Industry Observation

Understanding the integrated vacuum challenges of HVM EUV Lithography

David Engerran, Edwards Vacuum

2020 WILL BE REMEMBERED FOR MANY things. Certainly, among them in our industry will be the growing acceptance of extreme ultraviolet (EUV) lithography in high volume manufacturing (HVM) at the most advanced nodes. EUV lithography allows manufacturers to continue the reduction of feature and device sizes that has defined progress in semiconductor manufacturing from its earliest days. However, the investment required to use EUV in HVM puts tremendous pressure on manufacturers to maximize output to achieve an acceptable return. The overall throughput of the system is essentially fixed, so efforts to ensure ROI must focus on maximizing system availability and minimizing operating costs.

The use of shorter wavelength EUV illumination enables the creation of smaller features, but also makes the lithography system much more complex. EUV light is strongly absorbed by any matter and requires the use of reflective optics, a more powerful source, and, the focus of this article, vacuum containment of the entire beam path. The vacuum requirement is further complicated by the use of hydrogen to remove contaminants (primarily tin originating in the tin laser plasma source) from the surfaces of the critical mirrors that shape and focus the beam. The vacuum system must therefore be able to pump high volumes of hydrogen while maintaining the required vacuum levels.

Edwards position in the EUV market is unique. We have been involved in the technology's development and deployment for over 20 years. We have shipped more than 120 systems over the last 11 years and have more than 70 integrated systems currently installed, providing both vacuum and abatement for EUV processes. In 2017 we opened an advanced manufacturing facility for EUV vacuum systems in Cheonan, South Korea. We have strategically located service technology centers close to EUV customers around the world, from which we can dispatch experienced service personnel and provide advanced technical support. We are intimately familiar with the industry's EUV technology roadmap and have longstanding working relationships with EUV system providers. One lesson that we have drawn from this long and deep experience with EUV lithography is that success requires much more than the ability to pump a lot of hydrogen.

Maximizing availability

EUV lithography is the beating heart of next generation semiconductor manufacturing processes. Just as all blood flows through the heart, every layer in an IC begins with lithography. The lithography system must run all the time, and if it stops, so does everything else. Lithography throughput effectively gates production capacity, but the cost of additional capacity is very high, making lithography system availability the key to success. From our point of view in the sub-fab, maximizing availability requires, at a minimum, that all vacuum system maintenance is performed in the shadow of EUV system maintenance. This becomes increasingly challenging as EUV systems mature and their maintenance windows shrink. Ensuring that sub-fab systems do not impact EUV availability through unplanned down events starts with designed-in reliability and redundancy — pumps must not fail unpredictably. And if one does, the vacuum system and the EUV system it supports must be able to continue operating. Our EUV Zenith systems include hot-swappable pumps for fail-safe backup, and major maintenance procedures can be performed while the system remains online. All systems are designed for fast, efficient maintenance and use sophisticated analytics to predict the need for intervention. The latest data available at this writing confirm 99.9% average availability over all our integrated vacuum and exhaust management systems supporting EUV processes.

Continued from page 32

Minimizing Cost of Ownership

The footprint of a process tool largely determines its share of facility costs and ultimately, the productive capacity of a fab. For EUV systems, the sub-fab footprint of vacuum, exhaust management, laser, and other supporting equipment may be significantly greater than the footprint of the tool itself in the fab. The sub-fab footprint therefore determines the apportionment of facility costs and limits the number of systems in the fab. For example, in a fab with 20 EUV tools, a 10% reduction in sub-fab footprint might make room two more tools, distributing the cost of the building and similar shared assets over a greater number of devices. Improvements in pump and system design in our third-generation systems provide up to 20% reduction in system length compared to our second-generation systems with the same hydrogen pumping capacity. Other cost reducing advances in the third-generation systems include a 45% reduction in total energy equivalence and the ability to increase pumping capacity by simply adding a module using pre-plumbed connections in the initial system.

Ensuring safety

Safety is paramount. Designing safety into a system requires experience. Only experience allows the discovery of unforeseen or unforeseeable hazards. An excess of sensors and alarms may indicate a lack of understanding more than a guarantee of safety. Safety comes from careful monitoring of foreseeable vulnerabilities. In our systems, we also provide full containment within an interlocked safety enclosure to provide an extra layer of protection against unforeseen hazards.

The art of innovation lies in finding ways to ensure the safety of fab personnel, the surrounding community, and the environment, while also enhancing efficiency and reducing costs. EUV uses a lot of hydrogen and many of the safety concerns focus on hydrogen's high flammability. Traditional approaches include controlled burning and dilution. Controlled burning in a fuel-fired flame eliminates the flammability concerns but requires fuel gas, other utilities, and regular maintenance and emits carbon to the environment. Dilution is a well understood technology, but the large quantities of nitrogen needed may be cost-prohibitive.

Our fuel-free approach addresses the disadvantages of controlled burning and dilution while ensuring the safety of people and the environment. Fortunately, hydrogen itself has no negative environmental impact. Once its concentration is below the minimum flammability level, it is quite safe. Fuel-free hydrogen management relies on a keen understanding of flammability levels, dilution technologies and industry safety standards. The critical operation is the dilution of hydrogen with air, a counterintuitive approach. However, by keeping the critical path, where the mixture is flammable, very short and carefully monitored the gas is quickly diluted to nonflammable concentrations that can be safely conveyed through the fab and released directly into the atmosphere. Fuel-free hydrogen management eliminates the fuel cost and carbon emissions of controlled burning and the high cost of nitrogen for dilution.

Next generation EUV Lithography

We have been intimately involved in the evolution of EUV technology and we know from that experience that it will surely continue to change. We are especially focused on projects to add intelligence to sub-fab operations. These include the ability to respond automatically when a signal from the lithography tool indicates hydrogen has been disabled; the ability to automatically reconfigure the system to switch between standard-flow and high-flow particle flushing procedures; enhanced system monitoring and diagnostics to support predictive maintenance; and a next generation integrated control system to enhance the user experience and data handling capabilities, simplify system control, and prevent future obsolescence of legacy controllers and components.

Ultimately it is about managing risk

While practical choices about sub-fab support for EUV lithography may focus on maximizing availability and minimizing operating costs, but both must be viewed through the lens of risk management. Certainly, among the most important considerations in evaluating risk are the experience and domain knowledge of the solution provider. What programs do they have in place for data collection and evidence-based continuous improvement? What track record can they offer for demonstrated product performance and support? What relationships do they have with critical partners, i.e., the EUV lithography manufacturer? How are they positioned geographically and logistically to maintain their systems and respond to emergencies? What does their history say about their capacity for and commitment to innovation? The answers to these questions and more like them are critical in determining the likelihood and potential costs of failure and recovery in any risk analysis. They are especially important for systems supporting EUV lithography, where the costs of unplanned downtime can be so high. SD