SolidState TECHNOLOGY®
THE INTERNATIONAL MAGAZINE FOR SEMICONDUCTOR MANUFACTURING

# A new concept for etch and deposition
# chamber pressure control

**OVERVIEW** A variable-speed vacuum system, using compact dry pumps, provides a production-worthy alternative to traditional methods of chamber pressure control for aluminum etch and LPCVD nitride deposition. Application to a single-wafer metal-etch tool allowed the elimination of a throttle valve close to the process chamber, thereby removing one source of contamination and tool downtime. Similarly, applied to an LPCVD nitride furnace the new system eliminated the need for upstream pressure control and nitrogen ballasting, significantly reducing particles.

We describe a new method of controlling chamber pressure during wafer processing by upgrading the vacuum system. Also, we compare the process benefits obtained to previous chamber pressure control system technology. The new approach has been applied to two different systems in production fabs, namely a LAM single-wafer high-density plasma metal-etch tool in operation at ALTIS Semiconductor and a SEMI horizontal furnace in operation at STMicroelectronics-Rousset.

Our results show a reduction in particle count as well as improved process control stability for the LPCVD nitride furnace, potential improvement in yield for the metal etch application, and new process-diagnostic capabilities.

Previous industry attempts at using changes in vacuum pumping speed to obtain process pressure control have met with limited success; key limiting factors have been the monitoring and control of only one pump motor in the pumping system and the response time of the system. The achievable response time is a function of both the accuracy and speed with which the rotational speed of the vacuum pumps can be changed, and the distances that the vacuum pumps are from the process chamber. The current approach has been made possible by advances in both areas.

## Current practice for etch systems

Etch processes are some of the most aggressive and maintenance intensive in semiconductor wafer processing. For aluminum-etch processes, the main by-product is highly reactive aluminum chloride.

The vacuum system for etch processes typically requires a turbomolecular pump to obtain the desired process pressure at a particular flow rate. There is a need for two valve functions — vacuum isolation of the pumping system during process chamber preventative maintenance (PM) and the control of chamber pressure during the etch process. In most production etch systems, the desired process pressure is obtained using a throttle valve mounted between the process chamber and the turbopump — a “downstream control” system setup. The throttle valve can be a combined throttle-high-vacuum isolation valve or separate valves can be used for these two functions.

Pressure $P$ in the process chamber is determined by the delivered pumping speed $S$ under a constant gas flow: $(Q)$: $P = Q/S_{net}$

Current practice changes the pumping speed delivered to the process chamber by varying the conductance $C$ of the throttle valve, which in turn varies the overall conductance of the exhaust line: $1/S_{net} = 1/S_{pump} + 1/C$.

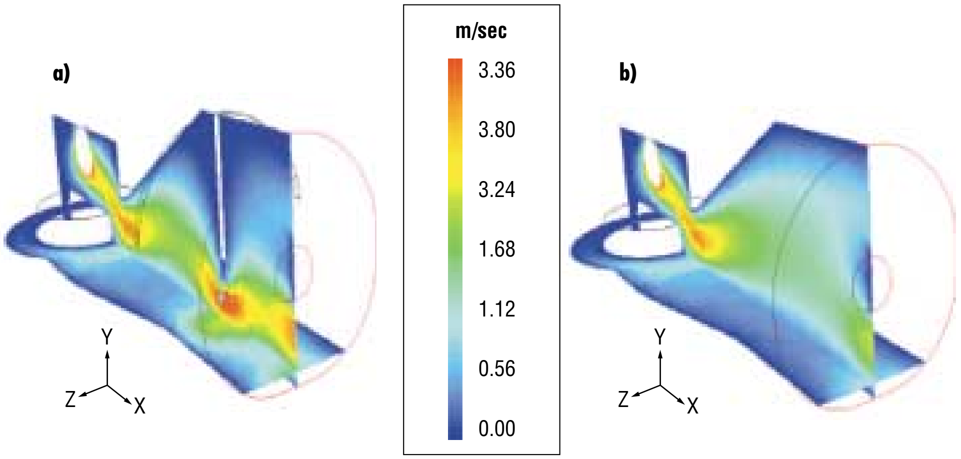

**Figure 1.** Gas velocity simulation (using FLUENT software) showing **a)** the presence of a throttle valve in a process gas flow, which creates a localized perturbation, compared to **b)** flow without valve.

The operation of the throttle valve, by design, results in the valve plate being in the process gas flow during etch with two major impacts on tool performance and the etch process. First, the creation of localized perturbations in the flow affects both the velocity of the gas and particle formation (Fig. 1).

**Kenneth Caldwell,** Alcatel Vacuum Technology, Annecy, France

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Second, inevitably, there is deposition of by-products on the throttle valve.

While a heated throttle valve reduces by-product deposition rate on the throttle valve plate, deposition still occurs. This material accumulates and eventually flakes off and becomes another source for particles that contribute to yield loss on processed wafers.

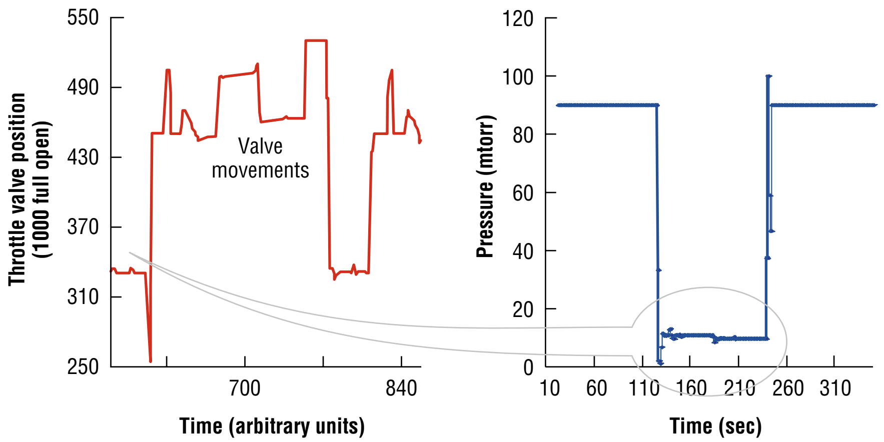

**Figure 2.** Throttle valve position used to maintain a 12mtorr pressure during processing.

To address this issue in fabs, the throttle valve is fully reconditioned during each scheduled PM of a chamber in an attempt to remove or minimize this source of contamination and associated yield loss.

Figure 2 shows variations in throttle valve position used to maintain a 12mtorr pressure during a process run. It moves a distance of 20% of its total opening to drive the chamber pressure to its process pressure after wafer transport, during which the chamber is being flushed with a nitrogen purge. Then, throughout this metal etch process step, the valve plate oscillates a distance equal to 6% of the total valve-opening diameter to maintain the desired pressure.

If one visualizes a valve plate that has some by-product deposition on it being rapidly moved back and forth in a highly corrosive gas stream, it is not difficult to understand the futility of predicting when particle flaking will occur.

To remedy this situation, we designed and implemented a chamber pressure management system that no longer requires a throttle valve for controlling process chamber pressure in an advanced metal-etch process. Eliminating the particle source that a throttle valve inherently represents can only improve system productivity by eliminating required PMs of this component.

## The new approach for etch systems

As seen above, the only two factors that impact the net pumping speed at the process chamber is conductance and system pumping speed. Our new approach maintains a constant, maximum conductance to the chamber by not throttling and varies the net speed to the chamber by varying the pumping speed of the pumping system.

For an etch system, two pumps must be monitored and controlled (i.e., the turbopump and the backing pump) to give the needed response time performance and a suitable flow vs. pressure curve.

To demonstrate the concept and feasibility of this approach with minimal changes to the existing installation, we retrofitted our new pumping system to the existing throttling gate valve (Fig. 3). During all process steps, the valve was driven to the fully open position; we restricted use of the valve to that of an open or closed vacuum isolation valve.

Our first installation of this new chamber pressure management system was on a single-wafer metal-etch tool running a 0.25µm process for logic and a 0.20µm process for 64Mb DRAM in a production wafer fab.

The main components of the tool upgrade included replacing the existing mag-lev turbopump on the etch chamber with one optimized for pressure control; prior work at Alcatel demonstrated the unsuitability of traditional turbopump designs for this purpose. A dry pump equipped with a new frequency converter backed the new turbopump. Both pumps were then interfaced to the proprietary Alcatel Control System (ACS). The ACS monitors and controls in parallel the dry pump and turbopump rotational speeds to obtain the needed net pumping speed and compression ratio for the desired chamber pressure profile and partial pressure gas ratios.

With this installation, we used a laptop PC during initial system set-up during which the ACS learns process recipes; re-programming the ACS for new recipes takes only 10 wafers/recipe.

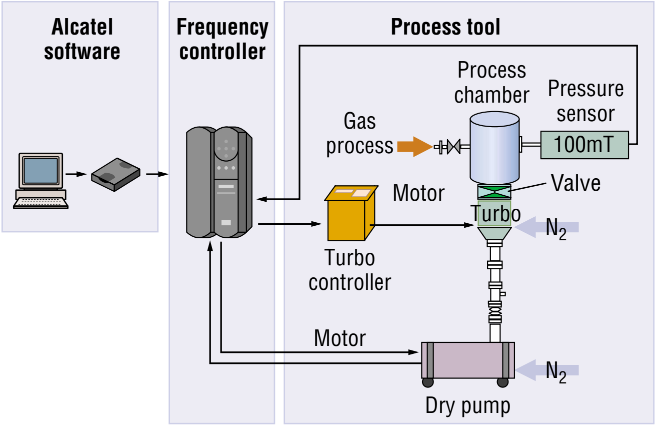

**Figure 3.** Chamber pressure management system.

Figure 4 compares before (conventional throttle valve pressure control) and after process profile (using our new pressure management system). This data shows normalized plasma intensity on the *y*-axis that is used for process control and end point detection. In general, the width and shape of the first peak in the plot give an indication of etch uniformity and etch rate; the slope gives information on microloading effects. These data show that, compared to the original configuration, there is no process shift with the new chamber pressure management system.

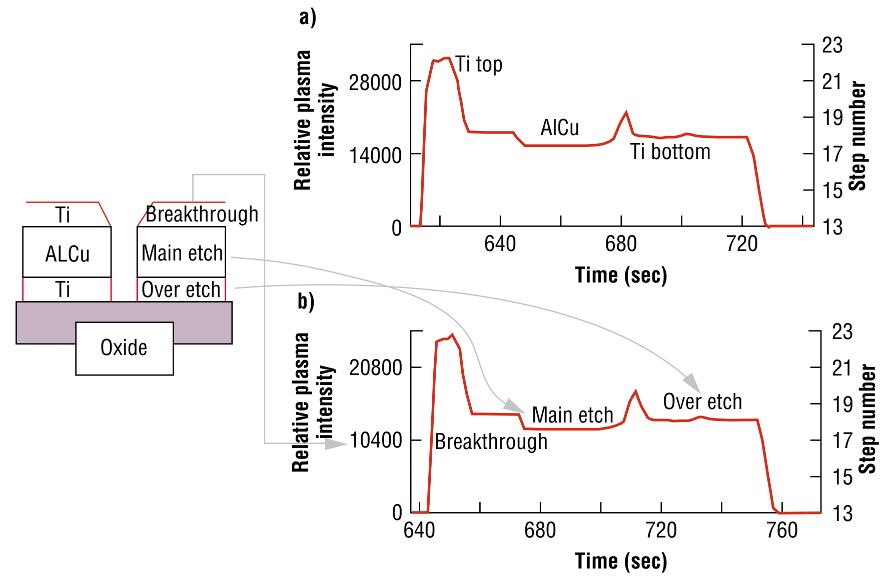

**Figure 4.** Comparison of a plasma etch process using **a)** an open-valve pressure control system and **b)** conventional throttle valve pressure control.

## Results

Configured with the pressure control system, we used the etch tool for both first and second metal levels, running a variety of full and split lots to compare yield results (see table). After inspection, the devices produced were deemed equivalent or superior to existing product based on internal yield metrics of the fab (i.e., first-past yield and final probe yield) except for the first split lot where the Alcatel system yield was significantly lower (because an incorrect pressure set point was programmed into the ACS on the first run).

### Comparison of electrical mean yields when etching*

| ALTIS semiconductor product and metal level | | Conventional pressure control normalized to 100% | Alcatel system compared to conventional pressure control (%) |
|---|---|---|---|
| SDRAM | M1 | 100 | 85.7 |
| 0.20µm (split lots) | M2 | 100 | 113.7 |
| | M1 & M2 | 100 | 100 |
| SDRAM 0.20µm (full lots) | M2 | 100 | 114 |
| Logic 0.25µm | M1 | 100 | 102.3 |
| (split lots) | M2 | 100 | 100 |
| | M1 | 100 | 97.6 |
| Logic 0.25µm (full lots) | M2 | 100 | 128.6 |

*Yields from the conventional approach were normalized to 100 to conceal actual fab yield data.

On one metal level for a high-production-volume device, for which the baseline yields are well characterized, as high as a 13% increase in first-pass yield was recorded on a split lot compared to the previous configuration. These results are very promising and show a potential for yield improvement, but are to be confirmed with long term testing.

The new system is now qualified for production in this fab. In addition, subsequent tests have started to demonstrate the long term benefits and performance of this chamber pressure management approach. These include increased tool availability due to eliminating the required PM of the throttle valve, and a reduction in process drift and yield degradation over time due to accumulation of by-product on the throttle valve, which has been eliminated.

In addition, use of this method for chamber pressure control gives additional benefits. As the rotational speed of the pumps is monitored and controlled, variations to this parameter can be used as a diagnostic. For example, we found through analyzing this data that a process chamber mass flow controller (MFC) was not set up with the right inlet pressure, resulting in gas pulses and plasma disturbances during processing. This defect was not detectable by the existing method of calibrating the MFC accuracy used by the process tool.

Another use was for leak detection on the system. Common practice is to leave the turbopump on while leak checking the process chamber. If there is a leak across the isolation valve seal, this masks other leaks in the chamber as this leak is partially pumped away by the turbopump.

## Current practice, LPCVD nitride

With the deposition of silicon nitride, ammonium chloride is the critical by-product. In low-pressure CVD furnaces, chamber pressure control is either via upstream pressure control (UPC) or via a throttle valve. UPC uses nitrogen ballasting at the furnace exhaust-pump inlet to maintain the desired chamber pressure during processing. Our new variable speed pumping system is retrofittable to both types of pressure control systems.

The initial installation was carried out on a SEMI horizontal furnace that used UPC to vary the mass flow to maintain the desired process pressure. MFCs delivered a fixed flow rate of dichlorosilane and ammonia to the furnace. Normal use of this system called for three particle-monitoring test wafers in each furnace. The particle control level for these test wafer was an average of ≤80 ≥0.3µm particles/wafer. When this level was exceeded, maintenance intervened. We selected this particular furnace for our tests because it had a very poor track record for unscheduled PMs because of particles. In the month preceding the retrofit of the new pumping system, there were two occasions where the particle-control value was exceeded.

## New approach with furnace systems

We applied our pressure control approach, using variable speed pumps, with this troublesome LPCVD nitride deposition system. We removed the upstream pressure control MFCs and eliminated the use of nitrogen injection for pressure control. Instead, the ACS processed the furnace pressure signal. The furnace pressure was regulated by changing the pumping speed of the pumping system through regulating the rotational speed of the dry pump as well as the roots blower.

With the new approach, it was also possible to remove a bypass pumping line used for high pressure in situ chamber cleans. Having only one pumping line without bypass eliminates dead zones in the line where none of the cleaning gas flows and provides a more thorough clean for the entire vacuum line.

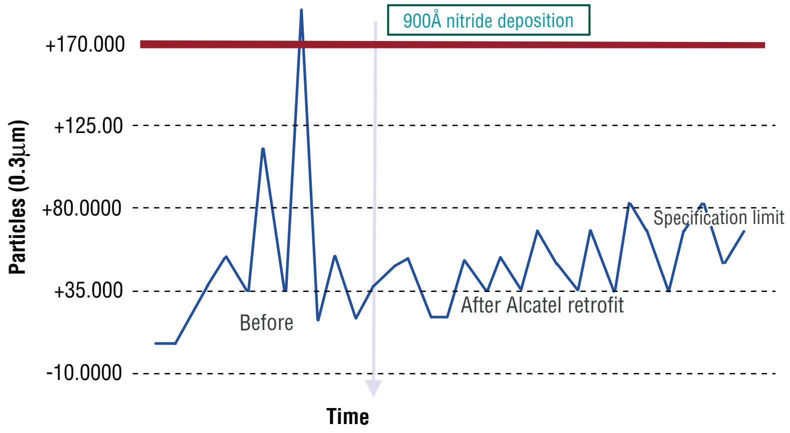

**Figure 5.** Rather than the wide excursions previously typical on the control charts from the furnace, the particle level remained within a much tighter range and showed only a gradual increase over time.

Eliminating the throttle valve on a furnace also stops the possibility of back diffusion of dry pump nitrogen-purge gas into the furnace during a process step change from low to high pressure, which can carry particles into the furnace. These phenomena can occur if furnace MFCs cannot supply enough flow to quickly stabilize the throttle valve position.

## Furnace results

After the retrofit, we documented a 14% decrease in average particle count measured on test wafers. More significant, however, was the process stabilization that resulted, achieving a CpK = 2.5 with the new process control system.

Rather than the wide excursions previously typical on the control charts from the furnace, the particle level remained within a much tighter range and showed only a gradual increase over time (Fig. 5). The control limit was not exceeded for over six weeks, compared to two occurrences in four weeks with the previous configuration.

## Conclusion

We have illustrated the suitability of a variable speed vacuum system as a production worthy alternative to traditional methods of chamber pressure control for aluminum etch and LPCVD nitride deposition. As process capable compact dry pumps become commercially available, an increasing number of applications will be suitable for the chamber pressure management pumping package described.

The single-wafer metal-etch tool upgrade allowed the elimination of a throttle valve close to the process chamber, thereby removing one source of contamination and tool downtime. Preliminary results also have demonstrated a potential enhancement in first pass wafer yield for a sub-0.25µm metal-etch process. A second phase of demonstration is underway that will verify the actual yield improvement and any long-term enhancements to tool availability and maintenance costs.

An LPCVD nitride furnace retrofit of the variable speed vacuum pumping system eliminated the need for upstream pressure control and nitrogen ballasting and significantly reduced particles. Improved process stability and an increase in the number of runs before maintenance intervention were achieved. A second phase is now in process and is focused on further reducing particles now that the process is under better control. A complete line and process analysis has been done to determine the optimum vacuum line design. This new line has been fabricated and installed, and includes selective heating of the vacuum manifold and a particle trap at the inlet of the dry pump.

In addition, other critical processes are under evaluation for this new approach to chamber pressure management. ■

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***KENNETH CALDWELL*** received his BS in mechanical engineering from Carnegie-Mellon University. He has been involved in the application, sales, and marketing of vacuum technology since 1980. Caldwell is semiconductor market manager at *Alcatel Vacuum Technology, 98 Ave. de Brogny, 74009 Annecy, France; ph 33/4-50 65-7777, fax 33/4-50 65-7582, e-mail ken.caldwell@an.cit.alcatel.fr.*