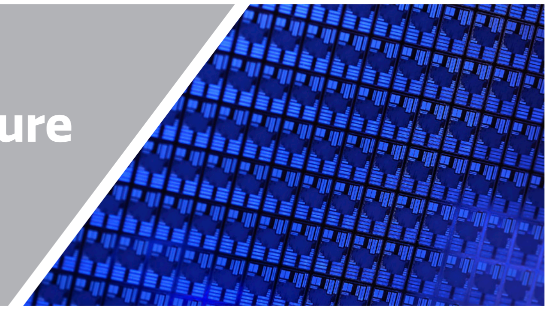
Application Note #23

Moisture Monitoring in Low-Temperature Silicon-Germanium Epitaxy

HALO QRP



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Low-Temperature Epitaxy for Advanced Semiconductor Devices

Moore's Law has guided the miniaturization of mainstream semiconductor device development for decades. With the move towards more and more mobile applications, modern semiconductor devices face the simultaneous challenges of running faster and cooler whilst consuming less power than ever before. As the industry moves "beyond Moore's Law", some of the upcoming applications re-shaping our world include:

- The "Internet of Things" (IoT), connecting homes, automobiles, and wireless devices through cloud-based services
- Interconnected traffic control systems and self-driving vehicles, which are seen as the future of transportation
- Smart power grids to tackle the challenge of diversified and more localized power generation and wider distribution
- Advanced satellite technology and autonomous weapons systems for security and defense

With the shrinking feature size of semiconductor devices, yet increased capability demand, even more controlled and precise manufacturing techniques will be required in advanced semiconductor processing. Low-temperature epitaxy is a key technology to provide the required level of device performance. However, contamination can negate all the advantages of the process. Oxide contamination prior to or during the deposition process, in particular, can cause dislocations and other related defects in the deposited Si_xGe_y layers. For the manufacturer, this means defective devices, leading to decreased yields and shrinking profit margins.

An Oxygen Problem or a Moisture Problem?

Oxide formation on the substrate results from the reaction with oxygen (O_2) and moisture (H_2O) contaminants. Leaks in the chamber or the gas handling system are common sources of contamination, especially for oxygen, which is very abundant in air. With the shift to lower deposition temperatures and pressures, however, H_2O has to be considered the main culprit for oxide contamination. While years ago 850°C was considered "low-temperature", nowadays some processes are pushing temperatures to below 500°C with dramatic consequences for the required gas and chamber purity. Moisture poses a particular challenge due to its "sticky" behavior at lower temperatures. In addition, modern epitaxy

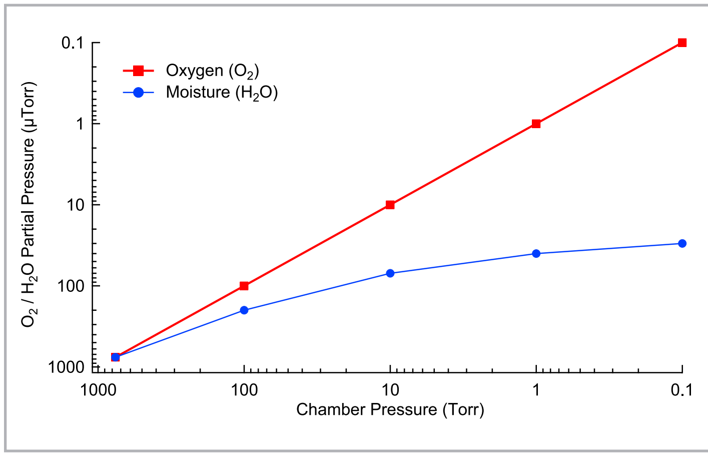

Fig. 1 Behavior of oxygen and moisture during chamber evacuation

tools operate at significantly reduced pressures (10 Torr and below), exacerbating the importance of H_2O monitoring. Figure 1 illustrates this issue: Assuming that the chamber initially contains the same concentration of O_2 and H_2O (here, 1 ppm_v) at atmospheric pressure, these two molecules behave entirely different when the chamber is evacuated. While O_2 is readily removed with the background gas, H_2O is removed at a much slower rate. The discrepancy between the partial pressures of O_2 and H_2O in the chamber becomes larger the lower the pressure. At ~10 Torr or below, moisture is completely dominating as a contaminant and remains in the chamber long after O_2 has been removed. It is apparent that under these conditions, H_2O monitoring is vital to ensure that the chamber is clean and ready for the start of the deposition process.

The HALO QRP and Epitaxy Tool Integration

In response to the need for process chamber moisture monitoring at lower pressure, Tiger Optics developed the HALO QRP. Based on Tiger's proven Cavity Ring-Down Spectroscopy (CRDS) technology, the HALO QRP has a much lower operating pressure range and improved measurement precision compared to previous generation analyzers. Optimized for monitoring in the low-Torr pressure range, the HALO QRP is the ideal H_2O real-time monitoring solution for modern epitaxy cluster tools. Its wide pressure range and fast speed of response allows tool integration with a manifold system to monitor all different chambers on the tool in unison with the process sequence. Figure 2 shows how the HALO QRP can be

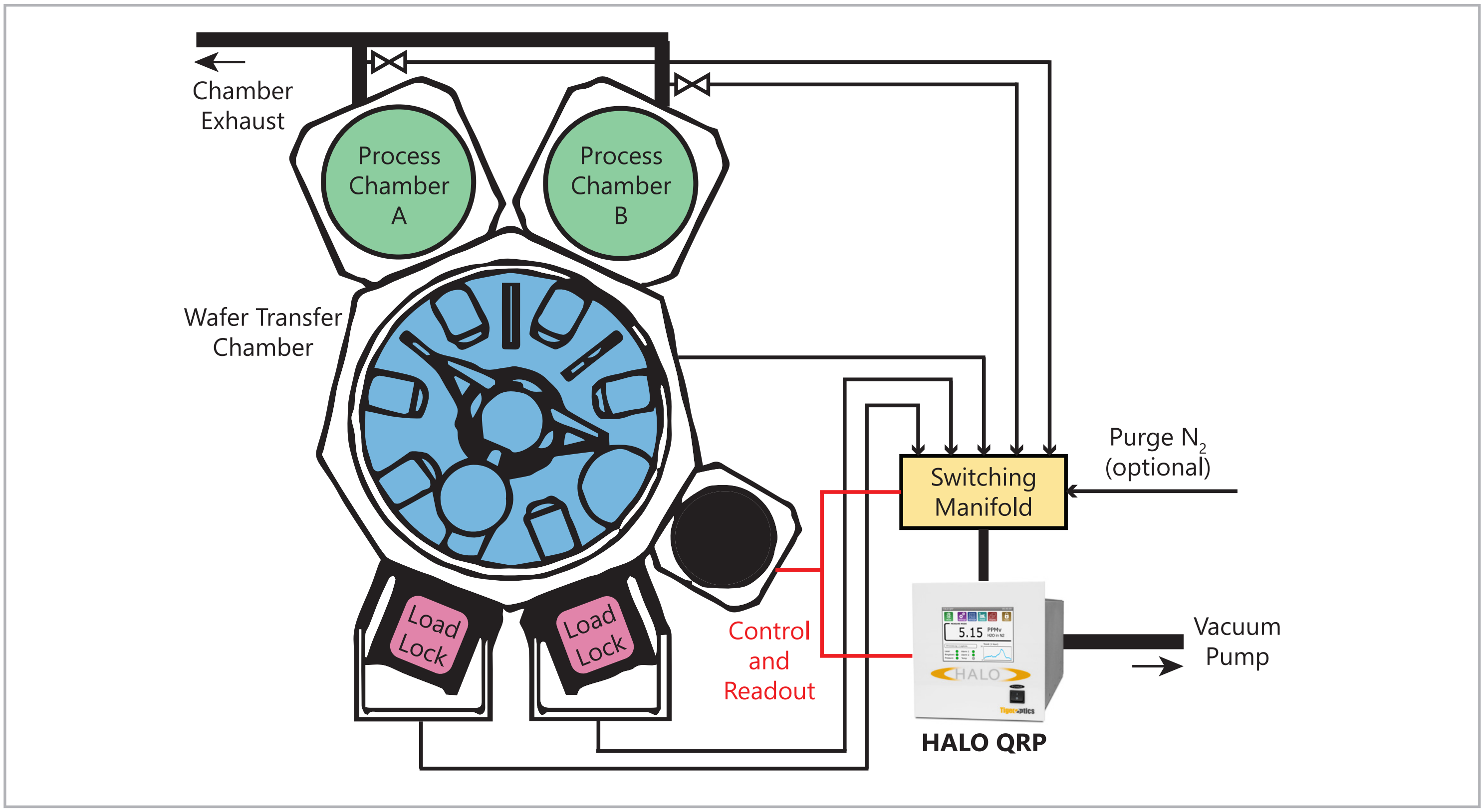

Fig. 2 HALO QRP integration on a typical epitaxy cluster tool

integrated into the epitaxy tool to verify moisture levels in the load locks, the wafer transfer chamber, and the deposition chambers after each cleaning and purge step and—most importantly—before the deposition process is initiated. The tool control software can directly communicate with the HALO QRP and the manifold, so the moisture measurement can be integrated seamlessly into the process sequence.

The HALO QRP is able to measure residual moisture levels in most purge and cleaning gases used in load lock, wafer transfer and deposition chambers, including nitrogen (N_2), hydrogen (H_2), helium (He), chlorine (Cl_2) and hydrogen chloride (HCl).

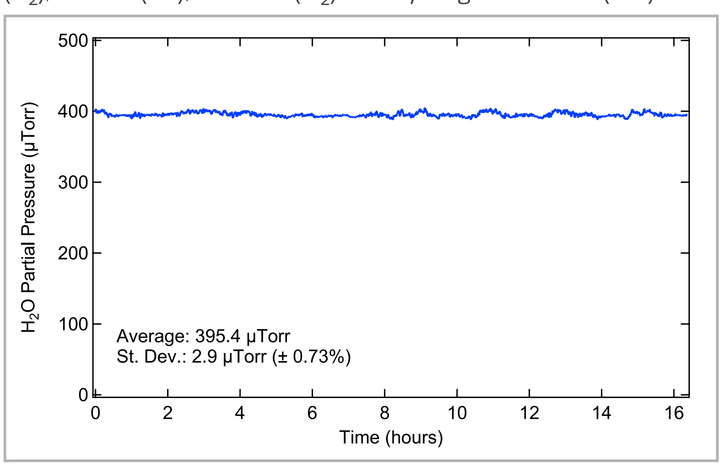

Fig. 3 HALO QRP measurement of 400 $\mu Torr_{pp}$ H_2O at 10 Torr

How to Optimize your Process with the HALO QRP

A combination of baking and purging is the two most common but slow way to remove moisture from the chamber. The importance of these steps increases dramatically in the low-temperature and low-pressure environment of modern epitaxy tools. Without suitable monitoring technology, the user can only determine the effectiveness of the baking and purging after the fact, which means by checking the wafers for defects after the process. At this point, the damage is already done and the wafers have to be discarded. To minimize the risk of wafer defects, users may choose to "play it safe" and introduce excess bake and purge steps, which cost time and money, especially on overall capacity-limiting bottleneck applications.

Tiger Optics' HALO QRP is the ideal solution to optimize this process. By exactly measuring residual moisture in the chamber during and after cleaning or purge steps, users can determine the exact moment when H_2O partial pressure in the chamber is sufficiently reduced to ensure a good process. By communicating with the tool control software and the switching manifold, the HALO QRP can monitor each process step and report real-time moisture concentration back to the tool control system to make safe and exact go/no-go decisions to prevent wafer defects, tool downtime, and wasted time and purge gas.

HALO QRP Performance and Ease-of-Use

The HALO QRP extends the operating range of Tiger's proven moisture analyzers to much lower pressure than previous analyzer generations. While the established HALO RP is limited to 50 Torr, the HALO QRP easily operates at 1 Torr or less. Figure 3 shows an example of a measurement of 400 μ$Torr_{pp}$ H_2O at 10 Torr. At this level of H_2O, the QRP operates significantly above its lower detection limit and yet way below its upper detection limit, which underscores the analyzer's large dynamic range. The QRP sets benchmarks in accuracy, precision and long-term stability. It also offers maximum versatility by operating as high as 100 Torr, with operation at atmospheric pressure (760 Torr) and higher as an option. Residual H_2O of 1 μTorr partial pressure and below is measured reliably over the HALO QRP's entire standard operating pressure range. While traditional instruments, such as residual gas analyzers, offer a more qualitative check of the overall chamber condition, the HALO QRP delivers highly specific and quantitative information regarding the presence of H_2O molecules, the most critical contaminant for modern low-temperature epitaxy.

The HALO QRP's installation is also extremely simple and does not require differential pumping or turbo molecular pumps. The house vacuum in most semiconductor fabs or stand-alone roots or scroll pumps are sufficient to operate the HALO QRP. The analyzer can communicate with the tool via serial connection or Ethernet, and the available touchscreen interface offers additional flexibility and ease-of-use for stand-alone or R&D use.

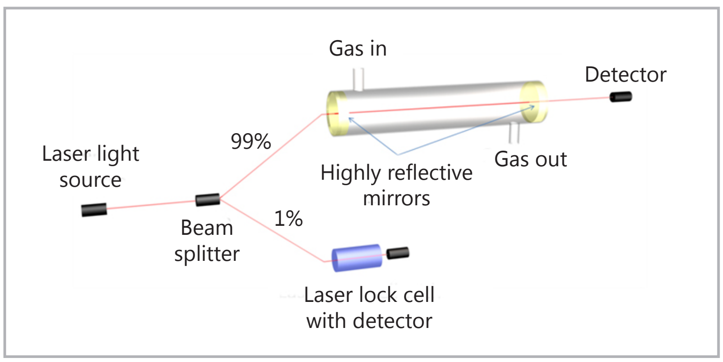

Fig. 4 Principle of Cavity Ring-Down Spectroscopy

Cavity Ring-Down Spectroscopy

All Tiger Optics instruments are based on CRDS. The key components of the CRDS system are shown in Figure 4.

CRDS works by tuning laser light to a unique molecular fingerprint of the sample species. By measuring the time it takes the light to decay or "ring-down", you receive an accurate molecular count in milliseconds. The time of light decay, in essence, provides an exact, non-invasive, and rapid means to detect contaminants.

Tiger Optics Overview

Tiger Optics introduced the world's first commercial CRDS analyzer in 2001. Today, our instruments monitor thousands of critical points for industrial and scientific applications. They also serve the world's national metrology institutes, where they function as transfer standards for the qualification of calibration and zero gases.

First ISO-Certified CRDS Company

Tiger Optics is the first CRDS Company certified to the ISO 9001:2008 and the current ISO 9001:2015 standard of process consistency and continuous quality improvement.

Tiger Optics, LLC
275 Gibraltar Road, Horsham, PA 19044
Phone: +1 (215) 656 4000 · Fax: +1 (215) 343 7168
sales@tigeroptics.com · www.tigeroptics.com

A Process Insights Company