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Authors
Choi, Jihong
Wang, Z.
Shen, W.
et al.

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CONDITIONING EFFECT ON PAD SURFACE HEIGHT DISTRIBUTION IN COPPER CMP

J. Choi[1], Z.Wang[2], W.Shen[2], D.A. Dornfeld[1] and W. Hsu[2]

[1]Department of Mechanical Engineering,
University of California, Berkeley,
CA 94720-1740.
[2]CMP group, Applied Materials, Inc. Santa Clara, CA

Abstract:

In this study, surface topographies of different pad samples from varying in-situ conditioning processes and differing pad life stages have been measured by white light interferometer. Copper removal rate and within wafer non-uniformity was monitored during pad degradation test. Pad surface height distribution, measured from white light interferometer, was more dependent on the plastic deformation and wear at the retaining ring and wafer contact region than on in-situ conditioning. Also, the overall removal rate in copper CMP was more dependent on the slurry flow than on pad surface height distribution.

Introduction:

Pad surface topography during a CMP process is a result of competing effects of glazing and roughing. Pad glazing is result of wear and plastic deformation under the contact area between pad and wafer, and pad and retaining ring. Roughing is result of cutting of pad material by diamond conditioning. Pad wear and plastic deformation generate flat surfaces, where increased real contact area reduces real contact pressure and hence material removal rate. Diamond conditioning continuously restores asperities, which apply higher local contact pressure on wafer and effectively remove wafer materials. Overall surface topography of a CMP pad is directly related to the real contact area and real contact pressure, which affects friction and tribological characteristics of CMP process and hence overall CMP performance. Among many different parameters representing CMP pad surface topography, surface height distribution is one of the key parameters sensitively changing with pad conditioning process [1, 2]. Several theoretical models integrate pad surface height distribution as a key input parameter [3, 4]. Hence it is important to understand how pad surface topography changes during process to characterize and optimize CMP pad conditioning process for better CMP performance.

A probability density function can effectively represent rough pad surface. Surface height map from white light interferometer is commonly used to characterize a rough surface. From a surface height map, distribution of surface height population can be obtained, and a probability density function is generated. In the schematic shown in figure 1, the probability P that surface height at an arbitrary position on a pad would have a value between a and b is integration of the probability density function from a to b. As more truncation of asperity tip by wear and plastic deformation occurs, skewness of pad surface height distribution function increases.

In this paper, variations in pad surface height distribution for varying aggressiveness of in-situ conditioning were investigated by white light interferometer, and surface topographies at different stages of pad life in copper CMP have been characterized. Also, copper CMP removal rate and uniformity variations were measured to investigate the correlation between pad surface height distribution and copper CMP performance.

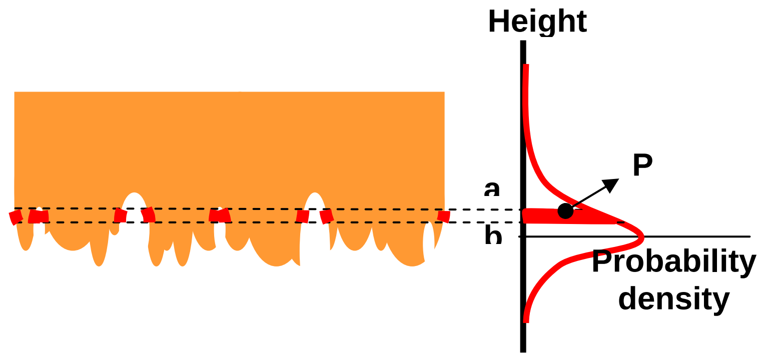


Figure 1: Probability density function representing pad surface height distribution

Experimental

Applied materials Mirra-Mesa 200mm CMP machine was used for this test. To avoid any head to head variation and platen to platen variation, only one head and platen was used for all tests. Slurry supply rate, setting of head pressure, and the rotation speed of platen and head were fixed for every test. In each test condition, fresh IC1010 pad was installed, and the pad surface was conditioned with 3M diamond conditioner disk for 15minutes with specific conditioner recipe, which determines the conditioner down force and conditioner RPM. At this stage, head was not in contact with the pad and only DI water was supplied. Platen RPM was tuned for four different conditioning recipes to match with conditioning disk RPM. Table 1 shows conditioning recipes used for four different conditioning processes. After pad break-in procedure, copper blanket wafers and test patterned wafers were polished as dummy wafers and monitoring wafers, respectively. Each polishing was done with in-situ conditioning, which used the same recipe as pad break-in procedure. Hence, one pad experienced only one conditioning recipe, which was used in-situ for process and ex-situ for break-in. Pad samples were taken before break-in, after break-in, and after finishing all polishing. Total time of polishing for each pad was 60minutes. For interferometer measurement, thin (~30nm) gold film was deposited on top of the sample surfaces.

To investigate pad surface topography variation during process, pad degradation test was performed. First, after pad break-in procedure with recipe 2, 50 copper blanket wafers were polished without any conditioning. Recipe 2 was chosen because it was the closest to normal conditioning recipe. Each wafer was polished for 2minutes. For comparison, same test was performed with in-situ conditioning with recipe 2. In both cases, samples were taken from the pad before break-in, after break-in, after polishing 4 wafers, and after polishing 18 wafers. For each monitoring wafer, copper thickness was measured before and after polishing by four point probe. 81 points were measured across the diameter with 5mm edge exclusion for each wafer.

	Down force	Rotation RPM
Recipe 1	High	High
Recipe 2	High	Low
Recipe 3	Low	High
Recipe 4	Low	Low

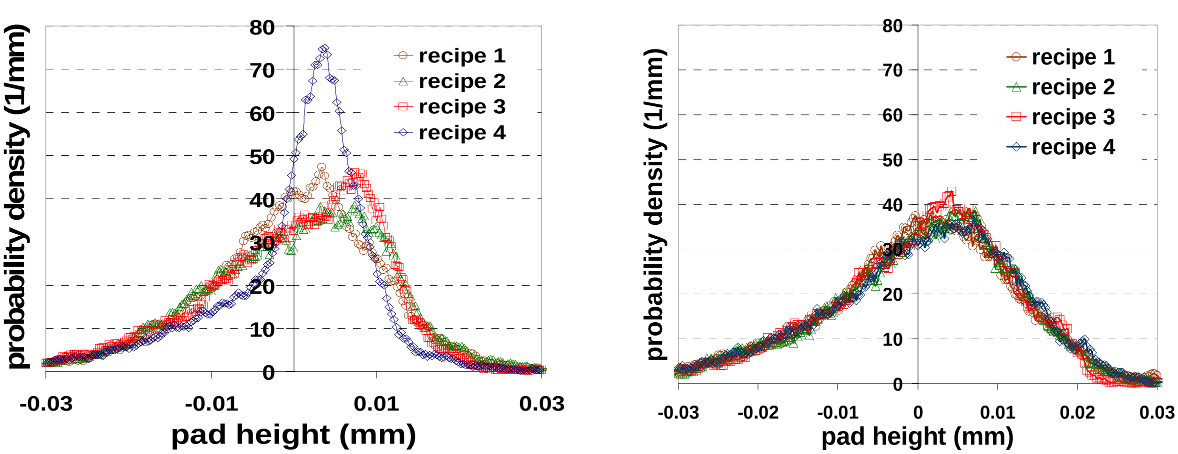
Table 1: Conditioning recipes

Result and Discussion

Effect of the aggressiveness of conditioning

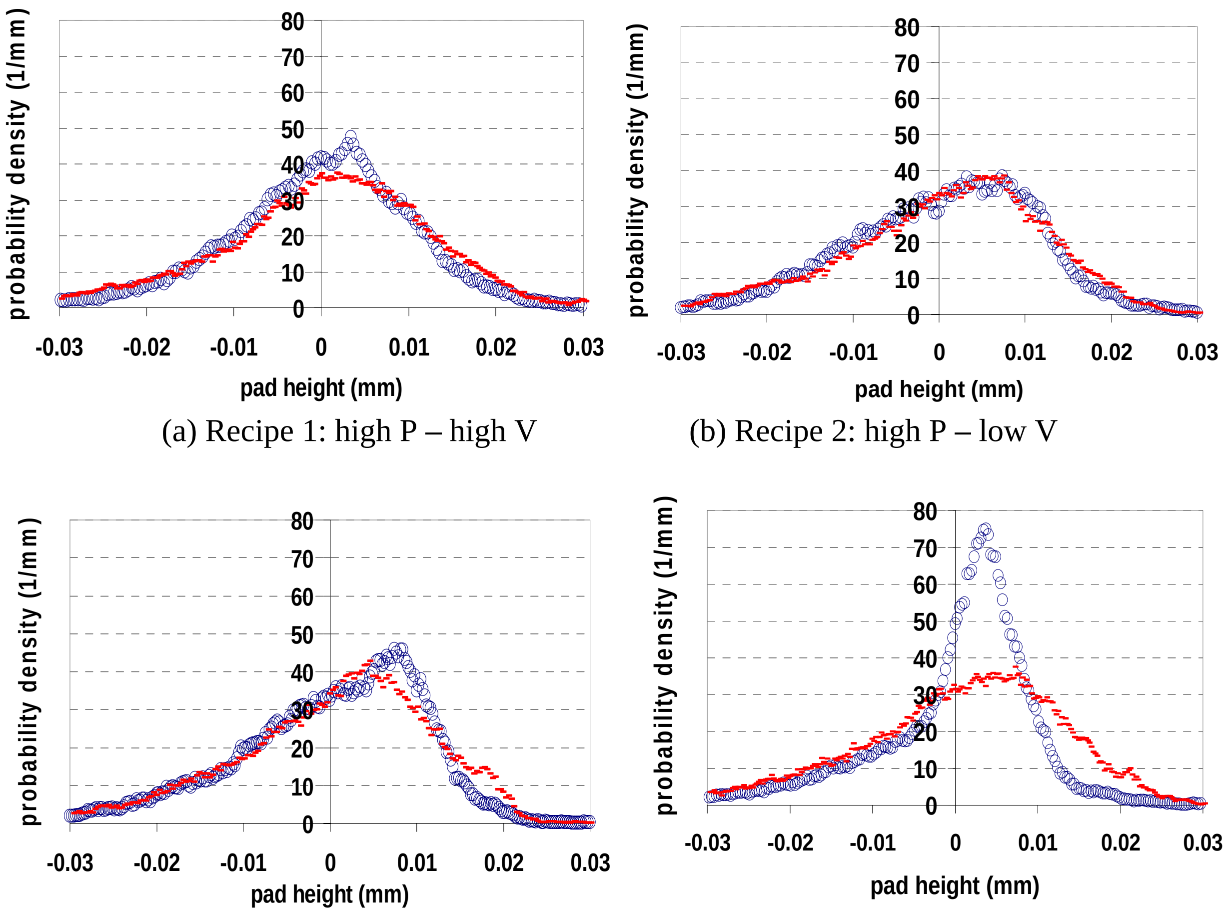
During pad break-in process, no contact between pad and retaining ring or between pad and wafer occurred. Hence, only diamond conditioning process modified pad surface topography. Variations in conditioner down force and rotation speed resulted in varying pad surface height distributions. Figure 2(a) shows pad surface height distribution from different pad break-in procedures. Recipe 4, which is a combination of low conditioner down force and low conditioner RPM was too gentle for pad conditioning, and the surface height distribution after break-in with recipe 4 was not much different from that of a fresh pad. Fresh pad surface has sharp height distribution, which has peak near the mean value. This is because of flat, fresh cut surfaces in a new pad surface from pad manufacturing process. Other three recipes showed slight variations between one another. Surface height distribution from the most aggressive conditioning process (recipe 1) was closest to a normal distribution. Lowering conditioner down force (recipe 3) skewed the distribution toward the surface. Lowering conditioner RPM (recipe 2) also skewed the distribution toward the surface with slight difference from recipe 3. Result shows that as the aggressiveness of the conditioning process increases, pad surface height distribution becomes closer to a normal distribution. After polishing for 60 minutes with four different in-situ conditioning recipes, pad surface height distributions became identical to each other (figure 2(b)). In this case, unlike the pad break-in process, pad surface topography is a result of competing effects of roughing and glazing. Identical pad surface height distributions of different samples from varying in-situ conditioning processes indicate that the effect of conditioning aggressiveness on final pad surface height distribution was negligible. Instead, plastic deformation and wear at the retaining ring contact region and wafer contact region dominated overall pad surface state. This shows that polishing dummy wafers with in-situ conditioning before actual process can stabilize pad surface state.

In figure 3, pad surface height distributions before and after polishing were plotted together for comparison for four different conditioning cases. For all cases, the slope of pad surface height distribution function near surface decreased after polishing, and the distribution became closer to a normal distribution. Pad surface asperities were recovered and surface roughness was enhanced during polishing with in-situ conditioning. Figure 3(d) shows significant change in pad height distribution before and after polishing with in-situ conditioning recipe 4. After pad break-in procedure, pad surface height distribution didn’t change from that of a fresh pad because pad conditioning was too weak (low down force and low rotation RPM). The blue line in the plot represents the pad surface height distribution after break-in with recipe 4. However, after polishing with in-situ conditioning, the surface height distribution changed to that of other three cases (red line in figure 3(d)).



(a) after pad break-in (b) after polishing 60 minutes

Figure 2: Pad height distribution before and after polishing



(a) Recipe 1: high P – high V (b) Recipe 2: high P – low V

(c) Recipe 3: low P – high V (d) Recipe 4: low P – low V

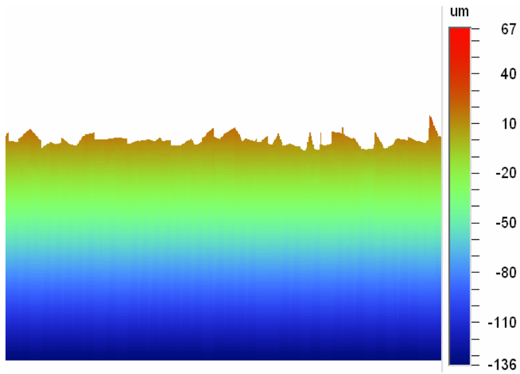
Figure 3: Comparison of pad height distribution change with different conditioning recipes
(○: before polishing, - : after polishing)

This suggests that conditioning of a pad surface with and without wafer polishing results in totally different surface height distributions. It can be attributed to variations of surface temperature, mechanical properties, and chemical effect of slurry on pad surface due to polishing. Further investigation has to be done for a better understanding of deterministic parameter.

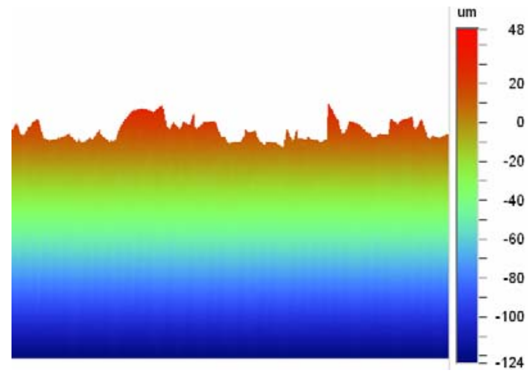
Pad degradation test

Pad surface topographies of a fresh pad, after break-in procedure, after polishing 36 minutes without conditioning and with conditioning, are shown in figure 4. Break-in procedure makes the fresh pad surface much rougher. After polishing wafers without conditioning, pad surface became smoother as a result of wear and plastic deformation. In the case of polishing with in-situ conditioning, pad surface looks smoother but more asperities can be observed than non-conditioned case. The surface height distributions of these surfaces are shown in figures 5a and 5b comparing the slope of pad height distribution near outer-most pad surface, with in-situ conditioning and without in-situ conditioning. As expected pad samples showed clear glazing effect after 36 minutes of polishing.

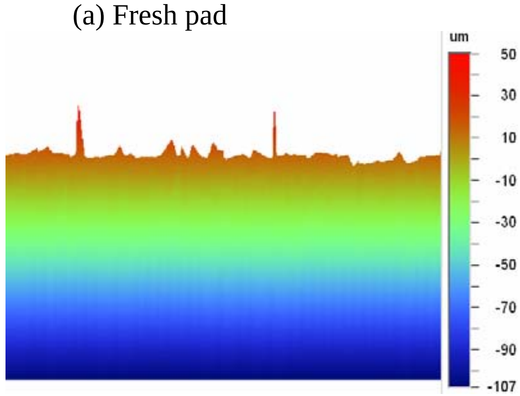
However, the copper removal rates for, both, with and without conditioning showed no clear difference between initial stage of polishing and after 36 minutes of polishing (figure 6(a)). Also, contrary to oxide CMP [5], removal rate without conditioning was higher than that with in-situ conditioning. This can be attributed to the effect of conditioner movement on slurry flow patterns over the pad. The movement of conditioner arm and the rotation of conditioner disk affects slurry flow pattern over the pad, which can affect pad temperature distribution, effective slurry supply rate, and, ultimately, the overall removal rate. Different removal rate profiles over a wafer from in-situ conditioned case (figure 7(a)) and from the case of polishing without conditioning (figure 7(b)) indicates that the slurry flow pattern was changed due to the conditioner movement.



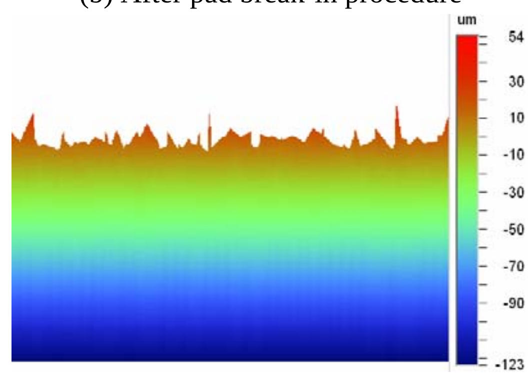
(a) Fresh pad



(b) After pad break-in procedure

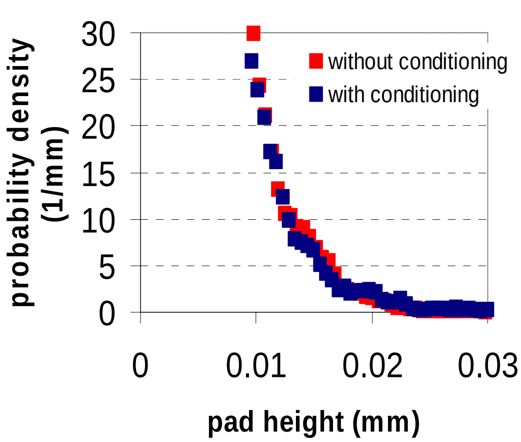


(c) After polishing 36 minutes without conditioning

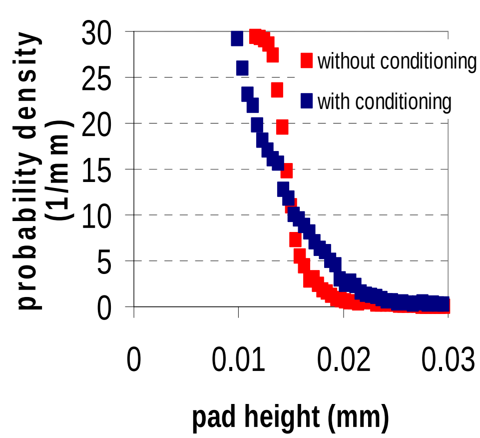


(d) After polishing 36 minutes with in-situ conditioning

Figure 4: Cross-section view of pad surfaces in different stage



(a) Fresh pad



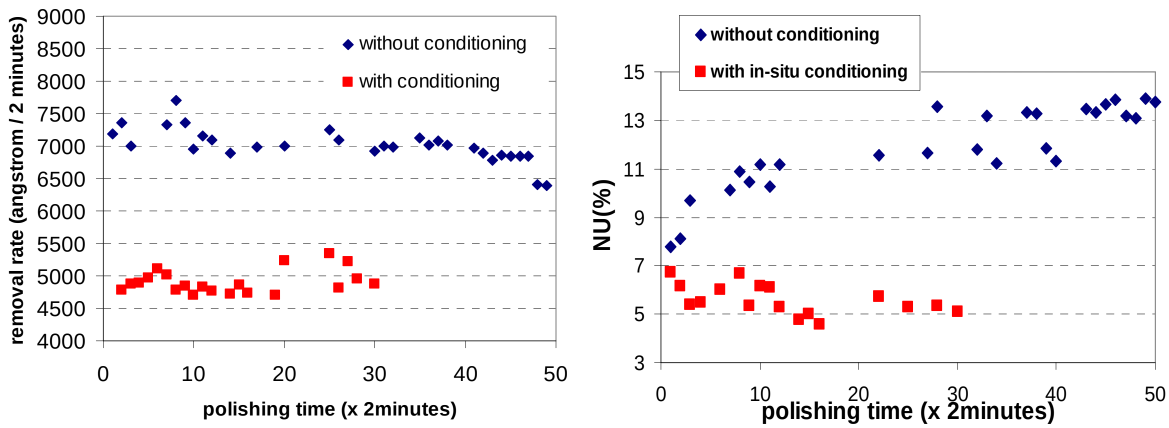
(b) after polishing 18 wafers

Figure 5: Comparison of pad height distribution change with and without conditioning

Within wafer non-uniformity (WIWNU) variations in both cases are shown in figure 6(b). WIWNU was defined as standard deviation of 81 measured values divided by the average. In the case of in-situ conditioning, WIWNU decreased as process continues and it increased in the case of polishing without conditioning. Without conditioning, severe by-product built-up was observed near the center of the pad, where the slurry supply tube was located. (figure 8). From the observation of removal rate and WIWNU, it is believed that the conditioner movement over the pad helps uniform distribution of slurry over the pad, and reduces effective slurry supply rate.

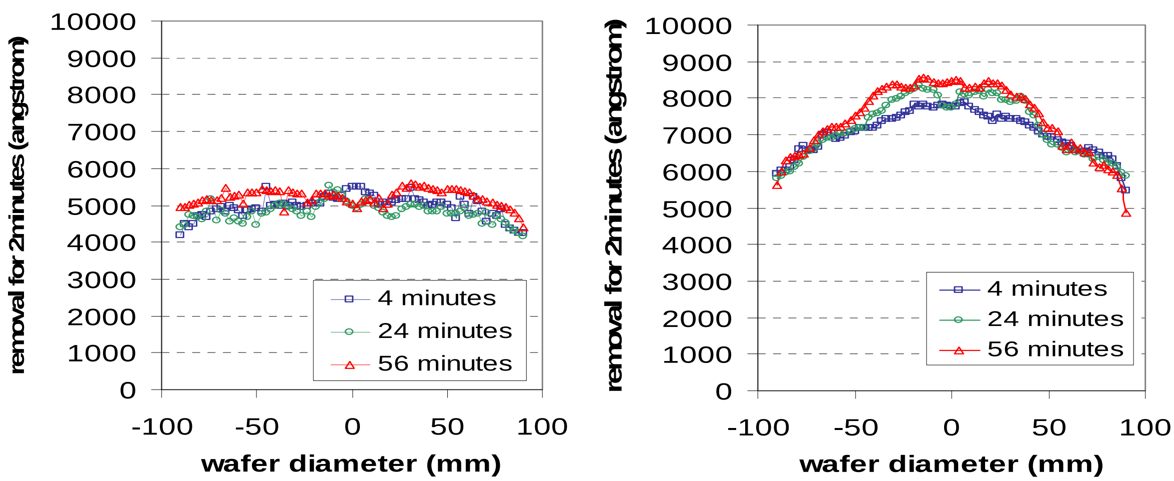
In the case of polishing without conditioning, non uniform pad wear and deformation occur. Also the by product built up near the pad center can affect the removal rate of the wafer edge area chemically. Figure 8 shows that only part of the wafer directly in contact with the region of by product built- up. Hence as polishing continues, WIWNU increased. With in-situ conditioning, non-uniformity of pad thickness and surface state over the pad becomes smaller as process continues, which reduces WIWNU.

Based on these observations, it can be concluded that the in-situ conditioning process affect not only pad surface topography but also its variation over the pad, and more importantly, the slurry flow pattern over pad, which greatly affect within wafer variation of the removal rate.



(a) Removal rate (b) WIWNU

Figure 6: Variations of removal rate and WIWNU



(a) With in-situ conditioning (b) Without conditioning

Figure 7: Removal rate profile across the wafer diameter

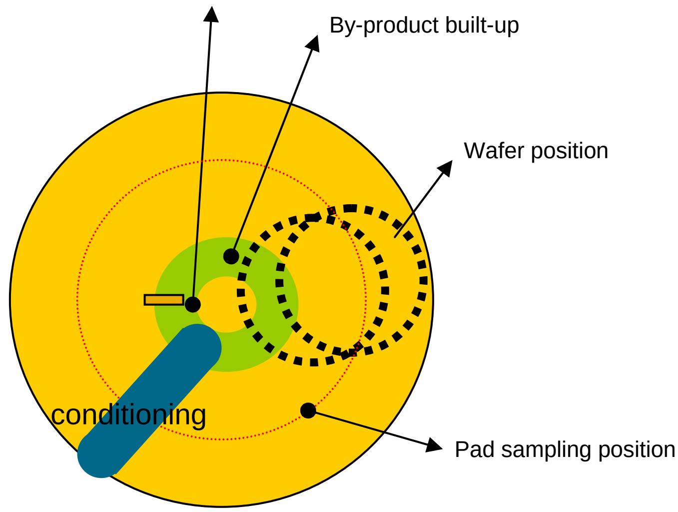


Figure 8: Schematic of experimental setup

Conclusion

Variations in in-situ conditioning aggressiveness did not make a clear change in pad surface height distribution during a CMP process. However, pad conditioning with differing conditioning aggressiveness without CMP operation generated varying surface height distributions. This suggests that the pad surface height distribution is more dependent on the plastic deformation and wear at the retaining ring and wafer contact region than the aggressiveness of in-situ conditioning during a copper CMP process.

In the pad degradation test, pad surface height distribution showed clear glazing effect. However, the removal rate variation was not clearly observed for the first 36 minutes of polishing. Also, the removal rate with in-situ conditioning was significantly lower than the case of polishing without conditioning. Observations of removal rate variation, WIWNU variation, and removal profile variation across the wafer, suggests that the slurry flow pattern over the pad was greatly affected by the movement of the conditioner. It is believed that the conditioner movement enhanced uniform slurry supply to the wafer contact region, and reduced the effective slurry supply rate, which reduced removal rate during process. This suggests that the in-situ conditioning affected overall copper CMP performance more by slurry supply mechanism than pad surface topography change.

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