W. L. Gore & Associates' Comments on Dossier Submitters' Draft EU REACH restriction on PFAS

Public consultation

Request for Derogation: Semiconductor manufacturing

July 2023

W.L. Gore & Associates GmbH (hereinafter "Gore") appreciates the opportunity offered by the public consultation process to provide comments on the Proposal for a Restriction of Per- and polyfluoroalkyl substances (PFAS) (hereinafter '**Restriction Proposal**').

With this submission, we would like to explain why we believe that a derogation for the **semiconductor manufacturing process** which is currently marked for reconsideration in the Restriction Proposal – is needed and justified.

The conclusions from our submission are summarised as follows:

- Fluoropolymer based solutions (whether it is cable assemblies, sealants, filters, or vents) are the only option currently on the market that can be used to achieve extreme cleanliness required during semiconductor manufacturing processes.
- Wires and cables incorporating fluoropolymer solutions also provide the only option for high performance signal transmission and power transmission applications while withstanding demanding physical and environmental conditions throughout millions of operating cycles required during semiconductor manufacturing processes.
- Almost all modern technologies, such as computer-based systems, telecommunication, security systems, automotive, defence and aviation, to name just a few, rely on use of semiconductors. With the European Chips Act, chips have been recognised as strategic assets for key industrial value chains. If a short (or no) derogation is granted for applications such as equipment and its components supporting semiconductor manufacturing processes, the EU would be faced with huge economic and strategic threat.

I. Derogation Request

Considering the arguments and evidence presented below, Gore respectfully requests to include the following derogation in Column 2, paragraph 5 of the proposed restriction:

Semiconductor manufacturing process until 13.5 years after EiF

This should be considered the minimum period as there are significant unknowns related to identifying alternatives and many specific uses within the semiconductor manufacturing process which require PFAS currently. The multiple categories of products which use PFAS and uncertainties related to substitution feasibility and timing are highlighted in a report submitted to the public consultation from SEMI Europe which indicates longer potential transition times.[1]

[1] https://www.semiconductors.org/the-impact-of-a-potential-pfas-restriction-on-the-semiconductor-sector/

II. Description of the End Use

Semiconductor devices (also known as “chips” or “integrated circuits”) are essential components of electronic devices. Semiconductor devices are extremely complex to manufacture, with leading devices requiring more than 2,000 process steps, hundreds of production materials, and approximately 26 weeks to manufacture and test. This requires the utilization of process chemicals, manufacturing equipment, and manufacturing facility infrastructure which use PFAS. Gore delivers mainly fluoropolymer-based cables, membranes, vents, and sealing solutions to help keep semiconductor manufacturing process pure, along with products for DUV[2], EUV[3] and emerging High-NA EUV[4] lithography equipment.

To clearly define the use we believe should fall under the proposed derogation, we provide below a description of the type of products and their reliance on PFAS. The product examples are all Gore products, as details of comparable products manufactured by other companies are not publicly available. We believe that these products are representative of products manufactured and placed on the EU market by other companies but are not intended to present an exhaustive list of possible products/applications of PFAS within the Semiconductor Manufacturing sector.

It is important that the semiconductor manufacturing process be understood as an umbrella term for what the industry needs to continue manufacturing semiconductors in Europe and should not be limited to the listed examples.

Based on the current proposal, we believe the following products in Table 1 are covered by the derogation proposed in Section I.

Table 1. Selected Semiconductor Manufacturing Products

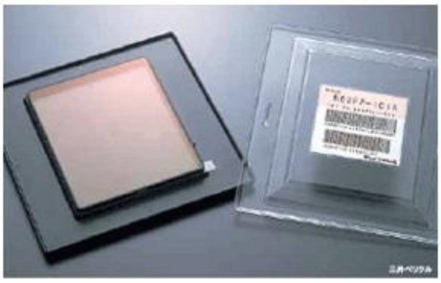
Product	Illustrations	Description
GORE® Ultraclean Static Round Cables & Assemblies.		Reliable cables for EUV (extreme ultraviolet lithography) and DUV (deep ultraviolet lithography), even over multi-million cycles. Designed for static or flexible applications, high purity cables can be found in the innermost parts of the equipment with the most

[2] Deep Ultraviolet Lithography
[3] Extreme Ultraviolet Lithography
[4] High Numerical Aperture Extreme Ultraviolet Lithography

GORE® High Flex Cables & Assemblies		extreme cleanliness requirements. Cables are engineered for improved signal integrity and transmission speeds. These are crucial for complex cable configurations that incorporate tubes for gas or fluid transport alongside cabling for data and for high- and low-power electrical signals.
GORE® Microwave/RF Cable Assemblies		Microwave/RF Assemblies for use in semiconductor aging tests are designed to deliver a consistent and reliable signal. Semiconductor devices are utilized in several sectors where dependability is vital, including aircraft and the military. Testing for the aging of semiconductors assures that the device will continue to operate reliably throughout its lifetime. Microwave/RF cable assemblies leveraging PFAS materials' unique combination of properties are the only option available to withstand the demanding conditions pertaining to electrical, mechanical, and environmental requirements.
GORE® Joint Sealant		Used to seal steel flanges or other process equipment where there is exposure to aggressive chemicals or high temperature process fluids used in semiconductor manufacturing. It can also seal applications where available bolt loads are low. The sealant is chemically resistant to all media (pH 0-14) except molten/dissolved alkali metals and elemental

		fluorine. Therefore it is versatile enough for use in strong alkali-, acid- and solvent-based chemical process systems.
GORE® Joint Sealant FT		Used to seal industrial equipment with tight tolerances for smooth and for narrow surfaces for containment of chemically aggressive and/or hazardous fluids.
GORE® GR Sheet Gasketing		Gasket sheet that is exceptionally resistant to creep, cold flow, and aggressive media reliably seals steel piping and equipment. The sheet needs to be strong, dimensionally stable, highly conformable to rough or irregular sealing surfaces, and compressible into a tough gasket that creates a tight, long-lasting seal.
GORE® Universal Pipe Gasket (UPG) Style 800/801		Provides a reliable seal for steel, glass-lined steel, and fibre reinforced plastic (FRP) flanges, in the full spectrum of strong acid, alkali, and solvent process media, including the most challenging thermal cycling and elevated temperature applications. The single gasket solution can reduce the process safety and production downtime risks caused using an incorrect gasket material.

GORE® Gasket Tape		Gasket tape is resistant to creep and designed to maximise the operational reliability of large steel-flanged applications (especially those with thermal cycling). The tape provides immediate reliable performance and extended durability for sealing challenges.
GORE® Ozonation Modules for Semiconductor & Microelectronics Fabrication Processing		Used to eliminate organic and inorganic contaminants from silicon wafers, logic and memory fabrication, flat panel displays, and photomasks. When it comes to silicon wafer and semiconductor cleaning processes, the industry is shifting to ozone water treatment for bubble-free ozone water with continuous, consistent high concentration and flow.
GORE® Microfiltration Media for Pre-Filters		Filters are applied in wafer cleaning tools to reduce wafer defects. They are also used in semiconductor-grade chemical production to ensure improved particle reduction and exceptional high purity. Microfiltration Media is used in pre-filter applications to offer a unique combination of high retention and flow to ensure repeatable high performance, consistent quality, and exceptional product cleanliness in critical semiconductor and microelectronics manufacturing processes.

Protective Vents	 	Protective Vents are utilized in: • FOUPs (Front Opening Unified Pod) that house wafers that are used to manufacture chips through the entire fabrication process. • Pellicle Frames which are used to protect the Photomask from any contamination. PTFE enables the lowest contamination, lowest particulation containment for wafers.

Almost all of these products are made of fluoropolymers which meet the criteria for Polymers of Low Concern (PLCs), under the definition provided by the OECD Expert Group on Polymers. The PFAS used for each product are listed in Table 2.

Table 2. PFAS used in Selected Semiconductor Manufacturing Products

Gore product	Type of PFAS	CAS number	Is this PFAS a PLC?
GORE® Ultraclean Static Round Cables & Assemblies	PTFE	9002-84-0	Yes
	PFA	26655-00-5	Yes
	FEP	25067-11-2	Yes
GORE® High Flex Cables & Assemblies	PTFE	9002-84-0	Yes
	PFA	26655-00-5	Yes
	FEP	25067-11-2	Yes
GORE® Microwave/RF Cable Assemblies	PTFE	9002-84-0	Yes
	PFA	26655-00-5	Yes
	ETFE	95038-71-5	Yes
Sealants and Gaskets	PTFE	9002-84-0	Yes
GORE® Ozonation Modules for Semiconductor & Microelectronics Fabrication Processing	PTFE	9002-84-0	Yes
	PFA	26655-00-5	Yes
GORE® Microfiltration Media for Pre-Filters	PTFE	9002-84-0	Yes

Gore product	Type of PFAS	CAS number	Is this PFAS a PLC?
Protective Vents	PTFE	9002-84-0	Yes
	PFA	26655-00-5	Yes
	[redacted]		

III. Reference in Restriction Proposal

Gore welcomes that the important function fulfilled by fluoropolymers used in the semiconductor manufacturing process is recognised by the Dossier Submitters. A derogation for the Semiconductor manufacturing process until 13.5 years after EiF has been proposed for reconsideration (Restriction report, paragraph 5ee, page 7).

It is also mentioned *'that the current wording of the derogation marked for reconsideration, ('the semiconductor manufacturing process') is ambiguous in regard to the precise uses and sub-uses that would be covered by the derogation. The wording needs to be adjusted and refined based on additional information. It is the understanding of the Dossier Submitters that a derogation for most uses related to the manufacturing process might be justified (as covered in Table A.49. of Annex A)* (Annex E, page 409).

Semiconductor manufacturing processes may involve as many as 2000 different steps and technologies are rapidly developing. If the derogation is granted only for selected pre-defined processes and equipment types, it is bound to omit an important process step causing manufacturing disruption. Therefore, to bolster Europe's competitiveness and resilience in semiconductor technologies, in line with ambitions of the European Chips Act, it is important to keep the derogation for semiconductor manufacturing sufficiently broad to cover applications needed to continue manufacturing semiconductors in Europe.

In Table 3 below, we provide information to supplement table A.49 with additional uses, properties, and examples of PFAS used in semiconductors manufacturing process. However, we believe it is important to recognise the list provided in table A.49 of Annex A, should not be considered as an exhaustive list of all possible applications and therefore the derogation should not be limited only to the precise list of uses and sub-uses.

Table 3. Recommended Additions to Table A.49 of Restriction Proposal.
Note: Additions are shown in blue

Use category	Sub-use	Properties
Photolithography	Filters	Chemical resistance Low extractables against solvents
Photolithography	Pellicle Frame filter	High airflow and low particle penetration Low outgassing Low Particle emission Low shedding
Plasma Etch and Wafer Cleaning	Filters Ozone functionalized water	Chemical resistance Thermal durability High retention and high flow Low extractables
Plasma Etch and Wafer Cleaning	Thermal insulation for wet solution	Low thermal conductivity Chemical resistance Thermal durability Less shedding Less gas
Plasma Etch and Wafer Cleaning	Thermal insulation for gas supply and exhaust in Plasma Etch	Low thermal conductivity Chemical resistance Thermal durability Less shedding Less gas
Wafer	Wet etch and clean filters	Chemical resistance Temperature resistance Low extractables
Wafer processing and transport	FOUPs - Front Opening Unified Pod / Front Opening Universal Pods	High airflow and low particle penetration Low outgassing Low particle emission Water spray washing resistance
Vapour deposition chamber	Thermal insulation for gas supply and exhaust in Plasma Etch	Low thermal conductivity Chemical resistance Thermal durability Less shedding Less gas use
Semiconductor Manufacturing Equipment & Infrastructure - Enabling Uses of Fluoropolymer Articles	Data, Power & Fluid Interconnects, sealants/piping	Chemical resistance Low volatility/high stability Thermal resistance

(polymer parts embedded within manufacturing equipment, spare parts and infrastructure, piping, tubing, gaskets, cables, etc.)		Cleanliness UV resistance Flame resistance Low dielectric constant Low dissipation factor Low outgassing factor Low coefficient of friction Stable electrical performance over high temperature

Dossier submitters noted that *'based on the available information for semiconductors no generally applicable alternatives are available' (Annex E, page 409).*

Based on experience and research conducted to-date, Gore agrees with the statement on lack of alternatives. With this submission, we intend to demonstrate that no available substances (including those listed in Appendix E2 of the restriction proposal for sealing applications) can achieve the sufficient performance required to meet demanding needs of semiconductor manufacturing processes, and thereby demonstrate that a derogation is needed and justified.

IV. Need and Justification for a Derogation

A derogation for Semiconductor Manufacturing is needed and justified. Without a derogation, the manufacturing of semiconductors, which are essential in many fields of modern life, would not be possible. We propose that a derogation is justified based on the following points:

- The **performance requirements** for Semiconductor Manufacturing applications.
- The **lack of availability of alternatives** that would provide the required level of performance.
- The **time required** for research and development to investigate and evaluate potential alternative materials, and if a feasible alternative is identified, the time required to identify, develop, test, and commercialize new Semiconductor Manufacturing products.
- The **large socio-economic cost** of restricting the use.

1. Performance Requirements in Semiconductor Manufacturing Processes

Requirements for materials to be used in Semiconductor Manufacturing can generally be considered in two categories. The first are requirements for a material to be present with the cleanroom environment of semiconductor manufacturing without having a detrimental impact on cleanliness and therefore yield. The second category is the performance requirements related to the function of the specific product itself, which are also demanding.

a. *Extreme cleanliness is critical during the semiconductor manufacturing process*

In 1965, American engineer Gordon Moore predicted the number of transistors per silicon chip would double about every two years. His prediction — now known as “Moore’s Law” — has held true for well over half a century. In that time, advancements in semiconductor wafer fabrication have yielded progressively smaller and smarter chips, enabling ever-smaller devices and even more powerful builds, as with SoC (System on a Chip) applications.

Wafer environmental contamination control is one of the key challenges for semiconductor manufacturing technology. As the ‘International technology Roadmap for Semiconductors 2.0’ predicts, the semiconductor manufacturing process will be required to meet ever growing contamination specifications, to meet the needs of increasing complexity and miniaturization of modern chips[5]. Any component and/or material applied in a semiconductor manufacturing process, besides fulfilling its intended function (whether it is signal transfer, sealing, fluid filtration, or transport of wafers), will need to meet these ever-growing contamination levels specifications.

There is a multitude of literature describing the correlation between semiconductor wafer contamination and manufacturing yield, defects, and performance. Within the semiconductor world, contamination in concentrations of ppt (parts per trillion) and particle sizes measured in nanometers could cause unacceptable defects, impacting yield. Yield *‘has been defined as the number of products that can be sold divided by the number of products that can be potentially made. In the semiconductor industry, yield is represented by the functionality and reliability of integrated circuits produced on the wafer surfaces’* (Semiconductor Industry Association, 2015). Contamination could be any foreign material that appears at the surface of the silicon wafer or within the bulk of the silicon wafer. A few of the key contaminants and mechanisms responsible for yield loss are airborne molecular contamination (further referred as AMC) or particles of organic or inorganic matter coming from the manufacturing environment or tools. Contamination may occur during any stage in the semiconductor manufacturing process and transport. The sources of contamination that need to be controlled during every step (out of up to 2000 steps) include: human pollution, traffic pollution, contaminants brought by cleaning solutions, materials/polymers outgassing, used chemicals and gases contamination or other processes pollution (mechanical abrasion, materials degradation) to name just a few. Effects of example

[5] Semiconductor Industry Association. (2015, 06 05). *THE INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS 2.0.* Retrieved from https://www.semiconductors.org/wp-content/uploads/2018/06/5_2015-ITRS-2.0-Yield-Enhancement.pdf

contaminants on wafers have been summarized in one of the chapters of 'Semiconductor Technologies 2010'[6], which would eventually lead to low yields and poor performance of semiconductor devices.

There is a multitude of defined (and future predicted) cleanliness requirements when manufacturing semiconductors. For an overview, please refer to (Semiconductor Industry Association, 2015) section 2.1. Wafer Environmental Contamination control, table YE3. We will use critical particle size (so called 'killer' particle size) and particulate cleanliness to better explain the concept of cleanliness in the semiconductor field. However non-particulate contamination is equally important.

Killer particles are defined as those particles with minimum size causing a significant effect on the yield of semiconductor manufacturing. Killer particle size prediction is based on DRAM (Dynamic Random Access Memory) half pitch value. It is assumed to be the size of 50% of DRAM half pitch, meaning the lower DRAM half pitch, the lower critical particle size is acceptable. DRAM half pitch is a unit of measure in chip fabrication technology and is defined as half the distance between cells in a DRAM memory chip. As the technology progresses, DRAM half pitch has been reduced over the years and is predicted to go down further. It is predicted that DRAM half value will decrease to 7.7 nm in 2028, which would mean the killer particle size would be 3.9 nm.

There are a number of necessary material properties that help ensure cleanliness in semiconductor manufacturing process, such as:

i. *Low outgassing of materials*

Outgassing from materials of construction in the cleanroom, wafer processing equipment, post processed wafers, and wafer environmental enclosures as well as inadequate exhaust and fugitive emissions from chemicals used in wafer processing are the main sources of AMC[7].

Because of the detrimental nature of any airborne molecular contamination on chips fabrication yields, materials with the lowest possible outgassing are required.

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[6] Bruno, B. J.-L. (2010). Contamination Monitoring and Analysis in Semiconductor Manufacturing. In J. Grym, *Semiconductor Technologies* (p. 59). Intechopen

[7] Semiconductor Industry Association. (2015, 06 05). *THE INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS 2.0.* Retrieved from https://www.semiconductors.org/wp-content/uploads/2018/06/5_2015-ITRS-2.0-Yield-Enhancement.pdf

ii. Low particulation of materials

ISO 14644-1 Cleanrooms and Associated Controlled Environments-Part 1: Classification of Air Cleanliness, defines classes of particulate cleanliness. For example, ISO Class 1, which is a requirement for wafer production, permits 10 particles per square meter of particle size of 100 nm.

As already mentioned, any material that comes in contact with the wafer can become a source of particulate contamination. This is especially important for Lithography cables. As vacuum cables flex and compress, if they contact each other, friction can cause the materials to shed particulates that can contaminate the vacuum environment. This would lead to the low threshold of contamination set by ISO standards to be exceeded. Therefore, materials with the lowest coefficient of friction are required.

iii. Low leaching of materials

The material must be compatible with the continual exposure of aggressive chemicals and not contaminate the system with particles, metals, or dissolved organics, during the life of the equipment. When exposed to such environments, materials must be able to withstand the exposure with minimized potential to leach contaminants. This property is especially important to various seals and gaskets used in the semiconductor manufacturing process but also ozonation modules, microfiltration membranes, and venting due to exposure to aggressive chemicals such as sulfuric acid, phosphoric acid, TMAH[8], and strong organic solvents.

b. Performance requirements are also driven by product function in the semiconductor manufacturing processes

Besides low outgassing, particulation and leaching which are strictly linked with cleanliness requirement for semiconductor manufacturing processes, each product type, whether it is a cable, sealant, filter, or vent will have its unique performance requirements driven by their intended purpose. For example, Microwave cable assemblies require low dielectric constant (in range of 1-2.2) to carry electrical signals with low loss and high signal velocity, while sealants and gaskets require sufficient temperature resistance of up to 260°C as well as chemical resistance to withstand harsh chemicals, such as hydrofluoric acid, sulfuric acid, or hydrogen peroxide encountered at various stages of semiconductor manufacturing processes (e.g. chemical wet etching[9]). We describe these unique performance requirements, per product type, **in more detail in Annex I.**

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[8] Tetramethylammonium hydroxide

[9] Wet etching is a material removal process that uses liquid chemicals or etchants to remove materials from a wafer

2. Assessment of Alternatives

Gore continually follows external developments of new materials while also pursuing an R&D program to develop novel materials that meet the market's needs. During our research, we have not encountered another material can provide sufficient combination of the above-mentioned cleanliness and functional-related performance requirements (e.g., chemical/thermal resistance, low outgassing/particulation, low dielectric constant and filtration efficiency). Consequently, any alternative material would have to be invented, which at best will be time consuming and costly, but is inherently unpredictable and may not be successful.

a. Why fluoropolymers can uniquely deliver the needed performance

Below we provide an overview of the unique combination of properties exhibited by fluoropolymers that enable extreme cleanliness throughout semiconductor manufacturing processes. Other functional properties of fluoropolymers linked with their end application are described in Annex I.

i. Low outgassing from fluoropolymers

Chemically inert fluoropolymers reduce outgassing of volatiles like C_xH_y and H_2O, which can diffuse into the vacuum vessel, contaminating the processing chamber and fogging the parabolic mirrors that are critical for imaging precision.

ii. Low particulation from fluoropolymers

PTFE has the lowest coefficient of friction ($\mu = 0.1$) compared to other common polymers (e.g. $\mu = 0.18$ for PEEK and $\mu = 0.26$ for Polypropylene)[10] which translates into low particulation. It is especially important in applications, such as lithography, that involve very high (› 20 million) numbers of cable flex-cycles at very high speeds.

iii. Low leaching from fluoropolymers

A key component of the chemical structure of fluoropolymers, including the PTFE molecule, is the presence of many carbon-fluorine bonds, one of the strongest chemical bonds known among organic compounds. Because the carbon backbone is protected by a fully fluorinated envelope, fluoropolymers resist attack by even the most highly corrosive chemicals and solvents precluding the possibility of chemical cleavage of the polymer chains. This effectively eliminates the possibility of chemical degradation to potentially produce leachables. Fluoropolymers are used in semiconductor manufacturing processes because they do not react with the chemicals, do not leach contaminants that can negatively impact yield, and are stable under process conditions including elevated temperature.

[10] https://www.lube-media.com/wp-content/uploads/2017/11/Lube-Tech106-PolymerTribology.pdf

b. Alternative materials assessment

In September 2022 we provided several SEAs prepared by eftec. The SEAs have been submitted to all 5 Dossier Submitters. Since this information was provided after the end of the Call for Evidence in September 2021, the SEAs are included as Attachments in Annex II to this derogation request. To make the information more easily available and to consider the information provided in the Restriction Proposal, we have summarized information on alternatives in **Annex I** to this document.

The key conclusions from Annex I are summarized as follows:

- Materials used in semiconductor manufacturing processes need to ensure sufficient functional performance, whether it is signal integrity of a cable or filtration performance of microfiltration media, without introducing contaminants into the process.
- There are currently no known alternative materials that would meet the necessary combination of demanding performance requirements of semiconductor manufacturing process. For example (for a full list of assessed alternatives per product type see Annex I):
    - FEP, PFA, PTFE and expanded PTFE all provide a dielectric constant in the desirable range of 1.0 to 2.2. A low dielectric constant drives the ability to carry electrical signals with low loss and high signal velocity. Alternative materials with somewhat comparable dielectric constants exist (polyethylene- PE, polypropylene- PP, foamed PE) but they have maximum continuous service temperatures in the 80 to 150°C range, falling below the requirements in semiconductor manufacturing (up to 260°C under vacuum).

    - Silica has a reasonably good maximum continuous service temperature and dielectric constant (still not as good as fluoropolymer-based material) but is a highly outgassing material that is not suitable for semiconductor manufacturing process applications.

    - Polyethylene (PE) material can be optimized to meet high airflow requirements for protective vents used in FUOPs but will then not meet high liquid retention and high particle retention requirements. Vice versa, if high liquid retention and high particle retention are optimized, then airflow requirements are not met.

    - Annex e2 of the Restriction Proposal also mentions ethylene propylene diene monomer (EPDM), silicone rubbers, polyetheretherketone polymer (PEEK), and hydrocarbon elastomers as potential alternatives for sealing applications in electronics and semiconductors. These materials do not meet the majority of semiconductor manufacturing process performance requirements. Silicone and EPDM have high outgassing and if used would result in unacceptable contamination. PEEK can be attacked, for example, by strong acids even at room temperature. At elevated temperatures it is more readily attacked even by weak acids and cannot function as a seal above 170°C[11].

3. Timeline

Despite the high cost of raw materials[12] and the inherent incentive to find cheaper alternatives, no viable alternative materials have been identified and developed to date for use in the semiconductor manufacturing process. Since an alternative material is not apparent for semiconductor manufacturing processing, a new material would need to be found or invented. Since the development process needs to begin with creating a new material, potentially a fluorine free polymer, the time needed for implementing alternatives is not known and very difficult to predict. Gore wishes to highlight that no material has been developed in almost a century, since PTFE's discovery that has the chemical, mechanical and thermal performance characteristics required that could displace this material in semiconductor manufacturing processing without unacceptable drops in yield and performance.

Examples from the past show that the time span to develop new materials can vary significantly. For example, the development of acrylic polymer took several decades. The process from the first synthesis of acrylic acid to the introduction of the commercial polymer, was an 85-year journey.[13] The development of PTFE from the "accidental" discovery to a commercial product took about 10 years, from 1938 to 1948,[14] and then decades more to mature that technology into the materials used today. Development advances over this time have had to occur in polymerization, finishing, lubrication and blending, pelletization, and extrusion to develop forms usable in end products. In the absence of such an initial unexpected discovery, we can only speculate that developing a new polymer to commercial availability will take more than 20 years.

The final optimised material will then need to be manufactured into a final product that can be evaluated and qualified both at a manufacture and end-use levels.

[11] Curbell Plastics. (2023). PEEK. Retrieved March 24, 2023, from curbellplastics.com: https://www.curbellplastics.com/Research-Solutions/Materials/PEEK
[12] The Restriction Dossier refers multiple times to higher costs of fluoropolymers (Annex E, page 285, 390, 444, 458, 504, ...)
[13] See https://www.ptonline.com/articles/tracing-the-history-of-polymeric-materials-part-20.
[14] https://www.teflon.com/en/news-events/history#:~:text=An%20Accidental%20Discovery&text=Roy%20J.,to%20form%20polytetrafluoroethylene%20(PTFE).

Table 4. Substitution Steps for Developing an Alternative to Fluoromaterials in Semiconductor Manufacturing Applications

Steps for substitution	What activities does this step entail?	Time required for step
Discovery	Identify and develop suitable alternative materials. Product Development from lab discovery to pilot scale.	**Unknown** Estimate 20 years
Development	Optimise material for specific application requirements.	4-5 years
Certification	Reliability testing of manufactured components.	2-3 years
Production	Supply chain development (new production capabilities and capacity for mass production).	2-5 years
Qualification and/or Validation	Development cycle of new end device.	2 years
Total		**Unknown** **(Discovery step plus 10-15 years)**

4. Additional Information

Specific information requested in the stakeholder consultation is available in the four SEAs (chemical manufacturing and industrial processes, electronics and telecommunication, vents, filters) which are attached as Annex II to this derogation request. The information provided in the SEAs include the following:

- Market and sales (Section 2.3 and 2.5.2);
- Types and volumes of PFAS used (Section 2.4, 2.5.3 and 2.5.5);
- Material flow, including emission volumes Section (2.4.3 and 2.5.3);
- Further information on alternatives (Chapter 3);
- Economic impacts (Section 4.3);
- Impacts on health and the environment (Section 4.4);
- Social and wider economic impact (Section 4.5); and

- Comparison of impacts and proportionality (Chapter 5).

As recognised by the Dossier Submitters, semiconductor manufacturing is a high technology sector with very specific performance requirements (no contamination, extreme cleanliness, high temperature for soldering, …) that combine applications addressed in other sectors. For this reason, the applications in the semiconductor sector have been spread over several different Gore product categories[15] and SEAs. The attached SEAs cover all products of our sealants and gaskets, venting, cable and cable assemblies' and filtration businesses. Therefore, it also contains information on other Gore products which fall under different applications/sub-uses than semiconductor manufacturing processes. Considering the short time period to adapt our Socio-Economic Assessments to the Restriction Proposal, it has not been possible for Gore to extract the information solely relevant to semiconductor manufacturing. We endeavour to provide further information within the subsequent 60 days SEAC public consultation planned for early 2024.

In the following sections, we therefore just present a high-level summary of parts of the SEA, but Gore kindly asks the dossier submitters, RAC and SEAC to review the entire documents:

a. *Impacts on Human Health and the Environmental*

Restriction of PFAS in Semiconductor Manufacturing would lead to reduced cleanliness during manufacturing as well as use of products with lower performance. The impact would be to both reduce manufacturing yield and reduce reliability of semiconductor components. Higher consumption of electronic and telecommunication products through shorter use-life and more frequent replacement would consequently increase both raw material consumption and the amount of waste generated, which itself has potential environmental impacts. The amount of waste electrical and electronic equipment (widely known as WEEE or e-waste) generated every year in the EU is increasing rapidly (European Commission, n.d.). It is now one of the fastest growing waste streams (European Commission, n.d.). The EU has introduced the WEEE Directive and the RoHS Directive to tackle the issue of the growing amount of WEEE. One of the primary priorities of these Directives is to prevent the creation of WEEE (European Commission, n.d.). This can be achieved, in part, by extending product use-life. According to Semiconductor Industry Association (SIA) without using PFAS, decrease in semiconductor yield would occur and therefore result in an increase in chemical, water and energy consumption, as well as waste generation.[16]

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[15] For example, harsh condition applications have been analyzed in chemical manufacturing, lack of contamination in pharmaceutical processing, extreme cleanliness in our filtration discussion, …

[16] https://www.semiconductors.org/the-impact-of-a-potential-pfas-restriction-on-the-semiconductor-sector/

b. Social and Economic Impacts

The restriction proposal concludes that *'Although no quantitative data is available, it is obvious that a potential non-availability of semiconductors would lead to extremely high economic impacts. Semiconductors are used in numerous articles. Not being able to manufacture, use, import or export these articles would lead to high producer surplus losses for manufacturers and employment losses due to business closures and to high socioeconomic costs to customers due to the unavailability of an unknown number of articles'. (E.2.11.5.2. page 402).*

Semiconductors are an essential component within electronic devices, which enable advances in communications, computing, healthcare, military systems, transport, renewable energy, and numerous other applications.

The recent semiconductor shortage, catalyzed by the Covid-19 pandemic, has highlighted the socio-economic impact of semiconductor supply chain delays. For example, the automotive industry, which is reliant on semiconductors for key functions of a vehicle, has been forced to cut production and therefore reduce supply.[17] This has put increased upwards pressure on the price of vehicles for consumers given the shortage in supply. Vehicle prices have not only increased for new vehicles, but they have also increased for used vehicles, since a shortage in supply of new vehicles has driven consumers to the used vehicle market[18]. Once again, this highlights the impact of a semiconductor supply chain disruption on businesses and consumers.

As explained in this submission, PFAS are the only substances known currently to offer the necessary technical performance in semiconductor production. According to an SIA white paper[19], the semiconductor industry was estimated as having global sales of $574 billion USD in 2022 (and according to many reports will grow to $1 trillion by 2030[i]) and the withdrawal of PFAS will have severe economic impacts. These impacts are significantly larger if the consequential effects of chip supply and the societal impact of loss of device functionality are also considered.

If manufacturers are no longer able to invest in innovations relying on PFAS, a further consequential impact will be significant disruption to the technology roadmap which would pose an enormous competitive disadvantage for semiconductor producers based in

[17] J.P. Morgan, 2021. Supply Chain Issues and Autos: When Will the Chip Shortage End? [WWW Document]. Research. URL https://www.jpmorgan.com/insights/research/supply-chain-chip-shortage
[18] O'Kane, S., 2021. The chip shortage is making cars more expensive. The Verge.
[19] https://www.semiconductors.org/the-impact-of-a-potential-pfas-restriction-on-the-semiconductor-sector/

jurisdictions where there are PFAS restrictions in place, as manufacturers attempt to develop the next materials and equipment, which would be a lengthy and demanding process with no certainty of success.

Being compelled to use materials of lower performance (as described in Annex I) would have severe consequences in the semiconductor manufacturing sector, and may cause manufacturers to reconsider their global manufacturing locations. Hence, if a short (or no) derogation is granted for applications supporting semiconductor processes, the EU would be faced with huge economic and strategic threat due to importance of semiconductors in most areas of modern life (defence, energy, healthcare, transport to name just a few).

c. Emissions

It is demonstrated in Section 2.4.3 of the SEAs that emissions from product manufacturing, service life, and end of life of products utilised in semiconductor manufacturing processes are negligible. As explained in earlier sections of this document, one of the key requirements of the semiconductor manufacturing process is extremely low particulation, outgassing and leaching, therefore no emissions are expected during service life. Additional information on responsible manufacturing, processing, and disposal of fluoropolymers and products made from fluoropolymers are provided in our derogation request for fluoropolymers.

Annex I –Alternative assessment

A. Cables and Cable Assemblies

R&D activities conducted	Gore continually follows external developments of new materials while also pursuing an R&D program to develop novel materials that meet the market's needs. In addition, semiconductor equipment companies have been performing trade studies and investing in non-PFAS alternatives that can be used with Cables and Cable Assemblies in clean environments for several years. However, no materials have been identified that can replace PFAS in all of Gore's products.

Performance requirements	***Ultraclean Static Round Cables & Assemblies and High Flex Cables & Assemblies for EUV (extreme ultraviolet lithography) and DUV (deep ultraviolet lithography)***
	
	Cables and assemblies used within DUV and EUV lithography machines are required to perform a combination of inter-related functions, such as:
	- Electrical signal integrity- as its primary function
	- Flexibility and durability- due to extremely high flex cycles at high speeds
	- Low particulation- to meet strict cleanliness requirements
	    o Mechanically robust, low-friction materials in lithography cables are needed to achieve the lowest rates of particulation over high (> 20 million) flex-cycles, even at higher speeds/acceleration. As vacuum cables flex and compress, if they contact each other, friction can cause the materials to shed particulates that can contaminate the vacuum environment.
	- Low outgassing- to meet strict cleanliness requirements
	    o Materials cannot lead to outgassing of volatiles like CxHy and H_2O, which can diffuse into the vacuum vessels of lithography equipment, contaminating the processing chamber and fogging critical components relating to imaging precision.
	    o Water pick-up is also one of the material properties that relates to outgassing in lithography applications.
	
	These properties, primarily provided by PFAS materials used as wire insulation and cable jackets, are fundamental requirements of the lithography application to provide fault-free wafer processing and productivity at highest wafer-per-hour rates.

Microwave/RF test cable assemblies

Microwave/ RF test cables are utilized in semiconductor aging tests. Semiconductor devices are utilized in several sectors where dependability is vital, including aircraft and the military. Testing for the aging of semiconductors assures that the device will continue to operate reliably throughout its lifetime. The device is subject to various conditions, such as temperature, moisture, irradiation, and electrical stress to simulate its aging in accelerated timeframe. Real-world conditions (e.g., thermal cycle/shock, mechanical vibration/shock, vacuum, highest/lowest microwave signal power, dynamic/static bends, contact with water/oil/chemical substances, pulling, crushing force, etc.) are simulated to ensure that the design specifications are met.

There is no single set of performance requirements for Cables and Cable Assemblies as a whole. Instead, the individual requirements vary by product type and in many cases are uniquely customized to the specific test or piece of equipment. These varied and demanding requirements require the availability of materials which can meet unique combinations of specifications.

Key performance requirements typically include:

Dielectric constant (ε_r)

Wire and Cables used for testing must have a minimal signal distortion under external influencing factors (e.g., high pressure, extreme temperatures, and exposure to harsh chemicals) and length of the test cable. The chosen material must therefore display a sufficiently low (‹ 2.5, and often ‹ 2.0) dielectric constant in order to ensure:

- ultra-low attenuation of microwave/RF signal over distance (i.e., improving signal resolution),
- low phase/amplitude change over a wide operating temperature range (-55 to +125°C), to allow the necessary measurement accuracy and precision of small signals on semiconductors,

	- electronics devices/equipment need to be tested at temperature range (-55 to +125°C)[20] to ensure they function properly; therefore, test cables need to operate in the same temperature environment (e.g., space qualified components), - short time delay of microwave/RF signal over distance to reduce signal distortion, and - low capacitance over distance, which also reduces signal distortion. <u>Low outgassing</u> As the specialty wires and cables are used for testing in clean rooms, no material contamination or loss/distortion of signal/data transmission due to degradation can be tolerated. Therefore, the material must show low outgassing in thermal-vacuum conditions, which ensures less contaminants to the surrounding instruments. Low water pick-up is one, but not the only, indicator of potential outgassing and is, therefore, a desirable material property. <u>Mechanical strength</u> The wires and cables and their materials must be highly durable and withstand frequent/rapid flexing, torsion, and pulling without compromising electrical performance under demanding environments (e.g., extreme temperatures).
Alternative materials known or discussed in Restriction Proposal and performance of such materials	<u>Combination of Dielectric Constant and Temperature Resistance</u> Low dielectric constant drives the ability to carry electrical signals with low loss, high signal velocity and smaller size. Figure 1 below provides a [redacted] and illustrates that FEP, PFA, PTFE and expanded PTFE all provide dielectric constants in the desirable range of 1.0 to 2.2. Alternative materials with somewhat comparable dielectric constants exist (PE, PP, foamed PE) but they have continuous service temperatures in the 80 to 150°C range, falling below the requirements in semiconductor manufacture (up to 260°C under vacuum). PFA and PTFE all meet these temperature requirements. Alternative materials which could provide continuous service temperature performance close to the application requirements (e.g. PEEK) have dielectric

[20] a microwave/RF test cable assembly has overall operating temperature derated to -55 to +125°C to account for self-generated heating from microwave signal(s) being transmitted in the worst-case scenario (e.g., highest operating temperature @ +125 C with highest possible microwave power being transmitted). In other words, when the ambient temperature is +125°C, the coaxial cable's center conductor and dieletric material could reach +200°C due to the microwave/RF energy being transmitted.

	constants in the undesirable range of ›2.5. **The ability of fluoropolymer materials to simultaneously provide the needed dielectric constant and service temperature performance cannot be found in alternative materials.** [redacted]

[redacted]

Low Particulation/Low Coefficient of Friction

The table below provides Dynamic Friction Coefficients for Some Common Groups of Polymers. It clearly shows that **PTFE has the lowest coefficient of friction which translates to the low particulation necessary to ensure sufficient cleanliness.**

Table 5. Dynamic Coefficient of Friction for Selected Polymers

Material	Coefficient of Friction	Material	Coefficient of Friction
PTFE	0.10	PVC	0.30
UHMWPE	0.12	HDPE	0.28
antistatic	0.12	LDPE	0.60
oil-filled	0.13	Polypropylene homo-pol	0.26
Nylon 6 Cast	0.26	Nylon 66	0.25
Nylon 6 Cast, oil-filled	0.14	Nylon 66 'Super Tough'	0.28
		Nylon 66, Extrd'd.	0.26
Acetal, homo-polymer	0.20	Acetal, co-polymer	0.18
PEEK, unfilled	0.18	PEEK 30%GR	0.30
PEEK 30% GF	0.31	PEEK, 30% carbon-filled	0.22
Polysulphone	0.37	PPO/PS	0.39

Chemical Resistance

Many polymers have unacceptable resistance to the aggressive chemicals used in semiconductor manufacturing which makes them unsuitable for use in selected applications.

Figure 2. Chemical Resistance[21]; Please note that PTFE is referred to as TFE.

	ETFE	FEP/TFE/PFA	FLPE	FLPP	HDPE	LDPE	PC	PETG	PP	PVC	TPE***
Acids, Dilute or Weak	E	E	E	E	E	E	E	G	E	E	G
Acids, **Strong/Concentrated	E	E	G	G	G	G	G	N	G	G	F
Alcohols, Aliphatic	E	E	E	E	E	E	G	G	E	G	E
Aldehydes	E	E	G	G	G	G	G	G	G	G	G
Bases/Alkali	E	E	F	E	E	E	N	N	E	E	F
Esters	G	E	G	G	G	G	N	G	G	N	N
Hydrocarbons, Aliphatic	E	E	E	G	G	F	G	G	G	G	E
Hydrocarbons, Aromatic	G	E	E	N	N	N	N	N	N	N	N
Hydrocarbons, Halogenated	G	E	G	F	N	N	N	N	N	N	F
Ketones, Aromatic	G	E	G	G	N	N	N	N	N	F	N
Oxidizing Agents, Strong	E	E	F	F	F	F	F	F	F	G	N

*Not for tubing chemical resistance (except PVC) **Except for oxidizing acids (See oxidizing agents, strong) ***TPE gaskets

EXCELLENT	GOOD	FAIR	NOT RECOMMENDED
30 days of constant exposure causes no damage. Plastic may tolerate for 30 years.	Little or no damage after 30 days of constant exposure to the reagent.	Some effect after 7 days of constant exposure to the reagent. The effect may be crazing, cracking, loss of strength or discoloration.	Immediate damage may occur. Depending on the plastic, the effect may be severe crazing, cracking, loss of strength or discoloration, deformation, dissolution or permeation loss.

As described above, alternative materials can sometimes meet specific requirements, but fail to meet the necessary combination of performance requirements:

[21] Eason, M., & Vogel, R. (2022, May). Sealing Devices and the need for PFAS. Valve World, 20-22.

	Polyethylene (PE) Polyethylene (PE) has been found to be a sufficient dielectric material in such basic household cable applications, such as cables used for satellite television and radio. However, the low service temperature range and low resistance to abrasion, water, oil, and chemicals makes PE unsuitable for semiconductor manufacturing processes. **Polyvinyl chloride (PVC)** PVC is the most popular jacket material for low performance products. In addition to its low resistance to abrasion and chemical substances, applications will be limited by its Continuous Service Temperature and the outgassing property in thermal vacuum conditions, making it unsuitable for semiconductor manufacturing processes. **Silicone / Silica Materials** Gore notes that SiO_2 (silica sand) can also be used as a dielectric material, but only for niche, low performance applications as it has many electrical and mechanical drawbacks. Silicone Elastomers are also not desirable in test cable applications due to their high outgassing property. All of this makes it unsuitable for semiconductor manufacturing processes. **Ethylene propylene diene monomer (EPDM)** For this material, the limitation comes from its high dielectric constant which makes it undesirable for electrical performance reasons. It is not suitable as an alternative for semiconductor manufacturing processes. **Polyetheretherketone (PEEK)** As for EPDM, PEEK has a high dielectric constant and relatively low Continuous Service Temperature, which makes it unsuitable for semiconductor manufacturing processes. **Polyimide (PI)** Potential alternatives to fluoropolymer insulation and jacket materials include polyimides, such as polyimide (Kapton). As mentioned, water pick-up is one material property that relates to outgassing in lithography applications. When compared

	with expanded PTFE and PFA, Polyimide shows significantly higher levels of water pick-up, which would produce unacceptable outgassing performance in lithography applications. The low surface energy of fluoropolymers make them particularly resistant to water pick up, even in microporous form. Polyimide also has a high dielectric constant (~3.4) which makes it unsuitable for many cable applications used in semiconductor manufacturing.
Products on market without use of fluoropolymers/ fluoromaterials	The market reflects the lack of viable alternatives, as 95% of high-performance (i.e., most demanding) microwave/RF coaxial cable utilizes PTFE as dielectric material. Also, over 95% of the same sectors use FEP or PFA as jacket material. Supporting information are listed below in Fig. 3 and 4 which highlight the limitations of many polymers. In these figures, “Wide” temperature range indicates -55 to +125°C. while “Narrow” indicates -40 to +85°C.

Fig. 3: Most Common Dielectric Materials in the Market Segment

Manufacturers	Dielectric Material	Temperature Range
Gore	ePTFE	Wide
EZ-Form	PTFE	Wide
	LD PTFE	Wide
Harbour Industries	PTFE	Wide
	LD PTFE	Wide
Winchester Electronics (Dynawave)	LD PTFE	Wide
Bel Group: Cinch (Semflex)	LD PTFE	Wide
	PTFE	Wide
Teledyne Storm	PTFE	Wide
	LD PTFE	Wide
SSI Cable Corp	PTFE	Wide
	LD PTFE	Wide
	PE	Narrow
Amphenol (Times Microwave)	PTFE	Wide
	LD PTFE	Wide
	fluorocarbon dielectric, TF4®	???
	FEP	Wide
Huber+Suhner	PTFE	Wide
	LD PTFE	Wide
	SPE	Narrow
Radiall	PTFE	Wide
	PFA	Wide
	SPE	Narrow
	PE	Narrow
	LD PTFE	Wide
Megaphase	PTFE	Wide
	LD PTFE	Wide
	Foam FEP	Wide
Carlisle IT	PTFE	Wide
	LD PTFE	Wide
	Carlisle IT Fluoropolymer	???
Junkosha	LD PTFE	Wide

Acronym	Scientific Name
PTFE	Polytetrafluorethen
LD PTFE	Low Density PTFE
ePTFE	Expanded PTFE
FEP	Fluorinated ethylene propylene
ETFE	Ethylene-tetrafluoroethylene
ECTFE	Ethylen-chlortrifluorethylen
PVC	Polyvinyl chloride
PE	Polyethylene
SPE	Foamed PE
PUR	Polyurethane

Remarks:

1) Takeaway: Fluoropolymers (e.g., PTFE) are widely used in the market segment as dielectric materials due to demanding real-world application conditions including wide service temperature range. On the contrary, non-fluoropolymers (e.g. PE) are used as dielectric materials only limited for non-demanding real-word application conditions including narrow service temperature range (e.g., residential applications).
2) See Fig. 1 for each fluoropolymer's Dielectric Constant (ε_r) vs. Maximum Continuous Service Temperature (MCST).
3) See Fig. 2 for Solvent Resistance Pattern of Various Polymers.
4) Source: Publicly available data sheets from internet.

Fig. 4: Most Common Jacket Materials in the Market Segment

Manufacturers	Jacket Material	Temperature Range
Gore	PFA	Wide
	ETFE	Wide
	ePTFE	Wide
EZ-Form	FEP	Wide
Harbour Industries	PVC	Narrow
	FEP	Wide
Winchester Electronics (Dynawave)	PUR	Narrow
	Fluoroplastics	???
Bel Group: Cinch (Semflex)	FEP	Wide
	ETFE	Wide
	PUR	Narrow
Teledyne Storm	FEP	Wide
	PUR	Narrow
SSI Cable Corp	PVC	Narrow
	FEP	Wide
Amphenol (Times Microwave)	PVC	Narrow
	PE	Narrow
	FEP	Wide
	ETFE	Wide
Huber+Suhner	FEP	Wide
	PUR	Narrow
	ETFE	Wide
	ECTFE	Wide
	PE	Narrow
Radiall	FEP	Wide
	PE	Narrow
	PTFE	Wide
	PVC	Narrow
Megaphase	FEP	Wide
CarlisleIT	FEP	Wide
	ETFE	Wide
Junkosha	PVC	Narrow
	Fluoropolymer	???

Acronym	Scientific Name
PTFE	Polytetrafluorethen
LD PTFE	Low Density PTFE
ePTFE	Expanded PTFE
FEP	Fluorinated ethylene propylene
ETFE	Ethylene-tetrafluoroethylene
ECTFE	Ethylen-chlortrifluorethylen
PVC	Polyvinyl chloride
PE	Polyethylene
SPE	Foamed PE
PUR	Polyurethane

Remarks:

1) Takeaway: Fluoropolymers (e.g., PTFE) are widely used in the market segment as jacket materials due to demanding real-world application conditions including wide service temperature range. On the contrary, non-fluoropolymers (e.g., PE) are used as jacket materials only limited for non-demanding real-word application conditions including narrow service temperature range (e.g., residential applications).
2) See Fig. 1 for each fluoropolymer's Dielectric Constant (ε_r) vs. Maximum Continuous Service Temperature (MCST).
3) See Fig. 2 for Solvent Resistance Pattern of Various Polymers.
4) Source: Publicly available data sheets from internet.

B. Sealants and Gaskets

R&D activities conducted	Due to the considerable challenges with finding substitutes to PTFE, Gore continues to keep updated on the current "state of the art" materials available. Gore continually follows external developments of new materials while also pursuing an R&D program to develop novel materials that meet their market. No suitable alternative material for sealing applications in semiconductor manufacturing processes is available.
Performance requirements	Performance requirements include the ability to simultaneously provide chemical resistance, temperature resistance, and be non-leaching/out-gassing. <u>Chemical resistance:</u> Chemical resistance to concentrated acids and bases. See Figure 2 in Annex I.A., above. <u>Temperature resistance:</u> Chemical resistance over a temperature range up to 260°C covering the breadth of highly aggressive chemicals such as concentrated acids and bases. <u>Non-leaching/ non-outgassing:</u> Non-leaching/outgassing to support extreme cleanliness
Alternative materials known or discussed in Restriction Proposal and performance of such materials	Detailed compatibility charts for materials can be found on many alternative product websites and catalogues. An example would be the Emmerson/Rosemont analytical publication[22] After material selection, other design factors including cleanliness (represented by low particulation and low leaching and outgassing) would be considered.[23]

[22] Emerson. (2006). Chemical Compatibility Chart. Retrieved March 24, 2023, from emerson.com: https://www.emerson.com/documents/automation/manuals-guides-chemical-compatibility-topworx-en-82210.pdf

[23] European Sealing Association (ESA). (2019). SEALING DEVICES REDUCTION OF FUGITIVE EMISSIONS DOCUMENT BEST AVAILABLE TECHNIQUES. Retrieved March 24, 2023, from ESAKnowledgebase.com: https://www.esaknowledgebase.com/wp-content/uploads/2019/11/ferd_5c_v2.pdf

	Key deficiencies of alternate materials: - **Ethylene propylene diene monomer (EPDM)** EPDM is dimensionally unstable above 150°C and not widely chemically compatible. It also does not meet the extractables and leachable requirements for semiconductor applications. It is used extensively as an “environmental” seal in outdoor equipment due to it being very UV stable and more resistant to biological growth. - **Silicone rubbers** Silicone is a high outgassing material and most Semiconductor Fabrication Plants do not allow this material in equipment since it tends to contaminate other critical processes easily. There are exceptions where it is used in processes less sensitive to cleanliness requirements such as Electroplating, but typically the cable stays below the wafer being processed, not above. - **Polyether ether ketone (PEEK)** PEEK is a technical non fluorinated polymer with good chemical resistance, but not PTFE levels of resistance. It can be attacked, for example, by strong acids even at room temperature. At elevated temperatures it is more readily attacked even by weak acids and cannot function as a seal above 170°C[24], while PTFE can function up to 260°C. - **Hydrocarbon elastomers** Hydrocarbon elastomers are much less durable than fluoropolymers which would result in much shorter service life. Also, they tend to be sensitive to damage from UV so would not be a viable option for processes that involve UV, including EUV Lithography.

[24] Curbell Plastics. (2023). PEEK. Retrieved March 24, 2023, from curbellplastics.com: https://www.curbellplastics.com/Research-Solutions/Materials/PEEK

Table 6 below shows the continuous use temperatures for a broader range of polymers, highlighting the unique high temperature capability of fluoropolymers.

Table 6: Working Temperature of Potential Alternative Materials to PFAS[25]

Polymer Name	Minimum operating temperature (°C)	Maximum operating temp (°C)
ABS - Acrylonitrile Butadiene Styrene	80.0	86
ETFE - Ethylene Tetrafluoroethylene	-100.0	140
EVA - Ethylene Vinyl Acetate	-60.0	45
FEP - Fluorinated Ethylene Propylene	-150.0	205
HDPE - High Density Polyethylene	-70.0	100
HIPS - High Impact Polystyrene	-20.0	60
LCP - Liquid Crystal Polymer	-50.0	200
LDPE - Low Density Polyethylene	-70.0	80
PA 6 - Polyamide 6	-20.0	80
PA 66 - Polyamide 6-6	-65.0	80
PAI - Polyamide-Imide	-196.0	220
PAR - Polyarylate	-95.0	130
PBT - Polybutylene Terephthalate	-40.0	80
PCTFE - Polymonochlorotrifluoroethylene	-250.0	150
PEEK - Polyetheretherketone	-70.0	154
PET - Polyethylene Terephthalate	-40.0	80
PP (Polypropylene) Homopolymer	-10.0	100
PSU - Polysulfone	-100.0	150
PTFE - Polytetrafluoroethylene	-200.0	260
PVC, Plasticized	-5.0	50
PVDF - Polyvinylidene Fluoride	-40.0	70
UHMWPE - Ultra High Molecular Weight Polyethylene	-30.0	110

Products on market without use of fluoropolymers/ fluoromaterials

We are not aware of products on the market within Semiconductor manufacturing process that would be a viable alternative to fluoropolymer-based products

[25] https://omnexus.specialchem.com/polymer-properties/properties/min-continuous-service-temperature

C. Microfiltration Media and Ozonation Modules

R&D activities conducted	We have not conducted research on alternatives. Our customers informed us that other alternative materials are not suitable.
Performance requirements	**Microfiltration membranes** Fluid purity is essential in semiconductor fabrication and microelectronics manufacturing processes, like wet etch and clean (WEC), photolithography and chemical mechanical polishing (CMP) operations. As transistors continue to shrink to ever smaller sizes, it becomes increasingly critical to have filtration capable to capture the tiniest particles in the nanometer range for effective micro-contamination control. - Highest retention rates (rated at 1-2nm for the most demanding filtration applications) - High flow rate to enable high process yields without sacrificing throughput - Thermal stability in range from 90 C to 150°C - Chemical resistance/inertness of the filter material to avoid leaching and shedding that would impact purity **Ozonation modules** Used to eliminate organic and inorganic contaminants from semiconductor wafer and photomask processes. - High ozone dissolution concentration (200mg/L) - High water entry pressure (WEP) of more than 0.40 MPa - Bubble- free solution
Products on market without use of fluoropolymers/ fluoromaterials	**Microfiltration membranes** Non-PFAS filter alternatives include polyethylene, polysulfone and nylons. Polyethylene and Polysulfone are the primary choices where temperature is below 60-70°C, pH is 4-8 range, and cleanliness of filtrate is not highest priority. Although Nylon can withstand higher temperatures (up to 205°C), it has very poor filtration efficiency due to poor microporous structure. Many processes within semiconductor manufacturing process are 90°C and above and would melt filters made with alternative materials.

	Even where alternative material, e.g., HDPE, can withstand higher temperatures, semiconductor manufacturing processes utilize concentrated Sulfuric acid, Phosphoric acid, TMAH, and strong organic solvents that leach out the processing aids found within such non-PFAS polymers, which will lead to wafer defects. **Ozonation modules** The industry traditionally uses chemical-based mixtures (e.g., SPM process- a mixture of sulfuric acid and hydrogen peroxide) for silicon wafers and semiconductor cleaning applications. There is, however, strong incentives to move towards an ozone functional water treatment. This is primarily because ozone converts back to water at the end of life, which eliminates the use of SPM chemical cleaning agents and reduces hazardous waste. Mechanical mixers are an alternative technology to obtain ozonated water, but this technology has not been accepted by the semiconductor industry because it leaves micro-bubbles (resulting from direct injection of ozone gas) in the ozone water that can lead to defects on the wafer during drying. It also does not have a filtration function to remove particles within ozone gas. Non-PFAS ozonation modules do not exist because ozone gas is such a strong oxidizer that it leads to module failure (material disintegration) and ozone gas escape. As shown in Figure 2 above, only fluoropolymers show excellent resistance to strong oxidizing agents. PVC is shown to be the only polymer listed with “good” resistance; however, Table 6 shows the maximum continuous use temperature is only 50°C, well below the requirement for this end use.

D. Protective Vents utilized in FOUPs and Pellicle Frames

R&D activities conducted	Gore continually follows external developments of new materials while also pursuing an R&D program to develop novel materials that meet the market’s needs. In addition, industry has been performing trade studies and investing in non-PFAS alternatives that can be used with vents in harsh environments for a number of years. However, no suitable materials have been identified that can replace PFAS in Semiconductor manufacturing equipment, such as FOUPs and Pellicle Frames

Performance requirements	Protective vents are used in the purge inlet and outlet ports of Front Opening Unified Pods (FOUPs) that house the wafers during the semiconductor manufacturing fabrication process. FOUPs are cleaned from use of strong acids and bases, including particulate formation, to maintain high cleanliness requirements through frequent high pressure N2 purges and water spray. Protective vents are also used in Pellicle Frame applications. Pellicle Frames are used to protect the photomask from any contamination. If any particles would enter, this would impact quality and lead to failures of semiconductor manufacturing processes. Pressure adjustment/equalization is essential to ensure the same pressure inside and outside of the pellicle frame. In the case of pressure differences the thin foil installed on the frame would deform/ripple which would impact (de-orient) the laser beam leading to quality impact and failures in the photomask process. Key protective vents requirements: 1. High air flow (80 liters per min @ 8 psid) during N2 purging, which provides the ability to equalize pressure 2. Chemical resistance to strong acids and bases potentially present in the FOUP housing the wafers 3. 99.7% particle filtration efficiency 4. Very low outgassing and low particulation from the vent filter itself
Alternative materials known or discussed in Restriction Proposal and performance of such materials	**High Density Polyethylene (HDPE) or polypropylene (PP)** HDPE and PP are not sufficiently chemically resistant, which results in the leaching of contaminants that would deposit on wafers and lead to chips defects. **Polyethylene (PE)** Does not meet sufficient combination of high air flow requirements with high liquid retention and high particle retention. PE material can be optimized to meet high airflow requirements for protective vents used in FUOPs but will then not meet high liquid retention and high particle retention requirements. Vice versa, if high liquid retention and high particle retention shall be reached airflow requirements are not met.

	Nonwoven PET materials PET nonwovens are used on a limited basis but have low particle capture efficiency (70-80% range) and is not applicable for the majority of chip manufacturing. They lead to high particle emission and potentially outgassing.
Products on market without use of fluoropolymers	There are no known alternative products commercially available that meet semiconductor manufacturing process requirements.

Annex II – Relevant SEAs

- Chemical Manufacturing and Industrial Processes
- Electronics and Telecommunication
- Vents
- Filters