Correlation of Large Particle Count Data in CMP Slurry with Production Wafer Defects

Jonathan Bennett
IM Flash Technologies, LLC
Lehi, UT, USA
JBennett@IMFlash.com

Michael A. Fury
Vantage Technology Corporation
Campbell, CA, USA
MFury@VantageTechCorp.com

***Abstract* - A Vantage SlurryScope was installed in an IMFT production fab CMP tool for slurry monitoring at point of use (POU). Data gathered over several weeks was compared to four different wafer yield metrics, including wafer defects associated with CMP scratching. A strong correlation was found between defects and the total particle count in the smallest (1.0-1.2µm) particle bin reported by the SlurryScope system. Discrete particle excursion events did not play a role in these correlations. The SlurryScope was then moved to the equipment chase to monitor large particles continuously in the slurry distribution system (SDS) main loop. Using the correlation methods learned at POU, a similar correlation was found between defects and drift in the measured total particle count. The SlurryScope data was also compared to a traditional offline monitoring method. The correlation coefficient was significantly higher for SlurryScope data in all four defect metrics included in this study.**

I. Introduction

Large particles in CMP slurry have been one of several known risks to wafer yield since the first implementation of CMP in 1989 [1]. Large particle counts (LPC) can produce divots, scratches and microscratches on the wafer surface, some of which result in yield loss and reliability degradation. Leading-edge device technologies with critical dimensions of 32nm and smaller are increasingly sensitive to LPC variations. Some of these variations are persistent, representative of a slurry lot or an SDS operating condition. Often, the variations are transient or short-term, resulting from day tank replenishment, filter changes, valve movement and other operational events. The traditional method of monitoring slurry LPC offline by sampling once daily provides some ability to track persistent LPC variations, but provides no insight to short-term variations. The risk to wafer yield becomes unacceptable at leading-edge technology nodes without such data to guide operational improvements. Real-time monitoring represents a new opportunity for the immediate containment of an LPC excursion or a system failure event. In addition, it provides greater statistical significance for the analysis of time-dependent trends.

II. Experimental

A. *Vantage SlurryScope Process Monitor*

The Vantage SlurryScope™ system (Vantage Technology Corporation, Campbell, CA, USA) is a process monitor that samples a continuous stream of undiluted CMP slurry at full polishing strength and reports large particle size distribution (PSD) in real-time. Measured slurry can be returned to the supply stream to eliminate slurry waste. This is shown schematically in Fig. 1. The SlurryScope has an internal liquid flow controller (LFC) to maintain the monitored flow at 15±1 ml/min as required for particle size calibration. Tool operation is described in greater detail elsewhere [2].

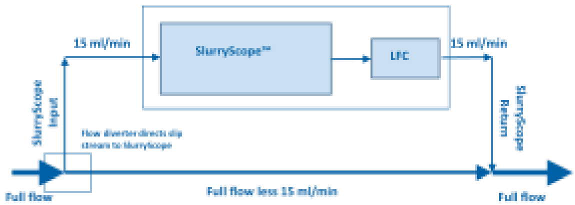

Fig. 1. Schematic diagram of SlurryScope slurry sampling configuration. Measured slurry can be returned to the supply stream, but was not in these experiments.

The SlurryScope operates over one of two ranges: 1.0µm to 10.0µm and above in 0.2µm sizing bin increments; or 0.8µm to 4.0µm and above in 0.1µm increments. Long-term slurry monitoring has been successfully implemented in production fabs with oxide [3], tungsten and copper silica-based slurries, and with several types of ceria slurries. The higher background scattering of ceria particles as compared to silica presents a particular challenge to the monitor's ability to discriminate LPC from the submicron particle majority. Nonetheless, the data presented in this study demonstrates the utility of these measurements even under such adverse conditions.

B. *Fab Evaluation Parameters*

The slurry used in these studies is a commercially available ceria with a solids content in the range of 1-5 wt% solids and a median particle size of 150nm. The SlurryScope model used here reports LPC in the range of 1.0µm to 10.0µm and above. The correlation of LPC to defect metrics was performed using only the particle count data in the 1.0-1.2µm size bin.

In the first study, the SlurryScope was installed in the CMP tool, under the polishing platen. Slurry was sampled at 15 ml/min from the line delivering slurry to the platen, immediately *before* the POU slurry filter. SlurryScope data collection began when the slurry delivery valve on the polisher opened, and terminated when the slurry flow rate to the monitor fell below 14 ml/min. For each wafer polished, the total data collection time was approximately 1 minute, with a 1 second data accumulation time for each SlurryScope data point. Polishing operations were monitored in this manner continuously for 40 days.

In the second study, the SlurryScope was installed in the equipment chase behind the CMP tool. The SlurryScope accumulation time was set to 10 seconds for each data point to reduce noise in the readings. In this installation, the slurry could be monitored continuously without being subject to polisher start-stop issues and idle time. Slurry operations were monitored in this manner continuously for 30 days.

III. RESULTS

A. CMP Polisher POU Installation

The raw SlurryScope data for the POU study is shown in Fig. 2, and includes one data point for every second of wafer polishing. Data points below 1×10^6 p/ml (particles per milliliter) were removed for scaling. Gaps in the data represent polisher idle time.

Fig. 3 shows the same data limited to the range of $1.7\text{-}2.6\times10^6$ p/ml. In addition, this data is color coded by slurry lot. There is a systematic clustering of data within each lot, with some indication of anomalous behavior toward the end of lot life in several cases. Interpretation of this behavior is beyond the scope of this paper.

The corresponding offline LPC monitor data is overlaid on the SlurryScope POU data in Fig. 4. While a general correlation can be surmised between the two data sets, the offline data set is far more sparse and subject to systematic slurry sampling and dilution measurement inconsistencies.

The normalized wafer scratch data is overlaid on the SlurryScope POU data in Fig. 5, with good qualitative correlation even across slurry lot changes. The second slurry lot from the end appears to be inconsistent with the others, showing an unusually high LPC corresponding to a relatively low scratch count as compared to the overall wafer data set.

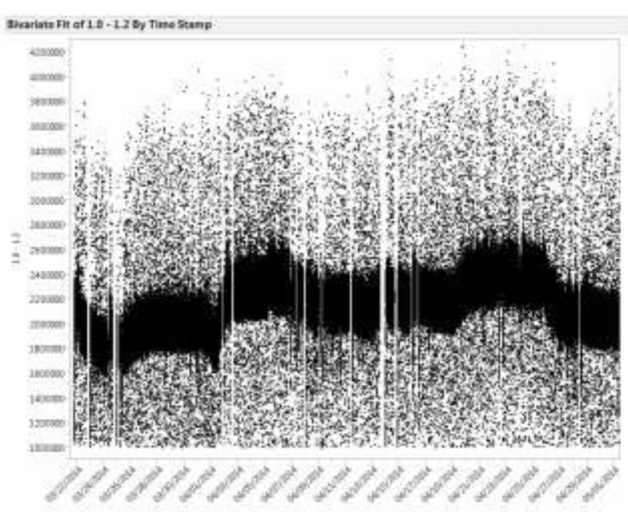

Fig. 2. Raw SlurryScope LPC data collected at POU over 40 days.

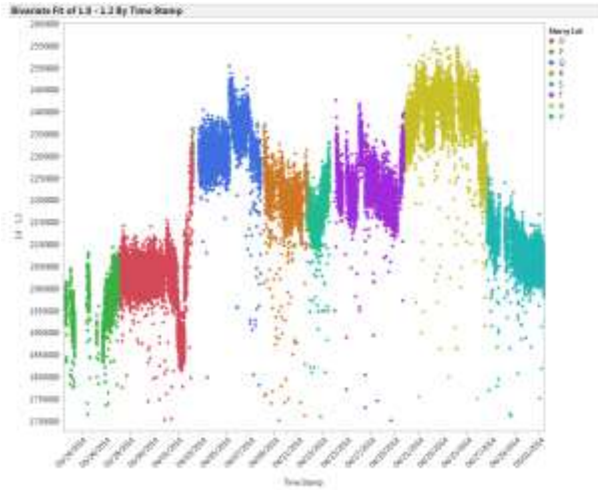

Fig. 3. Filtered SlurryScope data at POU, color coded by slurry lot.

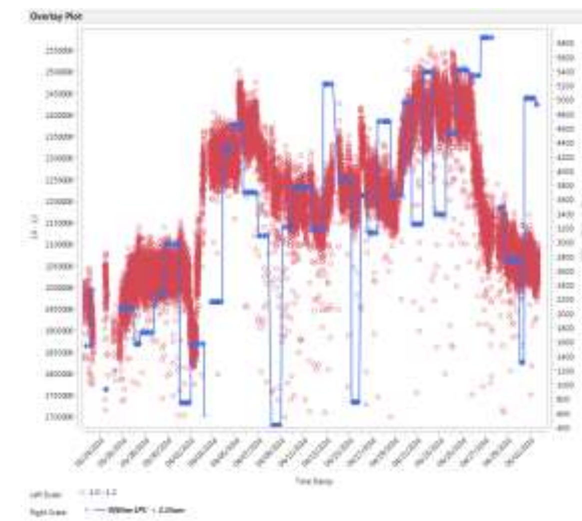

Fig. 4. Overlay of offline LPC monitoring on SlurryScope POU data.

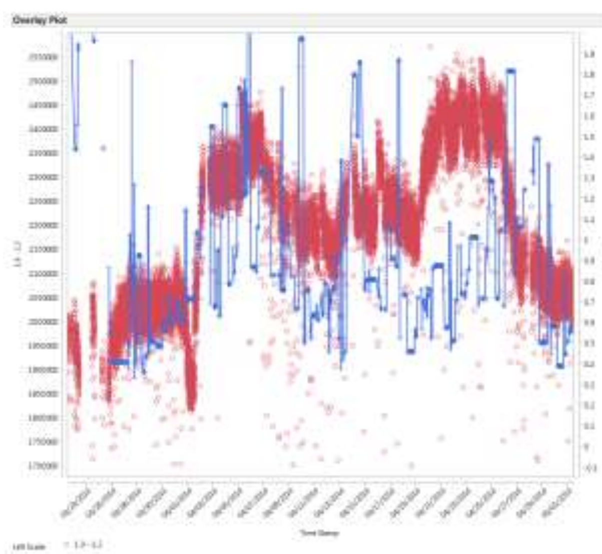

Fig. 5. Overlay of normalized scratch data on SlurryScope POU data.

One possible explanation for this inconsistency is the presence of soft agglomerates in this particular slurry lot that present themselves as LPC in optical light scattering, but readily separate under polishing conditions. Further study is required to validate this hypothesis, and is beyond the scope of this paper.

In an effort to better illustrate the correlation in these data sets, an 8^{ths} (eighths) analysis was conducted on the total defects data and the scratch data. In this analysis, the time sequence of the SlurryScope data is ignored, and the individual LPC data points are sorted from smallest to largest. The data set is then divided into 8 equal segments. The defect data is grouped with the corresponding LPC data points and plotted on the Y-axis with the mean and 1-sigma box indicated. Fig. 6 shows the 8^{ths} analysis for normalized total defects, while Fig. 7 shows the same for normalized scratch data. The correlation of higher LPC with higher total defects is evident. The scratch data peaks at group 6 and tapers off with increasing LPC. This is thought to be an artifact of the way the defect inspection tool classifies defects. At very high scratch densities, some of the overlapping scratches may be reported as divots or clusters rather than as scratches.

It is significant to note that the measured slurry was sampled *before* the POU filter. Some fraction of the measured LPC was filtered out of the slurry before it reached the wafer surface, yet this correlation to defects persists. This suggests that (1) particles smaller than the statistical filter pore size are responsible for the defects; and (2) the large particles that are reported by the SlurryScope monitor are a useful proxy for the total particle set responsible for slurry-related defects. It is important to remember that polishing defects can also arise from a number of sources not related to slurry.

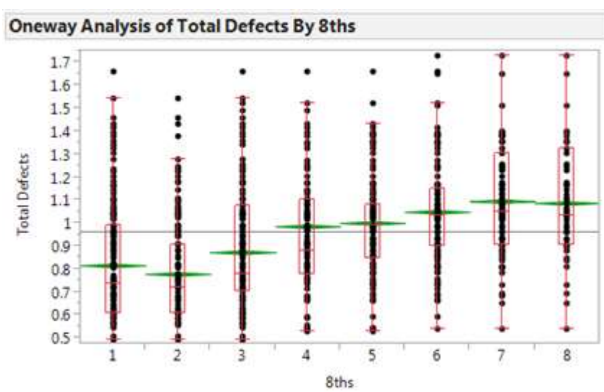

Fig. 6. Correlation between SlurryScope POU data and total defects by 8ths.

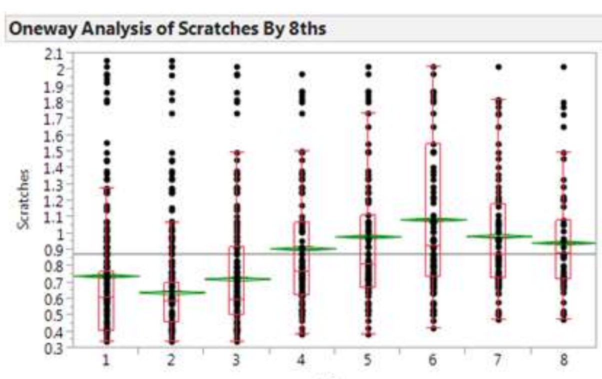

Fig. 7. Correlation between SlurryScope POU data and wafer scratch data by 8ths.

B. Equipment Chase Installation

The raw SlurryScope data for the equipment chase study is shown in Fig. 8. The data is color coded by slurry lot. In this instance, no data filter has been applied to the data set. The absence of noise compared to Fig. 2 is a direct consequence of the SlurryScope data accumulation time. In the POU study, data was recorded every 1 second due to the polishing time intervals of 60 seconds or less. In the chase study, slurry was monitored continuously, even during polisher idle time, and so the SlurryScope was set to accumulate data for 10 seconds before reporting each data point. In both cases, the LPC data is reported as the average number of particles per milliliter in the respective particle size bin over the designated data accumulation time.

The correlation of SlurryScope chase data to offline LPC measurements is shown in Fig. 9. A qualitative correlation can be surmised. The lot transition that is circled illustrates the lag time of almost two days before the offline procedure detected the LPC increase associated with the new slurry lot.

Normalized total defects are overlaid on the SlurryScope chase data in Fig. 10, with good qualitative trend correlation across slurry lots. This is especially true considering that the total defect metric includes defects that are caused by sources other than slurry.

C. Statistical Correlation Between LPC and Defects

Standard statistical methods can be applied to quantify the correlation of the various defect metrics to the corresponding LPC data from the SlurryScope and from the traditional offline metrology. As expected, there is considerable scatter in each of these data sets, resulting in somewhat low R^2 correlation factors, as shown in

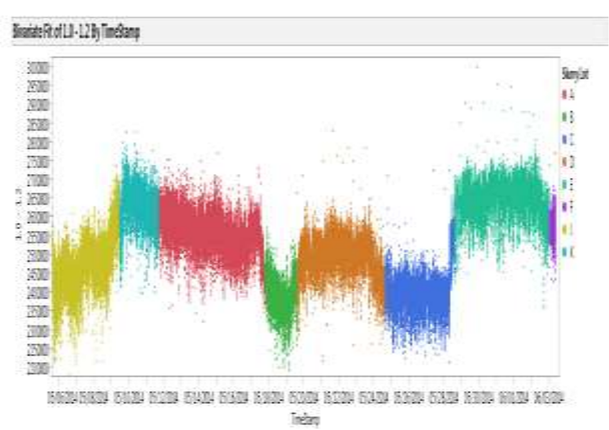

Fig. 8. Raw SlurryScope LPC data collected in the equipment chase over 30 days, color coded by slurry lot.

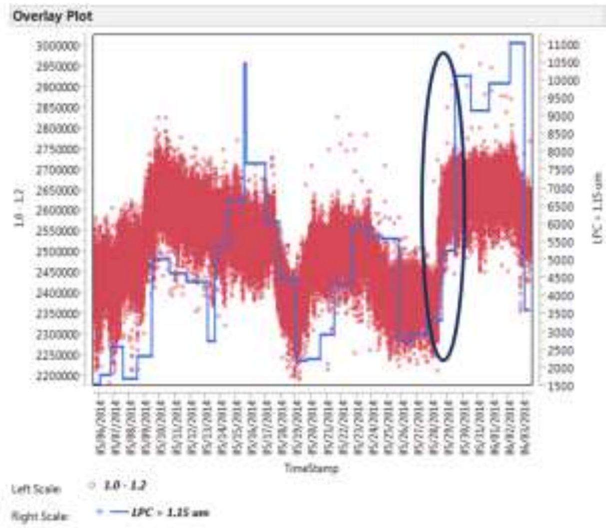

Fig. 9. Overlay of offline LPC monitoring data on SlurryScope chase data.

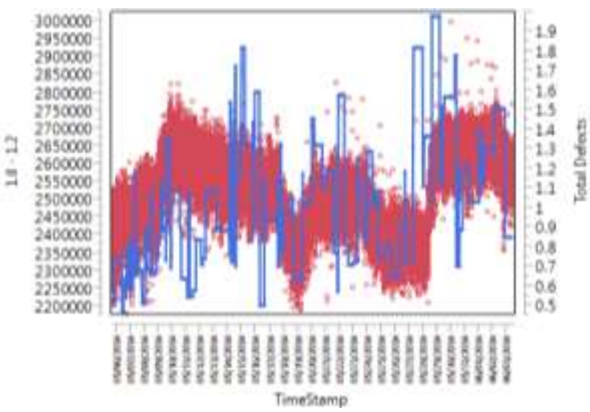

Fig. 10. Overlay of normalized total defects on SlurryScope chase data.

Table 1. It is significant to note that in the case of all four defect metrics, the correlation is 1.6 to 3.3 times better with the continuous SlurryScope data as compared to the sparse offline LPC data set.

It is anticipated that the SlurryScope correlation factors will improve with the implementation of automated wafer inspection algorithms that can remove defect data with a reasonable

Table 1. R^2 correlation factors for SlurryScope and offline LPC data to four wafer defect metrics.

R^2 Correlation	**SlurryScope (1.0 – 1.2 µm)**	**Offline LPC (> 1.15 µm)**
Total Defects	0.17	0.07
Scratches	0.08	0.03
Divots	0.18	0.11
Defect Clusters	0.20	0.06

probability of origins other than slurry. Until then, this kind of analysis will continue to suffer from low R^2 values. Nonetheless, the relative improvements achieved by using continuous SlurryScope data are apparent.

IV. Conclusions

This study used particle counts in the 1.0-1.2µm size bin. Such data sampling supports the hypothesis that particle counts larger than 1µm are a useful proxy for the PSD below 1µm. This tracking behavior also indicates that it is likely not necessary to directly measure particle counts ≤1.0µm (or ≤0.8µm), which would be an extremely difficult, if not impossible, technical challenge in an undiluted CMP slurry.

The SlurryScope sampling point in the POU portion of this study was at the valve manifold box before the POU filter. This location provided the SlurryScope with an opportunity to characterize all particles, some of which were removed by the POU filter before the slurry reached the wafers. Even so, the correlation between measured particle counts and wafer defects is compelling. This result is a further validation of tracking between large particles and the sub-micron PSD.

Qualitative correlation was established between SlurryScope data and the fab's traditional dilution particle count metrology, based on once daily sampling. The SlurryScope data correlation to wafer defect and yield metrics is more consistent and shows greater statistical significance than the traditional offline dilution particle data in all instances. Wafer defects from non-slurry sources are thought to be a contributing factor to the relatively low correlation factors.

Additional studies are planned to support the development of process control strategies based on real-time slurry data patterns. Using such data to temporarily suspend production or modify process or other operational parameters can result in systematic defect reductions.

Acknowledgment

Field support for these studies was provided by Stacy Forbes of Yarbrough Southwest and Kelly Barry of Vantage Technology.

References

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