

Vacuum systems for ALD

EXECUTIVE OVERVIEW

Atomic layer deposition (ALD) processes require vacuum conditions both for proper deposition and adequate purging of precursors from the chamber. Since the ALD process is surface driven, the high percentages of unreacted precursors that exit process chambers will tend to deposit inside vacuum pumps, which can result in pump failures after <100 wafers. Because of inherently different reaction mechanisms, vacuum systems for CVD do not work for ALD. Therefore, new and sophisticated hardware is needed, including reactive gas injection and pumps dedicated to each different precursor.

The increased use of atomic layer deposition (ALD) across the semiconductor industry [1, 2] has resulted in new challenges for vacuum and abatement subsystems. A few 300mm ALD processes have exhibited pump lifetimes of <100 wafers. To obtain a viable ALD tool cost-of-ownership, the pump's lifetime often needs to be improved by more than 100-fold.

One of the main challenges of ALD processes is the amount of deposition inside the vacuum pump [3]. The deposit is conformal in nature and occurs evenly throughout the pump (Fig. 1), which is not observed in dry pumps used on CVD chambers. A conformal film inside the pump fills the micron-sized internal clearances and causes it to seize, and also causes restart failures. If the conformal film does not adhere to the pump's surface, an abrasive powder can form that erodes the internal components of the pump.

Systems previously developed for chemical vapor deposition (CVD) often cannot be used for ALD processes because they tend to increase the amount of deposition inside the pump. Achieving a 100-fold improvement of pump lifetime in a cost-effective manner requires creative engineering and strong applications knowledge.

Unique ALD vacuum challenges

The majority of ALD precursors pass unreacted to the process dry pump [4],

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where they saturate the internal surfaces in the same manner as the wafer's surface is saturated (Fig. 2). Temperature changes and nitrogen purges have both been shown to be ineffective at displacing the precursors from the pump's surfaces before the next precursor flows to the dry pump. Hotter pumps are generally not better for ALD applications, because they neither stop the ALD reaction

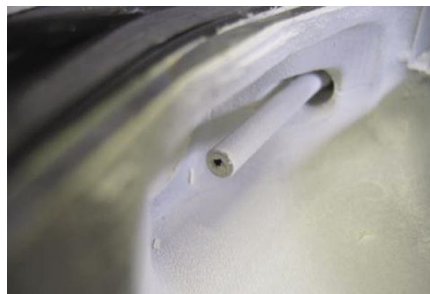


Figure 1. The conformal coating deposited on pumping surfaces used in ALD applications occurs evenly throughout the pump.

nor volatilize the film. In some applications, a hotter pump actually increases the amount of internal deposition.

Vacuum reliability issues observed during R&D may be vastly different from failure mechanisms observed in volume manufacturing. Significant delays can occur in a tool's transfer to manufacturing while it is proven as robust enough for high volume work. Also, pressure stability in the process chamber must be maintained regardless of the pumping solution.

All pumping mechanism types, i.e. screw, roots-claw, etc., are susceptible to the above issues. However, the details of the pump

design make some differences, such as clearances, materials, surface finishes, motor power, and monitoring. Field experience has shown that conditioning the chamber exhaust pre-pump makes the difference between a viable volume manufacturing solution and a nonviable one.

Since the problem is not one of dust handling or condensation prevention, two main approaches can be combined or used separately depending on the chemistry and ALD tool configuration: 1) preventing the precursors from reacting inside the pump, and/or 2) ensuring that the reaction is complete and by-products are managed outside the pump mechanism, i.e., with commonly used foreline traps [5].

Vacuum traps for ALD

While foreline traps are commonly used with other processes, many of these traps are not effective for ALD because they do not stop unreacted precursors. For a trap to be effective at preventing surface saturation of precursors inside the pump, it must react ~100% of the precursors inside the trap. To ensure that the reaction is complete often requires long residence times and significant conductance loss; CVD foreline traps typically do not provide enough residence time.

A reactive trap accelerates the reaction between the precursors to form solids, which are then trapped. The objective is to completely react out one precursor and then adequately trap the by-product. The trapping efficiency can be quite low if the pump can handle the by-product.

It is tempting to allow the deposit to form in the pump and to then use the same process chemistry (i.e. remote plasma cleans, etc.) that cleans the chamber to clean the pump. However, most in situ chamber cleans require plasma activation, i.e. fluorine radicals, and the complex structures and tight clearances in a vacuum pump create recombination surfaces so that most of the

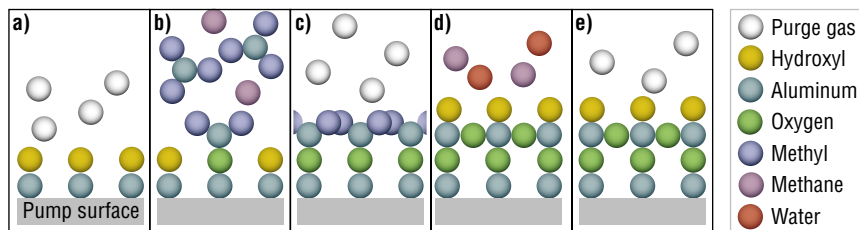


Figure 2. a) In the ALD process, a volatile precursor material adsorbs on exposed surfaces. The precursor is then exposed to a b) second chemical agent that c) converts it to its final stable form d) and e). The process is just as efficient on pump surfaces as it is on wafers, resulting in significant build-up and shortened pump lifetimes.

radicals do not reach the parts that need to be cleaned. Depending on the specific depositions that need to be removed, a nonactive etchant may be available to clean the pump.

ALD vacuum systems

Preventing the deposition reaction from occurring inside the pump also maximizes the lifetime, with approaches including a reactive gas injection system (ReGIS) and an alternating diverting system (ALDiS) developed by BOC Edwards. A divert pump may also prevent deposition, depending on the process chemistries and tool architectures.

ReGIS injects a gas that reacts with the ALD precursor(s) to form volatile chemical species. Since the by-products are volatile, the ReGIS prevents a thin film from forming inside the pump, which increases the lifetime. The injected gas's reaction with the precursors must be thermodynamically favored over the ALD deposition reaction. The system is currently installed worldwide on tungsten nitride chambers, and has demonstrated a 200-fold increase in pump lifetime. It was developed for this application because the process pressure was too low for traps to be effective.

Excess precursor can flow to a separate pump instead of the process pump. The separate pump is often called a "divert pump" because the excess precursor is being diverted from the process pump. Often one divert pump is used

per ALD precursor. Divert pumping has been shown to increase pump lifetime 10-fold. For example, a W-ALD chamber pump's lifetime was increased from 15,000 wafers to 150,000 wafers after a divert pump was installed.

For batch ALD tools, ALDiS is a diversion system that includes two pumps and an integrated valve optimized for ALD (Fig. 3). The valve switches between each pump in unison with the switching of the precursor flow into the batch reactor so that each pump sees only one precursor. This design prevents precursors from reacting inside the pump and avoids exhaust line blockages. The system is effective for batch tools because there is a long enough purge time between precursors to allow for switching between the pumps.

Several ALD processes use plasma to facilitate the deposition reaction at lower temperatures. In some of these plasma-enhanced ALD processes, the wafer surface and chamber gas

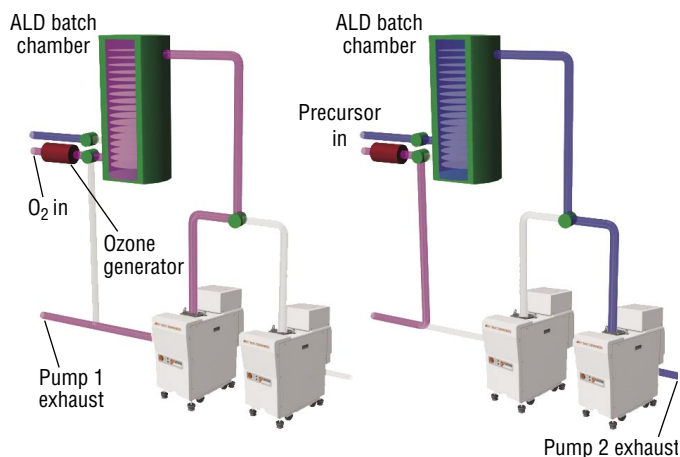


Figure 3. The ALDiS (alternating diverting system) uses separate pumps for each precursor. A valve automatically switches pumps as the ALD process switches between precursors. This solution is appropriate for batch ALD processes that have relatively long purge cycles.

temperature are too cold for any reaction to take place without plasma activation. It follows that there may be no need to purge the chamber

between precursor injections pulses, which would increase wafer throughput. Also, the pump temperature may be kept low enough to prevent reaction between precursors on the inner surfaces, depending on the specific materials. If the materials will react on the pump surfaces, the option of switching precursors to separate pumps is not viable.

Many of the issues faced by vacuum pumps also adversely affect the exhaust management system. In addition, the ALD precursors' complex chemical structures require innovative combustor designs to ensure complete destruction. Integrated vacuum and abatement subsystems provide a platform for monitoring pump and abatement system conditions.

Conclusion

There is no single "magic bullet" vacuum solution for ALD. Each ALD process may require a unique approach, and different OEMs may also require unique systems because of tool architecture variances. The drivers behind selecting the best technique include maximization of tool uptime and pump reliability, lowest CoO, footprint, and process stability. ■

References

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