

## Optimized AMC Monitoring for Lithography

**Dedicated molecular contamination monitors based on ion mobility spectroscopy (IMS) can detect NH<sub>3</sub> and SO<sub>2</sub> contamination events in real time as well as provide ppt level trends through long term averaging.**

193 nm lithography is the area in the semiconductor manufacturing process most impacted by airborne molecular contamination (AMC). Wafer and equipment isolation, chemical filtration, and purge gases are being utilized to minimize the impacts, and AMC monitoring equipment is becoming mandatory for retaining manufacturer's optical lens warranties as well as for sustaining process yields. It is apparent, however, that AMC monitoring needs and trends have changed over the past few years, and old techniques and methodologies based on sampling from centralized instruments are not suitable for today's strict monitoring environments.



**AirSentry II AMC Monitor**

Fortunately, recent technical advances in ion mobility spectroscopy (IMS) have made small, low-cost monitors available that have excellent sensitivity and stability. Previously, it has been cost prohibitive to conduct single point continuous monitoring of molecular contamination on a large scale (50-100 points) throughout a fab. The use of manufacturing friendly techniques and aggressive reduction of internal components has led to substantial cost savings near 50%. Now, IMS analyzers are assigned to monitoring single locations in real-time with the sensitivity needed to detect part-per-trillion (ppt) changes.

Conventional molecular contamination monitoring systems employ a multi-point air sampling system connected to a single analyzer or suite of analyzers. In this way, they draw in air from one sample point at a time while the other points remain unmonitored. However, significant issues arise in today's 193 nm semiconductor fabrication environment, and the restrictive monitoring techniques currently in use begin to show their weaknesses:

- The small time period of actual and recorded measurements per day at each sample location provide little useful data
- Contamination effects of long sample tubing lengths can interfere with the air sample causing a misinterpretation of actual vs. perceived contamination levels.
- Slow analyzer response and clear-down times when adjacent sample point concentrations differ greatly
- Minimal ability to perform sample averaging to increase sensitivity.

As an example, a 60 point sampling system with a ten minute sample cycle (9 minutes sample purge, 1 minute sample analysis) will take 600 minutes or 10 hours to sample all locations. As the concentration measured during purge is usually discarded, each location is monitored and collects true data for 1 minute every 10 hours, leaving each location unmonitored for the remaining 9 hours and 59 minutes. It is clear that this is not an adequate monitoring methodology for today's 193 nm lithography needs.

A dedicated, point-of-use monitor, however, offers advantages over a conventional multipoint sampling system:

- Continuous monitoring of a single sample point
- No sampling interruptions or missed contamination events
- Sample tubing length reductions from 20 - 30 meters to 2 – 3 meters.
  - (Reducing the sample tubing lengths minimizes interactions between contamination molecules and the tubing surface.)
- Sensitivity improvements of 5 to 10 times over existing technology.

## METHODOLOGY

Ion mobility spectrometry (IMS) has been employed for decades as a robust technique for measuring traces of chemicals in the air and on surfaces. Although most commonly associated with airport security screening systems and chemical warfare detection systems, IMS has also been successfully applied to microcontamination issues faced in semiconductor, flat-panel display, hard disk drive, pharmaceutical, and petrochemical industries.

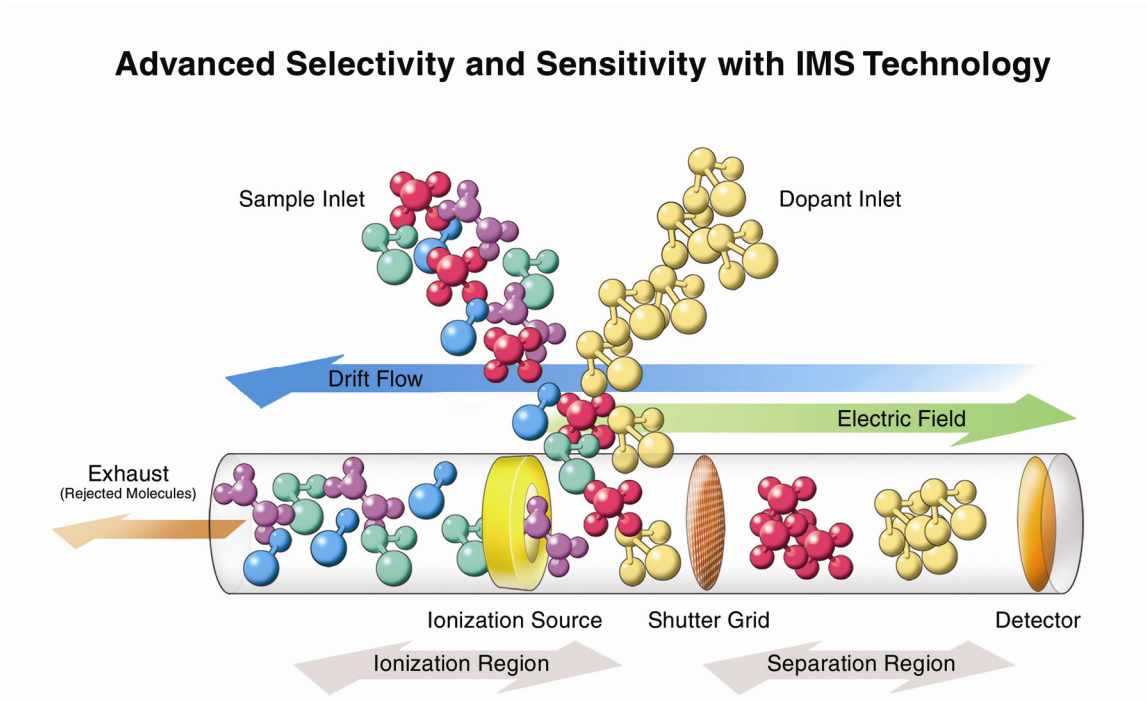
IMS monitoring systems contain an IMS cell, a means to introduce samples for analysis, capability to process the cell output signal and the ability to mix selective ionization control reagents with the sample stream to suppress non-analyte ion formation. Most IMS cells contain an ionization source, an electronic shutter to control the introduction of the ions into the separation or drift region, a high voltage supply to create an electric field gradient across the drift region, and an ion collector connected to an amplifier to generate a signal as a function of time. Analysis occurs at atmospheric pressure and one ion scan can be obtained in as little as 20 milliseconds.

When the ion shutter is pulsed open, a sample of ions is released into the drift region where they are accelerated toward the ion collector by the electric field. Ion species with different ion mobilities,  $K$ , will arrive at the collector at different characteristic drift times,  $t_d$ . Ion mobility can be empirically determined using the length of the drift tube,  $L$ , the voltage potential across the drift tube,  $V$ , and the drift time<sup>1</sup>.

$$K = \frac{v_d}{E} = \frac{L^2}{V * t_d} \quad (1)$$

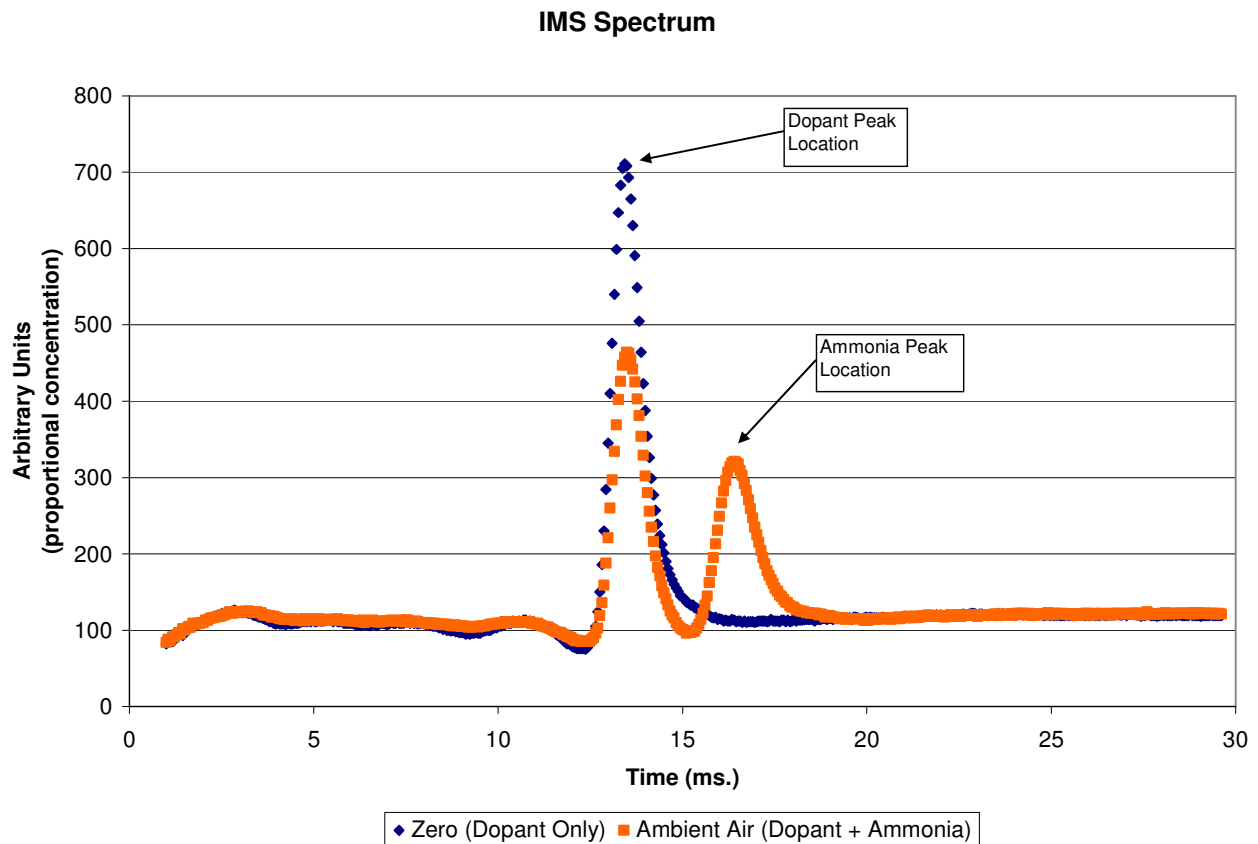
Thus, ions with a long drift time have a low ion mobility and ions with a short drift time have a high ion mobility. For a given IMS system, size, mass and mobility of the ions or ion cluster are what allow them to be separated at characteristic drift times. A simple illustration of this concept, seen in Figure 1, shows an ionized molecule with 4 atoms (yellow) having a shorter drift time and arriving at the detector ahead of the molecule with 5 atoms (red). Those molecules which are not ionized are swept to an exhaust port and never detected, thereby eliminating some molecules which might

otherwise be considered interferences. These unique properties allow an IMS cell to identify and monitor particular analytes of interest.



**Figure 1: Based on mobility, size, and mass, ion drift times will have a characteristic signature allowing individual ion species or ion clusters to be easily identified**

Analytical specificity can be further enhanced through the addition of ionization control reagents (dopants) to the sample stream. The dopants can suppress the formation of unwanted, non-analyte ion peaks, improving sensitivity and reducing potential interferences<sup>2</sup>. Figure 2 shows an example of the use of dopants to measure ammonia ( $\text{NH}_3$ ) in laboratory air. Even though many chemical species are present in the air, only the ion peak for ammonia and the ion peak for the dopant gas appear in the ion scan.



**Figure 2: Use of ionization control reagents improve sensitivity and reduce potential interferences. In clean air, only the reagent ion peak is present. When ammonia is in the air sample stream, an ammonia ion peak is detected.**

Optimization of monitoring system performance also includes the sample delivery system. The sample delivery system should be designed so there is minimal interaction between the delivery system and the air sample at the point of monitoring. Use of the shortest possible inlet lines and inert materials such as PFA or PTFE for tubing and connectors helps ensure rapid response times and accurate measurements. Potential surface interactions with the sample can be minimized by eliminating all valves, manifolds, regulators and pumps upstream of the IMS cell.

When the monitor is continuously sampling the same environment, sample averaging can be used to reduce the detection limit. For example, when the limit of detection for one minute samples is 120 ppt the limit of detection for a 60 minute rolling average is 8.2 ppt. In chemically filtered environments, like photolithography tools and bays, the concentrations are usually low and stable. An automated monitoring software package can simultaneously plot individual one minute data points and a long-term 60 minute running average. The one minute samples are used to immediately detect the onset of a contamination event while the long term running average is used to monitor background contamination at the lowest levels.

## DATA AND RESULTS

### Comparison between continuous and non-continuous monitoring

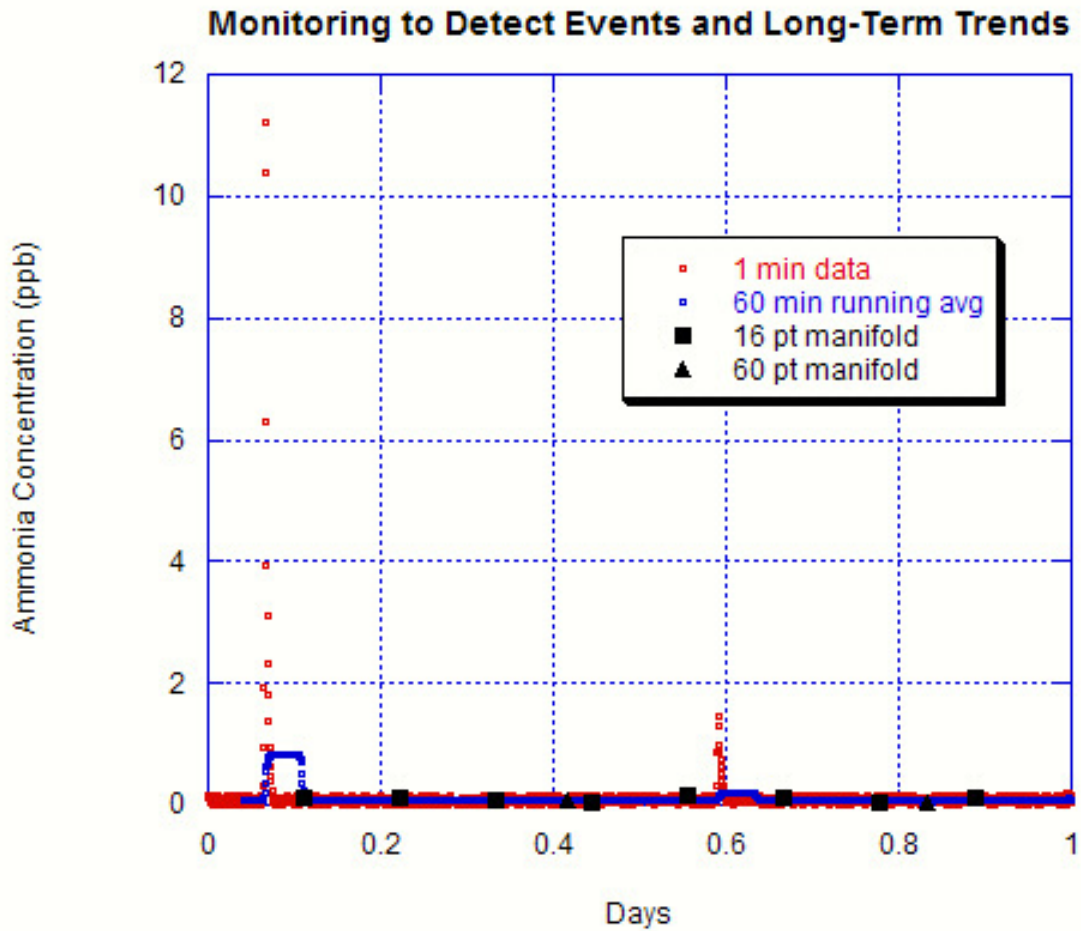
A typical manifold sampling molecular contamination monitor will select a sample line, purge for 9 minutes, perform a concentration measurement for 1 minute, and obtain one measurement point every 10 minutes. While the analyzer is purging, data collection can not be considered valid, as the detector needs time to equilibrate to the new sample point and must clear any remaining sample from the previous location from the surfaces that might be wetted.

A comparison of the monitoring coverage from a 60-point manifold system, a 16-point manifold system, and a point-of-use monitor is shown in Table 1. As the number of sample points increases, the amount of time spent monitoring an individual sample point decreases. In the extreme case of a 60-sample-point manifold system, each point is monitored for an average of only 2.4 minutes per day. Long-term changes in molecular contamination will be observed with a manifold monitoring approach, but many shorter duration contamination events observed by continuous monitoring can not be detected by a manifold system.

	Conventional 60 Sample Locations	Conventional 16 Sample Locations	New Dedicated Point-of-Use Monitor (AirSentry II)	Effect of Implementing Point- of-Use Monitoring
Avg. Time Monitoring Each Location/Day	2.4 min.	9 min.	1440 min.	Continuous real-time data obtained
Avg. Time not Monitored/Day	1437.6 min.	1431 min.	0 min.	No missed contamination events
Typical Sample Tube Length	50 meters	25 meters	3 meters	Minimal effects of tubing – contamination interactions
Typical Sensitivity	100 ppt	100 ppt	10 ppt	Improved sensitivity

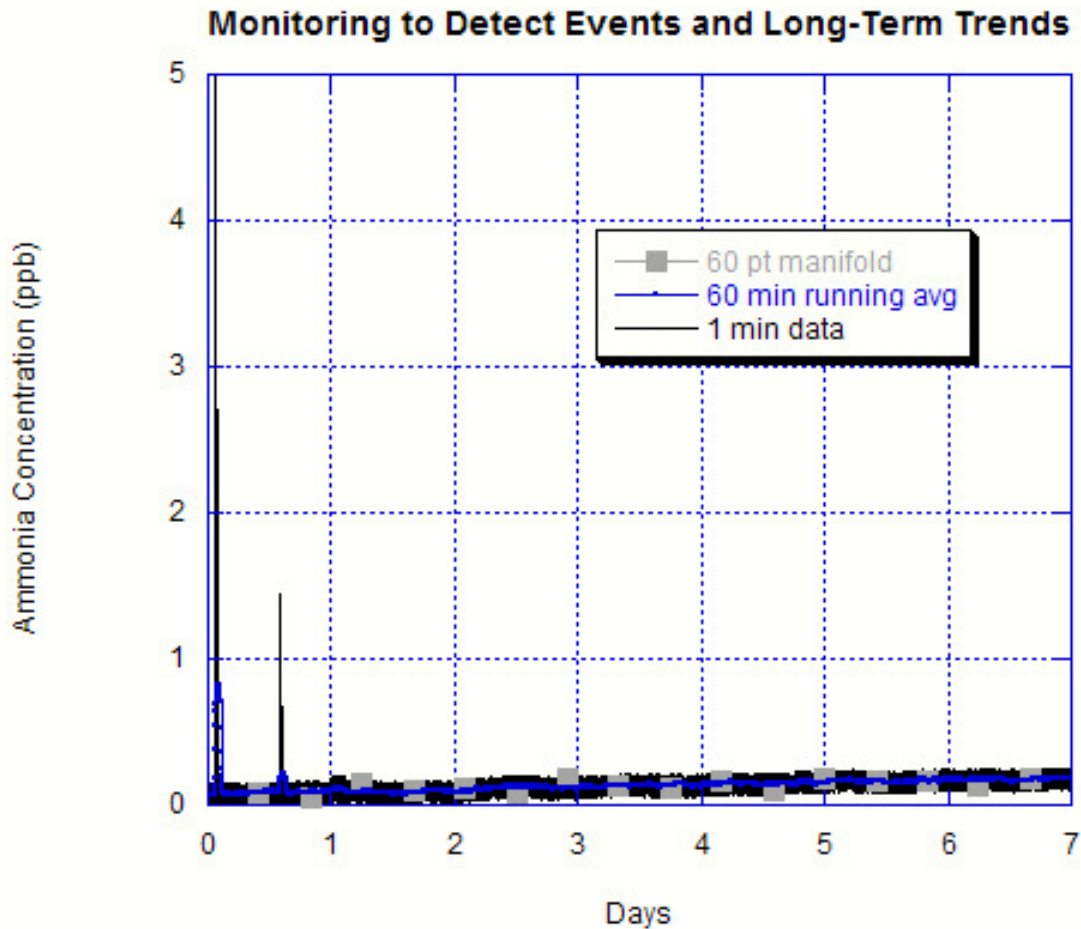
**Table 1: Benefits of implementing a continuous point-of-use monitoring strategy.**

Figure 3 compares the response of a continuous monitoring system in a realistic situation where the baseline concentration drifts and specific contamination events occur. Data corresponding to 1 minute samples shows the individual spikes while a 60 minute running average provides a very high sensitivity to detect longer term trends while “squaring off” the spikes. Continuous monitoring with a point-of-use monitor ensures that no events are missed. With manifold systems, many transient events are not observed



**Figure 3: Simultaneously tracked real-time data and running average data from a dedicated monitor compared to sampled data from 16 and 60 point manifold systems.**

Figure 4 shows a more challenging case, in which the background ammonia levels increased from 0.075 ppb to 0.170 ppb over a 7 day period. In addition, two “events” were detected on day one. Simulated data from a 60 point manifold monitoring system suggests an increase in ammonia concentration during the monitoring period, but because there are many fewer measurements, noise makes it difficult to accurately determine the magnitude of the concentration change, and the contamination spikes are missed entirely.



**Figure 4: Seven days of continuous monitoring detects transient contamination events and slow trends at low contamination levels which would be eclipsed by noise in a manifold system**

### Response and clear down time

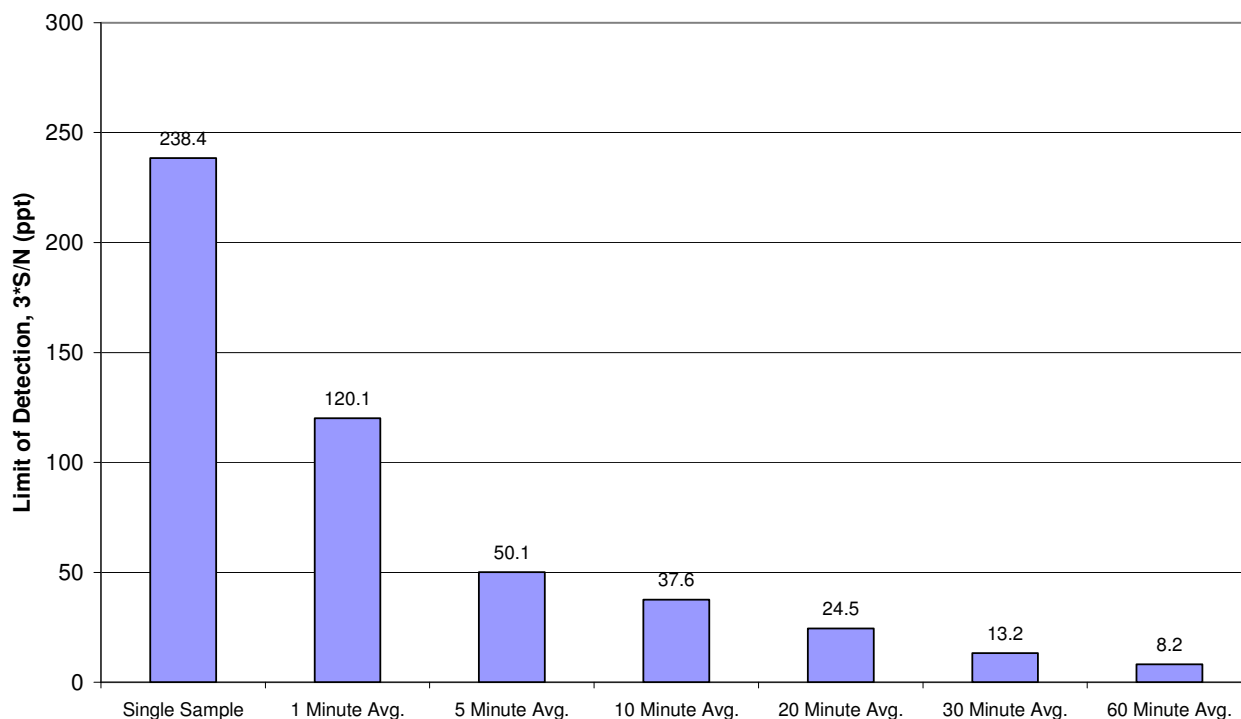
Analyzer response and clear down times are important considerations when evaluating a monitoring system. Response and clear down generally indicate the time necessary to reach 95% of the final concentration (response) or 5% of the initial concentration (clear down). The three largest factors influencing response and clear down times are: sample line length, the chemical compatibility of the “wetted” materials, and the age or exposure history of the sample line. The observed effect can be much more pronounced with older tubing that has been exposed to high levels of contamination. For example, if low vapor pressure acids like sulfuric and phosphoric acids adsorb to the inner walls of a long sampling line, response times can become very poor for measuring low levels of ammonia. Minimizing air sample line lengths and careful selection of the materials exposed to the samples accelerates response and clear down. Using dedicated monitors obviously facilitates this strategy.

### **Noise and detection limit considerations**

The detection limit of a monitoring system is almost always determined by the noise level; not by monitor's response to contamination or the resolution of the data output. Generally, the detection limit is defined as  $3\sigma$ , where  $\sigma$  is the standard deviation of the measurement noise. Noise is typically measured using clean dry air, which typically have extremely low concentrations of gas-phase contaminants in the stream. Because most photolithography tools are very clean, near or below the detection limit of most monitoring systems, noise is an important factor in monitoring these environments. For one minute sample intervals, the standard deviation measured on zero gas by the Particle Measuring Systems AirSentry II was 0.014 ppb of  $\text{NH}_3$  indicating a limit of detection of 42 ppt.

When the noise is random, the noise level can be reduced by averaging multiple measurements. The standard deviation of a series of measurements is then reduced by the square root of the number of measurements. The impact of averaging statistics on determining the concentration of ammonia contamination can then be successfully utilized, as exhibited in Figure 5. While the detection limit for a single measurement may be 0.24 ppb, averaging over increasing sample times drives that limit down, to 0.12ppb in one minute and ultimately to 8.2ppt after one hour of monitoring. Dedicated point-of-use monitors provide a greater number of measurements per unit time, resulting in a reduction of measurement error through statistics alone, ultimately providing a more precise determination of contamination levels in a shorter elapsed time than is possible through a manifold monitoring system. For the case of  $\text{SO}_2$ , the detection limit for one minute of sampling by the AirSentry II is 170 ppt, but after 15 minutes of averaging is 23 ppt.

## AirSentry II Ion Mobility Spectrometer Effect of Signal Averaging on Ammonia Detection Limit



**Figure 5: With continuous point-of-use monitoring, signal averaging provides significantly improved sensitivity.**

### FUTURE CHALLENGES

There have been significant advances recently in IMS analyzer technologies and chemistries. While this has decreased cost, improved detection limits and measurement stability, it has also created a new challenge. To fully utilize the capabilities of the new analyzer system, low-ppb and ppt-level calibration gases need to be generated. It can be very difficult to create stable ppt-level gas standards of reactive gases and transport them to an analyzer for calibration. An experiment comparing the stability of calibration data for NH<sub>3</sub> at zero, one ppb, two ppb and higher levels revealed an increase in noise at one and two ppb that vanished at higher concentration. This behavior suggests the instability is not due to the analyzer, but due to the calibration gas generation and distribution system, at least at low concentrations. It is anticipated that surface interactions will be even more significant at ppt level concentrations.

### CONCLUSIONS

The optimal approach to monitoring molecular contamination in critical lithography areas is to have dedicated point-of-use analyzers which provide continuous, real-time data for each location of concern. This approach ensures that contamination events are not missed and it allows for substantial improvements in sensitivity through sample averaging. By locating the analyzer at the point-of-use, sample tubing effects are minimized. The AirSentry II from Particle Measuring Systems utilizes IMS technology in a new, low cost, high sensitivity analyzer which enables

implementation of this continuous monitoring strategy. By using software to simultaneously track real-time contamination data and running average contamination data, a single monitor can both immediately identify contamination events and detect longer term shifts in background contamination levels on the order of 10 ppt.

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2. A. G. Harrison, *Chemical Ionization Mass Spectrometry*, CRC Press, Boca Raton, 1992.

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