Importance of Monitoring Slurry and Ultrapure Chemical Flow in CMP Applications

Budge Johl, DOW Electronic Materials

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Introduction

- As device line widths continue to shrink process requirements are becoming more stringent
  - Flow consistency of CMP slurries
  - Chemical flow in post-CMP cleaning applications
- Un-optimized liquid flow monitoring can result in higher cost-of-ownership (CoO)
- Monitoring and control of CMP slurry and ultrapure chemical flow is critical for CMP process consistency
- This led to the motive behind evaluating non-invasive ultrasonic flow monitoring technology for CMP process applications
Flow Meter Technologies

- There are a number of technologies available for monitoring flow including:
  - Paddle wheel
  - Turbine
  - Rotameter
  - Coriolis
  - Vortex
  - Differential pressure
  - Magnetic and ultrasonic
Flow Meter Technologies: Limitations

- Paddle wheel, rotameter and turbine flow meters can lead to particle generation and increased pressure drops.

- Abrasive particles in CMP slurries can effect the performance of paddle wheel, turbine, differential pressure, and vortex technologies over time.

- Coriolis technology and certain ultrasonic devices may be sensitive to presence of bubbles in the process fluid.

- In respect to the above issues the new ultrasonic technology was chosen for evaluation.
Considerations for Slurry Flow Distribution and Health Metrology

- Calculating slurry turnovers and potential shear exposure to slurry during its distribution is important for monitoring slurry health.

- Fluid mechanics
  - Flow instrumental in calculating Reynolds #

  Equation: \( Re = \frac{\rho v D}{\mu} \)

  where:
  \( \rho \) (rho) = fluid density
  \( v \) = mean fluid velocity
  \( D \) = pipe diameter
  \( \mu \) (mu) = fluid viscosity

- Flow regimes: Laminar vs. Turbulent; Transitional

- Note: The Transitional and High Reynolds may produce flow instabilities with chaotic eddies and vortices, resulting in excessive shearing/damage to slurry.

- Slurry Information Necessary for Optimum Slurry Distribution System Designs
Diagram Courtesy of BOC Edwards
SDS and Daytank on the Top Floor

Diagram Courtesy of BOC Edwards
ILD Slurry Flow Rate Response: Effects on TEOS RR

- Many factors come into play on RR Response
- Including: Down force, platen speed and slurry flow rate
Improper slurry flows may lead to poor wafer performance
- Including inconsistent defectivity, removal rate and planarization.

**Figure 1.** Change in Removal Rate with Varying Slurry Flow
Slurry Flow Monitoring: Filter Lifetime Effects

- Slurry flow monitoring can be useful in monitoring filter life at various locations in the fab including incoming, global loop and point of use.

**Figure 2.** Slurry Filter Life Monitoring (Correct Filter Change Timing)
The non-invasive ultrasonic unit in this study was exposed to bubbles and shown to detect and compensate for bubbles in the slurry stream.

High and low flow alarms can be set to warn the operator of out of control conditions.

The slurry was exposed to > 1,000 turnovers with the unit placed inline in the slurry global loop with no adverse effects on removal rate films or defectivity as shown in Figures 3 & 4.

Images Courtesy of Levitonix
Ultrasonic Flow Meter – Removal Rate Data

Figure 3. Effects of Inline Flow Meter on RR of Various Films
Figure 4. Effects of Inline Flow Meter on Cu Defectivity
Figure 5. Effects of Inline Flow Meter on Large Particle Size Distribution

Note: Decrease in particle size distribution due to MagLev pump as shown in previous studies.
Dynamic Flow Control
Schematic of Slurry Recirculation Loop Test Set-Up

Schematic and Figures (6 – 8) Courtesy: Precision Flow Control paper by Singh et al., CMP-MIC 2007
Figure 6. Filter pressure drop and flow rate data for slurry handling in MLC pump at 7,600 rpm, ~46 turnovers/hour and 5.3 Lpm (backpressure ~31 psi). Slurry recirculated with 1 µ filter.

Figure 7. Filter pressure drop and flow rate data for slurry handling in diaphragm pump at ~46 turnovers/hour and ~5.3 Lpm (backpressure ~32 psi). Slurry recirculated with 1 µ filter.
Slurry Dispense Flow Data using MLC Pump and Differential Pressure Flowmeter Control System

![Graph showing flow data](image)

**Figure 8.** Measured slip stream dispense flow rate and set-point flow rate data for 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 filter in the global loop.
Slurry Flow
Slurry Flow
Peristaltic Pumps & Slurry Flow
Peristaltic Pumps & Slurry Flow
Next-generation cleaning applications require more accurate control of ultrapure Post CMP cleaning chemistries.

Chemical flow monitoring and control is required for process consistency.
Post CMP Clean
Post CMP Clean
Post CMP Clean
Post CMP Clean
Summary

- No increase in large particle size distribution was observed with the inline ultrasonic flow meter used in this study

- Other benefits:
  - Easily monitor slurry and chemical flow rates
  - Convenient to monitor filter life
  - Improve wafer process consistency
  - Help prevent issues with alarm capability
  - Post CMP cleaning improvement by consistent chemical flow
Summary (continued)

- The ultrasonic flow measurement technology evaluated in this study showed:
  - Good bubble tolerance with bubble compensation
  - Wide flow range capability
  - Software with real-time charting for easy flow data review

- Dynamic flow control possible for consistent POU dispense

- The DOW Electronic Materials copper slurry used in this study was compatible with the fluid dynamic design of this non-invasive ultrasonic technology
Future Trends (Conventional vs. Next-Generation)

- **Conventional POU dispense**
  - Peristaltic pump system for slurry dispense to the CMP tool
    - Particle contamination from pump tubing
    - Pump frequent maintenance, and reduced uptime
    - Flow variations with tubing wear, feed pressure and time

- **Next-Generation POU dispense**
  - Advanced flowmeter technology coupled with:
    - Magnetically Levitated Centrifugal (MLC) pumps
    - Liquid Flow Controllers (LFC) for consistent liquid flow dispense
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Liquid Flow is Important
Avoid a Spike in the Flow

I told you there was a Spike in the flow!

Cartoon Courtesy of Chemical Processing Weekly
References


