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Metal fibers for HEPA and ULPA filtration

CONTENT

WHITE PAPER

Making the air we breathe virus-free

Aurélie Goux, Michiel Van Hooreweder

A **High Efficiency Particulate Air (HEPA) filter** is a type of air filter that meets a certain stringent standard of efficiency.

According to the American Department of Energy a filter is a HEPA filter if it can remove at least 99.97% of a monodispersed dioctyl phthalate (DOP) aerosol of 0.3μ.

An **Ultra Low Particulate Air (ULPA) filter** is a type of air filter having a minimum particle-collection efficiency of 99.999% (that is, a maximum particle penetration of 0.0010%) when tested in accordance with the methods of IEST-RP-CC007.

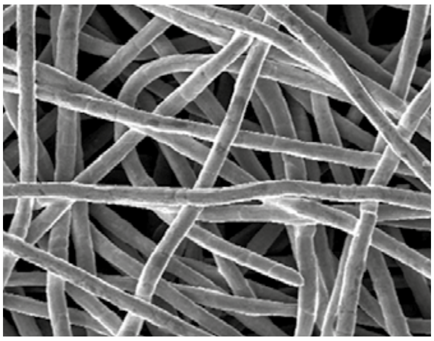
Bekaert has been active in High Efficiency Particulate Air (HEPA) filtration and Ultra Low Particulate Air (ULPA) filtration for mission critical applications for over two decades. Our traditional applications are in the nuclear and semiconductor industries where metal fiber filtration is able to realize log 9 filter ratings.

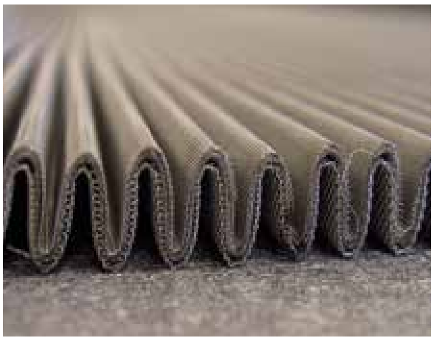
We also provide material for HEPA filters for medical applications (e.g. ventilation and HVAC equipment in hospitals) and in HEPA filters for air circulation in transport applications (e.g. HVAC systems in passenger cars, planes etc.).

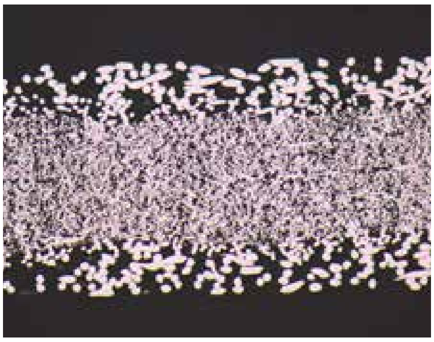
These applications are based on Bekipor® HA, our multi-layered metal fiber media that is thinner, lighter, and about ten times more permeable than any other metallic HEPA solution. Since the start of the COVID-19 crisis, Bekaert has been collaborating with a number of companies throughout the world to realize customized clean air applications using Bekipor® HA, to ensure that the air we breathe is virus-free.

AN INTRODUCTION TO METAL FIBERS FOR HEPA FILTRATION

Metal fibers – fiber material with a diameter less than 100 microns – exist in many forms, alloys and sizes. Structures and products incorporating metal fibers display excellent electrical, thermal, corrosion and mechanical properties. Each of these properties makes them suitable for a wide range of specific industrial applications, including filtration, heat-resistant textiles, conductive textiles and conductive plastics.







Sintered metal fiber media are widely used in liquid and gas filtration for various industries such as polymer production, chemical processes, power generation and oil filtration. Filters made from metal fiber media are cost-effective as they reduce maintenance requirements and minimize downtime.

This white paper focuses on the use of metal fibers as media for reusable HEPA filters for reusable facemasks to make the air we breathe virus-free. It also looks at HEPA and ULPA filtration for applications in the nuclear and semiconductor industries.

"

Collaborating with Bekaert on this new and innovative project was a positive experience. The deep filtration knowledge and timely support of their R&D team allowed us to speed up our development. I am confident to win more business together with Bekaert."

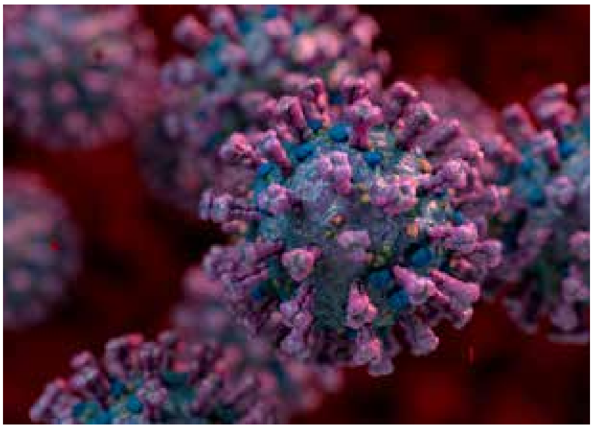
Rick Caouette
President/CEO - Global Filtration, Inc.

THE DISADVANTAGES OF DISPOSABLE FACEMASKS

The COVID-19 crisis has sparked a huge demand for personal protective equipment (PPE) around the world, especially for facemasks, both for frontline health workers as well as for people going about their everyday tasks such as work and shopping. Two types of washable masks are available on the market. One type is made of two parts: a washable envelope and a disposable filter that can reach HEPA standards. The other type is made from a single washable part and cannot reach HEPA standards.

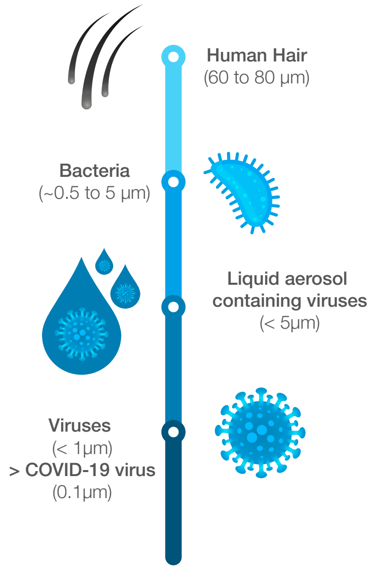
The majority of these facemasks are made from non-woven fabrics and plastics such as polypropylene. These however are not recyclable, nor are they biodegradable. It's estimated that a plastic facemask will last for up to 300 years in nature.

Not surprisingly, facemasks are causing a substantial increase in plastic waste streams and are already appearing in large quantities in the oceans. Here, facemasks can look like jellyfish or other types of foods for sea turtles, while the straps on masks can present entangling hazards. Moreover, the fibers in a face mask are micro-plastics, which can easily get into the food chain and have a significant negative impact on fish, other wildlife, and eventually humans.



THE ADVANTAGES OF REUSABLE HEPA FILTERS INCORPORATING METALLIC FIBER MEDIA FOR REUSABLE FACEMASKS

Meeting HEPA standards

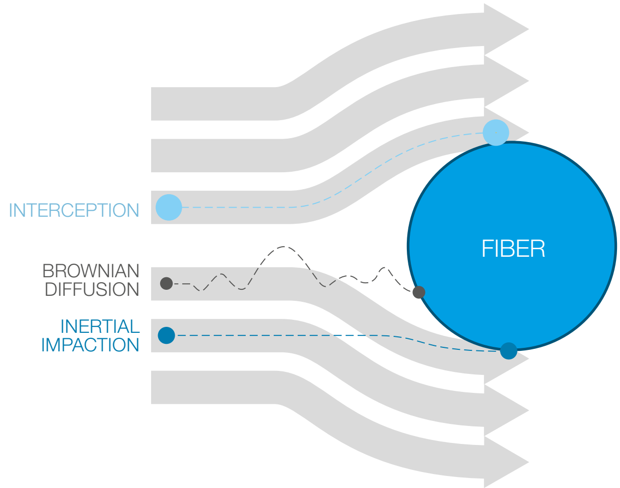


The average diameter of a human hair is 80 µm, while a typical bacteria is around 0.5 µm. The COVID-19 virus is generally around 0.1 µm: too small to be captured by any HEPA filter. However, when infecting a person, the virus is immersed in a liquid aerosol. When a person infected with the COVID-19 virus exhales, talks or coughs, he or she expels the virus in a bio-aerosol that is generally between 0.3 and 100 µm in diameter. In other words, the size of a bacteria or even a human hair. This size of particle can be captured by a HEPA filter. Facemasks are thus measured by their efficiency at filtering particles of 0.3 µm and larger. Indeed, according to the American Department of Energy a filter is a HEPA filter if it can remove at least 99.97% of a monodispersed dioctyl phthalate (DOP) aerosol of 0.3 µm.

The European Norm EN 1822:2009 defines classes of HEPA filters based on their efficiency at the most penetrating particle size (MPPS). A table of these classes is shown on page 9 of this white paper.

The structure of a HEPA filter usually consists of randomly arranged fibers which separate both the larger and smaller particles from the gas flow in three ways:

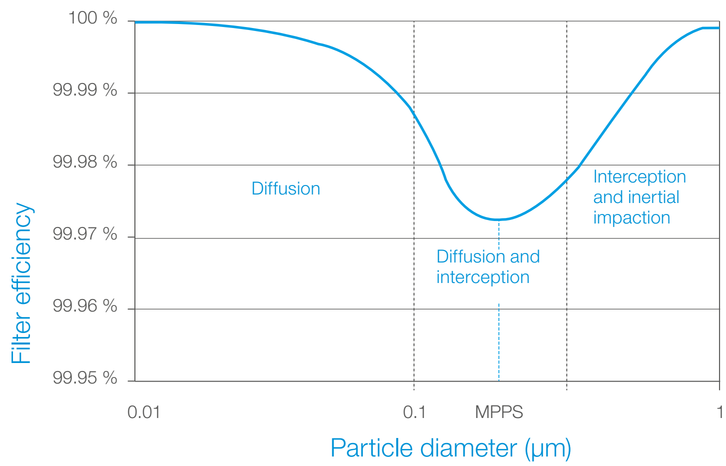
- **Diffusion**: This mechanism applies to small particles in combination with fine fibers and low velocities and is independent of the particle density.
- **Interception**: Particles travel along streamlines and are easily caught because of their size. The ratio of particle to fiber size is important.
- **Inertial impaction**: Particles deviate from the streamlines due to their inertia and impact on the fibers. It applies to large particles, high density, high velocity and small fibers.



The three particle capture mechanisms involved in HEPA filtration

The filter performance of a certain structure is influenced by the following parameters:

- Porosity
- Thickness
- Fiber diameter
- Aerosol to be filtered (particle size distribution, solid or liquid state)
- Testing conditions (face velocity, temperature, chemical composition of the gas).



The performance characteristics of facemasks need to comply with various regulatory standards around the world (see Table 1).

	Europe	US	China
Norm	EN149-2001	NIOSH-42 CFR 84	GB2626-2006
Filter performance	≥ 94%	≥ 95%	≥ 95%
Flow rate	95 L/min	85 L/min	85 L/min

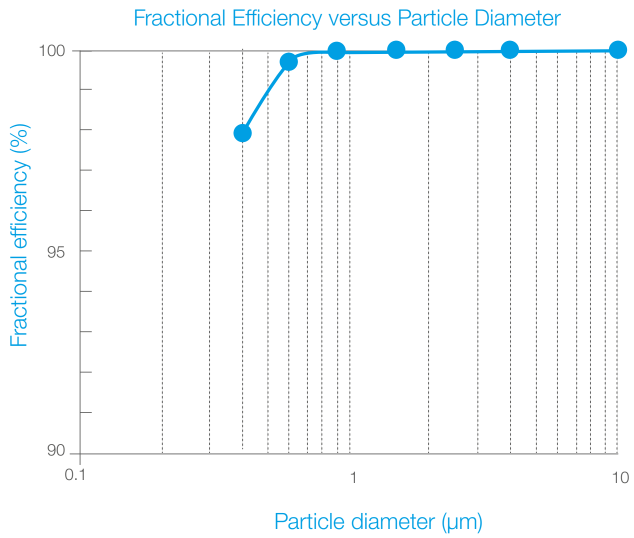
The Bekipor HA0123 HEPA filter medium is able to filter particles according to the US norm NIOSH 42 CFR 84 (see Figure 1).

The filtration process takes place within the filter media (depth filtration), where liquid aerosol particles will be mainly trapped via the two filtration mechanisms of diffusion and interception.

Ensuring reusability:
Metallic fiber based facemasks are 100% reusable after sterilization in a standard autoclave. This can happen in situ, thus avoiding time and costs of transportation to a sterilization facility.

Incorporating antiviral agents
Metals and alloys with antiviral properties (e.g. silver, copper, bronze) can be used in the metallic fiber media, or the fibers can serve as a substrate for antiviral coatings.

Providing permeability
Metallic filter media fully comply with the breathability norms. Facemasks incorporating metallic fiber media are thus as comfortable to wear as any other facemasks.



HEPA/ULPA FILTERS FOR OTHER HIGHLY DEMANDING APPLICATIONS

The disadvantages of traditional HEPA/ULPA filters

Most conventional HEPA filters are made from glass fibers but suffer from two main drawbacks. They incorporate a mechanically weak binder, and glass fibers are brittle. These two factors mean that traditional HEPA filters can be structurally damaged when subjected to high fluctuations in load, high airflow, high temperature, high humidity and heavy dust loads, or any combinations of these factors.

Other major disadvantages of glass fiber HEPA filters are that they deteriorate due to moisture condensation, do not withstand cleaning by means of back pulsing, and do not withstand high-pressure drops. Moreover, when spent, they need to be disposed, which is a hazardous and costly process.

These disadvantages are crucial for various applications where the filter needs to operate at high temperatures, high strength, and high efficiency at high flow rates.

The advantages of sintered metal fiber HEPA/ULPA filters

When compared to traditional filter fiber media, sintered metal fiber media offer the following advantages:

- High corrosion resistance
- High temperature resistance
- High heat dissipation
- Superior mechanical resistance.

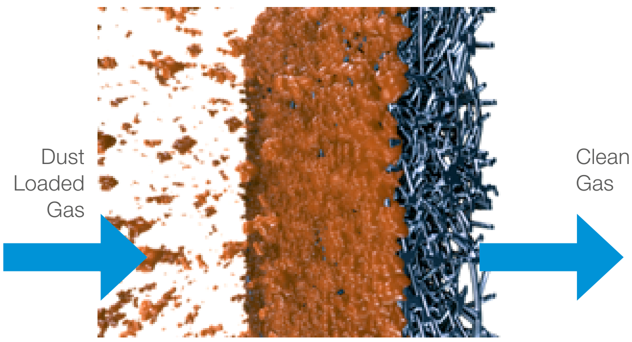
All these characteristics are extremely beneficial in numerous applications.

The multi-layered structure of the metal fiber media provides:

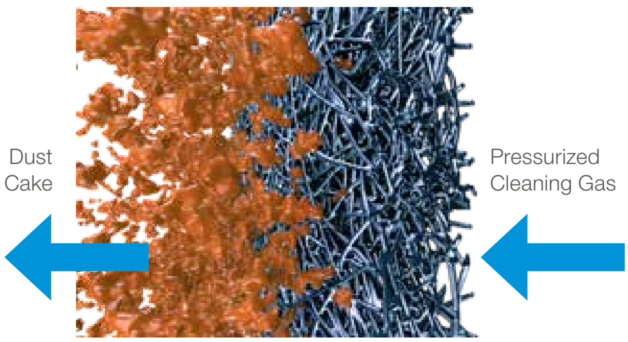
- Superior filtration efficiency
- High contaminant (dirt) holding capacity
- Low pressure drop
- Increased on-stream lifetime of the filter element.

Filter elements using metallic fiber media can be easily cleaned, both in place as well as off-line. The advantage of metal fibers over glass fiber solutions regarding cleanability should not be underestimated. With glass fibers, "clean in place" is not achievable as this requires high pressure resistance. This is not a characteristic of glass fiber filtration media. In the end, glass fiber filters can be damaged by high pressure cleaning, while metal fiber filters are much more durable.

FILTRATION CYCLE
Cake build-up



CLEANING CYCLE (Cleaning in place)
Back flush release cake



METAL FIBER MEDIA FOR FILTRATION APPLICATIONS IN OTHER INDUSTRIES


Typical HEPA filter from Porvair Filtration Group

From 1996, metallic solutions started to be developed to replace glass fiber HEPA filters for the nuclear industry to solve the previously mentioned drawbacks of glass fiber based media. However, improvements were necessary to the existing products; specifically, the weight of media needed to be reduced, and the permeability increased.

Bekaert rose to the challenge to search for improvements and designed a specific sintered metal fiber media for highly demanding applications: Bekipor® HA. This multi-layered metal fiber media is thinner, lighter, and about ten times more permeable than any other metallic HEPA solution.

Filtration characteristics of Bekipor® media tested according to ISO 29463-norm

Product name	Efficiency (% at 0.3 µm)	Air permeability (1) (l/min/dm² at 200 Pa)	Thickness (mm)	Weight (g/m²)	HEPA class (2)
HA1306	99.94	5.8	0.39	1050	H13
HA1403	99.998	2.8	0.33	900	H14
HA1404	99.991	4.4	0.44	1200	H14
HA1406	99.98	6.5	0.57	1200	H14
HA1407	99.992	6.9	0.60	900	H14

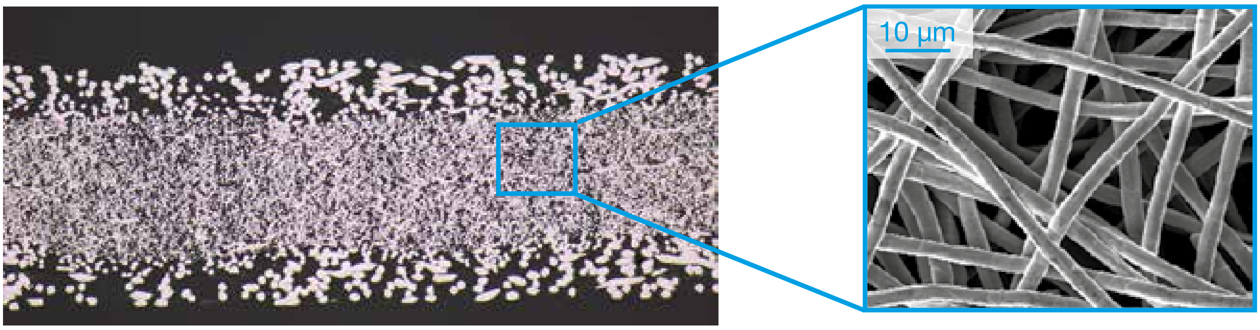
Filtration characteristics of Bekipor® media tested according to EN 143-norm

Product name	Efficiency (% at 0.3 µm)	Air permeability (1) (l/min/dm² at 200 Pa)	Thickness (mm)	Weight (g/m²)	HEPA class (3)
HA0123	89.4	23	0.5	600	P1
HA0204	99.6	3.2	0.29	900	P2
HA0206	99.91	5.5	2	2400	P2
HA0209	99.6	8.5	0.5	1050	P2
HA0210	98.8	10	0.43	1050	P2

These figures are for guidance purposes only and represent an average measured value. The suitability of a material for a specific application can be confirmed when we know the actual service conditions. Continuous development may necessitate changes in the technical data without notice.

(1) Air permeability dertermined according to ISO9237:1995
(2) HEPA class determined according to ISO 29463 at a face velocity of 3 cm/s
(3) HEPA class determined according to EN143:2000 at a face velocity of 27 cm/s

The multi-layered structure of Bekipor® HA



Bekipor® HA is capable of reaching high efficiencies at 3 cm/s, which is the face velocity at which HEPA media are validated for use in the nuclear industry. Its efficiency remains high even at increased face velocities of 6 cm/s. This enables the filter system to be operated at a double flow rate. Alternatively, the needed filter surface can be halved.

The Bekipor® HA media combines high porosity and permeability with very fine fibers enabling high efficiency filtration at low-pressure drop at the level of the finest sub-micron particles. Featuring high mechanical strength, thermal stability and chemical resistance, Bekipor® HA is the recommended medium for HEPA filters in nuclear applications.

Unlike alternative materials, metal fiber media can be pleated, enabling the reduction of size of the entire filtration system. They are on-line cleanable via back pulsing. Metal fibers can provide an all-welded metal solution with a longer service lifetime in comparison with glass fiber based filters.

The first HEPA filter was designed for a nuclear military application (the Manhattan Project). Since then, filters have evolved to satisfy the ever higher demands for air quality in various high technology industries such as aerospace, pharmaceutical processing, hospitals, health care, nuclear fuels, nuclear power, and electronic microcircuitry (computer chips).

HEPA FILTERS FOR APPLICATIONS IN THE NUCLEAR INDUSTRY

In the nuclear industry, HEPA applications include nuclear safety filters and ventilation systems. HEPA filters based on webs or sintered Bekipor® are implemented in two key application areas in the nuclear industry:

Waste container venting systems

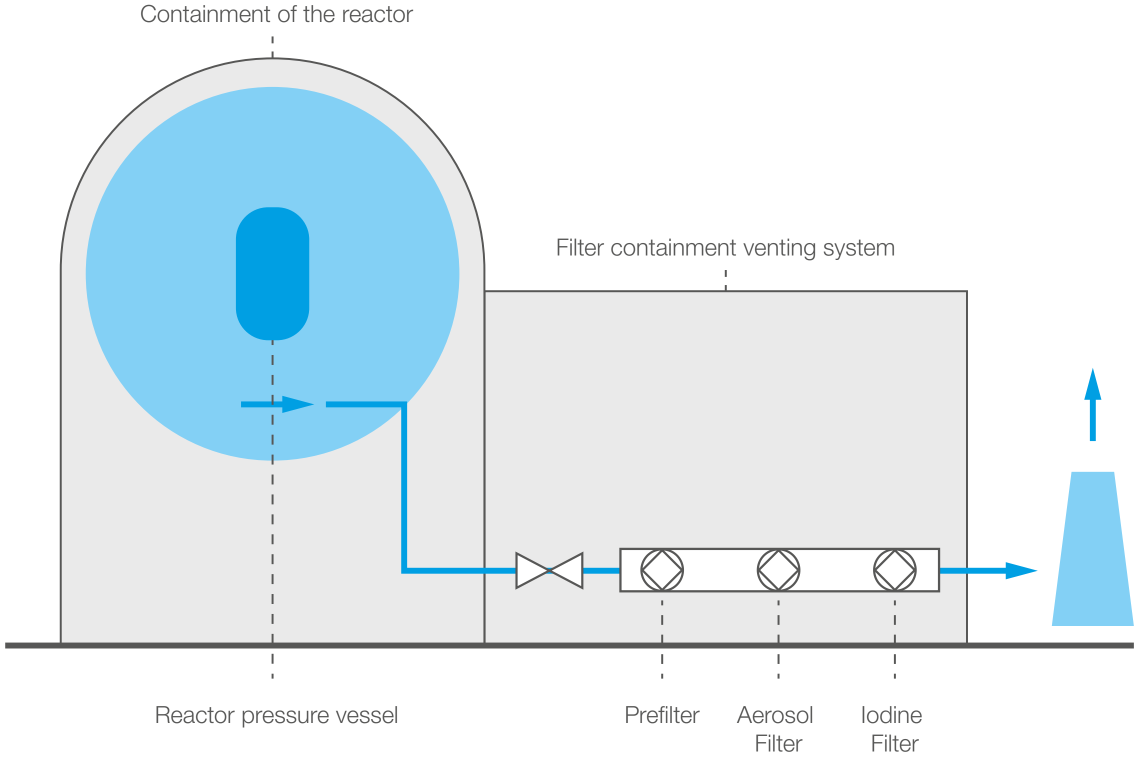
Radioactive waste containers need both to “breathe” (to allow the safe movement of air into and around the container as environmental conditions change) and to allow the diffusion or removal of generated gases (typically hydrogen in the short term and hydrocarbons in the longer term). There are well-documented cases of waste containers inflating like balloons because a venting arrangement was absent. The lack of any venting in such containers creates additional hazards once the compromised container is selected for re-packaging.

Nuclear filters from Porvair Filtration Group

Filter Containment Venting Systems (FCVS)

Metal fiber HEPA filters are used for FCVS systems that trap radioactive particles during an accident, while allowing the release of an eventual pressure build-up and/or the release of hydrogen gas (which can be a by-product of reactions) in the reactor.

Following nuclear accidents worldwide, some countries like France, Germany and Finland now stipulate the installation of such a venting system on any type of reactor, whether Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR) or Canada Deuterium Uranium (CANDU).



HEPA AND ULPA FILTERS FOR APPLICATIONS IN THE SEMICONDUCTOR INDUSTRY

In the semiconductor industry, metal fiber HEPA and ULPA filters are used for technical gas purification applications. In semiconductor production processes, both high-temperature corrosive and non-corrosive gases are released and need to be filtered. Examples include nitrogen, Cold Dry Air (CDA), oxygen, hydrogen, sulphur dioxide, boron trichloride and tungsten hexafluoride.

The difference between a HEPA and an ULPA filter is the efficiency at 'most penetrating particle size' (MPPS). An overview of the different HEPA and ULPA efficiency norms is shown in the table below. A filter can be called an ULPA filter if it achieves an efficiency of 99.9995% for the MPPS.

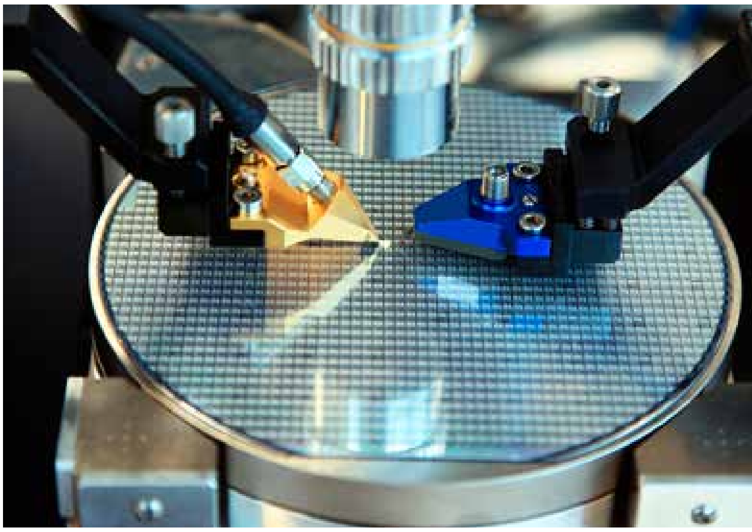
Varying efficiency levels of filters at the most penetrating particle size (MPPS).

H10 to H14 are HEPA filters; U15 to U17 are ULPA filters.

Integral efficiency [(1)] for MPPS	EN 1822	DIN 24183	DIN 24184	BS 3928	US Mil. Std. 292
≥ 85%	H 10	EU 10	Q	EU 10	-
≥ 95%	H 11	EU 11	R	EU 11	≥ 95%
≥ 99.5%	H 12	EU 12	-	EU 12	≥ 99.97%
≥ 99.95%	H 13	EU 13	S	EU 13	≥ 99.99%
≥ 99.995%	H 14	EU 14	-	EU 14	≥ 99.999%
≥ 99.9995%	U 15	EU 15	-	-	-
≥ 99.99995%	U 16	EU 16	-	-	-
≥ 99.999995%	U 17	EU 17	-	-	-

[(1)] The integral efficiency is the mean value of all local efficiencies measured over the filter's face area

Two types of filters for semiconductor industries can be distinguished:



Point of Use (POU) filters:

- In-line filters
- Surface-mount filters to reduce footprint
- Diffusers for chamber venting
- High temperature resistance
- Efficiencies of 9 LRV (Logarithmic Reduction Value) at 3 nm particle size, where LRV = -log(1-efficiency)
- Low pressure drop required.

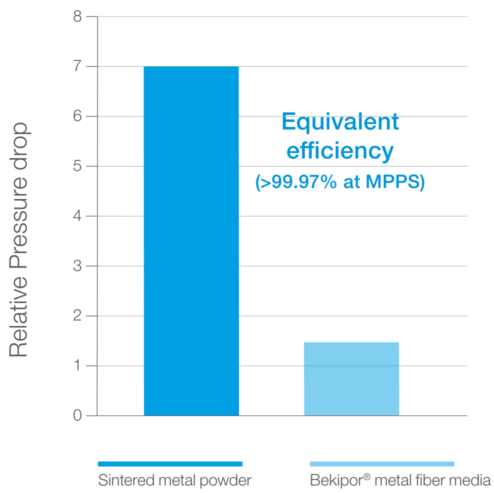
Bulk gas filters:

- High flow applications of 160,000 l/min
- Particle filter tubes
- Absorbent encapsulation discs
- Non-corrosive gases, primarily air derived (O_2, N_2 etc.)
- Certain corrosive gases (Cl and F based)
- Flat display screens and solar panels could use this technology
- Efficiencies to 9 LRV at 3 nm.

For filtration applications in the semiconductor industry, metal fiber media provide lower pressure drops at high efficiencies, which reduce energy costs and equipment footprint. They also provide corrosion resistance for specialty gases, and strength and durability to last the lifetime of the equipment.

Corrosion resistance, strength and durability are inherent to metallic filter media such as metal fibers and metal powders. However, metal fiber media show major advantages regarding pressure drop when compared to metal powder media. The difference is depicted in the graph below.

Advantages of Bekipor® metal fiber media over sintered metal powder



CONCLUSION

Traditional glass fiber HEPA and ULPA filters display limitations particularly in terms of temperature resistance, mechanical strength, humidity and moisture resistance, and ease of cleaning, which excludes their use in certain key application areas.

The use of HEPA grade sintered metal media filters removes these disadvantages. Their high corrosion resistance, temperature resistance, heat dissipation and mechanical resistance enables their use in the nuclear and semiconductor industries. Ease of cleaning is a further major advantage.

Metallic fiber based HEPA filters are particularly useful in these turbulent times when the demand for high efficiency, reliable and safe facemasks capable of keeping the air we breathe virus-free has never been greater.

Aurélie Goux

Aurélie is Global Product Development Manager at Bekaert Fiber Technologies. Her field of expertise is metal fiber media development for filtration applications. Aurélie has a PhD in Chemistry from the University Pierre and Marie Curie in Paris. Previously she worked as a post-doctoral fellow at the Leibniz Institute for Solid State and Materials Research in Dresden, Germany and at the University Henri Poincaré in Nancy, France. Before she joined Bekaert in 2011, Aurélie worked as R&D consultant at TMC Chemical in Eindhoven, The Netherlands.

Michiel Van Hooreweder

In his role as Market Manager Filtration EMEA at Bekaert Fiber Technologies, Michiel maintains close relationships with existing customers while looking for new customers and new metal fiber filter applications. He has a master's degree in Business Engineering with a focus on operations management and supply chain. Previous work experience includes business development roles in Malaysia and Canada, and product management with a flooring company.

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Bekaert is a world market and technology leader in steel wire transformation and coating technologies. To be the preferred supplier of steel wire products and solutions, we consistently deliver superior value to our customers worldwide.
Bekaert (Euronext Brussels: BEKB) was established in 1880 and is a global company with approximately 29 000 employees worldwide.

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