VSi PARYLENE

THE COMPLETE GUIDE TO

PARYLENE COATINGS

A comprehensive guidebook to determining parylene's applicability to your project.

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ADVANCING TECHNOLOGY TOGETHER

VSi is a forward thinking company that sees parylene as an important tool for advancing many of today's technologies.

Technology is constantly evolving, changing with it the limits of what we believe is possible. Yet, what does remain constant is the uniquely powerful role innovation plays to shake up entire industries. At VSi, innovation goes beyond simply manufacturing parylene to its highest quality standard. We seek to advance the implementation of parylene technology, as a whole, to an entirely new level of performance. We believe that a single component, well-designed and expertly integrated into your production, has the potential to turn an interesting product into the best-in-its-class. This passion for reimagining what is possible is at the heart of the VSI approach. We welcome you to experience the difference.

Welcome

VSI Parylene has prepared this comprehensive guidebook to help provide manufacturers from various industries with simple, straightforward information regarding the properties, benefits and applications of parylene.

The information you find contained in this handbook combines decades of direct experience with the most up-to-date research on parylene available. We hope it serves as a dependable resource as you evaluate and determine the applicability of various technologies, including parylene, to your product's development.

Parylene is not the right choice for every application. No technology is. But often for many engineers, parylene affords unparalleled protection, and therefore peace-of-mind, that simply no other coating offers. We invite you to learn more.

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SECTION I:

UNDERSTANDING PARYLENE

Since its discovery in the 1940's, parylene has increasingly become the conformal coating of choice for a wide variety of applications in the medical, aerospace, military, industrial and consumer electronics industries. This section covers what parylene is, how it works, and the unique benefits this chemistry provides.

What is Parylene?

Parylene is the trade name for a specific family of highly crystalline polymers commonly used as a film coating to protect sensitive devices and components from extraordinarily harsh environments. These environments span the gamut from outer space to the inside of the human body. Parylene coating offers exceptional performance in a wide range of applications due to its unique combination of robust material characteristics with a molecular-level deposition process not found in other conformal coatings.

This deposition process, known as Chemical Vapor Deposition (CVD), allows parylene vapor to penetrate the tiniest of crevices, unreachable by other conformal coatings, to deposit individual polymer molecules directly onto surfaces, essentially "growing" a film coating on site. Moreover, since the deposition process contains no liquid stage, parylene does not require the use of solvents or curing agents. The result is a chemically pure coating that can fully encapsulate complex shapes and surface topographies without voids, bubbles or pinholes at the microscopic level. This micro-scale of precision allows parylene to provide equivalent protection at less than 10% the mass of liquid conformal coatings, a critical benefit as devices continue to become smaller and more compact.

Today parylene protects a wide array of commonly used devices and components, increasingly becoming the conformal coating of choice for high value applications in the medical device, electronics, transportation, defense and aerospace industries. More common applications include printed circuit boards, electronic assemblies, digital displays, sensors, LEDs, MEMS, ferrite cores, implantable medical devices, needles, probes, gaskets and elastomeric seals among many others. .

Liquid Conformal Coating

Liquid conformal coatings are not truly conformal, and tend to collect and pool in low crevices while pulling away from raised edges and sharp points. Bubbling, cracking, pinholes and orange peel are typical in liquid coatings.

Parylene Conformal Coating

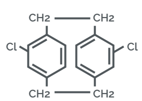
The major benefit of parylene's gaseous deposition process is its unique ability to penetrate and grow a thin, uniform coating molecule-by-molecule on surfaces that are simply unreachable by liquid coatings.

Parylene Coating Process

Parylene films are "grown" as vapor deposits molecule by molecule in a room temperature vacuum chamber. This Chemical Vapor Deposition (CVD) process provides many unique benefits compared to dip and spray coatings. Thin film deposition occurs directly on parts, anywhere the vapor reaches. Because the vapor is able to get in all the nooks and crannies, parylene thin film coatings are truly conformal.

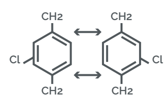
The end result is a pinhole free coating without any by-products. Parylene protects the most complex structures at a molecular level. It can encapsulate complex shapes and evenly cover sharp edges. The thin film is highly uniform, ranging from hundreds of angstroms to a hundred microns.

Sublimation



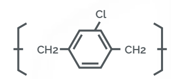
DIMER
150-175°C

Pyrolysis



MONOMER
650-690°C

Deposition

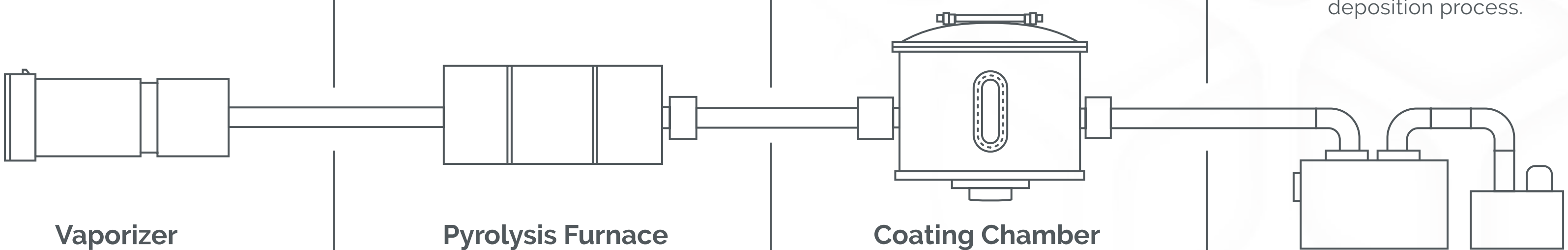


POLYMER
Room Temp. | 30-50 mTorr

Pump & Cold Trap

Cold Trap

Captures the excess parylene at the end of the deposition process.



Vaporizer

The process starts with granular dimer. The dimer is vaporized from a solid directly into a dimeric gas.

Pyrolysis Furnace

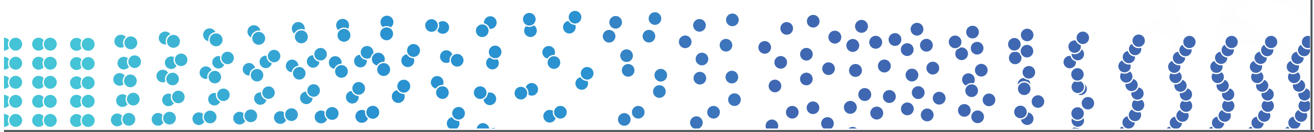
Next, the dimeric gas is heated to split the dimer molecule and produce a monomeric gas.

Coating Chamber

Lastly, the monomer gas is released into the coating chamber to deposit as a transparent polymer film.

Vacuum Pump

Removes all air and gasses from the chamber, enabling parylene deposition.



Uses Of Parylene

The 6 most common applications of parylene.

Biocompatibility

Parylene is an FDA-approved material that is recognized as safe for use on or inside the human body, meeting USP Class VI and ISO 10993 biocompatibility requirements. The effective use of parylene to eliminate problems related to microporosity and biofluid corrosion in medical devices has been well-documented for over 40 years.

Dry Lubricity

Dry film lubricity is an important consideration in the design, installation and function of disposable medical appliances like cardiac-assist devices (CADs), catheters, guidewires, and stents. Parylene's low coefficient of friction reduces insertion-force up to 90% when compared to uncoated devices, significantly reducing the potential of puncture damage or severe abrasion generated between the device surface and the vessel walls.

Dielectric Protection

Dielectric strength is a measurement of a conformal coating's insulation effectiveness. Parylene possesses superior dielectric strength (5OOO volts/mil at 1 mil], a low dissipation factor,and high surface and volume resistivity that remain virtually constant with changes in temperature. As a result, parylene is often used in space-limited designs to eliminate issues such as arcing and corona discharge.

Adhesion Tie Layer

When applied between metal or polymer substrates and a top coating, parylene behaves as an adhesion layer. Parylene's biostability and chemical inertness make it a unique solution for bonding drug and hydrophilic coatings to drug eluting devices including catheters.

Barrier Protection

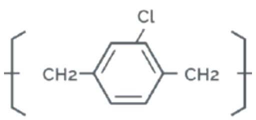
Permeation barriers for electronics are essential to ensure operational performance through a wide range of environments. Parylene offers excellent protection from airborne contaminants, corrosion, chemicals, gases and moisture. It accomplishes this level of protection with 10% the mass of spray or dip coatings.

Ruggedization

Parylene's conformal properties are used to add strength and rigidity to physically reinforce delicate connections on printed circuit boards (PCBs). Parylene's deep penetrating ability provides a conformal "jacket" that greatly reduces failures caused by solder fatigue from thermal cycling and vibration, without board redesign.

Common Parylene Variants

TYPE C



Parylene C is the most popular parylene type because it provides a combination of barrier and dielectric properties and offers cost and processing advantages.

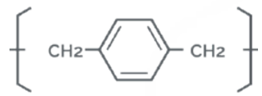
Parylene C is produced from the same raw material as parylene N but substitutes a chlorine atom for one of the aromatic hydrogens. This gives parylene C very low permeability for better protection from moisture, chemicals and corrosive gases.

Parylene C deposits much faster than other parylene types which allow a thicker layer to be applied with less machine time.

Parylene C is the best choice for:

- Implantable medical devices.
- Pinhole-free barrier layers to electronics or materials from harsh environments.
- Encapsulating electronics to provide dielectric protection.
- Meeting IPC-CC-830 or MIL-I-46058C standards.

TYPE N



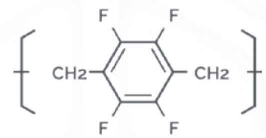
Parylene N is the base structure of the parylene group. Parylene N has excellent dielectric properties. It has a very low dissipation factor, high dielectric strength, and a low dielectric constant that does not change with frequency.

Parylene N is more molecularly active than parylene C during the deposition process. An advantage of the higher activity is increased crevice penetration, which allows parylene N to get farther into tubes and small openings. A disadvantage of the higher activity is slower deposition rates which increase the machine time and cost for thicker layers.

Parylene N is the best choice for:

- Dry lubricity.
- High frequency/RF applications because of its low dissipation factor at high frequencies.
- Applications that require a higher penetration factor.

TYPE F (VT-4)



Parylene F fills a niche because it is capable of higher operating temperatures and is more resistant to UV than parylene C or parylene N. Parylene F also has very good dielectric properties and good crevice penetration.

Parylene F is also produced from the same raw material as parylene N but instead substitutes four fluorine atoms for all four aromatic hydrogens.

A disadvantage of Parylene F is its cost. Of the three types of parylene discussed, it is the most expensive due to the combination of slow deposition rates and higher raw material costs.

Parylene F is the best choice for:

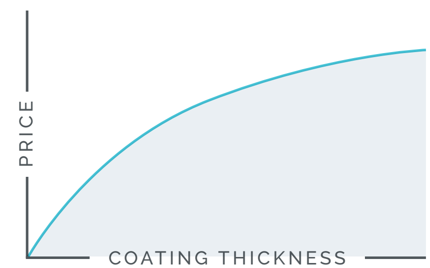
- Applications with higher temperature and UV requirements.

Key Cost Drivers

COATING THICKNESS
→ MACHINE HOURS

Optimal coating thickness is determined by your specific application and benefits desired.

As coating thickness increases, additional time inside the deposition chamber is required, increasing total machine hours.



MASKING COMPLEXITY
→ LABOR HOURS

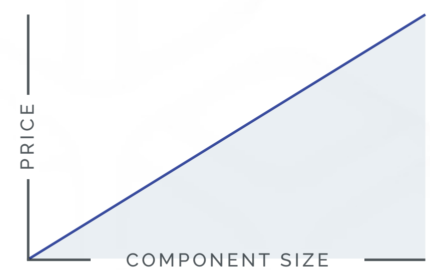
Masking complexity is determined by your product's design and operating requirements.

As complexity increases, operators must take more time to process each individual part increasing total operator hours.

SIZE OF COMPONENT
→ BATCH SIZE

Parylene coating is applied inside a vacuum deposition chamber of fixed, physical size.

As individual component size increases, total quantity of product's coated decrease reducing batch size.



SECTION II:

PARYLENE PROPERTIES

The increasing popularity of parylene coatings in the medical industry is due to both its unique chemistry and deep molecular reach. In this section, you will find technical details and real-world examples of parylene's electrical, mechanical, thermal and barrier properties and benefits.

Electrical Properties

Parylene is a material with exceptional electrical insulation properties that can be applied in a conformal thin film. This combination allows parylene to be used as a precision dielectric layer in a variety of applications. Parylene's breakdown voltage is determined by the coating thickness.

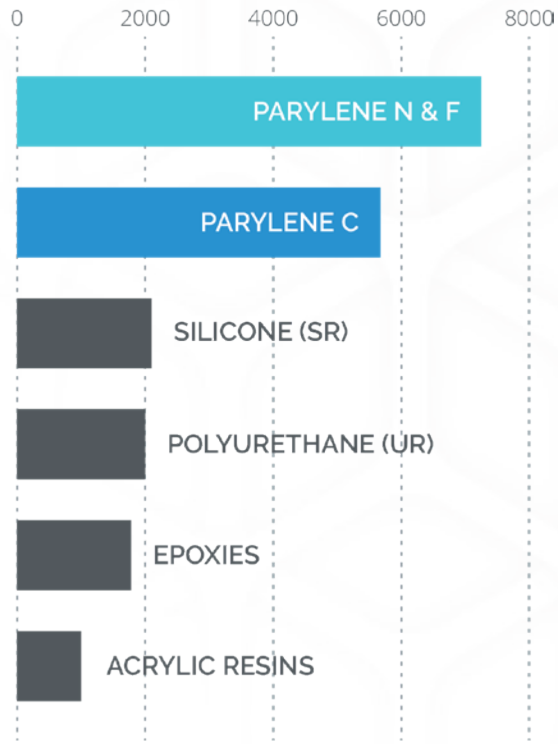
When compared to epoxy, silicones and urethane coatings, all parylene types have an extremely high dielectric strength. Parylene N is a unique dielectric material because of the extremely low dissipation factor which changes only slightly with frequency. The chlorine atom in parylene C increases the dielectric constant and dissipation factor when compared to parylene N.

Often used in:

- Cardiac-assist devices and other electrically sensitive implanted devices.
- Electronic circuits. (arc-over and corona discharge)
- Neural probes and stimulators.
- Magnets and ferrite cores.
- Micro transducers, MEMS and micro-coaxial probes.
- Semiconductor wafer-level test probes.

DIELECTRIC STRENGTH

(VOLTS/MIL)



ELECTRICAL PROPERTIES	Type C	Type N	Type F
Dielectric Strength *defines the maximum voltage required to produce a dielectric breakdown of the material. The higher the dielectric strength of a material the better its quality as an insulator.*	220 V/micron at 25.4microns 5600 V/mil at 0.001"	276 V/micron at 25.4microns 7000 V/mil at 0.001"	276 V/micron at 25.4microns 7000 V/mil at 0.001"
Volume Resistivity *is the electrical resistance through a cube of insulating material. The higher the volume resistivity, the lower the leakage current and the less conductive the material is.*	8.8×10^{16} ohm-cm at 23°C, 50% RH	1.4×10^{17} ohm-cm at 23°C, 50% RH	1.1×10^{17} ohm-cm at 23°C, 50% RH
Surface Resistivity *is the electrical resistance of the surface of an insulator material. The higher the surface resistivity, the lower the leakage current and the less conductive the material is.*	1×10^{14} ohms at 23°C, 50% Relative Humidity	1×10^{13} ohms at 23°C, 50% Relative Humidity	4.7×10^{17} ohms at 23°C, 50% Relative Humidity
Dielectric Constant (k) *A ratio measuring the ability of a substance to store electrical energy in an electric field.*	60 Hz 3.15 1 KHz 3.10 1MHz 2.95 6 GHz 3.06 - 3.10	60 Hz 2.65 1 KHz 2.65 1MHz 2.65 6 GHz 2.46 - 2.54	60 Hz 2.20 1 KHz 2.25 1MHz 2.42
Dissipation Factor (tan δ) *A measure of a dielectric material's tendency to absorb some of the AC energy from an electromagnetic (EM) field passing through the material.*	60 Hz 0.020 1 KHz 0.019 1MHz 0.013 6 GHz 0.0002 - 0.0010	60 Hz 0.0002 1 KHz 0.0002 1MHz 0.0006 6 GHz 0.0021 - 0.0028	60 Hz 0.0002 1 KHz 0.0002 1MHz 0.008

HIGHLIGHTED APPLICATION:

Dielectric Protection in Surgical Tools

Stray electrical paths can cause failures in any technology and may go unnoticed throughout the design process until exposure to real-world conditions and field use uncovers the problem. In the medical industry, stray paths can cause significant issues including technology failure, patient discomfort, or worse.

Parylene's exceptional dielectric strength, high volume resistivity, and low dissipation factor combined with its thin coating thickness allow it to serve as a precision electric insulation layer for most product designs. Parylene is applied only to specific components and so it is an agile solution when an unintended electrical path is found because existing products can be easily modified with a simple coated component with very minimal disruption to a forward-facing production process.

Read more about how we were able to assist a leading robotic surgical manufacturer quickly refit their existing products with a parylene-coated component and alter their production process in the case study **on our website.**

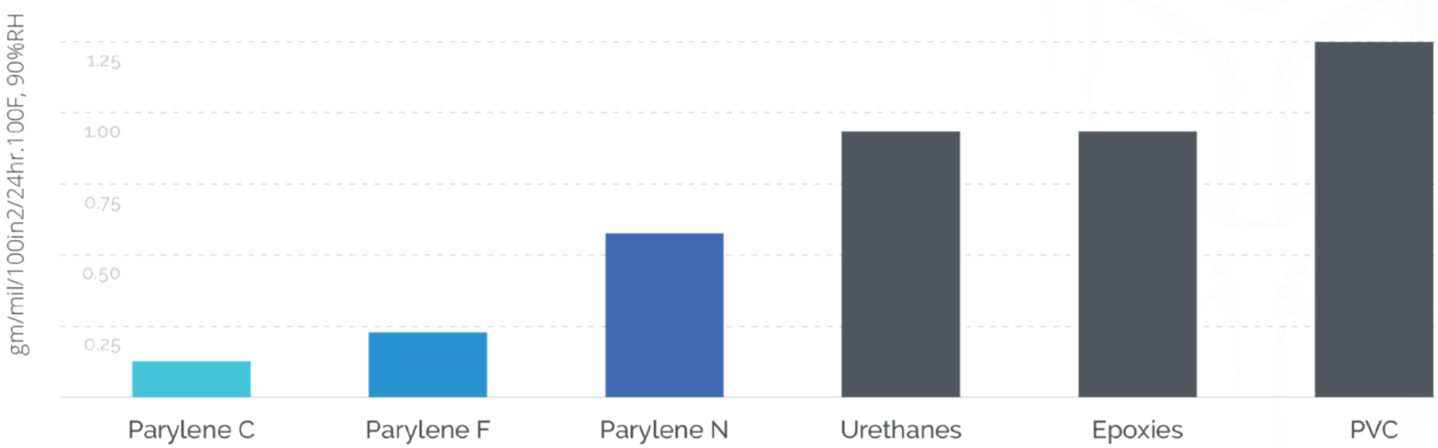
Barrier Properties

Parylene is an extremely effective moisture and chemical barrier layer that can be used to protect materials from an incompatible environment. Parylene is able to fully encapsulate medical devices, electronics and oxidative materials from harsh environments with a very thin and conformal parylene layer. Parylene is chemically resistant to almost every solvent, acid and alkaline chemistry commonly used. This allows parylene to be used in environments that simply are impossible for other conformal coatings.

Often used in:

- Stents, defibrillators, pacemakers and other devices permanently implanted into the body.
- Cochlear and intraocular implants.
- Printed Circuit Boards (PCB) and flex-circuits.
- Power supplies and sensors.
- Electronics for space and aerospace applications.
- Protection for plastic and elastomeric materials from harmful environments.
- Protective layer for 3D printed parts to improve compatibility with chemicals.
- Corrosion protection for metals.

MOISTURE VAPOR TRANSMISSION



GAS PERMEABILITY:

Gas permeability is a material property that defines the penetration of a gas through a solid membrane. A low gas permeability rate is very desirable for coatings that need to seal and encapsulate a part. Compared to epoxies, urethanes and silicones, parylene has considerably better gas permeability. The table below shows the gas permeability of parylene for common gases.

Gas permeability is expressed as (amount of gas) (thickness of membrane) / (membrane area) (time)(differential pressure of gas).

GAS	Type C	Type N	Type F
Nitrogen (N_2)	0.4	3.0	-
Oxygen (O_2)	2.8	15.4	16.7
Carbon Dioxide (CO_2)	3.0	84.3	-
Hydrogen (H_2)	43.3	212.6	

*Gas permeability at 25°C in (cc*mm)/(m2*day*atm)*

HIGHLIGHTED APPLICATION:

Preventing Plastic Leaching Into Sensitive Chemistry

Across the universe of applications, products may be jeopardized by exposure to any number of materials. These materials may interfere with the product's core functionality, shorten the product's lifespan, or quietly cultivate the seed of a problem that does not become known until a major failure occurs.

Parylene's powerful barrier properties effectively prevent exposure to most gases, liquids, and solids from becoming problematic. Plastics are known to leach into the products they protect and can become a serious issue if the leaching plastics interact with the substance they are containing and cause loss of purity or unwanted chemical processes.

Learn how we used a parylene coating as a protective barrier layer to prevent a plastic encasing from leaking contaminants into a sensitive chemical mix in the case study **on our website.**

CHEMICAL RESISTANCE

Parylene is insoluble in all common solvents, acids and alkalis used in processing and cleaning electronics. The table below reports testing that was performed on parylene test strips 12-35 microns thick. The test strips were immersed in test liquids until equilibrium swelling was reached.

The percent thickness change was either due to swelling or the solvent content of the film after surface drying. In no case was there a decrease in the original film thickness. After the strips dried, they all returned to their original thickness.

This testing demonstrates how parylene reacts to different chemicals. The minimal swelling and return to original thickness indicate parylene's resistance to the chemicals listed below

Inorganic Reagents	Parylene C % swelling	Parylene N % swelling
10% Hydrochloric (Non-Oxidizing Acid)	0.0% at 25°C 0.0% at 75°C	0.0% at 25°C 0.0% at 75°C
37% Hydrochloric (Non-Oxidizing Acid)	0.0% at 25°C 4.1% at 75°C	0.2% at 25°C 2.3% at 75°C
10% Sulfuric (Non-Oxidizing Acid)	0.3% at 25°C 0.2% at 75°C	0.1% at 25°C 0.2% at 75°C
95-98% Sulfuric (Non-Oxidizing Acid)	0.4% at 25°C 5.1% at 75°C	0.2% at 25°C 5.3% at 75°C
10% Nitric (Oxidizing Acid)	0.1% at 25°C 0.1% at 75°C	0.1% at 25°C 0.2% at 75°C
71% Nitric (Oxidizing Acid)	0.2% at 25°C 1.85% at 75°C	0.2% at 25°C Brittle at 75°C
10% Chromic (Oxidizing Acid)	0.1% at 25°C 0.0% at 75°C	0.1% at 25°C 1.2% at 75°C
74% Chromic (Oxidizing Acid)	0.0% at 25°C 7.8% at 75°C	0.3% at 25°C 8.2% at 75°C
10% Sodium Hydroxide (Base)	0.0% at 25°C 0.5% at 75°C	0.1% at 25°C 0.0% at 75°C
10% Ammonium Hydroxide (Base)	0.2% at 25°C 0.4% at 75°C	0.3% at 25°C 0.4% at 75°C
100% De-Ionized Water (Inert)	0.0% at 25°C 0.0% at 75°C	0.0% at 25°C 0.0% at 75°C

Organic Solvents	Parylene C % swelling	Parylene N % swelling
Isopropyl (Alcohol)	0.1% at 25°C 0.2% at 75°C	0.3% at 25°C 0.3 % at 75°C
Iso-Octane (Aliphatic Hydrocarbon)	0.4% at 25°C 0.5% at 75°C	0.2% at 25°C 0.3 % at 75°C
Pyridene (Amine)	0.5% at 25°C 0.7% at 75°C	0.2% at 25°C 0.4% at 75°C
Xylene (mixed)	2.3% at 25°C 3.3% at 75°C	1.4% at 25°C 2.1% at 75°C
Trichloroethylene (TCE)	0.8% at 25°C 0.9% at 75°C	0.5% at 25°C 0.7% at 75°C
Chlorobenzene (Chlorinated Aromatic)	1.5% at 25°C 2.0% at 75°C	1.1% at 25°C 1.7% at 75°C
O-Dichlorobenzene (Chlorinated Aromatic)	3.0% at 25°C 1.4% at 75°C	0.2% at 25°C 0.3% at 75°C
Trichlorotrifluoroethane (Fluorocarbon)	0.2% at 25°C 0.3% at 75°C	0.2% at 25°C 0.2% at 75°C
Acetone (Ketone)	0.9% at 25°C 0.9% at 75°C	0.3% at 25°C 0.4% at 75°C
2,4-Pentanedione (Ketone)	1.2% at 25°C 1.8% at 75°C	0.6% at 25°C 0.7% at 75°C

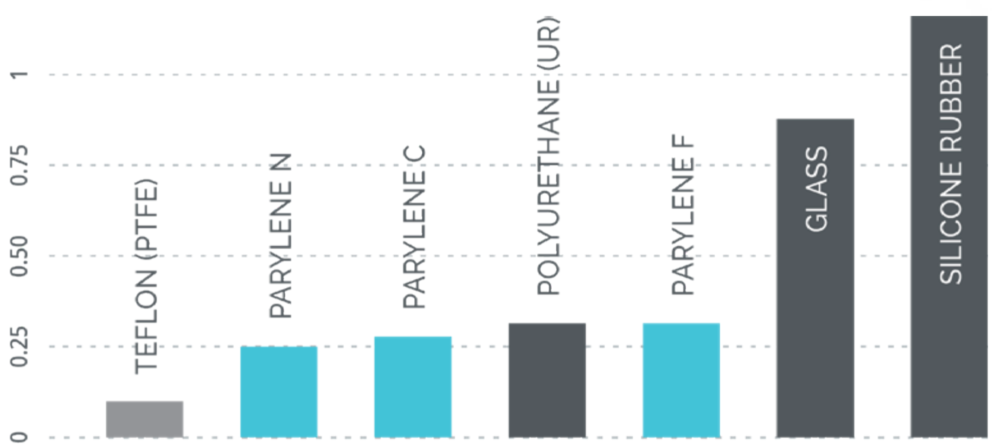
Mechanical Properties

Parylene is a crystalline polymer which results in generally high mechanical strength. Parylene has a relatively high tensile and yield strength compared to other polymer coatings. Parylene has a hardness higher than polyurethane and epoxy. However, it has the approximate hardness of human skin. Although parylene's wear resistance is substantial, it isn't recommended to be used in applications with repeated abrasion with harder materials.

Often Used in:

- Dry lubricity for catheters and guidewires.
- Dry lubricity for silicone parts and silicone cables.
- Dry lubricity for o-rings, seals and gaskets.
- Encapsulating circuit boards and electronics to reduce the effects of vibration.
- Add rigidity to a fragile component

COEFFICIENT OF FRICTION (μs)



HIGHLIGHTED APPLICATION:

Dry Lubricity on Medical Device Components

Unfortunately, cutting-edge medical technology and natural human biology are not always symbiotic without some help. Products intended to be embedded within or interact anywhere with the human body must adhere to the highest standards of quality and safety.

Parylene serves as an effective solution for applications where reduction in friction is necessary, but a wet lubricant cannot be used. In the cases of medical tubing and products such as catheters, parylene's dry lubricity improves the patient experience. Additionally, delicate parts that are subjected to movements and stress in the human body gain new strength from a parylene coating.

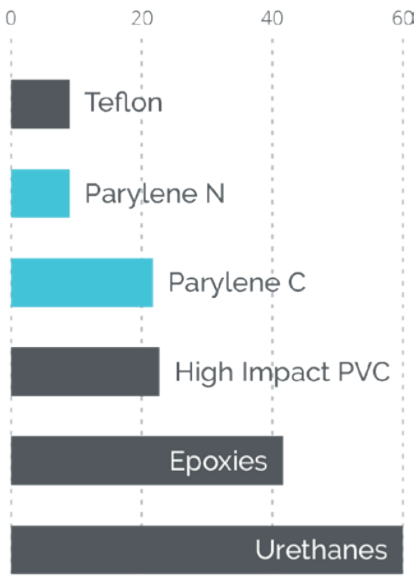
MECHANICAL PROPERTIES

	Unit	C	N	F	Acrylic	Epoxy	Urethane	Silicone
Young's Modulus The force is needed to stretch or compress a material. Stress/Strain.	GPa	2.8	2.4	3.0	0.014 - 0.069	2.41	0.007 - 0.689	0.006
	psi	400,000	350,000	435,000	2,000 - 10,000	350,000	1,000 - 100,000	900
Tensile Strength The force required to pull a material to point where it will break	MPa	68.9	48.3	55	48.26 - 75.84	27.58 - 89.63	1.21 - 68.95	2.41 - 6.89
	psi	10,000	7,000	7,800	7,000 - 11,000	4,000 - 13,000	175 - 10,000	350 - 1,000
Yield Strength The stress at which permanent (plastic) deformation occurs.	MPa	55.2	42.1	52	-	-	-	-
	psi	8,000	6,100	7,600	-	-	-	-
% Elongation to Break The ratio between the change in length and initial length that causes the material to break.	%	20% - 200%	20% - 250%	10% - 50%	2% - 5.5%	3% - 6%	>14%	10 0% - 210%
Elongation at Yield the ratio between the increased length and initial length at the yield point.	%	2.9%	2.5%	2.4%	-	-	-	-
Density The mass per unit volume.	g/cm3	1.289	1.11	1.652	1.19	1.11 - 1.40	1.10 - 2.50	1.05 - 1.23
	lb/ft2	80.5	69.3	103.1	74.3	69.3 - 87.4	68.7-156.1	65.5 - 76.8
Hardness (Rockwell) is a measure of the indentation resistance of a material. Testing is performed forcing a steel ball indenter into the surface of a material. The R scales tests between 10 and 60 kg.	R	R80	R85	R80	M68 - M105	M80 - M110	68A - 80D (Shore)	40A - 45A (Shore)
Coefficient of Friction is the minimum force required to get an object to slide on a surface, divided by the forces pressing them together. It is important to note that the difference in static and dynamic coefficient of friction is undetectable f or parylene.	static	0.29	0.25	0.35	-	-	-	-
	dynamic	0.29	0.25	0.39	-	-	-	-

WEAR AND ABRASION

Parylene wear and abrasion values compared to urethanes, epoxies, high impact PVC and Teflon are shown below. The data comes from a Taber abraser and wear tester. This data can be used to help designers understand how parylene will work in applications where friction with parylene is expected. The data was obtained using a C5-17 Clibrase wheel with 100 grams of weight

WEAR INDEX



Thermal Properties

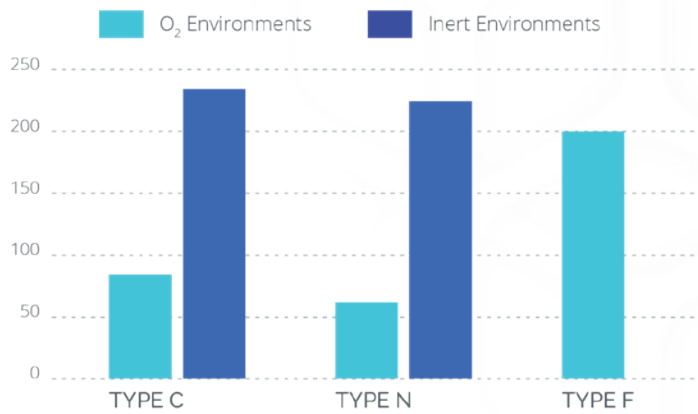
Parylene, like all polymers, has an ideal temperature operating range which is dependent on the application and environment. At temperatures outside the ideal temperature operating range, parylene will start to become translucent or yellow and will become brittle.

The operating temperature range increases significantly if parylene can be used in the absence of air or in inert atmospheres. In an oxygen-free environment, oxidative degeneration does not take place. Degradation is due primarily to the thermal cleavage of carbon-carbon bonds.

If high temperature is a concern, VSI recommends every application is looked at and tested individually. Each parylene type's melting temperature defines an upper limit. The table to the right gives guidelines for 1,000- hour use and continuous use to demonstrate parylene melting points.

On the other end of the temperature spectrum, parylene is outstanding in cryogenic applications. As an example, steel panels coated with parylene C that were chilled in liquid nitrogen to -160ºC withstood impacts of more than 100 in/lb. Unsupported 2-mil films of parylene C were flexed 190 degrees six times at -165ºC before failure occurred. At even lower temperatures, near absolute zero, tests show that parylene N provides the best electrical insulation of any known plastic. Neither electrical or physical properties are noticeably affected by cycling from -270ºC to room temperature. The cryogenic test results were published in volume 45: no. 14A "Modern Plastics Encyclopedia".

CONTINUOUS SERVICE TEMPERATURES (ºC)



THERMAL PROPERTIES

	Units	C	N	F	Acrylic	Epoxy	Urethane	Silicone
Melting Point	°C	290	420	435	85-105	-	~170	-
	°F	554	788	815	185 - 221	-	338	-
Short-term Service Temperature Recommended maximum temperature for 1,000 hours of use.	°C in oxygen environments	115	95	250	-	-	-	-
	°F in oxygen environments	239	203	482	-	-	-	-
	°C in inert environments	350	265	-	-	-	-	-
	°F in oxygen environments	662	509	-	-	-	-	-
Continuous Service Temperature Allowable temperature exposure for 10 years service life.	°C in oxygen environments	80	60	200	82	177	121	260
	°F in oxygen environments	176	140	392	179.6	350.6	249.8	500
	°C in inert environments	230	220	-	-	-	-	-
	°F in oxygen environments	446	428	-	-	-	-	-
Linear Coefficient of Thermal Expansion The relative change in length per degree temperature change.	ppm/°C at 25° C	35	69	45	55 - 205	45 - 65	100 - 200	250 - 300
Thermal Conductivity (k) is a material property describing the ability to conduct heat.	(W/(m*K) at 25°C	0.084	0.126	0.1	0.17 - 0.21	0.13 - 0.25	0.11	0.15 - 0.31
Specific Heat (c) the amount of heat per unit mass required to raise the temperature by one degree Celsius.	cal/(g*°C) at 20°Cv	0.17	0.20	-	0.25	0.25	0.42	0.35

SECTION III:

PARYLENE DESIGN GUIDELINES

Parylene is a robust material with a unique Chemical Vapor Deposition (CVD) process among conformal coatings. This process allows parylene to penetrate the tiniest of openings to fully encapsulate components and assemblies. In this section you will find design best practices for working with parylene to extract maximum benefits.

Masking Consideration

Parylene film is produced via deposits of individual monomer molecules onto surfaces as a gas. As a result, parylene is highly intrusive and will penetrate the smallest of openings to coat everything in its path. The masking process is therefore critical to the success of coated parts. Parylene repair and removal is often a difficult and costly process to implement. Below are design factors that directly impact the masking process.

BOARD SIMPLICITY

Design the board to make it efficient to mask and de-mask the areas to be free of Parylene. For example, flat solder pads are easier to mask when associated components are not yet attached creating complex 3D topographies.

MASKING TOLERANCE

Ensure there is space between components to allow masking materials to be applied efficiently and ensure secure coverage. For example, placing small resistors adjacent to a connector that will require masking may result in the resistor not being coated thoroughly with parylene.

MASKING SELECTION

Parylene offers a truly conformal coating without bridging, peeling or pooling. As a result, choose to mask only when absolutely needed. For example, un-plated holes and other low points will not pool. Heat sinks, dependent on coat thickness, may not meaningfully impact heat dissipation as there is no bridging between individual fins.

Component Consideration

When selecting components for your board, emphasis should be placed on "vapor-friendly" connectors. Doing so can drastically reduce the amount of masking required. Choose sealed connectors, switches and relays that have a closed back or bottom without vent holes or alignment pinholes.

PRE-SEALING CONNECTORS

Back-filling connectors prior to arriving at the masking stage will reduce overall process cost. Choose silicone or epoxy material to seal connector bases and openings.

MALE CONNECTORS

Where applicable, choose male pin type connectors for your board design. Male connectors simplify the masking process by mating with a simple boot to seal. Female sockets require careful and time consuming masking.

CABLES AND WIRES

Parylene is deposited inside a vacuum chamber of fixed size. To make efficient use of chamber's space constraints avoid cables and wires that protrude from your board. Selecting shorter cable and wires will increase density per batch, therefore reducing cost.

SECTION IV:

CHOOSING THE RIGHT CONFORMAL COATING

There are many things to consider when selecting a conformal coating for your specific application. This section covers several of the important material characteristics that should be part of your evaluation when comparing parylene to other coatings.

Determining Your Coating Requirements

Top 10 considerations when comparing conformal coatings

Biocompatibility:

Does the coating exhibit long-term compatibility with body fluids and tissues?

When applied onto the substrate, are there any toxic chemical interactions and/or byproducts that could be harmful to a patient or to the function of the device?

Parylene is 100% biocompatible.

Hydrophobic / Hydrophilic Characteristics

Does the coating aim for lubricity when dry or wet? (I.e. a cardiovascular catheter that is hydrophilic (slippery when wet) vs. a hydrophobic guidewire that is easy for a cardiologist to grip.)

Parylene is hydrophobic.

Coating Inertness:

Does the coating contaminate the substrate with outgassing from process catalysts, cure agents, solvents or plasticizers?

Parylene is 100% chemically inert.

Cure Temperature & Forces

Does the cure temperature of the coating exceed the performance range of the substrate?

Parylene does not require curing of any kind.

Cure Forces

Does the curing process degrade or distort the underlying substrate?

Parylene does not require curing of any kind.

Conformability

Does the coating offer conformability to highly variable surface geometries?

Does the coating maintain conformability at all magnitudes and surface feature sizes, from macro to micro?

Parylene is 100% conformal.

Finished Thickness

Does the finished coating meet tight dimensional tolerances while maintaining desired physical, chemical, or electrical protection that is free of voids and pinholes?

Parylene coating range is measured in microns and is free of voids and pinholes.

Mechanical Loading

Does the coating perform its function without significantly altering the physical or mechanical properties of the substrate?

Parylene's micron-thin film does not add meaningful mechanical load.

Resistance to Flaking

Does the coating sufficiently adhere to the substrate to avoid flaking?

Parylene has excellent adhesion to most substrates.

Sterilizability

Does the coating withstand the effects of sterilization processes?

Parylene withstands most sterilization processes.

VSi Total Solution

Helping you succeed at every stage of the product life-cycle

VSi uses a simple and transparent process to take parts from concept to production. VSi's Total Solution is designed to move customers through three key stages. We **prototype** to determine the feasibility, **develop** a robust process and **scale** for production.

The Prototype, Develop and Scale phases all occur at VSi's facility. For customers interested in owning their production, we can **transfer** parylene technology to their factory floor, VSi offers equipment, consumables and support through the Parylene-On-Demand (POD™) product line.

PROTOTYPE your Product

Test the feasibility of parylene in your application.

DEVELOP your Process

Build and validate a robust production process.

SCALE your Production

Ramp and dedicate production capacity with coating as a service.

TRANSFER our Technology

Strategically optimize your manufacturing process by bringing parylene in-house with POD™

The steps to parylene production.

I. PROTOTYPE

This phase is designed to test the feasibility of coating parylene for your products quickly and definitively. We also provide recommendations on how to improve your product's parylene manufacturability. This initial step provides clear feedback on whether parylene is right for your product's specific end-use.

Benefits include:

» Identification of areas of potential improvement, with concrete improvement suggestions

» Improved budgetary decision making based on quantified improvement potential

II. DEVELOP

After a successful application is established, the second step is to design a reliable coating process that is cost effective and able to deliver coated parts of consistently high quality. This phase is designed to provide you visibility and control through our process-driven quality management system (QMS) to ensure consistent results. This is a critical stage for regulated industries.

Benefits include:

» Establishment of work processes, quality assurance steps, process controls and documentation.

» Reduction of customer risk through increased visibility and control over development process.

III. SCALE

After product and process requirements are defined, you are ready to move into the production phase. This phase provides you with the ability to ramp up your production capacity quickly at VSI with a reliable and locked process. Scale is perfect for clients who require operational flexibility while maintaining high quality production. Scale provides the fastest track to get started quickly.

Benefits include:

» Technical expertise, flexible production capacity, and production efficiencies that can minimize per-part coating cost.

» Facilities, processes, and trained staff to meet broad industry requirements, including ISO, FDA, and ITAR

TRANSFER

As businesses and products evolve, there can be strategic benefits to bringing parylene technology in-house. VSi provides technology transfer options for clients who want maximum enterprise control over quality, production, cost and risk. VSi offers the POD™ parylene coating equipment and ecosystem to easily integrate parylene coating onto your factory floor.

Benefits include:

» In-house parylene coating can lower the total cost of coating, eliminate lead times, provide exponential scalability and eliminate shipping and handling risks.

» Complete transfer includes equipment, know-how transfer and ongoing support.

Learn more at
POD.VSIPARYLENE.COM

Quality Assurance & Regulatory Compliance

Producing competitive products for today's marketplace often requires the help of outside partners. As new technologies are continually developed, it is ultimately strict compliance to standards that guarantees these innovations make it to market. VSI's quality management system supports customers through this process by providing complete transparency in meeting all regulatory and customer requirements.

VSi complies with the following certifications and standards:

ISO 13485:2016 Certified

Safety and quality are non-negotiable in the medical devices industry. ISO 13485 sets out the regulatory requirements for a quality management system specific to the unique needs of the medical devices industry.

FDA 21 CFR 820 Compliant

Compliance to FDA's Quality System Regulation (QSR) provides a clear path to go from prototype through clinical trials and into production. Established best practices help ensure services consistently meet applicable requirements and specifications.

ISO 9001:2015 Certified

ISO 9001 certification ensures an organization's quality management system has consistent, repeatable processes in place in order to provide services that meet customer and regulatory requirements.

ISO Class 7 Clean Room Certified

Certified ISO class 7 (10,000 class) clean rooms provide a controlled environment where parts can be processed. Cleanroom environments effectively minimize particulates to protect parts from contamination.

VSi PARYLENE

GET THE ANSWERS YOU NEED WITH A

FREE CONSULTATION

Every application presents unique challenges. Over the course of thousands of engagements, we've seen and solved countless problems by working with our clients throughout every step of the development process.

If you think Parylene can help but aren't sure where to start, contact us for a free consultation and we will be happy to navigate you towards the right solution for your product

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POD

BRING PARYLENE IN-HOUSE

The complete parylene production system designed for easy process integration.

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