

Annex A - Table A.49. Uses and properties of PFASs in the semiconductor
Semiconductor Manufacturing

Use Category	Sub-Use
Photolithography	Photoacid generators
Photolithography	Antireflection coatings
Photolithography	Topcoats and Embedded Immersion Barriers Layers
Photolithography	Surfactants
Photolithography	Dielectric Polymers (PBO/PI)
Photolithography	Filters
Nanoimprint Lithography	
Photoresist	Epoxy, case masking
Color Filter photoresist for imaging semiconductor components "photopatterning"	
Plasma [Dry] Etch and Wafer Cleaning	
Vapour deposition chamber	Cleaning
Wet surface modification chemistries (eg. Wafer)	Wet etch
Advanced Semiconductor Packaging	Flux
Development of necessary chemistries and their packaging to be used for manufacturing of process recipes (Photo Acids, Polymer with Fluorine Groups, Monomers/prepolymers, Surfactants, Dyes etc.)	Semiconductor manufacturing - process chemistries

The use of fluoropolymers in process chemistry manufacturing equipment (Filtration system e.g. PTFE filters, Pump, etc.), production infrastructure (Blending Kettles, Piping, Valves, etc.) and evaluation tools (coating, exposure and development tools, NMR, IR, ICP/MS, Titrator, etc.)	Semiconductor manufacturing - process chemistries
The use of Consumable Materials for process chemistry development and manufacturing (air and wet chemical filters, seals/o-rings, piping/tubing, embedded lubricants (oils, greases, solids), non-process chemicals, replacement parts, release film for mold process etc.)	Semiconductor manufacturing
Articles to store, handle, and deliver liquid process chemicals (Bottle Cap Seals, PTFE inner, PTFE tape, Dip tube, O-ring, Packing, Connector, Valve etc.)	Semiconductor manufacturing
MEMS wafer process	Vapor HF Sacrificial Etch: Tool Parts, Seals, Fittings etc.
Semiconductor Manufacturing Equipment (photolithography coaters, scanners and developers, dry etch, ion implant, deposition, CMP, assembly test, metrology, pumps, point of use abatement equipment, spare parts, equipment repair, maintenance of articles and mixtures used etc.)	

Semiconductor Manufacturing Equipment & Infrastructure - Enabling Uses of Fluoropolymer Articles (raw materials including precursors, fluoropolymer parts embedded within manufacturing equipment, spare parts, equipment repair, maintenance of articles and infrastructure, filters, piping, tubing, gaskets, cables etc.)	Data, Power & Fluid Delivery and Interconnects, sealants/piping, waste removal used in semiconductor manufacturing
Plasma Etch and Wafer Cleaning	Filters Ozone functionalized water
Plasma Etch and Wafer Cleaning	Thermal insulation for wet solution
Wafer	Wet etch & clean filters
Heat Transfer Fluids	Equipment Chillers

Thermal Testing of Semiconductor Devices (in-line and end of line)	Equipment Chillers
Vacuum pump	Vacuum fluid
Plastics such as PC/ABS	
Fluoroelastomers, polymers including polyimides, polyamides, polyesters, polycarbonate etc.	
Adhesive, coating, lubricant	
Lubricants	
Semiconductor Manufacturing Equipment & Infrastructure - the design, manufacture and delivery of semiconductor manufacturing equipment	Semiconductor manufacturing
Reticle and pellicle manufacturing and all of its required chemicals, materials and tooling etc.	Semiconductor manufacturing - photolithography

Consumable Materials in semiconductor manufacturing equipment (air and wet chemical filters, seals/o-rings, piping/tubing, embedded lubricants (oils, greases, solids), non-process chemicals, replacement parts etc.)	Semiconductor manufacturing
Development of semiconductor manufacturing equipment (fluoropolymers, PFAS in mixtures etc.)	Production of semiconductor manufacturing equipment
The use of fluoropolymers and PFAS in mixtures in the production of semiconductor manufacturing	Production of semiconductor manufacturing equipment
Semiconductor Manufacturing infrastructure (production and storage, high purity water manufacturing/delivery systems, high purity chemical & gas delivery systems, air filtration systems, bulk chemical delivery systems treatment and distribution, planar chemical delivery systems, liquid waste collection system, abatement systems, semiconductor wastewater treatment and HVAC including corrosive exhaust ducting and treatment, facilities systems controls, gaskets for pipelines, etc.)	Support of semiconductor manufacturing (Chemical transportation, waste removal, waste treatment, etc.)
Plasma Etch and Wafer Cleaning	Thermal insulation for gas supply and exhaust in Plasma Etch
Vapour deposition chamber	Thermal insulation for gas supply and exhaust in Plasma Etch

Consumable Materials in semiconductor manufacturing infrastructure (air and wet chemical filters, seals/o-rings, piping/tubing, embedded lubricants (oils, greases, solids), non-process chemicals, replacement parts etc.)	Semiconductor manufacturing
Development of semiconductor manufacturing infrastructure equipment (fluoropolymers, PFAS in mixtures etc.)	Semiconductor manufacturing
Support equipment for SM Processes	Protection Equipment for Maintenance/Firefighting
Semiconductor Manufacturing Support Equipment (Automated Material Handling Systems, lab equipment such as Die yield/Failure Analysis, Pathifinding/R&D, Chemical evaluation, associated abatement systems etc.)	Support of semiconductor manufacturing
Consumable Materials in semiconductor manufacturing support equipment (air and wet chemical filters, seals/o-rings, piping/tubing, embedded lubricants (oils, greases, solids), non-process chemicals, replacement parts etc)	Semiconductor manufacturing
Development of semiconductor manufacturing support equipment (fluoropolymers, PFAS in mixtures etc.)	Semiconductor manufacturing
Wafer processing and transportation semiconductor manufacturing support systems - cassettes from front end to back end	FOUPs - Front Opening Unified Pod/Front Opening Universal Pod

Advanced Semiconductor Packaging	Encapsulants (epoxy underfills, mold compounds etc.)
Advanced Semiconductor Packaging	Thermal Interface Materials
Advanced Semiconductor Packaging	Adhesives
Advanced Semiconductor Packaging	Hydrophobic coating/hermetic seal packages
Advanced Semiconductor Packaging	Substrates including buildup/dielectric material
Advanced Semiconductor Packaging	MEMS anti-stiction layer/coating
Advanced Semiconductor Packaging	Die for chiplets
Advanced Semiconductor Packaging	Release sheet for thermocompression bonding process of semiconductor chips
Advanced Semiconductor Packaging	Packaging (bump, test, sort & assembly)

MEMS sensor packaging	Passivation gels and coating materials
MEMS sensor packaging	Chemically robust adhesives for chip and package component attach
MEMS sensor packaging	Soft adhesives for chip attach
MEMS sensor packaging	Air-permable membranes, protective meshes, and their hydrophobic and oleophobic coatings

industry identified by stakeholders - Updated since the Call for Evidence/Royal Haskoning studies

Properties	Examples of PFAS
- Strong electronegativity of F atom in the complex resist/chemical matrix allows for controlled generation of strong acid upon exposure to UV light	Fluorinated salts
- Low dielectric constant - Low refractive index - Good thermal stability - Good barrier properties	Acrylate and methacrylate-based copolymers
- Hydrophobicity	Fluoropolymers
- Uniformity in coating with minimal effect on properties provided by other critical resist/chemical ingredients (i.e., without impact to refractive indexes)	Non-polymeric PFASs (non-ionic)
- Hydrophobicity - Electrical non-conductivity - Thermal resistance	Water-insoluble C1 PFAS polymers
- Chemical resistance - Low extractables against solvents	Fluoropolymers
- Low surface adherence	Fluoropolymers
- Resistance to fire, grease, stain, etc.	Fluorotelomer-related compounds
- Anisotropic etching capabilities	PFC, HFC and HFO gases
Less shedding	PFC, HFC and HFO gases
- Wetting agents - Selective metal oxide removal	Fluorinated organic acids
- High-temperature thermal stability (>160 C)	Surfactants

High temperature stability up to 180°C Low Young's modulus Low tensile strength (i.e. high stretchability with low tearing risk) Low adhesion strength Chemical inertness	Fluoropolymer
Chemical resistance to HF vapor, low particle generation	Fluoropolymer

- Chemical resistance - Low volatility/high stability - Thermal resistance - Cleanliness - UV resistance - Flame resistance - Inertness - Purity - Low flammability - Temperature stability - Resistance to chemical permeation - Low coefficient of friction - Optical properties - Low dielectric constant - Low dissipation factor - low outgassing factor - Stable electrical performance over high temperature	Fluoropolymers (i.e., Teflon™, Viton™, PTFE, PFA, FEP, ETFE, PVDF, FFKM, etc)
Chemical resistance Thermal durability High retention and high flow Low extractables	Fluoropolymers
Low thermal conductivity Chemical resistance Thermal durability Less shedding Less gas	Fluoropolymers
Chemical resistance Temperature resistance Low extractables	Fluoropolymers
- High precision temperature control imparted by thermal stability - Viscosity vs temperature characteristics - Specific heat - Electrical conductivity characteristics	Hydrofluoroethers, perfluoropolyethers (including PFPMIE), and other fully fluorinated liquids (perfluorinated amines and perfluoroalkylmorpholines, PFPE, Butane, 1-ethoxy-1,1,2,2,3,3,4,4,4-nonafluoro-, 2,3,3,4,4-pentafluoro-5-methoxy-2,5-bis[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]tetrahydrofuran, Perfluamine, 1,1,1,2,2,4,5,5,5-nonafluoro-4-(trifluoromethyl)-3-pentanone PFCs HFCs HFOs

- High precision temperature control imparted by thermal stability - Viscosity vs temperature characteristics, - Specific heat and electrical non-conductivity characteristics - High boiling point - Low pour point - Non-flammability	Hydrofluoroethers, perfluoropolyethers (including PFPMIE), and other fully fluorinated liquids (perfluorinated amines and perfluoroalkylmorpholines, Reaction mass of 1,1,2,2,3,3,4,4,4-nonafluoro-N,Nbis(nonafluorobutyl)butan-1-amine and 1,1,2,2,3,3,4,4,4-nonafluoro-N-[1,1,2,3,3-hexafluoro-2-(trifluoromethyl)propyl]-N-(1,1,2,2,3,3,4,4,4-nonafluorobutyl)butan-1-amine
- Thermally stable - Non-flammable and insoluble in water, acids, bases and most organic solvents - Inertness - Low off-gassing and particle generation	Fluorocarbon ether polymers of polyhexafluoropropylene oxide,
- Flame retardancy	Perfluoroalkane sulfonic acids (PFSA), their salts and esters
- Cross linking agent for fluoroelastomers, monomer, high temperature composites and electronic materials	Bisphenol AF and its salts
Solvability	Perfluoroalkylethers
- Inertness - Low off-gassing and particle generation	PFPE Fluorosilicone PCTFE PTFE
- Chemical resistance - Low volatility/high stability - Thermal resistance - Cleanliness - UV resistance - Flame resistance - Inertness - Purity - Low flammability - Temperature stability - Resistance to chemical permeation - Low coefficient of friction - Optical properties	Fluoropolymers (i.e., Teflon™, Viton™, PTFE, PFA, FEP, ETFE, PVDF, FFKM, etc)

- Inertness - Chemical resistance - Low volatility/high stability - Purity - Low flammability - Temperature stability - Resistance to chemical permeation	Fluoropolymers (PVDF, PTFE, etc.)
Low thermal conductivity Chemical resistance Thermal durability Less shedding Less gas	Fluoropolymers
Low thermal conductivity Chemical resistance Thermal durability Less shedding Less gas	Fluoropolymers

Special requirements when F-containing gases come into play	Viton™ gloves, personal protective equipment for firefighters etc.
High airflow and low particle penetration Low outgassing Low particle emission Water spray washing resistance	Floropolymers

Temperature resistance Beneficial material flow Wetting, degassing and composite homogeneity Electrical non-conductivity	Fluoropolymers
High thermal conductivity/heat resistance Tear resistance High tensile strength Incorporation of various fillers into different resin systems - High-temperature thermal stability (>160 C) - Low surface tension	Fluoropolymers
- Solubility in organic solvents, low dielectric constants, and high thermal and thermo-oxidative stability	Fluorinated Tetracarboxylic acid anhydride derivatives, aromatic diamines, acrylate and methacrylate-based copolymers
- Unique hydrophobicity	Fluoropolymers
- High-temperature thermal stability (>160 C) - Electrical non-conductivity/low dielectric constant - Surface roughness/adhesion - Low coefficient of thermal expansion	Fluoropolymers
- Low coefficient of friction - Low surface energy - High thermal stability - chemical inertness - mechanical durability, - electrical insulation - low particle generation	Fluoropolymers Fluoroalkyl Silanes
- Heat-resistant - Releasability - Flexibility - Tensile strength	PTFE

Unique property: simultaneous high chemical stability against polar, unpolar and oxidative agents and acids Low Young's modulus that is constant over very wide operational temperature range (-50..175°C) High thermal stability No significant aging over product lifetime (up to 15 years)	Fluoropolymers
Unique property: simultaneous high chemical stability against polar, unpolar and oxidative agents and acids Low Young's modulus that is constant over very wide operational temperature range (-50..175°C) High thermal stability No significant aging over product lifetime (up to 15 years)	Fluoropolymers
Intermediate Young's modulus that is constant over very wide operational temperature range (-50..175°C) High thermal stability No significant aging over product lifetime (up to 15 years)	Fluoropolymers
Unique property: simultaneous high chemical stability against polar, unpolar and oxidative agents and acids Unique property: simultaneous hydrophobicity and oleophobicity High thermal stability up to reflow solder temperature (>260°C)	Fluoropolymers

Estimated Timeframe To Substitute with Non-PFAS Alternatives (Timeline commences after an invention is identified)	Element
25+ years	Process Chemistries
15-20+ years	Process Chemistries
25+ years	Process Chemistries
15-20+ years	Process Chemistries
15-20+ years	Process Chemistries Semiconductor device
15+ years	Process Chemistries
15-20+ years	Process Chemistries
15-20+ years	Process Chemistries Semiconductor device
15+ years	Process Chemistries
10+ years	Process Chemistries
3-15+ years	Process Chemistries
5 years	Process Chemistries
	Process Chemistries

	Process Chemistries
	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure Semiconductor Manufacturing Support Equipment Process Chemistries
	Process Chemistries
at least 20+ years	Process Chemistries Semiconductor Manufacturing Equipment
	Semiconductor Manufacturing Equipment

15+ years	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
	Semiconductor Manufacturing Equipment
	Semiconductor Manufacturing Equipment
	Semiconductor Manufacturing Equipment
8-14+ years	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure

8-14+ years	Semiconductor Manufacturing Equipment
10+ years	Semiconductor Manufacturing Equipment
15+ years	Semiconductor Manufacturing Equipment
15-20+ years	
10+ years	
10+ years	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
15+ years	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
	Semiconductor Manufacturing Equipment

	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
	Semiconductor Manufacturing Equipment
15+ years	Semiconductor Manufacturing Infrastructure
	Semiconductor manufacturing Infrastructure
	Semiconductor Manufacturing Infrastructure

	Semiconductor Manufacturing Infrastructure
	Semiconductor Manufacturing Infrastructure
Not known	Semiconductor Manufacturing Infrastructure
	Semiconductor support equipment
	Semiconductor support equipment
	Semiconductor support equipment
	Semiconductor support equipment

13 years	Semiconductor Device
20+ years	Semiconductor Device
20+ years	Semiconductor Device
10+ years	Semiconductor Device
10+ years	Semiconductor Device
15-20+ years	Semiconductor Device
10+ years	Semiconductor Device
	Semiconductor Device

10+ years	Semiconductor Device
10+ years	Semiconductor Device
7+ years	Semiconductor Device
at least 20+ years	Semiconductor Device