CleanRooms

Improving yield rates on existing CMP tools

How to get better results by improving materials integrity management and reducing wafer failures due to CMP slurry flow issues.

BY TAFT HU

Wafer failures during the CMP process occur due to two separate issues: mechanical problems and chemical (CMP slurry) flow problems. These failures can be observed by an end-point failure laser detection system after the CMP process. The following case studies will help you learn how to increase yield rates on existing CMP tools by improving materials integrity management and reducing wafer failures due to CMP slurry flow issues.

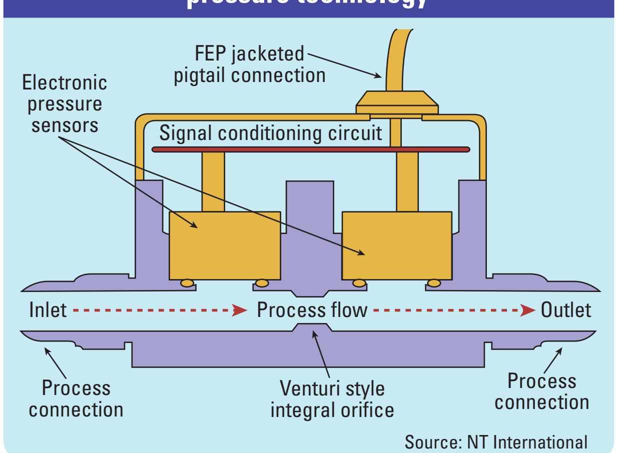
A prominent Taiwanese foundry has recently documented a significant reduction in wafer defects during its chemical mechanical planarization (CMP) process by upgrading existing tools with accurate slurry flow measurement and precise slurry flow control in several of its fabs.

To increase profitability, the foundry mandated that wafer failure during the CMP process needed to be reduced. It was recognized that to reduce failures during the CMP process would require either new tools or upgrading existing tools. Since new tool implementation was considered time-consuming and costly, upgrading existing tools was investigated first.

For a number of years, the Taiwanese foundry has relied on a leading original equipment manufacturer's (OEMs) CMP tools, which are fed pressurized liquid slurry from the downstairs bulk chemical delivery system. Peristaltic pumps are used at the tool to regulate the amount of slurry extracted from the pressurized bulk chemical delivery system for point-of-use polishing. On many of the CMP tools, paddlewheel flow meters are used to estimate the flow from the pumps, with the intention of setting alarms when the flow is too high or too low.

Peristaltic pumps regulate pressurized liquid by repeatedly squeezing a flexible tube in the same location with circular rollers. Each turn of the roller moves a small volume of the liquid forward. Peristaltic pumps are used for CMP applications because the pump tubing provides a straight flow path with no dead flow areas for slurry to agglomerate, harden, and contaminate the process.

Figure 1: A flow meter utilizing differential pressure technology



A flow meter provides signals for flow and pressure, letting the user more easily determine the source of flow irregularities.

Problems to address

The existing system, however, experienced a number of slurry flow issues that led to increased defects:

- The calibration of peristaltic pumps predicts the slurry flow at a given feed pressure to the pump. But at different pressures, the pump calibration is not accurate, resulting in incorrect slurry volumes.
- The slurry is monitored by paddlewheel flow meters, with the intention of providing alarms when the flow rate is out of specification; however, the paddlewheel flow meters did not provide accurate measurement, making the alarming capability meaningless.
- The current system was unable to change the flow rate fast enough to enable regular step changes in slurry recipes. The application requires a five-second or less response time to step changes in slurry flow.

CASE STUDY 1: Integrating flow measurement

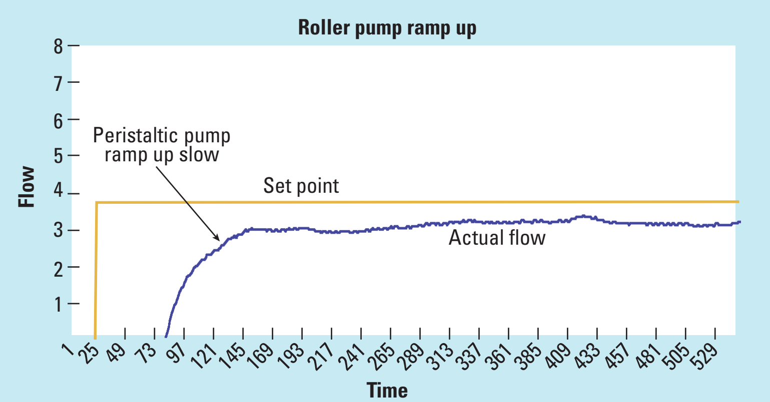
Because the slurry flow was out of specification, the foundry's wafers were being polished with the wrong slurry flow rate, which led to increased wafer failure. The fab needed to utilize flow measurement to monitor the existing peristaltic pump flow system and alarm when the flow was out of specification.

It was critical to use a flow meter technology that would properly detect low slurry flow conditions without risk of contaminating the system. As noted, the existing paddlewheel flow meters on the tool were unable to properly detect when the flow was out of specification, so wafer failures due to low slurry flow conditions could not be averted.

To meet the fab's requirements, the flow meter technology needed:

- High accuracy;
- Steady flow measurement (even in the presence of trapped bubbles);
- Straight flow path and no moving parts in the flow measurement that can cause particle generation;
- Flow-averaging options to eliminate false alarms due to brief peristaltic pump surges;
- To work at different feed pressures;
- Easy installation;
- Compatibility with slurry.

Figure 2: Lengthy slurry ramp-up time with only a persistaltic pump



Excessive ramp-up time by the fab's peristaltic pumps for a set-point change resulted in less slurry for a wafer than required, leading to potential scrap.

The CMP tool was installed with paddlewheel flow meters after the peristaltic pump, but the meters were unable to alarm properly, and low flow conditions that led to wafer failure were not detected.

Paddlewheel flow meters are suspect for this application because the moving parts are a source of possible particle contamination, and the paddle can become clogged with slurry and provide inaccurate flow measurement. Paddlewheel flow meters have different accuracies at different feed pressures, and, as noted, the feed pressure in CMP delivery systems is not constant. Additionally, bubbles in the liquid flow stream affect paddlewheel rotation and cause measurement inaccuracy.

The flow meters are to detect if the slurry flow rate is out of specification by 10 percent or more. But fluctuations in the slurry flow rate measurement from the paddlewheel made alarming difficult, and this situation was compounded by the paddlewheel flow meter creating a variable output even when the flow was constant. Variations from 20 to 80 percent of flow were experienced overall, rendering the alarms from the paddlewheel meaningless.

Ultrasonic flow meters were evaluated but were unable to produce a steady output for proper alarms. CMP slurry systems sometimes have bubbles in the flow stream that can be generated by a number of factors, including slurries themselves that often contain ammonium hydroxide or hydrogen peroxide. Gas bubbles in the liquid flow stream interfere with sound wave transmission and detection, thus affecting ultrasonic flow measurement. The company observed that the flow measurement from the ultrasonic units was erratic, even in the presence of steady flow.

A *differential pressure flow meter* measures flow using differential pressure technology. Pressure is measured before and after a fixed orifice in the flow stream. As liquid passes though the orifice, the two sensors measure pressure loss. The pressure loss is 3 PSID under nominal flow conditions and is relational to flow. The unit outputs a linear 4 to 20 mA signal for flow.

Finding the solution

After installing and evaluating several technologies, the foundry chose an electronic flow meter from NT International, a subsidiary of Entegris, Inc.(Chaska, Minn.).

The unit (Figure 1) has one percent accuracy, measures flow steadily (even in the presence of bubbles), has no moving parts, can be factory-manufactured with increased flow-signal averaging to eliminate false alarms due to peristaltic pump surges, maintains accuracy at different feed pressures, and is easy to install. In addition, differential pressure flow meters have been widely used for a number of years for CMP slurry applications in the semiconductor industry.

The device's flow meter provides signals for both flow *and* pressure. By utilizing the combination of flow output and pressure output, it's easy to determine the source of flow irregularities. This combination allows the equipment operator to monitor process conditions more effectively, create a redundant monitoring system for increased process integrity, and let system diagnostics take place with greater detail.

In addition, the measurement from the differential pressure flow meter experienced fewer fluctuations due to bubbles and changes in feed pressure than the paddlewheel flow meter. Thus, the differential pressure flow meter generated significantly fewer false alarms during regular processing.

CASE STUDY 2: Control improvements

The foundry wanted not only to measure the flow and alarm when out of specification, but wanted to *control* the flow. It is good to be able to use an accurate measurement device to alarm when the flow is out of specification so wafers are not processed with the wrong amount of slurry. Since peristaltic pumps operating in CMP tools for point-of-use flow regulation are inherently inconsistent, replacing the pump altogether with an alternate flow control mechanism is optimal.

In addition to the flow inconsistency issues, two of the foundry's fabs experienced a lengthy ramp-up time for the peristaltic pumps when initiating wafer polishing. The peristaltic pumps used for point-of-use slurry flow dispense required 40 to 60 seconds to ramp up from no-flow condition to the desired set point. This meant that the first wafer processed after a set-point change received less slurry than necessary, leading to potential scrap.

The excessive ramp-up time was considered unacceptable and needed to be five seconds or less for proper polishing. Figure 2 (above) indicates the time to approach the set point by a peristaltic pump in actual fab conditions. Also, note that the actual flow differed from the desired flow in this instance by 20 percent.

Integration of flow control

The foundry chose a device with three integrated components within one body: flow measurement, a stepper-motor-controlled diaphragm valve with fast response time that minimizes movement, and control software. The flow accuracy specification is one percent of full scale and the response time to set-point change, or change in feed pressure, is less than three seconds.

The device is used to replace the peristaltic pump for flow control. It fits directly into the peristaltic pump tray and receives the same signal as the peristaltic pump motor driver. The CMP tool sends a 0 to 10 volts DC signal to the peristaltic pump motor driver to control the pump speed and thus control the flow. This same signal is connected to, and controls the flow rate for, the device.

It was a major finding of these studies that you cannot assume that the product is safe just because the particles reside at lower levels than the wafer.

The lookup table and calibration sequence used for peristaltic pumps is also used for this device. Additionally, its flow and pressure measurement signals may be used for alarming, using open I/O channels on the CMP tool. Thus, replacing the existing peristaltic pump and associated control system is an uncomplicated installation.

Figure 3 (above) is a diagram defining the integrated flow controller and its interface to the CMP tool. The accuracy and response time has been better than expected and allows for significant CMP performance improvement. This was the first time that the foundry had seen the actual slurry flow remain at the desired level without fluctuations.

Benefits of accurate flow control

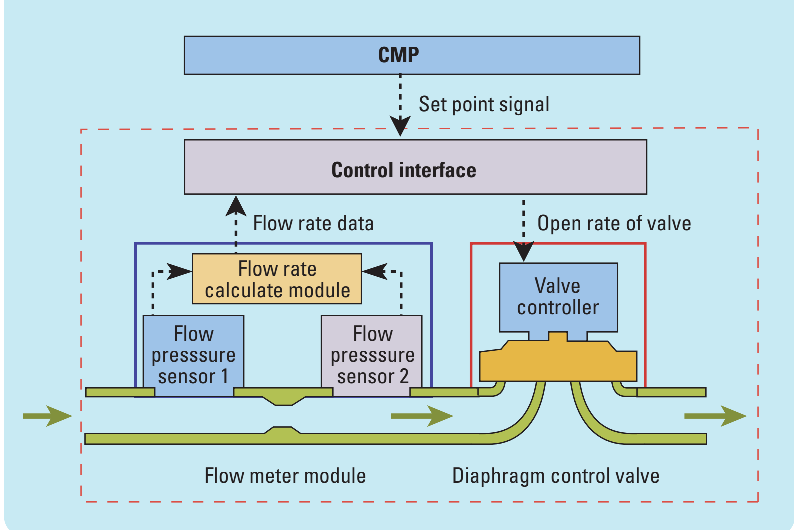
Previously, the foundry was unable to alarm properly. due to problems with the paddlewheel flow meter's accuracy and fluctuations in the actual flow rate from the peristaltic pump. Now, with accurate flow control installed, the flow rate is maintained well within specification, and failures due to slurry flow irregularities have been significantly reduced.

The company uses a laser system built into the CMP polisher to detect end-point wafer failures. The system is able to detect failures due to mechanical (non-slurry) issues and failures due specifically to slurry flow rate issues.

Before the flow control installation, slurry flow issues caused approximately half of the wafer failures as detected by the laser system after the CMP process. After the flow controller installation, however, failures due to slurry flow have all but disappeared and, as a result, overall failures have been reduced.

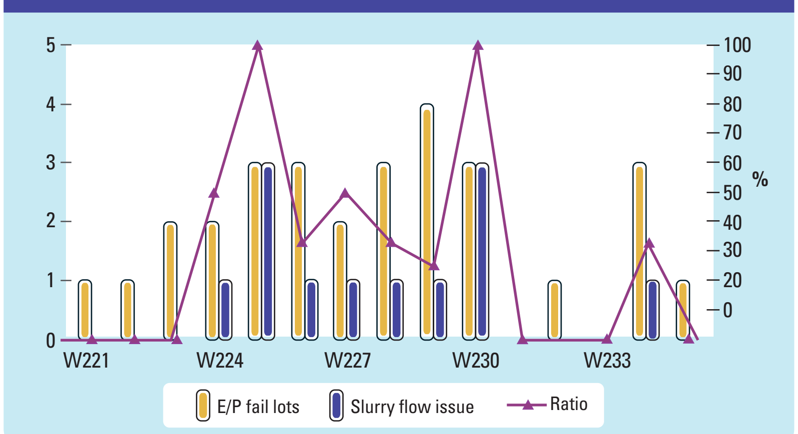
Figure 4 (below) illustrates the reduction in wafer failures using flow control. The purple bars depict overall failures, the blue bars illustrate failures due specifically to slurry flow issues, and the red line is the ratio of overall failures due to slurry flow issues.

Figure 3: A flow controller process



An integrated flow controller features flow measurement, a stepper-motor-controlled diaphragm valve with fast response time, and control software. This layout shows the flow controller and its interface to the CMP tool.

Figure 4: End point/wafer failure improvement with flow control



This bar chart indicates the reduction in wafer failures when using flow control. Note the improvement after the flow controller was installed after day W231.

Before day W231, the CMP tool used the peristaltic pump/paddlewheel flow meter system. On day W231 and after, the flow controller system was utilized. Note that the percentage of failures due to slurry flow issues (red line) dropped significantly after the flow controller was installed, and overall failures were reduced.

Peristaltic pumps require downtime for scheduled maintenance, such as calibration, tubing replacement, pump replacement, etc. Additionally, unscheduled downtime occurs due to false alarms, pump repair issues, investigating end-point failure/flow alarm issues, and other problems. Use of flow control, however, has significantly reduced tool downtime and wafer failure at the Taiwan fab, allowing the system to be more profitable.

Overall savings due to flow control installation include:

- Increased wafer yields;
- Decreased downtime from alarms;
- Decreased downtime from pump maintenance;
- Increased throughput;
- No need to replace or upgrade the CMP tools.

By installing accurate and precise flow monitoring and control, the Taiwanese foundry was capable of increasing tool uptime and reducing defects, effecting significant savings. Additionally, the company benefited by not having to upgrade to new and expensive CMP tools.

TAFT HU *is section manager for the Diffusion Engineering Department at Taiwan Semiconductor Manufacturing Company (Taiwan).* *The author would like to thank David Albrecht, senior applications engineer at NT International, and Domingo Ang, technical sales specialist at Entegris, for their technical knowledge of flow instrumentation and assistance developing this application.*

Printed in USA 3963-1910PEN-0704