymeric pads using a slurry diluted 1:9 with water as the lubricant, and hydrogen peroxide as the oxidizer, at a load of 2 PSI and a sliding speed of 0.96 meters per second. The total wear time was 715 minutes. The pad cut rate was also measured after each pad was removed. Center and edge scan areas were then located and reimaged.

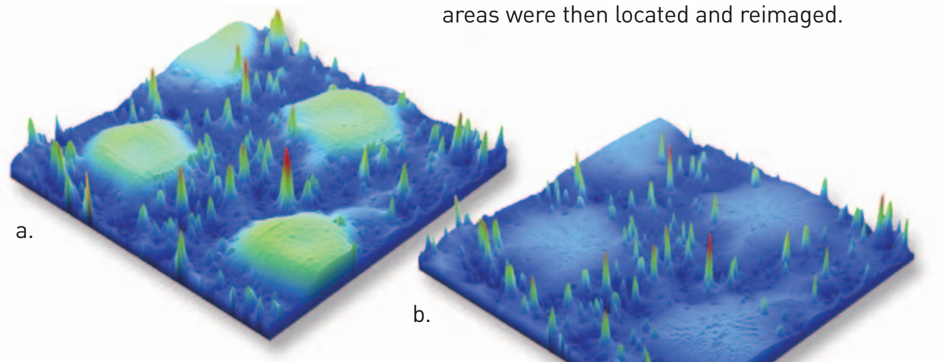

Figure 1. Three-dimensional interferometric images of a diamond group before (a) and after (b) wear testing. 5.0mm x 5.0mm FOV.

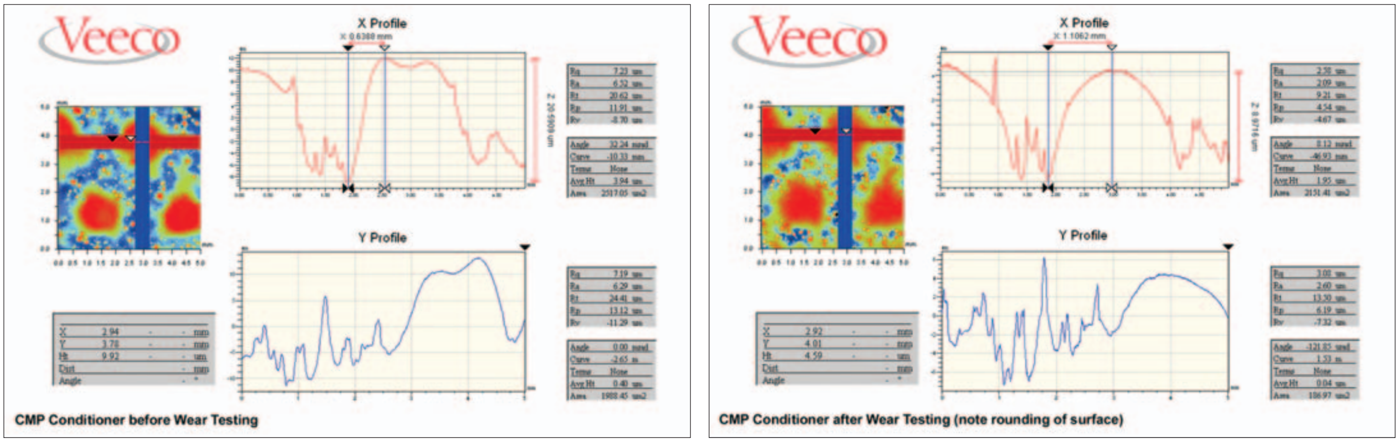

Figure 2. Two-dimensional before- and after-wear testing analyses of a CMP pad conditioner utilizing optical profiling data.

Diamond wear was measured on a conditioning tool by numerical matching of interferometry images taken in overlapping areas before and after extended wear testing. A matching algorithm found the largest common region shared by two images and reoriented the final image to produce the best possible match with the initial image in the binding metallization. Usable results were dependent upon the existence of an area within the conditioner, portions of the binding metallization, that were within the focal range of the interferometer and that were far enough from the polishing pad surface that there was little or no wear.

By characterizing the images using surface height probability density functions, peaks in the height distributions were identified that corresponded to single diamonds or groups of diamonds. Shifts in the peaks after wear testing then provided an estimate of the mean wear rate. The wear rate was very small, averaging 5 x 10-4 microns per minute over 710 minutes. The fact that wear at this level was detected at all was due to the profiler's high resolution and large sample area. Figure 2 shows two-dimensional Wyko Vision® analyses of the conditioner before and after wear testing.

In general, the higher diamonds were found to wear faster than shorter ones, and diamonds on the outside edge of the tool wore faster than ones in the center. This microwear was also shown to correlate with a gradual decline in pad cut rate.[6] At any time in the life of the conditioner, each diamond that produces a furrow on the pad surface should produce both cutting, in which material is removed from the furrow, and plowing, in which it is pushed aside. It was theorized that the cut rate decline corresponded to an increase in the proportion of pad material that was plowed rather than being cut as the sharp edges and points on the contacting diamonds wore down. From this information, the researchers concluded that the decline in cut rate with conditioner age was caused by an increase in plowing and decrease in cutting as contacting diamond tips and edges break down.

EVALUATING CONDITIONER DESIGNS

Later investigations utilizing many of the elements described above were able to characterize extended wear for innovative diamond conditioner designs, with an eye toward developing conditioner discs that will better resist corrosion and abrasive wear while maintaining proper CMP pad polish.[7] The researchers used a Wyko NT profiler to inspect the diamond conditioner surface both before and after the 30-hour conditioner wear and polishing process. A template was used to select the analysis regions to ensure that the same areas were imaged before and after the extended wear test.

The experimental designs were coated with a polytetrafluroethelene film to reduce substrate wear and chemical attack (see figure 3). Each diamond disc was used to condition multiple flat pads in a 30-hour wear test, which is comparable to commercial disc lifetimes. Periodically during the wear experiments, the conditioner was installed on a separate polishing tool for in-situ polishing of copper wafers. Real-time shear force, pad temperature and copper removal rates were measured. Optical interferometry was performed on selected areas of the conditioner surfaces before and after wear testing in order to quantify changes.

During an initial copper wafer polishing phase, the conditioner was used to break in a K-grooved pad for 30 minutes at 0.4 PSI using deionized water as the lubricant. Pad break-in was followed by 10 minutes of pad seasoning using

Figure 3. A prototype Mitsubishi Materials Corp. diamond conditioner disc coated with polytetrafluroethelene.

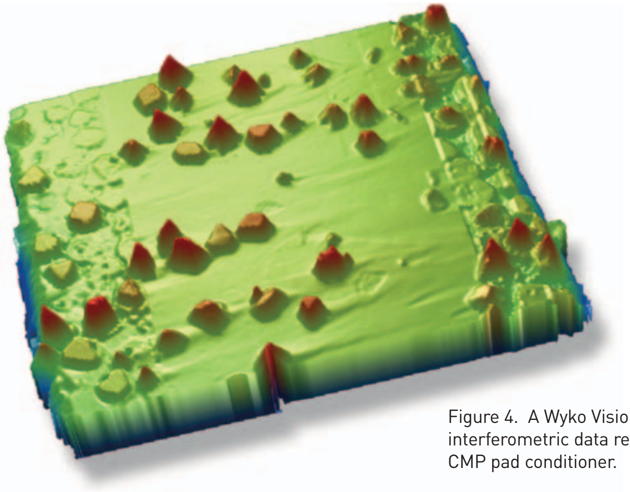

Figure 4. A Wyko Vision three-dimensional analysis of interferometric data reveals diamond structure on a CMP pad conditioner.

200-millimeter copper discs. Each copper wafer was polished for 1 minute at 2.5 PSI and a sliding velocity of 1.2 meters per second. After the initial wafer polishing phase, the conditioner was attached to the wafer carrier of the 100-millimeter polisher and used to abrade a flat pad at 2 PSI and 0.62 meters per second for 3 hours. No polishing was performed during this accelerated wear phase, but slurry was applied as in a normal copper process. The conditioner was then reinstalled on the polisher and used to polish 200-millimeter copper wafers on the original pad to complete the cycle. Polishing was preceded by dressing of the pad at 0.4 PSI with deionized water for 5 minutes, followed by 5 minutes of copper disc polishing with in-situ conditioning.

Interferometry analysis revealed that coating material from the diamond-free zones was laterally displaced by shear forces and plastic deformation, and ended up partly or totally covering some of the adjacent diamonds. Contours around several diamonds taken at the same level were also observed to tighten on the used conditioner, indicating that the coating immediately surrounding some of the diamonds had been displaced and that those diamonds were active.

Utilizing these results and concurrent data from optical microscopy and thermal observation techniques, the researchers were able to show that the coating on the conditioners provided protection from chemical and abrasive attack, proving that there was no decline in performance even after 30 hours. Further, one of the designs was shown to provide a mechanism for gradually exposing more diamonds to the pad.

CONCLUSION

Optical profiling's ability to investigate a large area at high resolution has aided in the development of a better method to monitor diamond conditioner wear, and has had a large role in the design of more efficient CMP pad conditioner designs. Veeco profilers provide researchers a fast, non-contact means of quantifying many aspects of the CMP process, and will continue to be invaluable in pursuit of ever smaller semiconductor features and faster processing.

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