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## Efficient Flow Control and Filtration in CMP Slurry Distribution

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# Overview

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- **CMP Slurry Point-of-Use (POU) Dispense**
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- **Experimental Data**
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  - **Filter Pressure Drop and Flow Rate**
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# Motivation

## CMP process and consumables must improve for future IC devices

- Smaller feature devices require more uniform and efficient global and local wafer planarization, lower defectivity, higher yield and reduced cost-of-ownership (CoO)
- Tighter specifications for slurry health control - mean and large abrasive particle management, real-time slurry blend quality monitoring, more use of POU filtration and demand of extended and consistent lifetime for filters
- Increasingly stringent flow consistency and accuracy requirements of slurry global loop distribution and point-of-use (POU) dispense
- Need to understand comparative CMP slurry handling characteristics of new pumping technologies to identify most efficient approaches for slurry delivery
- Recent studies reveal 10-15 % reduction in CMP slurry consumption with more accurate dispense flow control, without any adverse impact on the removal rate and device yield

# Objectives

- **Determine POU slurry dispense flow consistency**

evaluate performance of a dynamic closed-loop flow-control system employing a pre-pressure regulator, MLC (magnetically-levitated-centrifugal) pump and a differential pressure flowmeter

- **Explore slurry filter lifetime enhancement possibility**

perform silica slurry handling and filtration tests using MLC and AOD (air-operated-diaphragm) pumps to determine if MLC pump generates fewer large particles and results in filter lifetime increase

# CMP Slurry Point-of-Use (POU) Dispense

- **Conventional POU dispense** - Peristaltic pump system for slurry dispense to the CMP tool
  - particle contamination from pump tubing, risk of catastrophic failure,
  - pump frequent maintenance, reduced uptime and lower yield,
  - flow variations with feed pressure and time, even at constant pressure,
  - slow response and slurry loss
- **New generation POU dispense** – (1) MLC pump closed-loop flow-control system using pressure regulator and flowmeter - provides consistent slurry dispense, and (2) Liquid Flow Controller (LFC) employing an integrated valve and a flowmeter

# Slurry Flow Control: Challenges and Opportunities

- Single wafer aqueous processing needs greater control over critical liquid flow subsystems within the tool.
- CMP and electrochemical plating (ECP) create fundamental circuit elements
  - These mandates precise control of liquid flows within the process tools  
*(SST, Jan. 2006, Ed Korczynski).*
- CMP processes establish the requirements for liquid flow control in Semi Industry (both historic and technically)
  - It provided first technical target for flowmeter and flow-control suppliers to achieve.
  - CMP slurries are most challenging due to their sub-micron abrasive content , quick settling and/or agglomeration behavior, and potential of blocking the flow sensor (e.g., due to slurry abrasive coating).
- If a flow control system is able to successfully handle shear sensitive CMP slurries over extended periods of time, it would almost handle any other fluid

# Liquid Flowmeter Technologies

**Rotometer or paddlewheel** - has potential of catastrophic clogging and inaccuracies due to slurry particles getting into miniature bearing of the unit, making it undesirable for CMP slurry related applications, most units have been replaced

**Differential pressure** – well designed orifice configurations effectively suppress any slurry agglomerate clogging, not affected by micro-bubbles, may need fluid calibration, stable operation in many CMP slurry handling and delivery systems

**Ultrasonic** – slurry particle and bubbles scatter ultrasonic waves in some applications and add large noise to the signal, intelligent digital signal processing may account for multiphase flow, may be based on time-of-flight or Doppler principle

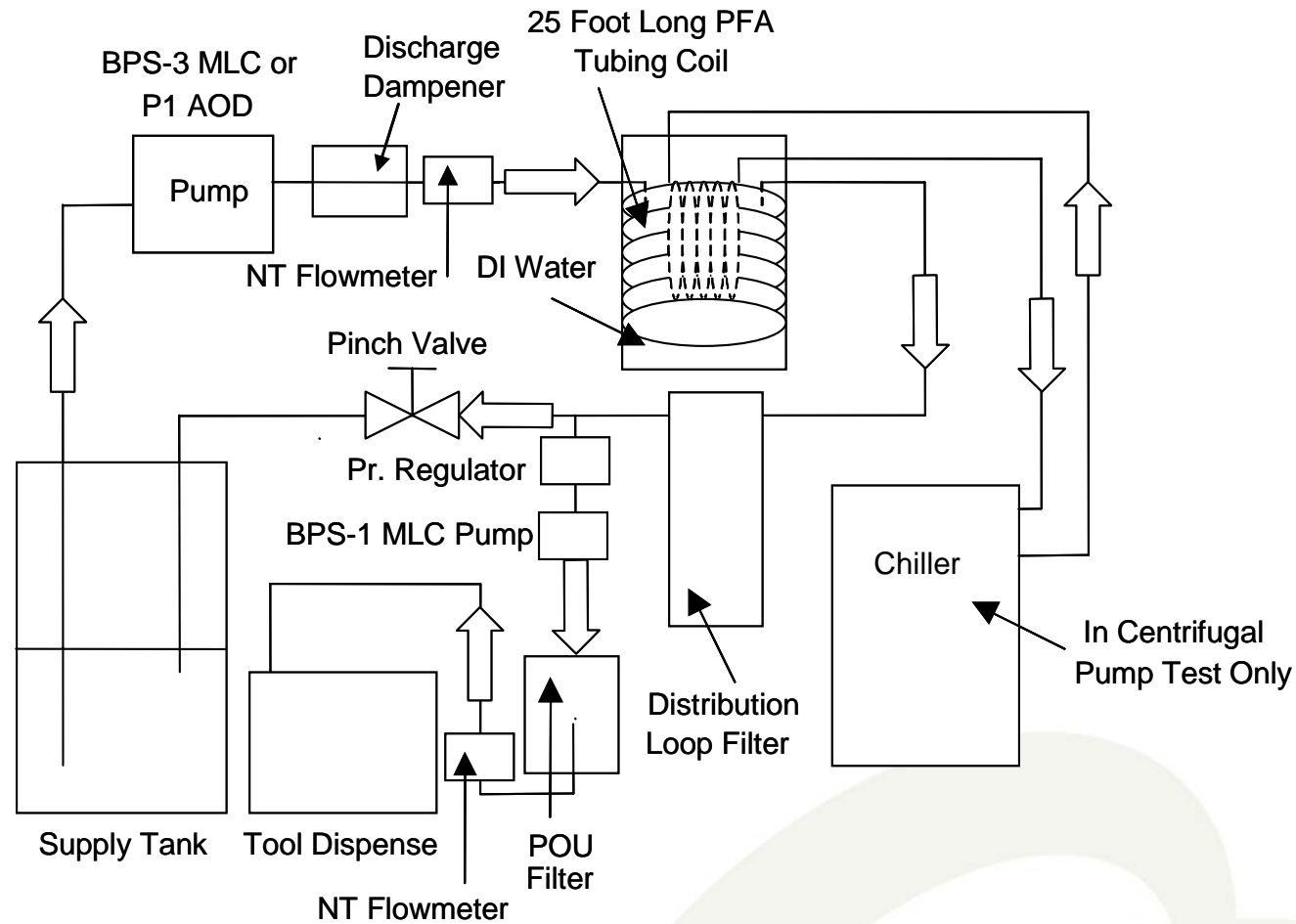
**Coriolis** – measures mass instead of volume and hence it is immune to fluid variations, may have sensitive to bubbles

**Vortex-shedding** – the bluff body can be a site for CMP slurry abrasive agglomeration, have limitations in measuring low flow rates due to requirement of minimum flow velocity (or Reynolds number ~10000) essential for linear vortex shedding

**Magnetic** – fluid to be measured must have a conductivity of at least 2  $\mu\text{S}/\text{cm}$  (or rather 5  $\mu\text{S}/\text{cm}$  for reliable operation)

[References: SST, Jan. 2006, Ed Korczynski; Flow Control, Sept. 2001, Richard Furness, pp. 46-54; Flow Measurement Engineering Handbook, 3rd Ed., Richard W. Miller, McGraw Hill, 1996, pp. 6.1-6.54]

# Equipment



**Schematic of Slurry Recirculation Loop Test Set-Up**

# Pump Handling and Filtration Test Cases

- A series of closed-loop slurry recirculation tests were performed. Large particle counts (LPC) were measured using PSS AccuSizer 780 APS system.
- Selected results of four tests from above experiments will be presented here. Test conditions were:
  - Test 1a - Silica-I (12.5 wt % solids) 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 (25 wt % solids) 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.

# Test 1: Silica-I Slurry Pump Handling and Filtration Data

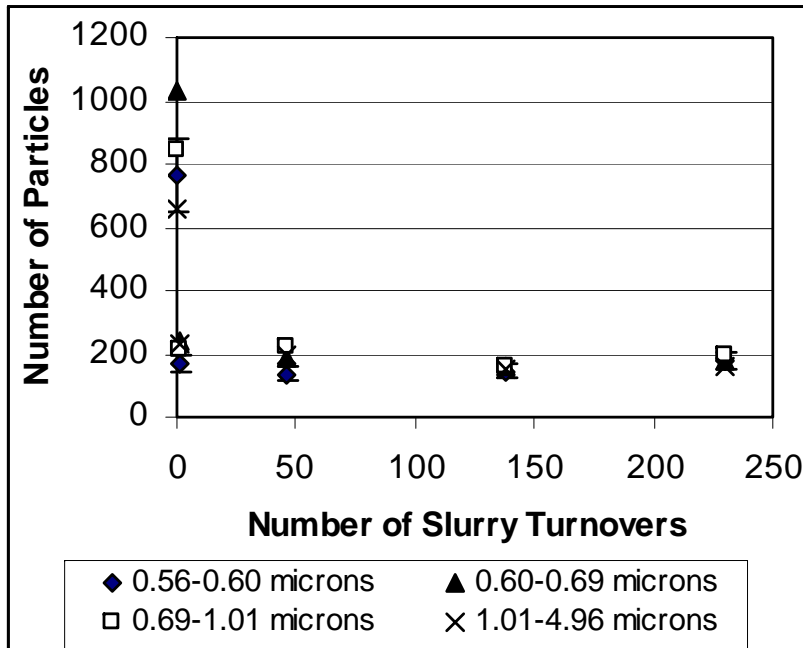


Figure 1. LPC variation in various size bins for Silica-I (~12.5 wt % solids) slurry recirculation in MLC pump (Levitronix BPS-3) at 7,600 rpm, ~46 turnovers/hour and 5.3 Lpm, (backpressure ~31 psi). Slurry recirculated with 1 micron rating Entegris Planarcap® LPX 1.0 filter. Test 1a.

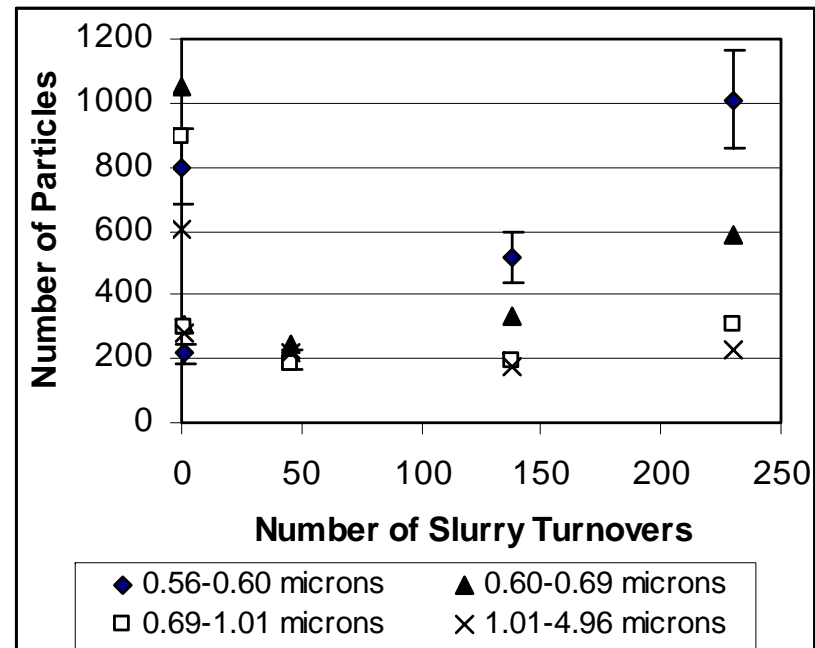


Figure 2. LPC variation in different size bins for Silica-I slurry recirculation in air-operated double diaphragm (AOD) pump (Wilden P1) at ~46 turnovers/hour and ~5.3 Lpm (backpressure ~32 psi). Slurry recirculated with 1 micron nominal rating Entegris Planarcap® LPX 1.0 filter. Test 1b.

# Test 1: Silica-I Slurry Handling and Filtration LPC Data

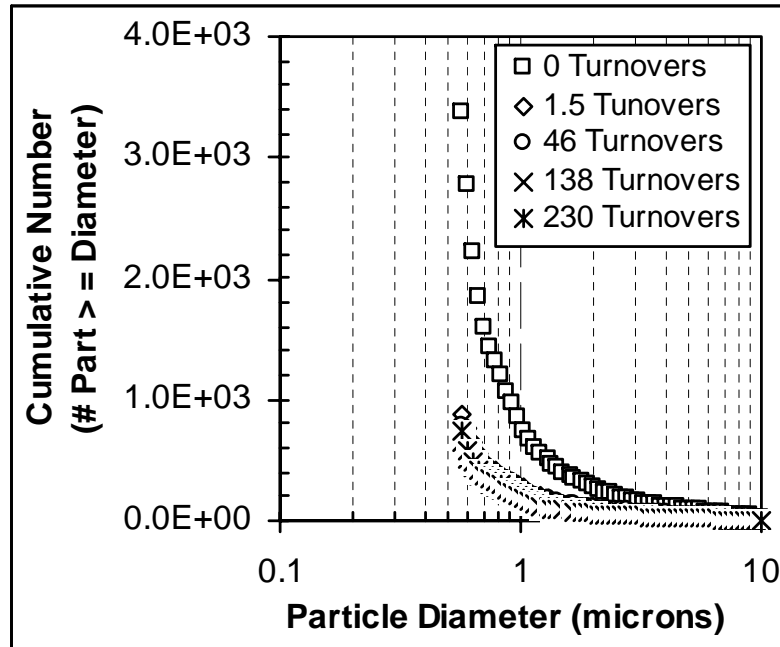


Figure 3. LPC data for Silica-I slurry handling in MLC pump at 7,600 rpm, ~46 turnovers/hour and 5.3 Lpm (backpressure ~31 psi). Slurry recirculated with 1 micron rating Entegris Planarcap® LPX 1.0. Test 1a.

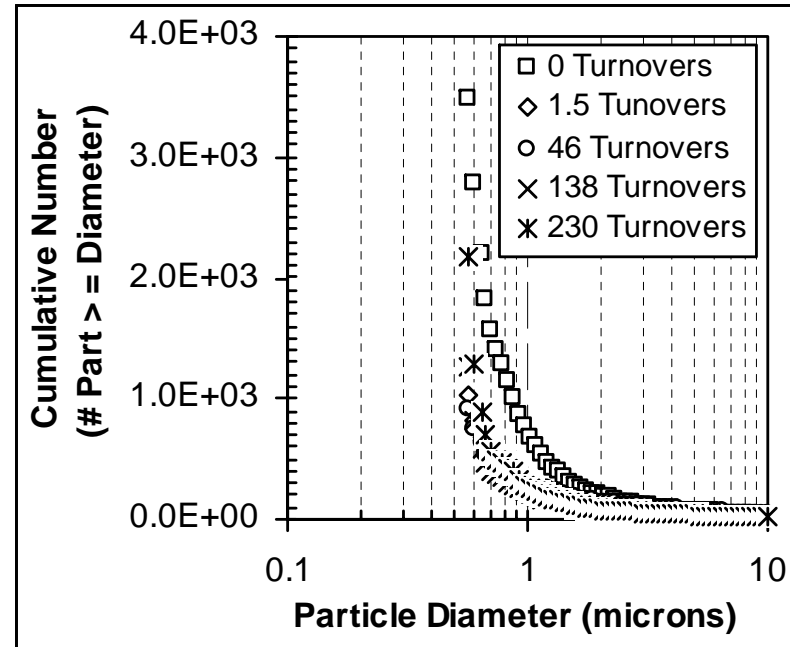


Figure 4. LPC data for Silica-I slurry recirculation in AOD pump at ~46 turnovers/hour and ~5.3 Lpm (backpressure ~32 psi). Slurry recirculated with 1 micron rating Entegris Planarcap® LPX 1.0. Test 1b.

# Test 1: Silica-I Slurry Filter Pressure-Drop and Flow Data

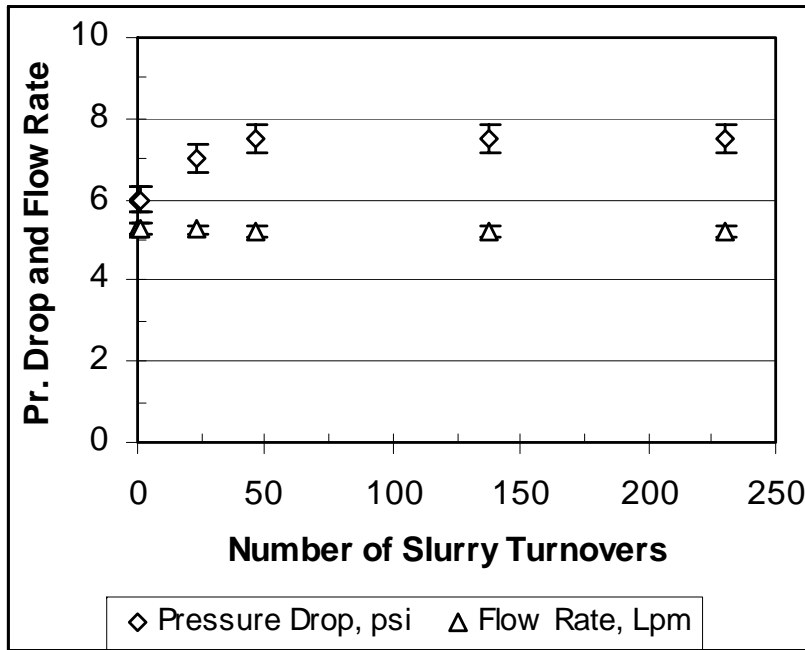


Figure 5. Filter pressure drop and flow rate data for Silica-I slurry handling in MLC pump at 7,600 rpm, ~46 turnovers/hour and 5.3 Lpm (backpressure ~31 psi). Slurry recirculated with 1 micron rating Entegris Planarcap® LPX 1.0. Test 1a.

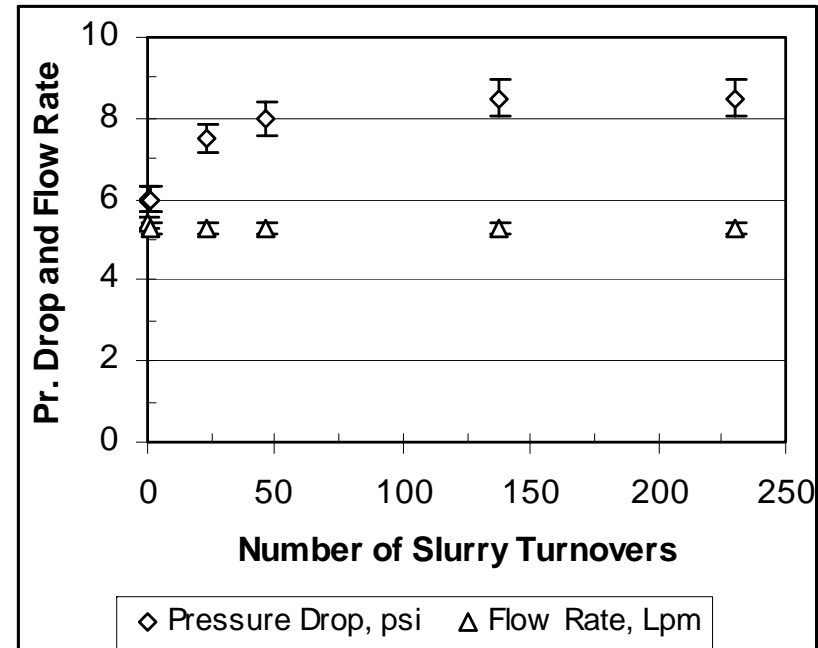


Figure 6. Filter pressure drop and flow rate data for Silica-I slurry handling in AOD pump at ~46 turnovers/hour and ~5.3 Lpm (backpressure ~32 psi). Slurry recirculated with 1 micron rating Entegris Planarcap® LPX 1.0. Test 1b.

# Test 2: Silica-II Slurry Filter Pressure-Drop and Flow rate Data with 1 Micron Nominal Rating Filter in the Loop

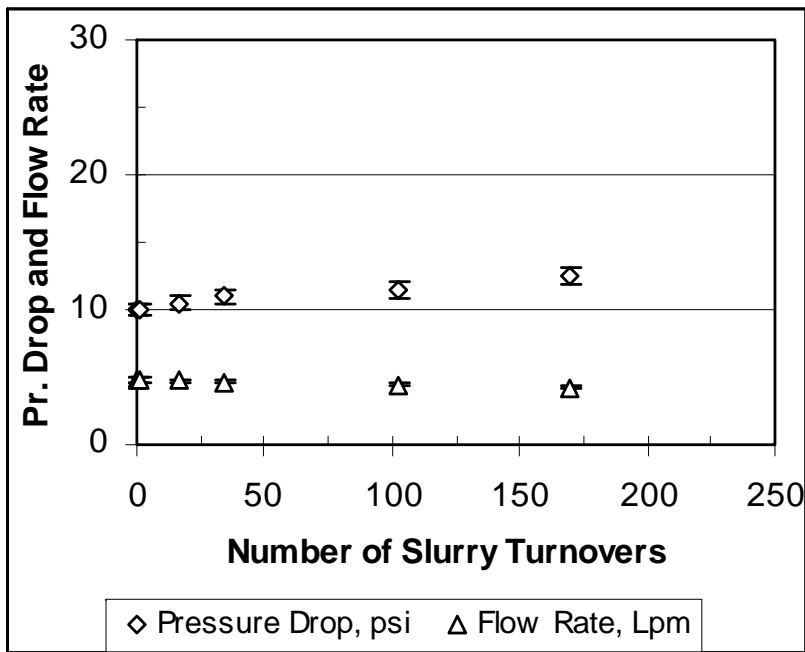


Figure 7. Filter pressure drop and flow rate data for Silica-II (~25 wt % solids) slurry handling in MLC pump at 7,600 rpm, ~34 turnovers/hour and 4.6 Lpm (backpressure ~32 psi). Slurry recirculated with 1 micron rating Entegris Planarcap® LPX 1.0. Test 2a.

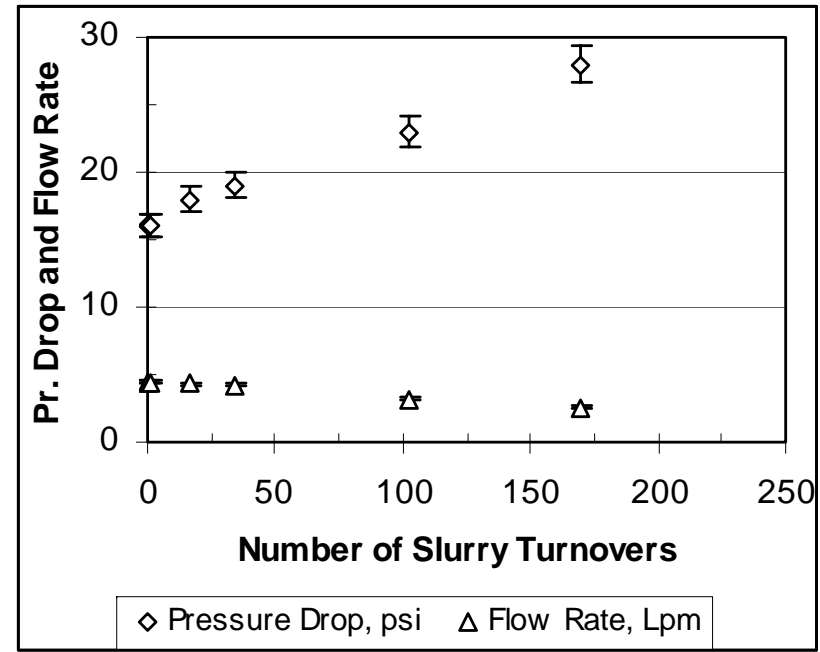


Figure 8. Filter pressure drop and flow rate data for Silica-II slurry handling in AOD pump at ~34 turnovers/hour and ~4.4 Lpm (backpressure ~34 psi). Slurry recirculated with 1 micron rating Entegris Planarcap® LPX 1.0. Test 2b.

## Test 2: Recirculated Silica-II Slurry Filtration Pressure-Drop Data with 0.5 Micron Nominal Rating Filter in a Single-Pass Test

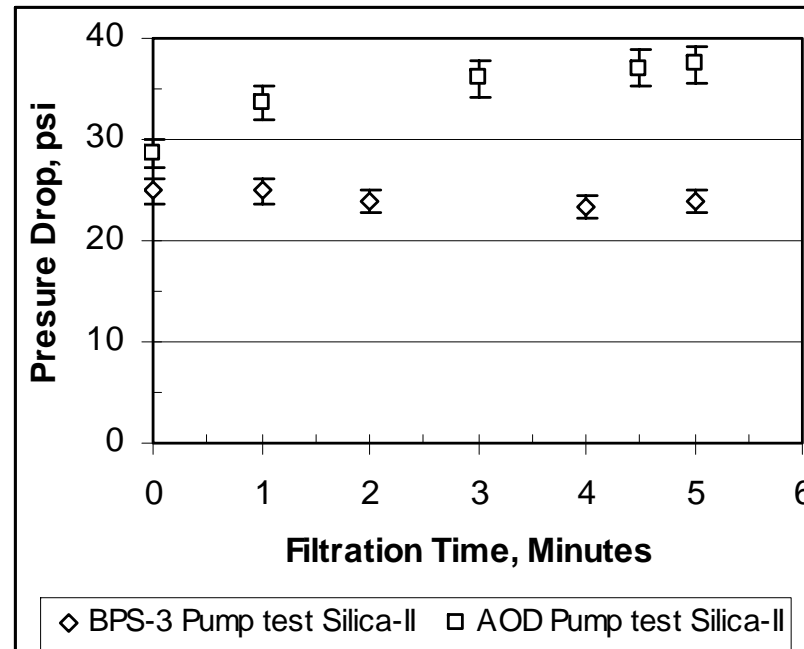


Figure 9. 0.5 micron rating filter pressure drop data for Silica-II (~25 wt % solids) slurry handling in MLC pump (Test 2a) and AOD pump (Test 2b) at ~34 turnovers/hour. Slurry recirculated with 1 micron rating Entegris Planarcap® LPX 1.0 filter in global loop in Tests 2a and 2b.

## (A) Results of Silica-I and Silica-II Pump Handling, Filter Retention, Pressure Drop and Flow Rate Tests

- Extensive handling tests of shear-sensitive silica abrasive slurries (Silica-I with ~12.5 weight % solids; Silica-II with ~25 weight % solids) using an air operated double diaphragm (AOD) pump generated significant number of large particle agglomerates. In similar tests, a MagLev centrifugal (MLC) pump generated fewer large particles than AOD pump for comparable turnovers.
- In MLC pump test with LPX 1.0 filter in the loop (for Silica-II) , initial flow rate through the filter was ~4.6 LPM with a pressure drop of ~10 psi, whereas after 5 hours continuous run (~170 slurry turnovers) these values were ~4.2 Lpm and 12.5 psi, respectively. In 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.
- This study shows 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 longer than other AOD or bellows pump based systems, when relatively open ( $\geq 1$  micron nominal rating) filters are used in the global loop and POU locations.

# Test 1: Silica-I Slurry Dispense Flow Data using MLC Pump and Differential Pressure Flowmeter Control System

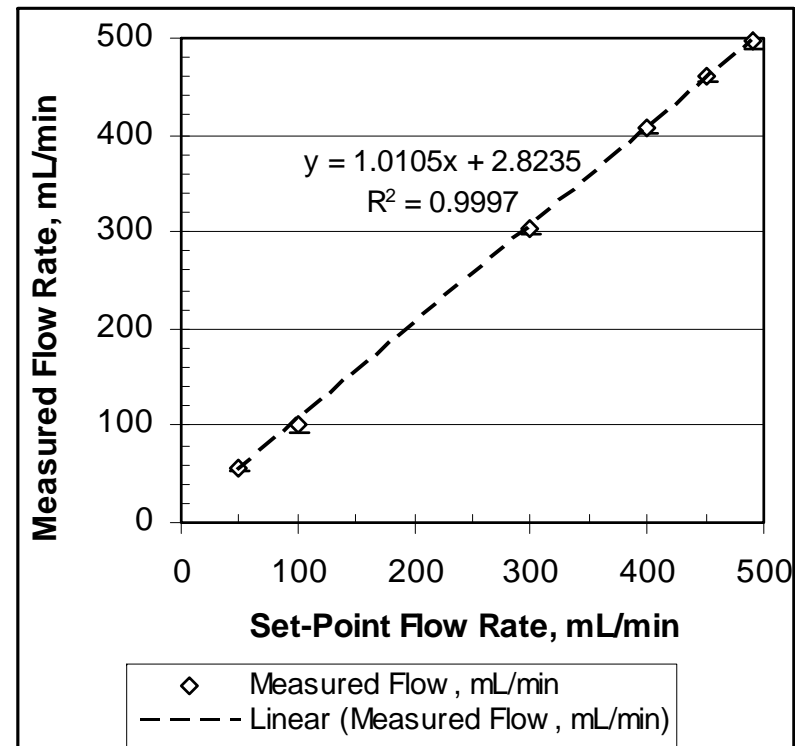
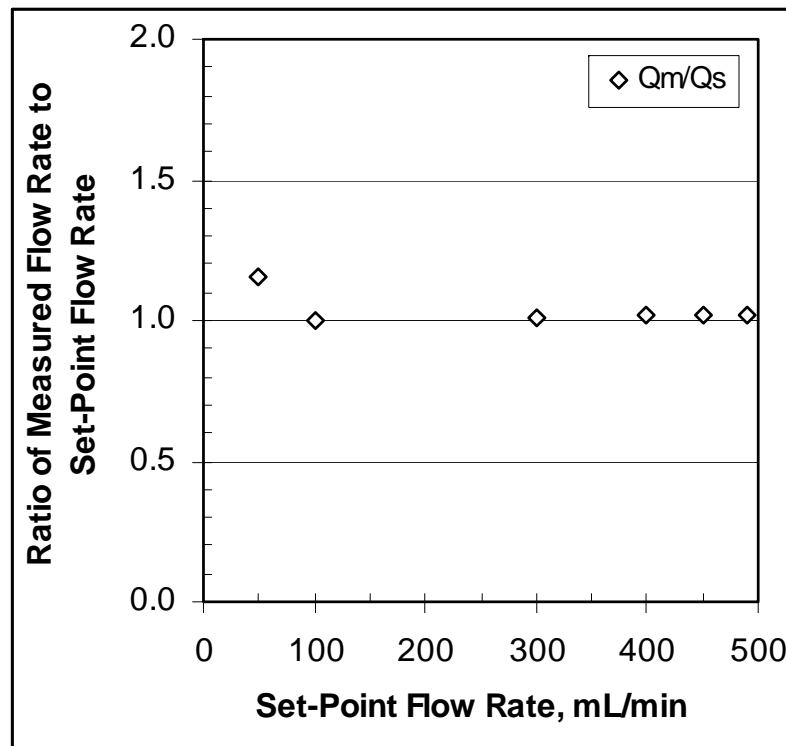


Figure 10. Measured slip stream dispense flow rate and set-point flow rate data for Silica-I slurry handling in MLC pump at 7,600 rpm, ~46 turnovers/hour and 5.3 Lpm (backpressure ~31 psi) in the global loop. Slurry recirculated with 1 micron nominal rating Entegris Planarcap® LPX 1.0 filter in the global loop. Test 1a.

## (B) Results of Flow Control using MLC Pump and Differential Pressure based Flowmeter in Silica-I

- 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).
- In general, the repeatability of the slurry dispense flow rate was  $\sim \pm 2$  % of the reading for above 20 % to the full flow range of the flowmeter (i.e., > 100 mL/min to 500 mL/min).
- The tested closed-loop flow-control system provides continuous and smooth (without pulsation) flow, independent from the pressure in the slurry global loop.
- The slip stream flow was simulated with bubbles and differential pressure based NT4400 flowmeter was found to be least affected by the bubbles presence as compared to an ultrasonic flowmeter.
- The above approach is very useful in applications with limited pressure budget and can be used for advanced process control, replace peristaltic pump systems and help in obtaining complete useful lifetime of the filter.
- This method provides precise closed-loop flow control, potential slurry saving based on reduced slurry flow rate, low cost of ownership and recurring maintenance, and high control resolution and extended flow range.

# Summary and Conclusions

- This study focused on slurry handling, filtration and flow control tests using an magnetically levitated centrifugal (MLC) pump (Levitronix BPS-3) and an air-operated double diaphragm (AOD) pump (Wilden AOD-P1) in a subsystem equipped with a pressure regulator and feedback loop control software.
- Results are presented for a point-of-use slurry delivery system feeding from a simulated global distribution loop. Tests were performed using ~12.5 and ~25 weight % solids fumed silica CMP slurries (Silica-I and Silica-II, respectively).
- Slurry recirculation tests using an MLC pump resulted in much smaller increase in pressure-drop through the filter, consistent flow rate, and negligible loop pressure pulsation and LPC increase in the 5-hour recirculation tests, with an 1-micron rating pleated depth filter (Entegris Planarcap® LPX ) in the loop.
- The above results would suggest much extended lifetime for 1-micron and more open rating point-of-use and global distribution loop filters for the MLC pump based delivery systems handling shear sensitive silica abrasive slurries.

## Summary and Conclusions (Contd...)

- Evaluation of a feedback loop flow control system employing a pressure regulator, a small MLC pump (Levitronix BPS-1), POU filter and a differential pressure based flowmeter in the slip stream (NT4400 Electronic Flowmeter) demonstrated good functionality and flow consistency.
- Above dispense system provided repeatable short-term and extended-period slurry dispense cycles over the tested flow range of 50 mL/min to 490 mL/min. This approach provides significant benefits for the advanced CMP processes due to very consistent slurry flow rate and ease of frequent flow adjustment.
- This method should eliminate slurry dispense flow rate drifts over time and particle contamination from peristaltic pump tubing, enhance filter lifetime, increase device yield, reduce possibility of catastrophic failure, and minimize system downtime and recurring costs due to frequent pump maintenance.

*Planarcap, Planargard, Mykrolis, NT, and Entegris are registered trademarks of Entegris, Inc., Levitronix is a registered trademark of Levitronix GmbH, AccuSizer is a trademark of Particle Sizing Systems*

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- Liquid Microcontamination Control Team at Entegris, Inc., for support of this study
- Levitronix CMP Users Conference Organizers for inviting me for this talk

## Entegris Corporate Profile

• Company founded as Flouroware in 1966 • Merged with Mykrolis in August 2005 • Corporate headquarters in Chaska (Minneapolis), Minnesota • 2,700 employees worldwide • Key manufacturing, sales and service facilities in the U.S., France, Germany, Malaysia, Singapore, Taiwan, China, South Korea and Japan • Delivers microcontamination control product and service solutions to the semiconductor industry and other industries including data storage