LIGHT SCATTERING ANALYSIS FOR UNDILUTED SLURRY MANAGEMENT

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***Abstract* - Continuous, real-time process monitoring of undiluted CMP slurry has been used in production fabs now for over three years. This field experience has brought to light several critical issues, two of which are discussed here. The first concerns the handling of dense ceria slurries which have high counts that can exceed the algorithm of the original SlurryScope™ system. A new algorithm that analyzes all of the light scattering data has been developed to address this for high density slurries. The second is that some facility layouts do not allow for locating the SlurryScope close to the slurry sampling tap-off point. The information lost as a result of long sampling lines is quantified.**

I. BACKGROUND

Correlation of large particle counts (LPC) with defect and yield metrics has long been a promise of proper implementation of undiluted slurry process monitoring [1]. Continuous, real-time metrology validating this correlation has now been in use in volume production for over three years in fabs in Asia and the US [2]. In addition to wafer defects, such metrology has also proven useful in monitoring the particle disruption impact of slurry lot and tank changes, filter changes, and other operational events in the fab [3]. The SlurryScope samples continuously at 15 ml/min, providing a statistically significant measure of subtle drifts in slurry properties, short-duration excursion events that cannot be captured by random or non-continuous sampling, and repeating cyclic shifts in slurry properties that only become apparent with long-term, continuous monitoring.

II. HIGH DENSITY CERIA SLURRY

During fab implementation of the SlurryScope technology, we observed that some optically dense ceria slurries are challenging to measure using SlurryScope standard operating mode, and may result in erroneous data, as exemplified by the small particle count roll-off shown by sample #3 in Fig. 1. The high scattering intensity of ceria and the optical coincidence of submicron particles, which are not resolved individually, causes these particles to be interpreted collectively as larger individual particles. User demand for measuring these process-critical ceria materials more accurately led to the development of a new algorithm for extracting useful process monitoring information.

In the SlurryScope standard operating mode, the instrument extracts information on large particles from the background scattering of the vast majority of submicron particles. In SlurryScope high density mode, all sensor data is analyzed with equal weighting instead of looking for signatures of individual large particles within a strong background. This is reported as a tracking parameter over time, or as an event count vs. normalized intensity (Fig. 2). This new methodology has demonstrated high sensitivity to changes in slurry properties comparable to the standard mode, but without being subject to data roll-off.

With the new algorithm, changes in slurry properties are monitored without relying on the identification of individual large particles. The concept of minimum particle size resolution is not applicable, as it is in a conventional particle sizing analysis tool.

Field testing is underway to fully characterize the behavior of this high density measurement mode with improved range capability. Sensitivity to subtle shifts in particle count and size distribution remains high. Data fingerprints for slurry transitions related to operational events in the subfab are being compared to results as they appear in standard mode.

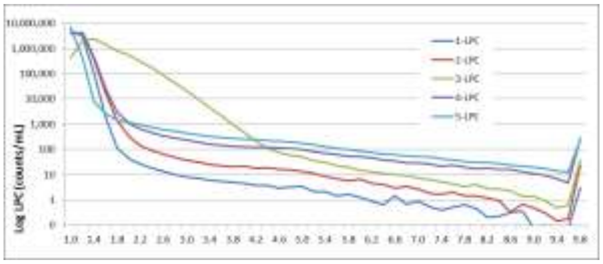

Fig. 1. LPC data roll-off in optically dense ceria slurry in SlurryScope standard mode.

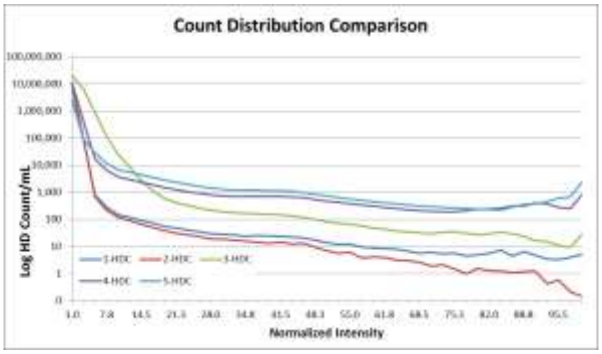

Fig. 2. Well-behaved data for optically dense ceria slurry in SlurryScope high density mode.

III. Sampling Line Data Loss

In addition to demonstrating sensitivity to physical and chemical changes in the slurry, SlurryScope implementation in manufacturing environments has shown a remarkable sensitivity to the length and orientation of the input lines that deliver slurry to the sensor unit. Excessive line length can result in loss of data integrity, potentially rendering subtle slurry changes undetectable.

Slurry manufacturers specify a minimum linear flow rate required to ensure that the particles remain uniformly suspended, and that the particle size distribution being delivered to the polisher is equivalent to the particle size distribution being dispensed at the source. Meanwhile, fluid flow through the SlurryScope is set at 15 ml/min in order to calibrate particle size. This set point falls below the slurry manufacturers' recommended minimum flow rate, which is typically in the range of 1.0±0.3 linear meters per second. This translates to a flow rate in the range of 475 ml/min in a ¼" diameter tube, or 206 ml/min in a 1/8" diameter tube. At the much lower controlled flow of 15 ml/min, the opportunity for particle settling and event mixing by diffusion is significant.

In the Vantage Technology laboratory, we constructed a recirculation loop that included a SlurryScope process monitor operating in standard mode and a particle injection port. An injection technique was chosen to provide a repeatable particle event profile, in terms of both peak particle count and profile shape. The length and orientation of the tubing between the injection port and the SlurryScope was varied to characterize the effects of tube diameter, length, and orientation on the resulting particle event profile as observed at the detector.

The test loop is illustrated in Fig. 3. For data clarity, DI water was pumped through the system. A stirred mixture of 13nm Alon-C fumed alumina particles [4] in water was injected for each experiment to capture the peak particle count and the particle count decay as a function of line length and line orientation. Repeatability of the 5 ml injection methodology was verified prior to continuing with the experimental matrix. Each data point was replicated 3 times and the average response times are reported here.

A typical particle decay signature is shown in Fig. 4, which also illustrates the rise time and decay time used to report the results of each line configuration change. The upper portion of Fig. 4 shows the output of the SlurryScope flow controller. The flow perturbation due to the particle injection is clearly visible, with a rapid recovery to the target flow rate of 15 ml/min. The different lines in the lower particle count decay curve represent different particle size bins, with smaller particles having the higher counts.

The effect of tubing diameter is shown in Fig. 5. The dramatic loss of peak particle count and the elongation of the particle excursion event represent an extreme case of how a less-than-optimum facilities installation can distort the detection and interpretation of particle events taking place in the slurry distribution system (SDS) loop or in the polisher itself at point of use (POU). While the small particle signal loss is ~50%, the large particle loss is over 80%. This is a direct consequence of the inadequate flow rate in the larger diameter tube to keep the particles suspended in the flow. The additional fluid volume in the larger diameter tube also tends to dilute the particle excursion event over time, diminishing the ability to recognize details of the profile of a specific type of event.

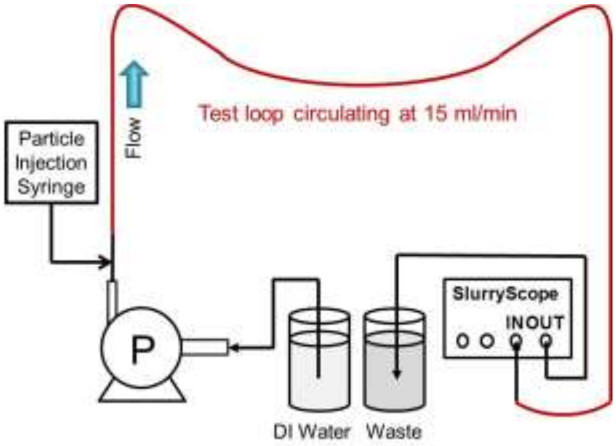

Fig. 3. Experimental test loop for characterizing information loss as a function of slurry line length and orientation.

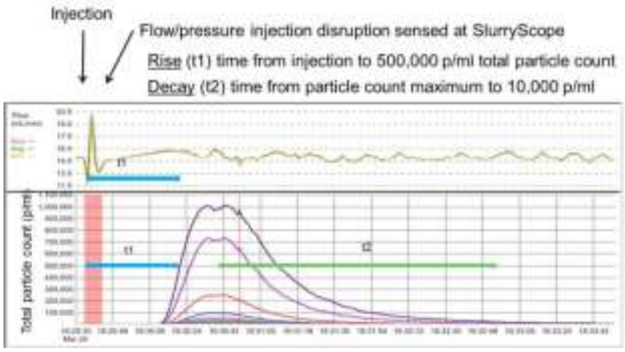

Fig. 4. Typical particle event decay behavior. Rise time is defined as the time from particle injection to a count of 0.5M particles per milliliter. Decay time starts at the particle count peak and continues to a level of 10k particles per milliliter.

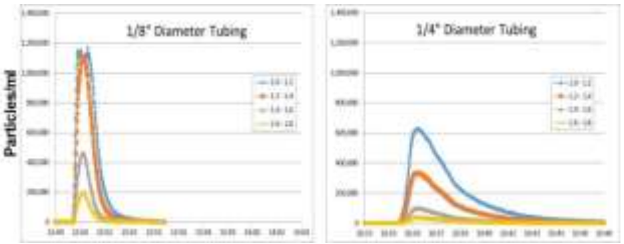

Fig. 5. Effect of tubing diameter. 1/8" diameter tubing: rise: 00:47; decay: 02:30. 1/4" diameter tubing: rise: 04:52; decay: 11:20. Loss of peak intensity is 50% to 80%, worse for larger particles.

The selection of tubing diameter for connecting an SDS feed or a polisher POU tap is independent of facilities location constraints. These results show that the use of ¼” tubing will never provide optimum data interpretation, and is not recommended for fab or subfab installations. Facilities already using ¼” tubing are advised to switch to 1/8” tubing at the earliest opportunity. Subsequent testing in this study was conducted using 1/8” tubing.

Sampling line length, on the other hand, is frequently subject to facilities constraints, and must be managed carefully if short runs cannot be implemented. The effect of tubing length is shown in Fig. 6. While the information loss is not as severe as with the ¼” tubing, the degradation is still apparent. Specific event signatures associated with filter changes and tank changes will be obscured and may become unrecognizable. Particle spikes due to spurious non-repeating events in the line will be attenuated and smeared out over time. In the extreme case, these events may pass without notice. This is a lost opportunity for identifying and eliminating the root cause of such random events, which are typically the unintended consequences of various routine operations in and around the CMP operation.

The high sensitivity of the SlurryScope to changes in particle characteristics extends to the orientation of the slurry delivery line. If a long run is required to connect the SlurryScope to its source, care should be taken to keep the run as horizontal as possible, minimizing vertical runs both up and down. The orientation test line used in this study is pictured in Fig. 7. In the upright block, there is a uniform rise of the slurry from entry to exit. The horizontal block is the same piece laid on its side, which introduces a number of short vertical transitions both up and down. The impact of orientation is shown in Fig. 8. While less severe than the effects of diameter and length for small particles, the data loss for larger particles is just as bad. This has strong implications for process monitoring of large particles typically associated with wafer defects.

IV. Conclusions and Recommendations

Solutions have been presented here for two operational issues that have been discovered in various fab installations of the SlurryScope process monitor. While standard LPC measurement mode provides robust tracking of slurry behavior for silica-based slurries and many ceria slurries, the high density mode can be applied to those ceria slurries whose background scattering intensity results in data roll-off at small particle sizes. Also, the length and orientation of the 1/8” tubing that brings the slurry stream to the sensor must be kept as short as possible with as little vertical travel as possible in order to be able to minimize slurry particle settling, and to reliably identify every particle excursion event. This condition will also improve sensitivity to subtle particle shifts associated with lot and tank changes, as well as with subsequent wafer defects.

Fig. 6. Effect of 1/8” tubing length. 5 meter run: rise: 00:47; decay: 02:30. 15 meter run: rise: 02:20; decay: 03:22. Loss of peak intensity is 10% to 50%, worse for larger particles.

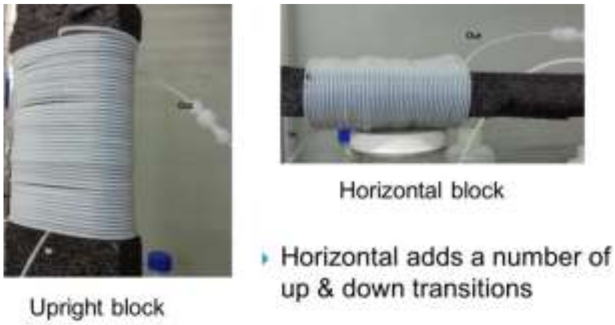

Fig. 7. Line configuration used to illustrate the effects of tubing orientation.

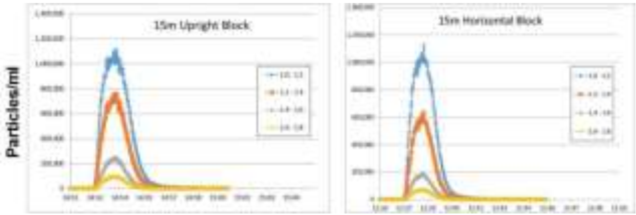

Fig. 8. Effect of 1/8” tubing orientation. 15m upright block: rise: 02:20; decay: 03:22. 15m horizontal block: rise: 02:12; decay: 03:57. Loss of peak intensity is 5% to 50%, worse for larger particles.

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