Optimizing Semiconductor HVAC Filtration

By Jürgen M Lobert and Joseph Wildgoose

Chemical air filtration combined with onsite analytical evaluation of filtered area and the filter solution provides cost reduction through lifetime optimization for semiconductor cleanroom operation

Airborne Molecular Contamination (AMC) control in semiconductor manufacturing process bays has historically been applied to unique problems such as unwanted doping or corrosion control on metal films. With the advent of the 65nm and 45nm technology nodes and their highly energetic UV light, the impact of AMC on exposure and metrology tool optics and photo masks has increased with decreasing exposure wavelengths. Increasing beam intensity at each node drives sensitivity to contaminants, causing new issues, such as reticle haze. As a result, AMC control has increasingly become necessary for photo lithography cleanrooms, but until recently, most of these chemical filtration solutions were targeted to individual tools or tool clusters.

Most new fabs are now being designed and built with provisions for using AMC filters in the ceiling grid, and existing fabs are upgrading to these filters by retrofitting air handlers. Cleanroom operators considering use of chemical HVAC filters can help optimize the chemical and physical performance by working closely with filter vendors to understand and define performance parameters and AMC reduction requirements by monitoring each over time.

Figure 1: Typical two-layer HVAC chemical filter for comprehensive removal of acids, bases and organic AMC

One approach for such cooperation is the combination of parts-per-trillion level AMC sampling to determine the cleanroom's air chemistry and filter performance with the customization of filter media to optimize filter life, removal efficiency and pressure drop. Off-the-shelf filtration solutions rarely satisfy AMC requirements and facility operator expectations in state-of-the-art semiconductor cleanrooms. With thousands of filters installed in modern photo bays, cost reductions are becoming an integral part of semiconductor manufacturing. In addition, increasing competitive pressures require a comprehensive understanding of cleanroom AMC levels and filter performance.

Cutting Edge Technology

Semiconductor processing requires UV light to create the smallest of features on silicon wafers for powerful processors and memory chips used in modern computers and consumer electronics. The latest generation of semiconductor exposure tools employs 193nm wavelength UV lasers. This energy content can easily split molecules into reactive fragments, which can trigger chemical reactions and adhere to optical surfaces, which can cost as much as $5 million, as well as $10k/h in downtime while optical surfaces are cleaned or replaced. In addition, corrosion of surfaces by acidic compounds and the build-up of haze through chemical reactions, such as acid-base combinations, have always been problematic, even in older technology nodes.

Traditionally, chemical filtration to remove AMC was applied through specific tool solutions such as filtration cabinets for lithography exposure tools, tool-top filters for coat/develop tracks and a multitude of point-of-use purifiers for targeted purging of critical cavities and surfaces. With maturing technology nodes, cost reduction becomes crucial in lithography cleanroom operation. Tool operators want to extend the lifetime of costly high-end tool filters; any maintenance they have to perform causes tool downtime, a significant expense in semiconductor manufacturing. The use of HVAC filters for the entire cleanroom (Figure 1) can prolong the life of such tool filters.

Separating the Good From the Bad and Ugly

There are numerous chemical air filter products on the market today, many of which claim to be high-performing and suitable for the protection of advanced semiconductor processes. In truth, however, not all product performance documentation is based on the same test conditions, making the selection of proper chemical air filter solutions a daunting task for end users or the engineering firms hired to make such decisions. Compounding this dilemma is the lack of an industry standard for filter performance testing that would aid end users in the selection of a system best tailored to meet their needs.

As a general guideline, the initial step in qualifying a chemical air filter should begin with vendor performance data generated from a full-scale laboratory system, showing low parts per billion (ppb; one molecule in one billion air molecules, 10^{-9}) challenge concentrations of the critical compound(s) of interest, or of a representative compound when the actual target compound is toxic or unstable. Testing smaller samples of filter media may be quicker and less expensive but extrapolating the results to full-scale performance is often non-representative for the actual filter. Requiring all vendors to submit full-scale test data expressed in standard units will provide the end user with a method for accurate and concise comparison of products.

The next step in filter selection should include a list of reference installations from a similar facility with similar processes. Additionally, those references should be accompanied by data collected over time from an actual installation that characterizes the product's initial removal efficiency at commissioning as well as its long-term performance to demonstrate the useful service life (Figure 2).

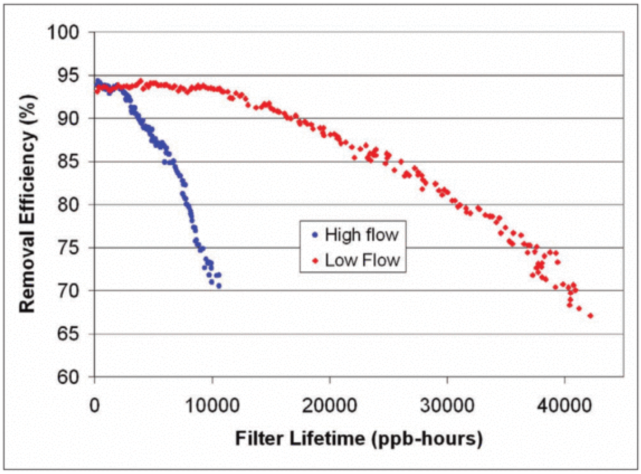

Figure 2: Filter lifetime curve for NH_3. Lifetime is expressed in ppb-hours. Multiplied with average ambient concentration of the AMC yields lifetime in hours

A major trend in filtration for many newer IC fabs is the desire to capture several categories of AMCs in a single, easy-to-use filter. This trend is based in part on the need to lower the cost of initial purchase, simplify installation and maintenance, minimize inventory and save on electrical operating costs due to lower pressure drop of a single filter. There are single filter solutions available that target and remove acids, bases and organic compounds, but not all are of equal value. It is important that a product has a balance in performance for all AMC categories so that the maximum lifetime for each is achieved when the filter is exhausted. A filter lasting four months for organics and 12 months for acids and bases will not provide a good return on investment. In this case, the "ink-jet cartridge" effect occurs: eight months of acid and base filtration capacity would be lost due to the need to replace filters for organic protection.

Facility managers should also determine if the chosen filter technology has the flexibility to provide different chemistry formulations that can evolve with the chemistry changes in the cleanroom. The AMC composition in a fab will change over time, as will the sensitivity of the manufacturing processes and tool-OEM specifications for ambient cleanliness. Ideally, the filter media formulation is configurable to meet the customer's future AMC needs with a cost-effective product that fits into the same installation footprint.

Finally, it is vital to gauge filter performance and cleanroom chemistry changes and to optimize filter lifetime. Facility managers and tool owners need reliable, pre- and post-installation AMC data, without which the integrity of the results is in question.

One in a trillion

Measurement of AMC in semiconductor cleanrooms has been commonplace for more than 10 years. Determination of ammonia levels that affect wafer surfaces (T-topping) started with 248nm technology and its increasingly sensitive resists. However, with the advent of 193nm UV exposure of wafers, a wide variety of other AMC issues has cropped up. Speciated measurements of acids, bases and organics became necessary and, in fact, were soon mandated by tool OEMs. AMC classes and measurement requirements were defined by SEMI and implemented into technology roadmaps by the ITRS. They typically consist of acids (A), bases (B), condensible organic compounds (C or O), dopants (D) and metals (M). C-class compounds also contain so-called refractory components (molecules containing Si, P, S etc.), which can cause severe and irreversible degradation of optical components by changing the refractive index of the optics.

Whereas health issues are typically defined in the parts per million (ppm) concentration range (one molecule in one million air molecules, 10^{-6}), AMC was found to affect processes and tools in the parts per billion (ppb) range, one thousand times less concentrated than typical OSHA requirements. With humans emitting ppm-level ammonia, benign hand lotions being made of silicon-containing compounds, and a suite of process chemicals in use, cleanroom AMC concentrations increase over time if they are not exchanged or filtered.

Modern AMC requirements for cleanroom ambient air has been as low as 0.1 ppb or 100 parts per trillion (ppt; molecules in one trillion gas molecules, 10^{-12}) — the equivalent of less than one person out of the Earth's entire population! Some purge gas specifications are now as low as 10 ppt for any one AMC class, making it a true challenge for analytical solutions to measure this concentration level. Suddenly, analytical laboratory environments are too dirty, chemically speaking, and most materials touching the sample gas can cause artifacts that are as large, or larger, than the AMC to be measured. Human breath, human perspiration, particles from fabrics, the pipette touching the (supposedly clean) counter surface, the quality of chemical supplies and the leaching of vial materials become obstacles in achieving detection limits that are necessary for confident results.

OEMs require low-level measurements of AMC throughout the wafer process due to the ever increasing sensitivity of resists and chip features, as well as staggering losses for every hour of process downtime. To meet these requirements, filter performance needs to be verified, AMC levels of compressed gases need to be checked and cleanroom ambient AMC levels need to conform to minimum standards – standards that are tightened year after year as the number of compounds to be measured expands. Considering these risks, the desire to measure AMC levels and see the results in real-time is understandable to meet the required low-level AMC measurements.

Whereas online measurement is possible for a few compounds, such as ammonia and perhaps a few volatile and non-reactive organic components, nature has placed constraints on our ability to measure everything in real-time, or at a low cost with minimal complexity. Sticky molecules, surface area on sample tubing, reactions in the sample path, interferences and low concentrations prevent us from measuring many, if not most, compounds in real-time using simple means. Strong acids (SO_2, HCl) don't work that way, nor do organic molecules of the highest interest (i.e., molecular weight). Thus far, we have not come up with a technology that measures it all at the same time and with minimal effort. Plus, the most reliable instruments for ppt-level analysis still require the most capable operators, yet running multiple gas chromatography-mass spectrometry (GC-MS) systems with advanced degree operators 24/7 is cost-prohibitive.

The current solution to these challenges is to measure the important compounds infrequently through grab sampling to generate a data set (Figure 3). Adsorbent traps such as Tenax TA, Carbotrap and Anasorb are commonly used to capture organic AMC, while deionized water impingers/bubblers are used to capture all soluble compounds like acids and bases in cleanroom air or supply gases. These devices allow a large amount of air drawn through them to concentrate the AMC in the traps—the air passes through, very much like an AMC filter—and is then analyzed for what has been captured with modern analytical machinery. Detection limits are inversely proportional to the amount of air collected; concentrations of 10 ppt can be achieved by collecting 30-500 liters of air with subsequent analysis on the most sensitive equipment.

Set-up, trapped air and sensitivity of equipment are not all that are required to achieve confident measurements. Detection limits (DL) need to be robust and laboratories must be capable of consistently performing this level of analysis. Laboratories are often geared toward general analysis and define their DLs by evaluating the size of signal achieved and its ratio to the background noise. A peak-to-noise ratio of 2–3 is typically found to be sufficient to define a DL and is very common in EPA-type applications using continuous monitors at the high ppb- to ppm-level. For single-point chromatography signals at the ppt-level, however, those quality standards are fundamentally inadequate, as they neither consider variability in sampling and analysis nor artifacts in the process of sample handling. A statistical approach to defining detection limits is essential and should entail a 99 percent confidence level to minimize false positive reporting to 1 percent or less. It is easy to "see" low-ppt level AMC, but it requires significant effort and focus to be able to report AMC with 99 percent confidence at 10 ppt or less.

Aside from experience in the industry and dedicated analytical solutions for semiconductor manufacturing cleanroom evaluation, quality becomes an overriding principle in

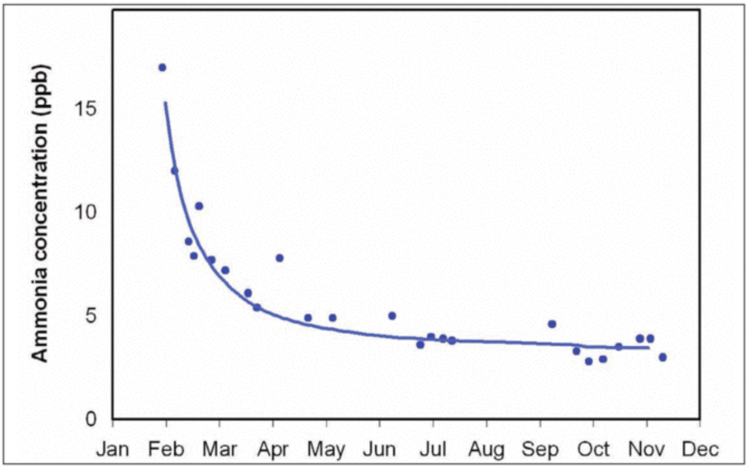

Figure 3: Cleanroom AMC concentration curve of NH_3 over time in an HVAC-filtered cleanroom. Concentration diminishes significantly and levels off at a concentration that was determined to be tolerable for the process.

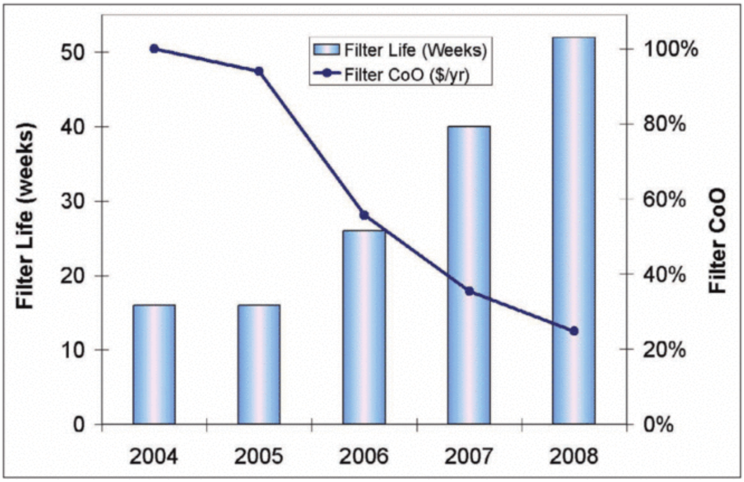

Figure 4: Example of cost reduction over time by increasing the filter lifetime.

delivering analytical solutions for AMC challenges. A proven record of expertise in the AMC filtration area as well as intimate knowledge of chemical filter products, semiconductor applications and litho-bay tools are essential, but laboratory quality and competence standards such as ISO 17025 accreditation are critical to help build confidence in choosing the right analytical solution.

Moving Forward

The most promising way to optimize cleanroom chemical filtration solutions is to tie filter performance, customized media and targeted filtration solutions to competent, high performance, and easy to use analytical solutions.

Accurate data gathered over an extended period of time is essential to gauge filter performance for all employed media and targeted AMC classes. Regular, although not continuous, monitoring of filter performance establishes a data set that allows engineers to evaluate the impact of the filter solution on AMC challenges and on the process sensitivity. Filter lifetime curves (Figure 2) need to be balanced with AMC concentrations in the cleanroom (Figure 3). The cleanroom operator or tool owner needs to find out first what level AMC can be tolerated by the process, and then determine how low the filter performance, or removal efficiency, can drop to maintain that AMC level. Combining both data sets allows the fab to push filter lifetime to its maximum for a reduced cost of ownership (CoO) without impacting the process performance. Note that in this scenario, filter lifetime is no longer defined in an absolute unit (e.g., ppb-hours), but rather is heavily dependent on process sensitivity and the tool owner's definition of tolerable AMC levels.

Based on the high cost of tool downtime and exposure tool repairs, filter deployments are first approached in a risk-averse fashion. However, with a steady stream of both upstream and downstream high-quality AMC data gathered both before and after filter deployment, a dataset can be established that allows the tool owner to gradually extend filter lifetime and allow for lower removal efficiency as AMC concentration diminishes.

Figure 4 shows an example of CoO reduction for an HVAC filtration solution as the lifetime of the filter was increased based on the data in Figures 2 and 3. Changes in design and media formulation can be included in this increase in lifetime as the need to remove one AMC class diminishes and the need to remove another class increases. This is known as the "lowest common denominator" principle.

In the above example, lifetime of the HVAC filtration solution was increased from 15 weeks to about one year as confidence in the product and analytical data grew. Ammonia concentration decreased over the same period from 18 ppb before filter deployment to a leveled-off value of about 6 ppb, which was found to be sufficiently low for process and tool protection needs. Utilizing the filters longer than one year would have increased NH_3 levels again, as removal efficiency dropped below a point where a steady-state NH_3 level could be maintained. That point was defined as the end-of-life for this particular filter model.

The best advice for HVAC chemical air filtration installation is not to take a vendor's initial specifications for granted. Modifications, customization, and validation of performance are essential in achieving targeted, optimized solutions and long filter lifetime. For optimum results, chemical HVAC filters need to be implemented as a team effort that provides hard data and competent solutions. G&I

Resources and Contacts

Entegris, Inc. Franklin, MA; www.entegris.com
SEMI standard F021-00-1102; www.semi.org
ITRS Roadmap for Semiconductors 2007; www.itrs.net

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