PFAS in Passive Electronic Components

Crucial for the (electronic) world to "go round"

Illustration 1: Overview passive electronic components

Product(s):

Passive electronic components:

- consist, for example, of capacitors, inductors/magnets, resistors, thermistors, substrates and interconnects, power, and high-frequency components.
- are indispensable - without them, no electrical and electronic equipment will work.
- protect semiconductors, filter signals, dampen and store electrical energy, measure pressure and temperature, and much more.

They are used in a vast variety of business sectors and applications:

- Disconnection for high-voltage lithium-ion batteries (e. g., in solar inverters, uninterruptible power supply (UPS), electrical vehicles)
- Overvoltage protection of I/O interfaces in wearables, smartphones, notebooks, tablets, smartwatches or even hearing aids
- Motor protection sensor (temperature sensor installed in motor)
- Frequency decoupling of signal and control circuits, filtering power supply lines, electromagnetic compatibility (EMC), industrial and automotive electronics, transponder coils
- Sensors, engine systems & lighting, EMC motors, electrical vehicles, general industrial applications, and photovoltaic inverters
- Sensors in heat pumps for domestic homes, which are an environmentally friendly replacement for gas- or oil-fired heating
- Power supplies, broadband transformers for DSL, common-mode chokes for CAN, Flex Ray and Ethernet, industrial applications (Green Energy and electrical vehicles)
- Power supplies, industrial automation, solar inverters, automotive filter solutions for electric vehicles, variable speed drives for industry/automotive/railway, infrastructure, renewable energies
- Thermal management of electrical vehicles (battery, motor, heating, ventilation, and air condition (HVAC))
- Energy efficiency of home appliances and industrial controls
- Medical devices such as apnea treatment, anesthesia machines, ventilators, CT scanners, X-Ray, etc.),
- Thermal management of electrical vehicles: heat pumps for motor, battery, and cabin cooling/heating
- Navigation and motion control of aircrafts and trains
- Predictive maintenance

Market Information:

Passive components, such as capacitors, resistors, inductors, or filters, are crucial to make the (electronics) world “go round”. There is no semiconductor component and no electronic circuitry which can work properly without passive components.
In 2022 the EMEA market size of passive components was 5.7 bn Euro.
Passive Components are used in the market segments of Telecommunication, Consumer & Home Appliances, Micromobility, Medical & Healthcare, Industrial & Energy and Automotive.

Requirements Profile

Unique combination of properties essential to ensure required specifications of passive electronic components:

- Environment-independent lifetime
- High temperature performance
- Electrical insulation; dielectric strength
- Chemical resistance against aggressive media
- Heat resistance at extreme temperatures and non-flammability
- Resistance against climatic influences (e. g. moisture, wetness, dust)
- Good mechanical properties (e. g. abrasion, surface tension, friction)

Identified PFAS Uses (exemplary)

In the final product

<table>
<tr><td>1. Insulation (coating/encapsulation) of electronic components</td><td>
Illustration 2: Sensors using PFAS in encapsulation
© TDK Electronics AG 2023</td></tr>
<tr><td>PFAS substance/substance group:
• Fluoropolymer</td><td>PFAS-containing material/component:
• encapsulation</td></tr>
<tr><td colspan="2">Reason for PFAS Use/ Requirements Profile:
• High temperature performance (up to 260°C)
• Electrical insulation; dielectric strength
• Chemical resistance against aggressive media
• Resistance against climatic influences (e. g. moisture and wetness)
• Good mechanical properties (e. g. abrasion resistance)</td></tr>
</table>

2. Sealing capacitors against the environment

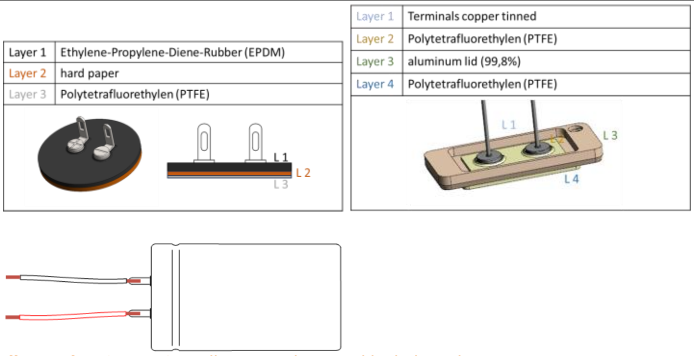


Illustration 3: PFAS sealing capacitors and isolating wires
© ftcap GmbH 2023

PFAS substance/substance group:

- PTFE

PFAS-containing material/component:

- Cover discs
- Cable sheaths

Reason for PFAS Use/ Requirements Profile:

- Temperature stability
- Electrical insulation
- Chemical resistance against aggressive media (for example electrolytes)
- Resistance against climatic influences (e. g. moisture, wetness and dust)
- significant increase in life time due to prevention of molecular electrolyte diffusion through the capacitor lid
- Connection options by soldering high-temperature stable insulated cables to the respective terminals

3. Insulation (insulated wire) of electronic components

Illustration 4: Transformers using PFAS insulated wire
© SUMIDA AG 2023

PFAS substance/substance group:

- ETFE

PFAS-containing material/component:

- encapsulation

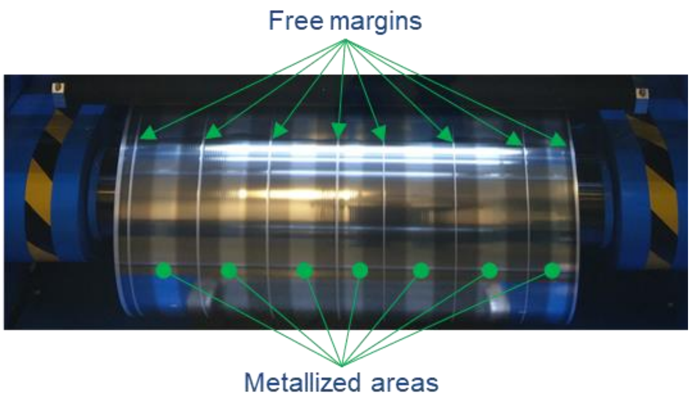
Reason for PFAS Use/ Requirements Profile:

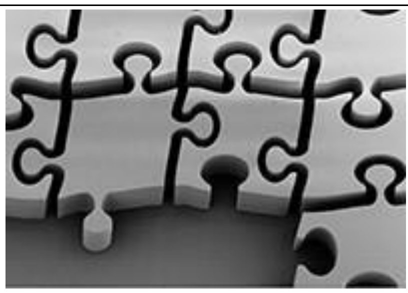
- High temperature performance (up to 260°C)
- Electrical insulation; dielectric strength
- Safety requirements according IEC Standards
- Resistance against climatic influences (e. g. moisture and wetness)
- Good mechanical properties (e. g. winding tension)

Besides those examples, PFAS are used in e.g.

- Wire sheaths, tubes, shrink tubes and membranes to provide electrical insulation and environmental resistance
- Insulators for HF applications, insulating films in capacitor to provide electrical insulation
- Sealing material (O-rings, grommets, glues, …) and lubricants to prevent penetration of liquids and gases
- Hydrophobic coatings
- Encapsulations and protective coatings to guarantee reliable usage in harsh environments
- Electretfoil (Electret with permanent electrical dipole) for microphones
- Fluoroelastomer used as adhesive and passivation gel
- Flame retardants to sustain safety features

In the manufacturing process, production machines and equipment

1. Achieve clearly defined free margins and built-in fuse function in the production of film capacitors	 **Illustration 5**: Metallized foil with free margins © ELECTRONICON Kondensatoren GmbH 2023
PFAS substance/substance group: • PFPE	**PFAS-containing material/component:** • Masking oil
Reason for PFAS Use/ Requirements Profile: • Non-outgassing oil with a low evaporation loss • Water and oil repellent properties • Chemical stability, non-corrosive, electrical insulation and high dielectric strength • Thermal stability, heat resistance at extreme temperatures and non-flammability	

2. Plasma dicing for thin wafers	 **Illustration 6**: Test structure illustrating flexibility of design for plasma dicing https://www.kla.com/advance/innovation/plasma-dicing-101-the-basics
PFAS substance/substance group: • C_3F_8, C_4F_8	**PFAS-containing material/component:** • Process gases
Reason for PFAS Use/ Requirements Profile: • The use of plasma dicing eliminates chipping effects, particle contamination and heat damage. It allows a reduced kerf width and a flexible chip shape. Altogether this technology increases the yield per wafer and reduces the scrap rate.	

As electronic components are also part of electric and electronic equipment used in production, PFAS are used as mentioned above and in addition in e.g.

- Process gas for MEMS RIE, DRIE and TVS diode
- Wafer carriers, sealing rings and handling tools, conveyor belts in powder coating processes where media resistance and scratch prevention are needed
- Heat transfer fluids for production machines but also in quality assurance e.g., for resistance measurements.

⇆Substitution

While some chemistries might offer a similar performance to PFAS for a particular parameter or property, it is the unique combination of properties that sets fluoropolymers apart and makes them vital for the electric components industry.

Alternative solutions are only partially available for some specific applications, for some no alternative is known at all.

- **PTFE, FEP, ETFE, PVDF or PFA:**
  - Exemplary use cases: electrical insulation on electronic components (cable sheath, shrink tubes, etc.)
  - Required characteristics: unique combination of heat resistance, electrical insulation, resistance to chemicals and mechanical properties such as abrasion resistance and flexibility
  - Alternatives: PVC or PP are already in use as wire insulation for low temperature applications, but they cannot be used if high operating temperatures (>105°C) are required. Polymers like PEEK or Polyimide are suitable for high operating temperature but have different mechanical and/or electrical properties compared with fluorinated polymers.

- **FKM or FVMQ:**
  - Exemplary use cases: O-rings and sealings
  - Required characteristics: unique combination of heat resistance, resistance to chemicals and mechanical properties such as flexibility
  - Alternatives: EPDM rubber, Nitrile rubber (NBR) or Hydrogenated NBR as sealings are not suitable in most applications due to their insufficient media resistance.

- **PFPE (example 1):**
  - Exemplary use cases: glue for attaching sensitive MEMS to pressure ports
  - Required characteristics: unique combination of wide application temperature range, resistance to chemicals and mechanical properties such as stability
  - Alternatives: Substitution only partially possible by glass solders with lead (Pb) content. Also, the substance lead (Pb) is affected by several regulations (RoHS, ELV, REACH) and should be avoided as PFAS-replacement for environmental reasons.

- **PFPE (example 2):**
  - Exemplary use cases: process aid in the manufacturing of film capacitors to define unmetallized area
  - Required characteristics: unique combination of electrical parameter and heat resistance
  - Alternatives: Not known.

- **PFPE (example 3):**
  - Exemplary use cases: heat transfer fluid for resistance measurement at NTC thermistors
  - Required characteristics: unique combination of wide application temperature range, resistance to chemicals, dielectric properties
  - Alternatives: Not known for a general replacement. Only in some specific cases, silicone oil can be used. But silicone oil is a banned substance for certain applications (e.g., automotive) and by customers.

- **PTFE tools**
  - Exemplary use cases: jigs and tools in the production of electronic components (e.g., wafer carriers, sealing rings and handling tools)
  - Required characteristics: unique combination of heat resistance, resistance to chemicals (e.g., against process aids) and mechanical properties (such as flexibility and stability) to prevent scratches on e.g., sensitive silicone-wafers
  - Alternatives: Not known.

- **Fluoropolymers and perfluoropolyether in coatings**
  - Exemplary use cases: coating/encapsulation of sensors in harsh environments
  - Required characteristics: unique combination of heat resistance up to 260°C, resistance to chemicals, resistance to moisture and wetness (hydrophobic properties), mechanical properties (stability), dielectric strength at high temperature.

- Alternatives: It is very likely that alternatives do not exist at all (based on experience from extensive R&D efforts).

- **C3F8, C4F8 (and CF4):**
  - Exemplary use cases: used for MEMS Reactive Ion Etching (RIE) and Deep Reactive Ion Etching (DRIE) to passivate the silicon surface
  - Required characteristics: Achievable aspect ratio (ratio of its width to its height)
  - Alternatives: Not known at all. A sufficient aspect ratio is only known to be commercially achievable with fluorinated process gases.

Safe Use: Prevention and Reduction of Emissions and Exposure

During the manufacturing phase, PFAS are handled with care and in accordance with applicable regulations regarding hazardous chemicals, occupational health and safety, as well as emissions to the environment. Whenever critical substances are used during the manufacturing phase, technical, organizational, or personal protective measures are established to protect both people and the environment from contamination. In the electronics industry, lead, hydrofluoric acid, and many other substances are already handled responsibly according to the state of the art. Closed systems, extraction and separation plants are commonplace.

There is no reasonably foreseeable emission of PFAS into the environment during use of electronic components.

The amount of PFAS, which can theoretically be emitted in the End-of-Life treatment, is also very limited. PFAS containing articles in electrical and electronic equipment are collected and dealt with in accordance with applicable regulations, e. g. Waste Framework Directive (WFD) 2008/98/EC, ELV Directive 2000/53/EC and WEEE Directive 2012/19/EU. If the components cannot be repaired or directly reused, they are sent for material or thermal recycling (a recent study by Conversio has shown that at its end-of-life approximately 85% of all fluoropolymers end up in waste-to-energy recovery incinerators). In these processes, the polymeric PFAS contained in our articles are either broken down into their original components or mineralized so that the PFAS properties are lost. Latest studies confirm that fluoropolymers at their end of life when incinerated under representative European municipal incinerators conditions do not generate any measurable levels of PFAS emissions and therefore pose no risk to human health and the environment.

Socio-economic Impact

Consequences of the Proposed Restriction

- Shortage of raw materials and waste of materials
  PFAS-containing products already placed on the EU market can no longer be supplied after the compliance enforcement date.
  Existing stocks of PFAS-containing components and equipment already placed on the market for the first time must be disposed of as hazardous waste, incl. almost all electric and electronic devices for second-hand use. Recycling industry is working with high volume processing, such as shredding, of different types of products with different compositions on a ton scale and not on a single piece scale. Given the extremely low threshold of 25 ppb, even a few materials containing PFAS would degrade extremely large quantities of recycled materials into hazardous waste.
  High amounts of high-quality material as well as still fully functional devices must be treated as hazardous waste instead of being recycled, reused and conserving resources. Instead, high amounts of virgin materials are required to cover the needs with the related environmental impact and the dependance on the sources, which are often outside of the EEA.

- Articles used as/in spare parts
  For telecommunication network infrastructure equipment, industrial printing equipment, industrial HVAC equipment products lifetimes and contracted maintenance periods usually extends to 10 to 15 years in the product's first application. In the case of certain medical equipment, monitoring & control equipment, and test & measurement equipment this extends even to 20 to 25 years. The availability of spare parts is essential to realize the lifetime potential of such products. Additionally, in the case of many B2B products (e.g., for example

medical equipment and monitoring & control equipment) manufacturers are obliged to make lifetime purchases of components and parts.
Especially where fluoropolymers are concerned, the design of PFAS-free spare parts is hampered by the fact that there is no drop-in alternative non-PFAS material.
The consequence of the above is that the lack of a spare part exemption will lead to the inability to repair products and to the premature obsolescence of those products.

- Manufacturing equipment and spare parts for the same
  "Hidden cross-section applications" such as seals, plain bearings, and lubricants in components (incl. spare parts), machines and plants are affected. Not only would it no longer be possible to build new facilities with existing technologies, but it would also be impossible to maintain or repair already existing equipment.

- Relocation of production to non-EU countries
  A consequence would be the shutdown of certain product lines and reduction of operations in the EEA accordingly. Affected production lines and operations would have to be transferred to non-EEA countries if PFAS are required by the manufacturing process (jigs, tools, process fluids, etc.).

- Relocation of invest
  Investments into operations located in the EEA countries where PFAS are required by the process (jigs, tools, process fluids, etc.) would be stopped. These investments are then redirected to facilities outside of the EEA.

- Interruption of supply chain
  Due to the lack of exemptions and derogations usable for the electronic components sector, production and sales would abruptly be interrupted as soon as the ban comes into force. Under the assumption that substitution of PFAS in electronic products is only possible by 2035, the currently proposed restriction would result in several years of disrupted supply.

For the electric components sector, the proposed restriction imposes a blanket ban on a huge number of substances in an undifferentiated manner and without proof of a specific risk. It is threatening production, research and development sites and activities in Europe and their competitiveness worldwide.

Also, the "hidden cross-section applications" such as seals, plain bearings and lubricants in components, machines and plant equipment are affected. Here, too, a ban would have far-reaching consequences for manufacturing sites even if PFASs were not added to the final product, so that the expected overall impact is likely to be much more serious.

PFAS are crucial as an enabling material not only to sustain our European production and business, but also for the ability to achieve the targets of strategic EU policies set in terms of the European Green Deal, European Chips Act, digitalization and decarbonization of European industry as well as the European re-industrial policies.

Burden of Proof and Analytical Aspects

Based on first experience, suppliers are able to confirm that PFAS are not intentionally introduced as additives or used in the manufacturing process for the related products. These substances may only be present as adventitious trace impurities (not intentionally added to the product).

The analytical process is complex due to the practically not limited list of PFAS substances and the extreme low threshold level. For solid PFAS which in addition might be inhomogeneous, it is even more complex. This will only be able to be carried out in a limited number of laboratories, leading not only to additional high costs but also to bottlenecks in testing. At the extremely low threshold, it will not be possible to introduce this as a routine test for production facilities at a reasonable cost.

The requested analysis to certificate PFAS free materials would lead to high costs and a critical number of requests for analysis in the limited number of available laboratories.

Required Transition Period and/or Derogations

Manufacturers of electronic components, working in conjunction with their materials and equipment suppliers, must typically proceed through multiple stages of research, technology integration, prototyping, and manufacturing ramp-up to achieve a product or process change effectively.
Many materials are unique and have specific technical requirements making it extremely challenging to find a viable alternative. For many of the uses of PFAS containing materials, no known alternatives exist. The indicative timelines to develop, qualify, and implement alternatives fall into the following broad categories:

- If a non-PFAS alternative exists and is already commercially available,
  - and no alterations to the infrastructure are necessary and it is demonstrated that the alternative provides adequate performance for a specific application, it typically takes 1 – 2 years to perform the required manufacturing trials, validation according to reliability standards like AEC-Q200 and/or IEC 60068 and successfully implement the alternative into high-volume manufacturing.
    In addition, customer- or application-specific validations of 6 months are common. For further official approvals and certifications that may be necessary, e.g., with UL or VDE, a further 6 to 12 months may be required.
  - If it is necessary to make alterations to manufacturing tools, products, processes, or facilities before the alternative can be introduced successfully, it may take 3 – 10 years or more to successfully implement the alternative.
- For certain applications, it is currently not possible to show that a PFAS-free alternative has the same specific properties. In such cases, it may even be necessary to invent and synthesize new chemicals, and/or develop alternative approaches to component manufacturing providing the required performance. Given that inventing new chemicals is an open-ended process without a specified timeline or guarantee of success, it may take 5 to more than 25 years to find suitable alternatives which then can be implemented.
- It is possible that in some cases it is found that a PFAS-free alternative is not able to provide the necessary chemical function. Where it is not possible to invent a PFAS-free alternative, it may be necessary to abandon the integrated circuit device structure and replace it with an alternative device structure that has the same performance. In some cases, the use of non-PFAS alternatives is prevented by the fundamental laws of chemistry and physics.

German manufacturers of electrical components are calling on the regulatory authorities to preserve the European production, labor, and sales market. Restrict PFAS only in areas where there is a real risk from PFAS and establish exemptions and derogations where PFAS are safe to be used and crucial in critical-to-the-world applications:

1. Introduce a reporting requirement to ensure sufficient data on use along the supply chain.

2. Fully exclude polymeric PFAS from the scope of the upcoming restriction; at least fluoropolymers/-elastomers and perfluoropolyethers.

3. Establish a 13,5-year exemption for the use of PFAS in electronic components and their manufacturing, to be reviewed for renewal at least two years prior to expiration. In this context it is very important to choose a wording that allows PFAS as ingredient within the components as well as the use of PFAS as process aids in the production of electronic components.

4. Establish a reasonable and practicable threshold for intentionally added PFAS levels of 0.1 percent by weight.

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