Airborne Molecular Contaminant Detection with the Vocus CI-TOF

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For semiconductor manufacturers, the accurate measurement of airborne molecular contaminants (AMCs) is critical for establishing effective process controls. As node technologies continue to advance, reducing in size and increasing in complexity, the effects of foreign molecular contaminants become increasingly detrimental to wafer production yields. Growing concerns related to material supply chains are forcing manufacturers of both small and large node technologies alike to pursue improvements in the monitoring of AMCs to implement effective preventive maintenance schedules that reduce downtime and ensure optimum wafer yields.

Along with the advancement of production processes and machines, there are emerging demands for higher performance analytical instruments that report AMC concentrations. To ensure stringent control over the macro and micro manufacturing environment, contaminants at parts-per-trillion volume (pptv) concentrations need to be inventoried. Ultra-fast instrument response is required to increase the sample throughput and provide alarm at early-stage AMC incidents.

Semiconductor manufacturing processes are subject to micro contamination attributed to the ambient air quality comprised of both external (make-up air) and internal (e.g., tools, chemicals, workers, material coatings) sources [1]. Cross contamination between ambient, process, and storage environments increases AMC complexity.

Although some sources can be identified, many are still difficult to understand and their impact on semiconductor fabrication (FAB) remains largely unknown. The availability of real-time, comprehensive measurements for contaminants at single-digit pptv sensitivity has not been widely implemented or readily available. For this reason, the Vocus CI-TOF shows promise as a powerful tool in the FAB environment.

Here we review the most important AMC categories, their impact on FAB, and demonstrate AMC monitoring under different scenarios with the Vocus CI-TOF.

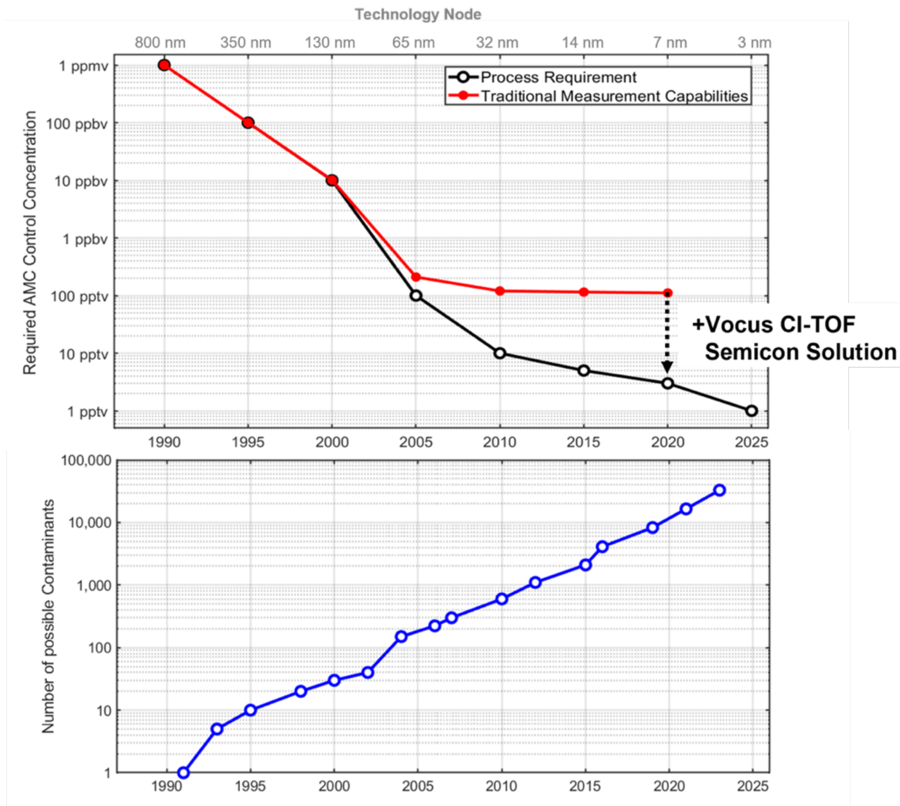


Figure 1. *Figure 1. Upper - Changes in technology have drastically reduced required AMC control concentrations across time. Capabilities of traditional AMC measurement techniques have not kept pace. The Vocus CI-TOF closes this gap. Lower - The number of AMC contaminants is increasing as the industry reduces feature size.*

Airborne Molecular Contaminants

Airborne molecular contaminant is a generic description of a substance in the form of a gas or aerosol that compromises the manufacturing process. In 2007 the International Roadmap for Devices and Systems (IRDS) introduced definitions for AMC categories: molecular acids, molecular bases, refractories, dopants, and condensables. Ten years later in their 2017 edition it was recognized that this approach was not enough as more contaminants were discovered that did not fall into any of these categories.

Current technologies used for AMC detection are limited by either by poor duty cycle and/or compound coverage. While chromatographic techniques are used less frequently, they persist despite their 30-minute temporal resolution and high cost of maintenance. Other online methods such as cavity ring-down spectroscopy (CRDS) measure compounds based on the extinction of their specific wavelength, which limits the performance to measure only one, or a couple of compounds, and reporting every few minutes. Thus, most available and deployed

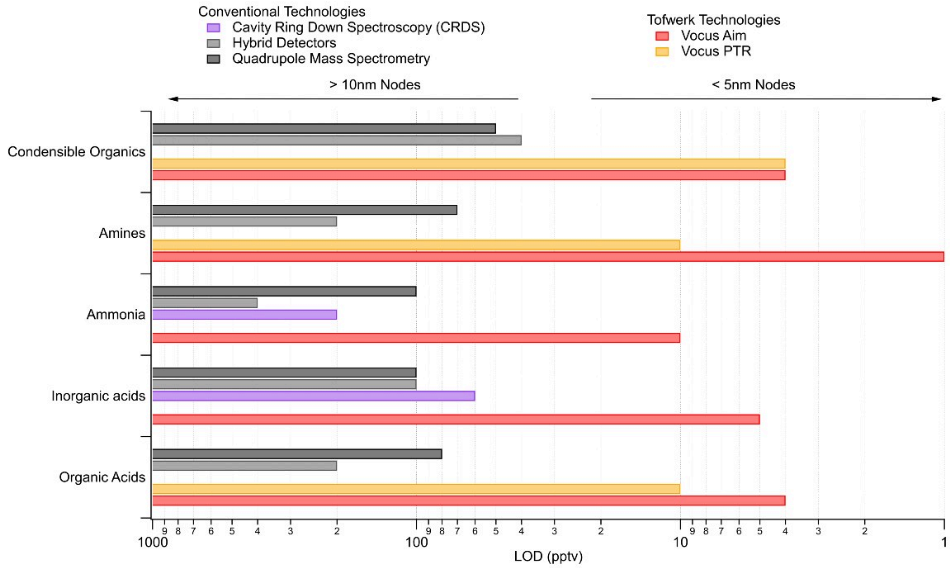


Figure 2. *Comparison of Vocus CI-TOF and other technologies used for AMC monitoring.*

technologies are limited to measuring only one AMC category.

The Vocus CI-TOF is a state-of-the-art solution for AMC monitoring. With one instrument, semiconductor manufacturers can measure several AMC categories simultaneously, in real time, with single-digit pptv detection limits. Vocus's full mass spectra acquisition improves retrospective analysis when new target compounds become of interest. These characteristics make the Vocus CI-TOF ideal for monitoring the most complex and demanding AMC environments, ensuring precise and constant air quality measurements that are applicable to a variety of FAB processes.

Molecular Acids (MAs)

The influence acids have on wafer yields presents a problem for semiconductor manufacturers. Inorganic acids are particularly relevant. They corrode metallic lines and pads, contribute foreign deposition on wafer surfaces, haze lithography masks, and deteriorate HEPA filters. The degradation of HEPA filters can lead to insufficient sanitization, the generation of unwanted boron species, and cause other effects that are detrimental to manufacturing processes, production instruments, and final products. The full effects of trace acid concentrations in the FAB remain uncertain since solutions offering real-time, comprehensive measurement of inorganic and organic acids with single-digit pptv sensitivity are not widely implemented or available. Current state-of-the-art methods for acid detection, as listed in the International Technology Roadmap for Semiconductors (ITRS) 2017 report, provide limited sensitivity (>100 pptv), while <5 pptV presence of total inorganic acids are required for most FAB areas practicing 5 nm processes or better. With single-digit pptv LODs, the Vocus CI-TOF provides precision MA monitoring, greatly outperforming currently deployed techniques.

Molecular Bases (MBs)

Among AMC compounds, ammonia, amines, and amides compose a special category. The basic property of these compounds make them undergo rapid acid-base reactions, forming small salt particulates that cause unwanted material deposition on various FAB surfaces. Furthermore, ammonia exhibits a strong affinity for metal surfaces such as copper, which leads to persistent FAB contamination risk. Although ammonia remains as the dominant base, various amines and amides can also be observed in FAB processes, causing the deterioration of lithographic performance and uneven etching. Therefore, reporting individual bases is required in order to understand their full impact on the manufacturing process and to elect the most efficient abatement strategy.

Measurements with the Vocus CI-TOF have demonstrated that MBs generally persist on FOUP surface materials longer than acids. Reactions between MBs and MAs at extremely low concentrations lead to the formation of new particulates, a process known as nucleation that can occur in the FAB. For this reason, the simultaneous monitoring of both MBs and MAs is critical. The Vocus CI-TOF registers trace levels of MAs and MBs in seconds, enabling manufacturers to elect the most efficient protocols to optimize FOUP cleaning.

Molecular Condensables (MCs) and Volatile Organic Compounds (VOCs)

This AMC category includes plasticizers, phosphates, antioxidants, siloxanes, and VOCs. The presence of VOCs contributes to salt formation on wafer surfaces, a process known as hazing. For example, the hydrolysis of acetic acid derived from methyl ether acetate (PGMEA) has been known to cause hazing. On the other hand, it has been demonstrated that refractive organosilicons alter the light scattering properties of optical lenses when they deposit during lithographic process [1]. The use of the Vocus CI-TOF for measuring these AMCs has been demonstrated in even the most challenging conditions with high accuracy and sensitivity.

AMC Detection Use Cases

The strategic placement of the Vocus CI-TOF in the different areas of the FAB ensures that environmental conditions are monitored effectively in order to improve control and minimize production failures associated with contamination. Because of its high sensitivity and ultra-fast time response, the Vocus CI-TOF provides results in real-time (seconds) while maintaining high throughput to reduce queue times between processes. These characteristics favor a diversity of FAB applications, including AMC control at the process and tool level, air chemical conditioning, FOUP monitoring, FOUP research and development, material optimization, forensic failure identification and remediation, leak detection, exhaust monitoring, establishing AMC baselines, and quality control.

Clean Room

Cleanroom design aims to maximize production yields for environmentally sensitive materials (microelectronics) and processes (wafer fabrication) [4]. Due to the need for a high degree of cleanliness when manufacturing semiconductors, cleanrooms are classified based on the number and size of particles allowed per volume of air. Hence, measuring airborne particle precursors becomes critical to meet stringent classification standards and to ensure a high production yield.

Cleanroom contamination can originate from a diversity of sources, including people, ventilation systems, and material off gassing. Even in the most pristine cleanroom environment, many compounds are still detected with the Vocus CI-TOF. Figure 3 shows an example of Vocus CI-TOF measurements in an ISO 6 cleanroom. Compounds of different AMC categories were sampled simultaneously revealing a wide variety of compounds, including inorganic acids, VOCs, and fluorinated compounds (with several PFAS).

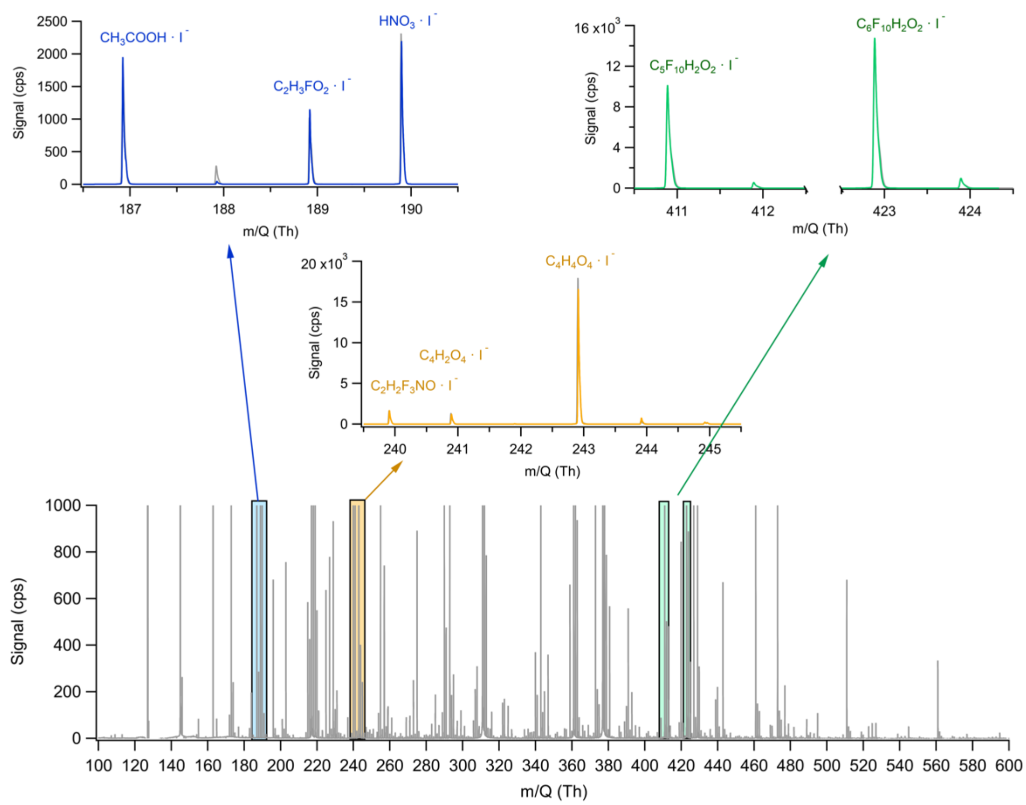


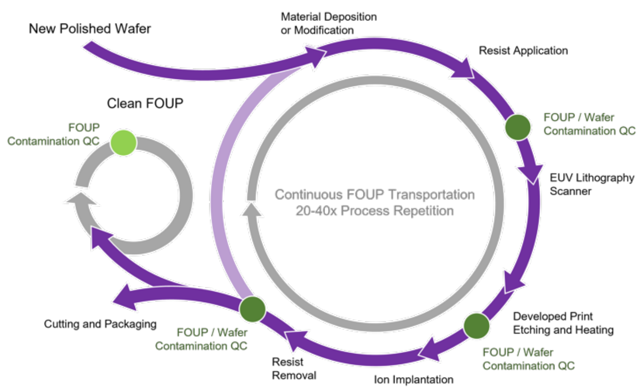
Figure 3. *Example mass spectrum from a cleanroom ISO 6. Several compounds are monitored simultaneously, independent of their AMC category or mass. Low mass molecules (blue), medium mass molecules (yellow) and high mass molecules (green).*

Material Outgassing

One of the most common outgassing sources in the FAB environment are the front opening unified pods; referred to as FOUPs. FOUPs are used to transfer wafers from one process to the next to reduce contamination risk. Studies have shown that cross contamination can occur when outgassed AMCs from contaminated wafers remain in a FOUP which then contaminates the next batch of clean wafers [2][3]. Wafer transport by FOUP between the many areas of a FAB presents the greatest potential for cross contamination.

Replications for both MA and MB FOUP outgassing were performed with the Vocus CI-TOF. In both instances, trace levels of AMCs were observed after more than 10 hours of continuous flushing, demonstrating the long residence time of some compounds and the importance of their traceability.

Results from this simulation demonstrate the potential for fast, high-precision FOUP screening using the robust Vocus CI-TOF technology. Integration of the Vocus CI-TOF in FOUP-by-FOUP or batch wafer processing provides precise detection of trace AMCs. Semiconductor producers will benefit not only from improved production yields but also reduced queue times, attributed to rapid analysis with the Vocus CI-TOF.



The Vocus CI-TOF is an innovative and robust real-time analyzer, and a critical component of any FAB pursuing optimal performance. With industry-leading sensitivity and minimal operational overhead, the Vocus CI-TOF provides comprehensive detection for a diversity of AMC categories. Producers will appreciate the utility of the Vocus CI-TOF in both real-time troubleshooting and retrospect evaluation.

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