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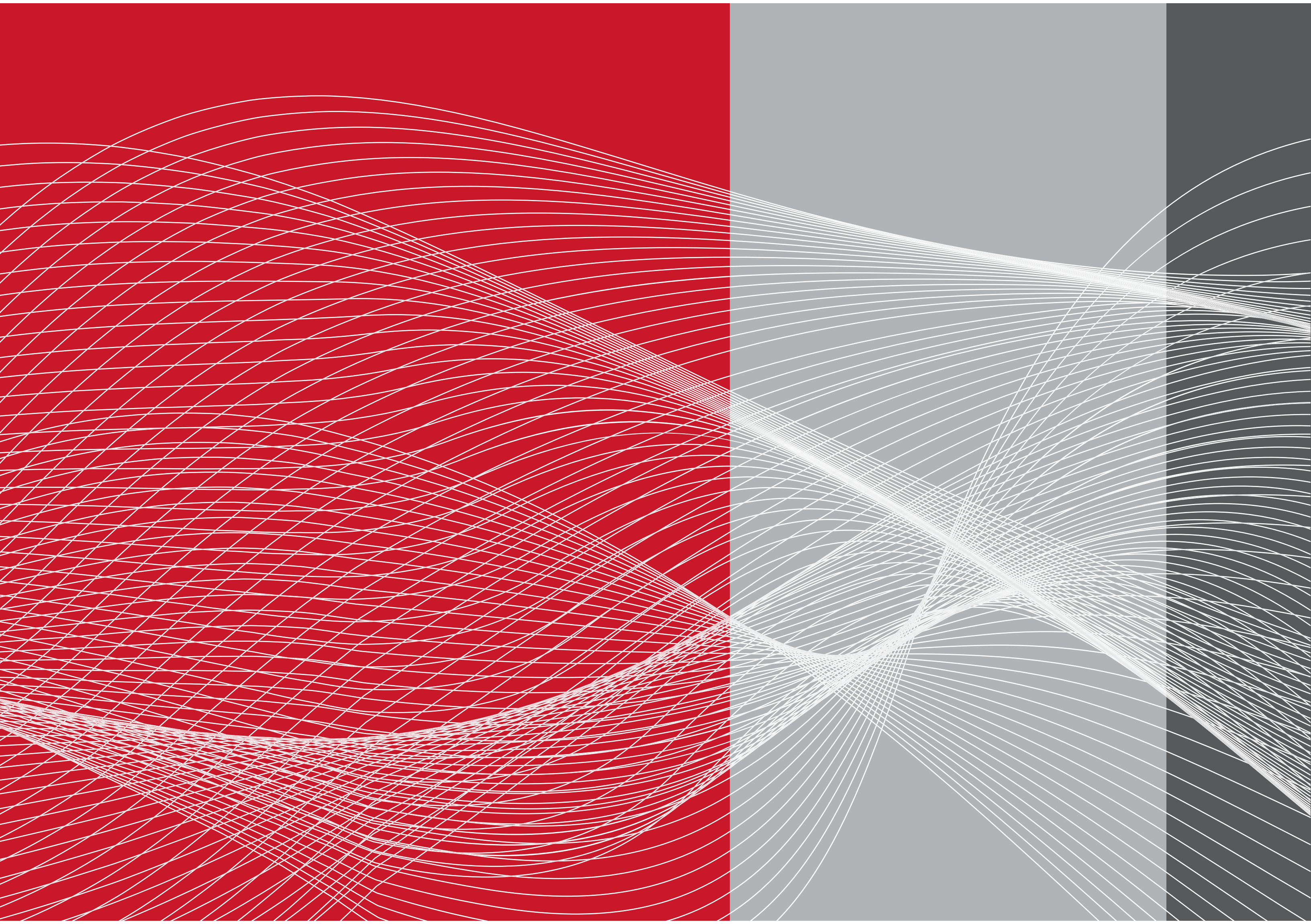
Avoid Airborne Molecular Contamination (AMC) with HEPA Filtration



HEPA & AMC Filtration Utilized in the Microelectronic Industry

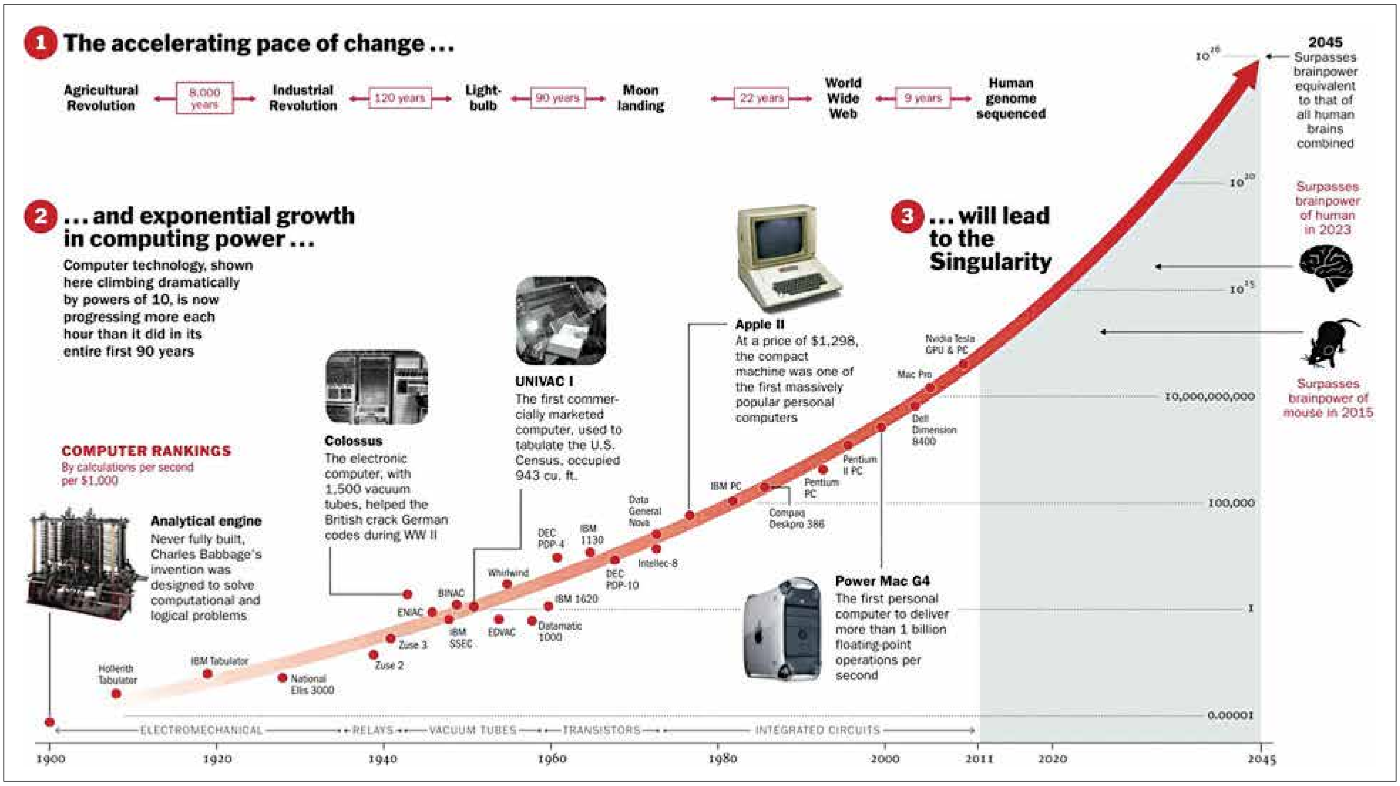
Short history of the Microelectronics Industry and how it has evolved specific to HEPA & AMC Filtration:

During the mid-1990's there was a marked increase in semiconductor demand due to a booming global economy. Increased chip prices, shortened product life cycle for MPUs (Microprocessors), which led Intel among others, the largest manufacturer to introduce chips more frequently to the market. Product innovation had also accelerated, made possible by an increase in Moore's Law, a stylized description of technology that stated the number of electrical components on a chip will double every eighteen months.

As the geometries of the integrated circuits decreased, there was a marked increase in awareness and therefore, demand to reduce not only particulate contamination but Airborne Molecular Contamination (AMC) in the cleanroom. Glass fiber filters, the traditional media utilized in the industry, did not measure up in many applications and the door opened for wider adoption of the PTFE membrane technology.

Motorola (now a SMIC facility) was an early adopter installing over 6000 PTFE filters at their facility in Tianjin, China in 1998. Ironically, the driving factor for the decision to use the membrane technology at the time was the filters excellent mechanical stability and durability.

The End of Moore's Law?



"Moore's law refers to an observation made by Intel co-founder Gordon Moore in 1965. He noticed that the number of transistors per square inch on integrated circuits had doubled every year since their invention. Moore's law predicts that this trend will continue into the foreseeable future."

> *I think the end of Moore's Law, as I have defined the end, will bring about a golden new era of computer architecture. No longer will architects need to cower at the relentless improvements that they know others will get due to Moore's Law. They will be able to take the time to try new ideas out in silicon, now safe in the knowledge that a conventional computer architecture will not be able to do the same thing in just two or four years in software. And the new things they do may not be about speed. They might be about making computation better in other ways.*
>
> *Source Unknown*

Protecting and Improving Yield

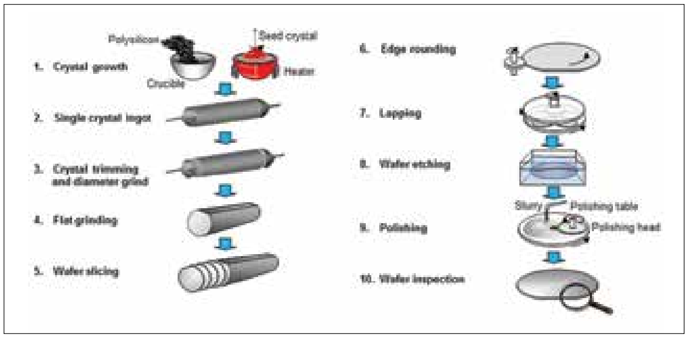
Product yield in simple terms relates to the proportion of finished product compared to the total of products that were scrapped and therefore, contributes to yield loss. Due to the multiple process steps, the risk of contamination and by default increased scrap rate, many of the Wafer manufacturers demanded ‘No Boron filters’ or a heavily reduced Boron content in traditional glass fiber media. Borosilicate glass fiber will actually increase the contamination in these particular applications when acids from certain process steps (Diffusion) are found to accelerate the release of B3 from the glass fiber filters into the cleanroom.

The traditional glass fiber media paper suppliers quickly developed a ‘low Boron media’ (LB, typically 8% Boron content by weight) to ‘compete’ with the membrane technology. Some end users at the time made the cost benefit analysis and chose the lower cost LB glass fiber media often coupled with chemical filters to address their specific applications. AMD in Dresden was one of the first facilities to install low Boron media. Although their original choice was to use the PTFE membrane filters, availability along with manufacturing capability and capacity was low, as demand far outweighed capacity for these filters at the time (circa 1997).

Industry Cleanroom Design Change

The design of cleanrooms for semiconductor facilities also started to change in this period from the traditional ballroom/plenum design to an FFU design. The mass adoption of the FFU (Fan Filter Unit) design which has proven to deliver specific flexibility benefits from an equipment support standpoint, low operating cost with advancement in the EC fan and smart controls technology, and the added benefit a negative plenum delivers from a contamination control standpoint.

Simultaneously, an increase in the use of mini-environments and/or SMIF (Standard Mechanical Interface) took place where widespread installations of the PTFE membrane filters was well underway. The PTFE filters were often combined with multi-layer AMC (Chemical/Carbon) filtration for the most critical process applications.



Wafer Process

Protecting wafers within their own mini-environments or pods/FOUPS (Front Opening Unified Pod) against a growing list of potential contaminants during the manufacturing process vastly improved the yield rate, but also increased operating costs. The PTFE membrane technology became the product of choice, coupled with the Fan Unit due to the lower initial resistance than glass fiber filters and very high filter efficiency at the MPPS. (MPPS of PTFE is typically 70nm). PTFE is installed in the most critical environments while the ‘background’ contamination level in the cleanroom, although less critical, still has the economic benefits of lower operating costs when utilizing PTFE.

In the 2000’s there was a rapid acceptance and increase of installations of PTFE membrane media mainly for the newer manufacturing hubs in Taiwan, Singapore and China. The major investments continued to migrate from the EU/US to the Asia region. The home grown foundries such as TSMC, UMC, and SMIC were now dominating the global manufacturing capacity landscape. Samsung and Global Foundries can be added to the ‘Top five’ which shows 80% of today’s capacity has its origins in Asia.

The early adopters of PTFE who had specific application needs from an AMC or durability standpoint were willing to pay a premium over glass fiber media. The industry in general (Microelectronic Cleanrooms) who were at the more competitive end of the business continued to utilize traditional or low Boron glass fiber technology while continuing to utilize PTFE membrane media for the tools.

The TFT-LCD industry recognized very quickly the benefits outlined associated with the PTFE membrane but were primarily driven by the advantages of lower pressure drop and therefore, lower operating costs due to their extremely high energy consumption.

As the feature size decreased and the wafer size increased, the cost of equipment to support these facilities sky rocketed during this period. A brand new Chip factory could cost over $10 Billion USD and yet have an expected ROI of 3 years. The operating costs were and are huge and the need for flexibility within the production space is vital as the technology is constantly evolving. The constant pressure to reduce cost, improve yield AND develop the next generation technologies drove many suppliers to be at their innovative best especially in the field of improved efficiency and lowest Total Cost of Ownership (TCO). PTFE filters was one of those innovations as pleating and testing capability vastly improved in this decade.

Sustainability and Energy Focus

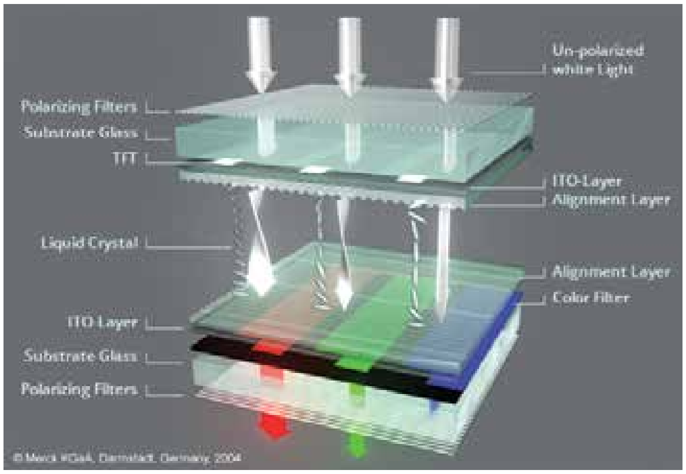
The energy consumed by some of the larger semiconductor or FPD (Flat Panel Display) facilities is staggering. A typical fab will consume as much power on average of approximately 50,000 homes. The MEGA Fabs or facilities will consume over 100MW or more than an automotive or refinery facility.

Flat Panel Display Assembly

A facility that is producing LCD (Liquid Crystal Display), PDP (Plasma Display Panel), LED (Light Emitting Diode), OLED (Organic Light Emitting Diode) or FED (Field Emission Display) need to maintain critical cleanroom cleanliness levels due to the high risk of contamination during multiple process steps.

Thin Film Transistor, (TFT-LCD) facilities need vast cleanrooms due to the size of the screens now being produced with a typical air cleanliness requirement of ISO 5 with IS0 4 in controlled zones. The large amount of air movement has made the manufacturers pay attention to optimization of the FFU/Controls and filters for these MEGA facilities.

HEPA & AMC Filtration Utilized in the Microelectronic Industry



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Display Funtionality

The initial resistance to airflow for a PTFE membrane filter v a Borosilicate glass fiber filter is typically 50% less when comparing the same filter efficiency and filer pack depth. This can represent hundreds of thousands of dollars in reduced operating costs. An additional benefit of the very low resistance of PTFE to airflow is the reduction in pack depth or media area when compared to glass fiber that has added reduced weight benefits and reduction of fan size in certain instances.

A Flat Panel Display (FPD) facility can have ceiling heights of between 10m and 15m. They also normally have much larger areas under filter coverage > 200,000m^2 is not unusual. They typically operate in the ISO 5 to ISO 7 range.

The good news is there is no regulatory requirement driving cleanliness classes or ACH therefore factory owners have aggressively reduced the typical air change rates and average room velocity as mentioned previously during the past twenty years. There are limits to decreases in ACH, filter coverage, and average room velocity based on risk evaluation to exposed product, recovery time, and ability to maintain temperature control.

Cooling

With high internal heat loads (up to 1000 w/m^2) from the process equipment, the equipment must be cooled with sufficient cleanroom ACH or by other sources. The average across the entire space is typically 200-250 W/m^2

Dehumidification

The source of moisture is fresh air and adjacent spaces with no humidity control. Fresh air requirements are based upon minimum requirements to meet building codes, process exhaust, and pressurization.

Economies of Scale

Economies of scale driven by an ever increasing demand for the PTFE membrane filters has reduced the manufacturing cost significantly, allowing the end user to make an easy decision when faced with choosing PTFE or glass fiber especially in microelectronic applications due to the three main benefits previously mentioned.

- Lowest Contamination (When compared to Glass Fiber Media)
- Lowest Operating Cost (When compared to Glass Fiber Media)
- Highest Durability (When compared to Glass Fiber Media)

AMC– ‘the norm’

The control of Airborne Molecular Contamination (AMC) is now the norm in advanced Wafer or FPD facilities. The PTFE membrane technology is also ‘now the norm’ in the most critical process areas.

Most products have a product life cycle. The PTFE membrane technology is no different. Widespread acceptance of the product has reduced manufacturing and sales cost. The last 10 years has seen the price decrease by as much as 50%. PTFE combined with a robust AMC management from the front to the back end of a facility is ‘now the norm’.

The PTFE membrane technology makes excellent technical and commercial sense and is ideally suited to work very effectively in the environmental conditions demanded from the microelectronic industry.

HEPA/ULPA Filter Construction and Testing Options

This table provides a thorough overview of the options available for each of our HEPA and ULPA filters, allowing you to make informed decisions for a given application and configuration. Each feature is denoted as standard (•), optional (Option), or not available (▨).

	MEGAcel® I ePTFE*	MEGAcel® II ePTFE*	MEGAcel® III ePTFE*	MEGAcel® I eFRM	MEGAcel® II eFRM	MEGAcel® III eFRM	AstroCel® I	AstroCel® II	AstroCel® III
Expanded PTFE Membrane (ePTFE)	•	•	•						
Expanded Fluororesin Membrane (eFRM)				•	•	•			
Glass Fiber Media							•	•	•
Hot Melt Separators		•	•		•	•		Option	Option
Ribbon Pleat								•	
Dimple Pleat								Option	
String Pleat								Option	Option
Embossed/Close Pleat	Option			Option			Option		
Aluminum Separator	•			•			•		
Vinyl Coated Aluminum Separator	Option			Option			Option		
Plastic Separator	Option			Option			Option		
Stainless Steel Separator	Option			Option			Option		
Urethane Pack to Frame Sealant	•	•	•	•	•	•	•	•	•
Silicone Sealant							Option		
64 mm to 149 mm Frame Depths		•			•			•	
V-Style Packs			•			•			•
Gel Seal Filter & Knife Edge	Option	Option	Option	Option	Option	Option	Option	Option	Option
PU-EPDM-Neoprene Gasket	Option	Option	Option	Option	Option	Option	Option	Option	Option
Silicone Gasket							Option		
Painted/Stainless Steel Faceguard	Option	Option		Option	Option		Option	Option	
Fabricated Aluminum Frame	Option		Option	Option		Option	Option		Option
Extruded Aluminum Frame	Option	•	Option	Option	•	Option	Option	•	Option
Stainless Steel Frame	Option	Option	Option	Option	Option	Option	Option	Option	Option
Galvaneal/Galvanized Frame	Option		Option	Option		Option	Option		Option
Particleboard/Plywood Frame	Option			Option			Option		
Plastic Frame	Option			Option			Option		
High Temperature (≥65°C / 149°F)							Option		
Factory Testing - Suitable for Common Test Aerosols (Concentration & Equipment Specific) *DOP*, PAO, PSL, DEHS *Nuclear Market Only*	•	•	•	•	•	•	•	•	•
Field Testing - Suitable for Common Test Aerosols (Concentration & Equipment Specific) PAO, PSL	•	•	•	•	•	•	•	•	•
EN1822: E10 to U17 (ePTFE H13 to U17 only, eFRM H13 and H14 only)	•	•	•	•	•	•	•	•	•
IEST-RP-CC001: Type A-E, H-K	•	•	•	•	•	•	•	•	•
IEST-RP-CC001: Type F-G		•						•	
UL-900/ULC-S111	Option	Option	Option	Option	Option	Option	Option	Option	Option
UL-586							Option	Option	
FM 4920								Option	
Centerboard for PD or Upstream Concentration Measurement		Option			Option			Option	

Microelectronic Industry

It has been a long time since the main concern of contamination in a semiconductor cleanroom were from particles. Airborne Molecular Contamination (or AMC) has been one of the major sources of contamination in advanced manufacturing facilities as the geometries on the integrated circuit has continued to shrink.

AMC (Airborne Molecular Contamination) Standards

Definition of the contamination source of AMC (Airborne Molecular Contaminants)

- **SEMI F21-1102**

Semiconductor Equipment and Materials International (SEMI) officially released SEMI F21-95 Standard (1996 Edition), and the revised version of the SEMI F21-1102 Standard (2002 Edition) for Classification of Airborne Molecular Contaminants in the Purified Environment. In the standard, the AMC's are classified into four categories, acids, alkalis, condensable materials and dopants.

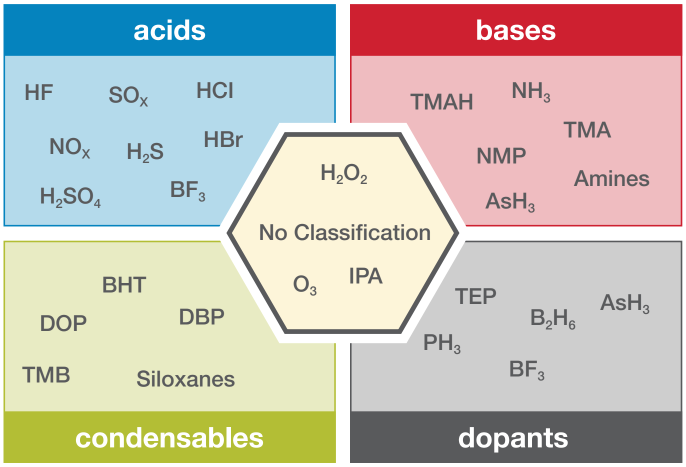
The magnitude combination of each category produces a classification of the description environment. The name of each category begins with the letter "M", followed by the first capital letter of the category name, A, B, C, and D.

		Concentration Grade				
		1pptM	10pptM	100pptM	1000pptM	10000pptM
AMC Classification	Acids	MA-1	MA-10	MA-100	MA-1,000	MA-10,000
	Alkalines	MB-1	MB-10	MB-100	MB-1,000	MB-10,000
	Condensables	MC-1	MC-10	MC-100	MC-1,000	MC-10,000
	Dopants	MD-1	MD-10	MD-100	MD-1,000	MD-10,000

Acid AMC (MA), alkaline AMC (MB), condensable AMC (MC) and dopant AMC (MD)

- MA acid corrosiveness materials; their chemical reaction produces positive charge, such as HF, SO2, HCl, HBr, Cl2 and so on;
- MB alkali corrosiveness materials; their chemical reaction produces negative charge, such as NH3, CH3NH2, [(CH3) 3N], morpholine, etc;
- MC is a kind of chemical substances that can be deposited on clean surfaces (excluding water), such as silane, esters, di-tert-butyl-m-cresol and macromolecular hydrocarbons;
- MD dopants, a kind of chemical element, can change the electrical properties of semiconductors, such as boron (Be), phosphorus (P), arsenic (As) and other compounds

The name of each category should represent the maximum gas phase concentration, which is expressed as an integer of pptM (pptM 1x10-12).



Airborne - transport pathway of the contamination from the source to the product by convective or diffusive processes in air

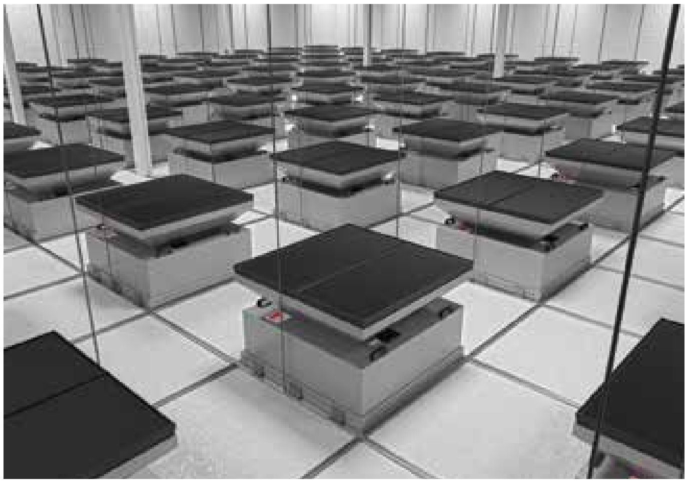
Molecular - contaminant is highly diluted in the air and has no agglomerate characteristic as particles

Contamination - compound is of potential damage to the product or production tool in contact with the molecular compound

Definitions and Sources of AMC

Source: IONICON

Category		Contaminant	Source	Adverse Effect	Bad Results	Countermeasure	Test Analysis
Category	**MA**	Acid gas (HF, HCl, H_2SO_4, H_3PO_4, $-Cl_2$, NO_x, SO_x)	External air, chemicals in dustfree room, etc.	Commonly contaminated metals, hard disks, wafer surface contamination, chemical photoresist resolution of bad salt particles, Haze phenomenon	Abnormal welding of aluminum/copper wiring, element impedance anomaly	Installation of acid removing chemical filter	IC
	MB	Base gas (NH_3, organic amines, ammonia	NH_4OH-H_2O_2 can easily hydrolyze and separate out	Easy to have neutralization reaction with H^+ in chemical photoresist	Bad lithography	Installation of alkali removing chemical filter	IC
	MC	Condensables: VOCS, Siloxane Gas	Sealant, polymer	Easy to attach to the CVD film on the surface of wafer/ glass, and the occurrence of Haze phenomenon	Abnormal LCD display, foreign body, and defective Gate oxide film with poor voltage withstanding	Installation of VOC removing chemical filter, sealing reagent-free operation outside the dust-free room	ATD-GC-MS ICP-MS
	MD	Dopant (B, P) boron particle (B_2O_3), BF_3 Gas	Release of boron and HF reaction in the glass fiber filter, release of reaction between BPSG related materials and HF	Wafer surface contamination, impedance change	Abnormal critical voltage	Use an activated carbon filter, or a boron-free HEPA filter	ICP-MS



IRDS-International Roadmap for Devices and Systems

IRDS was initiated by five main chip manufacturing areas, Europe, Japan, Korea, Taiwan and the United States. The purpose of IRDS is to ensure the performance improvement of integrated circuit (IC) and IC products based on cost effectiveness, so as to sustain the health and success of the semiconductor industry.

Critical AMC Concentration for the Iindividual Processes

	Acids		Bases	Sulphur Compounds	Refractory Compounds	Other Corrosive Species	Metals	Dopants	Organics	
IRDS recommended AMC concentrations for advanced technology nodes (update 2017)	**Total Organic Acids**	**Total Inorganic Acids**	**Total Bases**	**Total Sulphur Compounds (organic, inorganic)**	**Total Refractory Compounds**	**Total Corrosive Species**	**Total Metals**	**Total Dopants**	**Volatile Organics with GC MS retention time >= Benzene calibrated to Hexadecane**	**Condensable Organics (boiling point > 150 deg. C)**
AMC examples	Acetic acid, Formic acid, Oxalic acid	HCl, HF, HBr, HNO3, SO2, H2S	Ammonia, NMP, TMAH, Trimethyl-amine	DMS, DMSO, H2S, Mercaptanes	Siloxanes, Silanol, HMDS, HMDSO, S- and P organic compounds	Cl2, O3, F2, H2O2	Cu, Fe, Mg, Na, Ca	BF3, BCl3, AsH3, PH3, TEP	PGMEA, Ethyllactate, etc	DOP, BHT, etc
AMC sensitive process area/wafer surfaces	**All contaminant concentration in air. Units in ppbV**									
Cleanroom lithography wafer stage & reticle library	2	5	20*	Unrelated	2	Unrelated	Unrelated	Unrelated	26*	Unrelated
Cleanroom lithography - inspection tools stage	2	2	2	Unrelated	TBD	Unrelated	Unrelated	Unrelated	Unrelated	1
Reticle storage inside stocker, inside inspection tool, inside pod, inside exposure tool library	<0.2	<0.2	<0.2	Unrelated	TBD	Unrelated	Unrelated	Unrelated	Unrelated	<0.1
Salicidation (wafer environment, FOUP inside)	5	2	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated
Gate/Furnace area (wafer environment)	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	2	Unrelated
Exposed copper (wafer environment)	0.5	TBD	2	2.5 (1 for H2S)	Unrelated	1	Unrelated	Unrelated	Unrelated	Unrelated
Exposed copper (inside FOUP)	0.1	0.2(HCl), 5(HF), HBr(TBD), HNO3(TBD)	TBD	5 (H2S TBD)	Unrelated	TBD	Unrelated	Unrelated	Unrelated	Unrelated
Exposed aluminum wafer environment (FOUP inside)	TBD	0.1 for HCl, 0.2 for HF, HBr TBD, HNO3 TBD, total inorganic acids TBD	Unrelated	Unrelated	Unrelated	TBD	Unrelated	Unrelated	Unrelated	Unrelated
AMC sensitive process area/wafer surfaces	**Surface analysis SEMI E45-1101. Units in E+10 atoms/cm2/day**									
Gate/Furnace area (wafer environment)	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	Unrelated	0.5	0.5	Unrelated	Unrelated

**Process tool filter with 99% removal efficiency required.*

TBD = to be determined

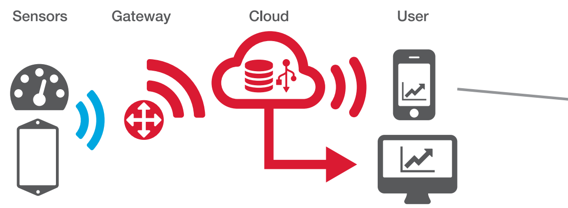
Note: AAF recommends to keep cleanroom AMC level on lowest possible level due to area pressure differences.

Critical AMC, Sources, Effect and Measurement Method

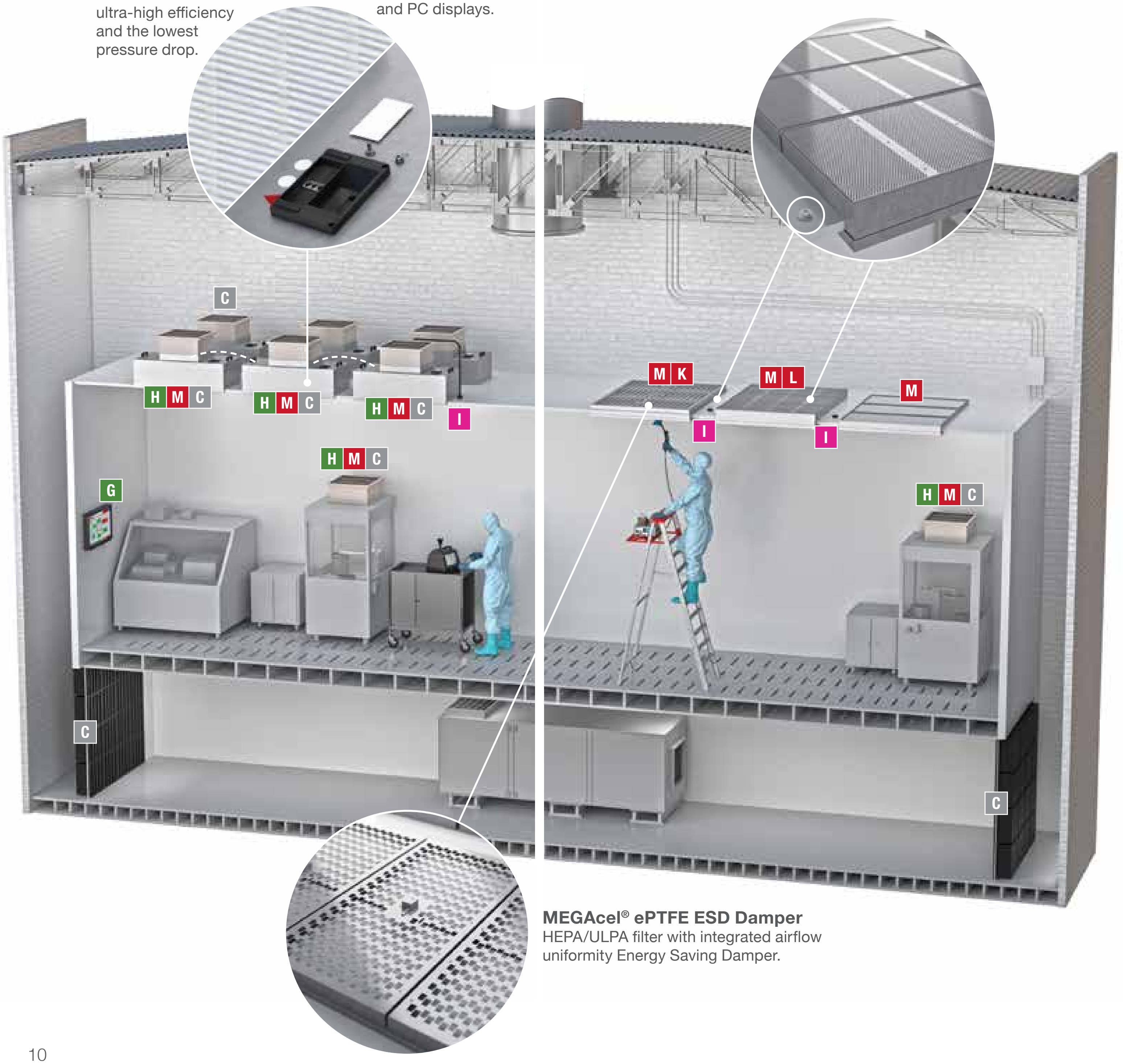
		Examples	Source	Adverse Effect	Bad Results	Countermeasure	Analysis Method
Category	**Acids**	HF, HCl, SO2, CH3COOH, (COOH)2	Process chemical, exhaust cross contamination, outside air	Lens and mask hazing, surface corrosion, haze/particle formation from surface deposited contamination	Yield loss, line corrosion, device failure over time, reliability issues	AMC filter, good exhaust design, proper site selection, proper tool maintenance procedures	Impinger sampling + IC, online monitoring, passive sampling + IC
	Bases	Ammonia, Amines, NMP	Process chemical, exhaust cross contamination, outside air, agriculture	Resist issues, surface corrosion, haze/particle formation from surface deposited contamination	Yield loss, line corrosion, device failure over time, reliability issues	AMC filter, good exhaust design, proper site selection, proper tool maintenance procedures	Impinger sampling + IC, online monitoring, passive sampling + IC
	Sulfur Compounds	H2S, SO2, Mercaptanes, DMS	Process chemical, exhaust cross contamination, outside air, agriculture	Surface corrosion, hazing	Yield loss, line corrosion, device failure over time, reliability issues, high maintenance and replacement cost	AMC filter, good exhaust design, proper site selection, proper tool maintenance procedures	"UV Fluorescence IMS PTR-MS"
	Refractory Compounds	Silanol, Siloxanes, Mercaptanes, HMDS, HMDSO	Process chemical, outside air	Hazing, SiO2, P and S compound deposition	Yield loss, high maintenance and replacement cost	Proper cleanroom system material selection, AMC filter, proper site selection	TD-GC MS, PTR-MS
	Other Corrosive Species	Cl2, F2, O3	Process chemical, exhaust cross contamination, outside air	Corrosion	Yield loss, surface and line corrosion, equipment corrosion	AMC filter, proper site selection, proper tool maintenance procedure	IMS / online devices, impinger + IC (some), passive sampling + IC (some)
	Metals	Ca, Mg, Na, Cu	Particles, process chemicals	Changing electrical properties, short between lines	Yield loss, line damage, reliability issues	Particle filters, AMC filters, proper tool maintenance procedures	Witness wafer + ICP MS (SEMI E45-1101)
	Dopants	BCl3, BF3, PH3, B2H6, AsH3	Process chemicals, by-products from reaction between HF and glass fiber filters	Changing electrical properties, short between lines, surface corrosion	Yield loss, line damage, reliability issues	PTFE filter, AMC filter, proper tool maintenance procedure	PTR-MS, Witness wafer + ICP MS (SEMI E45-1101)
	Organics	PGMEA, Ethyllactate, DOP, BHT	Process chemicals, outside air, exhaust cross contamination	Surface deposition of carbon particles, hazing	Yield loss, high maintenance and replacement cost	AMC filter, proper tool maintenance procedure, proper cleanroom system material selection	PTR-MS, TD-GC MS

Illustration of Equipment and Test Protocol in the Microelectronics Industry

Historically the need to control particulate in semiconductor applications has been addressed with conventional HEPA/ULPA filtration. In the last decades the need to control AMC (Airborne Molecular Contamination) has increased where specific grades of chemical filters and membrane ULPA filters have been deployed. Reduction of energy consumption by optimizing construction and media types has become ‘the norm’ as the industries thirst for lower operating costs and increased yields continues to drive our product development and technical leadership in this segment.



Sensor360®
Cloud-based air quality and pressure drop measurement technology.

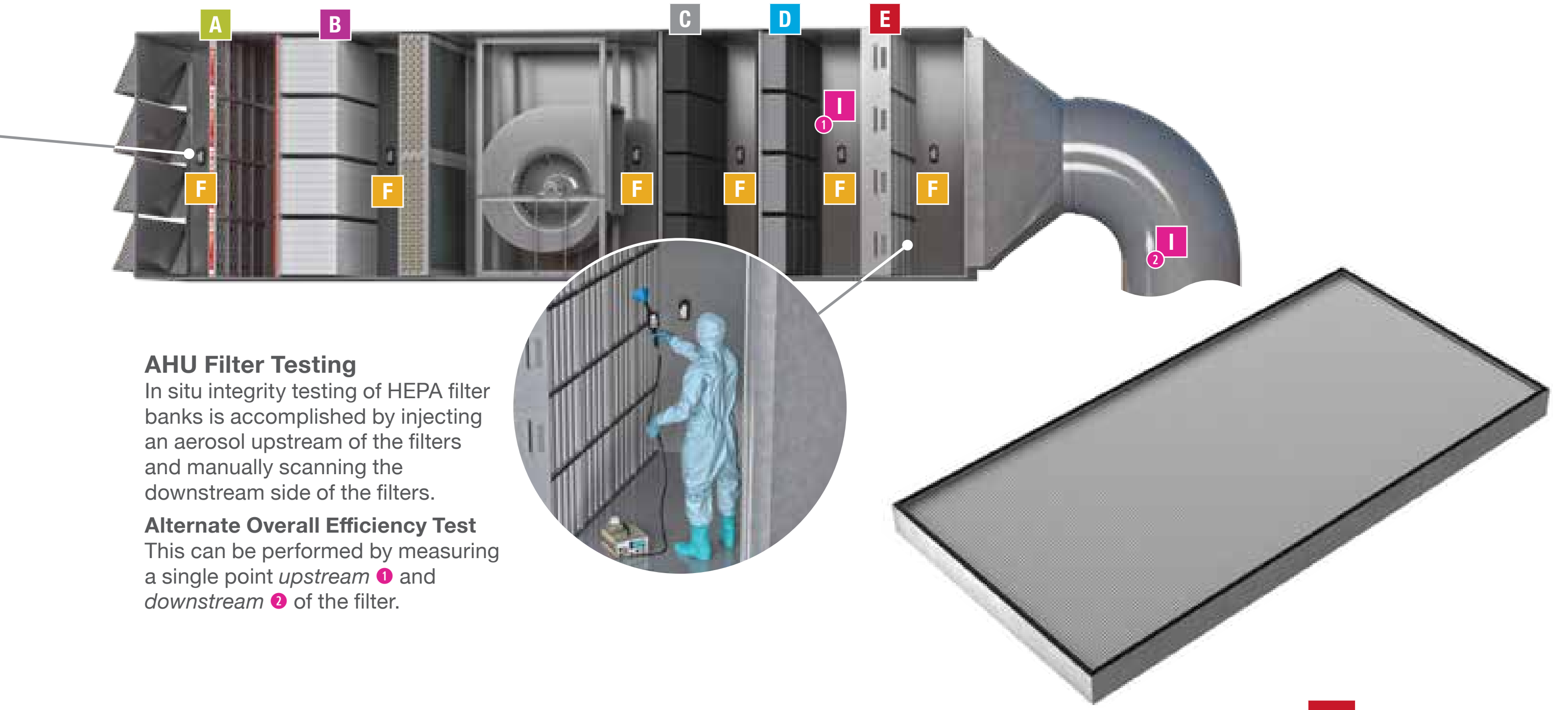


MEGAcel® ePTFE HEPA/ULPA Filter
High tensile strength, boron-free media with ultra-high efficiency and the lowest pressure drop.

AstroDrive™
Control options range from 0-10 V potentiometers to fully customizable PLCs and PC displays.

MEGAcel® ePTFE Walk-on Back Plate
For open plenum applications, HEPA/ULPA filters can be supplied with walk-on back plates to facilitate ease of maintenance.

MEGAcel® ePTFE ESD Damper
HEPA/ULPA filter with integrated airflow uniformity Energy Saving Damper.



AHU Filter Testing
In situ integrity testing of HEPA filter banks is accomplished by injecting an aerosol upstream of the filters and manually scanning the downstream side of the filters.

Alternate Overall Efficiency Test
This can be performed by measuring a single point *upstream* ① and *downstream* ② of the filter.

MEGAcel® ePTFE M
The industry standard with the lowest TCO and durability. The cleanest product for the most sensitive processes.

H J K L N

A	MEGApleat®
B	DriPak® NX
C	VariSorb®
D	VariCel® VXL
E	MEGAcel® III
F	Sensor360®
G	AstroDrive™
H	AstroFan® FFU
I	Test Port
J	AstroHood® S-III
K	ESD Damper
L	Walk-on Back Plate
M	MEGAcel® ePTFE
N	In-room HEPA Test Bench

AstroHood® S-III
Disposable ducted HEPA with integrated centerboard test port and diffusion disc.

AAF International Plant Locations

AAF, the world's largest manufacturer of air filtration solutions, operates production, warehousing and distribution facilities in 22 countries across four continents. With its global headquarters in Louisville, Kentucky, AAF is committed to protecting people, processes and systems through the development and manufacturing of the highest quality air filters, filtration equipment, and associated housing and hardware available today.

Contact your local AAF Flanders representative for a complete list of AAF Flanders Air Filtration Product Solutions.

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