This application note discusses how Tiger Optics’ ultra-trace moisture analyzers help semiconductor manufacturers ensure purity of their bulk gases. We take a look at the drivers for the semiconductor industry pushing analyzer performance to new heights, and we show how Tiger’s latest H₂O analyzer, the HALO KA Max H₂O, meets this challenge by reaching unprecedented levels of detection sensitivity and speed of response.

Modern Applications Propelling Semiconductor Manufacturing

The semiconductor market is seeing a new era of innovation, with new applications fueling demand for advanced semiconductor devices that put more stringent requirements on reliability, power handling capability and power consumption, while packing more functionality into a smaller package and decreasing technology nodes. Among these demanding applications are increasingly more powerful smartphones and tablets that aim—at the same time—to improve battery life. More recently, automotive sensor systems, the Internet of Things (IoT), the next generation of wireless communication (5G), and smart power grids have emerged as applications with enormous expansion potential over the coming years and decades. Future self-driving vehicles (as illustrated in Figure 1), for instance, require massive amounts of computing power to process the input from cameras and sensors in real-time; and the necessary high-performance processors must be both reliable and power-efficient.

The Demand for Higher-Quality Gases and Better Analytics

To meet the challenges of these new applications, the semiconductor industry’s International Roadmap for Devices and Systems (IRDS) outlines manufacturing quality as one key aspect; therefore, semiconductor device manufacturers are implementing more stringent control into all aspects of the manufacturing process, from the cleanroom environment and the wafer processing tools to the raw materials used for production, many of which are gases. Consequently, improved gas quality control is one of the most important measures that are employed by semiconductor fabs to increase yields and reduce failure rates.

With the need to monitor and ensure stricter and more consistent gas quality comes a demand for more sensitive and accurate analytical technologies. At the same time, speed of response has become more important as well, as fab operators rely heavily on real-time process control to increase throughput.

Tiger Optics has been serving the semiconductor industry since its inception in 2001 with its array of laser-based moisture analyzers. In many state-of-the-art semi fabs, Tiger’s Cavity Ring-Down Spectroscopy (CRDS) analyzers are the gold standard for ensuring quality of the major bulk gases that are used in the manufacturing process, which are typically N₂, CDA, O₂, H₂, Ar, and He. With H₂O as one of the most critical gas impurities, Tiger’s analyzers serve a crucial role in the fab due to their ultimate sensitivity, fast speed of response, and excellent reliability.

A Sticky Situation—The Difficulty of Trace H₂O Detection

H₂O is a high priority for gas quality control in a fab, as it is very destructive to processes and one of the most difficult contaminants to avoid due to its prevalence. From an analytical point of view, moisture detection in gases tends to be a difficult task owing to the molecule’s tendency to stick to surfaces. For analytical techniques that rely on physical interaction with the H₂O molecule, it is therefore very hard to achieve fast speed of response. Furthermore, detection limit requirements are stringent for semiconductor device manufacturing, ranging from low-part-per-billion (ppb) levels down to well into the...
parts-per-trillion (ppt), which is beyond the sensitivity limit of many trace detection technologies.

The most critical aspects of a successful moisture measurement for this application are:
1. Sensitivity & Accuracy of Zero Baseline
2. Baseline Stability
3. Speed of Response

Accuracy of Zero Baseline
Having a true zero is essential to ensure the analyzer’s baseline accuracy. Most traditional analyzers rely on a zero gas to calibrate the instrument’s baseline. But at ppt-levels of H\textsubscript{2}O, is there really such a thing as a “zero gas”? While modern purifiers are quite effective in removing moisture, such low H\textsubscript{2}O levels are typically below most purifiers' manufacturer specifications. Consequently, measurement techniques that rely on calibration using a zero gas can struggle to obtain an accurate zero due to the difficulty of removing H\textsubscript{2}O completely from the “zero gas”. In contrast, Tiger’s CRDS systems do not rely on a zero gas measurement to obtain the instrument’s zero calibration. Tiger’s analyzers use a “spectroscopic zero”, a wavelength where H\textsubscript{2}O does not absorb, to determine the true measurement baseline, independent of the presence of H\textsubscript{2}O in the gas. During measurement operation, the analyzer continuously references the concentration readings against this true zero to maintain absolute accuracy.

Baseline Stability
Another critical aspect of trace moisture measurement is the long-term stability of an instrument’s zero. Most traditional analyzers experience drift in their calibration, which requires periodic “re-zeroing” of the analyzer. So what happens if the zero gas is slowly increasing its moisture content? Such a “moisture creep” can easily be caused by a failing purifier; and a slow rise in H\textsubscript{2}O may be indistinguishable from instrument drift. In this case, the periodic zeroing of the analyzer leads to a moving offset that can mask a slow but real increase in moisture levels in your sample gas. Thus, a potential threat to your process can become undetectable.

Sensitivity & Accuracy of Zero Baseline

Tab. 1 HALO KA Max H\textsubscript{2}O and HALO KA H\textsubscript{2}O detection specifications

<table>
<thead>
<tr>
<th>Gas Matrix</th>
<th>HALO KA Max H\textsubscript{2}O</th>
<th>HALO KA H\textsubscript{2}O</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Detection Limit (LDL)*</td>
<td>Precision (σ) @ zero</td>
</tr>
<tr>
<td>In N\textsubscript{2}</td>
<td>100 ppt</td>
<td>40 ppt</td>
</tr>
<tr>
<td>In He</td>
<td>100 ppt</td>
<td>10 ppt</td>
</tr>
<tr>
<td>In Ar</td>
<td>100 ppt</td>
<td>20 ppt</td>
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<tr>
<td>In H\textsubscript{2}</td>
<td>100 ppt</td>
<td>30 ppt</td>
</tr>
<tr>
<td>In O\textsubscript{2}</td>
<td>100 ppt</td>
<td>20 ppt</td>
</tr>
<tr>
<td>In CDA</td>
<td>100 ppt</td>
<td>30 ppt</td>
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*defined as the larger of 3σ over 24 hours or the dry-down limit
HALO KA H₂O—The State-of-the-Art Moisture Analyzer for Modern Semi Fabs. Most advanced semiconductor fabs employ Tiger Optics’ CRDS trace H₂O analyzers as the preferred technology to comply with SEMI F112 standard. The analyzer of choice for many fabs is the HALO KA H₂O (Figure 2, left). With a detection limit of 300 ppt in N₂ (specified as 3σ over a 24-hour period) and even lower in other bulk gases, the KA fits the needs of most advanced semiconductor fabs. In addition, the HALO KA saves significant space in the analyzer rack compared to the competition, since two analyzers fit within one 19” slot. In addition to high performance and reliability, the HALO KA also delivers fabs considerable savings in operating cost, with no requirements for maintenance, field calibration or spare parts.

HALO KA Max H₂O—Tiger’s New Flagship H₂O Analyzer. Tiger Optics’ new HALO KA Max (Figure 2, right) is an ideal choice for electronic gas makers and semiconductor manufacturers requiring detection limits for H₂O below 100 ppt. This next-generation analyzer touts both lower detection limits and faster speed of response. It is Tiger Optics’ first moisture analyzer that offers a detection limit of 100 ppt (3σ/24h or dry-down limit) in all of the major semi bulk gases. This new performance benchmark makes the HALO KA Max the new flagship among Tiger’s line of trace moisture analyzers (shown in Figure 3).

To illustrate the HALO KA Max’s excellent baseline performance, Figure 4 shows a reading in dry N₂ over an 18-hour timeframe (black trace). The measurement demonstrates the HALO KA Max’s capability to measure comfortably below 100 ppt, which actually challenges the ability of most sampling systems to achieve such a low H₂O level. Even more impressive is the analyzer’s precision at near-zero levels (measured as 1σ), which is only 12 ppt in this example. The HALO KA Max’s guaranteed specifications call out a precision at zero of 40 ppt in N₂ and as low as 10 ppt in He. For comparison, the red trace shows the baseline performance of the HALO KA, which also demonstrates excellent performance well below 1 ppb, exhibiting a measurement precision (1σ) of 74 ppt with a guaranteed precision specification of 100 ppt in N₂.

The key to the HALO KA Max’s excellent detection limit is its entirely new electronic and optical platform, allowing the analyzer to operate with lower measurement noise. In addition, however, the new platform has more computing power, an optimized fluid path, and improved wetted materials, allowing also for enhanced speed of response. This is important for preserving the analyzer’s real-time detection capability when approaching low-ppt H₂O levels. Moisture dry-down time increases exponentially with lower concentrations. At some point, the analyzer’s speed of response would become too slow to be useful for real-time process control. The HALO KA Max’s optimized design allows it to exhibit a speed of response at ppt to ppb levels that other instruments only achieve at much higher concentrations. Figure 5 illustrates this fact impressively by simulating a process control situation with a 1 ppb control limit and occasional H₂O spikes of only a few parts per billion (denoted by the orange markers). Not only does the HALO KA Max’s sensitivity pick up even the smallest spike
without any ambiguity, but its incredible speed of response at such low levels also instantly displays the upset. This means that your process can be protected immediately from the excess moisture. Once the H$_2$O source is removed, the analyzer also returns back to below the control limit within minutes, so the process can resume with minimal delay. While the HALO KA Max performs this exercise with considerable ease, it should be noted that most other analyzers would neither have the sensitivity nor the speed to respond these simulated moisture upsets with the same kind of precision.

**Conclusion**

In summary, Tiger’s current portfolio of ultra-trace moisture analyzers allows modern semiconductor fabs to protect their processes from upsets in their gas quality more efficiently and reliably than ever before. By employing the HALO KA H$_2$O and the HALO KA Max H$_2$O, fabs are ready to meet the quality demands for present and upcoming high-performance devices.

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**Cavity Ring-Down Spectroscopy**

All Tiger Optics instruments are based on CRDS. The key components of the CRDS system are shown in Figure 6. 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**

Founded in 2001, Tiger Optics has been the preferred provider for high-performance, laser-based gas analyzers to advance industrial standards and enable cutting-edge research. By leveraging the expertise of scientists, engineers and industry specialists, we offer advanced total solutions, field support, analyzer training, and advice to help customers improve yields and reduce costs. By creating out-of-the-box solutions that deliver fast, reliable and stable measurements, Tiger Optics supports continuous innovation for gas & chemical production, semiconductor fabrication, and many other markets.

**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.

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**References**
