

Advancing Semiconductor Manufacturing

Ultra-High-Purity Fluid Handling and Precision Injection Molded Fluoropolymer Components

How advanced fluoropolymers improve yield, reliability, and process purity across the semiconductor fluid path.

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Executive Summary

Semiconductor manufacturing demands exceptionally pure materials, precise component geometries, and chemically resistant fluid handling systems. A single source of contamination, whether from an extractable ion, a trace metal, or an out-of-tolerance molded part, can affect wafer yield and process uptime.

This white paper brings together Pexco's fluoropolymer expertise across two disciplines that are often sourced separately: ultra-high-purity Altaflo® tubing and pipe for chemical and ultrapure water distribution, and precision injection molded fluoropolymer components for valves, fittings, and other critical semiconductor equipment. Presented together, they show how semiconductor OEMs, tool builders, and fabs can work with one engineering partner across the entire fluid path, from raw resin to finished, validated component.

1. Why Fluoropolymers Matter for Semiconductor Manufacturing

Fluoropolymers are a family of high-performance polymers built around a fluorine-carbon backbone. That structure gives them a combination of properties that few other plastics can match: high chemical resistance, low friction, high thermal stability, and excellent electrical insulation. These attributes make fluoropolymers the preferred choice for components that must perform in the challenging, high-purity environments found across electronics, chemical processing, aerospace, automotive, and medical manufacturing.

Pexco works with several fluoropolymer resins to meet the diverse needs of semiconductor manufacturers, including PFA, FEP, PVDF, and ECTFE. Each material offers a distinct balance of purity, mechanical performance, and chemical compatibility, and Pexco's engineers and materials specialists guide customers toward the material best suited to a given application, whether that application calls for extruded tubing, molded valve bodies, or fittings.

2. Selecting the Right Fluoropolymer

Fluoropolymer selection should be driven by the purity, temperature, and chemical resistance requirements of the specific process step. The table below summarizes how Pexco's core fluoropolymer families compare.

Material	Key Characteristics	Best Suited For
UHP PFA (Ultra-High Purity)	Maximum purity, extremely low extractables, exceptional chemical resistance, smooth inner surface, high-temperature performance up to 500°F (260°C)	Ultrapure chemical delivery, semiconductor wet-bench and dispense components
HP PFA (High Purity)	High purity with excellent chemical resistance, superior thermal stability, reduced contamination risk vs. standard fluoropolymers	High-purity chemical transfer, pharmaceutical/biotech, laboratory systems, semiconductor support processes
FEP	Excellent flexibility and optical clarity	Fluid handling where visual flow inspection or added flexibility is valuable

Material	Key Characteristics	Best Suited For
PVDF	High mechanical strength and good chemical resistance where extreme purity is not required	PVDF is used for processing water in semiconductor applications.
ECTFE	Excellent mechanical durability and resistance to aggressive chemicals	Applications requiring toughness alongside chemical resistance

Table 1. Core fluoropolymer families and recommended applications.

HP PFA and UHP PFA are the preferred materials for high-purity and contamination-sensitive chemical distribution systems, particularly in semiconductor manufacturing. While UHP PFA is the premium choice for the most stringent purity requirements, HP PFA offers an excellent balance of purity, chemical resistance, and thermal performance for demanding applications. Key advantages include extremely low contamination levels, broad chemical compatibility, high-temperature resistance up to 500°F (260°C), excellent electrical insulation properties, and smooth extruded or molded surfaces that help minimize particle generation and contamination risk in critical process environments.

Pexco manufactures products from a broad range of fluoropolymers, including PFA, FEP, PVDF, ECTFE, PTFE, ETFE, PCTFE, and THV. For semiconductor fluid-path applications, PFA, FEP, PVDF, and ECTFE are typically the most relevant materials and are therefore the focus of this paper.

3. Ultra-High-Purity Fluid Handling: Altaflo® 480 UHP PFA Tubing

Pexco's Altaflo® 480 Ultra-High Purity PFA tubing and pipe is produced exclusively from 100% virgin-grade Daikin AP-231 SH resin, a semiconductor-grade material chosen for its combination of purity and mechanical reliability. Altaflo 480 meets or exceeds key SEMI F57 requirements, helping semifab operators reduce contamination, increase wafer yields, and maximize system uptime.

Independent testing by CT Associates and Balazs Analytical Services, performed to the SEMI F57 specification with additional hydrochloric acid (HCl) extraction testing, confirms Altaflo 480's performance across four categories of contamination and durability. Full test results are provided in the Technical Data Appendix; highlights include:

- Total organic carbon (TOC): surface extractable TOC of 100 µg/m², approximately 0.2% of the SEMI F57 limit of 60,000 µg/m².
- Ionic contamination: all measured anions other than fluoride were below the reporting limit; fluoride extraction (680 µg/m²) is approximately 1% of the SEMI F57 limit.
- Metallic extractables: nearly all elements were below the reporting limit, with the tightest measured result, nickel, at the SEMI F57 acceptance level.
- HCl extraction: in a 12-day dynamic extraction test using 35% HCl, surface and mass extraction rates measured 0.7% and 2%, respectively, of a major semiconductor equipment manufacturer's specification.

Beyond purity, Daikin's AP-231 SH resin gives Altaflo 480 a high degree of chemical resistance and mechanical reliability, including an upper service temperature of 500°F (260°C), enhanced resistance to aggressive

fluorosurfactants that helps minimize stress cracking, and a flex life comparable to PTFE. Altaflo 480 meets or exceeds ASTM D6867-03 for PFA tubing.

Altaflo 480 tubing and pipe is produced and packaged in a clean room manufacturing facility, from the point raw material is introduced through extrusion and final packaging. The optional ALTAPAK packaging adds surfactant cleaning, DI rinse, and nitrogen purge performed within a class 100 clean room. Standard lengths run from 25 ft. to 1,000 ft., with custom lengths, precision cutting, and assembly services such as heat forming, flaring, and slitting available on request, along with same-day shipping on standard orders.

4. Precision Injection Molded Fluoropolymer Components

Semiconductor components frequently require complex geometries, precise shapes, and tight tolerances, all while working with fluoropolymer materials that are, by nature, difficult to shape. Injection molding is Pexco's preferred method for manufacturing consistently accurate, uniform, high-performance components, using a process that spans mold design and fabrication, material selection, injection, cooling and solidification, demolding, and quality control.

Net Shape Molding

Net shape molding produces a mold that closely matches the final component's shape and size. Pexco has developed proprietary tooling systems and molding techniques built specifically for the semiconductor realm, supported by solid modeling, mold flow analysis, finite element analysis, and an internally developed interactive tool design system. To meet semiconductors' tight tolerance requirements, Pexco uses 3D CT scanning of a component's internal and external geometries, generating a plot of up to 1.2 million datapoints that is integrated with CAD/CAM software to guide exacting tool modifications. This approach minimizes waste, reduces production time, and supports highly accurate component manufacturing.

Insert Molding

Insert molding places a component into the mold before the fluoropolymer is injected around it. Pexco's innovative tool designs, fixturing, and robotic material placement techniques enable the over molding of delicate inserts that were previously considered too thin or complex to position and hold precisely within the mold.

Direct Gating and Hot Runner Systems

Pexco's proprietary direct gating and hot runner systems give engineers greater design flexibility to maximize component performance, minimize waste, and reduce cost when developing next-generation products.

5. Selecting a Semiconductor Fluoropolymer Manufacturing Partner: Key Considerations

Quality semiconductor components require precision and tight tolerances at every stage of manufacturing, particularly for parts that must maintain integrity in challenging working environments. When evaluating a fluoropolymer component or fluid handling manufacturer, semiconductor OEMs, tool builders, and fabs should weigh the following:

1. Capability for quality production: confirm the material meets the purity standards and chemical composition required for the intended semiconductor application.
2. Industry expertise: confirm the manufacturer has expert-level knowledge and demonstrated experience working with semiconductor materials and processes.
3. Clear communication: confirm procedures and channels exist for addressing concerns, discussing progress, and making adjustments throughout the project.
4. Testing and validation procedures: confirm the manufacturer's product testing policies ensure the final product consistently meets set standards.
5. Quality control measures: confirm the measures in place to ensure uniform, consistent components across production runs.
6. Compliance with standards: confirm the manufacturer is current on relevant compliance requirements and follows best-in-business practices.

6. Integrated Engineering, From Concept to Production

Pexco supports semiconductor projects from initial material selection through prototype development, tooling, cleanroom production, custom assembly, validation, and full-scale manufacturing. The team can quickly evaluate ideas, create samples from 3D CAD models using stock materials, produce resin cut or layered prototypes, or provide soft, bridge tooling to test components before a significant capital investment is made. Pexco also conducts rigorous testing and validation of components in the intended semiconductor application to confirm performance under actual operating conditions.

Working with a single engineering partner across both extruded fluid handling products and molded components reduces the complexity of coordinating multiple suppliers and helps accelerate development timelines.

7. Performance Validation and Industry Compliance

Validating a semiconductor fluoropolymer component requires more than confirming dimensional accuracy. Pexco's recommended validation program spans:

- SEMI F57, SEMI C90, and SEMI F104 compliance testing, confirming components will not contaminate ultra-pure water and liquid chemical distribution systems as referenced in our Technical Guide.
- Total organic carbon (TOC) testing.
- Ionic contamination analysis.
- Metallic extractables testing.
- HCl extraction testing.
- ASTM mechanical property testing, including flex life (ASTM D2176), flex modulus (ASTM D790), tensile strength (ASTM D1708), elongation (ASTM D638), and hardness (ASTM D2240).
- Chemical compatibility verification against process-specific chemistries.

Pexco has met the SEMI F57 and SEMI C90 standards, and Altaflo 480 Series UHP and 451 Series HP PFA tubing resin comply with UL 94 V-0 requirements and meets or exceeds ASTM D6867-03. Once mass manufacturing procedures are in place, stringent quality checks and inspections are implemented at every stage to guarantee the final product consistently meets the client's specifications.

8. Why Pexco

Pexco has a passion for problem-solving and prides itself on being a trailblazer in fluoropolymer manufacturing. Backed by more than 50 years of experience and the most advanced technology available, Pexco offers the tools and expertise to ensure semiconductor components and fluid handling products are manufactured to perform at their peak.

With deep engineering expertise in fluoropolymer tubing, pipe, and precision molded components, Pexco is able to use high-grade, high molecular weight resins selected for their end-use performance, purity, chemical resistance, and reliability. Extrusion and molding are carried out in cleanroom manufacturing environments using proprietary production processes designed to protect products from outside contaminants at every stage. Combined with rapid prototyping capability, rigorous validation, and responsive supply chain support including same-day shipping on standard orders, Pexco gives semiconductor customers a single, integrated engineering partner across the entire fluid path.

Frequently Asked Questions

What is the cleanest fluoropolymer for semiconductor fluid handling?

High-purity PFA is generally preferred because of its low extractables and outstanding chemical resistance. Pexco's Altaflo 480 UHP PFA tubing is manufactured from 100% virgin-grade Daikin AP-231 SH resin and tests well within SEMI F57 limits.

What other products does Pexco offer for semiconductor fluid handling?

Beyond Altaflo 480 UHP PFA tubing and pipe, Pexco's semiconductor fluid handling lineup includes Altaflo® 451 HP PFA tubing, which offers excellent purity and chemical resistance for high-purity applications that don't require the most stringent UHP-level specifications, and Altaflo® 500 PVDF tubing and pipe, valued for its mechanical strength and chemical resistance in general chemical transfer and process water applications where extreme purity isn't required. Together with the molded components covered in this paper, these products let Pexco support the full semiconductor fluid path, from ultra-high-purity chemical delivery to general process fluid handling, through a single manufacturing partner.

Why are extractables important in semiconductor fluid handling?

Organic, ionic, and metallic contaminants leached from tubing or components can reduce wafer yield and damage sensitive semiconductor processes, particularly in ultrapure water and chemical distribution systems.

Why use injection molding instead of machining for semiconductor components?

Injection molding enables complex geometries, high repeatability, lower material waste, and scalable production, all while holding the tight tolerances semiconductor components require.

What standards does Pexco meet for semiconductor materials?

Pexco has met the SEMI F57, SEMI C90, and SEMI F104 standards, and Altaflo 480 tubing meets or exceeds ASTM D6867-03.

Conclusion

Semiconductor manufacturers increasingly need integrated partners capable of delivering both ultra-high-purity fluid handling products and precision fluoropolymer components. By combining advanced materials expertise with validated manufacturing processes across extrusion and injection molding, Pexco helps customers reduce contamination, improve reliability, and support next-generation semiconductor manufacturing from a single engineering partner.

Technical Data Appendix: Altaflo® 480 UHP PFA Tubing

Testing performed by CT Associates and Balazs Analytical Services according to the SEMI F57 specification, with additional HCl extraction testing. All values represent surface extractable results leached at $85 \pm 5^\circ\text{C}$ for 7 days unless otherwise noted.

Total Organic Carbon (TOC)

Parameter	Reporting Limit	Altaflo 480 UHP PFA / SEMI F57 Limit
Total TOC, $\mu\text{g}/\text{m}^2$	40	100 / $\leq 60,000$

Table 2. Total organic carbon results vs. SEMI F57 limit.

Ionic Contamination

Ion, $\mu\text{g}/\text{m}^2$	Reporting Limit	Altaflo 480 UHP PFA	SEMI F57 Limit
Bromide	1	*	≤ 100
Chloride	0.5	*	$\leq 3,000$
Fluoride	20	680	$\leq 60,000$
Nitrate	1	*	≤ 100
Nitrite	0.5	*	≤ 100
Phosphate	1	*	≤ 300
Sulfate	1	*	≤ 300

Table 3. Ionic contamination results. * = analyte not found at or above the reporting limit.

Metallic Extractables

Element, $\mu\text{g}/\text{m}^2$	Reporting Limit	Altaflo 480 UHP PFA	SEMI F57 Limit
Aluminum	0.02	0.1	≤ 10
Arsenic	0.5	*	—
Barium	0.02	*	≤ 15
Boron	0.2	3.1	≤ 30
Cadmium	0.07	*	≤ 5
Calcium	1	*	≤ 20
Chromium	0.07	*	≤ 1
Copper	0.1	*	≤ 15
Iron	0.2	*	≤ 5
Lead	0.1	*	≤ 1
Lithium	0.07	*	≤ 2

Element, $\mu\text{g}/\text{m}^2$	Reporting Limit	Altaflo 480 UHP PFA	SEMI F57 Limit
Magnesium	0.05	*	≤ 5
Manganese	0.07	*	≤ 5
Nickel	0.1	1.0	≤ 1
Potassium	0.2	*	≤ 15
Sodium	0.1	*	≤ 15
Strontium	0.02	*	≤ 0.5
Titanium	0.1	*	—
Tin	0.05	*	—
Vanadium	0.07	*	—
Zinc	0.1	0.6	≤ 10

Table 4. Metallic extractables results. * = not found at or above the reporting limit. — = not currently required by SEMI F57-0314; acceptance limit not yet established.

Hydrochloric Acid (HCl) Extraction

Performed in a 12-day dynamic extraction test using 35% HCl.

Parameter ($\text{ng}/\text{cm}^2/\text{day}$)	Altaflo 480 UHP PFA	Major Semiconductor Equipment Mfr. Spec
Surface contamination	0.14	<20
Bulk contamination	0.012	<0.5

Table 5. HCl extraction results vs. equipment manufacturer specification.

Physical Properties

Property	ASTM Method	Units	Value
Upper Service Temperature	—	—	500°F
Specific Gravity	D 792	—	2.15
Tensile Strength	D 1708	PSI	4,500
Elongation	D 638	%	400
Hardness	D 2240	Shore D	60
MIT Flex Life	D 2176	KCycles	1,750,000
Flex Modulus	D 790	PSI	90,000

Table 6. Physical properties of Altaflo 480 UHP PFA tubing.

Altaflo 480 UHP PFA tubing meets or exceeds ASTM D 6867-03 (Standard Specification for PFA Tubing). Values above are based on tests performed at 73°F and can vary by application based on temperature, chemical concentration, pressure, and other parameters; consult factory for application-specific guidance.

Precision Injection Molding Reference Data

- CT scan dimensional verification: up to 1.2 million critical dimensional measurements per component, integrated with CAD/CAM software for tool correction.
- Modeling methods: net shape molding and insert molding, supported by solid modeling, mold flow analysis, and finite element analysis.
- Tooling technology: proprietary direct gating and hot runner systems.
- Compliance: components manufactured to meet SEMI F57 and SEMI C90 requirements as applicable to the application.