MICRO

Defect Reduction and Yield Enhancement Strategies for Semiconductor and Advanced Microelectronics

Ultrapure Fluid/Slurry Delivery

Using liquid flow controllers to enhance CMP tool performance

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A microprocessor-based flow controller system has shown several advantages over the traditional peristaltic pump setup in tests run on polishing tools at AMD's Fab 25.

A*dvanced Micro Devices' Fab* 25 in Austin, TX, is a high-volume, state-of-the-art microprocessor device production facility. Like other such facilities, Fab 25 has numerous chemical-mechanical planarization (CMP) tools, each of which uses a system of peristaltic pumps for process fluid delivery. At various times during each CMP process, these pumps may be delivering tungsten or oxide slurries, DI water, or ammonium hydroxide. These fluids are dispensed onto the polishing substrate, and mechanical force is applied to create the desired planarized surface. The chemical interaction and the mechanical force combine to achieve the desired effect on each wafer.

Peristaltic pumps have been used to dispense the necessary chemicals since the development of CMP tools. Before the advent of fabwide chemical delivery systems, many chipmakers simply pumped slurry and other chemicals out of nonpressurized drums, and the peristaltic pumps provided the necessary pressure to dispense the slurry onto the wafers. However, with the coming of state-of-the-art pressurized chemical delivery systems, pressure no longer needs to be provided by each tool.

Problems with Peristaltic Pumps

Although proved to be functional, peristaltic pumps create several problems when used in a CMP process. First, tubing breakdown caused by the pump design generates particles, which are detrimental to any semiconductor process. Second, the pumps do not provide consistent flow control and therefore introduce potential process variability. Third, peristaltic pumps require significant maintenance to keep functioning properly, which leads to tool downtime and excessive repair costs. Fourth, the pumps used on most CMP tools do not incorporate any type of closed-loop feedback system. Lack of feedback can lead to dry

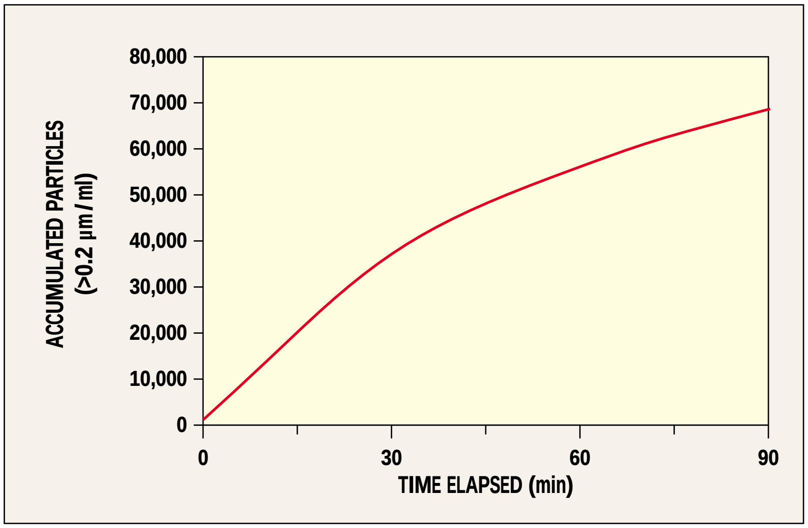

Figure 1: Tubing particle generation during peristaltic pump use.

polishing or inconsistent flow rates, either of which can cause wafer surface microscratching or even breakage.

Figure 1 details the particle generation of a typical peristaltic pump, using standard ethylene/propylene tubing recommended by the manufacturer. The chart illustrates the amount of accumulated particles (≥0.2 µm) versus time. As shown, nearly 70,000 particles are generated in the first 90 minutes—more than enough to have a severe impact on CMP process yield. Further, as the ethylene/propylene pump tubing wears, it releases soft polymer particles, which ultimately are either passed onto the wafer or attach themselves to downstream tubing. Figure 2 shows an analysis of the composition of the recommended ethylene/propylene pump tubing. The materials used include elements and additives that can affect processes randomly and unpredictably. Any extraneous particles introduced into the chemical flow stream can cause defects.

In many cases, flow rates must be changed to optimize a process. Sometimes, these changes may even occur in sequential steps of a process. Therefore, the tool must be able to reliably call for various flow rates. Depending on the process, peristaltic pumps may not be able to deliver the linearity and repeatability required for optimal performance. Since pump linearity varies, routine multipoint calibrations must be performed, which are time-consuming and somewhat subjective. Calibrations may vary depending on the technician performing the job. This type of inconsistency ultimately can lead to process variability.

The amount of scheduled monthly maintenance needed for a fully functional peristaltic pump system may average anywhere from 2 to 4 hours. Associated maintenance—in order of frequency, from most to least often—includes replacement of the ethylene/propylene pump tubing, replacement of downstream system tubing and fittings, replacement of mechanical pump heads, and replacement of pump motors on failure. Failure to perform routine ethylene/propylene tubing replacement can result in bursts and possible hazardous chemical leakage. Replacement of downstream tubing and fittings ensures that extraneous polymer accumulation on inner walls of the fluid path is minimized. Pump head breakdown can also lead to catastrophic chemical leakage, and pump head and motor failure often lead to dry polishing and subsequent wafer damage.

Failure to perform routine ethylene/propylene tubing replacement can result in bursts and hazardous chemical leakage.

Most peristaltic pumps lack a feedback system, so they fail to inform the process tool when the flow rate decreases or when there is no chemical present. Therefore, the tool is unaware that the chemical is not being dispensed properly, so wafers may be damaged until an operator intervenes. It is even possible for a pump motor or head to fail without any alert to the tool. Further, as supply pressures change, the pumps may dispense varying flows, adding inconsistency to the process, which adds to the process engineers' difficulties in diagnosing problems.

To eliminate some or all of these problems, equipment engineers at Fab 25 began researching alternatives to the peristaltic pumps. Since the tubing was causing much of the particle generation, the first alternative involved changing from an ethylene/propylene-based polymer tubing to silicone-based tubing. The silicone-based tubing greatly minimized the generation of particles and downstream line contamination compared to the original tubing, but the tubing life was reduced so drastically that it was not practical in a high-volume

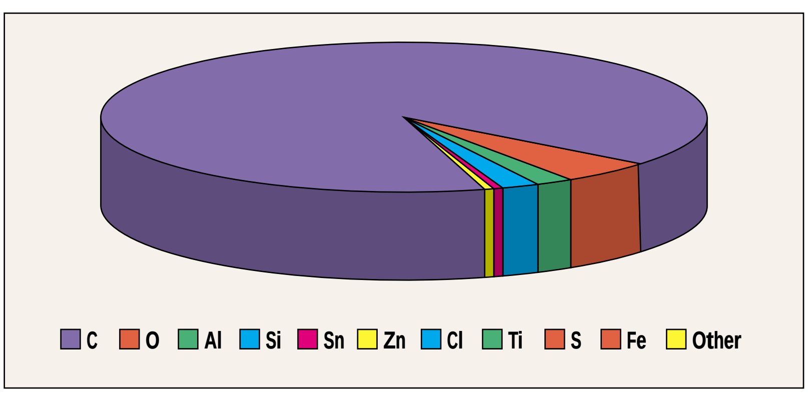

Figure 2: Elemental composition of peristaltic pump tubing.

production environment. Further, the problems involving the pumps were still not corrected. Other nonperistaltic pump alternatives were also evaluated, such as gear pumps, that ultimately resulted in early mortality rates.

The Benefits of Liquid Flow Controllers

The engineers then began looking into liquid flow controllers. These units do not perform a pumping function; they rely on the pressurized chemical delivery system in the fab to provide pressure. The controllers use a flow sensor combined with a proportional control valve. After the desired flow rate is input, the actual flow rate is monitored via the incorporated flow sensor and the integrated valve adjusts the flow accordingly.

Because of size restrictions on the tool, it was critical that whatever flow control system was adopted be similar in size to the peristaltic pump setup. During this investigation, some existing liquid flow control options did not meet the critical size dimensions. Ease of system integration was another important factor, since it was necessary to minimize the time needed to perform retrofits.

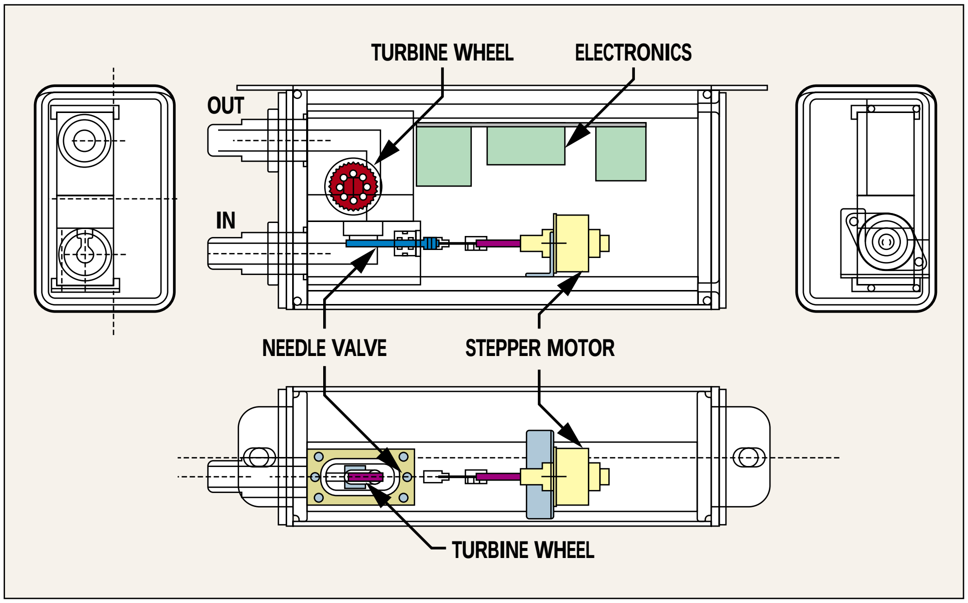

Figure 3: Internal diagrams of flow controller.

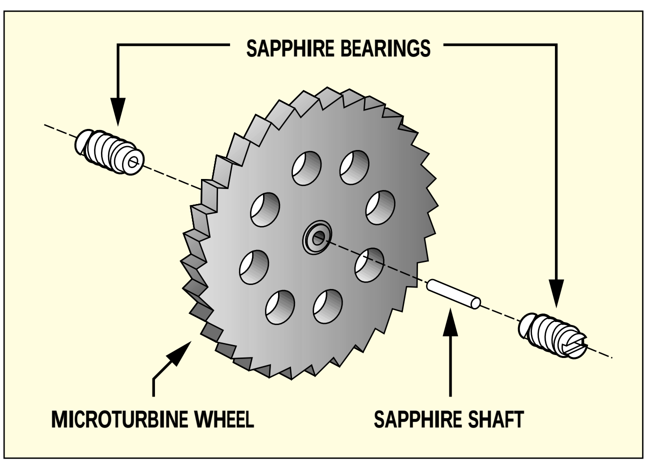

Figure 4: Diagram of flow controller's turbine wheel and bearings.

A new microprocessor-based Teflon liquid flow controller met the size, performance, and integration requirements sought by the engineers (Model 401 Flo-Controller, McMillan Co., Georgetown, TX). This product incorporates both a flow sensor for monitoring of flow rates and an integrated needle valve (see Figure 3). The heart of this flow control system is the flow sensor, which uses the Pelton turbine wheel concept. This design type allows usage of a subminiature microturbine wheel, which weighs <1 g and is about the size of a quarter in both diameter and thickness. The turbine wheel is supported on a small sapphire shaft held in position by two sapphire bearings, illustrated in Figure 4. Because of the extremely light weight of both the wheel and shaft, the microturbine wheel virtually floats in the liquid. This flotation effect causes the turbine wheel to be suspended in the middle of the bearings and thus eliminates shaft and bearing wear, resulting in no particle generation. As liquid flows through the controller, it is directed onto the teeth of the wheel using a precision-machined orifice, which is sized according to flow range. The flow is projected onto the wheel, spinning the wheel faster as flow increases at a speed proportional to the increase in flow rate.

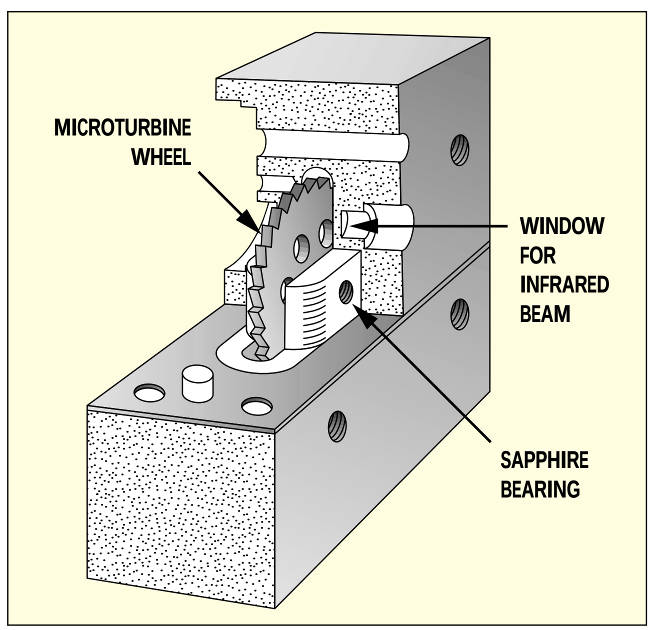

Figure 5: Cutaway of flow controller's internal flow sensor design.

The microturbine wheel features eight small holes, spaced evenly around the center of the wheel. As the wheel spins, an infrared beam is projected through a Teflon window and onto the wheel, as shown in Figure 5. A sensor on the other side of the wheel detects each hole and translates those signals into pulses; as the wheel spins faster, it generates more pulses, and when the wheel stops, the pulses cease as well.

The integrated needle valve serves as the flow control device. The needle valve design was chosen because it generates very few particles when activated and provides linear, reliable control. A sapphire shaft moves in and out of Kalrez seals, positioned by a bidirectional stepper motor (as shown in Figure 3).

By taking advantage of materials such as Teflon, sapphire, and Kalrez, the liquid flow controller is compatible with nearly all chemicals and slurries used in the CMP process. Further,

The heart of the flow control system is the sensor, which uses a Pelton turbine wheel.

its compact footprint is nearly identical to that of a peristaltic pump, allowing the units to be installed in the same location as the pumps.

Integrating and Testing the Flow Controller

Integration was a simple procedure. The fab engineers selected an existing AurigaC CMP tool (SpeedFam-IPEC, Chandler, AZ) as a beta installation for the flow controllers. Since the tool had been in long-term service, trends and data would be easy to track and monitor. This type of polisher uses six peristaltic pumps to dispense chemicals and water onto the wafers. These pumps are mounted together on a panel as depicted in Figure 6, and the wiring for the pump

Figure 6: Photo of pumps installed on CMP tool.

Figure 7: Photo of controllers installed on CMP tool.

controllers is routed to a fluid-free cabinet of the tool.

To replace the peristaltic pumps, an anodized-aluminum panel with appropriate mounting hardware was needed for the new flow controllers. The fab engineers also requested that the flow controller manufacturer install special liquid-tight connectors on the flow controllers to allow panel installation. The new panel, with all flow controllers mounted, fit in the same location as the pumps. The flow controllers use the same electrical signals and plumbing as the peristaltic pumps, so wiring and installation were quick and easy. Removal of the pumps and installation of the flow controllers was accomplished in as little as 6 hours, with no software changes or upgrades required for operation. The installed flow controller system is shown in Figure 7.

The controllers/tool interface is similar to that of the pumps. As flow requirements change, the tool sends an analog 4-20 mA signal to the flow controller, requesting a certain flow rate. The controller compares that signal to the signal of its internal flow sensor and then adjusts the flow rate using its internal needle valve to match the two signals. If the controller cannot achieve the requested flow rate, perhaps because of a pressure delivery problem, the internal microprocessor signals the tool and the operator that an error condition has occurred. This safeguard feature can automatically halt the process, preventing possible wafer damage. As pressure to the tool varies, the controller will automatically make small adjustments to compensate and keep the flow rate stable.

Test Results

In all of the problem areas, the flow controllers compared quite favorably with the peristaltic pump design. Since the flow controllers do not generate a significant amount of particles, the level of defect density was expected to decrease greatly. This hypothesis proved to be true, as revealed by the

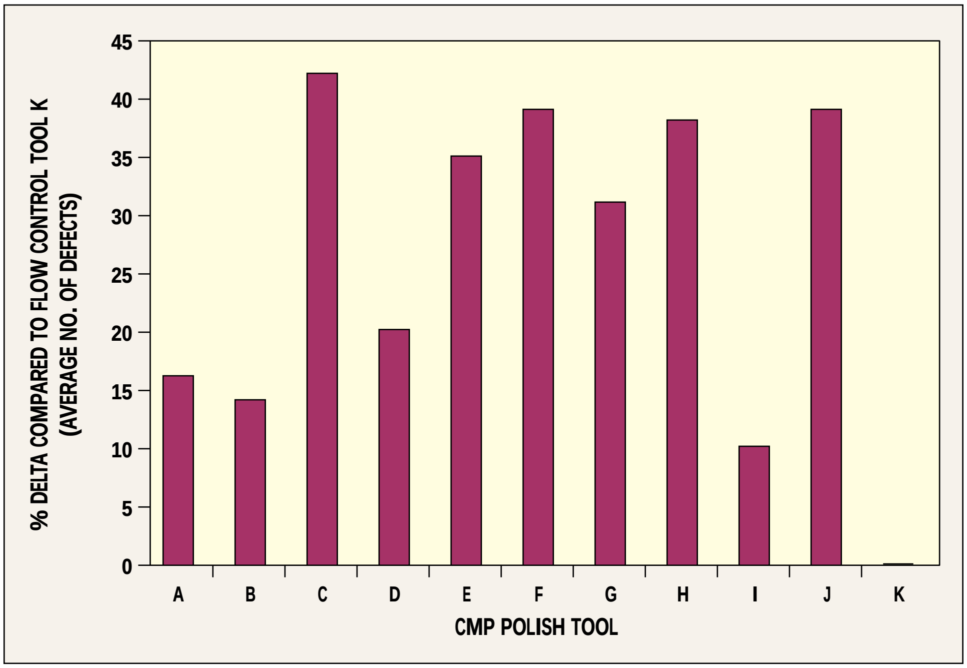

Figure 8: Comparison of wafer defects, generated by CMP tools with and without flow controllers, over time.

The downstream tubing stayed clean as well. While the inner wall of tubing downstream of the peristaltic pumps had a visible buildup of polymer and slurry particles after just a few days, the tubing downstream of the flow controllers was clear and clean after 90 days, with no evidence of polymer buildup. This improvement occurred because the ethylene/propylene tubing was removed, leaving only Teflon and Tygon tubing in the fluid delivery path.

In case a change in flow rate occurs, the liquid flow controllers feature ±0.2% full-scale or better repeatability and ±2.0% full-scale or better linearity. This ensures that when the tool calls for varying flow rates, the controllers will deliver the flow accurately and repeatably. This feature has helped to minimize process variability and has allowed the fab's process engineers to fine-tune their processes and achieve optimal performance. The flow controllers have also required up to 50% fewer calibrations than those needed for the pump systems.

Maintenance has also been greatly reduced. An optical inspection–based postanalysis of a flow controller with more than 90 days of continuous slurry delivery service showed no wear or extraneous particle buildup. Tubing replacements are estimated to be needed once every 12–18 months with the flow controller system, compared with once every 30 days for the peristaltic pumps. Figure 9 illustrates the annual replacement-part costs for one tool with peristaltic pumps, compared with the annual costs of a tool with flow controllers. It also shows the estimated costs of ownership, including parts and downtime, for each type of tool over that same period. Of course, it is hard to precisely estimate the monetary benefits of a system that provides tight control over flow rates and reduces defects, but annual savings of several hundred thousands of dollars per tool are possible.

tool defect results seen in Figure 8, which were generated on TEOS wafers run through a standard unpatterned wafer inspection tool (6400 series; KLA-Tencor, San Jose). As the figure shows, CMP tools A through J used peristaltic pumps to dispense chemicals, while Tool K used the liquid flow controllers. During a 3-month period, the tools with the peristaltic pumps averaged 28% more defects than the tool equipped with the controller system. Tool K's performance remained extremely stable and consistent throughout the testing period.

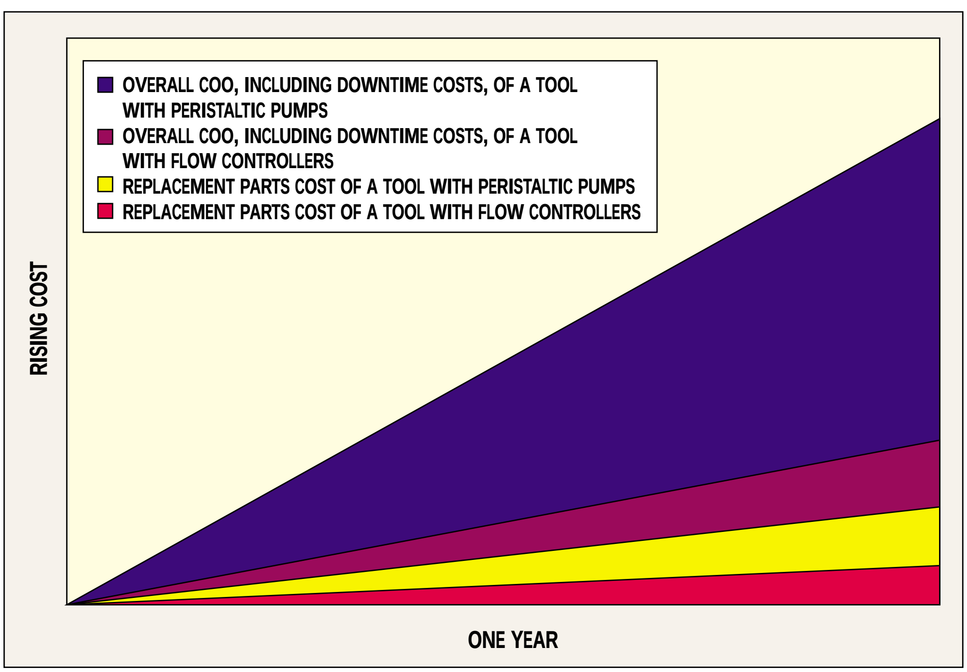

Figure 9: Cost of ownership (COO) trend chart for CMP tool maintenance.

When a peristaltic pump fails, it can take 1 to 2 hours to replace the suspected unit. In the event of a premature failure of a flow controller, because of the panel-mounted design, one controller can be removed and replaced with another in <2 minutes. The technician simply disconnects the power and plumbing, lifts the controller out of its cradle, and installs and connects the new controller.

The flow controllers also furnish critical feedback information to the tool. They provide an analog output indicating actual flow rate, as well as an error output for notification and process termination if desired. As updated software packages for the polishing equipment become available, it may be possible for process engineers to correlate flow rate trends with production yields and acquire real-time data.

Conclusion

Tests at AMD's Fab 25 have shown that a new liquid flow controller system can be a successful alternative to the peristaltic pump systems found on most CMP tools in facilities using pressurized chemical distribution systems. Lower maintenance costs, improved tool downtime, and enhanced yields are key benefits seen in the conversion from the potentially process-degrading peristaltic systems to the flow controller units. In addition to the results seen at Fab 25, early evaluations of the flow controller system at AMD's Fab 30 in Dresden, Germany, are positive.

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