Point-of-Use Exhaust Control for Semiconductor Manufacturing: Saving Energy, Saving Money, Improving Yield

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Abstract
A means to reduce energy consumption while improving both operator safety and product yield is discussed. Furthermore, details of a simple, reliable, fail-safe system for reducing the overall flow of air through the facility are given.

Introduction
One of the greatest points of energy waste within a semiconductor cleanroom is the exhaust extraction system. This is in the main due to antiquated exhaust system designs. In recent years a better understanding of new and better designs is beginning to change IC manufacturers’ practices. IC manufacturers can now regard the level of yield achieved at process sign-off as a level that can be maintained indefinitely.

For atmospheric processes it is now possible to replace the historic practice of balancing and rebalancing a facility to satisfy yield and EH&S (environmental health and safety) issues with a “set-it-and-forget-it” policy. Many facilities now incorporate these changes into their energy conservation strategies.

Semiconductor fabrication is an energy-intensive manufacturing process, and recent studies by both SEMATECH and the United States Environmental Protection Agency (EPA) have identified the heating, ventilation, and air-conditioning (HVAC) system as the largest electricity consumer. During the process of transforming silicon into tiny, valuable semiconductors, these facilities must also process a river of air flowing through the building: 20 million pounds of air per day [1]. This huge quantity of air is known throughout the industry as “makeup air” (Figure 1), a name derived from the need to replace both clean and contaminated air removed by the exhaust system.

The Need to Reduce Air Flow
Makeup air entering the facility must be meticulously prepared, a process involving refrigerating it to remove moisture containing contaminants, then reheating, rehumidifying, and filtering the air to deliver it at precise specifications. In addition, in order to meet EPA standards, air leaving the facility may go through one of several abatement processes, such as burning or scrubbing, to remove toxins before release into the atmosphere.

The more air moving through the exhaust system, the greater the energy consumed by the makeup and abatement equipment. All experts agree that reducing the volume of air flowing through the HVAC system will directly reduce the facility’s energy consumption.

Facility managers can reduce this air flow by implementing two important conservation practices that are not possible with conventional HVAC designs: reducing excess exhaust flow and turning the exhaust flow down when the equipment is idle. (There is worldwide agreement that equipment is in stand-by mode more than 50% of the time.)
DRAWBACKS OF TRADITIONAL SYSTEMS

EH&S considerations have established adequate exhaust flow out of the cleanroom as essential to the safety and health of employees conducting processes there. This concept is simple. To guarantee a safe working environment, enough air must flow through an open process into the exhaust system to scavenge away all contaminated air and to prevent the air from backstreaming. But air pressure fluctuations in the exhaust system itself directly affect the exhaust flow rate and compromise scavenging capability. Traditional HVAC systems (Figure 2) cannot regulate the exhaust pressure or maintain consistent flow at the point of use, so they cannot guarantee that fluctuations will not drop the process exhaust flow into the unsafe range. Therefore, prudent HVAC practice dictates cleanroom exhaust flow levels that are significantly higher than is essential to maintain safety.

These exaggerated flow rates create excessive demands for the makeup air required to repressurize the cleanrooms. As a result, the equipment required to process this huge volume of air must be sized for the excess capacity. This equipment not only represents an inflated capital investment but also uses excessive amounts of energy. Traditional systems cannot regulate air flow more precisely, because of their basic design. Conventional exhaust systems control air flow with a combination of reactive electrical controls and fixed mechanical valves, the latter first developed for fireplaces in medieval castles known today as dampers or butterfly valves. These traditional hybrid systems use locked mechanical valves at the exhaust inputs and locate electronically controlled, variable-speed fans at the exhaust output. Such designs have major drawbacks.

When an unavoidable, usually man-made, fluctuation is introduced in a building exhaust system, these reactive systems respond slowly to correct the problem. They must first recognize the fault, then measure its magnitude, and finally, slowly correct it. By design, conventional, reactive systems let a problem develop at the exhaust input before they can acknowledge it and respond. During the time it takes to notice and correct the problem, product contamination and exposure of workers to health problems may arise.

The complexity of the exhaust network further hinders these hybrid systems. The exhaust network resembles a tree, with exhaust input points located at the tip of each branch (the tools) and the electronic control point (the output) at the opposite end, the trunk. The fan at the output pulls all the individual tools’ exhaust into one large river of air, an aggregate exhaust flow. At best, this design confines the electronic system to controlling the average flow from all collection points. To compensate for this design flaw and to avoid slowing production when exhaust fluctuations occur, current HVAC implementation plans use delay alarms and excessively high exhaust flow settings.

To further complicate matters, in conventional facilities, all equipment of the same type is interconnected.
through a common exhaust system using locked mechanical valves. This design creates two significant problems. Increasing the air flow in one device will decrease the air flow in adjacent systems, a phenomenon called “crosstalk.” Therefore, if a process requires changes between different flow rates to optimize yields or ensure safety, the exhaust flow at the tool level is impossible to balance. Furthermore, adding or removing any tool to or from the exhaust system requires rebalancing of the local system, a costly, non-productive process. Consequently, conserving energy by turning down the exhaust flow for an idle tool is impossible with this design.

**EXHAUST-BALANCING SYSTEMS**

However, an exhaust-balancing system (Figure 3) represents a completely different design that avoids all these drawbacks, as well as producing added advantages. FABS (Facilities Automated Balancing System) is a proactive system that isolates an individual process from pressure fluctuations in the house exhaust system. This system also treats crosstalk as just another form of pressure fluctuation and proactively eliminates the phenomenon. Therefore, it allows one to reduce exhaust flows (Figure 4), to fine-tune a critical process that requires multiple set points, and to turn down the exhaust level when equipment is idle.

The concept of this system puts active controllers (Figure 5) at each branch of the exhaust system (each point of use). This design for point-of-use control is based on a single mechanical part powered by air flow and gravity. When the air pressure within the building exhaust system fluctuates, a “floating piston” uses the energy of the fluctuation against itself and responds within milliseconds, creating stable pressure or flow at the process (Figure 6). Unlike mechanically locked valves, this point-of-use, proactive system corrects pressure fluctuations before they impair the process.

Installing a suitable process controller at the exhaust output of process equipment guarantees that one can precisely regulate the air flow at the points of use throughout the entire fab. Thus FABS allows the responsible process engineer to customize the exhaust flow rate for each step in the process to achieve maximum yield.

This system saves energy in three ways. Firstly, because one can now accurately regulate exhaust pressure fluctuations (from ±30% to ±2%), one can determine the minimum process or safety exhaust level and set the air flow at this level. It is no longer necessary to provide an additional 30% margin to compensate for low exhaust swings. Secondly, the excess volume flowing into the abatement equipment is reduced, and therefore the energy required to burn or scrub that exhaust is reduced. Thirdly, since the system corrects for crosstalk before it affects a process, it eliminates the need for a traditional damper lockout procedure. Now operators can turn down the exhaust when the equipment is in idle mode (from 100% to a possible 10%).

Moreover, FABS generates these savings while increasing product quality and yield. By assuring a smooth, uninterrupted, scavenging flow of contaminated air through the process, it can eliminate particle and vapour contamination at the source. As a result, it ensures a contamination-free environment, improving product quality and reducing wafer scrap.

The cost savings and operating benefits realized from this system extend beyond process control into other areas. Because it eliminates the time required to balance and rebalance the air flow systems, it reduces a facility’s time to first silicon, decreasing the time to market and minimizing facilities build-out.
Another operating benefit is that facilities no longer need to control the process air flow, but can merely deliver a minimum exhaust pressure. The process engineer controls flow at the point-of-use level, creating increased efficiency for both the process engineer and the facilities department.

**MONITORING AND CONTROL**

In addition, FABS provides centralized monitoring and real-time control of a complete exhaust management system via Progressive Technologies’ Supervisor (Figure 7). This is used at the point of use and comes with a large (2 inch by 6 inch) LCD display, which is an operator’s window into the process. Installing it at a process controller allows the operator to view a continuous 60 second graphic representation that shows exactly how the system is performing. The operator can examine the process pressure or exhaust flow. Then, if necessary, the operator can make real-time adjustments and see the system’s response. All Supervisors can now be interconnected and linked to the building management system, making fine-tuning an exhaust flow a simple process. Such flexible control is in stark contrast to today’s lockout policy.

**CONCLUSION**

Recent industry and government studies have focused attention on the value of increasing worker safety and decreasing the tonnage of greenhouse gases released during energy production [2]. The exhaust-balancing system described here promotes these goals while improving a facility’s competitive advantage. It is now possible to maximize yield and worker safety, while simultaneously reducing energy consumption and manufacturing costs. The design demonstrates responsible environmental citizenship and is consistent with the situation following the Kyoto Protocol.

**REFERENCES**


**ABOUT THE AUTHOR**

Dan has a BSEE from the University of Delaware, and a MSEE from the University of Michigan. He has 9 years of design and development experience in defense electronics and industrial control prior to joining PTI in 1992. At PTI he has held the positions of Applications Manager and Director of R&D. He has responsibility for new product development servicing end user, OEM and systems customer needs in the Semiconductor Industry as well as other airflow critical industries.

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