Insitu CMP Monitoring and Control via Pad Surface Friction and Wear Data Collection

John H. Givens, Ph.D., Michael Vinogradov

Center for Tribology, Inc., 1715 Dell Avenue, Campbell, CA 95008, www.cetr.com

Introduction

With the semiconductor industry still prescribing and advancing the technological needs of circuit density and speed according to Moore's Law, device designs have put more burdens on the technologists to find additional process margin in materials and geometries. And, the production requirements for High Volume Manufacturing (HVM) demand more intuitive and predictive capabilities in order to minimize process interruptions, excursions and yield loss. These documented needs continue to push the process and manufacturing engineers to find and implement robust monitoring systems.

CMP still remains a process that receives high visibility and continuous scrutiny. It is not only an extremely enabling technology for the advancement of device integration, circuit density and wafer yield, but also the only HVM proven process truly capable delivering both local and global planarization. However, CMP still maintains it premier position as the process that every managing director of a device production facility loves to hate. Even though CMP is the only major process step where the operator can actually visually observe the work, this infamous status still resonates from the same fundamental questions that have been asked for the past 17 years.

- How is CMP affected by upstream processes?
- What is happening to the wafer during the process?
- Why is it so sensitive to changes in the consumables?
- How can the process become more stable or better?
- Why is CMP expensive?
- How does CMP affect downstream processes?

This paper is focused on presenting and discussing the utility of an *insitu* pad surface monitor that collects and processes data via friction and wear signatures. The PadProbe™ is a contact metrology instrument that provides a direct measurement of the health/status of the process and consumables via the pad surface. The ability of this metrology technique to perform in HVM has been previously discussed and presented by device manufacturers. The capability of the PadProbe™ to perform continuous consumable monitoring and qualification will be presented.

Experimental

The PadProbe™ system consists of a contacting sensory head, control unit and supporting components. The system utilizes two strain gauges to measure pad friction and a displacement gauge to measure pad wear. This metrology unit has been

successfully installed and utilized on all major rotary platforms for 200mm and 300mm CMP. A typical installation is shown in Figure 1. The workings of the PadProbe^{TM} have been described in previous publications [1, 2].

The data to be presented and discussed has been generated and collected from commercially available polisher configurations in standard ULSI applications. For consumables, various slurries and pads from commercial suppliers were characterized based upon the device manufacturer process of record for the given CMP application.

Results and Discussion

There have been numerous papers and presentations discussing the tribological nature of the pad surface [3, 4]. For an initial endeavor, a fundamental experiment consisting of an IC1000/Suba4 k-groove pad (Rohm & Haas), DI water and changing rotational velocity was performed. The resultant data from the PadProbe^{TM} is shown in Figures 2 and 3. Figure 2 reveals that nature of friction for the pad surface after a standard conditioning process. One can see that as the rotational speed increases, the friction between the sensor surface and the pad surface decreases to a value of approximately COF = 0.3 at 120rpm. A straight forward conclusion is that the PP sensor experiences increasing hydrodynamic lift with the change in velocity.

This statement is further supported by the pad wear data shown in Figure 3. The thickness change registered after the conditioning process should be a fixed value. Any change in this value based upon the pad velocity would be derived from the previously mentioned hydrodynamic lift. The movement of the sensor shown as a change in pad thickness as a function of time at 40rpm reveals a positive delta of 5μm that saturates at approximately 15μm. As expected, this is very similar to other referenced works for slurry film thickness between a wafer and pad [4]. The higher velocities in this experiment did not show the same drift as these conditions were sufficient to essentially provide an instantaneous lift. Another point of discussion from this data is the revealing nature of the platen run out. With the PP sampling data at 1/sec and the pad rpm less than 60rpm, the amplitude of the data oscillation shows 5 um of systematic variation.

The art (science?) of conditioning the pad surface has received much scrutiny, development and ire of CMP engineers and scientists over that last 15 years. The requirement of surface refreshment is essential in all CMP processes. A repeatable and stable process is driven by the quasi-steady state response of the pad surface to the wafer and slurry cross-section during the polish. The act of conditioning, whether by mechanical or chemical means, removes residual slurry components, polish by-products and worn pad contact area. There is a direct correlation between the conditioning process and the performance of the polish system. Figures 4, 6 and 8 show the pad friction data for the oxide removal rate monitor wafers across 25 wafer runs with 3kgf, 4kgf and 6kgf of exsitu conditioning, respectively. The data for 3kgf and 4kgf show a distinct “first wafer effect” where the initial wafers (1-5) have a distinctly different friction response from the subsequent wafers. This is an indication of inadequate surface stabilization as a result of insufficient pad conditioning. This response is not shown by the 6kgf process.

The data for 3kgf also shows pad friction drift across the 25 wafer run which in-turn indicates inadequate pad conditioning for process stability. The 6kgf data in Figure 8 does not show a first wafer effect but variability across the wafer runs. A variable response as this would point to an over conditioned pad surface. With the exception of the first wafer effect, the 4kgf conditioning process would appear to provide the best pad surface stability which should lead to a consistent polish process.

Figures 5, 7 and 9 further substantiate the previous discussion concerning process stability versus pad conditioning. The data for 3kgf and 4kgf in Figures 5 and 7 show the correlation between the first wafer effect for friction and low removal rate. Figure 5 also confirms the inadequate conditioning of the 3kgf process as shown by the continuous change in RR across the 25 wafer run. The 6kgf conditioning process is proven to over-condition the pad surface by the drop in RR during the wafer runs. The RR data for wafer 15 can not be explained by pad friction. Another uncontrolled variable is a probable source for this variation. Figure 7 provides the correlation between a stable pad friction response and a consistent oxide removal rate. However, the 4kgf process will need modification to eliminate the initial pad surface response resulting in a low removal rates.

Conclusions

The PadProbe™ has been shown to be a critical insitu monitor of the health and stability of the CMP consumables and processes. A 15μm hydrodynamic lift (water film thickness) was readily determined between the sensor and pad surface. The PadProbe™ provided a direct characterization method for determining the (in) adequacy of the conditioning process to stabilize the pad surface and provide consistent removal rate performance. With PadProbe™ in constant contact with the pad surface during the life of the consumable, it is a "constant on" metrology unit that can provide insight into all factors that provide memory or affect the surface response of the pad. This information has been proven to be invaluable in HVM applications.

References

[1] S. Hosali, et al, CMP-MIC 2005, pp. 115 – 118.
[2] Y. Yamada, et al, VMIC 2006.
[3] C. Gray, et al, CMP-MIC 2005, pp. 97 – 104.
[4] G. Muldowney, CMP-MIC 2005, pp. 105 – 112.

Figure 1. A typical configuration of the CETR Padprobe^{TM}. The PP is mounted on an HVM Strasbaugh polisher in this photograph.

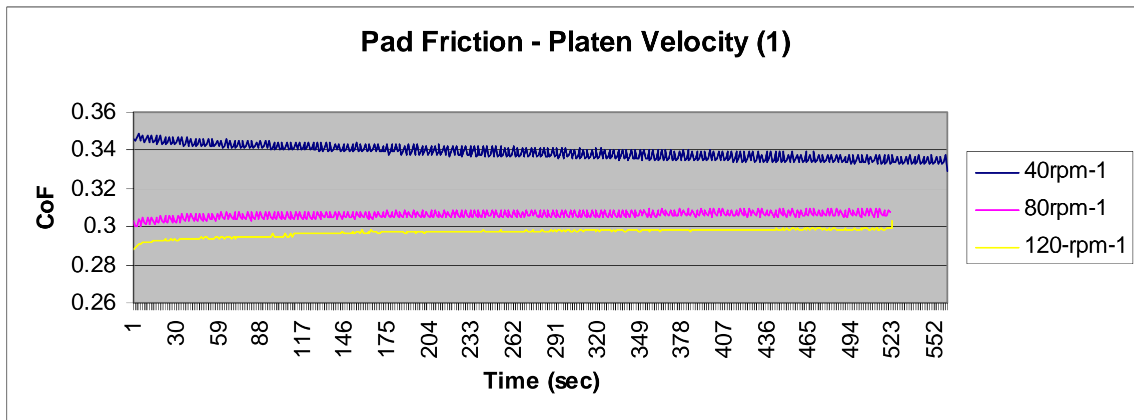

Figure 2. A plot of pad friction at different velocities is shown in this figure. The decreasing CoF with increasing velocity is driven by hydrodynamic lubrication.

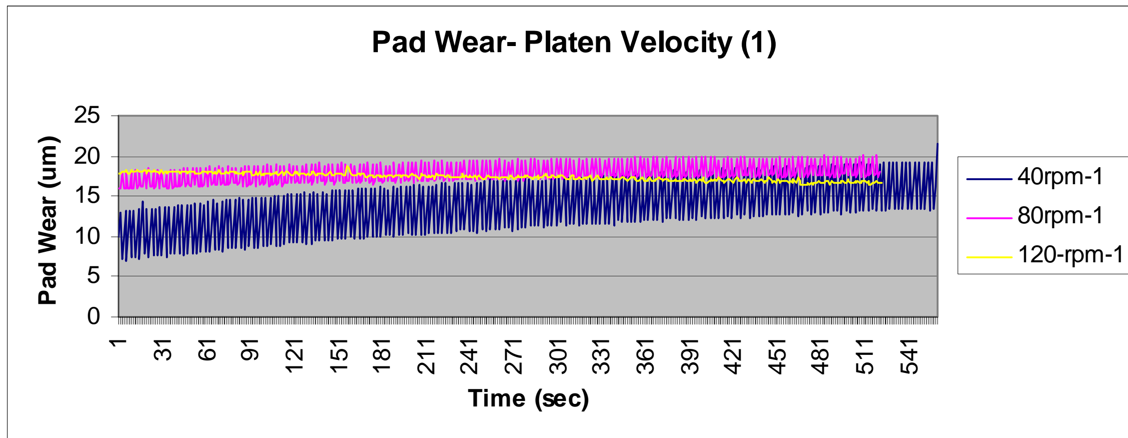

Figure 3. A plot of pad wear for different platen velocities is shown. The 40rpm data of the graph shows the hydrodynamic lift of the sensor for this pad is approximately 5μm.

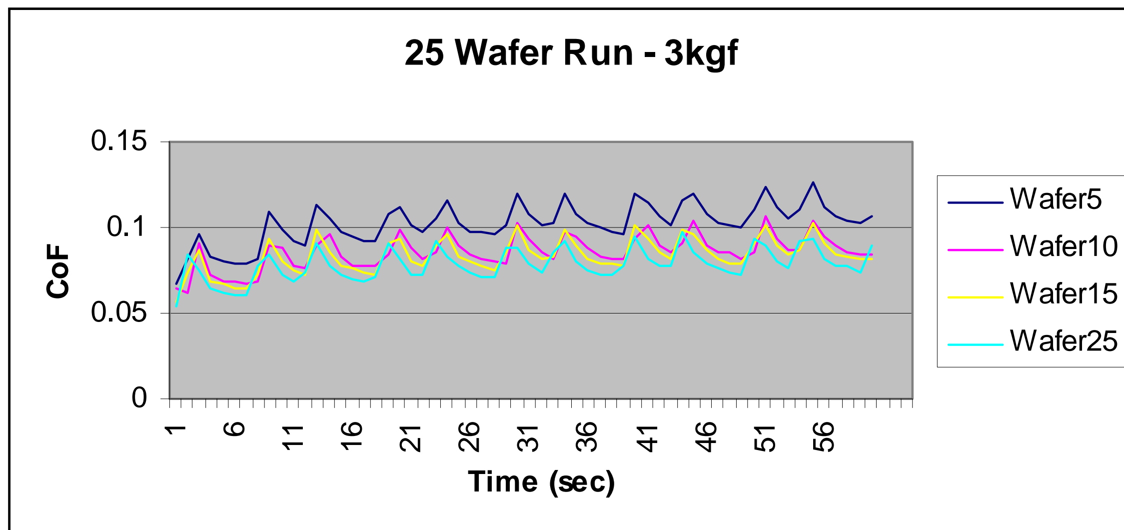

Figure 4. This graph shows the friction response of multiple rate monitor wafers across a 25 wafer run. The data shows a "first wafer effect" for slot 5 and a continuous decrease in friction for each subsequent wafer.

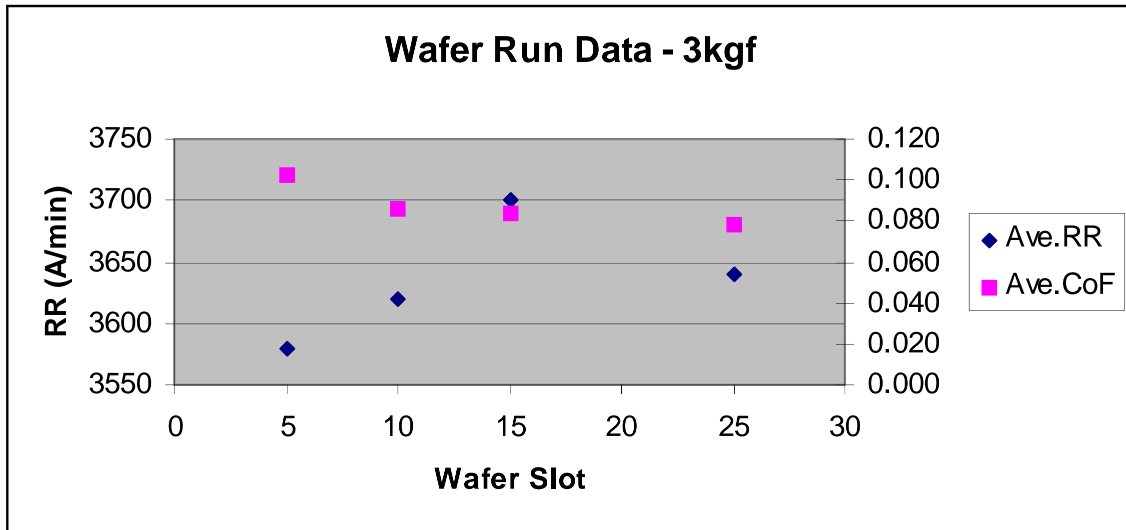

Figure 5. This graph shows the correlation between RR and friction at 3kgf of exsitu conditioning. The 3kgf conditioning process is not capable of stabilizing the pad surface for a consistent removal rate.

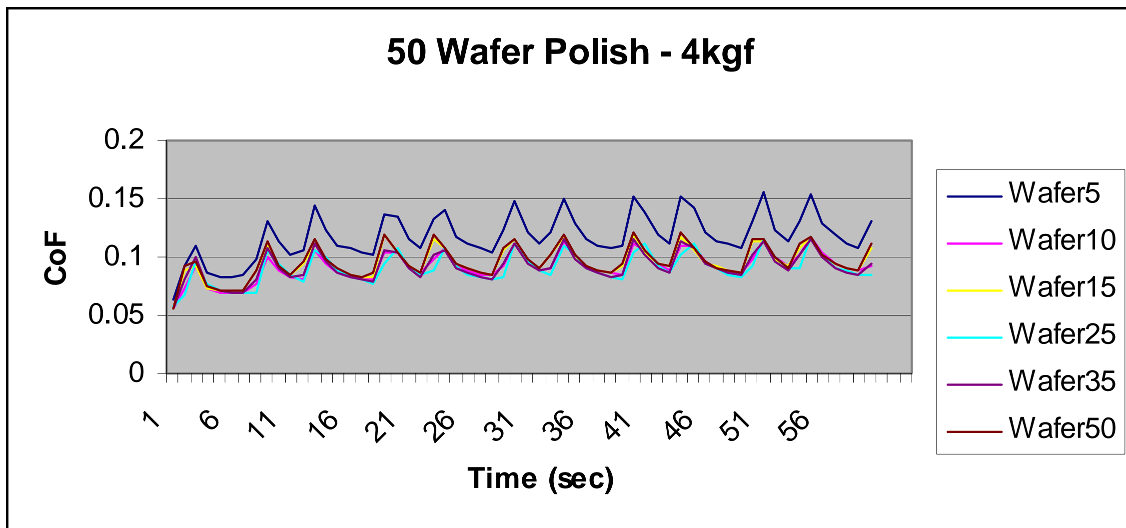

Figure 6. This graph shows the friction response of multiple rate monitor wafers across a 50 wafer run with 4kgf of exsitu conditioning. The data shows a “first wafer effect” for slot 5 and a consistent friction value for each subsequent wafer.

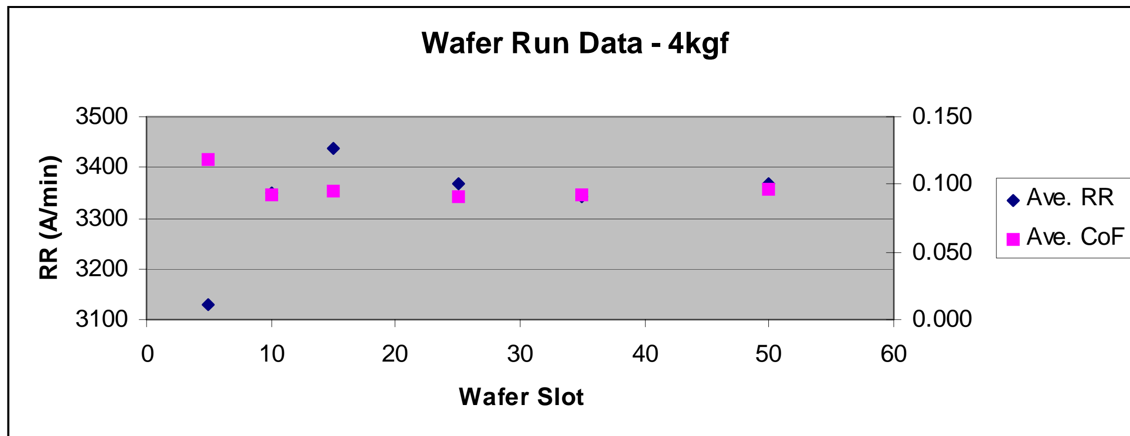

Figure 7. This graph shows the correlation between RR and friction at 4kgf of exsitu conditioning. The 4kgf conditioning process is shown to be capable of stabilizing the pad surface for a consistent removal rate.

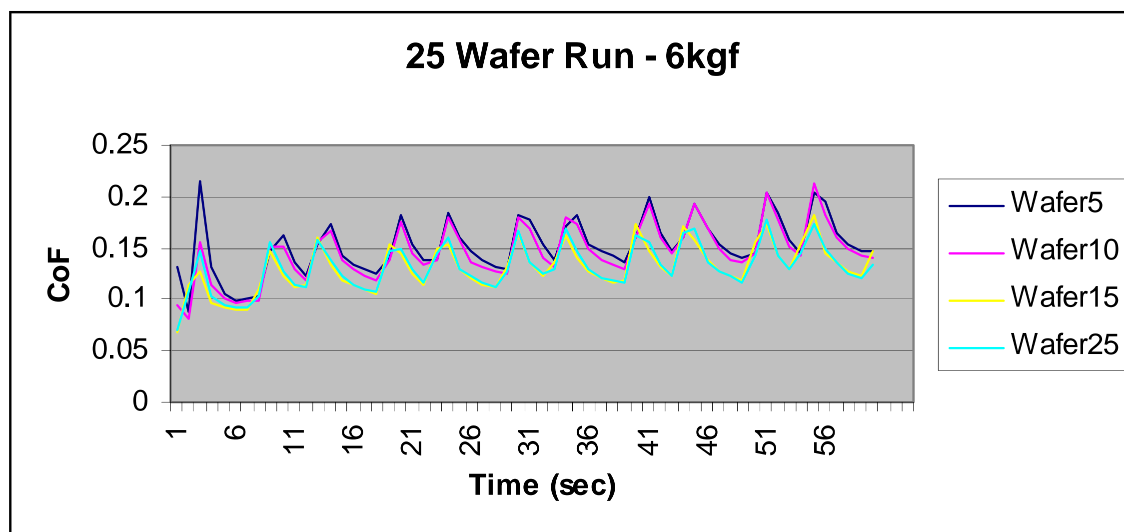

Figure 8. This graph shows the friction response of multiple rate monitor wafers across a 25 wafer run with 6kgf of exsitu conditioning. The data shows inconsistent friction values across the 25 wafer run.

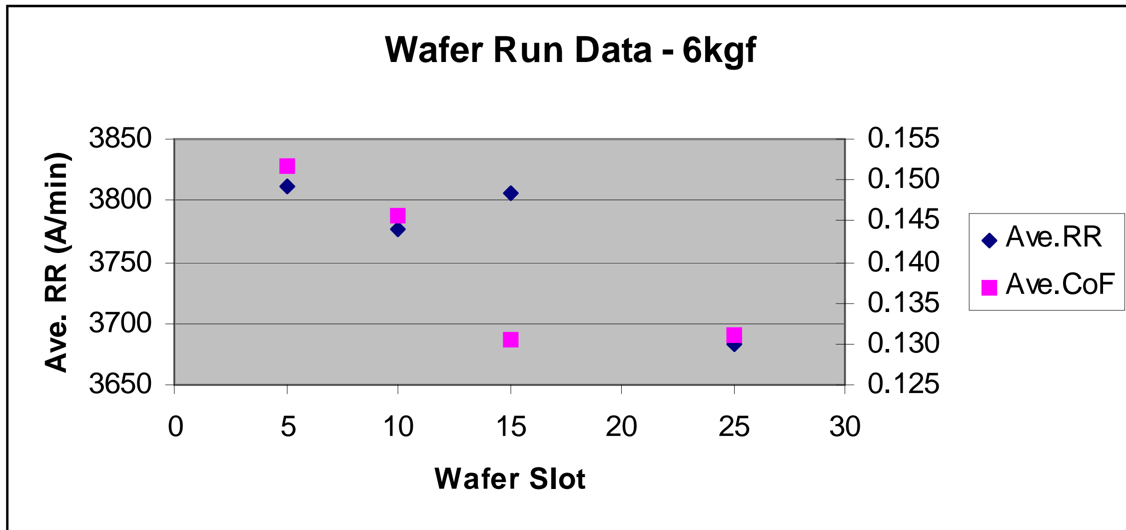

Figure 9. This graph shows the correlation between RR and friction at 6kgf of exsitu conditioning. The 6kgf conditioning process is shown to be over conditioning the pad surface for a inconsistent removal rate response.