

## In AMC Monitoring, Simple Designs Go a Long Way

### Occam's Razor

Latin:	Entia non sunt multiplicanda praeter necessitatem
Translation:	“Entities should not be multiplied unnecessarily”
Modern:	“All other things equal, the simplest solution is best”

### AMC History

Over the past five years, airborne molecular contamination (AMC) has moved to the forefront as one of the hot topics in the semiconductor industry. Leading edge semiconductor manufacturers processing 300 mm wafers and using 193 nm exposure wavelengths for photolithography are seeing some nasty effects from this gas-phase form of contamination. Ammonium sulfate hazing on 193 nm optical elements and reticles are wreaking such havoc that a competitive advantage is gained by effectively being able to monitor for and reduce this form of contamination.

Over the past several years, different sensor and detection technologies have been adapting themselves by increasing their complexity, in order to meet the requirements needed for effective AMC monitoring. Technologies such as chemiluminescence, ion chromatography, pulsed fluorescence, cavity ring-down, and ion mobility spectrometry are but a few of the technologies which have been implemented for the detection of AMC. While each of these techniques have their strengths and weaknesses, one critical attribute stands out when considering AMC monitoring techniques: simplicity. Complex designs only add to the uncertainty in the measurement by introducing opportunity for the sample to be altered prior to detection, or creating potential hardware failure points which require regular preventative maintenance. For AMC monitoring equipment, the principle of Occam's razor appears to ring true – *all other things being equal, the simplest solution is best.*

### Design Attributes of AMC Monitors

In evaluating the simplicity of each of these AMC monitoring techniques, a simple table can be created that provides a direct convenient comparison of the relevant design attributes of a contamination monitor. An example has been provided below for a number of AMC monitors.

AMC Monitoring Technique	Upstream Sample Tubing	Sample Manifold*	Upstream Hardware Components	Sample Time	Calibration Methodology
<b>Chemiluminescence</b>	10-15 feet	Optional	Manifold Capillary Solenoid valves NH <sub>3</sub> Moly-converter NH <sub>3</sub> Scrubber	300 seconds	Gas-phase using NO <sub>2</sub> , NO, and NH <sub>3</sub>
<b>Impinger + IC</b>	3 feet	Optional	DI water containers Syringes Injection system	6 to 24 hours for sample collection 7 to 14 days for lab analysis	IC calibrated using liquid-phase NH <sub>4</sub> <sup>+</sup> or other ions  Impinger sample collection efficiency not typically calibrated or accounted for
<b>Tenax + GC/MS Or Tenax + IC</b>	6 inches	No	Charcoal Filter Glass wool Injection system Capillary column Cryotrap Thermal desorbers	6 to 24 hours for sample collection 7 to 14 days for lab analysis	MS calibrated using vapor-phase hydrocarbon standards  Sorbent tube sample collection efficiency not typically calibrated or accounted for
<b>Cavity Ring Down</b>		Optional	Solenoid valves Optics Cavity chamber		Gas-phase using NH <sub>3</sub>
<b>Pulsed Fluorescence</b>	10 feet	Optional	Manifold Solenoid valves Hydrocarbon kicker Optics	300 seconds	Gas-phase using SO <sub>2</sub> permeation devices
<b>Ion Mobility Spectrometry</b>	6 inches (internal)	No	None	10 seconds	Gas-phase using NIST traceable permeation devices (for NH <sub>3</sub> , SO <sub>2</sub> , Cl <sub>2</sub> , HF, etc.)

**Table 1: Design Attributes of AMC Monitoring Techniques**

\* With a sample manifold, upstream sample tubing lengths typically extend > 100 meters

For the past 10 years, Particle Measuring Systems has been a leader in designing and providing AMC monitors to the electronics industry. During this time, we have gained important insights in understanding why the above attributes are so vital to consider when selecting an AMC monitor. Let's consider the various design attributes:

### **Sample Tubing before the Detector**

Gas-phase molecules are in constant motion at standard temperature and pressure. They are constantly colliding, reacting, or interacting with other molecules or the container in which they are enclosed in, which, in this case, would be the sample tubing upstream of the monitor. For a given size diameter of sample tubing, longer lengths of tubing have a larger surface area for molecular contamination to interact with by either collecting (or *sticking*) to the wall surface, reacting with the material the tube is made of, or reacting with other contamination that has collected on the tube walls. Consider a monitor that uses 6 inches of 1/8" outer diameter tubing (such as an IMS analyzer) compared to a molecular analyzer pulling from a sample manifold using 100 m of 1/4" outer diameter tubing. The surface area inside of the IMS analyzer is about 1.2 in<sup>2</sup> vs. a surface area of 2326.4 in<sup>2</sup> for an analyzer with a sample manifold and 100 m of tubing. Those three orders of magnitude difference can have a detrimental impact on the quality of results that the analyzer is expected to report.

From a monitor perspective, longer sample tubing, or greater surface area, ultimately lead to longer response and clear-down times, or even missed contamination events. For example, consider a 0.5 ppbv ambient NH<sub>3</sub> concentration sample being pulled into an AMC monitor. If that ambient air changes quickly from 0.5 ppbv of NH<sub>3</sub> contamination to 15 ppbv of NH<sub>3</sub> contamination, the monitor should immediately read 15 ppbv. However, because sample tubing upstream of the detector needs time to equilibrate to the new conditions, what will be detected by the monitor will be an exponential decay of concentration up to the 15 ppbv level, which will be proportional to the length of sample tubing. Thus, longer lengths of sample tubing will cause a delayed response to contamination changes, whether that change is from a response to a high concentration event or a clear-down due to cleaner environments.

### **Sample Manifolds**

As noted in the table above, sample manifolds have made their way into AMC monitoring techniques over the past few years. While there are benefits to sample manifolds, such as reducing the cost per sample point, there are many disadvantages as well. Most sample manifolds use a valve or combination of valves to sequentially sample from many different locations. Each sample is transported to a central location where the AMC monitor is located, and software outputs the concentration of contamination at that sample location prior to moving on to the next location. One drawback is monitor equipment downtime (scheduled or unscheduled). By having a central analyzer, when that analyzer goes down due to equipment failure or preventative maintenance, none of the sample points can be monitored. The high cost of many of these central analyzer technologies do not allow for a spare analyzer to be on hand for a "hot-swap". Point-of-use analyzers do not suffer from this issue, as each monitor is located at its actual sample point of interest. Should a point-of-use monitor need repair, it can be simply swapped with another analyzer to ensure the critical point will always be monitored. Moreover,

the low cost of point-of-use analyzers allow for a hot spare to be available to rotate in or out should the need arise.

Additionally, because sample manifolds are typically sequential, time must be allowed to purge the common sample lines when rotating from one sample point to the next. This is especially important when moving from high concentration sample areas to low concentration sample areas. Because there will always be some amount of “common” sample line in-between the manifold and the detector that all sample travels through regardless of which sample port is actively being sampled, time spent purging must be endured with manifold systems. A typical purge time at each sample point is no less than nine minutes to allow thorough evacuation and equilibrium of the common lines and detection system. Because the measurement may contain remnants of contamination from the previous sample location, time spent purging is meaningless and does not represent the true concentration of AMC at the sample location. After purging, a sample is typically analyzed for a one minute period of time, after which the manifold moves to the next sample point and continue the purge/sample sequence.

The amount of time sampling with real-time point-of-use monitors as compared to manifold sampling systems is clearly illustrated below. For example, a 60 point manifold will only capture a true representative sample for 3 minutes a day, with the remaining time spent either purging that sample line or sampling from other locations. A 16 point manifold will only capture a true representative sample for 9 minutes each day. The continuous point of use monitor on the other hand samples from a specific location for 1440 minutes each day; other locations are also monitored for 1440 minutes per day with dedicated point of use monitors.

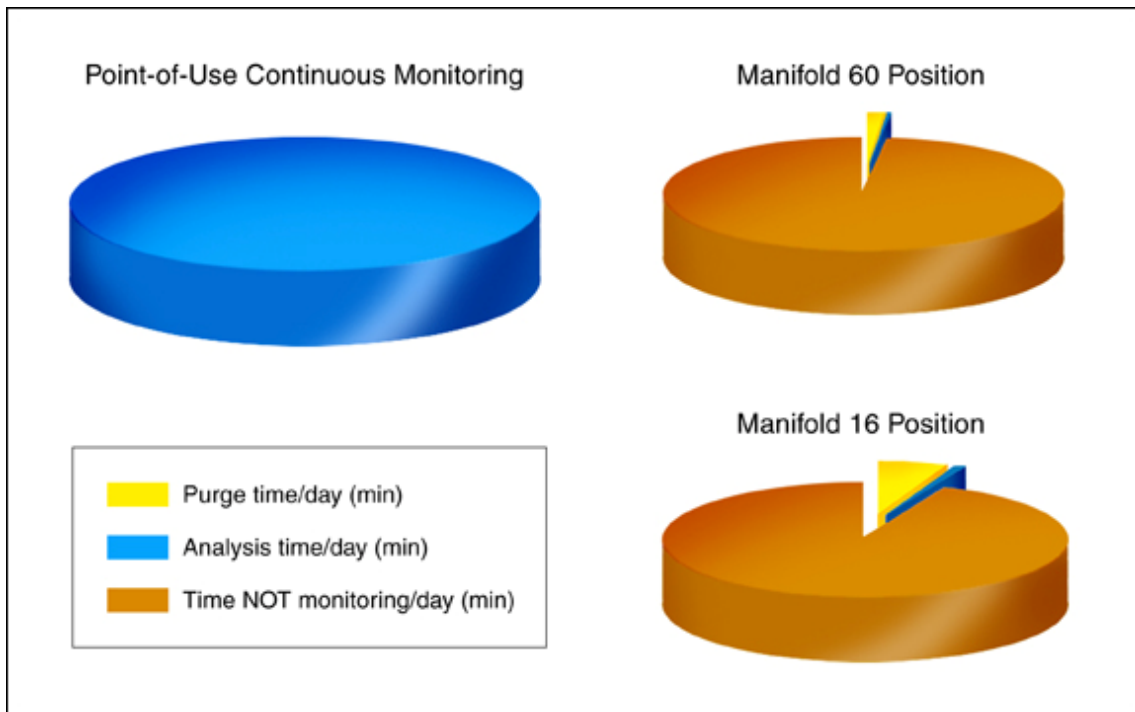


Figure 1: Analysis time for continuous analyzers vs. analyzers with manifolds

## **Upstream Components**

Many AMC monitors have evolved from old monitoring techniques, with increasingly complicated systems put in place to make up for weaknesses in those techniques. Often, hardware must be installed upstream of the detection system in order for the sample to be properly conditioned or setup prior to entering the detection mechanism. As seen in the tables above, that hardware can consist of valves, pumps, catalytic converters, etc. These components, and all hardware, are potential failure points within the monitor, and often require preventative maintenance. Mean time to failure (MTTF) and mean time between failures (MTBF) are often much shorter with additional upstream hardware, and mean time to repair (MTTR) is normally much longer. Being prepared for these failures and adding the cost of service for preventative maintenance can significantly increase the cost-of-ownership of the AMC monitor. With the sample interacting with each of these pieces of hardware, another opportunity exists for the sample to be changed prior to reaching the AMC monitor. Even more, these additional hardware items can contribute to contamination being detected in the air sample. In essence, with upstream components, rarely will the sample entering the AMC monitor be representative of the actual air sample in the environment due to effects caused by additional hardware upstream of the AMC detection system.

## **Calibration**

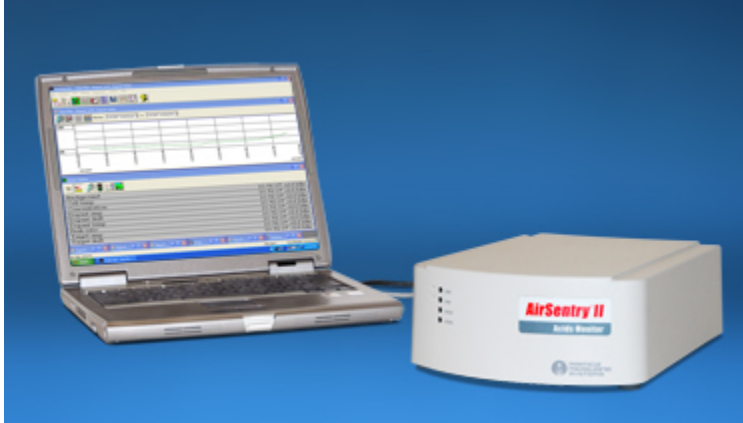
Airborne molecular contamination is just that – airborne. AMC is contamination as it exists in the gas-phase. AMC monitors are supposed to detect contamination in the gas-phase, and so calibration of the AMC monitor should be done with traceable gas-phase contamination standards. Techniques such as Ion Chromatography (IC) or Mass Spectroscopy (MS) use liquid standards for calibration, and do not concern themselves with the collection efficiencies of the techniques that are used to convert the air samples into a liquid sample capable of being injected into these monitors.

## **Sampling Time**

The less time it takes for the AMC monitor to detect the air sample, the better. Excess time only provides additional opportunities for contamination in the air sample to interact with itself. Reactions may occur that create new molecules that are not representative of the actual air sample, contaminants within the sample may break down and so the monitor may not detect components that are actually there, or again the container the air sample is entrapped in may contribute to contamination in the stream that may then be falsely associated with the environment where the air sample was taken. These concerns are especially valid with impingers or sorbent tubes, which collect air over a long period of time by trapping it in a medium. De-ionized (DI) water is a common impinger medium, and charcoal is common for sorbent tubes. Each of these techniques, due to the length of time to not only collect the sample, to transport it to a laboratory for analysis, and while the sample is in-queue for analysis, allow ample opportunity for the sample to be altered.

## IMS Design Simplicity

Ion Mobility Spectrometry (IMS) is one of the most widely used techniques in the semiconductor industry to monitor AMC contamination. The preference for using IMS to monitor AMC contamination generally stems from the fact that it is a continuous real-



time technique, is highly sensitive (< 70 pptv detection limits), and has a simple design.

The picture here illustrates the pneumatic and detection diagram of the AirSentry II<sup>®</sup> IMS analyzer from Particle Measuring Systems.

Figure 2: AirSentry II AMC Monitor

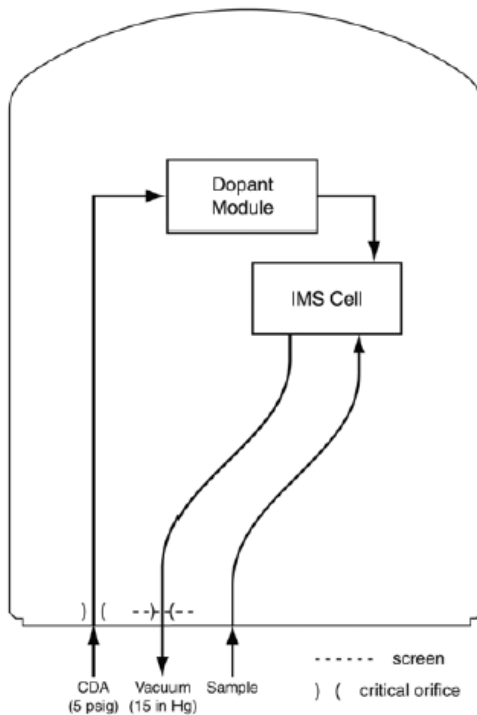


Figure 3: AirSentry II analyzer image showing Sample Routing of AirSentry II IMS Analyzer

It is apparent that the AirSentry II product has been simply designed, as there are no hardware components upstream of the IMS detection cell, and only a minimal amount of sample tubing is internal to the analyzer (about 6 in. of 1/8" PFA tubing). Because the AirSentry II is a point-of-use monitor, it is placed at the area of concern and does not rely on additional sample tubing to transport the sample from one location to another. There

are no unnecessary hardware components that could act as failure points, and this design virtually eliminates preventative maintenance.

The simple design allows the AirSentry II to have some unique advantages relative to other monitoring techniques. Because of minimal upstream sample tubing and hardware, the AirSentry II is able to achieve detection limits below 70 pptv. This limit of detection is defined as 3 times the noise at zero, therefore, zero noise is typically less than 20 pptv. In addition, there exists in the AirSentry II only one consumable item which needs to be changed at no less than 5 year intervals, and so there are no mechanical hardware failure points and minimal service requirements.

## Conclusions

In summary, attributes of a given AMC monitor must be considered when implementing a monitoring strategy for molecular contamination control. Simpler designs have fewer hardware failure points, require less preventative maintenance, and provide less opportunity for the sample air to be altered prior to the monitor's detection system. To recap on the important attribute considerations:

### Sample tubing before the detector

- Longer sample tube lengths provide greater surface area for AMC to interact or react with.
- Longer sample tube lengths will slow down the response to contamination events.
- Point-of-use monitors with little to no tubing are best for minimizing any potential for the sample to be altered prior to introduction into the AMC monitor.

### Sample manifolds

- When monitoring one sample location, all other locations are not being monitored (blind to any contamination events)
- When manifold systems or the analyzers they are connected to go down due to failure or for preventative maintenance, all sample points are not able to collect data.
- When switching between sample points in a manifold system, purge time becomes a substantial period of the time spent sampling a given location (typically 90% of the sample time spent at a given location, leaving only 10% for obtaining actual representative sample data).
- Low cost, compact, point-of-use monitors are intended to be used at the critical sample point. Many of these point-of-use monitors are distributed throughout the cleanroom or on critical equipment (such as 193 nm stepper/scanners and tracks) and therefore do not need a manifold.

### Upstream components

- Any component upstream of the detection system will interact with the sample, either altering the contaminants in the sample stream or contributing contamination to the sample stream.
- Additional mechanical components are always prone to failure, and typically require preventative maintenance on regular intervals. Components that can fail or that require service can significantly increase the cost-of-ownership of a monitoring system.

- AMC monitors with minimal components (hardware) upstream of the detection system provide the best opportunity to truly measure a representative air sample from the monitoring location of concern.

#### Sample Time

- The longer it takes to transport a sample from the monitoring environment to the detection system, the higher the likelihood of the sample being altered or contaminated.
- Sample techniques which capture the air sample on a media over a very long period of time are susceptible to sample damage from reaction of the sample with the media, the media enclosure material, or contaminants trapped within the media.
- Samples that must be transported to a laboratory are subject to sample alteration, reaction, and decay while in-route or waiting (in-queue) for analysis.

#### Calibration

- AMC is contamination as it exists in the gas-phase. Calibration of an AMC monitor thus needs to be done with traceable gas-phase calibration standards.
- Liquid calibration techniques are not representative of a gas-phase calibration, as they assume 100% efficiency of collection, which is never the case.
- Collection efficiencies in DI water or sorbent media can range from 40 – 98% depending upon the AMC contaminant. The collection efficiency of SO<sub>2</sub> is particularly poor, for example. Lower collection efficiencies will indicate a lower concentration than what actually exists in the monitoring environment, therefore reported output is falsely low.

When considering an AMC monitoring strategy, it is the small things that usually count the most. Many AMC monitoring companies tout the limit of detection as the main technical point to focus on. However, while detection limits are a factor, it is also imperative to consider all aspects of a given monitor, including design attributes. A simple design often increases the effectiveness of the monitoring solution, reduces downtime, and provides a more accurate representation of the true AMC levels within critical lithography equipment, process bays, or cleanroom facilities.

#### Author

Steven Rowley is the Molecular Contamination Product Line Manager for Particle Measuring Systems and has been involved in contamination control for over 10 years at Particle Measuring Systems, Texas Instruments, and Research Electro-Optics. Steven has a B.S. Chemical Engineering from the Colorado School of Mines, and an MBA from the University of Colorado.