Question 8:
Other identified uses –
Analysis of alternatives and socio-economic analysis

- Confidential attachments are referenced by file name in square brackets. These files are contained in the zip-file which we upload as confidential attachment.

Executive summary

We would like to provide input on the use of PFAS

- in our *semiconductor/MEMS-based sensors in semiconductor packages* (e.g., pressure and inertial sensors; semiconductor packages are produced by *Advanced Semiconductor Packaging*, the term used in Annex A, table A.49).
  Hint: In the next step of added value these sensors delivered by us will typically be assembled on Printed Circuit Boards (PCBs) for electronic circuits (e.g., ectronic Control Units for vehicles, or in consumer applications like smart watches or wearables).
- as process medium for vapor phase soldering of *Power-Semiconductor modules* used in inverters for battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV)

We strongly appeal to add the following derogation to the proposed directive:

By way of derogation, paragraphs 1 and 2 shall not apply to:

A.) *Adhesives, gels, membranes and coatings used in semiconductor/MEMS-based sensors in semiconductor packages (including raw materials to produce these products)*

B.) Vapor phase soldering of Power-Semiconductor modules to coolers

We provide the following input (the sub-chapters are referenced with the letters a) to g) used in the description of question 6):

Table of Content

0) Introduction and details on proposed derogations

0.1) Definition of Terms

We produce *semiconductor/MEMS-based sensors* (e.g., pressure and inertial sensors), *ASICs and Power-Devices in semiconductor packages*, which are typically assembled on Printed Circuit Boards (PCBs) for electronic circuits (e.g., Electronic Control Units for vehicles, or in consumer applications like smart watches or wearables), as well as *Power-Semiconductor Modules* which are directly assembled on a cooling unit for applications mainly focusing on the electrification of vehicles. Concerning the terms of Annex A, table A.49:

- "Semiconductor Components" include **Chips** manufactured by "Semiconductor Manufacturing Processes". ASIC-, MEMS- and Power-Semiconductor-Chips are covered by this definition.
- "Semiconductor Products" include semiconductor/MEMS-based sensors, ASICs and Power-Semiconductor Devices **in semiconductor packages** e.g., pressure and inertial sensors and all materials contained in them. Example pictures can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].
- "Semiconductors" is an abbreviation for "Semiconductor Products and Components"

In our industry also the term "semiconductor device" is frequently used, this is a synonym for "semiconductor products" in the sense above.

0.2) Related input by industry associations

PFAS-affected semiconductor devices are also listed in

- comment #4449 by the European Semiconductor Industry Association ESIA (RCOM part 18), file "Updated Annex A Table A.49.pdf".
- the white paper "PFAS-Containing Materials Used in Semiconductor Manufacturing Assembly Test Packaging and Substrate Processes" published by the Semiconductor Industry Association SIA under https://www.semiconductors.org/pfas/

0.3) Details on proposed derogations

We strongly appeal to add the following derogation in the proposed directive:

By way of derogation, paragraphs 1 and 2 shall not apply to:

A.) *Adhesives, gels, membranes and coatings used in semiconductor/MEMS-based sensors in semiconductor packages (including raw materials to produce these products)*

B.) Vapor phase soldering of Power-Semiconductor modules to coolers

For clarification of A.) here is a breakdown:

A1.) Passivation gels for media and corrosion robustness in semiconductor/MEMS-based pressure and inertial sensors in semiconductor packages

A2.) Membranes for media robustness in semiconductor/MEMS-based pressure sensors in semiconductor packages

A3.) Adhesives for media robustness or mechanical stress decoupling in semiconductor/MEMS-based pressure, acceleration and inertial sensors in semiconductor packages

A4.) Anti-adhesive coatings for semiconductor microelectromechanical systems (MEMS, micromachines), including raw materials for the synthesis of the coating precursors

As pointed out in the ECHA webinar on 2023-04-05 such type of derogations generally would also include the whole supply chain down to the raw materials to be able to produce the products. We strongly recommend that this should be explicitly stated in a derogation to avoid legal uncertainties.

0.4) Structure of this document

Chapter	Content of chapter	Input for topics defined in chapter 0.3
1.1	Introduces different MEMS-based pressure sensor package concepts and describes the use of PFAS-based **passivation gels** in these housings that are widely used in automotive and consumer electronics applications. In addition, the chapter describes the use of PFAS-based passivation gels in automotive inertial sensors.	A.1
1.2	Explains the use of PFAS-based pressure-transmitting **membranes** and PFAS-based sealing adhesives that are both used in a specific realization of MEMS pressure sensors with an ultra-low g sensitivity that targets smartphones and wearables.	A.2, A.3
1.3	Details the use of PFAS-based **adhesives** in MEMS differential pressure sensors that are used in automotive tank pressure sensing applications.	A.3
1.4	Discusses the use of PFAS-filled **adhesives** in MEMS acceleration and inertial sensors used for automotive applications.	A.3
1.5	Describes the crucial role PFAS-based **anti-adhesion coatings** play for enabling highly sensitive and robust acceleration, yaw rate and inertial MEMS sensors.	A.4
2.1	Explains a PFAS **process medium** essentially needed for vapor phase soldering of Power-Semiconductor modules to coolers of inverters	B

1.) Semiconductor/MEMS-based pressure and inertial sensors in semiconductor packages

1.0) Introduction

Micro**e**lectro**m**echanical **s**ystems (MEMS) are produced with semiconductor processes, using semiconductor materials. A wide range of different MEMS based sensors are available for measuring a multitude of different environmental properties, such as acceleration, yaw rate, or pressure (inertial sensors combine acceleration and yaw rate MEMS). In the construction of these sensors, PFAS play a crucial role in some different functional elements.

It is currently not possible to demonstrate that a non-PFAS alternative can meet the application-specific performance requirements for the kind of MEMS-based sensors and applications described below. In such cases, it may be necessary to discover novel chemicals and/or different ways to create sensors that provide the required performance. Invention is a never-ending process with no set deadline or guarantee of success. It is therefore necessary to (i) outline our specific applications that rely on PFAS materials for specific performance requirements, and (ii) highlight the need of derogations for our specific uses of PFAS materials in MEMS based sensors.

1.1.) Passivation gels in semiconductor/MEMS-based sensors in semiconductor packages

Media-robust MEMS pressure sensor package approaches and material requirements

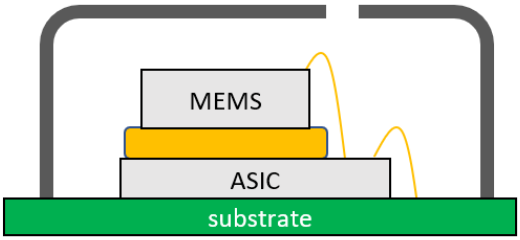
For pressure sensing, the semiconductor device needs a connection to the outer world, which provides sufficient pressure transmission from the application environment to the MEMS sensing element. The simplest solution is adding an opening in the package of the semiconductor sensor that provides pressure equilibrium between the environment and the package interior. Using this approach is only possible in extremely clean environments, free of dust and chemicals, and with low ambient humidity levels, due to the delicate assembly of the pressure sensor.
Pressure sensors in most applications, however, are in close contact to harmful chemicals, dirt, liquids, and dust contained within the application environment (automotive sensors are operated in corrosive environments, e.g., within combustion gases; consumer electronics sensors in wearables and smartphones are exposed to aggressive every-day media such as salt water and sweat or aggressive household cleaning agents). Therefore, pressure sensor packages need a sealing that protects the sensitive semiconductor chips and their electrical interconnects from these harmful media while transmitting the pressure from the application environment to the MEMS sensing element.
Both for automotive and consumer electronics applications, sensor package miniaturization is a key system requirement that enables integration in systems with restricted space (notably highly integrated smartphones and wearables). At the same time, package miniaturization and the associated reduced raw material consumption is beneficial for the environment and reduces the manufacturing cost, enabling both important safety and comfort applications that are nowadays indispensable in our life.

The industry has developed multiple solutions to fulfill these requirements. These different embodiments of MEMS pressure sensor packages are schematically shown in [PS_confidential_BO2023a] and described below:

Open cavity sensor package without media robustness

In [PS_confidential_BO2023a] (a), a MEMS pressure sensor housing without media protection is described:

(a)

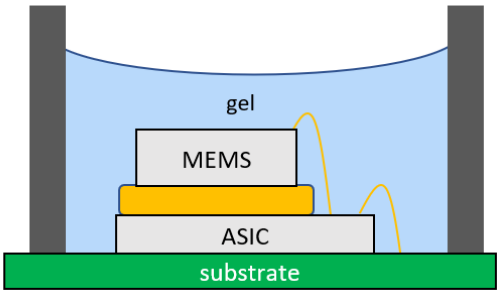


The MEMS and ASIC (application-specific integrated circuit) chips are assembled on a carrier substrate. The chips are electrically connected to each other and to the substrate by bond wires. For mechanical protection of the sensitive chips and bond wires, the substrate is encased by a metal lid. To facilitate pressure access from the external environment to the MEMS chip, one or multiple holes are manufactured in this metal lid. In this approach, liquid and condensing humidity, corrosive media, chemical solvents, and other harmful substances that are present in the application environment can reach the chips as well as the substrate and the electrical interconnections between these elements. During the product's lifetime, these agents can lead to electrical shorts, electro-corrosion, and other material defects which lead to a sensor device failure.

Open cavity sensor package with passivation gel

A package approach that provides high media robustness while maintaining a small sensor housing size is shown in [PS_confidential_BO2023a] (b):

(b)

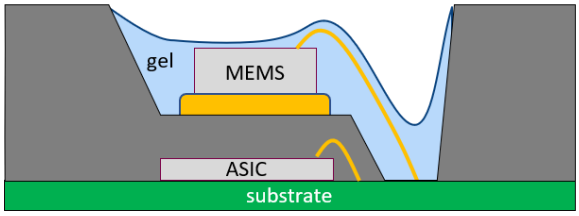


Here, the chip stack is enclosed by a cylindrical metal or plastic lid. The lid is then filled by a passivation gel that completely encapsulates the chips and bond wires. The gel transfers the environmental pressure to the MEMS membrane while protecting the chips and substate against chemical agents that are present in the application environment.

Mold-premold package with passivation gel

A related approach that is widely used in automotive applications is shown in [PS_confidential_BO2023a] (d):

(d)



Here the ASIC is assembled on a substrate and encapsulated by epoxy mold compound. The mold compound housing is structured to provide a cavity in which the MEMS is attached. The electrical connection between the MEMS and ASIC chips is again realized by bond wires and electrical routing in the substrate.
The ASIC is protected against harmful media from the application environment by the mold encasing. It is not possible to protect the MEMS chip in the same way because it needs direct pressure access to the environment. Therefore, the exposed MEMS chip, bond wires, and the exposed substrate area are protected from the application environment by a gel encapsulation.

For this approach, a suitable gel must fulfill multiple requirements:

i. Before curing, the gel must possess suitable rheological properties to enable void-free encasing of the chips in an industrial process that is reproducible and stable.

ii. The gel must possess a very low hardness (low Youngs modulus) that is stable and soft over the full operation temperature range (-40 to +150°C for automotive applications (Automotive Electronics Council, 2014). The hardness must be measurable with corn (¼ corn) penetration according JIS K2220 with 30-80 mm/10. This low hardness is required to avoid transfer of mechanical stress to the MEMS chip that leads to sensor signal drift.

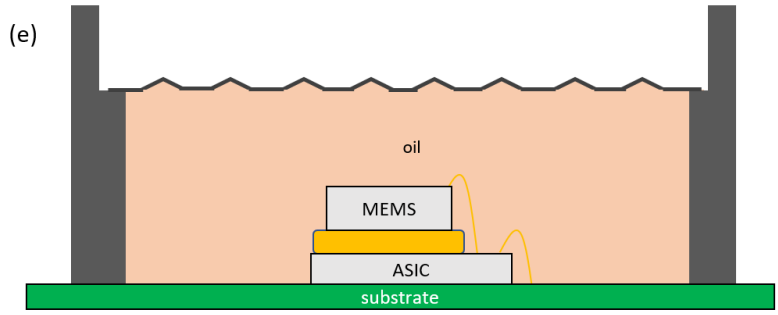
iii. The gel must have suitable chemical robustness to prevent degradation over the full product lifetime by thermal and chemical loads present in the application environment.

iv. The gel must possess sufficient low permeation to prevent diffusion of corrosive ions withing the gel, thereby protecting the MEMS and ASIC chips and the wire bond connections from corrosion and device failure during the product lifetime.

The approach [PS_confidential_BO2023a] (c) can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

Oil buffer package

An approach for a media-robust pressure sensor that makes use of a hermetically sealed housing is shown in [PS_confidential_BO2023a] (e):



Here, again the chip stack is encased by a cylindrical metal housing. In contrast to the other approaches [PS_confidential_BO2023a] (a)-(d), the package interior is completely sealed towards the application environment by a very thin metal membrane that is welded or crimped to the metal housing. Transfer of the pressure from the environment via this metal membrane to the MEMS chip is facilitated by completely filling the sensor housing with a suitable incompressible liquid, e.g., a mineral oil.

While providing unrivalled media robustness, two severe drawbacks are associated with this package concept in comparison with the other approaches:

i. To achieve sufficient mechanical robustness of the steel membrane, a certain minimum membrane thickness must be maintained. This makes the membrane mechanically stiff and reduces the sensitivity of the sensor. This is partially counteracted by introducing an undulation of the membrane to reduce its stiffness and by increasing the membrane diameter to reduce its bending rigidity, resulting in a corresponding increase of the sensor size.

ii. Thermal expansion of the oil inside the sensor package leads to thermomechanical stress on the MEMS membrane and a strong, nonlinear drift of the sensor signal over the operation temperature range.

Due to these limitations, such oil buffer packages are limited to applications with low pressure accuracy requirements that can incorporate the comparatively large sensor housing dimensions.

1.1a.) Annual tonnage, emissions, and type of PFAS

Type of PFAS

In automotive and consumer electronics MEMS pressure sensors, as well as in automotive inertial sensors, PFAS-based gels are quintessential passivation materials that provide the media robustness of the sensor devices required by customers and qualification standards. These media robustness requirements account for environmental aspects in the application that need to be withstand over the full product lifetime (e.g., exposure to vehicle exhaust gases, corrosive media, fuel vapor).

The used PFAS can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].
These gels are not considered process chemicals but remain in the sensors at the mg level. The sensors will be recycled with the vehicle according to European laws (European Parliament and Council, 2000).

We note that all of these gels are polymeric PFAS. They are not declared as hazardous material according to the hazardous substances ordinance (GefStoffV) according to their material safety datasheets (MSDS).

Information on emissions can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

Besides pressure sensors with gel encapsulations, we additionally produce automotive inertial sensors that use the same PFAS passivation gels. Their unit sales volumes and associated gel consumption during production, however, are low compared to the above numbers. They are used in safety-critical applications e.g., Electronic Stability Program (ESP).

1.1b.) Key functionalities provided by PFAS for the relevant use

The affected semiconductor MEMS pressure sensors are used for e.g., break booster, diesel particle filter, manifold air, barometric, airbag, and tank pressure sensor automotive applications [PS_confidential_BO2022]. The gels protect the MEMS chips that necessarily need to be exposed directly to e.g., corrosive or otherwise harmful environments against humidity or particle induced short circuits.

More information from internal research can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

As detailed above, besides PFAS-membrane-based constructions, gel passivation is the only known approach that enables the realization of sufficiently miniaturized sensor housings with high media robustness. While oil-filled pressure sensors in a stainless-steel housing exist as an alternative construction, their bulky size (12mm and above housing diameter even for industry-leading very miniaturized devices, see e.g., (Intel, 2023), prevents their use in consumer electronics applications where sensor package sizes below 4mm are a hard integration requirement. An increase in sensor size beyond this limit is not possible, since the sensors then would physically not fit anymore in the very small wearables (e.g., smart watches) or very thin cellphones.

Due to their unique chemical properties, PFAS-based materials are the only known material class that, as passivation gels, can provide the necessary protection simultaneously against humidity, polar and nonpolar solvents, acids, and oxidative agents. Robustness against combined exposure to these agents is essential e.g., for exhaust gas sensors, but also sensors in consumer products (wearables) and sensors for future "green" hydrogen fuel cell applications.

1.1c.) The number of companies affected

Our competitor analysis clearly shows that the vast majority of our competitors also use PFAS-based gels for pressure sensors [Gel_confidential_BO2023a].

1.1d.) Alternatives

In the chemical sciences, there are no known alternative material classes besides PFAS-based materials that provide sufficiently low hardness which is required for passivation materials in pressure sensors and simultaneous chemical robustness against humidity, organic solvents, and oxidative agents (Osram Opto Semiconductors, 2014), (Merkel, Bondar, Nagai, Freeman, & Pinnau, 2000). For a wide range of applications, no alternative materials are available that can replace PFAS-based gels. This is illustrated in the confidential attachment [Gel_confidential_SE2023] which compares the chemical robustness of PFAS-based gels and non-PFAS passivation gel materials. The exceptionally high media-robustness of PFAS-based gels compared to other passivation gels is further demonstrated by a material characterization study in the confidential attachment [Gel_confidential_BO2004].

Only for a small subset of automotive applications (e.g., barometers for engine control units and pressure sensors in H_2-fuel cells), where only protection against humidity is necessary, phenyl silicones could potentially substitute fluorinated gels. Their viability needs to be confirmed experimentally (see below).

For all applications that require chemical robustness against exhaust gases from internal combustion machines, and/ or fuel gases, no viable alternatives are known. Consumer electronics sensors used in wearables require stability against a large variety of everyday fluids and chemicals that can only be provided by PFAS-based materials [Gel_confidential_SE2019]. Additional information supporting this statement is provided in the confidential attachment [Gel_confidential_BO2023].

1.1e.) Status of R&D processes for finding suitable alternatives

We didn't conduct specific R&D in the past, but started this program in 2023.

1.1f.) Substitution timeline (technically and economically feasible)

Only for the small subset of automotive applications where only protection against humidity is necessary, phenyl silicones could potentially substitute fluorinated gels. For these applications, evaluation of phenyl silicones would involve a new development or formulation adjustment of such substances with possible suppliers, (2 years), evaluation of their processability in sensor assembly mass production (1 year), and for each sensor platform conducting product specific media tests (1 year per platform). If all activities are evaluated positively, each application must be released by a full product validation (1 year). Therefore, even if alternatives are known today, it is expected that it would require at least 13,5 years after EiF to fully qualify a new gel alternative. We expect that not all customer specifications would still be complied with, so that the redefinition of reduced requirements with the customers has also to be considered, potentially adding 1-2 years to the above given duration estimates.

Concerning development costs, derived from our knowledge of technology and product development we assume

- 5 Mio. EUR for gel development and following verification with a pilot product
- 500k EUR per changed product for development and validation

As detailed above, for applications where robustness against organic solvents is required, no known chemical alternatives for PFAS-based gels exist. If there were no permanent derogation, sensors serving such automotive applications would need to be developed from scratch with completely different design concepts (e.g., using an oil-buffer package).
Besides the core sensor housing (1st level package), the 2nd level package for the vehicle assembly would need to be newly designed, because the package size of such sensors would significantly increase.
Because of the broad portfolio we estimate that this transition would not be feasible within 13,5 years after EiF but would take approx. 15-18 years (8-10 years to evaluate new product concepts for the complete affected portfolio and applications, 5-6 years to develop them to series maturity and 2-3 years for qualification incl. OEM level) and would cost 40-50 Mio. EUR development costs for the industry.
This very significant effort for pressure sensors with exclusive use in applications associated with combustion engines must be weighed against the fact that within the EU their sales volume (and the associated PFAS release) will extremely ramp down in in the same timeframe due to the “end of combustion” legislation. On the other hand, for aftermarket of combustion vehicles such sensors would be needed in low quantities for a long time after 2030.

As detailed above, for consumer electronics applications that require media robustness, the oil buffer package is no viable approach due to its too large housing size. In case of no permanent derogation, no alternative approach that could substitute the existing sensor package types is known.

In summary, our use of fluorocarbon-containing gels has no known substitute that can cover all applications, and a rather large effort to find an alternative substance is required before following steps of qualification may be done.

1.1g.) Socio-economic impacts

For automotive pressure sensors related to internal combustion engines, without derogation the stop of product lines of the respective automobiles and complete stop of operations inside the EEA are likely outcomes, as also the vast majority of our competitors use PFAS-containing passivation gels for pressure sensors [Gel_confidential_BO2023]. This would also be valid for trucks, the resale market, and car rental market since this is a new placing on the market. For economic zones not affected by a PFAS ban, the likely outcome is substitution with products of competitors producing outside the EEA.

All our automotive low-pressure sensors make use of PFAS-containing gels. For consumer electronics sensors used in wearables, severe loss of product functionality and reliability and associated sales declines are expected.

Information on revenues and financial impact can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

1.2.) Membranes and Sealing Adhesives in semiconductor/MEMS-based pressure sensors in semiconductor packages

In consumer pressure sensor applications, e.g., in smart phones and especially in wearables, simultaneous media robustness and ultralow g-sensitivity (i.e. low sensor drift when

changing the orientation of the device) are important requirements. To achieve the ultralow g-sensitivity, a protective gel coating of the MEMS cannot be applied (due to the gravity force of the gel on the MEMS). Instead, for these applications we therefore apply the package approach [PS_confidential_BO2023a] (c) that is described in detail in a section of "Media-robust MEMS pressure sensor package approaches and material requirements" in Chapter 1.1).

The present chapter provides detailed information on the specific materials used as vent membranes and side seal adhesives and replacement options by non-PFAS materials.

1.2a.) Annual tonnage, emissions, and type of PFAS

Information on the used PFAS, the used quantity and the emissions can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

1.2b.) Key functionalities provided by PFAS for the relevant use

This information can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

1.2c.) The number of companies affected

We have no information about that.

1.2d.) Alternatives

This information can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

1.2e.) Status of R&D processes for finding suitable alternatives

We don't anticipate any suitable alternative membrane and sealing gel material, and also no different sensor concept (see a).

1.2f.) Substitution timeline (technically and economically feasible)

As we don't anticipate a technically feasible substitution, no reliable timeline can be provided here.

A full assessment of alternative membranes and sealing gels would require ~4 years with unclear outcome. Only in case this would be successful additional 4 years and in sum >5Mio. EUR would be needed for product development and validations based on that.

1.2g.) Socio-economic impacts

We provide information on that in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

1.3.) Adhesives in semiconductor/MEMS-based tank pressure sensors in semiconductor packages

The present chapter describes the use of PFAS-based adhesives in MEMS tank pressure sensors.

The purpose of a tank pressure sensor in automotive applications is the detection of mechanical defects and leaks in the tank and gasoline system that leads to emission of fuel to environment. The basic operation principle is as follows: A differential pressure sensor with two pressure inlets is used to measure the pressure difference between the ambient environment of the car and the inside of the fuel tank. When operating the car, the fuel pump generates a very minor underpressure (on the order of -10mBar) inside the tank. In case of a leakage in the tank system, this underpressure relative to the ambient environment is reduced. By monitoring the pressure difference between the ambient environment and the tank, leaks can therefore be detected by a MEMS differential pressure sensor.

A representative construction of the 2nd and 1st level sensor housings of a typical differential pressure sensor module for tank pressure sensor applications is shown in [PS_confidential_BO2023]. The differential pressure MEMS chip is situated in the mold cavity of the 1st level sensor package. The MEMS is glued to the mold surface by a soft PFAS-based chip adhesive. The construction is such that the pressure inlet from the tank is connected to the MEMS chip backside. The ambient pressure is applied to the MEMS front side.

The adhesive used to attach the MEMS to the mold package need to fulfill two crucial functions:

i. The adhesive must provide a mechanical decoupling of the very sensitive MEMS chip from the sensor package. It therefore must possess a Young's Modulus <10MPa that it stable over the full operational temperature range of the tank pressure system (-40°C – 125°C). The Youngs modulus must not change significantly during the sensor lifetime. Otherwise, the resulting change in stress that acts on the MEMS chip will lead to a pressure error and sensor drifting out of the specification.
ii. The MEMS adhesive is the pressure seal between the tank system (connected to the MEMS chip backside) and the ambient environment to the car. It therefore must possess a very low permeation coefficient for fuel vapor to prevent leakage of fuel components in the environment.

In the USA, the evaporative emission of fuels from vehicles is regulated by EPA standards, see e.g., 40 CFR Part 1060 (EPA, 2023) and 40 CFR part 1051 (EPA, 2023). In the European union, similar regulations apply, see e.g., mission Regulation (EU) 2017/1347 (European Commission, 2017) and further standards referenced within.
To comply with these standards, car manufacturers specify maximum allowed evaporation leakage rates for tank pressure systems. The allowed evaporation rates for our tank pressure sensors that are validated in standardized tests are on the order of 1mg/day.

1.3a.) Annual tonnage, emissions, and type of PFAS

For automotive tank pressure sensor applications, PFAS-based adhesives are quintessential for the MEMS chip die attach. These adhesives are no process chemicals but remain in the sensors at mg level.

The used PFAS can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

This type of PFAS is polymeric PFAS which is not declared as hazardous material according to the hazardous substances ordinance (GefStoffV) according to their material safety datasheets (MSDS).

Information on amount of PFAS used can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

1.3b.) Key functionalities provided by PFAS for the relevant use

Due to the connection of the MEMS backside to the tank (see description above), the adhesive is exposed to fuel vapor and liquid fuel over the full sensor lifetime (>15 years). Fuels are composed of nonpolar solvents (methanol, ethanol, linear and, iso- and cyclo-alkanes). The MEMS chip adhesive must be able to withstand these agents for >15 years

i. without significant degradation of its adhesion to the silicon chip and mold compound (to prevent leakage),

ii. without a significant change of its fuel vapor permeation coefficient (to prevent leakage)

iii. without a significant change of its low Young's modulus (to prevent sensor signal drift and measurement errors) over the full operational temperature range (-40°C – 125°C) [Adh_confidential_BO2007]

iv. without a swelling due to absorption of fuel components (to prevent sensor signal drift and measurement errors)

Due to their unique chemical properties, PFAS-based adhesives are the only known material class that can provide the necessary protection and long-term stability against nonpolar solvents with a sufficiently low permeation coefficient [Gel_confidential_BO2016]. The exceptional stability of PFAS-based materials against such polar solvents are detailed in the study report [Gel_confidential_BO2004]. The unique stability of PFAS-based materials compared to other soft polymers is further documented in the comparison table [Gel_confidential_SE2023]

1.3c.) The number of companies affected

We have no information about that.

1.3d.) Alternatives

In the chemical sciences, there are no known alternative material classes besides PFAS-based adhesive that provide simultaneous chemical robustness against fuels, the required low Shore hardness, and low fuel vapor permeation rates required in tank pressure sensor applications.

No alternative materials are available that can replace PFAS-based chip adhesives for this application.

We note that the oil buffer package [PS_confidential_BO2023a] (e) described in Chapter 1.1 is not a viable construction alternative that could replace our current PFAS-based solution since it does not allow measurement of differential pressure signals.

1.3e.) Status of R&D processes for finding suitable alternatives

As we don't see any suitable alternative adhesive the R&D would need to focus on different sensor concepts to fulfill the (legal) requirements. The comments in 1.1e) also apply here.

1.3f.) Substitution timeline (technically and economically feasible)

As we don't see any suitable alternative adhesive the R&D would need to focus on different sensor concepts. We don't have a timeline yet, but this would mean at least a >10 years project of development and industrialization including all necessary validations without clear outcome. If that would be successful, after that period a process adjustment and re-qualification for the sensors would be necessary. Even a 13.5 year derogation would not be enough time to perform this program with an unpredictable end concerning technical solutions.

1.3g.) Socio-economic impacts

For automotive tank pressure sensors related to internal combustion engines, stop of product lines and associated stop of production inside the EEA are likely outcomes. For vehicles sold and produced inside the EEA, alternative means of tank leakage detection that are not based on pressure sensors would be required. For economic zones not affected by a PFAS ban, the likely outcome is substitution with competitor products from outside the EEA.

Information on revenue can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

Socio-economic impacts are similar to those described in chapter 1.1g.

1.4.) Adhesives in semiconductor/MEMS-based acceleration and inertial sensors in semiconductor packages

1.4a.) Annual tonnage, emissions, and type of PFAS

Soft PFAS-based adhesives are used in one of our automotive MEMS acceleration sensor platforms and in one of our automotive MEMS inertial sensor platforms running in series production in high volume (end of production planned 2030). The adhesives are used to attach the MEMS chip to the carrier substrate of the sensor package.

The adhesives are no process chemical but remain in the sensors at mg level. The sensors are recycled with the vehicle according to European laws (European Parliament and Council, 2000) and so should not be emitted to the environment.

Information on the used PFAS can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

We note that the PFAS-based materials contained in the adhesive are considered as "polymers of low concern" according to the OECD (see e.g., (Korzeniowski & et al., 2022)).

Information on usage and emissions can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

1.4b.) Key functionalities provided by PFAS for the relevant use

A soft PFAS-based adhesive is used as a chip bond adhesive for MEMS sensor chips that are sensitive to mechanical stress in a mold package. The use of PFAS-based fillers with a high volume ratio (ca. 30-50%) leads to an adhesive with a low-to-intermediate Young's modulus that is rather stable over temperature. The inert nature of the PFAS-based materials prevents aging of the fillers over the product lifetime that could lead to a modulus change and a drift in the sensor signal. Such drifts can e.g., lead to violations of safety requirements of Airbag systems.

1.4c.) The number of companies affected

We have no information about that.

1.4d.) Alternatives

Based on supplier feedback, another soft polymer filled adhesive is available as a potential alternative. However, this proposed alternative has a significantly lower modulus compared to the currently used adhesive. In the case of a replacement, the impact of the modulus change of the adhesive on the sensor performance and reliability is unknown.

We note that the proposed potential alternative adhesive contains chemicals that are assumed to be compromising human health (2-Phenoxyethylacrylat, CAS-Nr. 48145-04-6).

1.4e.) Status of R&D processes for finding suitable alternatives

R&D activities to evaluate replacement adhesives have not been started yet.

1.4f.) Substitution timeline (technically and economically feasible)

A full assessment of alternative adhesives would require at least 4 years. In case this would be successful, additional 4 years and in sum >3 Mio. EUR would be needed for product development and validations based on that to implement the adhesive change for the affected sensor platforms.

1.4g.) Socio-economic impacts

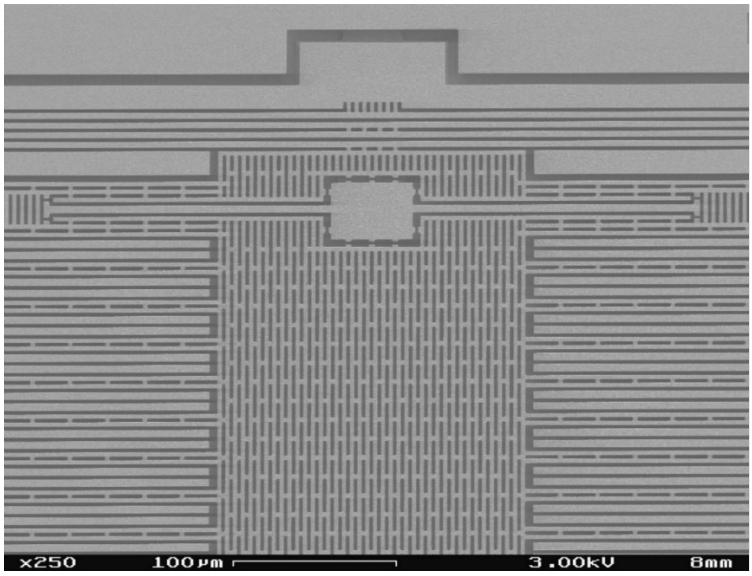
We don't use this adhesive in the newest generation of our acceleration sensors in series production and don't plan it in the upcoming generations (the mechanical stress issue is solved in other ways). That means that even with a "short" derogation we might be forced to heavily invest in the re-development of the older generation which is already ramping down slowly until approximately 2030. In comparison, the amount of fluoropolymer we use per year (also ramping down) is low compared to total PFAS emissions. So, the benefits of the use far outweigh the costs/risks.

In case of a ban without derogation there would not be enough time to evaluate, develop, and release an alternative (see f.)) and also Tier1s and OEMs would not be able to switch to a newer, PFAS-free generation of acceleration sensors in such a short timeframe. That means that delivery would have to be stopped which would affect >10 OEMs.

Information on revenue can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

1.5.) Anti-adhesive coatings for semiconductor microelectromechanical systems (MEMS, micromachines)

Semiconductor MEMS components such as motion sensor chips contain microscopic moving structures made of silicon and other semiconductor related materials. These small movable functional elements in the size of only a few micrometers respond to physical quantities such as acceleration. (Laermer, Schilp, Funk, & Offenberg, 1999). To avoid electrical short-circuits or damage at high external forces / accelerations, stop structures must be embedded at which silicon surfaces are allowed to touch each other. Since all surfaces exert attractive forces on each other and since the spring forces acting against those surface forces have to remain quite small (typical spring forces of acceleration sensors lie in the range of 0.5 to 30 µN depending on the area of application / required sensitivity and component size), the attractive surface forces have to be carefully controlled to ensure that the movable silicon structures never stick together. If the functional elements would stick together, they would no longer be able to move, resulting in a complete failure of the sensor function (Ashurst, Carraro, & Maboudian, 2003).



Electron microscopic image of a MEMS acceleration sensor chip core made of silicon.

Of the two general approaches discussed in fundamental research:

1. physical modification – roughening the surfaces to reduce effective contact area
2. chemical modification – altering the chemical composition of the surfaces (Ashurst, Carraro, & Maboudian, 2003),

only the chemical modification of the surface is suitable for industrial use in commercial mass production because the physical approach conflicts with other requirements for the manufacturing process (e.g., precise control of structural widths on the nm scale) and cannot be controlled as precisely as is required for industrial mass production with high reliability standards.

Therefore, coating the silicon surfaces with a high-performance anti-adhesive coating is the most important measure against stiction failures of MEMS.

1.5a.) Annual tonnage, emissions, and type of PFAS

Fluoroalkyl silanes with a sufficient perfluoroalkyl chain length are currently the only known precursors that enable highly effective and durable/reliable anti-stiction coatings (ASCs) for semiconductor-based MEMS sensors. The material we use is a PFHxA related substance and thus also PFAS. In the following we also refer to the restriction process for PFHxA which has been ongoing before the PFAS restriction process. We cite p. 17 of the final opinion of RAC and SEAC on the Annex XV dossier proposing restrictions on undecafluorohexanoic acid (PFHxA), its salts and related substances (Committee for Risk Assessment and Committee for Socio-economic analysis, 2021).

> *Specifically, it is not clear to SEAC if anti-adhesive coatings for semiconductor microelectromechanical systems (MEMS, micromachines; discussed in comments #860 and 893) would be covered. In case that would not be the case, a separate derogation of those should be considered, as SEAC supports a 12-year derogation also for MEMS. A wording proposal was included in comment #860, reading: "Paragraphs 1 and 2 shall not apply to anti-adhesive coatings for semiconductor microelectromechanical systems (MEMS, micromachines), including raw materials for the synthesis of the coating precursors".*

The amount of material required for semiconductor MEMS production is very small compared to other uses of PFAS (details see confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8]).
This small amount is due to the fact, that an ultra-thin (molecular) layer is sufficient.

We are working on further reductions of material consumption: currently we phase in an optimized process on our existing tools, based on extensive test series, that needs 30% less fluoroalkyl silane per wafer. And we are working on the introduction of another optimized process on a new kind of deposition tools, based on decades of process development by the tool supplier, that needs even 75% less fluoroalkyl silane per wafer to produce the ASC layer.

Workers and service personnel do not get into direct contact with the precursor substance or the coating in the production process.

The coating is hermetically sealed during the production process and does not enter the environment later in the application. And this small amount of PFAS will be recycled with the devices according to the WEEE directive (European Parliament and Council, 2012) or (European Parliament and Council, 2000).

1.5b.) Key functionalities provided by PFAS for the relevant use

As explained above, high-performance anti-adhesive coatings are essential to meet both the performance and reliability requirements of today's sensors and systems. Fluoroalkyl silanes with a sufficient perfluoroalkyl chain length are currently the only known precursors that enable both highly effective and durable/reliable anti-stiction coatings (ASCs) for semiconductor-based MEMS sensors (Mayer, de Boer, Shinn, Clews, & Michalske, 2000), (Psarski, et al., 2018).

The exceptional performance of perfluoroalkyl compounds is related to several unique properties offered by no other molecular film surface coating. These unique properties are directly linked to the chemical nature of the C-F bond, the most import material properties being:

- ultra-low surface free energy, resulting in very low adhesion forces (Janssen, De Palma, Verlaak, Heremans, & Dehaen, 2006) (Srinivasan, Houston, Howe, & Maboudian, 1998), (Zhuang, et al., 2007), (Bhushan, Kasai, Kulik, Barbieri, & Hoffmann, 2005)
- very low polar fraction of surface energy (Zhuang, et al., 2007), (Janssen, De Palma, Verlaak, Heremans, & Dehaen, 2006)
- low friction (Singh, Yoon, Han, & Kong, 2007), (Bhushan, Kasai, Kulik, Barbieri, & Hoffmann, 2005)
- low particle generation during coating process (Ashurst, Carraro, & Maboudian, 2003)
- excellent thermal stability up to more than 420°C, required for the subsequent wafer bonding process (Srinivasan, Houston, Howe, & Maboudian, 1998), (Zhuang, et al., 2007)
- chemical robustness
- high wear resistance (Bhushan, Kasai, Kulik, Barbieri, & Hoffmann, 2005)
- long-term stability [ASC_confidential_BO2023]
- minimum particle generation during use (Singh, Yoon, Han, & Kong, 2007)
- excellent electrical isolation

Because the anti-stiction coating must be applied prior to bonding the MEMS silicon wafer to a protective cap silicon wafer, it must be able to withstand a bonding temperature of more than 420°C without significant degradation and not compromise the mechanical stability and the long-time robustness of the wafer bond (Farrens & Sood). Since an anti-stiction coating applied by vapor phase deposition (VPD) inevitably covers all structures in a MEMS sensor core and since MEMS acceleration sensors and gyroscopes rely on capacitive electrical detection (Vigna, Ferrari, Villa, Lasalandra, & Zerbini, 2022), (Laermer, Schilp, Funk, & Offenberg, 1999), the coating must also have extremely good electrical isolation.

1.5c.) The number of companies affected

We have no information about that.

1.5d.) Alternatives

Due to the very small feature sizes of MEMS devices, only materials that can be deposited very homogeneously in ultra-thin (molecular) layers even in complex micrometer scale structures (narrow channels, undersides, undercuts, ...) are suitable for MEMS surface coatings. A suitable method that meets these requirements as well as the need for a low level of particle generation is gas phase deposition from molecular vapor, preferably carried out with reactive functionalized silanes (Ashurst, Carraro, & Maboudian, 2003), (Europa Patentnr. DE 103 55 038 B4, 2004), (USA Patentnr. US 10900123 B2, 2021).

Reactive silanes not falling under the PFAS definition are not able to fulfill the above listed properties of fluoroalkyl silanes used today in a comparable manner. This is especially the case for the combination of ultra-low surface energy and very high temperature stability (> 420°C, required for chip encapsulation process) (Zhuang, et al., 2007).
Although an excessive length of the perfluoroalkyl chain has some technical disadvantages, a longer perfluoroalkyl chain length results in higher intermolecular interactions, therefore helps the formation of very dense and stable self-assembled monolayers (SAMs) and also better shields the underlying silicon oxide surfaces from each other due to the higher film thickness on the silicon oxide.
As a result, surface free energy (which determines adhesion forces) is known to increase when going from longer to shorter perfluoroalkyl chains (Psarski, et al., 2018).
Accordingly, C10 perfluoroalkyl (e.g., FDTS, containing C8F17- as a functional group) and C8 perfluoroalkyl (e.g. FOTS, containing C6F13- as a functional group) have been regarded as the most suitable materials for anti-stiction / low-friction and hydrophobic MEMS coatings in the scientific community for at least the last 25 years (Mayer, de Boer, Shinn, Clews, & Michalske, 2000) (Ashurst, Carraro, & Maboudian, 2003), (Zhuang, et al., 2007), (USA Patentnr. US 7443001 B2, 2008) (Psarski, et al., 2018).

Increased failure probability due to poorer anti-stiction properties of a coating material cannot be tolerated neither for automotive applications nor for consumer applications (or most other applications). However, increased failure probabilities could then only be prevented by changes in the chip design that result in poorer product performance in decisive functional parameters (e.g., sensitivity) and/or significantly larger chips.
A deterioration of the functional sensor performance is generally not acceptable for the customers and results in corresponding sales losses.
Significant increases in chip size would not only increase production costs, but also lead to increased material and energy consumption, as more silicon wafers would have to be

manufactured, larger chips would inevitably require larger sensor packages with more plastic, etc.
In addition, an enlargement of the sensors, especially in the application for mobile devices but also for various other applications, would not be accepted by the customers due to the existing size restrictions for electronic components.

Apart from the question of anti-stiction performance, no reliable data on the long-term stability (including but not limited to mechanical wear and particle formation) of possible alternative materials are available so far.
Up to now there is no suitable alternative described in literature or known from our research (cf. 1.5e.)

1.5e.) Status of R&D processes for finding suitable alternatives

More than 20 years ago we decided to use perfluoroalkyl silanes as an anti-stiction coating from a wide range of possible materials. Triggered by various reasons including the increasing worldwide concerns regarding PFCs and PFAS, we have intensified our efforts on identifying and evaluating alternative ASC materials in 2019, paying special attention to PFAS-free materials. However, our studies and experimental results clearly demonstrate that fluoroalkyl silanes are still unsurpassed in their technical performance and can probably never be replaced by PFAS-free materials without severe debasements of device performance and required chip sizes [ASC_confidential_BO2023].
We are committed to finding alternatives and have recently again increased our efforts. To secure progress in the search for new materials, a new deposition tool specifically dedicated to the application of various test coatings on MEMS wafers was purchased and set up in the beginning of 2023 at our central research department.

Details are presented in the confidential attachment [ASC_confidential_BO2023].

1.5f.) Substitution timeline (technically and economically feasible)

Due to the complexity and interdependence of physical and chemical influences in MEMS systems and the associated manufacturing process as well as the extensive reliability testing and release processes required especially for automotive applications, the start of production with a PFAS-free anti-stiction coating of the sensor product portfolio under development would require at least 7 years from today, even under favorable circumstances. For products currently already being in series production or in development, a changeover would take even more time, since in the very probable case that no fully adequate replacement with the same performance can be found, product designs and/or specifications would have to be adapted or sensor components / products would have to be replaced by new components or products. Here as well, extensive qualifications and approval procedures in both automotive and consumer applications would be required, including testing on the end product (e.g., an automobile or mobile phone), involving customers. A time frame of 13.5 years from entry into force should already be considered as critical here.

1.5g.) Socio-economic impacts

Information on production quantities and market can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

These sensors are indispensable sensing organs for safety and comfort systems in vehicles (airbag, vehicle stability control, autonomous driving) and in countless consumer applications (smartphones, tablets, wearables) and they enable system sales of more than US$ 240bn in the value chain (Bundesministerium für Bildung und Forschung, 2020), Page 5.

Worldwide such systems save lives, make traffic safer, reduce energy consumption and enable the comfort we are accustomed to in all situations of life - but this can only be guaranteed with small, smart and affordable sensors that work fault-free and reliable.

A complete ban of fluoroalkyl silanes in the EU within the framework of a broad PFAS restriction would make MEMS acceleration sensors and IMUs (Inertial Measurement Units) from European production considerably more expensive, larger and poorer in quality in the future.
A complete ban would endanger the competitiveness of the European MEMS, system, and automotive industries in important key technologies. It would once again expose the global supply chains to considerable risks, this time especially with regard to the availability of acceleration sensors and IMUs. It would risk the loss of technology leadership and market shares due to low product quality and associated financial losses.

Considering the negative impact on industry and consumers, the extremely low annual demand for fluoroalkyl silanes used for the production of MEMS components and the minimal risk of human exposure, we strongly recommend including a derogation for fluoroalkyl silanes for semiconductor MEMS production.

1.6.) Summary of substitution challenges

PFAS substances provide significant benefits throughout their supply chain. They feature unparalleled chemical and thermal resistance, as well as exceptional electrical performance. Their stability, combined with these features, corresponds to unique, durable, and long-lasting performance in applications, contributing to product life extension. Furthermore, the longevity of fluoropolymers makes them ideal materials for the development of innovative technologies.

Alternative material evaluations have indicated that, when available, they frequently fail to match the critical performance characteristics of PFAS substances and lack the range of properties required for electronic and semiconductor applications, such as high chemical and thermal resistance. The proposed restriction will result in increased costs and reduced productivity, both in the performance of the product applications and in their use, creating an additional burden on customers, potentially limiting their choices, and reducing the incentives for technological advancement.

Products produced with alternatives having lower durability and reliability would also result in higher maintenance and replacement frequency and eventually increased waste.

We, as experts, are concerned that regulations aimed at restricting PFAS, regardless of which group it belongs to, would result in "regrettable substitutions," in which a regulated chemical is substituted with an unregulated compound that may be equally or even more harmful

(Blum, Balan, Scheringer, & et al., 2015). We would like to emphasize the significance and necessity of a novel regulatory approach—regulating PFAS compounds as a class. A PFAS restriction proposal that differentiates between the various PFAS groups based on their risk profiles and properties, as well as one that recognizes the safe use of fluoropolymers and their importance for applications, should result in an exemption from any regulatory action under the proposed PFAS restriction (Balan, Mathrani, Guo, & Algazi, 2021).

Assuming that alternatives are already available, which is not the case, chip supply disruptions will undoubtably occur due to the PFAS restriction. The chip supply chain has already experienced difficulties in recent years resulting in shortages across numerous economic sectors and major societal effects. Supply disruptions have threatened the semiconductor industries, not only in the automotive sector but also in the consumer electronics sector. The recent supply chain shortage has highlighted the limited availability of skilled engineers in the semiconductor industry due to the complexity of its products. This limited availability will only be exacerbated by the fact that due to PFAS restriction proposal engineers will be diverted from their typical functions of R&D to focusing on innovations of PFAS-free products in an unfeasible amount of time.

While the proposed 12-year derogation alleviates some of the uncertainty about the amount of effort required to identify PFAS-free alternatives, and our company is diligently working to identify PFAS in products and prepare to provide information to ECHA on the use of PFAS-related substances in the semiconductor industry, the fact remains that 12 years is an insufficient period to completely phase-out PFAS in the semiconductor manufacturing process. According to our evaluation, a derogation period of at least 15 to 20 years is more reasonable as an adequate compliance time frame.

2.) Power-Semiconductor modules

2.1.) Process medium in vapor phase soldering (of Power-Semiconductor Modules)

Within the electrified powertrain of battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV), the so-called power module switches the DC current from the battery to generate the AC current for the electrified motor. By each switching step, heat is generated within the power module. For this reason, the power modules need an active cooling – a connection to the cooling water circulation within the BEV or PHEV.

In order to optimize the efficiency of the whole system, an optimization of the thermal path from the power module towards the cooling water of the car is mandatory. Within our products we realize this by a metal connection of the Power-Semiconductor modules on a cooler - by directly soldering them on a cooler (a picture can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8]).

The cooler together with the power modules is mounted into a housing. By adding other electronic components for the functionality and the safety of the final product, the so-called power inverter is assembled. The Inverter is beside the battery and the e-motor the main component of the electrified power train.

The Power-Semiconductor modules are used for the inverter of electric drive applications. During operation and because of power loss heat is generated in the application. Therefore

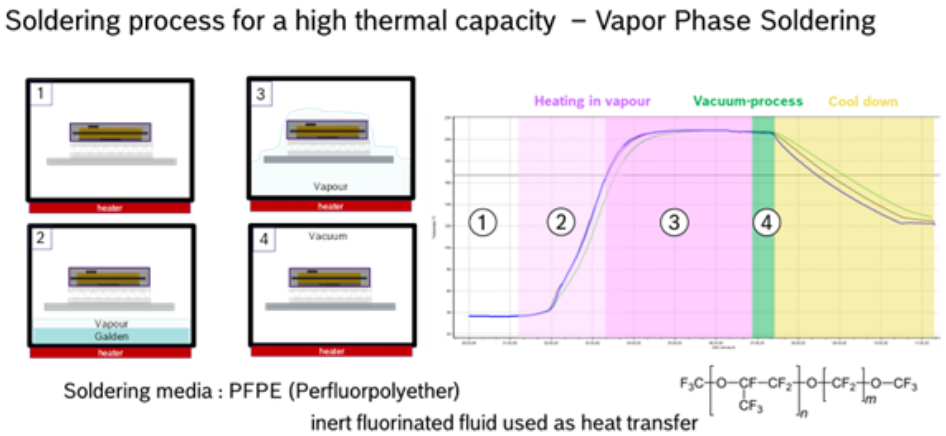
- The high-power semiconductor on a power substrate needs to be thermally well connected to a specific heat sink for the use in a related inverter ECU.
- To ensure a sufficient heat dissipation the heat sink required for this is therefore large.
- The connection between power module and heatsink is performed via soldering. Because of the mentioned required size of the heat sink a soldering process e.g., with reflow is not feasible.
- Intensive investigation had shown that this specific use case could only be soldered with the vapor phase soldering method.

Soldering three power modules on such a high thermal mass in reasonable time, with no overheating, energy efficient, in high volumes and with a high process robustness (low number of failures) is a challenge.

Vapor phase soldering, also known as condensation soldering, uses the enthalpy of condensation released during the phase change of a heat transfer medium from the gaseous to the liquid state to heat the assembly.

In the sketch below, the working principle and the subsequent process steps are shown:

1. The product (three power modules + solder preform + cooler) is introduced into the process chamber. The bottom and the sidewalls of the process chamber are heated.
2. The process media, the PFPE (Perfluoropolyether) is injected into the process chamber, in a liquid form. By heating up, the PFPE evaporates within the process chamber.
3. The vapor condensates on surfaces which are colder than the boiling point of the media. By condensation on the product, heat is transferred to the parts and the solder can melt, until the entire assembly has reached the temperature of the vapor. The temperature which is generated during the process is largely identical to the boiling point of the used liquid, so that an optimal protective gas atmosphere is formed. Oxidation of the soldered parts is widely excluded.
4. When the solder is melted, there is a vacuum step to reduce voids (due to outgassing) within the soldering area. After the vacuum step, the product is transferred into a cooling chamber. Cooling traps within the equipment ensure that the process media is condensating and recovered for the next soldering run and as low as possible PFPE is emitted to the environment.
5. For some products there is a cleaning step after the soldering on the cooler. The cleaning step is needed to get rid of flux residuals from the soldering process. The flux cleaning is a wet chemical cleaning process with some dedicated flux cleaning media. Residuals of the soldering media PFPE are not chemically solvable. But due to the mechanical abrasion of spray cleaning or rinsing some of the PFPE is removed from the surface. Afterwards only traces of the material can be detected. The cleaning media and the water used for rinsing are collected, treated and disposed of as chemical waste.



For the assembly of our products, we use a Pb-free solder, with a melting Temperature of ~220°C. For a robust processing, a soldering media is needed, which has a boiling point of ~240°C. One of the unique properties of the PFPE is, that the boiling temperature can be tuned, by adjusting the chain length of the polymer used.

For the manufacturing of electronic devices in high volume, also other positive characteristics of the vapor phase soldering process are very important:

- fast and largely independent of the geometry and mass of the to be soldered parts
- no cold zones e.g., in the shadow of large components.
- due to the process related max temperature and the uniform heating, no overheating of the components.
- allows soldering with low activated fluxes, as little to no oxidation takes place during the completely oxygen-free soldering process.
- **process is about 10 times more energy-efficient than conventional convective manufacturing processes**. Therefore, less CO_2 footprint.
- **Enable soldering of parts with high thermal capacity** (e.g., heatsink to semiconductor)
- The process liquid is kept in a closed circuit of the equipment (99,997% of the used PFPE stays in the system and is reused in the following soldering steps)

2.1a.) Annual tonnage, emissions, and type of PFAS

Vapor phase soldering enables a high heat transfer in reasonable time. PFPE (Perfluoropolyether) is used in vapor phase soldering equipment as process media (also known as Galden which is a trademark. See also 1.1.6a in question 7). These liquid PFAS-polymers are composed of carbon, fluorine, and oxygen. Perfluoropolyether's are among the most stable bonds in carbon chemistry. The fluorine atoms on the outside shield the carbon chain. They thus protect the more sensitive C-C bonds from chemical and thermal effects. They have excellent heat transfer coefficients as well as good dielectric properties.

Amount of PFPE used during the soldering process / yearly tonnage

A small amount of the media will be consumed during the soldering process, e.g., during the vacuum step (see point 4 in the sketch above) in the soldering chamber. Within the equipment, cooling traps are used to regain the soldering media from the atmosphere, which is pumped from the process chamber. But not all PFPE can be trapped inside the equipment. A compensation and refilling of the soldering media are needed.

Information on quantities used emissions can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

We are already in discussion with the equipment supplier to either reduce the amount of process media, which is consumed during production, or to trap or treat the remaining PFPE during the process.
The goal is to reduce the losses of PFPE as much as possible.

Neglectable amount of PFAS remaining on the product

The process medium used for the vapor phase soldering containing PFAS is circulated within the process chambers of the soldering equipment.
Before the soldered modules leave the machines, the condensed medium on the power module is largely dried in a specific section of the machine and returned to the reservoir. However, a small amount remains on the soldered modules and cooler. Some of the products have a flux cleaning process step in which also PFPE is mechanically removed during the cleaning or rinsing process. The remaining soldering media PFPE can only be detected using high resolution surface analysis techniques like

XPS (X-ray photoelectron spectroscopy),
TOF-SIMS (Time-of-flight Secondary-ion mass spectrometry) or
LIMS (laser ionization mass spectrometer)

A quantitative measurement of the remaining media on the surface of the product is very difficult. The Aluminum (Al) based cooler, which we typically use for our products consists of Aluminum plates, which are cut, formed, and brazed. For the metal brazing of Al based plates typically a fluorine (F) containing solder/flux system is used. The F is still detectable within the final product. In a high-resolution quantitative analysis, it is almost impossible to separate the detected F signal from the brazing with a F signal from the soldering media PFPE.

The only measurement of PFPE which we can use for a quantitative calculation of the remaining amount of PFPE on the product is a LIMS (laser ionization mass spectrometer) measurement.
During the LIMS measurement a focused laser beam is pulsed on the sample. The laser beam generates ions from the surface, which are analyzed with time-of-flight mass spectrometry to identify the composition, concentration, and in the case of organic molecules structural information's also. By knowing the measured area, the volume of the equipment, the pressure drops during the measurement and the molar mass of the molecules, one can calculate the mass of the material evaporated by the laser.

An estimate for the extremely low quantity remaining on the top- and bottom-surface of the cooler/product after the processing can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

Due to low amounts of residues on the parts to be soldered, there is a very low to nearly zero emission into the environment in the use-phase and end of live-phase with our products.

2.1b.) Key functionalities provided by PFAS for the relevant use

Vapor phase soldering is used, when electrical components are soldered to the high thermal mass of the heat sink (cooler). The heat sink can be copper or aluminum-based structures and can have a mass of typical 0,4 – 1,0 kg. The state-of-the-art soldering for these applications is the vapor phase soldering.

A general description of the soldering process can be found in (Illés, Géczy, Medgyes, & Harsányi, 2019).

The fluids required for vapor phase soldering are specially developed for the requirements of this process. They are characterized by the highest thermal stability, show no deterioration over time, have unmatched chemical and solvent resistance: They are chemically inert, non-corrosive, nontoxic, nonflammable and electrically non-conductive fluids, which are needed for heat transfer of the electronic parts to be soldered.

Another unique characteristic of PFPE is the required boiling point of ~ 240°C, which is required for the soldering process.

2.1c.) The number of companies affected

We do not know the exact number. Vapor phase soldering is not only used for Power-Semiconductors.

There are several vapor phase equipment manufacturers, e.g.
Rehm Thermal Systems GmbH
ASSCON Systemtechnik-Elektronik GmbH
IBL-Löttechnik GmbH

2.1d.) Alternatives

To our knowledge **no suitable alternative** material is available. Details see chapter 2.1e.

2.1e.) Status of R&D processes for finding suitable alternatives

The vapor phase soldering is required for products with a high thermal mass, which are currently in development and ramp up for automotive applications within BEV or PHEV. Alternative soldering methods were investigated in advance of the product development. However, due to the very high thermal mass of the heat sink, vapor phase soldering was

chosen as the most energy effective and only target-oriented method. The process was especially newly adopted/developed for these applications. An alternative is currently also on theoretical point of view to our knowledge not available.

We performed research on market and academic level to evaluate alternative soldering media which have a boiling point of 240°C and the required properties like PFPE.

We contacted the three main soldering equipment manufacturers, to ask for alternative soldering media:

Rehm Thermal Systems GmbH
ASSCON Systemtechnik-Elektronik GmbH
IBL-Löttechnik GmbH

We also have statements from one of the major soldering media (Trademark Galden) supplier SOLVAY GmbH and from the company 3M (*EHS Challenges and Analytical Methodologies session at the SEMI Technical Symposium: Innovations in Semiconductor Manufacturing during SEMICON® West, July 16, 2001) regarding possible alternative media.

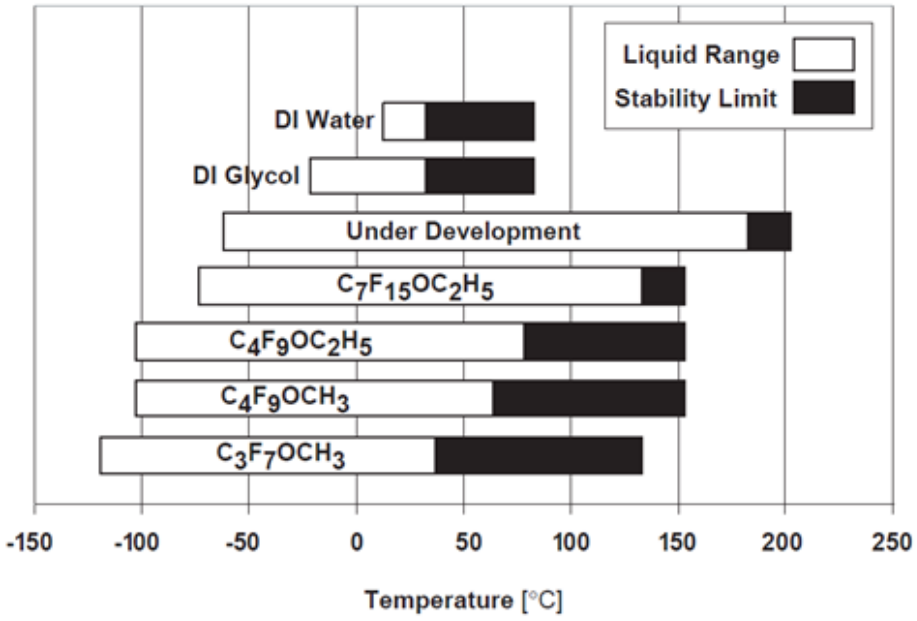


Table of soldering Media and their boiling point *.

From all the feedback we can conclude that in the needed temperature range, (we need for vapor phase soldering 240°C) there is no alternative media known, which consists of a different material class and has no other limits / restrictions.

→ To our knowledge **no suitable alternative** material is available.

The only known media, which were identified, and which have the same functionality, consists of Perfluorocarbon (PFC)- compositions, or chlorofluorocarbon (CFC). They are of

the same chemical family of PFAS, or also very harmful to the environment like CFC. So, they cannot be considered as an alternative soldering media.

2.1f.) Substitution timeline (technically and economically feasible)

Typical timeline for the implementation of a new technology and process, new equipment in case alternatives would be available for these kinds of applications can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

The base requirement for this described timeline is a positive scouting of potential alternatives.
As mentioned above especially the **positive scouting of alternatives is currently not available and not foreseeable.**

2.1g.) Socio-economic impacts

The vapor phase soldering will be the standard assembly technology of new products (semiconductor power modules) for electric drive applications currently in ramp up.
The ramp up includes the invest and build of the machines and related production lines.

Effect of no derogation:

- Actual products and products currently under development could not be assembled.
- Scrap of newly installed machines and process equipment

A EiF without an exemption or derogation of min 13,5 years would therefore directly lead to a stop or relocation of the production, redesigning and qualification of material and products. In addition, scrap and replacement of manufacturing equipment.

As shown at chap. 2.1e a redesign with related process development requires an estimated timeline of 8 – 13 years (**if solution is available**).

Without a derogation it would not be possible to manufacture the original designed power modules for electric car drive in EU. Supply contracts could therefore not be fulfilled. In final consequence a stop of car production at OEMs is highly to be expected as a relocation outside EU including all qualifications is not possible within 18 months transisition time. Contract penalty in the region of 10s million EUR , loss of reputation and loss of customers would be the consequence. As a subsequence job loss in the European Union will also appear.

As PFPE has

- no entries and limitations on e.g., the safety data sheet
- no legal related limitations outside the EU

companies outside of the EU are not covered by this EU restriction.
As PFPE is not intentionally remaining on the product, companies outside of EU would therefore be able to use the most efficient manufacturing processes for these kinds of power modules.
Information on invests and revenues can be found in the confidential attachment [02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8].

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List of confidential attachments

[02_Confidential_PFAS_Feedback_to_ECHA__Att_Question_8]
[Adh_confidential_BO2007]
[ASC_confidential_BO2023]
[Gel_confidential_BO2004]
[Gel_confidential_BO2016]
[Gel_confidential_BO2023]
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