The Era of Nanoscale Fabrication: Protecting Yield Through High-Purity Chemical Transfer

ALMATEC® E2.0 SERIES AODD PUMPS ADDRESS THE CHALLENGES OF SHRINKING PROCESS NODES AND TIGHTENING CONTAMINATION TOLERANCES

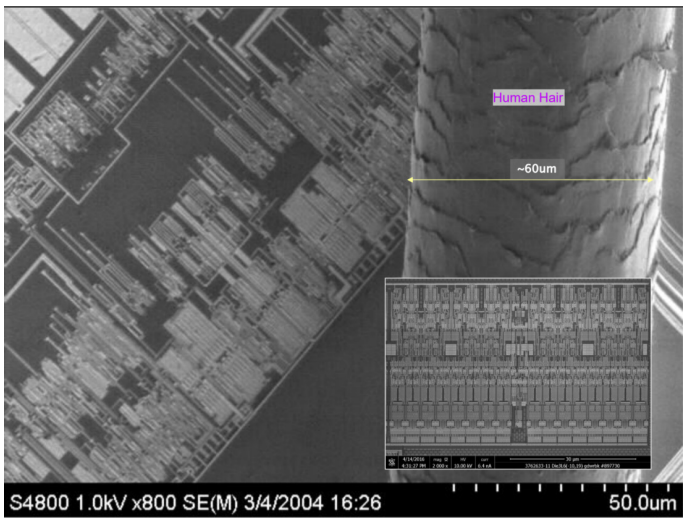
May 2026

By: Bruce Xu

Introduction

Semiconductor manufacturing has entered an era where dimensional tolerances are measured in single-digit nanometers. Advanced process nodes at 10 nm, 7 nm, 5 nm and below now require device structures that are thousands of times smaller than the diameter of a human hair (approximately 40 to 120 µm). At these scales, particles invisible to conventional inspection methods can create pattern defects, trigger electrical failures or even result in catastrophic yield loss. In fact, wafer surface contamination alone can account for up to 70% of total yield loss, according to the International Technology Roadmap for Semiconductors (ITRS).

As process nodes and device structures continue to shrink, controlling contamination becomes exponentially more challenging. Playing a vital role in helping to control contamination in these demanding



Invisible Precision: A Size Comparison Between Chip Circuit Structures and Human Hair

manufacturing processes are air-operated double-diaphragm (AODD) pumps. Today, AODD pumps that are engineered to deliver high-purity performance are more crucial than ever in helping semiconductor operations maintain operational reliability, process repeatability and yield protection.

This white paper examines how advanced AODD pumps are engineered to address the challenges posed by shrinking process nodes and tighter contamination tolerances in next-generation chemical transfer processes in semiconductor manufacturing.

Challenge

For decades, AODD pumps have been a trusted choice for transferring fluids in semiconductor manufacturing, thanks to their efficient and reliable operation. AODD pumps move fluid through a reciprocating cycle powered by compressed air. Air alternately fills the chambers behind two diaphragms connected by a shaft. As one diaphragm advances, it displaces fluid from the pump chamber, while the opposing diaphragm retracts to draw fluid into the pump chamber through check valves. This alternating motion produces a gentle, positive-displacement flow that is self-priming, capable of dry running and free of dynamic shaft seals. Because the process fluid remains isolated from the air drive and mechanical components, the design helps preserve chemical integrity and reduce the risk of contamination.

However, despite these advantages, semiconductor chemical delivery systems impose requirements that exceed the capabilities of conventional industrial AODD pump designs. Fluids such as photoresists, solvents, acids and etchants must be transferred with ultra-high purity, where even trace contamination can compromise wafer yield, damage process equipment or trigger costly downtime. Industrial-grade AODD pumps designed for general chemical handling often fall short in these ultra-clean environments because their materials, surface finishes and structural configurations are not optimized for contamination-sensitive processes.

Common pain points include:

- **Contamination risks** – Metallic wear, particle shedding and chemical residue accumulation can introduce impurities into sensitive processes.
- **Operational instability** – Flow pulsation and pressure fluctuations can lead to process variability and inconsistent chemical dosing.
- **Limited process repeatability** – Performance variability between cycles can undermine precision metrology and high-volume manufacturing consistency.
- **Maintenance-driven downtime** – Complex disassembly, limited serviceability and frequent diaphragm replacement increase operational costs and the risk of production interruptions.

Manufacturing Method: Five-Axis Computer Numerical Control (CNC) Precision Machining

To meet the increasing demands of nanoscale fabrication, some AODD pump manufacturers have developed more precise manufacturing methods in recent years. This is because the quality of pump components is just as important as the pump's design itself. Surface imperfections, inconsistent geometries or residual tool marks can lead to particle generation, chemical entrapment and contamination, all of which can compromise wafer yield or cause costly downtime.

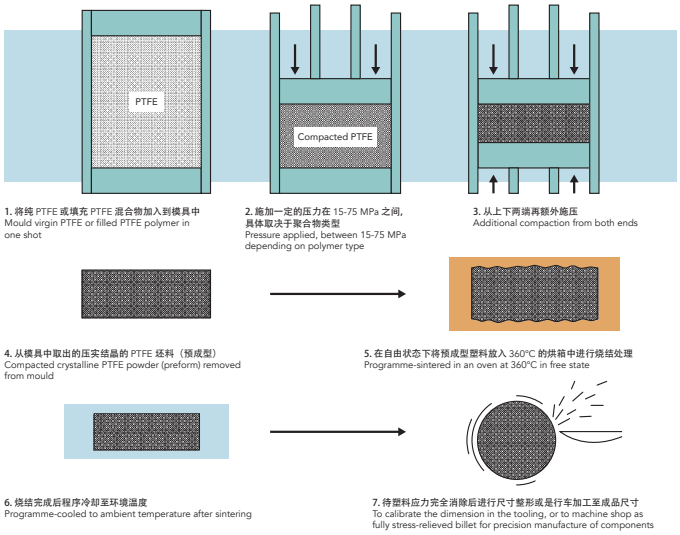
Traditional machining methods introduce variability that becomes increasingly problematic at nanoscale tolerances. Multiple setups can create alignment errors, resulting in rough surface transitions, ridges or microscopic pockets where particles accumulate. Repeated tool changes and handling increase the likelihood of embedding debris into critical wetted surfaces, elevating contamination risk. Inconsistent internal geometries can also complicate cleaning, sterilization and validation, ultimately affecting process reproducibility.

Five-axis CNC precision machining of critical wetted components directly addresses these challenges. By enabling complex internal geometries to be produced in fewer setups, this approach minimizes repeated clamping and repositioning common in conventional multi-step machining. The result is reduced tool changes and less handling, lowering the potential for surface defects. Continuous, uniform internal surfaces with smooth transitions decrease particle entrapment risk, while consistent surface conditions improve cleanability and support reliable, repeatable chemical transfer in demanding semiconductor applications.

With highly uniform and predictable internal geometries, AODD pumps help semiconductor manufacturers maintain process integrity, reduce contamination incidents and maximize throughput, turning precision machining into a direct contributor to yield and operational efficiency.

Material Selection: High-Purity PTFE Wetted System

In high-purity semiconductor processing, wetted components must resist corrosive chemicals, maintain dimensional stability and produce minimal particles. That's why it's crucial for AODD pumps to utilize wetted components made from high-purity PTFE sourced from leading global suppliers. PTFE is chemically inert against a wide range of aggressive chemicals and does not deform even above its melting point, making it ideal for ultra-high-purity applications.



Because PTFE does not flow above its melting point, it cannot be processed using conventional melt-based techniques. Instead, manufacturing PTFE components requires specialized forming and sintering methods. The material begins as a fine powder that is shaped through compression molding into a preform. That preform is then subjected to high-temperature sintering — a process similar to powder metallurgy, which fuses the particles into a dense, mechanically stable structure suitable for high-purity semiconductor applications.

After sintering, precision machining achieves the final component geometry, producing internal surfaces optimized for smooth flow and chemical compatibility. This methodology ensures:

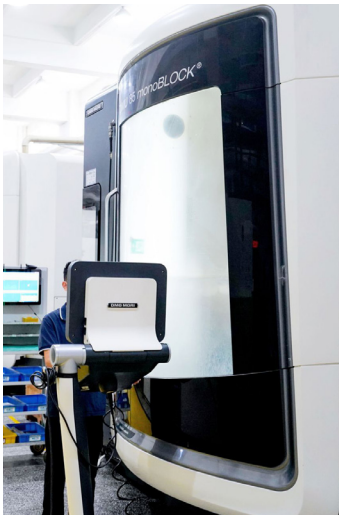
- High material purity free from contaminants
- Exceptional chemical resistance against corrosive media
- Structural stability for long-term operational reliability
- Optimal machinability for precise surface finishing and cleanability

By combining material selection with precision manufacturing, AODD pumps can minimize contamination risk and maintain process repeatability, a critical factor in semiconductor fabrication.

Structural Design

Operational Stability

Mechanical instability and uneven sealing forces in conventional pump designs can lead to diaphragm fatigue, leakage and particle generation — all of which threaten process consistency and wafer yield. Structurally optimized AODD pump designs address these risks by enhancing mechanical stability, sealing integrity and installation flexibility.



Optimized rigidity and advanced connection methods reduce operational vibration, lowering peak vibration amplitude by approximately 20%. This reduction decreases fatigue stress on critical components and supports long-term system reliability during continuous operation. A ring-fastening housing further improves performance by distributing clamping forces evenly across the diaphragm sealing surface, enhancing torque tolerance while reducing the likelihood of leaks or diaphragm damage during repeated cycling. In addition, standardized bottom-suction and top-discharge port configurations promote efficient drainage and process compatibility, while configurable center housings allow the pump to adapt to installation constraints without compromising structural integrity or performance.

Together, these structural enhancements minimize operational risk, extend service life and ensure consistent performance in high-purity semiconductor chemical transfer applications.

Human-Centered Optimization

AODD pumps used in high-purity semiconductor processes must support both process integrity and operator efficiency. Excessive maintenance complexity, difficult handling and poor ergonomic design can extend service time, increase contamination exposure and elevate the risk of handling errors within cleanroom environments. Pumps engineered with human-centered design principles help mitigate these risks while reinforcing cleanroom discipline and operational reliability.

A tool-free rotating drain structure enables faster, more thorough cleaning, reducing maintenance time and minimizing operator interaction with critical wetted areas. Integrated dual-side handling points provide a secure grip and controlled transport during installation or service, lowering the likelihood of accidental impact or mishandling. Reinforced packaging protects precision-machined components from transit and handling damage before installation, preserving surface integrity from the outset. In addition, QR-code traceability labeling enhances quality assurance by simplifying documentation, inspection and audit compliance, supporting the rigorous validation standards required in semiconductor manufacturing.

These features streamline routine maintenance, reduce handling risk and support contamination-control practices essential in semiconductor chemical-transfer operations.

Solution

E2.0 Series AODD Pumps from Almatec, a product brand of PSG, a Dover company, leverage decades of diaphragm pump innovation and market feedback to optimize performance in high-purity environments. Through five-axis CNC precision machining, high-purity PTFE wetted systems and optimized structural designs, the E2.0 Series is specifically engineered to meet the extreme purity, safety and reliability requirements of nano-scale semiconductor chemical transfer.

The E2.0 Series refines its AODD operating principle through advanced materials, precision manufacturing and structural optimization. Its solid PE or PTFE housing, diaphragm-less platen structure with metal-core isolation and exterior metal-free construction prevent contact between process media and structural components, safeguarding high-purity chemistries. The maintenance-free PERSWING P® air control system eliminates dead-center stalling while enabling smooth diaphragm actuation, reducing pulsation and ensuring consistent flow and pressure even under fluctuating process conditions.

In addition, structural innovations, including center block construction, optimized wall thicknesses, flanged connections and an innovative ring-tightening structure, enhance mechanical integrity and long-term dimensional stability. Upgraded fastening materials improve creep resistance, supporting consistent sealing performance over extended service intervals. Modular construction, recessed tie rods and ergonomic handling features simplify maintenance while minimizing exposure of wetted surfaces, reducing downtime and contamination risk.

Together, these design advancements deliver:

- **Minimized contamination risk** – Fully inert wetted materials, isolated diaphragm structure and precision surfaces prevent particle generation and chemical degradation.
- **Enhanced operational stability** – Smooth air-driven diaphragm motion, pulsation-control options and optimized flow paths ensure consistent delivery under varying process conditions.
- **Improved usability and serviceability** – Modular architecture, maintenance-free air control and accessible service features reduce downtime and protect critical surfaces.

With gentle displacement, infinite air-driven flow control and the ability to safely handle aggressive, high-purity chemicals, the E2.0 Series provides a robust, contamination-resistant pumping solution tailored to semiconductor manufacturing.

Conclusion

As advanced process nodes continue to shrink into the single-digit nanometer range, process purity, operational stability and integration reliability become crucial factors for yield and throughput. In these high-purity environments, AODD pumps play an even more important role in controlling contamination risks through chemical fluid transfer.

Application Case Studies

High-Purity Electronic Chemical Central Supply System

In advanced semiconductor fabrication facilities, centralized electronic chemical supply systems store, condition, meter and distribute ultra-high-purity process chemicals to multiple tools across the fab. These systems are foundational to wet process operations, where contamination control and flow stability directly influence defect density and yield.

Challenges

Centralized supply environments impose stringent performance and purity requirements. Conventional pump technologies may introduce risks through particle generation, elastomer degradation, metallic ion contamination or unstable transfer behavior.

Key operational challenges include:

- Maintaining ultra-low particle and ionic contamination levels
- Ensuring compatibility with aggressive electronic chemicals
- Achieving stable, repeatable performance across parallel pump arrays
- Supporting predictable flow for metering, batching and distribution
- Enabling safe, rapid maintenance without compromising cleanliness
- Integrating within enclosed cabinets and secondary containment systems

Almatec E2.0 Series AODD Pump Advantages

Within centralized supply architectures, the Almatec E2.0 Series can be installed in sealed cabinet systems to support continuous and batch chemical transfer while preserving process purity.

Performance advantages include:

- Contamination-controlled transfer enabled by inert PTFE-wetted components and non-metallic fluid paths
- Consistent flow across parallel pumps, supporting balanced distribution loops and redundancy strategies
- High-purity retention through smooth internal geometries that minimize particle traps and stagnant zones
- Operational resilience under continuous duty cycles and fluctuating demand
- Service-friendly design allowing maintenance without disturbing critical wetted surfaces or cabinet cleanliness

By combining chemical inertness with repeatable flow performance, the advanced diaphragm pump design of the E2.0 Series supports both purity assurance and operational reliability in centralized chemical delivery systems.

Chemical Distribution System (CDS) Integration

Chemical Distribution Systems (CDS) deliver electronic-grade chemicals from day tanks or small containers to point-of-use tools within compact, height-restricted cabinet environments. These systems must maintain chemical integrity while operating under dynamic demand conditions and frequent cycling driven by tool recipes.

Challenges

CDS installations present unique mechanical and operational constraints that can affect pump reliability and contamination control.

Common challenges include:

- Frequent start/stop cycles driven by intermittent tool demand
- Limited cabinet space and vertical clearance restrictions
- Cavitation risk during rapid cycling or low suction head conditions
- Residual chemical retention that may increase contamination risk
- Maintaining consistent delivery at low and moderate flow rates

E2.0 Series AODD Pump Advantages

The E2.0 Series is well-suited for CDS integration, enabling reliable chemical transfer while supporting purity and delivery stability in confined cabinet environments.

Performance advantages include:

- Reliable self-priming, ensuring dependable startup after container changeout
- Stable flow during frequent cycling, supporting repeatable tool performance
- Reduced cavitation risk through optimized diaphragm actuation and fluid dynamics
- Minimal residual retention (due to five-axis CNC precision machining), lowering contamination and cross-chemical interaction risks
- Compact footprint, enabling installation in high-density cabinet configurations

With precise engineering, compact design and consistent flow control, the E2.0 Series ensures reliable, contamination-minimized chemical transfer while maximizing uptime in tight CDS environments.

Through innovative design and engineering, AODD pumps are prepared to meet the demands of the nanoscale fabrication era. High-purity PTFE-wetted components ensure chemical inertness while minimizing the risk of particle generation. Five-axis CNC precision machining delivers consistent internal geometries that improve cleanability and reduce contamination traps. Vibration-reducing structural designs enhance operational stability, supporting process consistency in sensitive applications. At the same time, human-centered usability enhancements promote safer, more efficient maintenance, helping protect both equipment performance and uptime.

Engineered to perform across a wide range of high-purity semiconductor applications such as centralized chemical supply systems and compact CDS installations, AODD pumps support contamination control, process repeatability and system reliability. As tolerances tighten and process complexity grows, advanced AODD pump technology — such as the Almatec® E2.0 Series — will become increasingly important for protecting yield and supporting the ongoing progress of semiconductor manufacturing.

About the Author

Bruce Xu is a Product Manager for PSG Asia. He can be reached at bruce.xu@psgdover.com. PSG Asia is a leading provider of pump, metering and dispensing solutions, enabling the safe and efficient transfer of critical and valuable fluids in applications where performance and reliability matter most. It serves as a world-class manufacturing center for RedScrew and Blackmer® S Series Screw Pump technologies while supporting products from the Wilden, Quattroflow and Almatec brands. Serving customers across a wide range of industries, PSG Asia is committed to helping businesses improve efficiency, reduce energy consumption, and overcome complex fluid-handling challenges through innovative solutions and a customer-focused approach. PSG Asia is part of PSG, a Dover company. To learn more about PSG Asia, visit psgdover.com.cn.