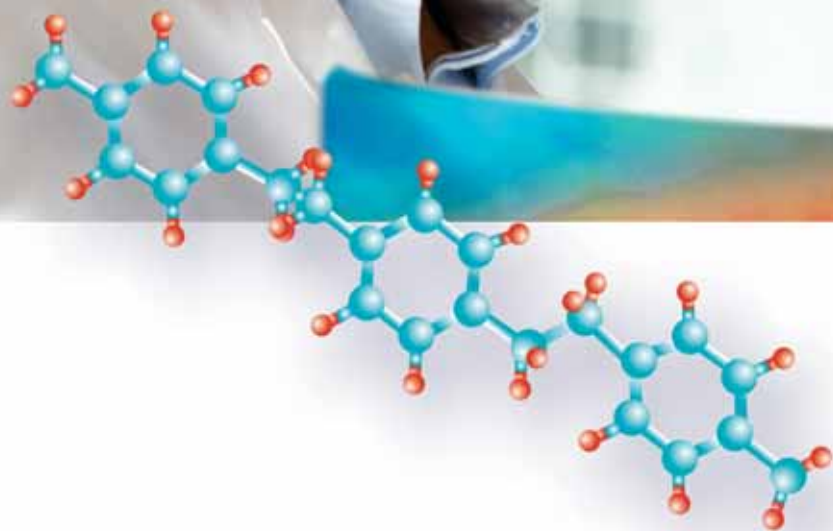




SPECIALTY COATING SYSTEMS™



Structural integrity.

SCS PARYLENE PROPERTIES

No other company understands Parylene coatings better than we do. SCS is the direct descendant of the companies that developed Parylene and began using it in commercial applications. We have been providing Parylene coating services, equipment and materials for more than 35 years, as well as aggressively researching and developing new Parylene variants and application processes to find innovative coating solutions for customers' advanced technologies.

Introduction

Parylene is the generic name for members of a unique polymer series. The basic member of the series, Parylene N, is poly(para-xylylene), a completely linear, highly crystalline material. Parylene N is a primary dielectric, exhibiting a very low dissipation factor, high dielectric strength, and a low dielectric constant invariant with frequency. The crevice-penetrating ability of Parylene N is second only to that of Parylene HT®. The Parylene structures are shown in Figure 1.

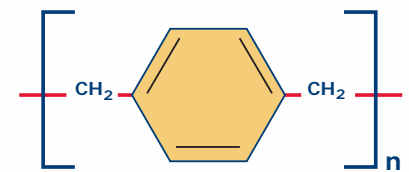
Parylene C, the second commercially available member of the series, is produced from the same raw material (dimer) as Parylene N, modified only by the substitution of a chlorine atom for one of the aromatic hydrogens. Parylene C has a useful combination of electrical and physical properties plus a very low permeability to moisture and corrosive gases.

Parylene D, the third available member of the series, is produced from the same raw material as the Parylene N dimer, modified by the substitution of chlorine atoms for two of the aromatic hydrogens. Parylene D is similar in properties to Parylene C with the added ability to withstand slightly higher use temperatures.

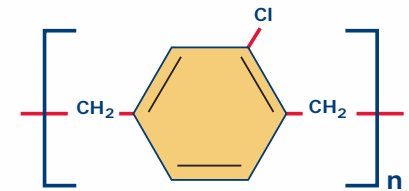
Parylene HT, the newest commercially available Parylene, replaces the alpha hydrogen atom of the N dimer with fluorine. This variant of Parylene is useful in high temperature applications (short-term up to 450°C) and those in which long-term UV stability is required. Parylene HT also has the lowest coefficient of friction and dielectric constant, and the highest penetrating ability of the four variants.

Due to the uniqueness of vapor phase deposition, the Parylene polymers can be formed as structurally continuous films from as thin as several hundred angstroms to 75 microns.

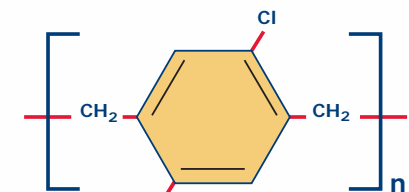
Figure 1. Parylenes N, C, D and Parylene HT Chemical Structures



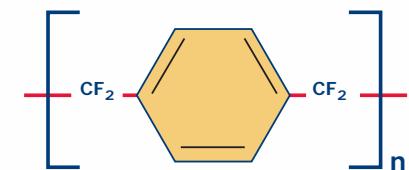
Parylene N



Parylene C

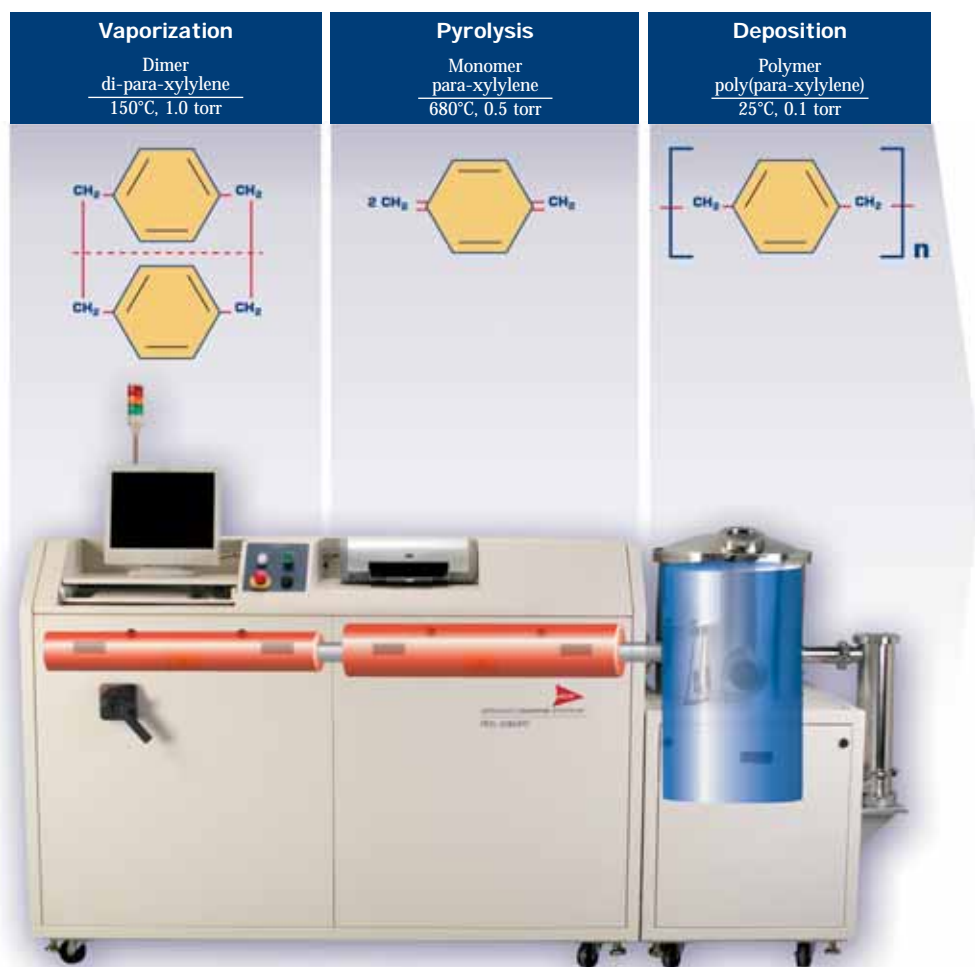


Parylene D



Parylene HT®

Figure 2. Parylene Vapor Deposition Polymerization (VDP)
(Parylene N illustrated)



The Deposition Process

The Parylene polymers are deposited by a process which in some respects resembles vacuum metallizing. Unlike vacuum metallization, however, which is conducted at pressures of 10^{-5} torr or below, the Parylenes are formed at around 0.1 torr. Under these conditions, the mean free path of the gas molecules in the deposition chamber is on the order of 0.1 cm. The deposition is not line of sight, and all sides of an object to be coated are uniformly impinged by the gaseous monomer, which results in a truly conformal, pinhole-free coating. Parylene deposition equipment can be configured to meet the requirements of the substrates to be coated. Substrates are required to have only a reasonable vacuum tolerance.

The deposition process consists of three distinct steps as outlined in Figure 2.

The first step is the vaporization of the solid dimer at approximately 150°C. The second step is the quantitative cleavage (pyrolysis) of the dimer vapor at the two methylene-methylene bonds at about 680°C to yield the stable monomeric diradical, para-xylylene. Finally, the monomeric vapor enters the room temperature deposition chamber where it spontaneously polymerizes on the substrate. The substrate temperature never rises more than a few degrees above ambient.

No liquid phase has ever been isolated, therefore Parylene suffers none of the fluid effects that can cause pooling, flowing, bridging, meniscus or edge-effect flaws. Parylene also contains no solvents, catalysts or plasticizers that can leach or outgas from the coating.

Properties

The electrical, barrier, mechanical, thermal, optical, biocompatibility and other properties of Parylenes N, C, D and Parylene HT are discussed below. These properties are compared to those reported for other conformal coating materials such as acrylics, epoxies, polyurethanes and silicones.

A. Electrical Properties

The electrical properties of Parylene are shown in Table 1.

1. Thin Film Dielectric Properties

One of the features of Parylene coatings is that they can be formed in extremely thin layers. The breakdown AC voltages of Parylene N, C and Parylene HT films have been determined as a function of polymer thickness. The data in Table 1 show that Parylenes have excellent dielectric withstanding voltages. It has also been demonstrated that the voltage breakdown per unit thickness increases with decreasing film thickness.

2. Circuit Board Insulation Resistance

A critical test of the protection afforded by a Parylene coating is to coat circuit board test patterns (as described in MIL-I-46058C) and subject them to insulation resistance measurements during a temperature-humidity cycle (MIL-STD-202, methods 106 and 302). In brief, this test consists of 10 cycles (one cycle per day), with each cycle consisting of seven steps. The seven steps range from low temperature, low humidity (25°C, 50% RH) to more severe conditions (65°C, 90% RH). Resistance readings are taken initially and at the 65°C, 90% RH step for each cycle of the 10-day test.

Results are shown in Table 2 for Parylene C coating thicknesses from 50.8 μm to 2.5 μm . It is interesting to note that even for the very thin coatings (2.5 μm), the insulation resistance values are about one order of magnitude above the prescribed specification.

B. Barrier Properties and Chemical Resistance

1. Barrier

The barrier properties of the Parylenes are given in Table 3. The water vapor transmission rates (WVTR) are again compared with those of other conformal coating materials. The WVTR for Parylene C is superior to the most common polymeric materials.

Circuit boards coated with SCS Parylene HT were salt-fog tested by an independent testing facility. The coated boards showed no corrosion or salt deposits after 144 hours of exposure in accordance with ASTM B117-(03) (See Figure 3). Boards coated with Parylene C exhibited similar results.

2. Chemical Resistance

The Parylenes resist room temperature chemical attack and are insoluble in all organic solvents up to 150°C. Parylene C can be dissolved in chloro-napthalene at 175°C, and Parylene N softens at the solvent's boiling point (265°C). Both polymers are resistant to permeation by most solvents. Parylene HT films do not swell significantly with exposure to automotive chemicals and fluids, and there are no perceivable changes in the film's optical or mechanical properties.

Figure 3. Circuit boards after 144 hours of salt-fog exposure



Coated with SCS Parylene HT



Uncoated

Table 1. Parylene Electrical Properties

Properties	Method	Parylene N	Parylene C	Parylene D	Parylene HT	Acrylic (AR) ^{a,b}	Epoxy (ER) ^{a,b}	Polyurethane (UR) ^{a,b}	Silicone (SR) ^{a,b}
Dielectric Strength V/mil	1	7,000	5,600	5,500	5,400	3,500	2,200	3,500	2,000
Volume Resistivity, ohm-cm, 23°C, 50% RH	2	1.4×10^{17}	8.8×10^{16}	1.2×10^{17}	2.0×10^{17}	1.0×10^{15}	1.0×10^{16}	1.0×10^{13}	1.0×10^{15}
Surface Resistivity, ohms, 23°C, 50% RH	2	1.0×10^{13}	1.0×10^{14}	1.0×10^{16}	5.0×10^{15}	1.0×10^{14}	1.0×10^{13}	1.0×10^{14}	1.0×10^{13}
Dielectric Constant									
60 Hz	3	2.65	3.15	2.84	2.21	–	3.3 – 4.6	4.1	3.1 – 4.2
1 KHz		2.65	3.10	2.82	2.20	–	–	–	–
1 MHz		2.65	2.95	2.80	2.17	2.7 – 3.2	3.1 – 4.2	3.8 – 4.4	3.1 – 4.0
Dissipation Factor									
60 Hz	3	0.0002	0.020	0.004	<0.0002	0.04 – 0.06	0.008 – 0.011	0.038 – 0.039	0.011 – 0.02
1 KHz		0.0002	0.019	0.003	0.0020	–	–	–	–
1 MHz		0.0006	0.013	0.002	0.0010	0.02 – 0.03	0.004 – 0.006	0.068 – 0.074	0.003 – 0.006

^aHandbook of Plastics, Elastomers, and Composites, Chapter 6, "Plastics in Coatings and Finishes," 4th Edition, McGraw Hill, Inc., New York, 2002.

^bConformal Coating Handbook, Humiseal Division, Chase Corporation, Pennsylvania, 2004.

Test Methods:

1. ASTM D 149
2. ASTM D 257
3. ASTM D 150

(International conversion chart on back cover.)

Table 2. Parylene C Circuit Board Screening

Insulation Resistance (ohms), MIL-STD-202, method 302

Parylene Thickness (μm)	Initial Measurement	Precycle	Step 5 Cycle 3	Step 5 Cycle 7	Step 5 Cycle 10	Step 7 Cycle 10
	25°C, 50% RH	25°C, 90% RH	65°C, 90% RH	65°C, 90% RH	65°C, 90% RH	25°C, 90% RH
50.8	2.0×10^{14}	1.8×10^{13}	2.3×10^{12}	2.5×10^{11}	1.4×10^{11}	7.5×10^{12}
38.1	5.0×10^{14}	2.4×10^{13}	8.6×10^{11}	1.9×10^{11}	1.1×10^{11}	5.2×10^{12}
25.4	2.0×10^{14}	9.2×10^{12}	8.1×10^{11}	3.4×10^{11}	1.3×10^{11}	6.3×10^{12}
12.7	5.0×10^{14}	2.3×10^{13}	4.1×10^{12}	2.4×10^{11}	1.1×10^{11}	4.7×10^{12}
7.6	5.0×10^{14}	2.7×10^{13}	4.4×10^{12}	9.0×10^{10}	4.7×10^{10}	2.9×10^{12}
2.5	5.0×10^{14}	3.2×10^{10}	1.3×10^{11}	1.1×10^{11}	6.4×10^{10}	2.3×10^{12}

(International conversion chart on back cover.)

Table 3. Parylene Barrier Properties

Polymer	Gas Permeability at 25°C, (cc·mm)/(m ² ·day·atm) ^a				Water Vapor Transmission Rate (g·mm)/(m ² ·day)
	N ₂	O ₂	CO ₂	H ₂	
Parylene N	3.0	15.4	84.3	212.6	0.59 ^b
Parylene C	0.4	2.8	3.0	43.3	0.08 ^c
Parylene D	1.8	12.6	5.1	94.5	0.09 ^b
Parylene HT	4.8	23.5	95.4	–	0.22 ^d
Acrylic (AR)	–	–	–	–	13.9 ^e
Epoxy (ER)	1.6	2.0 – 3.9	3.1	43.3	0.94 ^e
Polyurethane (UR)	31.5	78.7	1,181	–	0.93 – 3.4 ^e
Silicone (SR)	–	19,685	118,110	17,717	1.7 – 47.5 ^e

^aASTM D 1434

^bASTM E 96 (at 90% RH, 37°C)

^cASTM F 1249 (at 90% RH, 37°C)

^dASTM F 1249 (at 100% RH, 38°C)

^eCoating Materials for Electronic Applications, Licari, J.J., Noyes Publications, New Jersey, 2003.

(International conversion chart on back cover.)

C. Thermal, Cryogenic, Vacuum and Sterilization Properties

1. Thermal

Based on an Arrhenius extrapolation of test data, Parylene C is expected to survive continuous exposure to air at 80°C for 10 years (100,000 hours). In oxygen-free atmospheres, or in the vacuum of space, the Parylenes are expected to perform similarly on continuous exposure to 220°C. Parylene HT has been demonstrated to survive continuous exposure to air at 350°C.

In all cases, higher temperature shortens useful life. If the requirements for your application are near or exceed this time-temperature-atmospheric conditions envelope, it is recommended that you test the complete structure under conditions more closely resembling the actual conditions of intended use.

Parylene may be annealed to increase cut-through resistance, increase hardness and improve abrasion resistance. This is the result of polymer density and an increase in crystallinity.

General thermal properties are summarized in Table 4.

2. Cryogenic

Unsupported 50.8 μm films of Parylene C can be flexed 180° six times at -200°C before failure occurs. Comparable films of polyethylene, polyethylene terephthalate and polytetrafluoroethylene fail at three, two and one flexes, respectively.

Steel panels coated with Parylene C and chilled in liquid nitrogen at -196°C withstood impacts of more than 11.3 N·m in a modified Gardner falling ball impact test. This compares with values of about 28.2 N·m at room temperature.

Supported films of Parylene N withstand thermal cycling from room temperature to -269°C without crackling, peeling from substrate, or degrading of electrical properties.

3. Vacuum Stability

Vacuum tests conducted at the Jet Propulsion Laboratory show that total weight loss at 49.4°C and 10^{-6} torr was 0.12% for Parylene C and 0.30% for Parylene N. Volatile collectible, condensable material values were less than 0.01% (the limit of sensitivity of the test) for both polymers.

4. Parylene Sterilization

Parylenes N and C were exposed to a variety of sterilization methods including steam autoclave, gamma and e-beam irradiation, hydrogen peroxide plasma, and ethylene oxide. Post-sterilization analysis compared the impact of these agents on sterilized samples versus unsterilized control samples. Further details on the sterilization tests can be reviewed in the SCS Biomedical Technologies brochure.

D. Physical and Mechanical Properties

Physical and mechanical properties of the Parylenes are summarized in Table 5. Because of their high molecular weight (~500,000) and because the melting temperatures and crystallinity are high, the Parylenes cannot be formed by conventional methods such as extrusion or molding. Solubility in organic or other media, except at temperatures above 175°C, is so low that they cannot be formed by casting.

Impact resistance is high when the Parylene polymers are supported on test panels. Gardner falling ball impact tests on 25.4 μm thick Parylene C coated steel "Q" panels are in the 28.2 N·m range.

Wear index values (measured on a Taber® Abraser machine using CS-17 "Calibrase" wheel with 1,000 gram weight) were 22.5 for Parylene C and 8.8 for Parylene N. By comparison, polytetrafluoroethylene is 8.4, high impact polyvinylchloride is 24.4, epoxy is 41.9 and polyurethane is 59.5.

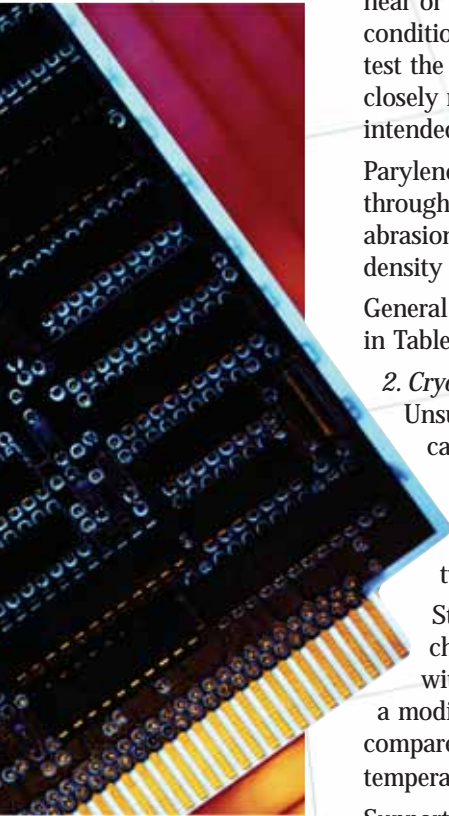


Table 4. Parylene Thermal Properties

Properties	Method	Parylene N	Parylene C	Parylene D	Parylene HT	Acrylic (AR)	Epoxy (ER)	Polyurethane (UR)	Silicone (SR)
Melting Point (°C) ^a	1	420	290	380	>500	85 – 105 ^b	NA	~170 ^b	NA
T5 Point (°C) (modulus = 690 MPa)	2, 3	160	125	125	377	–	110	~30	~125
T4 Point (°C) (modulus = 70 MPa)	2, 3	>300	240	240	>450	–	120	–	~80
Continuous Service Temperature (°C)	–	60	80	100	350	82 ^b	177 ^b	121 ^b	260 ^b
Short-Term Service Temperature (°C)	–	80	100	120	450	–	–	–	–
Linear Coefficient of Thermal Expansion at 25°C (ppm)	4	69	35	38	36	55 – 205 ^{b,c}	45 – 65 ^{b,c}	100 – 200 ^{b,c}	250 – 300 ^{b,c}
Thermal Conductivity at 25°C (W/(m•K))	5, 6	0.126	0.084	–	0.096	0.167 – 0.21 ^{c,d}	0.125 – 0.25 ^{c,d}	0.11 ^{c,d}	0.15 – 0.31 ^{c,d}
Specific Heat at 20°C (J/(g•K))	–	0.837	0.712	–	1.04	1.04 ^b	1.05 ^b	1.76 ^b	1.46 ^b

^aThe temperature at which heat flow properties show signs of change.

^b*Handbook of Plastics, Elastomers, and Composites*, Chapter 6,

^c*Plastics in Coatings and Finishes*, 4th Edition, McGraw Hill, Inc., New York, 2002.

^d*Coating Materials for Electronic Applications*, Licari, J.J., Noyes Publications, New Jersey, 2003.

^e*Lange's Handbook of Chemistry*, 5th Edition, McGraw Hill, Inc., New York, 1999.

Test Methods:

1. DSC
2. Taken from Secant modulus-temperature curve (except Parylene HT)
3. ASTM 5026 (Parylene HT only)
4. TMA
5. ASTM C 177 (except Parylene HT)
6. ASTM 1461 (Parylene HT only)

(International conversion chart on back cover.)

Table 5. Parylene Physical and Mechanical Properties

Properties	Method	Parylene N	Parylene C	Parylene D	Parylene HT	Acrylic (AR) ^{a,b}	Epoxy (ER) ^{a,b}	Polyurethane (UR) ^{a,b}	Silicone (SR) ^{a,b}
Secant (Young's) Modulus (psi)	1, 2	350,000	400,000	380,000	370,000	2,000 – 10,000	350,000	1,000 – 100,000	900
Tensile Strength (psi)	3	7,000	10,000	11,000	7,500	7,000 – 11,000	4,000 – 13,000	175 – 10,000	350 – 1,000
Yield Strength (psi)	3	6,100	8,000	9,000	5,000	–	–	–	–
Elongation to Break (%)	3	Up to 250	Up to 200	Up to 200	Up to 200	2 – 5.5	3 – 6	>14	100 – 210
Yield Elongation (%)	3	2.5	2.9	3.0	2.0	–	–	–	–
Density (g/cm ³)	4	1.10 – 1.12	1.289	1.418	1.32	1.19	1.11 – 1.40	1.10 – 2.50	1.05 – 1.23
Index of Refraction (n _D ²³)	5, 6	1.661	1.639	1.669	1.559	1.48	1.55 – 1.61	1.50 – 1.60	1.43
Water Absorption (% after 24 hrs)	7	Less than 0.1	Less than 0.1	Less than 0.1	Less than 0.01	0.3	0.05 – 0.10	0.6 – 0.8	0.1
Rockwell Hardness	8	R85	R80	R80	R122	M68 – M105	M80 – M110	68A – 80D (Shore)	40A – 45A (Shore)
Coefficient of Friction Static	9	0.25	0.29	0.33	0.15	–	–	–	–
Dynamic		0.25	0.29	0.31	0.13	–	–	–	–

^a*Coating Materials for Electronic Applications*, Licari, J.J., Noyes Publications, New Jersey, 2003.

^b*Handbook of Plastics, Elastomers, and Composites*, Chapter 6,

^c*Plastics in Coatings and Finishes*, 4th Edition, McGraw Hill, Inc., New York, 2002.

Test Methods:

1. ASTM D 882 (except Parylene HT)
2. ASTM D 5026 (Parylene HT only)
3. ASTM D 882
4. ASTM D 1505
5. Abbe Refractometer (except Parylene HT)
6. ASTM D 542 (Parylene HT only)
7. ASTM D 570
8. ASTM D 785
9. ASTM D 1894

(International conversion chart on back cover.)

E. Optical Properties and Radiation Resistance

1. Optical Properties

Parylene exhibits very little absorption in the visible region and is, therefore, transparent and colorless. Below wavelengths of about 280 nm, all the Parylenes absorb strongly, as shown in Figure 4.

The Fourier Transform infrared spectra for 12.7 μm Parylene films are shown in Figures 5, 6, 7 and 8.

2. Radiation Resistance

Parylenes N, C, D and Parylene HT films show a high degree of resistance to degradation by

gamma rays in vacuum. Tensile and electrical properties were unchanged after 1,000 kGy dosage at a dose rate of 16 kGy/hr. Exposure in air leads to rapid embrittlement.

Although stable indoors, Parylenes N, C and D are not recommended for long-term use when exposed to direct sunlight (UV light). Parylene HT exhibits significant resistance to UV light, with no property degradation from accelerated exposures of up to 2,000 hours in air.

Figure 4. Ultraviolet Spectra of Parylenes N, C, D and Parylene HT

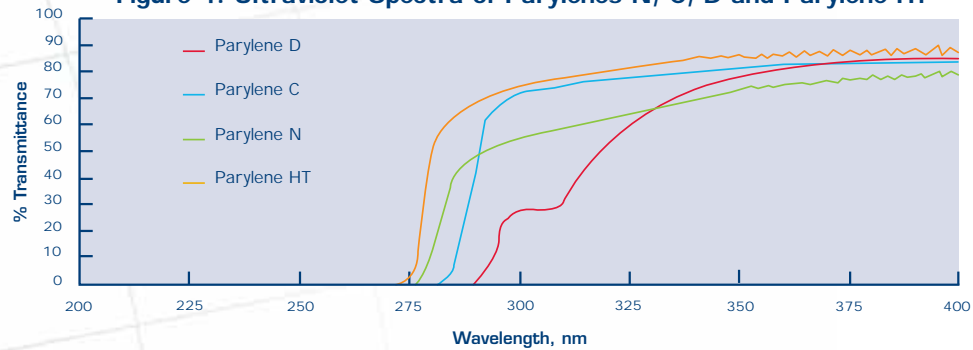


Figure 5. FTIR Absorbance Spectrum of Parylene N

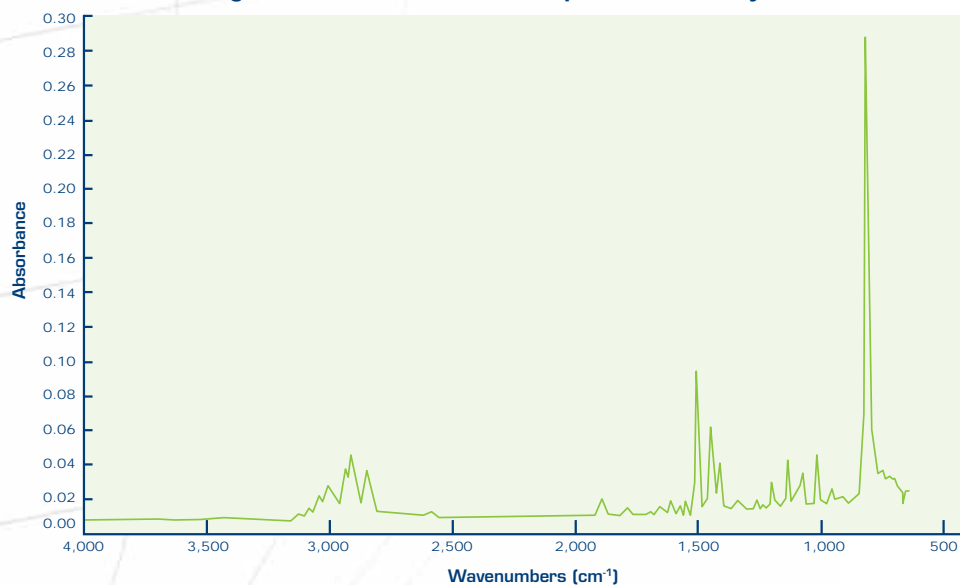


Figure 6. FTIR Absorbance Spectrum of Parylene C

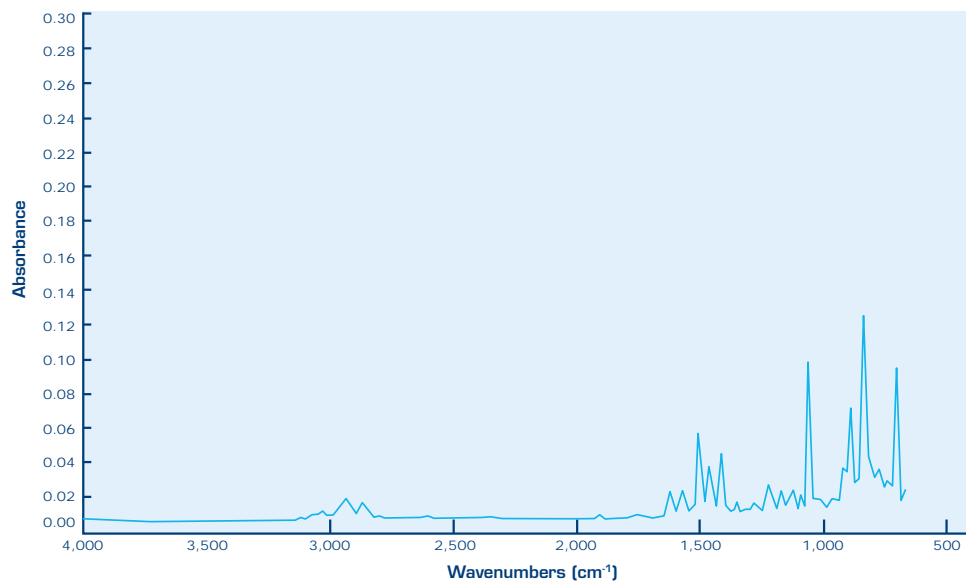


Figure 7. FTIR Absorbance Spectrum of Parylene D

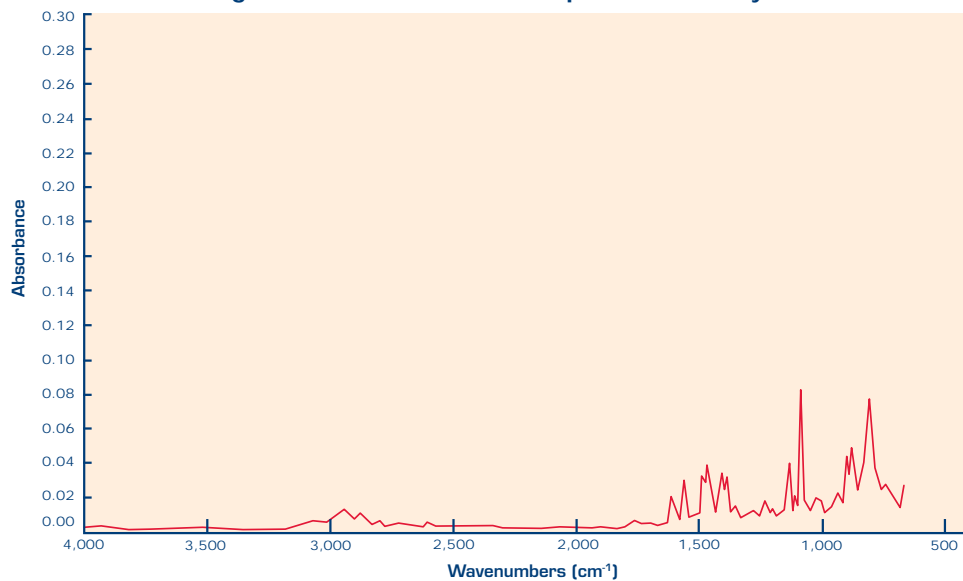
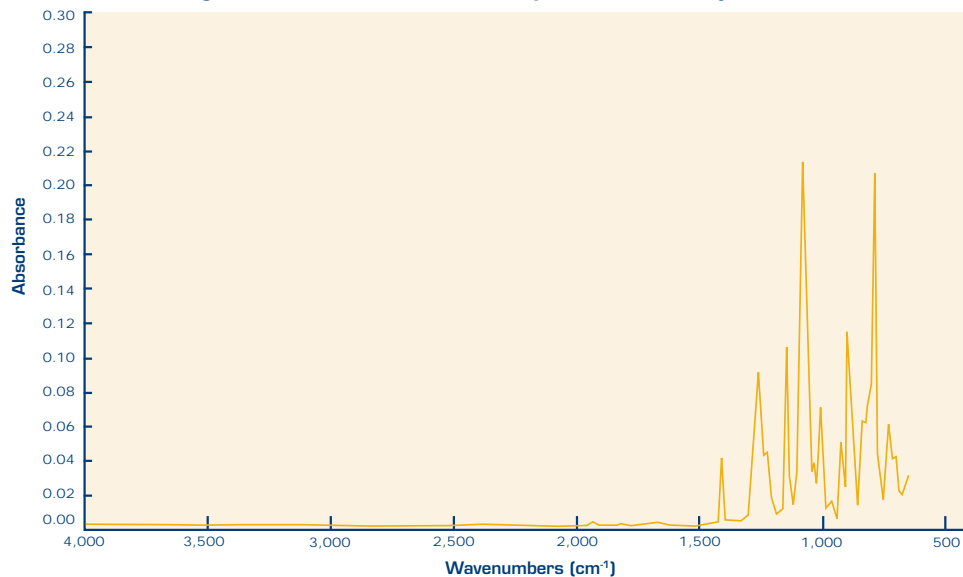


Figure 8. FTIR Absorbance Spectrum of Parylene HT



F. Biocompatibility and Biostability

SCS Parylenes N, C and Parylene HT have been tested according to the Biological Evaluations requirements of ISO 10993. Further, the biocompatibility and biostability of SCS Parylenes have been demonstrated in a wide range of medical coating applications over the past three decades.

Adhesion

Optimal adhesion of Parylene to a wide variety of substrates can be achieved by a simple treatment with a solution of an organic silane prior to Parylene coating. Silane pre-treatment techniques were originally developed for electronic components and assemblies and do not affect any of the substrate or coating properties. These adhesion promotion techniques are now applied to numerous other substrates. Silane can also be vapor phase applied if non-liquid application is preferable.

Applications

Automotive

Ultra-thin SCS Parylene coatings protect critical sensors, circuit boards and other electronic components from harsh chemicals, fluids and gases. They also protect components at high temperatures encountered during prolonged use in automotive and heavy-duty engines and systems.

Electronics

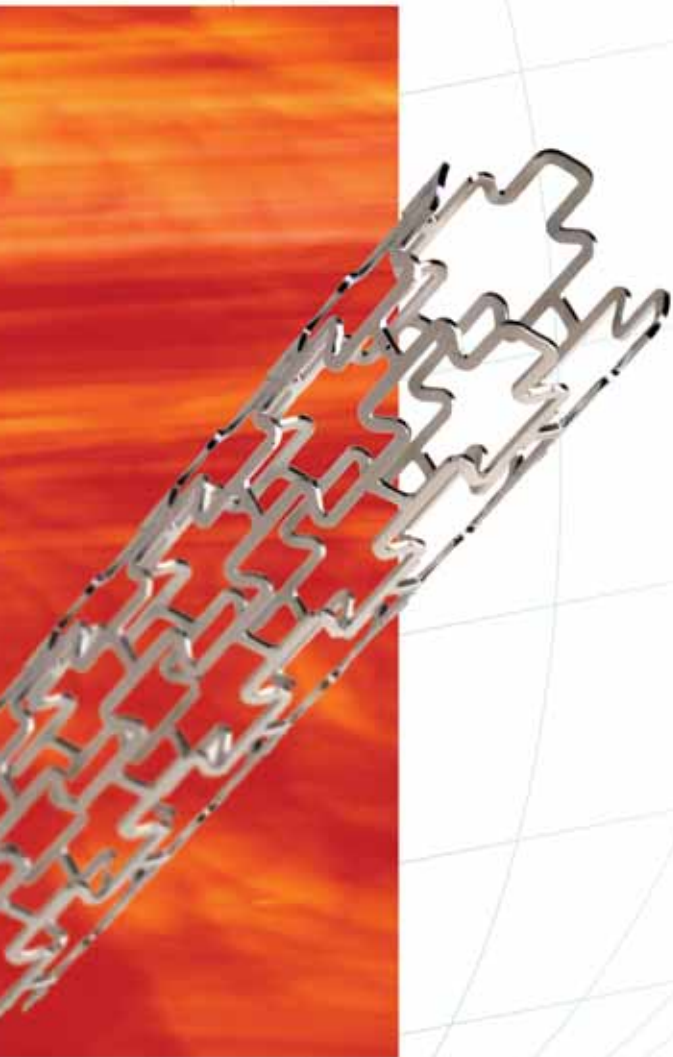
SCS Parylene coatings are conformal and uniform, ensuring complete coverage of circuit boards, ferrite cores and other electronics packages, such as MEMS, labs on chips and electrowetting lenses. SCS Parylene C coatings have been shown to suppress the formation of tin whiskers that can result from the use of pure tin plating.

Medical

SCS Parylenes, listed in the FDA's Biomaterials Compendium, provide an ideal surface modification for implantable and non-implantable devices such as catheters, seals, stents, cochlear implants, surgical tools, pacemakers and components. The coatings protect devices and components from moisture, biofluids and biogases and serves as a biocompatible surface for tissue contact.

Military/Aerospace

SCS Parylenes offer extreme tolerance of severe environments and are used in many military and aerospace applications, including equipment for international space programs. Parylene coatings are also excellent for electronics used in aerospace applications and military vehicles and equipment, to protect against elements such as dust, sand, moisture, and chemical and biological agents.



Stent courtesy of MeKo, Germany

Standards and Certifications

Each SCS customer has very unique and exact product and performance specifications that must be met. SCS experience and expertise is leveraged on every project – from the initial planning phases, to advanced engineering, to the development of customer-specific application processes – in order to meet the most challenging customer specifications and quality requirements.

The following is a brief overview of the standards and certifications to which SCS and/or SCS Parylene coatings comply:

- All U.S. and European coating facilities are ISO 9001:2000 certified.
- SCS maintains ISO 14644 cleanrooms.
- SCS coating centers are experienced in the Production Parts Approval Process (PPAP).
- SCS Parylenes N, C and Parylene HT are ISO 10993 and USP Class VI certified.
- SCS maintains comprehensive U.S. FDA Device and Drug Master Files that may be referenced in FDA submissions by SCS commercial coating service customers.
- SCS Parylenes meet the requirements of IPC-CC-830.
- SCS Parylenes are listed on the QPL for MIL-I-46058C.
- SCS Parylene C is UL (QMJU2) recognized.
- SCS Parylene coating services, raw materials and equipment comply with the European Union's RoHS Directive 2002/95/EC.

If you have any questions or would like more detail on the information presented here, please contact SCS.

Product Safety

Specialty Coating Systems has compiled the information contained herein from what it believes are authoritative sources and believes that it is accurate and factual as of the date printed. It is offered solely as a convenience to its customers and is intended only as a guide concerning the products mentioned. Because the user's product formulation, specific use application, and conditions of use are beyond SCS control, SCS makes no warranty or representation regarding the results that may be obtained by the user. It shall be the responsibility of the user to determine the suitability of any products mentioned for the user's specific application. SCS urges you to review, prior to use, the Material Safety Data Sheets (MSDS) for any SCS products mentioned herein. These documents are available by contacting SCS.

This information is not to be taken as a warranty or representation for which Specialty Coating Systems assumes legal responsibility nor as permission to practice any patented invention without a license.

Table 6. International Conversions

To convert g/cm ³ to kg/m ³ , multiply by 1,000.
To convert psi to MPa, divide by 145.
To convert J/(g•K) to Cal/(g•K), divide by 4.184.
To convert W/(m•K) to Cal/(s•cm•K), divide by 418.4.
To convert (g•mm)/(m ² •day) to (g•mil)/(100in ² •day), multiply by 2.54.
To convert (cc•mm)/(m ² •day•atm) to (cc•mil)/(100in ² •day•atm), multiply by 2.54.

Innovative solutions for advanced technologies.

Specialty Coating Systems leads the industry in providing Parylene solutions for our global customers' advanced technologies. SCS is the direct descendant of the companies that originally developed Parylene, and we have more than 35 years of experience and expertise that we leverage on every project for our customers – from the initial planning phases, to advanced engineering, to the development of application processes.

Our worldwide resources include highly experienced sales engineers, some of the world's foremost Parylene specialists, and expert manufacturing personnel working in nine state-of-the-art coating facilities around the globe. In addition to Parylene coating services, we design and manufacture industry-leading Parylene deposition systems; liquid spray, dip and spin coating systems; ionic contamination test systems; and UV and thermal cure units. Our equipment is used in environments that range from small university and research labs to high-volume production applications.

Our extensive and proactive approach to production and quality requirements – testing, validating, documenting and processing – provides our customers peace of mind and minimizes their resources needed to meet the most challenging industry specifications and quality requirements.



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