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Gas-Phase Contamination Control For Semiconductor Clean Rooms

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The need for critical control of particulates, temperature, relative humidity, noise and vibration in microelectronics clean rooms is well known. In clean rooms, HVAC design engineers must deal with the fact that as device geometry decreases the effect of gas-phase contamination on product yield increases.

The existence of airborne gas-phase contamination in semiconductor wafer fabrication facilities (fabs) is widely accepted and documented.[1,2,3,4,5,6,7] Designers are just beginning to understand the impact of contaminant levels on product yield rates. Generally, effects such as corrosion on wafer surfaces, wafer haze, optics haze, unintentional doping and interference with packaging operations cause problems.[3,6] The decision to use gas-phase contamination control equipment for a particular situation is quite involved and is typically owner-driven. This article presents the application of gas-phase contamination control equipment from the design engineer's perspective.

The *ASHRAE Handbook—HVAC Applications* Chapter 41 provides design information that is independent of the application. This article discusses controlling gas-phase contamination in semiconductor fabs, which involves the following:

1. Determination of gas-phase contaminant classification.
2. Identification of the contaminants.
3. Identification of the control methods and HVAC systems which require gas-phase filtration.
4. Selection and specification of the gas-phase contamination control equipment and systems.
5. Verification of gas-phase equipment performance and ongoing performance verification.

Gas-Phase Contaminant Classification

Traditionally, classification of semiconductor clean rooms has focused on the control of particulates. Federal Standard 209E, the recent ISO Draft Standard 14644-1 and similar standards are widely used. A Federal Standard 209E Class 1 clean room is limited to 1 particle per cubic foot at 0.5 microns and larger.

SEMI Standard F21-95 provides a method of classifying microelectronics clean rooms with respect to molecular contamination levels.[8] It is the gas-phase equivalent to particulate-related standards like Federal Standard 209E. SEMI F21-95 classifies a clean room based on the category of the gas-phase contaminant and the allowable concentration level of each category. The allowable concentrations of the different categories need not be the same, and the classification of different functional areas in the fab may vary (i.e. photo, implant, diffusion thin films etc.).

The four categories of gas-phase contaminants are:[8]

1. Acids (Category A): a corrosive gas that reacts chemically as an acid (an electron acceptor).
2. Bases (Category B): a corrosive gas that reacts chemically as a base (an electron donor).
3. Condensables (Category C): a contaminant whose boiling point is typically above room temperature and is capable of condensing on the wafer surface.
4. Dopants (Category D): a contaminant that modifies the electrical properties of semiconductor material.

The SEMI F21-95 classification is identified by the letter "M," followed by the category designator, which is followed by the allowable contamination in parts per trillion molar (ppt). Thus a classification of MA-10 is interpreted as having a maximum allowable cumulative concentration of 10 ppt of all acid category gas-phase contaminants. *Table 1* gives the SEMI F21-95 classifications.

Federal Standard 209E and SEMI F21-95 provide direction for classifying clean rooms based on allowed particulate levels and gas-phase contaminant levels. Unfortunately, the standards do not provide direction to apply those classifications to specific manufacturing environments. The SIA "National Technology Roadmap For Semiconductors" and SEMATECH's Technology Transfer 95052812A-T present recommendations which can be used to develop gas-phase contaminant classifications.[9,10] A typical pre-gate oxidation classification for 0.25-micron technology as identified in SEMATECH 95052812A-T is shown in the top row of *Table 2*.

Identification of Contaminants

The contaminant list is most often based on a combination of experience, owner input, the project utility matrix and the building chemical code study (see *Table 3* for a partial list of typical contaminants by category). The building utility matrix and chemical code study are standard design documents that identify the

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chemicals used in the facility. The anticipated contaminants are usually dependent on the functional area of the fab in question. Sources of contamination are:

1. Outside air (up to 6 cfm [2.83 L/s] per square foot of clean room).
2. The HVAC system construction materials.
3. The facility's construction materials.
4. The process tools and production materials.
5. Production personnel.

Material Category	1 pptM	10 pptM	100 pptM	1000 pptM	10,000 pptM
Acids	MA-1	MA-10	MA-100	MA-1000	MA-10,000
Bases	MB-1	MB-10	MB-100	MB-1000	MB-10,000
Condensables	MC-1	MC-10	MC-100	MC-1000	MC-10,000
Dopants	MD-1	MD-10	MD-100	MD-1000	MD-10,000

Table 1: Classification of airborne molecular contaminants.[8]

Process Step	Max. Sit Time	MA (pptM)	MB (pptM)	MC (pptM)	MD (pptM)
Pre-Gate Oxidation	4 hr	13,000	13,000	1,000	0.1
Salicidation	1 hr	180	13,000	35,000	1,000
Contact Formation	24 hr	5	13,000	2,000	100,000
DUV Photolithography	2 hr	10,000	1,000	100,000	10,000

Table 2: Projected AMC limits for the 0.25 μm process.[1]

Control Methods and Systems

The control methods most often employed for gas-phase contaminants are source control, ventilation control and control by removal with gas-phase filters. This article focuses on removal control of contaminants with gas-phase filters in a semiconductor facility may be used in outside air makeup air-handling units (100% outside air), central recirculation air-handling units and ceiling-mounted fan-powered HEPA filters. Also the filters may be used locally at the process tool or in a combination of these locations. Gas-phase contaminant filters are always followed by final HEPA or ULPA filtration.

Outside air makeup units distribute air throughout the facility to provide makeup air for exhaust and pressurization. Contaminants present in the outside air will be distributed throughout the facility if removal control is not employed in these units. Contaminants typically found in outside air are sulfur dioxide, nitrogen dioxides, volatile organic compounds and ammonia.[4]

Control, through the use of filters in recirculation AHUs or through fan-powered HEPA filters, can be achieved on a functional area basis if the HVAC system for each area is physically isolated. This approach is attractive because not all areas require the same level of control, and not all areas are subject to the same contaminants. The critical process areas identified in SEMATECH 95052812-TR are shown in *Table 2*.

In polished wafer manufacturing facilities, HVAC systems that serve areas used for final cleaning, inspecting and packaging should be considered for gas-phase contaminant control. It may be necessary to remove contaminants in all areas where wafers are processed, stored or handled in open containers.

Selection of Equipment

With respect to microelectronics, gas-phase media and equipment selection is a specialized and rapidly changing field. The primary processes of adsorption and chemisorption through the application of activated carbon and activated alumina media are standard. The binders and the activation agents in the media, the packaging and the physical characteristics vary.

U.S. manufacturers dealing in the microelectronics industry currently offer similar variations of the same product. The classic packed bed bulk media filter is a mainstay of the industry, although carbon–impregnated fiber filters, bonded bulk media filters and extruded media products are available.

The following parameters should be defined in the specification:

1. The anticipated contaminants and the challenge concentrations.
2. The filter efficiency or the allowable downstream concentration.
3. The desired filter service life or the contaminant holding capacity.
4. The total flow rate, face velocity, allowable pressure drop and the dimensional limitations.
5. The allowable particulate generation rate of the gas-phase equipment.

If the owner of the facility cannot provide the expected challenge concentrations, the engineer can obtain data from field measurements, or from similar projects. Field measurements from facilities that are in operation require trained personnel and specialized equipment to obtain accurate information without affecting production.

Chapter 41 of the *ASHRAE Handbook—Applications* addresses sampling and measurement techniques in *Table 12* and *Table 13* respectively. Obtaining specification values from field measurements of the planned facility requires the facility to be in operation before the measurements can be obtained. This implies that the actual purchase and installation of the gas-phase equipment will take place after construction is complete. Some typical concentrations obtained from the literature and the authors' experience are shown in *Table 3*.[5,6]

A gas-phase filter's efficiency is dependent on the media, the contaminant, the face velocity, the bed thickness, the cumulative time the media has been exposed, temperature and relative humidity. The specified efficiency is a tradeoff between the space contamination level and the total cost of ownership of the gas-phase filters. For the same face velocity a higher efficiency is obtained at the cost of higher resistance to airflow, more space requirements, as well as higher installation, operational and maintenance costs.

The gas-phase equipment at a minimum should reduce the inlet contamination levels by an order of magnitude. In critical applications initial efficiencies greater than 99%, with change-out efficiencies of 90% may be required. Of course the specified efficiency will be a dependent on the expected inlet concentration and the required downstream concentration.

Efficiency =

$$\left\{1-\left(\frac{\text{Outlet Concentration}}{\text{Inlet Concentration}}\right)\right\}\times 100$$

Category	Contaminant	Concentration Range Low ppb	 High ppb
Acids	Acetic	10	250
	Hydrochloric	0.1	200
	Hydrofluoric	0.1	200
	Nitric	0.1	200
	Sulfuric	0.1	200
Bases	Ammonia	10	200
	NMP	0.1	300
	All Other Amines	0.1	150
Condensables		10	250
Dopants	Boron (Note 1)	Not Detectable	200
	Phosphorous (Note 2)	Not Detectable	5
Outside Air	NO (Note 3)	5	300
	Sox' (Note 4)	3	150

Note 1: As Boric Acid or BF3; Note 2: As Organo Phosphate; Note 3: Primarily No$_2$.
Note 4: Primarily So$_2$.

Table 3: Typical clean room contaminants and concentrations.[14]

Steady-state models for determining the required gas-phase equipment outlet concentration may be found in the references.[10, 11]

Filter life is a function of the type and mass of media, the inlet concentration, the allowable downstream concentration, temperature, relative humidity, and the airflow rate. In the authors' experience, filter life in a microelectronics facility can range from six to 18 months under normal operating conditions. However, a chemical spill, a failure of an exhaust system, or any event that results in abnormally high inlet concentrations can require immediate replacement of gas-phase media. Specification of the filter contaminant holding capacity is an alternative to specification of the filter life.

The filter face velocity is dependent on the airflow rate and physical dimensions of the filters, but limits on pressure drop, and required efficiencies place constraints on the velocity. Lower face velocities result in higher efficiencies and lower pressure drops, but require more space for installation. Face velocities in the range of 500 fpm (2.54 m/s) are typical and result in pressure drops in the range of 0.50 in. w.g. (125 Pa).

The application of gas-phase control equipment in a semiconductor facility requires an evaluation of possible detrimental effects on the clean room environment. Gas-phase filters can contribute to both gas-phase and particulate contamination problems. Some manufacturers perform limited tests on the contribution of gas-phase contaminants to the airstream.[12] However, very little useful data is available on the particulate generation rate of gas-phase filters. A possible solution is to limit the particulate generation rate of gas-phase filters to that of particulate type prefilters routinely applied in clean room applications.

Verification of Performance

From a design engineer's perspective, verification or testing of equipment performance has four related subparts:

1. Gas-phase media testing.
2. Manufacturer's performance testing.
3. Installed equipment testing.
4. Ongoing performance verification.

The specification for gas-phase contamination equipment should reference a standard test procedure. This allows comparisons between different products, and insures correct application of a given product.

A general standard (or combination of standards) should address all four subparts of performance testing and should standardize the test contaminants, the inlet concentrations, the filter's physical dimensions, the airflow, the temperature, and the relative humidity. Measurements of filter efficiency, pressure drop, particulate generation, and service life of the filter will then provide performance parameters which could be compared with other products.

There are currently no standard procedures for general performance testing of gas-phase contamination equipment as herein described. There are media testing standards for physical characteristics of the media and performance of the media alone. However, performance of the media alone does not provide absolute or relative measure of the media's performance in actual operating conditions.[13] This topic is treated significantly in the literature, and manufacturers have developed their own recommended practices and procedures.

ASHRAE Standards Project Committee 145P, *Test Methods for Assessing the Performance of Gas-phase Air Cleaning Equipment* is working to develop a standard to address media testing lab-based duct-mounted equipment testing, and field based installed equipment testing.

At this time the best approach may be judicious use of the standards available and specification of an in-place test subsequent to construction to verify the installed performance. The test procedure should be included in the specifications, and an independent testing contractor should be employed to perform the testing.

Determination of the timing for filter change-out can be obtained by several methods. None are completely satisfactory. Media testing can be performed at regular intervals to determine remaining capacity, and predict remaining filter life. Test coupons placed downstream of the chemical filters can be used to monitor downstream contamination levels and also predict filter life.

Removal of media for testing in an operational clean room supply airstream is problematic, and there is a time delay in obtaining the results of the test. Predicting filter life with test coupons at the very low concentrations involved in clean room applications is difficult, and again there is a time delay in obtaining the results. A clean room can operate under unacceptable conditions for some time while awaiting the results of media testing or test coupon results.

Electronic gas-phase monitors designed for real time monitoring of contamination levels respond very quickly to changes in the measured variable. They are capable of detecting contaminant levels in the ppb range, and are available for a wide range of contaminants. The major disadvantage of real-time gas-phase monitors is the relatively high cost when compared to media sampling or test coupons. Current detection limits for the four classes of contaminants described herein are:

1. Acids = 3 ppb
2. Bases = 3 ppb
3. Condensables = 10 ppt
4. Dopants = 1 ppt

Conclusion

As device geometry continues to decrease the effect of gas-phase contamination on product yield rates will increase. The challenge to the design engineer will become even greater because the acceptable levels of contamination will drop below the current detection limits. Application of gas-phase equipment however, will continue to be applied using the following procedure:

1. Gas-phase classification of the environment.
2. Identification of the contaminants and the concentrations.
3. Careful selection of the HVAC systems requiring gas-phase control equipment.
4. Specification of the equipment as outlined in this article.
5. Measurement and verification of equipment performance.

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14. Sources for the data in Table 3 are Extraction Systems, Lockwood Greene Engineers and Purafil Inc. ■

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