Precision Flow Control and Enhanced Filter Lifetime in Magnetically Levitated Pump Based CMP Slurry Delivery Systems

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SUMMARY AND CONCLUSIONS

Chemical Mechanical Planarization (CMP) must continuously improve to meet the stringent requirements of next generation IC device manufacturing. Precision flow control of CMP slurry is critical to achieving a repeatable planarization process, minimizing slurry waste, and reducing cost-of-ownership (CoO). Monitoring and controlling slurry large particle concentration through filtration is also essential in maintaining slurry health during its lifecycle. This study reports data of slurry handling, filtration, and flow control using magnetically levitated centrifugal (MLC) pumps and air-operated double diaphragm (AOD) pumps. Results are presented for a point-of-use (POU) slurry delivery system feeding from a simulated global distribution loop.

Tests were performed using ~12.5 (Silica-I) and ~25 (Silica-II) weight percentage of solids silica abrasive oxide CMP slurries. Extensive handling tests of shear-sensitive silica slurries using an AOD pump generated significant number of large particle agglomerates. In similar tests, an MLC pump generated fewer large particles than an AOD pump for comparable turnovers. A filter of nominal rating 1.0 micron was used in the global loop for these tests. In comparison to similar AOD pumps, slurry recirculation tests using an MLC pump in five-hour recirculation tests (with one-micron pleated-depth-filter in the loop), show a much smaller increase in filter pressure-drop and minimal slurry loop pressure pulsation with time. This would suggest significantly enhanced filter lifetime for the MLC pump based slurry delivery systems handling shear sensitive silica slurries, as compared with the AOD pump systems.

Evaluation of a closed-loop flow-control system employing a pre-pressure regulator, an MLC pump, and a differential pressure based electronic flowmeter in the slip stream demonstrated good functionality and dispense flow consistency, and resulted in repeatable short-term and extended-period slurry dispense cycles over the tested flow range of 50 mL/min to 490 mL/min. This approach will provide significant benefits in advanced CMP processes by eliminating inconsistent slurry flow and particle contamination from peristaltic pump tubing, enhancing filter lifetime, increasing device yield, reducing the possibility of catastrophic failure, and minimizing downtime and labor costs due to frequent pump maintenance and replacement.

1. INTRODUCTION

The repeatability and uniformity in CMP processing depends upon the consistency of slurry quality, the integrity and cleanliness of slurry delivery system and the polishing tool set, and efficient and consistent dispense of slurry at the CMP tool. Large particles in slurry can be managed by using optimum filtration in the global loop and point-of-use (POU). The efforts should focus on not creating large particles during slurry distribution and selectively removing them employing filtration if they are created due to less than optimum slurry handling. Recent studies reveal a 10-15 % reduction in CMP slurry consumption with more accurate dispense flow control, without any adverse impact on the removal rate and device yield. It is important to understand the comparative handling characteristics of new pumping technologies to identify the most efficient approaches, which meet the increasingly stringent flow consistency and accuracy requirements of slurry global loop distribution and POU dispense, lower defectivity, higher yield and reduced CoO.

CMP process establishes the requirements for liquid flow control in Semi Industry due to both historic and technical reasons. It provided first technical target for the liquid flow control optimization. CMP slurries are most challenging due to their sub-micron abrasive content, quick settling and/or agglomeration behavior, and have a potential of blocking the flow sensor (e.g., due to slurry abrasive coating). Typical CMP slurry filter flow resistance increases over its lifetime, resulting in a drop in the slurry flow rate. The main objective of this study was to determine POU slurry dispense flow consistency of a closed-loop flow-control system employing a pre-pressure regulator, an MLC pump and a differential pressure flowmeter. The other objective was to perform silica slurry handling and filtration tests using a diaphragm and an MLC pump to determine if the MLC pump generates fewer large particles and results in slurry filter lifetime enhancement.

2. POU DISPENSE FLOW CONTROL

Conventional POU dispense systems use peristaltic pump for slurry dispense to CMP tool. These systems may have particle contamination from pump tubing, risk of catastrophic failure, frequent pump maintenance and reduced uptime, flow variations with feed pressure changes and time (and even at constant pressure), slow response and slurry loss. New generation POU dispense systems use an MLC pump in a dynamic feedback closed-loop flow-control system employing a pressure regulator and flowmeter for consistent slurry dispense to the CMP tool. Another approach is to use a Liquid Flow Controller (LFC) consisting of an integrated flow control valve and flowmeter system. LFCs may have limitations in usage with relatively low pressure global loop distribution applications, requiring slurry filtration at the POU.

The closed-loop POU flow control system installed on a slip stream from the global loop (slurry recirculated using Levitronix® BPS-3 MLC pump) employs a pre-pressure regulator, a bearing-less pump system with controller and PLC software, and a differential pressure flowmeter. The sensor signal of the flowmeter (Entegris® NT®4400) is fed to the pump controller of a small MLC pump (Levitronix BPS-1) in the slip stream. The closed-loop flow controller runs on the pump controller itself. The pre-pressure regulator is used to ramp down the fluid inlet pressure to the slip stream consisting of BPS-1, POU filter and NT4400 flowmeter.

The pre-pressure regulator also dampens the pressure fluctuations coming from the global distribution loop line. BPS-1 pump speed and the pre-pressure are set, so that the actual flow (signal coming from the flowmeter) corresponds to the set-point flow signal. This intelligent POU slurry dispense system provides a flow alarm, whenever actual and set-point flow rate values don't correspond. Thus, low flow conditions are detected, for example caused by line clogging. In addition, a trend warning is provided, which enables failure prediction and scheduling of the preventive maintenance. This so-called Dynamic Condition Trending (DCT) feature is designed specifically for the Levitronix MLC pump system controller, operating on pump speed information.

3. FLOWMETER TECHNOLOGIES

Common liquid flowmeter technologies include:

(i) Rotometer or paddlewheel – Have potential of catastrophic clogging and inaccuracies due to slurry particles getting into miniature bearing, making it undesirable for CMP slurry. Most units in CMP slurry applications have been replaced.

(ii) Differential pressure – Well designed orifice configurations effectively suppress any slurry agglomerate clogging potential in shear sensitive slurries. These units are not significantly affected by micro-bubbles and may need fluid calibration. Differential pressure based units have been extensively used in fab slurry handling and delivery systems.

(iii) Ultrasonic – Slurry particle and bubbles may scatter ultrasonic waves and add large noise to signal. Intelligent digital signal processing may account for multiphase flow. These units are based on the time-of-flight or Doppler principle.

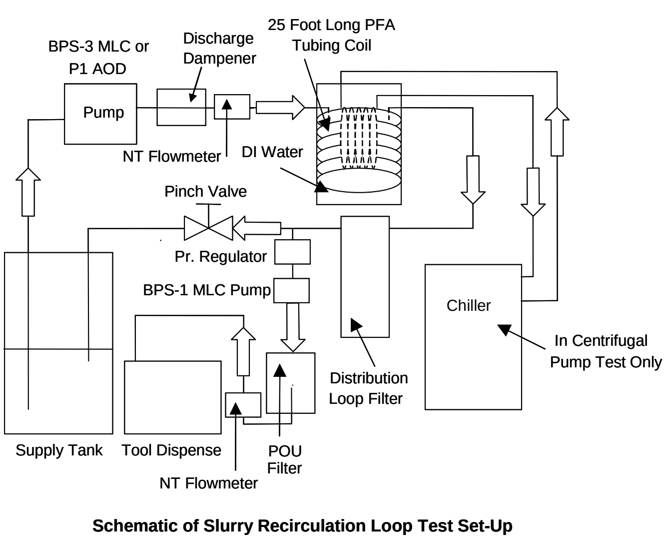
(iv) Coriolis – Measures mass instead of volume and hence it is immune to fluid variations. May be sensitive to bubbles.

(v) Vortex-shedding – Bluff body can be a site for slurry agglomeration. May have limitations in measuring low flow rates due to a minimum flow velocity requirement (or Reynolds number ~10,000), essential for linear vortex shedding to occur.

(vi) Magnetic – Measured fluid must have a conductivity of at least 2 μS/cm (or rather 5 μS/cm for reliable operation).

4. EXPERIMENTAL SETUP AND PROCEDURE

This study focused on slurry handling, filtration, and flow control tests using MLC pumps (Levitronix BPS-3 and BPS-1), an AOD pump (Wilden AOD-P1 in the global loop), differential pressure flowmeter (NT4400), a pre-pressure regulator and closed-loop flow-control software developed for Levitronix pumps. The slurry was recirculated in a closed-loop and provided an option for slip stream flow measurement (see Schematic of test set-up). Slurry samples were collected from supply tank and analyzed at different time points. LPC measurements were made using PSS AccuSizer™ 780 APS.



Schematic of Slurry Recirculation Loop Test Set-Up

The cumulative numbers of particles size $\geq$ 0.56 micron were measured to monitor the LPC increases in the slurry samples. The temperature of the slurry was maintained within 3 °C of the ambient value using a chiller and auxiliary tank with DI water for the MLC pump tests. There were no metallic wetted parts in the flow path of the CMP slurry.

Tests were performed using ~12.5 and ~25 weight % solids silica CMP slurries (Silica-I and Silica-II, respectively). The slurry flow rate was measured using NT® electronic flowmeters in the global distributor loop and at the POU locations. The recirculation loop slurry flow rate was ~ 5.3 Lpm at a global loop pressure of ~31 psi (for Silica-I) and ~ 4.5 Lpm at a global loop pressure of ~32 psi (for Silica-II).

5. RESULTS AND DISCUSSION

To quantify the effects of pump handling on shear sensitive silica slurries a series of closed-loop slurry recirculation tests were performed. Selected results of four tests from these experiments will be presented here for brevity. Test conditions of these test were: **Test 1a -** Silica-I recirculated for a total of 230 turnovers (TOs) using an MLC pump at 7600 rpm, ~46 turnovers (TOs)/hour, 5.3 Lpm flow rate and ~31 psi backpressure (Pb). **Test 1b** - Silica-I recirculated for 230 TOs using AOD pump at ~46 TOs/hour, 5.3 Lpm, and ~32 psi Pb. **Test 2a -** Silica-II recirculated for 170 TOs using MLC pump at 7600 rpm, ~34 TOs/hour, 4.6 Lpm, and ~32 psi Pb. **Test 2b -** Silica-II recirculated for 170 TOs using an AOD pump at ~34 TOs/hour, 4.4 Lpm, and ~34 psi Pb. The above four tests were performed for 5 hours each and employed an Entegris Planarcap® LPX 1.0 filter in the global loop.

Figure 1 shows the LPC data in 4 selected particle size range bins of 0.56-0.60, 0.60-0.69, 0.69-1.01, and 1.01-4.96 microns for the slurry samples from MLC pump Test 1a. The source slurry LPC data at zero turnovers are also included in this figure. **Figure 2** presents data from a similar test using AOD pump. It can be seen that an MLC pump generated negligible and AOD pump generated significant number of large particle agglomerates in these tests for comparable turnovers. **Figures 3 and 4** show complete cumulative LPC data for Tests 1a and 1b. **Figure 5** for the MLC pump test illustrates a much smaller increase in pressure-drop through the filter, consistent flow rate, and negligible loop pressure pulsation in Test 1a (with an 1-micron filter in the line), as compared with the AOD pump Test 1b (see **Figure 6**).

In the MLC pump test with LPX 1.0 filter (for Silica-II), the initial slurry flow rate through the filter was ~4.6 LPM with a pressure drop of ~10 psi, whereas after 5 hours continuous recirculation test (~170 slurry turnovers) these values were ~4.2 Lpm and 12.5 psi, respectively. In a comparable AOD pump test, initial flow through the LPX 1.0 filter was ~4.4 Lpm (pulsating significantly) with a pressure drop of ~16 psi, whereas after 5 hours continuous run these values were ~2.6 Lpm and 28 psi, respectively (see **Figures 7 and 8**). The final samples of the recirculated Silica-II slurry from Test 2a and Test 2b were filtered in single pass mode using a 0.5 micron graded density depth filter and the pressure drop results are included in **Figure 9**. These results illustrate a rapid pressure drop increase in case of the AOD pump recirculated slurry sample and have similarity with the behavior seen with 1.0 micron filter in **Figures 7 and 8**.

The above results show the benefits of an MLC pump in handling shear-sensitive CMP slurries in single-pass applications and under normal turnovers (~100) expected in a typical fab operation. Since, the MLC pump generated far fewer >1 micron particles, the filter lifetime for this pump-based slurry delivery systems should be much longer than other AOD (or bellows pump with similar handling characteristics) based systems, when relatively open (≥ 1 micron nominal rating) filters are used in the global loop and POU locations.

Evaluation of a closed-loop flow-control system employing a pre-pressure regulator, an MLC pump, POU filter and a differential pressure flowmeter in the slip stream demonstrated good functionality and dispense flow consistency. Dispense flow repeatability data were obtained using Silica-I slurry with BPS-3 pump and NT4400 flowmeter in the global loop. Actual dispense flow rate was measured at operating set-point conditions of 50, 100, 300, 400, 450, and 490 mL/min (i.e., 10, 20, 60, 80, 90, and 98 % of the full flow range for the slip stream flowmeter NT4400). This system provided repeatable short-term and extended-period slurry dispense cycles over the tested flow range of 50 mL/min to 490 mL/min. In general, the repeatability of the slurry dispense flow rate was ~ ± 2 % of the reading for above 20 % to the full flow range of the flowmeter (i.e., > 100 mL/min to 500 mL/min), see **Figures 10-12**.

Testing was conducted at recirculation loop pressures of 5, 15, and 30 psi and the slip stream dispense flow was found to be unaffected (beyond experimental uncertainty) by the changes in the global loop pressure. The slip stream flow was simulated with air bubbles and differential pressure NT4400 flowmeter was found to be least affected by the bubbles presence as compared to an ultrasonic flowmeter. The tested subsystem provides continuous and smooth (without pulsation) flow, independent from the pressure in the slurry global loop. The approach is very advantageous in applications with limited pressure budget due to lower loop pressures and can be used for advanced process control.

This POU CMP slurry dispense system can replace fab peristaltic pump systems and help in obtaining complete useful lifetime of the filter. Due to its precise closed-loop flow control, this method should result in potential CMP slurry consumption saving from reduced slurry flow rate setting, lower cost of ownership, minimal maintenance, and high control resolution with extended flow range. This should also provide significant benefits by eliminating flow rate drifts over time and particle contamination from peristaltic pump tubing, enhancing filter lifetime, reducing the possibility of catastrophic failure, and minimizing system downtime and recurring costs due to frequent pump maintenance.

ACKNOWLEDGMENTS

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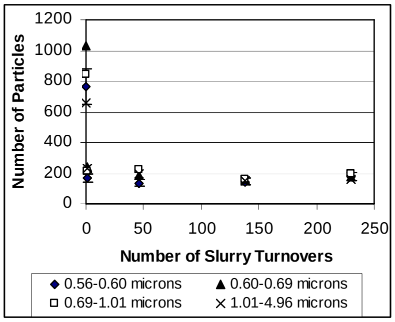

Figure 1. LPC for Silica-I in MLC pump at 7,600 rpm, ~46 TOs/hour, 5.3 Lpm, ~31 psi Pb, and with 1-μm filter. Test 1a.

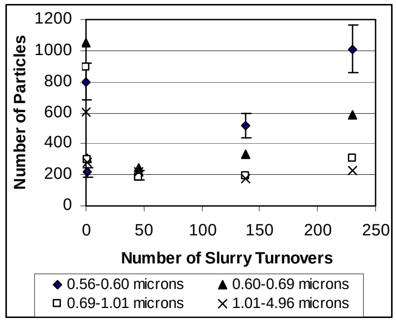

Figure 2. LPC for Silica-I in AOD pump test at ~46 turnovers/hour, ~5.3 Lpm, ~32 psi Pb, and with 1-μm filter. Test 1b.

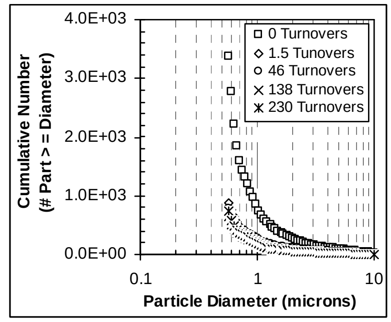

Figure 3. LPC for Silica-I in MLC pump at 7,600 rpm, ~46 TOs/hour, 5.3 Lpm, ~31 Pb, and with 1-μm filter. Test 1a.

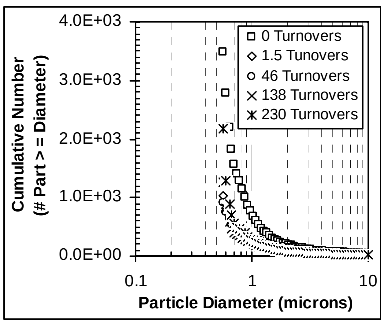

Figure 4. LPC for Silica-I handling in AOD pump at ~46 TOs/hour, 5.3 Lpm, ~32 Pb, and with 1-μm filter. Test 1b.

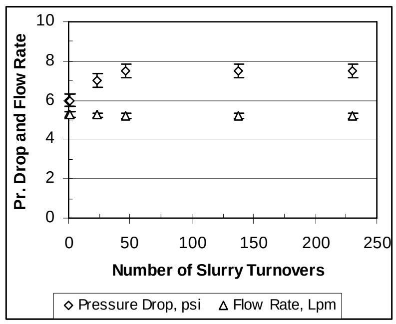

Figure 5. Filter pr. drop and flow rate for Silica-I in MLC pump at 7,600 rpm, ~46 TOs/hour, 5.3 Lpm, ~31 psi Pb. Test 1a.

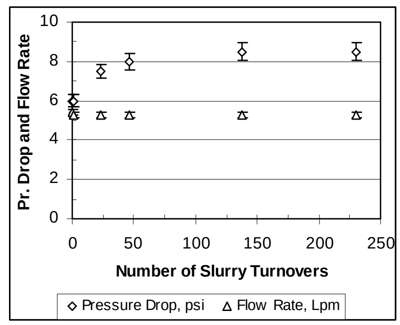

Figure 6. Filter pr. drop and flow rate for Silica-I in AOD pump at ~46 TOs/hour, 5.3 Lpm, ~32 psi Pb. Test 1b.

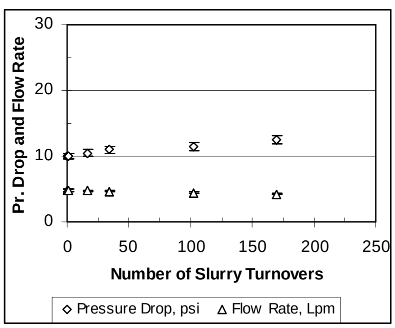

Figure 7. Filter pr. drop and flow rate for Silica-II in MLC pump at 7,600 rpm, ~34 TOs/hour, 4.6 Lpm, ~32 psi Pb, Test 2a.

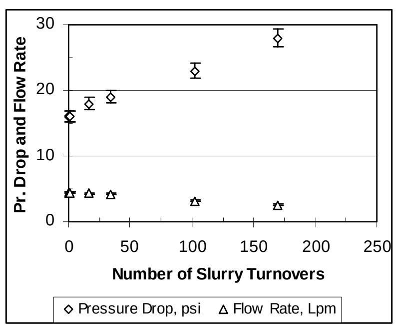

Figure 8. Filter pr. drop and flow rate for Silica-II in AOD pump at ~34 TOs/hour, ~4.4 Lpm, ~34 psi Pb. Test 2b.

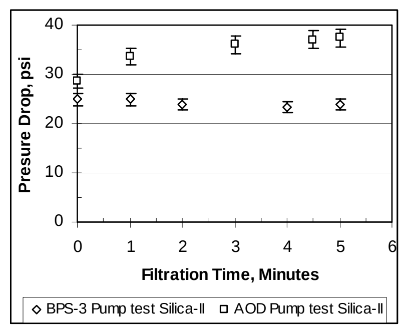

Figure 9. 0.5 micron filter pr. drop for Silica-II from MLC pump (Test 2a) and AOD pump (Test 2b) recirculated slurry.

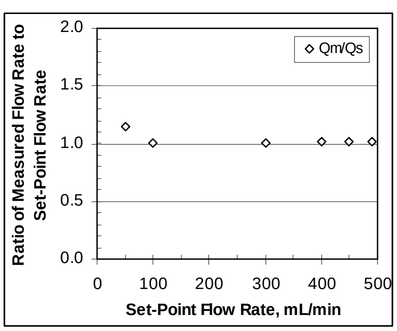

Figure 10. Measured POU dispense flow rate and set-point flow rate data for Silica-I in MLC pump at 7,600 rpm. Test 1a.

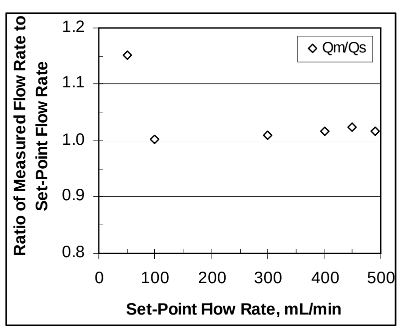

Figure 11. Measured POU dispense flow rate and set-point flow rate for Silica-I in MLC pump (magnified Y axis). Test 1a.

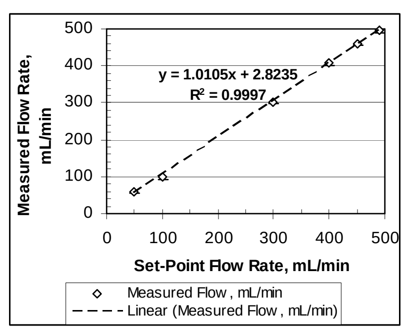

Figure 12. Measured POU dispense flow vs. set-point flow data for Silica-I in MLC pump at 7,600 rpm and ~46 TOs/hour. Test 1a.