

New Wafer Cleaning Methods

Require Advanced

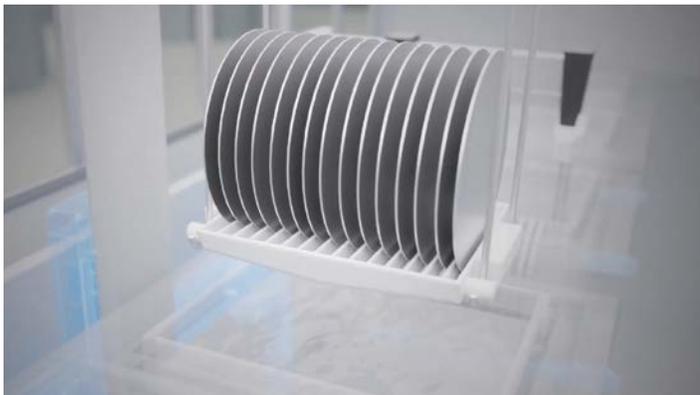
Automation Solutions



The semiconductor industry is projected to reach \$1 trillion in revenue by 2030, driven primarily by the growth of AI and cloud computing applications and increased demand for electric vehicles. To meet this increasing demand for semiconductors, manufacturers constantly strive to meet two competing goals: to pack more chips onto each wafer and to improve the percentage of defect-free chips per wafer, referred to as the yield. But manufacturing ever more chips on a single wafer requires that each chip be made of smaller, more complex features which, in turn, introduces new challenges in manufacturing and risks reducing yield.

One of these manufacturing challenges is how to effectively clean wafers that contain features – the elements that make up the circuits – as small as a few nanometers. And advanced chips such as 3D NAND – which use vertical structures to improve speed and reduce footprint – introduce even more complications for wafer cleaning, with hidden surfaces and the potential for pattern collapse. In fact, the importance of wafer cleaning – which was once viewed as less critical to chip manufacturing than processes such as lithography and deposition – has moved to the forefront of discussions as a key factor in fab throughput and yield.

As a result, manufacturers of wafer cleaning tools are working diligently to improve existing cleaning methods and to develop new methods that can effectively address these extremely small, complex features without damaging them.



▲ *As complexity increases and feature sizes decrease, wafer cleaning becomes more challenging – and more critical to throughput and yield.*

BATCH PROCESSING VERSUS SINGLE-WAFER CLEANING

Wafer cleaning is commonly done via batch processing, in which a cassette holding multiple (typically 25) wafers is transported between process tanks that contain various chemicals for cleaning, rinsing, and drying. This method not only supports high throughput, it also allows both sides of a wafer to be cleaned at the same time. But as the features on a wafer shrink and their complexity increases, the lack of precision and control in batch cleaning process begins to

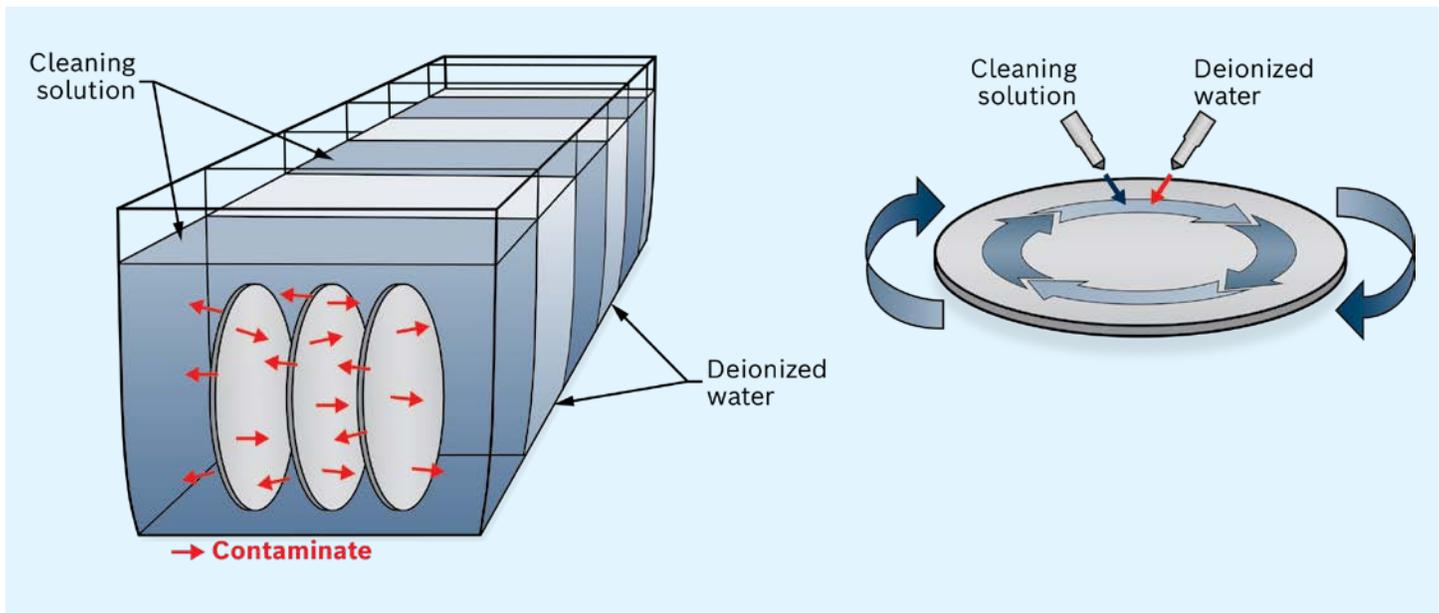
render this method ineffective. Because of this, manufacturers of advanced semiconductors and MEMS (microelectromechanical systems) are moving from batch cleaning systems to single-wafer cleaning for better effectiveness and improved yield.

With single-wafer cleaning, a wafer is placed on a spinning assembly inside a cleaning chamber, and the spinning wafer is sprayed with various solutions for cleaning, rinsing, and drying. The single-wafer cleaning process uses highly advanced algorithms and feedback to control every variable of the cleaning process, which results in more precise and uniform cleaning performance. Batch processing tools typically use an automated gantry system to move cassettes of wafers from one cleaning tank to the next. Semiconductor wafers are extremely valuable, and with each processing step, their value increases. This means that if the wafer handling system fails to perform correctly, it could turn an entire batch of wafers – worth hundreds of thousands of dollars – into scrap.

Although single-wafer cleaning systems handle just one wafer at a time, the wafer transport becomes even more critical, since the wafer is handled directly instead of being contained in a cassette. Any errors or variables – from mispositioning the wafer by just fractions of a millimeter to vibrations from the spinning assembly – could result in severe damage to the pattern features and significantly reduce yield. To address these risks – and the associated cost and yield impacts – manufacturers of wafer cleaning tools need handling and transport systems that can provide extremely smooth, precise, and reliable motion to avoid damaging wafers or interfering with the cleaning process.

CHALLENGES AND SOLUTIONS FOR WAFER HANDLING IN CLEANING APPLICATIONS

Whether in batch or single-wafer cleaning systems, the automation that handles and transports wafers needs to meet the requirements mentioned above for smooth, precision motion. But the automation system should also be able to withstand harsh chemical vapors and meet the



▲ Wafer cleaning has traditionally been done via batch processing (left), single-wafer cleaning (right) is becoming the preferred method for smaller, more complex feature sizes.

OEM's footprint constraints. And since cleaning can account for anywhere from 20 to 40 percent of wafer processing steps, if a cleaning tool becomes unavailable for even a few hours, it can significantly disrupt the fab's operation, making it critically important that automation systems are designed to operate for millions of cycles without failure or unplanned downtime. Take, for example, a lift and spin assembly, used in single-wafer processing to lift the wafer into the cleaning chamber and then spin it during the cleaning process.

To ensure that the wafer moves smoothly and precisely to the required position for cleaning, the lift axis needs to maintain a very tight motion trajectory with high stiffness. Then, once the wafer is in place, the spin axis needs to rotate the wafer at speeds of 2000 rpm or more with very low vibration. So viewing the system holistically – not just in terms of mechanical components and drive technologies – is critical. Take the balancing requirement, for example. The rotary motor, which spins the wafer, is balanced by the motor manufacturer during its production. But for this application, the entire spin assembly needs to be designed with balance and vibration in mind – so subtle design elements, such as the symmetry of the assembly, become especially important. For this type of application, the best solution is often a custom, electromechanical subassembly, which can be designed to meet the rigidity, vibration, and reliability targets, with a form and footprint that best fits the available space.

Custom subassemblies marry guide and drive technologies – such as linear guides and precision ball screws – with a drive and control scheme that can provide smooth, precise motion with the profile and settling parameters required by the application. Even the highest-performing mechanical systems will struggle to meet positioning and handling requirements if the drive and controller lack the bandwidth and speed necessary to produce the required motion profiles.

Wafer handling and positioning applications often require controls with advanced functions, such as gain scheduling, to compensate for friction, backlash, or system disturbances. And for real-time control and minimal jitter, manufacturers of semiconductor processing equipment – including cleaning tools – are transitioning from other fieldbus protocols to EtherCAT, which also provides the advantages of reduced network hardware and wiring costs. Some semiconductor tool manufacturers are also beginning to transition from hardware-based safety systems, which use components such as guards and sensors, to drive-based functional safety, such as the Fail Safe over EtherCAT (FSoE) protocol, which is suitable for safety applications up to the IEC 61508 SIL 3 level.

A manufacturer who has experience in wafer cleaning applications – and who understands the tool and processes – can approach the wafer handling system with a holistic view and design a subassembly that meets these design and performance criteria, along with other requirements that are unique to batch and single-wafer processing.

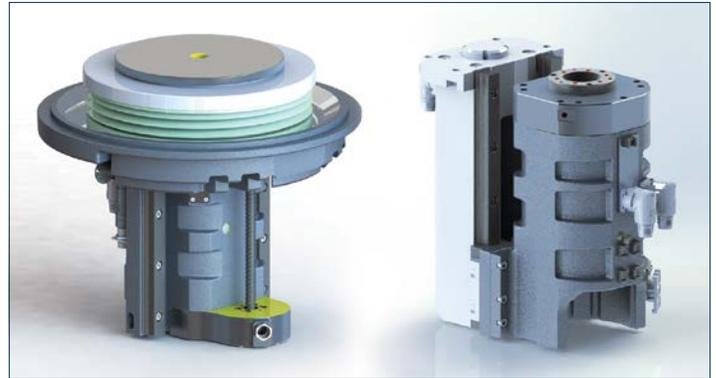
CASE STUDY: A BALANCED APPROACH TO HANDLING FOR SINGLE-WAFER CLEANING

For a single-wafer cleaning application, a customer needed an assembly to lift and spin individual wafers. To position the wafer correctly, the lift axis needed to be very rigid, with minimal deflection and extremely smooth motion. And because vibration would cause uneven distribution and agitation of the cleaning fluids, the spin axis had to meet a very stringent balance specification and exhibit low vibration, even at high rpm. The lift and spin assembly also had to fit into a tight space inside the tool, limiting both the size and the shape of its footprint.

Using our off-the-shelf linear motion components, motors, and drives, the design and application engineers at Rexroth's Semiconductor Center of Competence developed a custom lift and spin subassembly that met the customer's performance and reliability requirements and that was easy to install and remove from the tool.

By working closely with the customer, Rexroth's engineers also incorporated some very specific design requests, such as providing a feedthrough on the spin motor to accommodate plastic tubing and wiring that was necessary for the process. When the customer expressed that they wanted the ability to take a single chamber offline for maintenance while keeping the other chambers operating as normal, Rexroth engineers decided that it would be best

to use an individual controller at each chamber. To stay within the footprint constraints, compact high-power-density controllers designed specifically for this type of challenge were used. Each of these controllers interfaced with all the axes in its chamber – including servo motors, stepper motors, and I/O – and networked to the supervisory controller for coordination between chambers.



▲ Single-wafer cleaning involves lifting a wafer into position and then rotating it at high rpm for the cleaning process. A custom-built lift and spin assembly from Rexroth provides smooth, precise vertical positioning and a balanced rotating mechanism to ensure minimal vibration.

The lift and spin assembly was designed, prototyped, and tested at the Rexroth facility, in collaboration with the customer. This made design review and changes fast and efficient, ensuring an optimized end product that met the customer's cost targets and build schedule.

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