STUDY ON ALTERNATIVES TO FLUOROPOLYMERS

FOR PUMPS AND FLOWMETERS FOR ULTRAPURE FLUID HANDLING IN MICROELECTRONICS PRODUCTION

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PURPOSE: This report gives a summary of the testing and study done on alternatives to fluoropolymers used in Levitronix pumps and flowmeters, which are used in ultrapure fluid handling circuits of equipment for chemical delivery and wet processing in Microelectronics (Semiconductor) manufacturing.

SCOPE: Pumps and flowmeters for ultra-pure fluid handling.

Contents:

1 Introduction and Background

1.1 Levitronix Products and Applications

With more than 100,000 units Levitronix® is the worldwide leader in magnetically levitated bearingless motor technology, specialized in supplying process equipment for Microelectronics (Semiconductor), Pharmaceutical and Bioprocessing. The products range from pump systems, mixers and blowers to ultrasonic flow sensors and viscometers. Levitronix products are enabler components for example for bioprocessing drugs like the corona vaccines and for manufacturing of high-tech chips for example for electric car vehicles and other devices for renewable energies.

The technology of the bearingless motor permits a motor and a magnetic bearing to be combined into a single unit (see *Table 1*) with products that achieve maximum reliability, long life, and the ability to process in the harshest environments like for example pumping of aggressive chemicals for Semiconductor production.

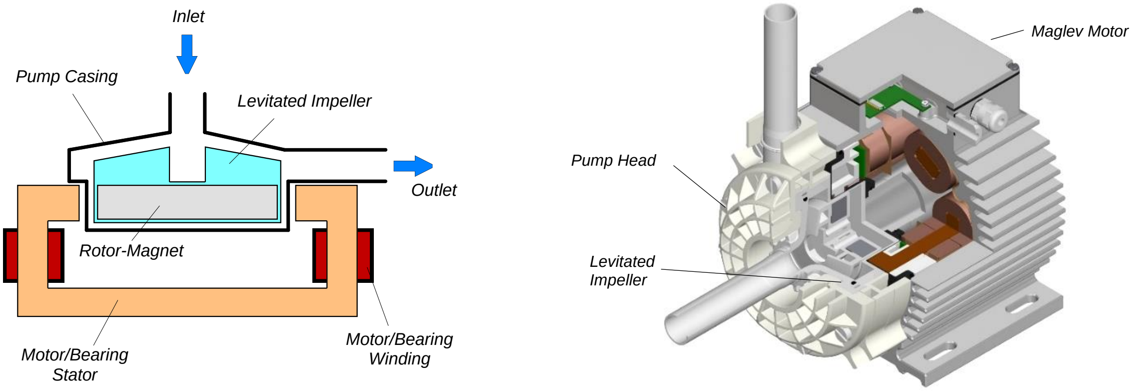


Table 1: Bearingless motor technology for ultrapure pumps in Semiconductor production

As a complementary product Levitronix is also producing non-invasive ultrapure ultrasonic flow sensors for Bioprocessing and Semiconductor manufacturing to enable full flow handling solutions.

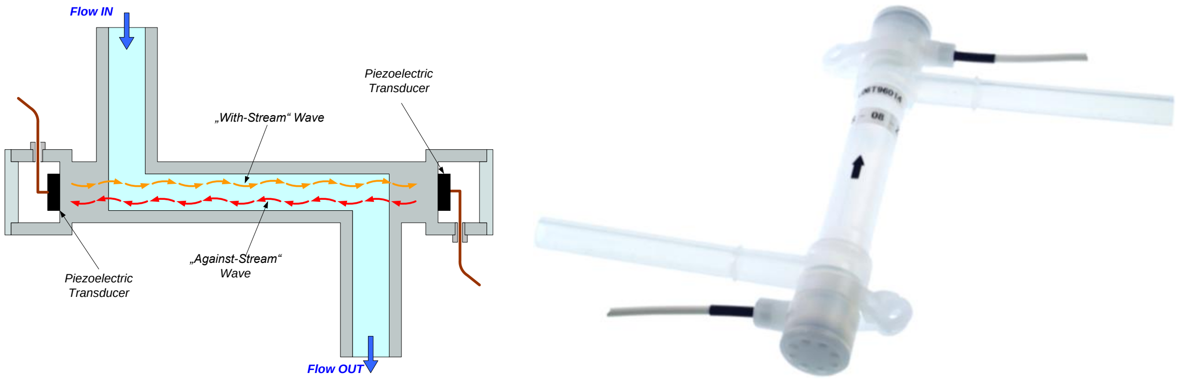


Table 2: Ultrasonic flow sensor technology for ultra-pure fluid handling

Levitronix® has been a key participant in the Microelectronics industry for over 20 years, providing ultrapure pump systems, mixers, and flow sensors that enable chip manufacturers globally to process smallest wafer structures. Levitronix® is the market leader in several applications, including single-wafer processing (cleaning and etching), CMP slurry delivery, or plating.

To meet the high purity demand in semiconductor manufacturing, wafer cleaning has become one of the most critical operations. Lowest particle contamination is of major importance to obtain a high yield and high efficiency of the usage of precious materials (rare earth) and aggressive chemicals. In comparison to Levitronix® pumps, pneumatic pumps wear out due to friction of check valves, bellows, diaphragms, and other components. Wear can cause particle shedding that causes wafer defectivity. Furthermore, the pulsating flow of pneumatic pumps may reduce filters performance due to increased particle release. Levitronix® pump systems are designed for demanding wet cleaning applications where ultrapure and pulsation-free processing ensure the highest yield.

1.2 Ultrapure Fluid Handling in Semiconductor Production

As mega-trends, such as artificial intelligence and robotics, smart homes and smart cars, smart medical devices, and the Internet of Things evolve to meet growing needs for speed, scale, and reliability, they force integrated circuit (IC) manufacturers to increase processor power efficiency and memory size. At the same time, device manufacturers striving to meet new worldwide consumer and business data demands at lower costs and lower waste of precious materials face significant challenges in terms of process control, yield, and economics.

Table 1 illustrates the history and the future demand to reduce the smallest wafer structures. 5nm small structures already became reality and 1 nm structures are under investigation. For the purity demand of fluid handling circuits this means that unpurities in the atomic size range must be considered during Microelectronics production.

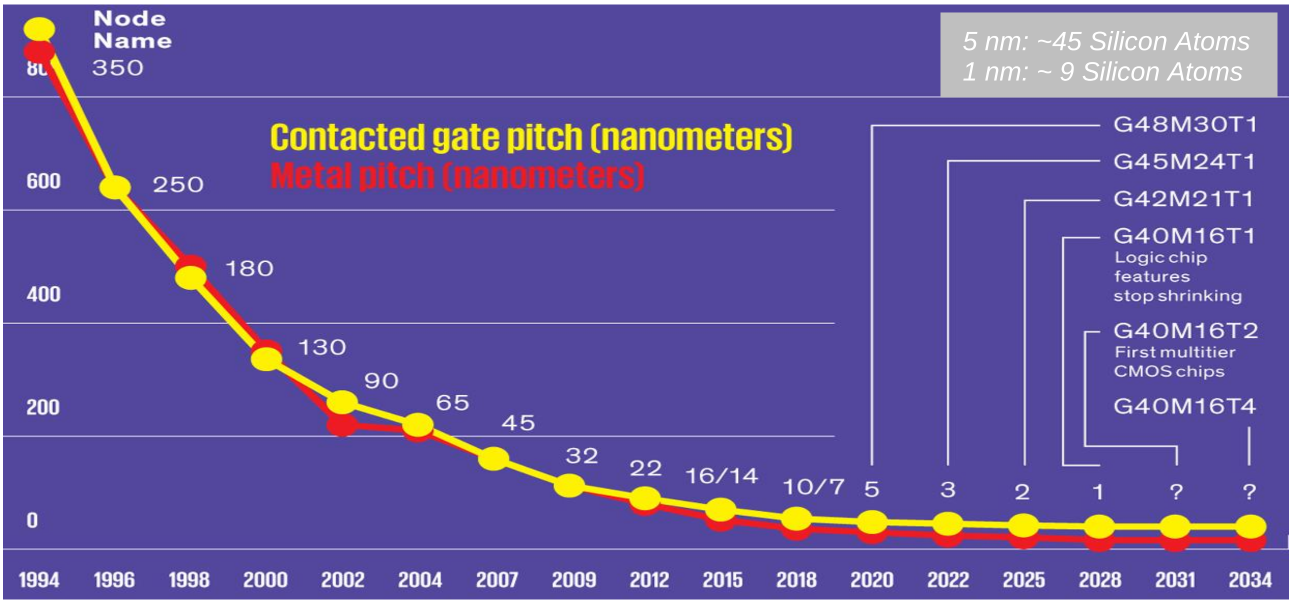


Table 3: History and outlook of gate pitches (smallest structures) of semiconductor chips

According to the ITRS (International Technology for Semiconductors) roadmap (see *REF 2* under "*8 Yield Enhancement*") the critical killer particle size in semiconductor chemistries at 10nm processing structures is 1 particle/ml for > 5nm particle sizes! To find a 5 nm particle on a 300 mm wafer is like looking for a disc with 0.4 m diameter on the Earth's surface!

This demands increasing purity on processing chemistries and the wet materials used in fluid handling components like pumps, valves, sensors, tubings and fittings. The purity demand for semiconductor chemistries is approaching the ppq level (1 part per quadrillion): this is like finding a little fish in the San Francisco bay (see *REF 1*). This means that also the wet materials for the Levitronix pump heads have to meet the highest levels of purity even when pumping most aggressive chemicals.

1.3 PTFE and PFA

During the last decades the fluoropolymers PTFE and PFA evolved as the only possible solution in fluid handling for microelectronics production. PTFE and PFA have unique chemical resistance properties against aggressive chemistries like strong acids, bases and solvents up to temperature of 200°C (see *REF 6*, *REF 7*, *REF 8*, *REF 9*, *REF 10*). High purity grades of resins have been developed by companies like Chemours and Daikin, meeting the specific purity demand and barrier properties needed for ultrapure fluid handling with aggressive chemistries. The whole supply chain from resin manufacturers, to extruding, sintering and moulding suppliers down to the component's producers (like Levitronix) have designed and developed processes over more than 20 years in order to enable the manufacturing of those challenging materials. Hence Levitronix pump heads for microelectronics production are all produced with fluoropolymers like PFA or PTFE (for high temperature applications).

2 Main Requirements for Alternatives

2.1 Chemical Resistance

When selecting alternative materials for ultrapure fluid handling, the first most important factor is that these must be perfectly resistant against the chemistries used in microelectronics wet production processes as wafer cleaning, wafer etching, chemical delivery and photolithography. The slightest attack of the wet material can cause contaminations resulting in expensive wafer losses. *Table 4* shows some typical aggressive chemistries used in these applications.

Name	Formula	Concentration Range	Temperature Range	Semiconductor Process Type	**PTFE / PFA Suitability**
Hydrochloric Acid	HCL	up to 38%	20 – 70 °C	Wafer cleaning	Suitable
Hydrofluoric Acid	HF	up to 48%	20 – 70 °C	Wafer etching	Suitable
Sulfuric Acid	H_2SO_4	> 98%	20 – 180°C	Wafer cleaning	Suitable
Phosphoric Acid	H_2PO_4	> 85%	20 – 180°C	Wafer etching	Suitable
Nitric Acid	HNO_3	up to 68%	20 – 50 °C	Wafer etching/cleaning	Suitable
Perchloric Acid	$HClO_4$	up to 70%	*No info. available*	Wafer cleaning	Suitable
Acetic Acid	CH_3COOH	*No info. available*	*No info. available*	Wafer etching	Suitable
Isopropyl Alcohol (IPA)	C_3H_8O	up to 99.9%	20 – 70 °C	Wafer cleaning	Suitable
Ammonium Hydroxide	NH_4OH	up to 25%	20 – 70 °C	Wafer cleaning	Suitable
Sodium Hydroxide	NaOH	up to 50&	*No info. available*	Wafer etching	Suitable
Potassium Hydroxide	KOH	up to 50%	up to 70°C	Wafer etching	Suitable
Acetone	$(CH_3)_2CO$	up to 99.8%	20-50 °C	Wafer cleaning	Suitable
Xylene	$(CH_3)_2C_6H_4$	*No info. available*	*No info. available*	Wafer cleaning	Suitable
Hydrogen Peroxide	H_2O_2	up to 30%	20 – 70 °C	Wafer cleaning	Suitable
Bromine	Br	*No info. available*	*No info. available*	*No info. available*	Suitable
Ozone Water	$O_3 + H_2O_2$	up to 200 ppm	20 – 40 °C	*No info. available*	Suitable

Table 4: Typical chemicals used in chemical delivery and wet processing in semiconductor fabs

Note 1: Mixtures of these chemistries (like "aqua regia" and "piranha" solutions) are used, which result in a higher aggressivity as the single components.

Over the last 20 years Levitronix invested significantly in testing most of these liquids to show chemical compatibility and resistance of its pump heads made from PTFE and/or PFA to prove years of perfect operation.

2.2 High Purity

The SEMI F57-0120 standard (see *REF 3*) specifies minimum performance requirement for ultra high purity polymer for ultrapure fluid handling in the Semiconductor industry. It defines ionic, TOC (total organic carbon) and metal limits in the lower µg/m^2 range. It has to be mentioned that high-end-chip manufacturers like Intel, Samsung and TSMC require much lower limits (sometimes non-detectable values) to get reasonable yields, when manufacturing 5 nm or smaller structures.

To meet these levels organic and inorganic processing aids and additives are not allowed. Special moulding tools and cleaning procedures are required during the production process of the polymers, which in most present polymers other than PFA and PTFE are not available.

2.3 Low Permeability

Excellent barrier properties are needed to avoid that aggressive chemicals are penetrating the environment through the fluid handling components. Furthermore, encapsulated parts like the Levitronix metallic rotor have to be protected by low permeable encapsulation (today PFA or PTFE) to avoid corrosion of the rotor which can result in severe contamination of wet processes.

3 Study on Alternatives to PTFE and PFA

3.1 Stainless Steel and Titanium

Stainless Steel and specifically Titanium have a wide chemical resistance against acids, bases and solvents. However, at higher concentrations and temperatures of the aggressive chemicals these materials start to corrode. But the main problem is their tendency to release metallic ions even in water. The concentrations of these ions are significantly above the levels specified in SEMI F57-0120 standard (see *REF 3*). This has been verified by performing leachout testing at a 3rd party laboratory (see Test report *REF 4*). Pieces of two Titanium grades and Stainless Steel (1.4435) have been immersed 7 days in 85°C ultrapure water. After 7 days the metal ions where measured and compared to the specifications in SEMI F57-0120 as shown in *Table 5*. Most of the ions measure where significantly above the level allowed (see red values in *Table 5*). Titanium showed significantly lower levels than Stainless Steel but still significantly above the allowed levels and furthermore Titanium is much too expensive.

It must be emphasized that these values are even much higher if exposed to aggressive chemicals. Pump heads made from ultrapure PFA resin used in Levitronix pumps show no or only minor content of metal ions (see *REF 5*).

Parameter	Titan Disc Grade 5, 19x2 mm	Titan Disc Grade 5 anodized, 19x2 mm	Stainless Steel Disc 1.4435, 30x2 mm	RL	Spec.
Al	280	13,1	138	0,50	10
Ba	19,8	2,6	8,9	0,25	15
B	8,5	6,6	14,7	1,00	30
Ca	512	607	162	0,50	20
Cr	<	<	0,48	0,25	1
Cu	<	<	0,92	0,25	15
Fe	28,7	0,68	41,3	0,25	5
Pb	<	<	0,12	0,05	1
Li	0,91	0,17	0,32	0,05	2
Mg	25,4	74	4,7	0,25	5
Mn	11,1	15,9	2890	0,05	5
Ni	45	57	1510	0,25	1
K	115	276	19,8	0,25	15
Na	79	4890	19,6	0,25	15
Sr	10,0	4,2	2,2	0,05	0,5
Zn	9,9	20,1	72	0,25	10

Table 5: Metal ions measured for Titanium and Stainless Steel after 7 days immersion in 85C ultra-pure water

Note 1: See for detailed report REF 4. *Note 2: All red values are above the specification limits in SEMI-F57 (see right column labeled with Spec.).*

3.2 Glas and Ceramics

Glas and all ceramic types have a certain potential concerning the chemical resistance, but they are much too costly, almost impossible to be processed into big, precise and complicated structures like pump, valve and fitting parts. Furthermore, they are too brittle and delicate to be used.

3.3 Polypropylene (PP)

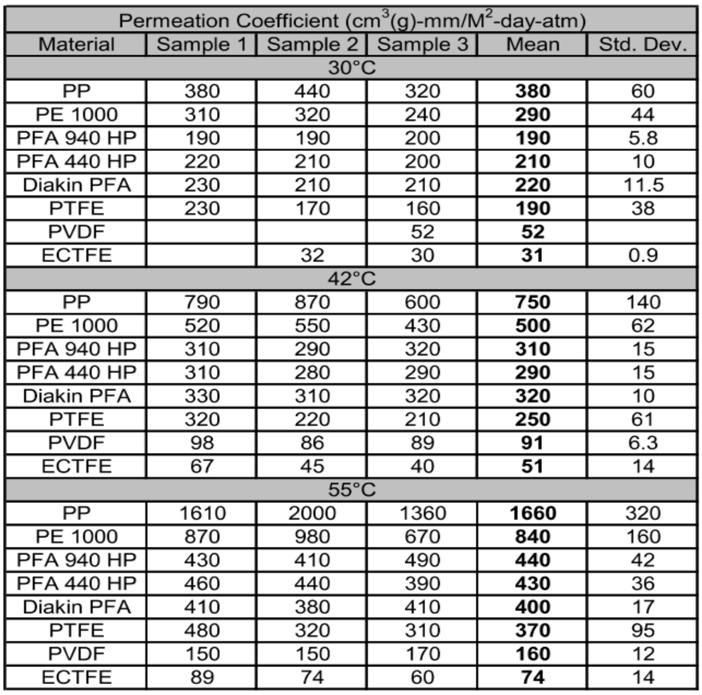
One of the first candidates of non-fluoropolymers is polypropylene (PP). Polypropylene is well known to have a wide chemical resistance against a wide range of chemicals and at the same time is significantly less costly than PFA or PTFE.

There are numerous general guidelines available (see *REF 12*, *REF 13*, *REF 14*, *REF 15*), which document the chemical resistance. Some of these guidelines have been studied to find out the suitability of polypropylene for the chemistries shown in *Table 4*. *Table 6* illustrates that while polypropylene is resistant to a lot of chemicals at room temperature, its chemical resistance decreases significantly at increased temperature, which are key for many processes in the semiconductor production.

Name	**Concentration Range**	**Temperature Range**	**Suitability for the Relevant Chemistry**
Hydrochloric Acid	up to 38%	20 – 70 °C	In general satisfactory for up to 60°C.
Hydrofluoric Acid	up to 48%	20 – 70 °C	Satisfactory at 35% concentration and 21°C temperature. Attack at 35% concentration and 60°C temperature.
Sulfuric Acid	> 98%	20 – 180°C	Satisfactory at 98% concentration and 21-60°C temperature. Severe attack at 98% concentration and 100°C temperature.
Phosphoric Acid	> 85%	20 – 180°C	Satisfactory at 85% concentration and 21-60°C temperature. Attack at 85% concentration and 100°C temperature.
Nitric Acid	up to 68%	20 – 70 °C	Satisfactory for low concentrations (< 10%). Sever attack at higher concentrations.
Perchloric Acid	up to 70%	*No info. available*	Poor resistance.
Acetic Acid	*No info. available*	*No info. available*	Suitable for up to 60°C.
Isopropyl Alcohol (IPA)	up to 99.9%	20 – 70 °C	Suitable for up to 60°C
Ammonium Hydroxide	up to 25%	20 – 70 °C	Suitable for up to 60°C
Sodium Hydroxide	up to 50%	*No info. available*	Suitable for up to 100°C
Potassium Hydroxide	up to 50%	up to 70°C	Suitable for up to 100°C
Acetone	up to 99.8%	20-50 °C	Marginal resistance.
Xylene	*No info. available*	*No info. available*	Attack at 21°C and severe attack at 60°C.
Hydrogen Peroxide	up to 30%	20 – 70 °C	Suitable for 21°C temperature. Attack at 60°C.
Bromine	*No info. available*	*No info. available*	Severe attack.
Ozone Water	up to 200 ppm	20 – 40 °C	Severe attack.

Table 6: Chemical resistance properties of polypropylene
Note 1: Analysis based on literature research (summary of REF 12, REF 13, REF 14, REF 15)

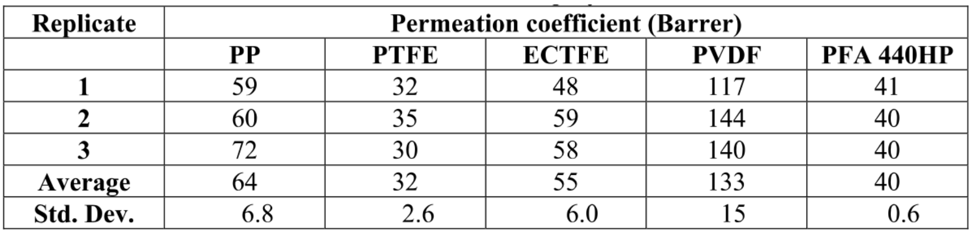
As mentioned in *Section 2.3*, low permeability of chemical molecules through the plastic encapsulation of the impeller is at most important for its lifetime and to avoid the contamination of the semiconductor wet processes and hence failures in wafer processing. *Levitronix* did extensive testing at a 3rd party lab with various chemistries to determine the permeation rate of various materials (see *REF 22*). *Table 7* summarizes the results for hydrochloride acid (HCL) at 35% concentration and various temperatures. *Table 8* summarizes the results for hydrofluoric acid (HF) at 33% concentration and various temperatures. HCL and HF are very representative for permeation testing as they are widely used in liquid mixtures of wet semiconductor processes and chemical delivery systems.



Permeation Coefficient (cm^3(g)-mm/M^2-day-atm)					
Material	Sample 1	Sample 2	Sample 3	Mean	Std. Dev.
30°C					
PP	380	440	320	**380**	60
PE 1000	310	320	240	**290**	44
PFA 940 HP	190	190	200	**190**	5.8
PFA 440 HP	220	210	200	**210**	10
Diakin PFA	230	210	210	**220**	11.5
PTFE	230	170	160	**190**	38
PVDF			52	**52**	
ECTFE		32	30	**31**	0.9
42°C					
PP	790	870	600	**750**	140
PE 1000	520	550	430	**500**	62
PFA 940 HP	310	290	320	**310**	15
PFA 440 HP	310	280	290	**290**	15
Diakin PFA	330	310	320	**320**	10
PTFE	320	220	210	**250**	61
PVDF	98	86	89	**91**	6.3
ECTFE	67	45	40	**51**	14
55°C					
PP	1610	2000	1360	**1660**	320
PE 1000	870	980	670	**840**	160
PFA 940 HP	430	410	490	**440**	42
PFA 440 HP	460	440	390	**430**	36
Diakin PFA	410	380	410	**400**	17
PTFE	480	320	310	**370**	95
PVDF	150	150	170	**160**	12
ECTFE	89	74	60	**74**	14

Table 7: Permeation rates of HCL (35%) through various materials

Note 1: Chart from testing at 3rd party by Levitronix (see REF 22).



Replicate	**Permeation coefficient (Barrer)**				
	PP	**PTFE**	**ECTFE**	**PVDF**	**PFA 440HP**
1	59	32	48	117	41
2	60	35	59	144	40
3	72	30	58	140	40
Average	64	32	55	133	40
Std. Dev.	6.8	2.6	6.0	15	0.6

Table 8: Permeation rates of HF (33%) through various materials

Note 1: Chart from testing at 3rd party testing organized by Levitronix (see REF 23).

The fluoropolymers like PFA and PTFE have significantly better barrier properties compared to polypropylene and polyethylene. This translates into a faster attack of the impeller rotor and a significant lower lifetime, which is unacceptable in Semiconductor processing and delivery applications as it leads to very short maintenance intervals and high potential for expensive wafer losses.

Concerning the purity properties of polypropylene, the main problem is that most resin types have additives (mostly tallow additives) to be better processable by injection moulding. These additives leach out over time when exposed to chemicals and cause a very high risk for contamination.

The mechanical properties (for example tensile strength and the E-module) of a typical polypropylene (see *REF 11*) starts to decrease significantly at temperatures > 90°C. This is a problem as Levitronix pump heads have to withstand static pressures significantly above 6 bar. This could be improved by additives, but this causes again high risk for potential contaminations. Hence polypropylene is not suitable for higher temperature fluids in semiconductor processing.

3.4 Polyethylene (PE, LDPE, HDPE)

Polyethylene plastics (PE, LDPE or HDPE) have very similar properties like polypropylene.

As for polypropylene there are numerous general guidelines available (see *REF 16*, *REF 17*, *REF 18*, *REF 19*), which document the chemical resistance. Some of these guidelines have been studied to find out the suitability of polyethylene for the chemistries shown in *Table 4*. *Table 9* gives a similar picture as for polypropylene. While polyethylene is resistant to a lot of chemicals at room temperature, its chemical resistance decreases significantly at increased temperature.

Name	**Concentration Range**	**Temperature Range**	**Suitability for the Relevant Chemistry**
Hydrochloric Acid	up to 38%	20 – 70 °C	In general satisfactory for up to 60°C.
Hydrofluoric Acid	up to 48%	20 – 70 °C	In general satisfactory for up to 60°C.
Sulfuric Acid	> 98%	20 – 180°C	Severe attack.
Phosphoric Acid	> 85%	20 – 180°C	Satisfactory at 60°C. Not sufficient mechanical strength at higher temperatures.
Nitric Acid	up to 68%	20 – 70 °C	Satisfactory for concentrations < 30% and 60°C temperature. Attack at > 30% and 60°C temperature.
Perchloric Acid	up to 70%	*No info. available*	Satisfactory for concentrations < 50% and 21°C. Attack at 60°C for < 50%.
Acetic Acid	*No info. available*	*No info. available*	Suitable at < 10% for up to 60°C. Attack at 60°for > 10% at 60°C.
Isopropyl Alcohol (IPA)	up to 99.9%	20 – 70 °C	Suitable for up to 60°C
Ammonium Hydroxide	up to 25%	20 – 70 °C	Suitable for up to 60°C
Sodium Hydroxide	up to 50%	*No info. available*	Suitable for up to 60°C
Potassium Hydroxide	up to 50%	up to 70°C	Suitable for up to 60°C
Acetone	up to 99.8%	20-50 °C	Suitable for up to 60°C
Xylene	*No info. available*	*No info. available*	Server attack at 21-60°C.
Hydrogen Peroxide	up to 30%	20 – 70 °C	Suitable for 21°C temperature. Attack at 60°C.
Bromine	*No info. available*	*No info. available*	Severe attack.
Ozone Water	up to 200 ppm	20 – 40 °C	Attack.

Table 9: Chemical resistance properties of polyethylene

Note 1: Analysis based on literature research (summary of REF 16, REF 17, REF 18, REF 19).

According to *Table 7* the barrier properties of PE are better than polypropylene but still inferior to the fluoropolymers.

Concerning the purity and mechanical properties the same applies to polyethylene as for polypropylene.

3.5 Polyetheretherketon (PEEK)

Polyetheretherketon (called PEEK) is a thermoplast known for its excellent robustness up to 200°C.

Table 4 shows a summary of the chemical resistance properties for the fluids mentioned in *Table 4* based on the data mentioned in *REF 12*, *REF 13*.

Name	**Concentration Range**	**Temperature Range**	**Suitability for the Relevant Chemistry**
Hydrochloric Acid	up to 38%	20 – 70 °C	Suitable for < 10% and up to 70°C. Some effect at higher concentration and temperature.
Hydrofluoric Acid	up to 48%	20 – 70 °C	Severe attack.
Sulfuric Acid	> 98%	20 – 180°C	Severe attack.
Phosphoric Acid	> 85%	20 – 180°C	Suitable for up to 80% and 200°C (no information for > 85%)
Nitric Acid	up to 68%	20 – 70 °C	Severe attack at concentrations > 10%.
Perchloric Acid	up to 70%	*No info. available*	Suitable for up to 100°C.
Acetic Acid	*No info. available*	*No info. available*	Suitable for up to 100°C.
Isopropyl Alcohol (IPA)	up to 99.9%	20 – 70 °C	Suitable for up to 23°C (no information for up to 70°C)
Ammonium Hydroxide	up to 25%	20 – 70 °C	Suitable for up to 23°C (no information for up to 70°C)
Sodium Hydroxide	up to 50%	*No info. available*	Suitable for up to 100°C.
Potassium Hydroxide	up to 50%	up to 70°C	Suitable for up to 100°C.
Acetone	up to 99.8%	20-50 °C	Suitable for up to 100°C.
Xylene	*No info. available*	*No info. available*	Suitable for up to 23°C (no information for higher temp.)
Hydrogen Peroxide	up to 30%	20 – 70 °C	Suitable but for up to 100C but no concentration information.
Bromine	*No info. available*	*No info. available*	Severe attack.
Ozone Water	up to 200 ppm	20 – 40 °C	Suitable for 23C but no information about concentrations. Some attack at elevated temperatures.

Table 10: Chemical resistance properties of PEEK

Note 1: Analysis based on literature research (summary of REF 12, REF 13).

Unfortunately, PEEK has various deficits concerning its chemical compatibility for chemistries like Hydrofluoric Acid, Nitric Acid and Sulfuric Acid. This clearly limits its usage for Semiconductor wet processing application.

PEEK can be injection molded, extruded, or pressed in blocks but it needs very complex know how and it is also very expensive.

4 Summary and Conclusions

4.1 Summary

Some selected potential alternatives for the fluoropolymers PFA and PTFE have been studied and tested for their usage in wet Semiconductor processing in context with the Levitronix pumps and flowmeters. The study on these alternatives is very representative for further alternative polymers like PVC, CPVC, PPSU and others. All these alternatives cannot match the unique combination of properties of PFA and PTFE concerning chemical compatibility, purity, inertness and chemical barrier properties. The biggest problem is chemical resistance and connected to this the purity needed in ultrapure fluid handling.

In the foreseeable future there is no alternative visible to fluoropolymers like PFA and PTFE for components used in ultrapure fluid handling for Microelectronics production.

If alternatives should appear in the future (which is very unlikely at the moment) it would need further several years of tuning and adapting the whole supply chain from resin manufacturer, to resin processing (moulding, extruding and machining) and component suppliers to meet the high demand of purity and chemical resistance needed to manufacture high-tech chips for the present and future need in applications like smart phones, PC, data processing, Internet of Things, Artificial Intelligence, compact and efficient life science devices and electrical car vehicles.

4.2 Conclusions

A ban of fluoropolymers from their application for ultra-pure fluid handling in microelectronics production would ban crucial enabler components like the Levitronix pumps and flowmeters and cause severe disruptions for manufacturing important high-tech chips. It would not only pose a high risk to companies like Levitronix but also lead to a regression in advanced technologies that enable modern life in Europe.

A 5 or 12 year derogation to a ban does not make any sense as there are no alternatives today and no alternatives will be developed just for Europe. It would just mean that important technologies would leave the Swiss and European market towards USA and Asia.

5 References

Reference # and Title or File	Note
REF 1: Clean Chemical Delivery Entegris Whitepaper 8524.pdf	*White paper from Entegris emphasizing the purity in ultrapure fluid handling.*
REF 2: ITRS 2.0 Technology Roadmap 2015.pdf	*International Technology Road Map established by a group of semiconductor industry experts.*
REF 3: Semi F57-0120 2020.pdf	*Specifications for high purity polymer materials for ultrapure fluid handling in semiconductor industry.*
REF 4: Leachout Testing Steel vs Titan vs PTFE Carbon Semi-F57 ATU Test 1 - 2017-08-04.pdf	*Leachout testing, organized by Levitronix at a 3rd party laboratory to measure metal ion contamination in ultrapure water with Stainless Steel and Titanium.*
REF 5: Leachout Testing LPP-600.29 Semi-F57 Balazs 2021-06-16.pdf	*Leachout testing, organized by Levitronix at a 3rd party laboratory to measure metal ion contamination in ultrapure water with a PFA pump head.*
REF 6: PFA Chemical Compatibility Bartle Data.pdf	*Chemical compatibility data from Schmidt-Bartle for PFA.*
REF 7: PFA Chemical Compatibility CPLabSafety Data.pdf	*Chemical compatibility data from CPLabSafety for PFA.*
REF 8: PTFE Dupont Handbook H-37051-3	*Handbook of Dupont about properties of PTFE.*
REF 9: PTFE Chemical Compatibility Bartle Data.pdf	*Chemical compatibility data from Schmidt-Bartle for PTFE.*
REF 10: PTFE Chemical Compatibility CPLabSafety Data.pdf	*Chemical compatibility data from CPLabSafety for PFA.*
REF 11: PP Datasheet Flinthills 2017-02	*Datasheet of a polyproplene type at Flinthills.*
REF 12: PP Chemical Compatibility Ineos Data.pdf	*Chemical compatibility data from Ineos for polypropylene. This polyproplene is used in the Levitronix pump heads for life science, where the chemicals are diluted or have low aggressivity and the temperature is below 40°C.*
REF 13: PP Chemical Compatibility CPLabSafety Data.pdf	*Chemical compatibility data from CPLabSafety for polypropylene.*
REF 14: PP Chemical Compatibility Celltreat Data.pdf	*Chemical compatibility data from CELLTREAT Scientific Products for polypropylene.*
REF 15: PP Chemical Compatibility Prinsco Data.pdf	*Chemical compatibility data from Prinsco for polypropylene.*
REF 16: PE Chemical Compatibility Ineos Data.pdf	*Chemical compatibility data from Ineos for polyethylene (HDPE). This polyethylene is used in the Levitronix mixer cups for bioprocessing, where the chemicals are diluted or have low aggressivity and the temperature is below 40°C.*
REF 17: PE Chemical Compatibility CPLabSafety Data.pdf	*Chemical compatibility data from CPLabSafety for polyethylene.*
REF 18: PE Chemical Compatibility Equistar Data.pdf	*Chemical compatibility data from Equistar for polyethylene.*
REF 19: PE Chemical Compatibility Craemer Data.pdf	*Chemical compatibility data from Craemer for polyethylene.*
REF 20: PEEK Chemical Compatibility Victrex Data.pdf	*Chemical compatibility data for PEEK Victrex.*
REF 21: PEEK Chemical Compatibility CPLabSafety Data.pdf	*Chemical compatibility data from CPLabSafety for PEEK.*
REF 22: Permeation Testing CTA Report LTX 1092 2299.pdf	*Test report of permeation testing of various materials with HCL done at 3rd party by Levitronix.*
REF 23: Permeation Testing CTA Report LTX 1098 2118.pdf	*Test report of permeation testing of various materials with HF done at 3rd party by Levitronix.*

Table 11: List of reference documents