

A Primer of Filtration of Gas Phase Contaminants in the Semiconductor Industry

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OVERVIEW

The filtration of gas-phase contaminants, or **airborne molecular contamination (AMC)**, as opposed to particles, was first brought to the attention of the semiconductor industry when it was discovered that weak bases poisoned **chemically amplified resists (CARs)** used in **deep ultraviolet (DUV)** lithography.

DUV primarily refers to light wavelengths of 248, 193 and 157 nanometers (nm), generated respectively by KrF, ArF and F2 excimer lasers.

Weak bases of primary concerns are:

Ammonia (NH₃)

Real-time detection of airborne contaminants in DUV lithographic processing environments/Contamination of Positive Deep UV Photoresists. Proceedings – Institute of Environmental Sciences 1995, *Kim R. Dean and Ronald A. Carpio, Sematech*

Amides (e.g. NMP, DMF, DMA)

Journal of Photopolymer Science and Technology, Vol 4, (1991) *O. Nalamasu, M.Cheng, A.Timko, V.Pol, E.Reichmanis, L.Thompson*

Various Organic Amines.

The mechanism for resist poisoning, whereby bases impede the acid catalysis in post exposure delay (PED), is well understood and manufacturers of photoresists have worked diligently to decrease sensitivity to this reaction. (See drawing #1 below)

The harmful effects of other non-polar organics and acidic species was less well defined, but thought to be responsible for:

Contaminant	Effect
Acids	Etching of surfaces Haze formation
Condensable Organics	SiC formation Delay of incubation time in CVD Wetting problems
Dopants	Higher contact resistance Unintentional Doping

Source: Jürgen H. Bügler Fraunhofer Institute of Integrated Circuits Device Technology. Erlangen, Germany 2001

Many of these effects were not considered to be of great significance at larger process nodes; however, this set of contaminants is thought to represent the largest mass of gas-phase molecules.

Source: Chemically clean air: an emerging issue in the fab environment
Semiconductor International September 1996 pages 115 ~122
John Mikulsky, Balazs Analytical Laboratory

The earliest filter systems supplied by Donaldson Company and installed on DUV lithography steppers and tracks contained trays of activated carbon. These systems comprised large semi-industrial housings located in the sub-fab with air ducted to the roof of the tool. Carbon was selected from the many available media options because it has the unique ability to effectively filter amides, non-polar organics and a limited volume of acidic species using a single media platform. Citric acid was eventually selected as an impregnant for a precise portion of the carbon media due to its demonstrated efficiency at removing polar bases such as ammonia, as well as physical stability and extremely low off-gas characteristics under typical operating conditions.

In the late 1990's a number of manufacturers introduced the use of **ion-exchange resins** (IER), also referred to as polymeric catalysts, for this application. Although expensive compared with carbon, IER has both high efficiency and good capacity for ammonia and organic amines. However, the adsorption mechanism is strictly a surface chemical reaction with little or no capacity for non-polar organics or acids. IER removal efficiency for amides is still a subject for debate, with overall capacity (service life) and removal efficiency dependent on other variables.

As the use of these so-called **amine or chemical filters** became increasingly accepted in the fab, track and stepper OEMs, particularly those in Japan, sought to integrate filter systems into their tools. This move increased the demand for lightweight, low-pressure drop filters that could be mounted above the existing particulate (HEPA or ULPA) filters on the roof of the tool. Often, filter effectiveness was sacrificed in favor of very low pressure drop and light weight to minimize tool vibration. Other drawbacks of tool-mounted filters include reduced temperature and humidity control, as well as greater risk of worker exposure to harmful emissions from process tools that vent post-process air directly into the cleanroom environment.

In the years following 2001, the filter market has changed substantially as scanner manufacturers began recognizing the significance of organic and acidic contamination on their lens systems. Initial investigations revealed ammonium sulfate and magnesium sulfate deposits, but other laser-induced damage to anti-reflective coatings has also been documented, albeit not published. The mechanism whereby damage is done is still not fully understood, but the cost of tool downtime and repair is significant. In 2002, the reticle industry began to find similar problems.

Source: EMC 2003 19th European Mask Conference on Mask Technology. Investigation of reticle defect formation at DUV lithography, *K. Bhattacharyya, W. Volk, B. Grenon, D. Brown, J. Ayala*

While an awareness of the need for filtration grows rapidly as these contamination issues come to light, filtration strategies adopted by OEMs, fabs and consequently filter manufacturers are not all the same.

APPLICATIONS

An overview of the most common applications is given in figure 1 on next page.

There are two main ways to minimize the harmful affects of gas-phase contamination




- (i) **Full fab, area or zone filtration**, in which the entire volume of air that enters the cleanroom environment (a combination of intake air & recirculated air) is chemically filtered,
- (ii) **Mini-environment filtration**, where only the air that will be in contact with critical processes or components is chemically filtered.

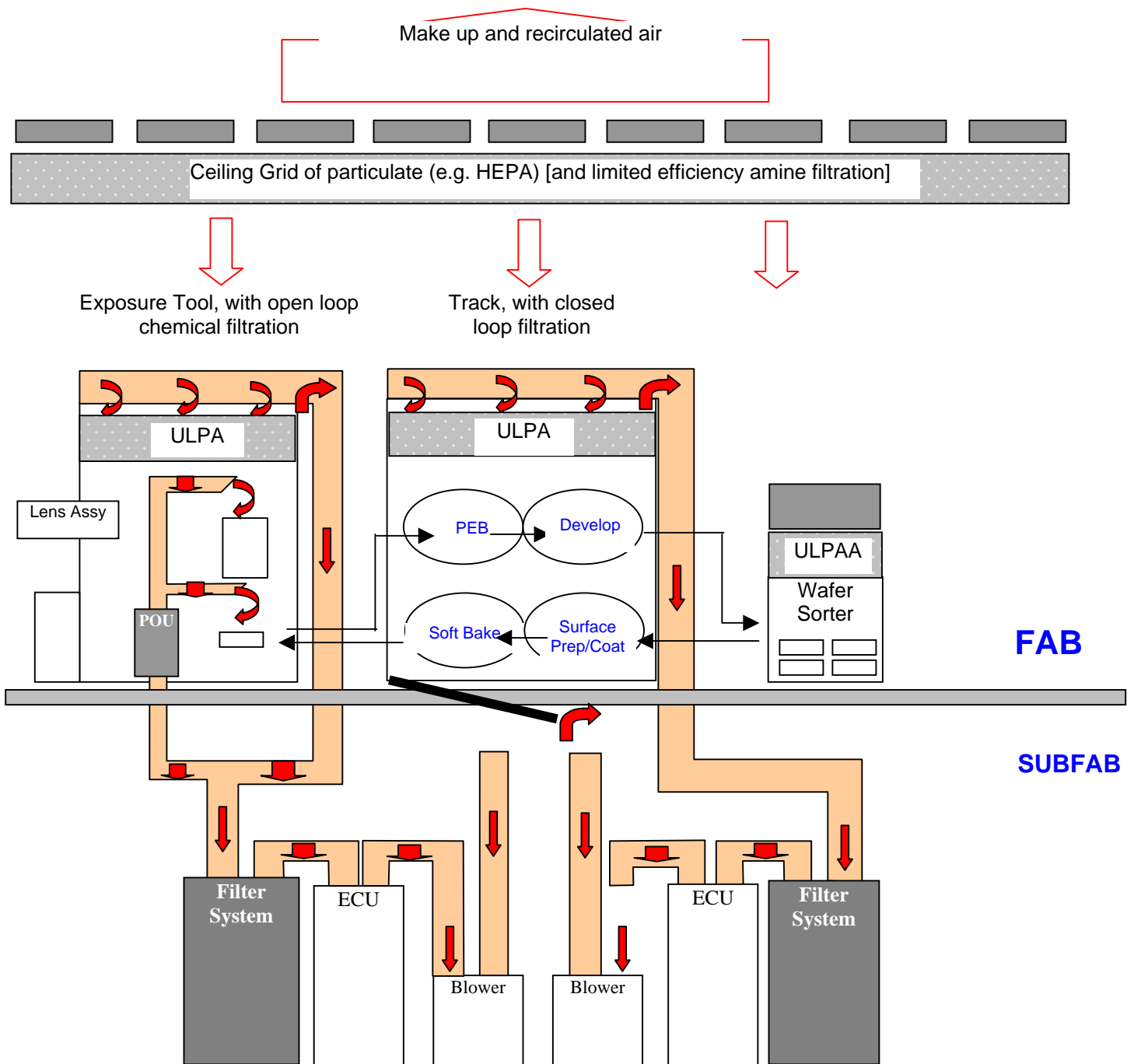
Potentially requiring the greatest number of filters, the zone filtration market attracts the largest number of filter suppliers. Accordingly, prices are quite competitive. The primary technology in use is a pleated, lofted-carbon media that may or may not contain chemical impregnants. Frames are generally made of cardboard and are disposable after use. Such filters usually have good initial removal efficiencies, but suffer relatively rapid degradation in performance. Based on anecdotal information, customer satisfaction is generally believed to be poor, but warranty claims are rare -- because price points are low or because performance specifications are neither well-documented nor fully understood.

Mini-environment filtration is a more specialized area with fewer participants. Because the cost impact of contamination in terms of damaged optics, yield loss and tool downtime is high, mini-environment filters must be thoroughly characterized with test data available to support product performance claims. Tool OEM's usually choose to qualify filter suppliers for use with their tools and many fabs strictly follow OEM recommendations. However, as fabs begin to understand the difficulties inherent in a one-size-fits-all approach to chemical filtration, such recommendations are coming under increasing scrutiny, irrespective of any cost saving that are available through direct purchasing from the filter manufacturer.

Figure 1
Overview of filter elements in standard lithography area tool configuration

Applications

- Particulate filters 
- Chemical filters 
- Airflow 



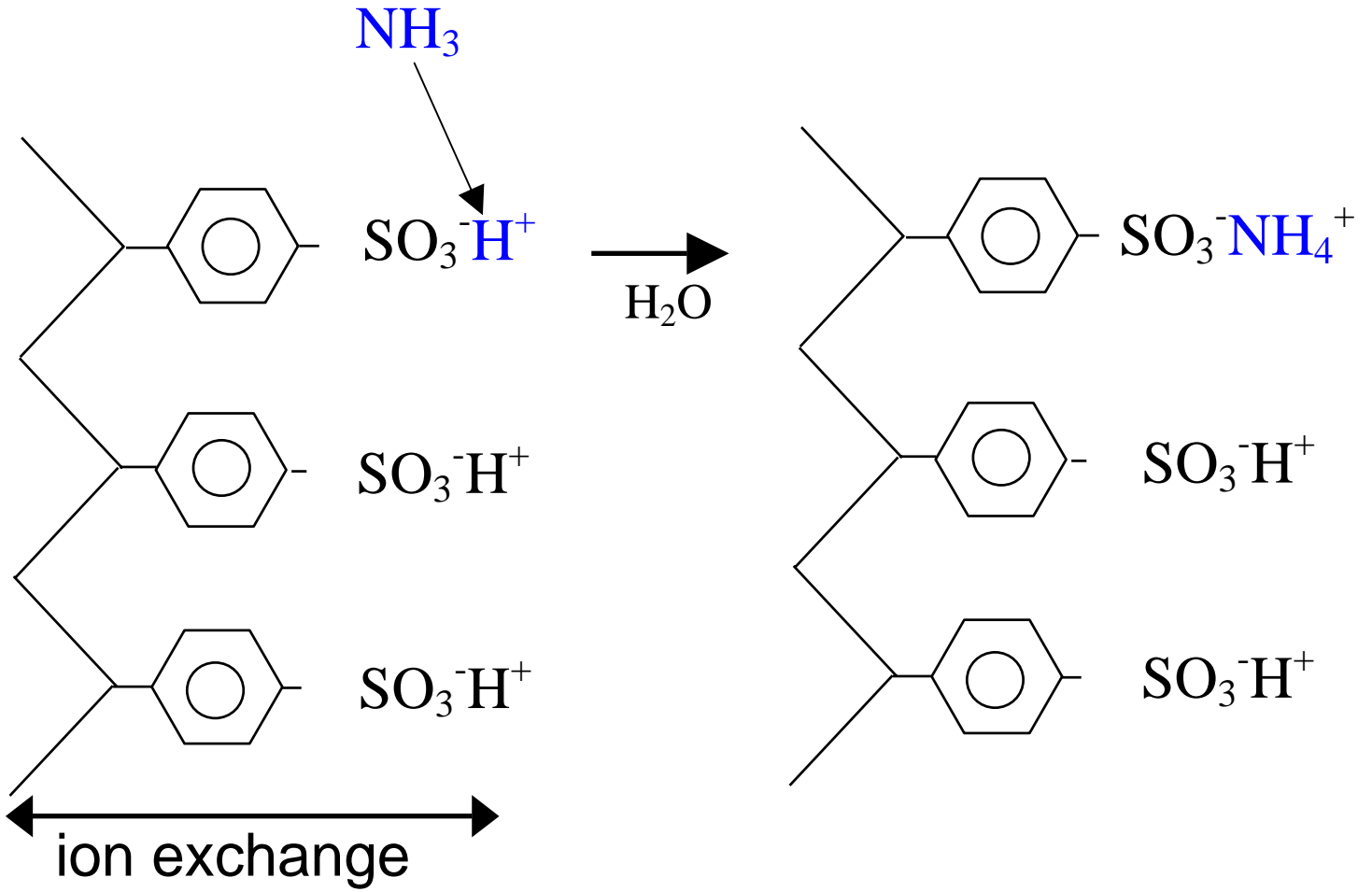
TECHNICAL CONSIDERATIONS

In some ways use of the word “filter” with respect to control of gas phase contamination is unfortunate given the difference between HEPA and ULPA particulate filters and so-called chemical filters.

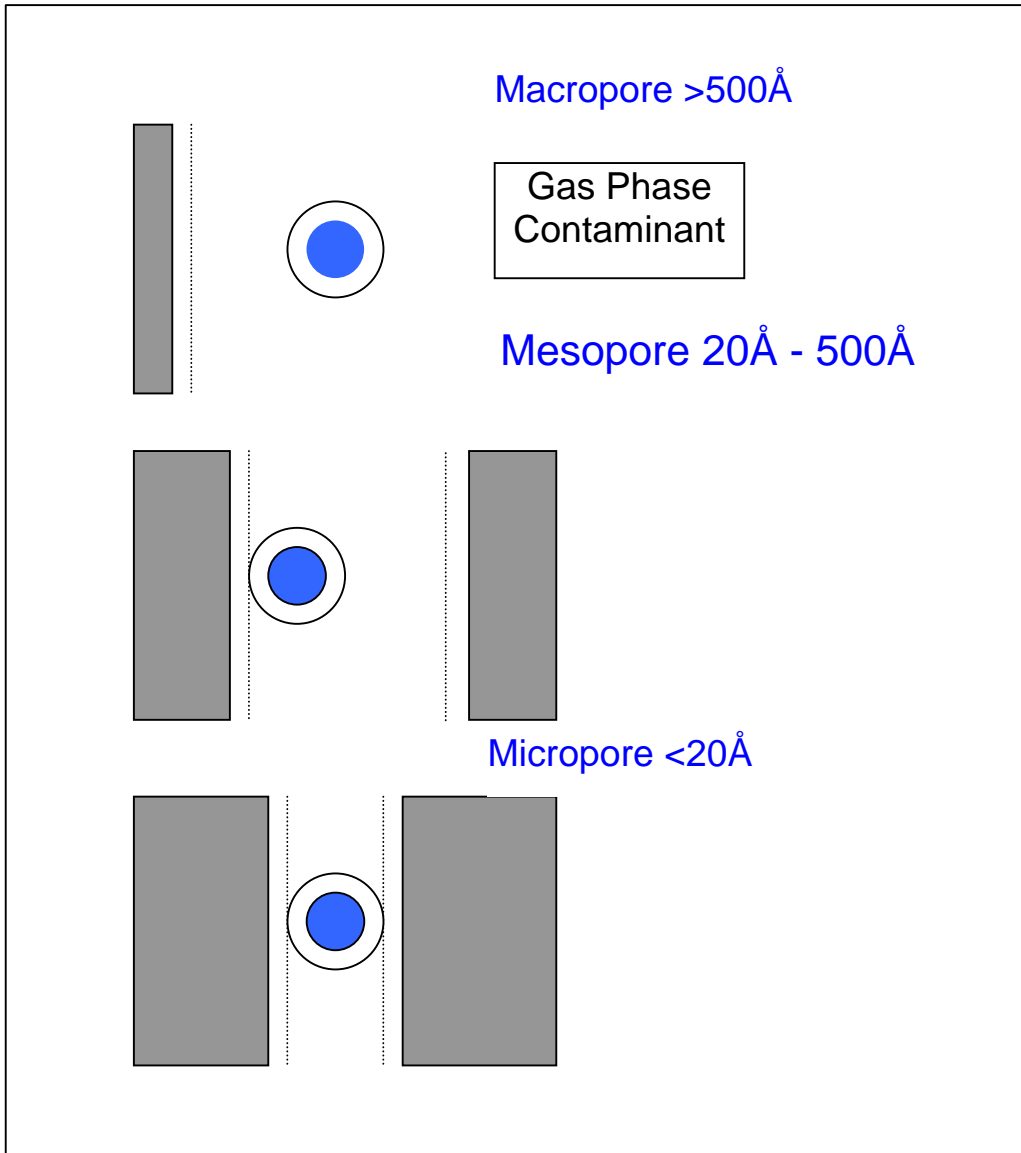
Differences Between Particulate and Chemical Filtration

<i>Chemical</i>	<i>Particles</i>
<ul style="list-style-type: none">• Designed to filter gases	<ul style="list-style-type: none">• Designed to filter particles
<ul style="list-style-type: none">• Constant pressure drop over time, regardless of loading	<ul style="list-style-type: none">• Pressure drop increases as filter loads
<ul style="list-style-type: none">• Efficiency decreases as filter exhausts	<ul style="list-style-type: none">• Efficiency increases as filter exhausts
<ul style="list-style-type: none">• Very dynamic contamination input levels (e.g. acids, bases, organics in rapidly changing concentrations)	<ul style="list-style-type: none">• Defined contamination input (e.g. particle size, physical form, particle type, etc.)
<ul style="list-style-type: none">• Changes in environmental conditions (e.g. humidity, etc.) can significantly affect filter performance	<ul style="list-style-type: none">• Changes in environmental conditions will not generally affect filter performance
<ul style="list-style-type: none">• Interactions between gases can result in physical changes (e.g. from gas-phase to solid or liquid form)	<ul style="list-style-type: none">• Particles can coalesce to form larger particles or rub together to form smaller particles, but will not change physical form
<ul style="list-style-type: none">• Part-per-billion, even part-per-trillion levels of chemical contamination can adversely affect critical processes or tools	<ul style="list-style-type: none">• Usually less sensitive to low level particle contamination passage
<ul style="list-style-type: none">• Extreme sensitivity of processes and tools makes measuring filter performance very difficult	<ul style="list-style-type: none">• Particle measurement is comparatively simple and well understood

The mechanism of adsorption for IER is a surface chemical reaction as below



Physical adsorption of non-polar organics is a function of induced polarity via Van der Waals forces. The effectiveness of this force is a function of both the structure of the carbon, specifically the availability and distribution of pores sizes, and of the molecular weight of the contaminant itself.



Given that the total Van der Waals force on any molecule is a function of the total attraction between that molecule and the adjacent filter media, the force with which any molecule is held within the structure of the carbon will depend on the total volume of appropriately sized pores within a particular carbon. Accordingly, not all carbons will have the same removal efficiency for any set of contaminants. Furthermore, the presence of other contaminants with greater degrees of attraction may degrade the calculated theoretical capacity for any particular contaminant taken on its own.

CONCLUSION

Today, filtration of gas-phase contaminants in the semiconductor industry continues to grow in urgency and application; and nearly everyone involved in the industry recognizes their effectiveness.

As demand for chemical filter applications in mini-environments has increased, fabs have recognized that a one-size-fits-all approach to chemical filtration is ineffective, regardless of cost savings. While costs will always be a factor, filtration strategies for gas-phase contaminants must first protect against lens degradation, yield loss and tool downtime. Process and tool protection, after all, was and is the primary purpose of any filtration strategy.

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