

ION MOBILITY THEORY AND APPLICATIONS

Real-time monitoring, sensitivity, selectivity, and response speed make IMS the monitor of choice

Ion Mobility Spectroscopy (IMS) has gained widespread acceptance in many applications for detecting and identifying contaminant molecules. In this article, we will investigate how this technology works, look at the various industries that use IMS monitors, and discuss monitoring applications and examples.

Theory of IMS

IMS is an ionization-based time-of-flight technique performed at atmospheric pressure. The heart of IMS is the sample cell, and its operation is illustrated in Figure 1.

A continuous ambient air sample is drawn over a semi-permeable membrane. The membrane serves to protect the interior of the cell from particles and moisture, provide a degree of contaminant selectivity, and allow various levels of sensitivity based on ambient contamination conditions. The molecules of interest permeate through the membrane, and are picked up by purified dry instrument air which sweeps across the membrane and delivers the sample to the reaction region. There, the sample is ionized by low-level beta energy emitted

by a sealed nickel-63 radiation source.

The ionized sample drifts through the cell under the influence of an electrostatic field. A shutter grid is biased electrically to either block the ions or allow them to pass through. This shutter grid is pulsed to periodically allow the ions into the drift region. There, they begin to separate out based on their size and shape while flowing counter to a drift gas flow, which is introduced at the end of the drift tube. The smaller ions move faster than larger ions through the drift tube and arrive at the detector. A collector (Faraday plate) located at the end of the tube detects the arrival of the ions and produces a current. This current is amplified to produce a time-of-flight spectrum. A microprocessor evaluates the spectrum for the target compound and determines the concentration based on the peak height. Because of the specificity of the membrane, enhanced ionization, and time-of-flight, there is the highest degree of certainty that the analyzer is measuring only the compound of interest, even in the presence of other interferents.

IMS Applications

IMS is utilized in several industries including semiconductor, hard disk drive manufacturing, pharmaceutical and medical, industrial, airport security, and chemical agent detection.

Semiconductor

- Photolithography patterns small images onto a wafer, which undergoes subsequent processing to build very fine surface circuit structures. IMS is implemented to detect bases such as ammonia, N-Methyl-2-pyrrolidone (NMP), and other amines which can affect or neutralize the photoresist causing resist and image degradation. In addition, ammonia can combine with acidic gases to produce haze on the optical elements causing transmission loss or hotspots on the optical lenses.

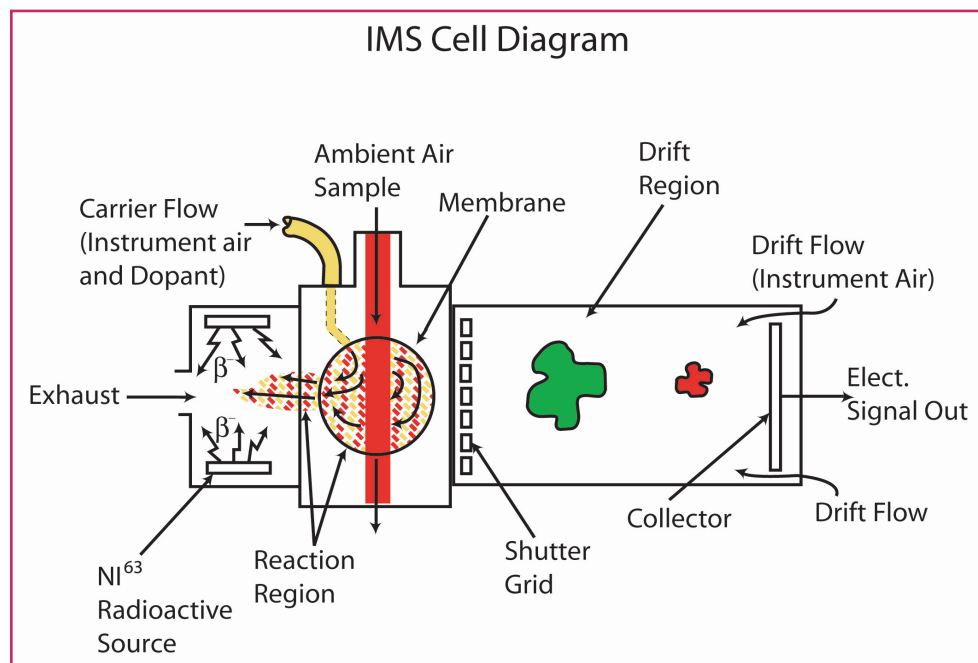


Figure 1. General operation of an IMS analyzer cell

- IMS is also employed to monitor for total acids in metal deposition, etch, and copper CMP processes. Corrosion, pitting, and pinholes are yield-limiting effects that can be contributed to trace acidic gas conditions.

Hard Disk Drive

- IMS is implemented to detect acidic gases because of their corrosive influence on the storage media as well as the inductive read/write and giant magneto resistive heads.

Pharmaceutical and Medical Device Manufacturing

- Vaporized hydrogen peroxide is used as a sterilant, and verification of the equipment cleaning process is of utmost importance. IMS is implemented to ensure on-line control and accurate measurement as well as measuring ambient residual levels for worker safety.

Industrial Monitoring

- Monitoring of HCl and HF in continuous source emission is federally regulated. The highly corrosive nature of both compounds has made accurate monitoring at the ppb/ppm levels difficult by other analytical sampling techniques. IMS is the only technology currently available to provide reliable monitoring under harsh stack environments.

Petrochemical

- IMS is implemented to analyze for trace ammonia in ethylene and light hydrocarbon streams. Catalyst poisoning in the polymerization process can occur if the ammonia concentration in the ethylene feedstock exceeds a critical level.

Chemical Agent Detection

- IMS is also used to combat terrorism for explosive detection in airport security and chemical weapons agent detection. For example, when your luggage is wanded at the airport, the cloth is placed into an IMS monitor for analysis of trace quantities of molecules used in explosive devices.

Application Example

In modern semiconductor manufacturing, production fabs are producing 90nm gates, development is working on 70nm, and research labs are investigating the feasibility of production down to and past 50nm technology. In order to accomplish these very tight design rules, photolithography, reticle, and resist manufacturers are pushing their areas of expertise and technology to the limits. Due to the high cost of this equipment, semiconductor manufacturers cannot afford for these tools to not produce a quality product or be down for long periods of time. This equipment, however, is extremely sensitive to molecular contamination, which when severe, detrimentally impacts yield and equipment downtime. Monitoring for molecular contamination therefore is essential for successful production environments.

As briefly mentioned above, molecular contamination, such as airborne ammonia or amines, will interact with chemically amplified photoresist causing the printed critical dimensions to vary prior to etching. In addition, ammonia can also react with sulfur containing acidic gases to form ammonium sulfate which creates a salt-like deposit on reticles and final optical elements. In order to avoid costly problems associated

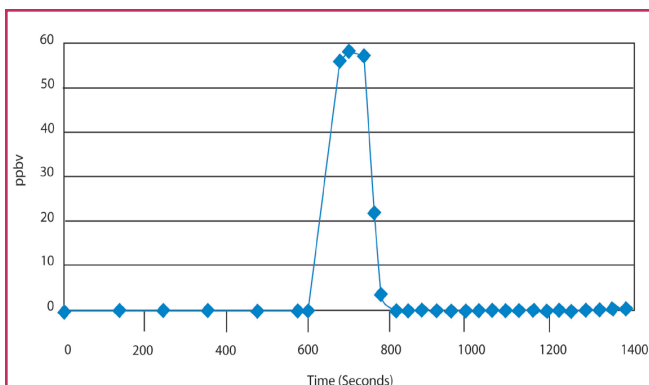


Figure 2. IMS analyzer response to 50 ppb NH₃ event

with these issues, a real-time analyzer with sub-ppbv ammonia sensitivity is a necessary monitoring tool for semiconductor manufacturers to remain competitive. Figure 2 shows Molecular Analytics AirSentry-IMS® response to a 50 ppb ammonia event. Background contamination conditions are very low and stable, indicating little to no contamination is present in the area. The contamination event occurs at $t=630s.$ and is detected within the first 30 seconds. After the contamination event subsides at $t = 720s.$, the response of the analyzer returns to baseline conditions within 90 seconds. Yield losses, wafer reworks, and equipment downtime could be severe if an event of this magnitude occurs during wafer processing. Alarms could be set to identify when a contamination event occurs, such as the one below, and the appropriate personnel could determine the cause of the event and how to best handle wafers that may have been exposed during this time period.

Conclusions

IMS is a growing technique for an expanding number of applications in many industries. Perhaps the greatest advantage of IMS is the versatility of the technique. The same instrument, by properly selecting the temperature, flow rates, membrane type, drift-tube polarity, and other parameters, can be used to specifically monitor scores of compounds. Limits of detection are in the sub-ppbv range for many compounds. Real-time monitoring, sensitivity, selectivity, and response speed make this technique preferable to other monitoring methods.¹

Reference

- 1 A. T. Bacon, R. Getz, J. Reategui. "Ion-Mobility Spectrometry Tackles Tough Process Monitoring," *Measurement and Control*, (June, 1991).

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