

Next-Generation Monitoring of Airborne Molecular Contaminants in Cleanrooms

T-I Max

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Airborne Molecular Contaminants in Cleanrooms

The dust-free and controlled environment of a cleanroom is vital to prevent product failure in semiconductor manufacturing, but controlling particulates in cleanrooms is not nearly sufficient to protect semiconductor devices that feature structural sizes on a molecular level. Micro-particles are the main source of physical contamination, but modern filtration systems for air supply, cleanroom attire and specialized surface materials have been successful in keeping particle contamination under control. There are, however, molecular contaminants, which can range from small inorganic molecules like acids and bases, to more complex organic species like VOCs. These molecules are known to cause chemical contamination, i.e., they react with the materials and surfaces of the semiconductor devices to cause oxidation, unintended doping, dislocations, and more.

This class of contaminants is collectively known as Airborne Molecular Contaminants (AMCs). They are harder to control than particles. Firstly, the molecules are much smaller than particles and require more advanced chemical filtration of the cleanroom air. Secondly and more importantly, however, many AMCs are created within the cleanroom itself. For instance, HF is used for wafer cleaning within the process, and NH₃ is emitted naturally by any person present in the cleanroom.

As feature sizes have decreased over the decades, both devices and equipment became more and more susceptible to significant damage from AMCs.¹ They can have various detrimental effects: Acids, such as HF or HCl, can cause



Fig. 1 Technician inspecting a silicon test wafer for potential damage



Fig. 2 Tiger Optics T-I Max NH₃ cleanroom ammonia analyzer

micro-corrosion and accelerate oxidation. Bases, such as NH₃, can cause hazing and attack coatings on the optics of UV lithography equipment. Hydrides, such as AsH₃, PH₃, or B₂H₆, can cause unintended doping, which can dramatically impact a device's functionality.

Monitoring AMCs is Key to Contamination Prevention

Because many AMCs are generated within the cleanroom, they cannot be completely avoided, even though wafers are shielded as much as possible from exposure nowadays, e.g., by transporting them in closed pods (FOUPs) between process steps. Precise monitoring of the cleanroom environment for these molecules has emerged as a key for semi fabs to further mitigate the threat of AMCs. By immediately detecting the presence of harmful molecules, engineering controls can be implemented to protect devices and processes from exposure. Due to the low concentration of AMCs and the need for fast detection, measurement instruments have to fulfill stringent requirements. As a result, ultra-sensitive laser-based analyzers have emerged as the primary class of instrument used to detect small AMCs, such as HF, HCl or NH₃. Semiconductor fabs require all of these molecules to be measured at levels below 1 part per billion (ppb) with a response of 1-3 minutes to any presence of molecules. More importantly, the instrument's readings have to return to baseline as fast as possible after the molecules' presence is eliminated to minimize delays in the manufacturing process. The International Roadmap for Devices and Systems (IRDS) even calls out detection requirements below 0.1 ppb as part of the future technological challenges.¹

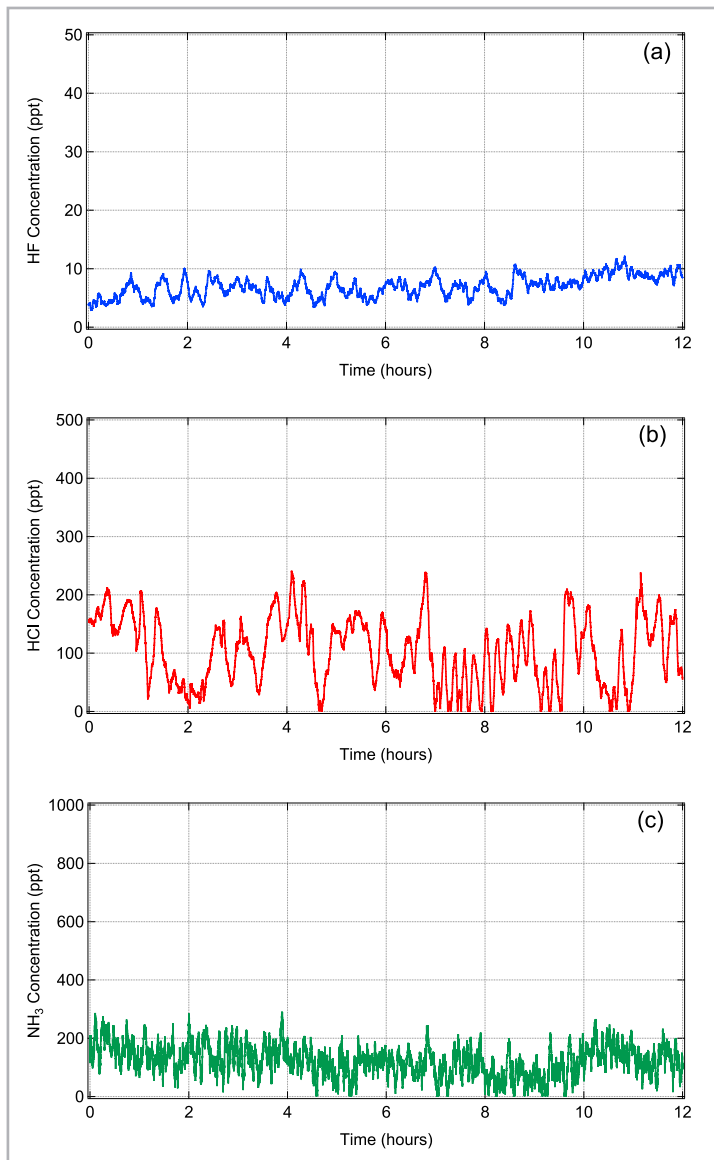


Fig. 3 Zero baseline data for the T-I Max series over 12 hours; (a) for HF, (b) for HCl, and (c) for NH₃.

Introducing the T-I Max Next-Generation AMC Monitors

To address this challenge, Tiger Optics has developed the T-I Max series of cleanroom analyzers for detecting AMCs like HF, HCl, and NH₃ with unprecedented speed and sensitivity. The T-I Max (Figure 2 shows the NH₃ version) is based on Tiger's powerful Cavity Ring-Down Spectroscopy (CRDS) technology, but uses an all-new electronic and optical platform that enables lower measurement noise and up to ten times faster measurement rate. This platform takes CRDS to the next level and dramatically lowers detection limits compared to previous-generation analyzers.

Figure 3 shows typical baseline data of the T-I Max for HF, HCl, and NH₃. The detection limits vary somewhat for the different analytes, with the T-I Max HF capable of reaching

single-digit parts-per-trillion (ppt) levels. But also the slightly less sensitive T-I Max HCl and T-I Max NH₃ reach detection limits well below 1 ppb. In addition to improved sensitivity, increased measurement speed was a particular focus of the T-I Max development. The new electronics is one important factor in improving speed of response. Another one is an intelligent software that adjusts data filtering automatically to achieve low-noise data without compromising speed. But electronics and software alone cannot guarantee optimum speed of response; the sampling system inside the analyzer is even more critical.

Reducing Physical Speed Limitations

The main reason why laser-based analyzers work so well for this application is the fact that the measurement is contactless. HF, HCl, and (particularly) NH₃ easily stick to surfaces. At ppb-levels, this surface interaction becomes the dominating limitation for achieving low baseline levels and fast speed of response. Even in optical analyzers, surfaces cannot be eliminated entirely. It is, therefore, important to limit surface interactions as much as possible. In the T-I Max, improved flow path, low-pressure operation, and optimized materials result in an analyzer that is able to meet the speed-of-response

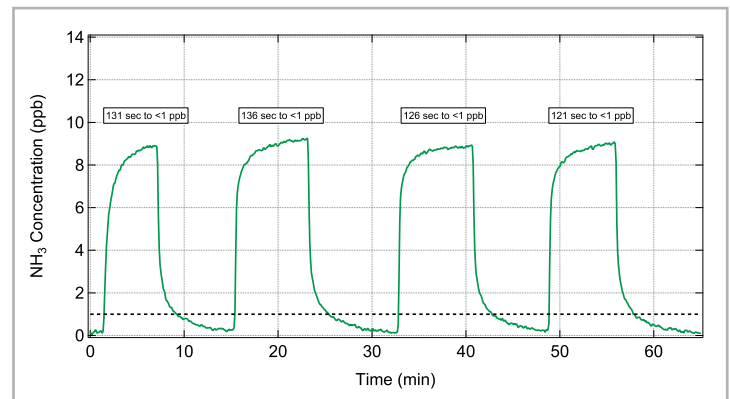


Fig. 4 Speed of response demonstration for the T-I Max NH₃, showing repeated low-level ammonia exposure and clear-out.

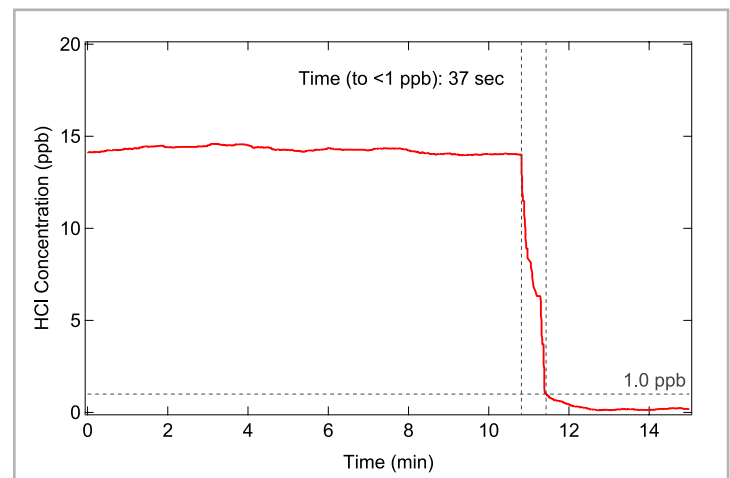


Fig. 5 Low-level HCl clear-out demonstration for the T-I Max HCl



Fig. 6 Tiger Optics GO-cart for mobile AMC monitoring

These measurements demonstrate in impressive fashion the T-I Max's near-instant response at molecule concentrations that challenge any other, more traditional AMC monitoring technology.

Changing the AMC Monitoring Game

The capabilities of modern CRDS analyzers such as the T-I Max series allow semiconductor fabs to dramatically improve cleanroom AMC control. The analyzers' ppt-level sensitivity ensures that even the smallest release does not go unnoticed. Their real-time speed of response also allows the detection of the release before it can cause significant harm to any devices. Rather than tracking down causes of device failures after the fact, immediate action can be taken to prevent devices from being exposed to AMCs. Similarly, the fast return of the analyzer to its baseline after the AMC release is under control allows fabs to continue operation as soon as possible, preventing costly delays.

Another advantage of Tiger's AMC monitors is their ability to operate semi-mobile. While rack-mounted monitors are still most common, with fixed sampling points being manifolded into the system, T-I Max analyzers can be moved relatively easily to different places within the cleanroom to closely monitor critical environments, locations with potential for

requirements of the most demanding customers.

Figure 4 demonstrates this ability for NH_3 , the molecule with the most severe surface interaction. The measurement shows repeated low-level ammonia exposure with the goal to achieve NH_3 clear-out to <1 ppb in under 3 min. The T-I Max NH_3 masters this experiment with ease, dropping below the target mark consistently in just a little over 2 minutes. Even faster than the ammonia model is the T-I Max HCl. As seen in Figure 5, the clear-out time to <1 ppb from a 15-ppb HCl exposure is a mere 37 seconds.

release (tools being cleaned, for instance), or to identify AMC sources. Tiger Optics also offers the GO-cart, a complete AMC monitoring system on wheels (see Figure 6) that can fit all three T-I Max models and a low-power, fanless vacuum pump. For convenience, a central touchscreen controls all three analyzers at once.

Cavity Ring-Down Spectroscopy

All Tiger Optics instruments are based on CRDS. The key components of the CRDS system are shown in Figure 7 below.

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.

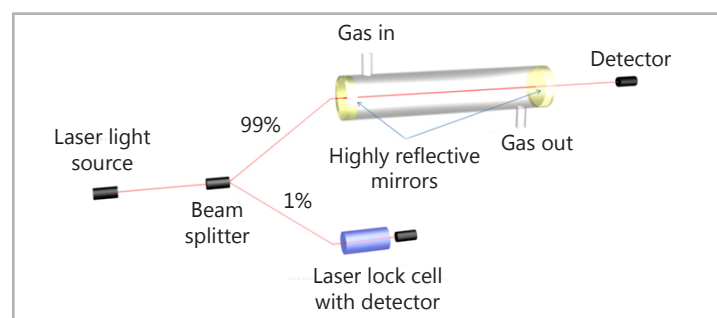


Fig. 7 Principle of CRDS

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.



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References

¹International Roadmap for Devices and Systems, 2017 Edition, Yield Enhancement, IEEE (2017).

Tiger Optics

275 Gibraltar Road, Horsham, PA 19044
Phone: +1 (215) 656 4000 • Fax: +1 (215) 343 7168
sales@tigeroptics.com • www.tigeroptics.com
www.process-insights.com