Factsheet “PFAS and Semiconductors”

Use sector: Electronics and Semiconductor (Annex E.2.11. of the PFAS restriction dossier under REACH)

Product(s):

- Semiconductors are applied fpr instance in devices for automotive, medical products, power management products, MEMS – pumps, sensors, displays.
- They enable the key functionality of applications in automotive: multiple safety functions, communication functions, control functions. In medical applications: devices emit defined electrical stimulation pulses and triggers cell mechanisms in the body. In concrete terms, insulin production can be increased. Further medical application: micropumps for medication.
- Typical customer sectors: Automotive, medical health care products, telecommunication (NetCom), digitization, digitalization, electronic devices, consumer, industrial, aerospace.

Market Information:

- German Electro and Digital Industry – Facts & Figures (August 2023, details see https://www.zvei.org/en/business-cycles-markets/sector-overview):
  - Turnover of €224.5 billion 2022
  - At present 903,700 domestic employees
  - Additional 811,000 employees abroad (2021)
  - Investment, 2021: €7.2 billion (+10.4%)
  - R&D, 2022: €22.1 billion (+3.9%)
- The semiconductor industry is very much connected with actual political strategies such as The European Chip Act | EU Green Deal | Digital Transformation.

Requirements Profile

The advantages of PFAS are the combination of different physical and chemical properties for the individual application, e.g.:

- Very good chemical resistance in aggressive media
- Very high temperature resistance
- UV resistance
- Low friction, minimal wear (particle minimization!)
- Low surface tension
- Inertness
- Purity and chemical compatibility
- Generation of highly reactive species in the plasma that react with silicon oxide to form volatile compounds such as tetrafluoro silane (SiF4)
- Very low refractive index, very low surface energy
- Hydrophobic and oleophobic → barrier in multi-layer systems
- Flame resistance

Identified PFAS Uses

For clarification, the following list contains examples, many more identified uses exist. Almost none of those found in process chemicals, manufacturing equipment and in finished products have identified alternatives.

In the final product

1. Substrates in advanced semiconductor packaging

PFAS substance/substance group:	**PFAS-containing material/component:**
• Fluoropolymers	• Thermal interface materials and film layers
Reason for PFAS Use/ Requirements Profile: • High thermal stability	

2. Die attach adhesive in semiconductor packages

PFAS substance/substance group:	**PFAS-containing material/component:**
• Polytetrafluoroethylene (PTFE)	• Adhesive between silicon and substrate
Reason for PFAS Use/ Requirements Profile: • To prevent adhesive bleed during application and cure that would otherwise result in device failure	

3. Molding compounds in semiconductor packages

PFAS substance/substance group:	**PFAS-containing material/component:**
• Fluoropolymer and fluoropolymer based resins	• Substrate core – PTFE, Substrated dielectric/buildup – Fluoropolymer based resins
Reason for PFAS Use/ Requirements Profile: • High-thermal conductivity; critical properties considered when selecting a molding compound include its glass transition temperature, moisture absorption rate, flexural modulus/strength, coefficient of thermal expansion, thermal conductivity, chemical inert, and adhesion properties.	

4. Passivation gels for MEMS sensors

PFAS substance/substance group:	**PFAS-containing material/component:**
• Fluoropolymer and fluoropolymer based gel	• Gel for sealing the MEMS
Reason for PFAS Use/ Requirements Profile: • Suitable rheological properties, very low hardness, high thermal stability, low permeation, oleophobic and hydrophobic properties, high chemical stability => corrosion prevention, long term stability	

5. Membranes for MEMS sensors

PFAS substance/substance group:	**PFAS-containing material/component:**
• Fluoropolymer	• PTFE-based mebrane for encapsulation of the MEMS
Reason for PFAS Use/ Requirements Profile: • High thermal stability, oleophobic and hydrophobic properties, high chemical stability, highly flexible, long-term stability	

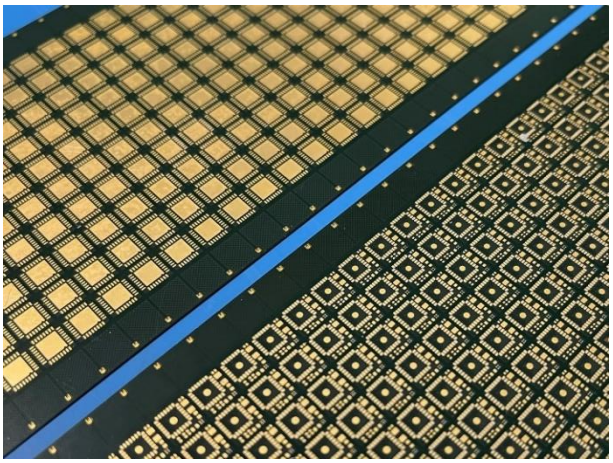
6. Anti-stiction coating for MEMS sensors

PFAS substance/substance group:	**PFAS-containing material/component:**
• Polymeric PFAS	• Surface coating on MEMS
Reason for PFAS Use/ Requirements Profile: • High thermal stability, low surface energy – anti-stiction properties, high wear resistance, long term stability, low particle generation	

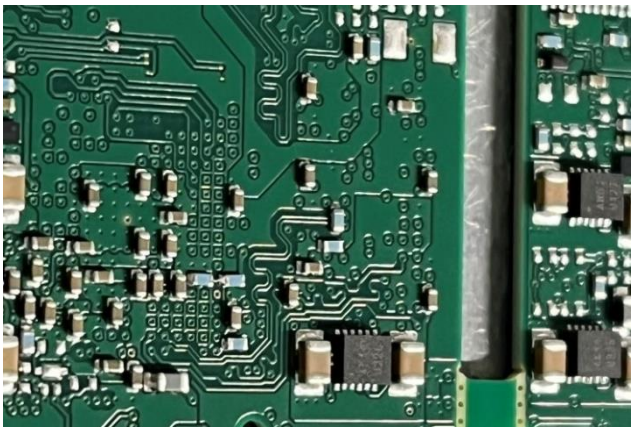
7. Underfill in MEMS sensors for stress reduction

PFAS substance/substance group:	**PFAS-containing material/component:**
• Fluoropolymer • Flourinated Siloxanes and Silicones,	• Underfill which fills the space in flip chip devices
Reason for PFAS Use/ Requirements Profile: • High thermal stability, excellent stress reduction, low warpage, long term stability	

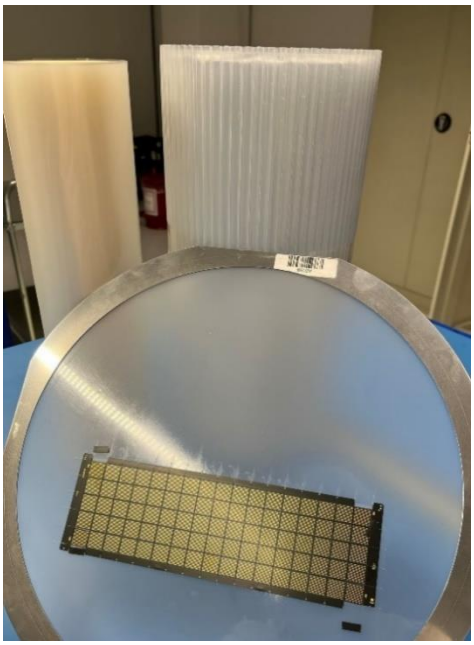
8. Printed Circuit Boards (PCB)

PCB for SMT (Surface Mount Technology) and COB (Chip on Board) processes in industrial/automotive quality for high performance / high longevity applications	 Fig. 1, PCB, ©Swissbit
PFAS substance/substance group: •	**PFAS-containing material/component:** • PCB
Reason for PFAS Use/ Requirements Profile: • High Frequency • Heat resistance • Flame retardancy • Water and oil repellant (Low Water absorption) • Low CTE, low-k	

9. Passive Components

Components in different form factors for placement on PCBs	 Fig. 2, ©Swissbit
PFAS substance/substance group: •	**PFAS-containing material/component:** •
Reason for PFAS Use/ Requirements Profile: • Chemical resistance • High temperature resistance • Constant dielectric properties	

10. Die Attach Film (DAF)

Die Attach Films are used for bonding and stacking silicon dies in various systems in packages	 Fig. 3, ©Swissbit
PFAS substance/substance group: •	**PFAS-containing material/component:** • DAF
Reason for PFAS Use/ Requirements Profile: • Photoactive sensitive • High thermal stability • Chemical resistance • Anti-adhesion or release: mechanical separation of adhesive	

11. ETFE Molding Tape

Molding release tape is used in Semiconductor Molding applications (Transfer/Compression Molding) to protect Tooling from the mold and produce defined surface properties like roughness etc.

PFAS substance/substance group:	**PFAS-containing material/component:**
• ETFE	• Molding Tape
Reason for PFAS Use/ Requirements Profile: • High thermal stability • Chemical resistance • Anti-adhesion or release: mechanical separation of adhesive	

12. Photoresists for image applications
These materials stay in the final device to act as color filters or microlenses for image reconstruction by cameras in cellphones or detection systems for automotive, space or medical applications. There are different versions of color and infrared filters and microlens materials.

PFAS substance/substance group:	**PFAS-containing material/component:**
• PFAS – variety	• Surfactant; additive; photoacid generators
Reason for PFAS Use/ Requirements Profile: • Due to the strong electronegativity of the fluorine atom in the resist complex, the excellent thermal stability, the controlled acid generation under exposure with UV light and the characteristic as surfactant to ensure optimal coating uniformity for ultrathin layers without affecting the refractive index.	

Within Process

1. Etch process

Etch process by using carbon fluorine gases as process gas for structuring silicon, dielectric layers, metal layers, among others, in semiconductor manufacturing.

PFAS substance/substance group:	**PFAS-containing material/component:**
• Poly/Perfluorinated Chemicals (PFC's)	• CF_4, C_2F_6, C_3F_8, C_4F_8, C_5F_8, CHF_3, CH_3F
Reason for PFAS Use/ Requirements Profile: • Patterning and cleaning of silicon dioxide form volatile chemical species with silicon-based materials at a temperature compatible with the surrounding materials and the device structure under fabrication. • Anisotrophic etching capabilities and high reactivity for high-sensitivity inertial sensors, combined with very high mask selectivity, of importance for MEMS products especially applications of through-the-wafer etches like membrane type sensors	

2. Plasma insitu cleaning of deposition chambers
Vapour deposition in-situ cleaning

PFAS substance/substance group:	**PFAS-containing material/component:**
• Poly/Perfluorinated Chemicals (PFC's)	• CF_4, C_2F_6, C_3F_8, C_4F_8, C_5F_8, CHF_3, CH_3F
Reason for PFAS Use/ Requirements Profile: • Plasma insitu cleaning of deposition chambers	

3. Photolithography

In photolithography photoresist is used for structuring of each layer within building a semiconductor device. Photoresist is used to pattern structures to underlying layers. Photoresist is removed at the end of the

processing flow in most cases. In some cases, it is intentionally left in the final product to obtain the desired properties in the product.

PFAS substance/substance group: • PFAS – variety	**PFAS-containing material/component:** • Surfactant; additive; photoacid generators
Reason for PFAS Use/ Requirements Profile: • Due to the strong electronegativity of the fluorine atom in the resist complex, the excellent thermal stability, the controlled acid generation under exposure with UV light and the characteristic as surfactant to ensure optimal coating uniformity for ultrathin layers without affecting the refractive index.	

4. Sintering process of Power modules on a heatsink.

PFAS substance/substance group: • Fluoropolymer	**PFAS-containing material/component:** • PTFE-based release membrane
Reason for PFAS Use/ Requirements Profile: • High thermal stability, low surface energy – anti-stiction properties	

5. Vapour phase soldering

PFAS substance/substance group: • Fluoropolymer	**PFAS-containing material/component:** • PFPE-based liquid
Reason for PFAS Use/ Requirements Profile: • High thermal stability, not flammable, no reactivity at high temperature	

For Equipment and Process Tools

1. Lubricants for equipment

PFAS substance/substance group: • Fluorosilicones, PTFE, PFPE, PCTFE	**PFAS-containing material/component:** • Lubricant for contact points in equipment and in high speed vacuum pumps
Reason for PFAS Use/ Requirements Profile: • Inertness, low gas formation, low viscosity and thermal resistance at operating temperatures as high as 130 °C as well as sealing, lubrication, cooling and corrosion protection	

2. Equipment Chillers

PFAS substance/substance group: • Heat transfer fluids (HFE's, PFCs, HFO's, Fluorinated ketones, PFPE's)	**PFAS-containing material/component:** • Heat transfer fluids for semiconductor equipments
Reason for PFAS Use/ Requirements Profile: • Usable at in a wide range of temperatures (-60 °C to +125 °C) with high precision control; high thermal stability (e.g. set point within ±0.1 °C) • Must simultaneously possess a high boiling point, a low pour point, high thermal conductivity and high resistivity and the ability to maintain the lowest operational set point while avoiding a catastrophic phase shift to a solid form, as the refrigerant must remain in a gaseous or liquid form to remain pumpable and useful for temperature control.	

3. Production infrastructure

Production infrastructure for central pure water and chemical distribution systems, o-rings, gaskets, wafer carrier, roboter arm, baths, valves, fittings.

PFAS substance/substance group:	**PFAS-containing material/component:**
• PTFE, PVDF, PFA, PFE, ETFE, ECTFE, PCTFE, FKM, FFKM, sulfonated TFE	• Piping, o-rings, wafer carrier
Reason for PFAS Use/ Requirements Profile: • Chemical resistance, thermal resistance, purity, flame retardancy, permeation resistant, electrically insulative, low coeffient of friction, bacterial growth resistent	

Substitution

- For most uses of PFAS in semiconductor manufacturing and semiconductor devices there are no drop-in substitutes.

- PFAS materials have unique thermal, chemical, and electrical requirements that have made functionalities in semiconductor electronics possible in the first place, and which many applications today would be hard pressed to imagine without. Furthermore, it is now clear that there are a variety of semiconductor assembly processes and a complex supply chain infrastructure that make investigating the use and replacement of PFAS difficult to fully review. For many uses, no suitable substitutes are known. Consequently, no timeframe can be given for when substitutes will be available. Research on alternatives is first needed to determine their suitability for achieving performance as well as reliability data. This means alternatives will have to be validated if any are found, which will then have to be qualified in the products and their supply chain on a wide range of materials and processes for a device/application, which will tie up a lot of resources and time. (Source: PFAS-Containing Heat Transfer Fluids Used in Semiconductor Manufacturing, and PFAS-Containing Articles Used in Semiconductor Manufacturing - Swissbit)

- “The continued use of per- and polyfluoroalkyl substances (PFAS) by the European semiconductor industry will be essential to achieve these ambitious EU goals as both semiconductor manufacturing and semiconductor products rely on PFAS use at present. Therefore, the semiconductor industry is actively exploring non-PFAS alternatives as part of its commitment to sustainability. While the industry recognizes the importance of transitioning away from PFAS, the current technological limitations do not allow to manufacture semiconductors without their use. Hence, the industrial and societal transformation towards carbon neutrality will not be feasible without PFAS use.” (Source: The European Semiconductor Industry and PFAS, Summary paper, Brussels, 13 July 2023; https://www.eusemiconductors.eu/sites/default/files/20230713_ESIASummaryPaper-PFAS.pdf)

- For most uses of PFAS in semiconductor manufacturing and semiconductor devices a time horizon of more than 12 years seems reasonable, in some cases there will be no substitution.

Safe Use: Prevention and Reduction of Emissions and Exposure

- Emissions can arise during semiconductor manufacturing and in the End-of-Life phase of semiconductor devices. During usage of semiconductor encapsulation system are in place.

- Potential emissions of gaseous PFAS are prevented or at least reduced by Abatement systems.

- Worker´s Protection at the workplace is secured by use of PPE and closed exhaust systems.

Socio-economic Impact

Consequences of the Proposed Restriction

- Conflicts with political goals and strategies (e.g., self-sufficiency/green deal)
  European Chip Act, Green Deal, Digital Transformation

Required Transition Period and/or Derogations

- "Given the lack of alternatives for most applications of PFAS in the semiconductor industry and the long substitution timelines, it is not only imperative to grant the 12-year derogation proposed for the semiconductor manufacturing process and semiconductor products, but also to support research and development that would enable the semiconductor industry to collaborate globally with a view to effectively replace PFAS eventually. It will be crucial to fund and conduct research to where possible identify alternative chemistries that are preferable from an environmental point of view and to develop measurement, recycling, treatment, and abatement technologies to prevent environmental releases for uses to which no alternative can be found. For the strategic independence of the EU, it must be ensured that semiconductors can continue to be manufactured and put on the market in Europe and that stable and sustainable supply chains remain in place." (Source: The European Semiconductor Industry and PFAS, Summary paper, Brussels, 13 July 2023; https://www.eusemiconductors.eu/sites/default/files/20230713_ESIASummaryPaper-PFAS.pdf)

- All exemptions granted should include a review option for further extension if no substitutes are available.

Our sector offers:

Commitment to further investigations (R&D), financial and time support, open communication.

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