An in-situ sensor for reduced consumable usage through control of CMP

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Abstract

We have observed a high correlation between the spatial temperature variation across a polishing pad and the spatial wafer uniformity during CMP. The observations were made using an infrared sensor mounted on the head of a Strasbaugh 6EC polishing tool which facilitated radial temperature measurements of the polish pad. The variation of the temperature profiles was then compared with the measured spatial variation in wafer film thickness after polish. We found that the process conditions greatly influenced the temperature profiles which correlated well with polish uniformity. These results show that spatial removal rate variation across a wafer may be obtained in-situ during polishing thus providing an opportunity for process monitoring and control. In-situ monitoring and control is not only important for improved product quality but it is also useful for reducing the use of dummy and look-ahead wafers, with improved process and cleaning reduction.

Introduction

Although it is widely used, the Chemical-Mechanical Polishing (CMP) process is still poorly understood. It is believed to work through the combined effects of a chemical reaction at the surface of the wafer, and the physical abrasion which occurs between the slurry, the pad, and the wafer [5]. This poor process understanding has led to difficulties in achieving reliable process performance. In particular, the wafer to wafer variation in the average removal rate, wafer-level polishing uniformity, within-die variation in the polishing of patterned wafers, and end-point detection remain substantial obstacles. The need to understand process fundamentals as well as to provide in-situ measurements for diagnostics and control have led to the development of several sensors for CMP.

Real-time in-situ sensors developed to date include methods for: measuring changes in the motor current, estimating the remaining film thickness, and monitoring average pad temperature. Post-process ex-situ or in-line sensors are most commonly used for obtaining full-wafer thickness measurements. Only the post-process full-wafer measurement system provides a clear measure of wafer-level uniformity. However, the process is expensive and provides marginal insight into particular causes of the non-uniformities measured.

In this work, we propose an in-situ radial uniformity sensor based on extensions to the infra-red (IR) temperature measurement systems previously reported [4]. This sensor may not only be used for process diagnostics or end-point detection, but may also provide information on radial uniformity.

CMP Temperature Sensors

Temperature sensing systems typically available on CMP tools are currently small spot sensors which are focused at a particular point on the surface of the CMP pad. As shown in Figure 1, this temperature sensor is limited because the single point sensor captures only the temperature variation in time along a single radius of the CMP pad, and not the variation in space (from the inner to outer radius of the CMP pad). The variation of these traces in time are often less than one degree celsius, while, as pointed out in [1], the variation in space can be as much as twelve degrees Celsius. Time-series measurements of temperature provide little information about spatial uniformity. Effective correlations from temperature measurements to removal rates given in [2] and the spatial temperature variation described in [1] outline opportunities for correlating spatial temperature measurements to spatial polishing uniformity. A proposal for developing a spatial map of the removal rate across the wafer based on measurements from an infra-red (IR) camera for use in process control and end-point detection is given in [3]. We suggest that developing a full image of the removal rate across the wafer is extremely difficult, but developing a simple radial removal rate profile is less complex and more robust to noise. We have performed initial experiments which verify that radial temperature measurements can be correlated to radial uniformity. In addition, these experiments indicate that measurements are sensitive to variations in the processing conditions and the life of the consumable in the CMP process.

Experimental Setup
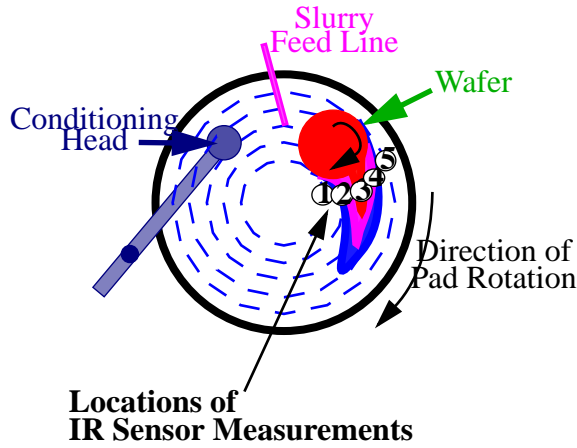
The experimental setup is shown in Figure 1. The

Figure 1: A CMP tool and IR sensor measurement setup.

locations of the radial temperature measurements are equidistant from the edge of the wafer carrier. Each radial measurement point is thus equally affected by the cooling of the CMP pad after exiting from under the wafer. The slurry is applied behind the wafer carrier (the heat source) to allow all the measurement points to be equally affected by the slurry flow rate.

Three wafers were run at each of three process settings for two minutes. The process settings were as follows: a) the baseline process for the CMP tool, b) the baseline process with the slurry flow reduced, and c) the baseline process with the table speed increased. The exact process settings are included in Table 1; all other settings were held constant for all trials. The time-series for each wafer were truncated to a fixed time interval (40 seconds after the polish began to 4 seconds before the polish finished). The time-series for each wafer was time-averaged to give an average temperature during the process at a given spatial location.

Table 1: Process Settings and Results

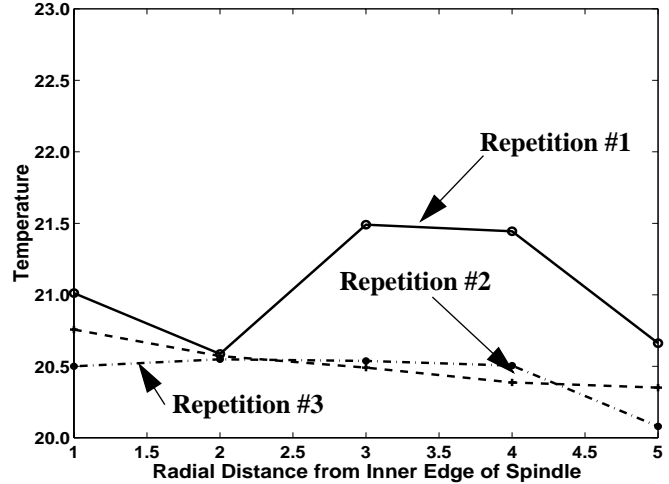| Process	Table Speed (rpm)	Slurry Flow Rate (ml/min)	Average Removal Rate (A/min)	Average Temperature
A	25	150	845	20.47
B	50	150	1037	21.89
C	25	75	750	20.57

Results and Discussion

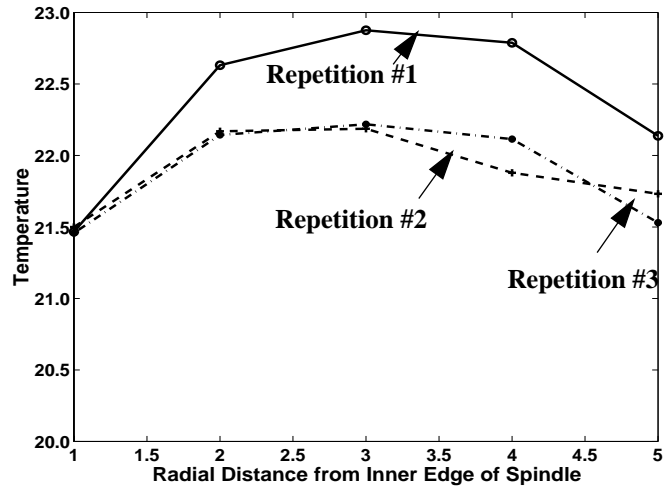**Figure 2: Radial temperature profile of the baseline CMP process.**

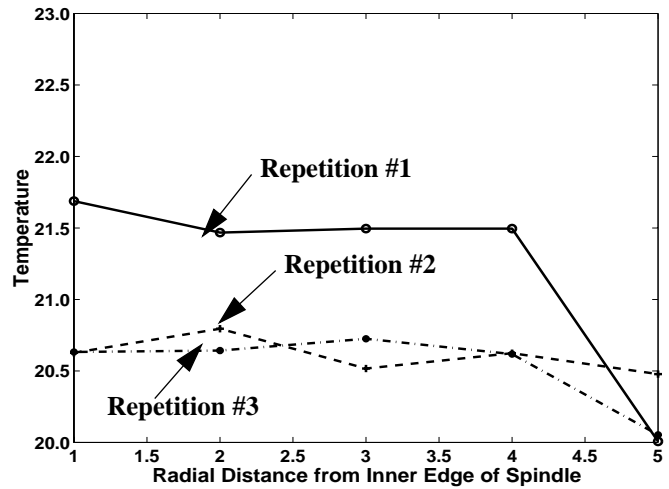**Figure 3: Radial temperature profile of the high speed CMP process.**

igure 4: Radial temperature profile of the low slurry CMP process.

The radial temperature profiles for the baseline pro-

cess, high speed process, and low slurry process are shown in Figures 2, 3, and 4 respectively. The first effect we notice is that each process has a characteristic shape. The high speed process has a higher average temperature and a larger curvature while the baseline and low slurry processes have lower temperature and smaller curvature. The latter processes are also difficult to distinguish. These observations are consistent as they confirm the significance of speed as a key CMP process variable compared to slurry flow rate which is not as significant. The second key observation is that the first repetition for all three process settings (the solid lines) is significantly higher than the later repetitions. This is because a new pad was used in this experiment. It is known that during the initial pad "break-in" period, the removal rate drops off exponentially before stabilizing. This demonstrates the potential use of the radial temperature profile as a monitor for pad break-in period.

The average of the two repetitions after the break-in period for each temperature profile are shown in Figure 5. The effects of the process conditions on temperature
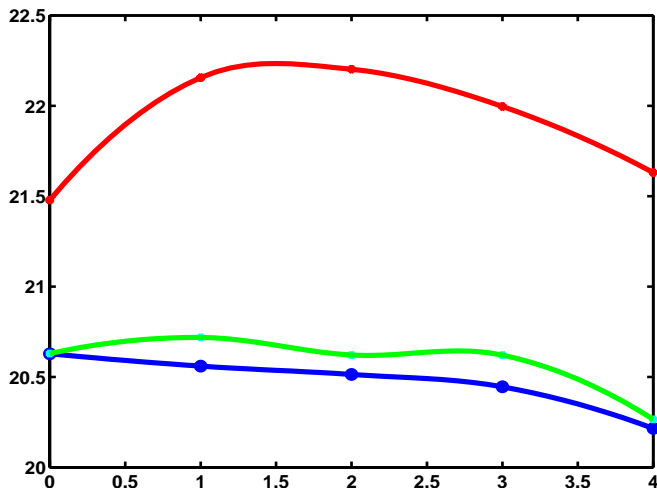

Figure 5: Temperature Profiles for all three processes constructed from experimental replicates two and three.

profile is more distinct. As noted earlier, the high speed process has a significantly higher average temperature and a larger curvature than the baseline and low slurry processes. The higher average temperature is due to the increased removal rate (due to higher speed). The higher curvature should correspond to a significant increase in the within-wafer non-uniformity. The low-slurry process differs only slightly from the baseline process; the decreased slurry rate has caused a slight increase in the average temperature as well as the curvature of the temperature profile. This should result in a slight increase in the radial non-uniformity of the low-

slurry process.

Comparison of Temperature and Polish Non-uniformity

The goal was to compare the non-uniformity of the temperature profile to the non-uniformity of the polished wafers. Temperature non-uniformity was defined as the ratio of standard deviation to the mean of the obtained temperature profile, which was constructed out of the measurements over 5 wafer polishing runs. Wafer thickness non-uniformity was similarly defined based on a 49 point radial measurement using a Tencor SM300. A plot of the wafer and temperature non-uniformity is shown in Figure 6 and a good correlation is
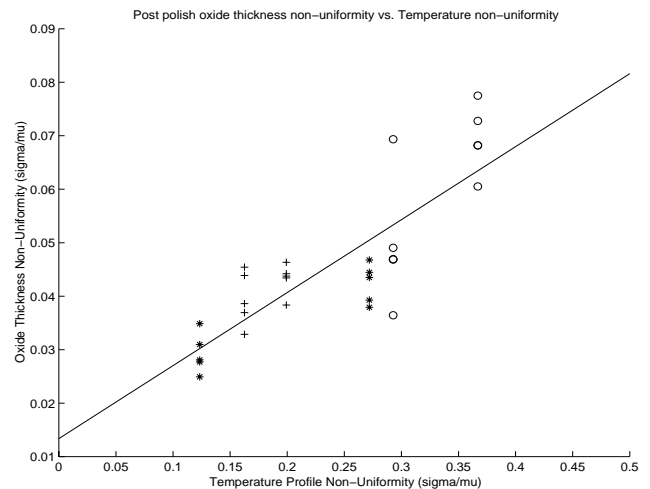

Figure 6: Comparison of Thickness and Temperature Profile Uniformitie

apparent.

Use for In-Situ Real-Time or Run by Run Process Control of CMP

The in-situ radial uniformity sensor has many possibilities for use in both real-time and run by run process control of CMP. One possibility for compensation would be to condition the pad in areas which need an increased removal rate (as measured by the in-situ temperature sensor).

Similar to the strategy suggested in [3] with the full-wafer removal rate profile, a second control scenario might be to utilize process conditions to compensate for the measured radial removal rate profile. A particular example might be the use of back pressure (which is known to contribute to different radial removal rate profiles). The amount of applied back pressure could be adjusted in real-time or run by run basis to compensate for discrepancies in the measured temperature profile.

A third scenario, also suggested for use with the full-wafer removal rate profile in [3], might be the use

of the temperature sensor profiles for end-point detection. This has more recently been investigated in [4]. In particular, the polishing of different materials is likely to lead to different temperature signatures. Therefore, when the polishing process changes from one material to another, the temperature sensor would be able to detect the change.

Conclusion

The temperature sensor has been shown to be a promising tool for gaining insight into the chemical mechanical polishing process. The profiles are indicative of the quality of polish and they vary depending on the process conditions. They may thus be useful in a control strategy which optimizes both removal rate and polish uniformity. We are looking into creating an empirical model to relate the material removal rate at various points on the wafer to the observed radial temperature profiles.

The point sensor only gives a rough estimate of the temperature at a single point during each run. This is inconvenient, in that it requires many wafers to achieve a trace of the profile. To get the spatial information that we need for each wafer the solution is an infra-red camera. There has been some previous work looking into the possibilities that an infrared camera can offer; we hope to apply the concept of uniformity control by implementing an IR camera during CMP. We will also attempt an implementation of a run by run controller utilizing the camera as an in-situ measurement of uniformity of polish.

References

[1] R. Lane and G. Mlynar, CMP-MIC, p. 139, 1997.

[2] H.-W. Chiou, L.-J. Chen, H.-C. Chen, CMP-MIC, p.131, 1997.

[3] US Patent # 5196353.

[4] L.-J. Chen, Y.-L. Huang, Z.-H. Lin and H.-W. Chiou, "Pad thermal image endpointing for CMP process", in Proc. CMP-MIC Conf., pp. 28-32, Santa Clara, CA, Feb 1998.

[5] L. M. Cook, "Chemical processes in glass polishing," *J. Non-Crystalline Solids*, Vol. **120**, pp. 152-171, 1990