

Annex A - Table A.49. Uses and properties of PFASs in the semiconductor industry identified by stakeholders - Updated since the Call for Evidence/Royal Haskoning studies
Semiconductor Manufacturing

Use Category	Sub-Use	Properties	Examples of PFAS	Estimated Timeframe To Substitute with Non-PFAS Alternatives (Timeline commences after an invention is identified)	Element
Photolithography	Photoacid generators	- 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	25+ years	Process Chemistries
Photolithography	Antireflection coatings	- Low dielectric constant - Low refractive index - Good thermal stability - Good barrier properties	Acrylate and methacrylate-based copolymers	15-20+ years	Process Chemistries
Photolithography	Topcoats and Embedded Immersion Barriers Layers	- Hydrophobicity	Fluoropolymers	25+ years	Process Chemistries
Photolithography	Surfactants	- 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)	15-20+ years	Process Chemistries
Photolithography	Dielectric Polymers (PBO/PI)	- Hydrophobicity - Electrical non-conductivity - Thermal resistance	Water-insoluble C1 PFAS polymers	15-20+ years	Process Chemistries Semiconductor device
Photolithography	Filters	- Chemical resistance - Low extractables against solvents	Fluoropolymers	15+ years	Process Chemistries
Nanoimprint Lithography		- Low surface adherence	Fluoropolymers	15-20+ years	Process Chemistries
Photoresist	Epoxy, case masking	- Resistance to fire, grease, stain, etc.	Fluorotelomer-related compounds	15-20+ years	Process Chemistries Semiconductor device
Color Filter photoresist for imaging semiconductor components "photopatterning"					
Plasma [Dry] Etch and Wafer Cleaning		- Anisotropic etching capabilities	PFC, HFC and HFO gases	15+ years	Process Chemistries
Vapour deposition chamber	Cleaning	Less shedding	PFC, HFC and HFO gases	10+ years	Process Chemistries
Wet surface modification chemistries (eg. Wafer)	Wet etch	- Wetting agents - Selective metal oxide removal	Fluorinated organic acids	3-15+ years	Process Chemistries
Advanced Semiconductor Packaging	Flux	- High-temperature thermal stability (>160 C)	Surfactants	5 years	Process Chemistries
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				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				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	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		Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure Semiconductor Manufacturing Support Equipment Process Chemistries
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				Process Chemistries
MEMS wafer process	Vapor HF Sacrificial Etch: Tool Parts, Seals, Fittings etc.	Chemical resistance to HF vapor, low particle generation	Fluoropolymer	at least 20+ years	Process Chemistries Semiconductor Manufacturing Equipment
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
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	- 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)	15+ years	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
Plasma Etch and Wafer Cleaning	Filters Ozone functionalized water	Chemical resistance Thermal durability High retention and high flow Low extractables	Fluoropolymers		Semiconductor Manufacturing Equipment
Plasma Etch and Wafer Cleaning	Thermal insulation for wet solution	Low thermal conductivity Chemical resistance Thermal durability Less shedding Less gas	Fluoropolymers		Semiconductor Manufacturing Equipment

Wafer	Wet etch & clean filters	Chemical resistance Temperature resistance Low extractables	Fluoropolymers		Semiconductor Manufacturing Equipment
Heat Transfer Fluids	Equipment Chillers	- High precision temperature control imparted by thermal stability - Viscosity vs temperature characteristics - Specific heat - Electrical conductivity characteristics	Hydrofluoroethers, perfluoropolyethers (including PPFMIE), 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, 1,1,1,2,2,4,4,5,5,5-nonafluoro-4-(trifluoromethyl)-3-pentanone PFCs HFCs HFOs	8-14+ years	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
Thermal Testing of Semiconductor Devices (in-line and end of line)	Equipment Chillers	- 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 PPFMIE), 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	8-14+ years	Semiconductor Manufacturing Equipment
Vacuum pump	Vacuum fluid	- 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,	10+ years	Semiconductor Manufacturing Equipment
Plastics such as PC/ABS		- Flame retardancy	Perfluoroalkane sulfonic acids (PFSA), their salts and esters	15+ years	Semiconductor Manufacturing Equipment
Fluoroelastomers, polymers including polyimides, polyamides, polyesters, polycarbonate etc.		- Cross linking agent for fluoroelastomers, monomer, high temperature composites and electronic materials	Bisphenol AF and its salts	15-20+ years	
Adhesive, coating, lubricant		Solvability	Perfluoroalkylethers	10+ years	
Lubricants		- Inertness - Low off-gassing and particle generation	PFPE Fluorosilicone PTFE PTFE	10+ years	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
Semiconductor Manufacturing Equipment & Infrastructure - the design, manufacture and delivery of semiconductor manufacturing equipment	Semiconductor manufacturing	- 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)	15+ years	Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
Reticle and pellicle manufacturing and all of its required chemicals, materials and tooling etc.	Semiconductor manufacturing - photolithography				Semiconductor Manufacturing Equipment

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				Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
Development of semiconductor manufacturing equipment (fluoropolymers, PFAS in mixtures etc.)	Production of semiconductor manufacturing equipment				Semiconductor Manufacturing Equipment Semiconductor Manufacturing Infrastructure
The use of fluoropolymers and PFAS in mixtures in the production of semiconductor manufacturing	Production of semiconductor manufacturing equipment				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.)	- Inertness - Chemical resistance - Low volatility/high stability - Purity - Low flammability - Temperature stability - Resistance to chemical permeation	Fluoropolymers (PVDF, PTFE, etc.)	15+ years	Semiconductor Manufacturing Infrastructure
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	Fluoropolymers		Semiconductor manufacturing Infrastructure
Vapour deposition chamber	Thermal insulation for gas supply and exhaust in Plasma Etch	Low thermal conductivity Chemical resistance Thermal durability Less shedding Less gas	Fluoropolymers		Semiconductor Manufacturing Infrastructure
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				Semiconductor Manufacturing Infrastructure

Development of semiconductor manufacturing infrastructure equipment (fluoropolymers, PFAS in mixtures etc.)	Semiconductor manufacturing				Semiconductor Manufacturing Infrastructure
Support equipment for SM Processes	Protection Equipment for Maintenance/Firefighting	Special requirements when F-containing gases come into play	Viton™ gloves, personal protective equipment for firefighters etc.	Not known	Semiconductor Manufacturing Infrastructure
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				Semiconductor support equipment
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				Semiconductor support equipment
Development of semiconductor manufacturing support equipment (fluoropolymers, PFAS in mixtures etc.)	Semiconductor manufacturing				Semiconductor support equipment
Wafer processing and transportation semiconductor manufacturing support systems - cassettes from front end to back end	FOUPs - Front Opening Unified Pod/Front Opening Universal Pod	High airflow and low particle penetration Low outgassing Low particle emission Water spray washing resistance	Fluoropolymers		Semiconductor support equipment
Advanced Semiconductor Packaging	Encapsulants (epoxy underfills, mold compounds etc.)	Temperature resistance Beneficial material flow Wetting, degassing and composite homogeneity Electrical non-conductivity	Fluoropolymers	13 years	Semiconductor Device
Advanced Semiconductor Packaging	Thermal Interface Materials	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	20+ years	Semiconductor Device
Advanced Semiconductor Packaging	Adhesives	- 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	20+ years	Semiconductor Device
Advanced Semiconductor Packaging	Hydrophobic coating/hermetic seal packages	- Unique hydrophobicity	Fluoropolymers	10+ years	Semiconductor Device

Advanced Semiconductor Packaging	Substrates including buildup/dielectric material	- High-temperature thermal stability (>160 C) - Electrical non-conductivity/low dielectric constant - Surface roughness/adhesion - Low coefficient of thermal expansion	Fluoropolymers	10+ years	Semiconductor Device
Advanced Semiconductor Packaging	MEMS anti-stiction layer/coating	- Low coefficient of friction - Low surface energy - High thermal stability - chemical inertness - mechanical durability, - electrical insulation - low particle generation	Fluoropolymers Fluoroalkyl Silanes	15-20+ years	Semiconductor Device
Advanced Semiconductor Packaging	Die for chiplets				
Advanced Semiconductor Packaging	Release sheet for thermocompression bonding process of semiconductor chips	- Heat-resistant - Releasability - Flexibility - Tensile strength	PTFE	10+ years	Semiconductor Device
Advanced Semiconductor Packaging	Packaging (bump, test, sort & assembly)				Semiconductor Device
MEMS sensor packaging	Passivation gels and coating materials	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 tempeature range (-50..175°C) High thermal stability No signifiant aging over product lifetime (up to 15 years)	Fluoropolymers	10+ years	Semiconductor Device
MEMS sensor packaging	Chemically robust adhesives for chip and package component attach	Unique property: simultaneous high chemical stability angainst polar, unpolar and oxidative agents and acids Low Young's modulus that is constant over very wide operational tempeature range (-50..175°C) High thermal stability No signifiant aging over product lifetime (up to 15 years)	Fluoropolymers	10+ years	Semiconductor Device
MEMS sensor packaging	Soft adhesives for chip attach	Intermediate Young's modulus that is constant over very wide operational tempeature range (-50..175°C) High thermal stability No signifiant aging over product lifetime (up to 15 years)	Fluoropolymers	7+ years	Semiconductor Device
MEMS sensor packaging	Air-permable membranes, protective meshes, and their hydrophobic and oleophobic coatings	Unique property: simultaneous high chemical stability angainst polar, unpolar and oxidative agents and acids Unique property: simultaneous hydrophobicity and oleophobicity High thermal stability up to reflow solder temperature (>260°C)	Fluoropolymers	at least 20+ years	Semiconductor Device

