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.

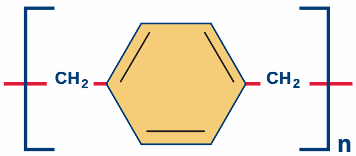
Parylene C, the second commercially available member of the series, is produced from the same raw material (dimer) as Parylene N, modified only by the substitution of a chlorine atom for one of the aromatic hydrogens. Parylene C has a useful combination of electrical and physical properties plus a very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

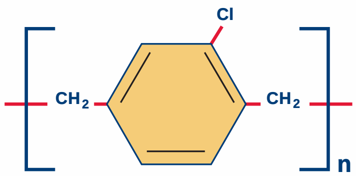
Parylene HT, the newest commercially available Parylene, replaces the alpha hydrogen atom of the N dimer with fluorine. This variant of Parylene is useful in high temperature applications (short-term up to 450°C) and those in which long-term UV stability is required. Parylene HT also has the lowest coefficient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

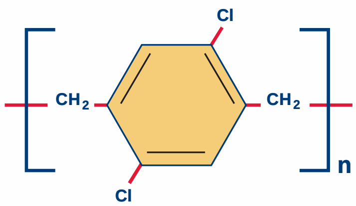
Figure 1. Parylenes N, C, D and Parylene HT Chemical Structures



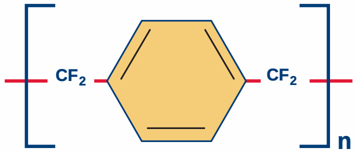
Parylene N



Parylene C

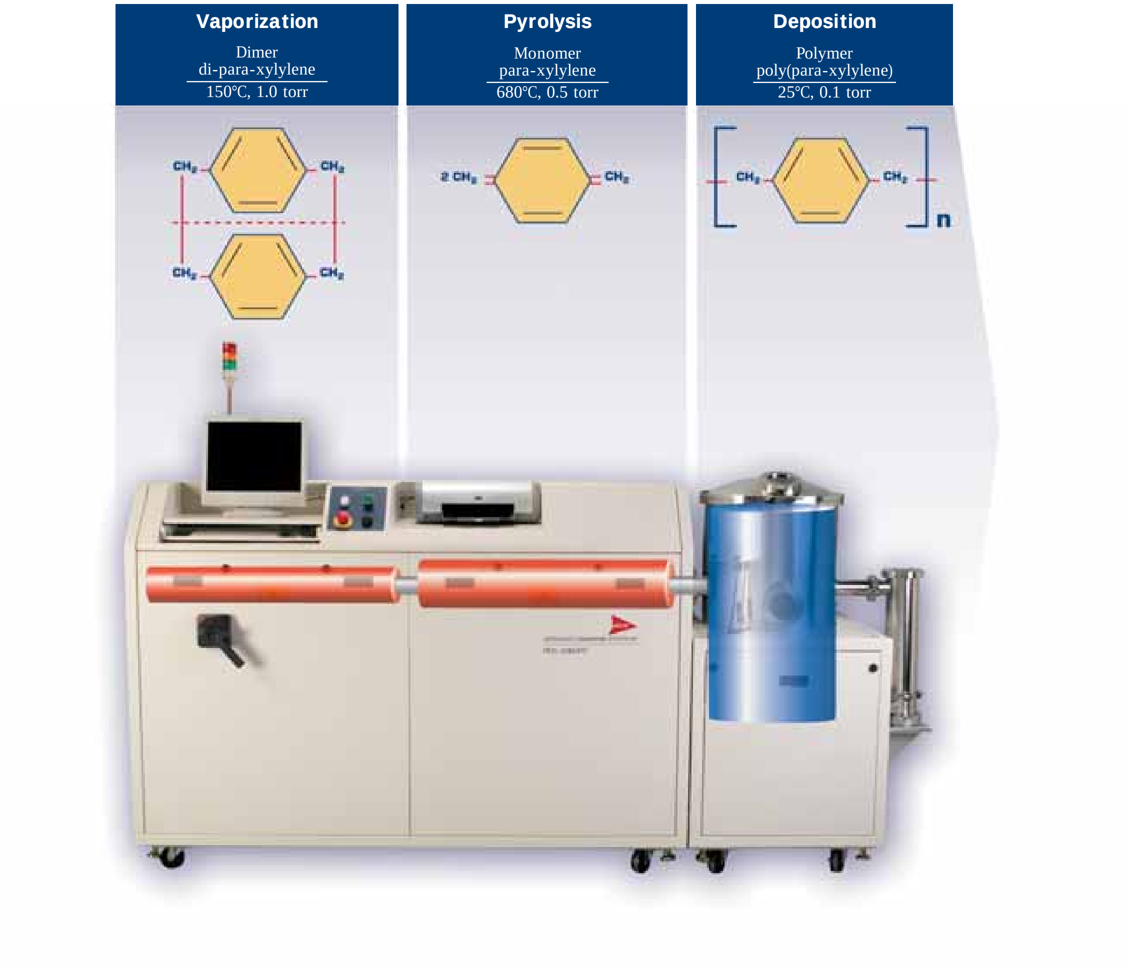


Parylene D



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.

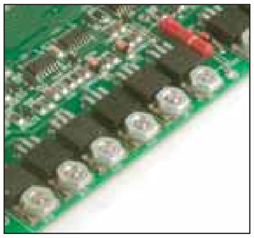
B. Barrier Properties and Chemical Resistance

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.

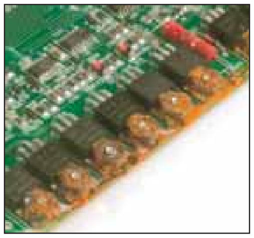
   Circuit boards coated with SCS Parylene HT were salt-fog tested by an independent testing facility. The coated boards showed no corrosion or salt deposits after 144 hours of exposure in accordance with ASTM B117-(03) (See Figure 3). Boards coated with Parylene C exhibited similar results.

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, 23ºC, 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, 23ºC, 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

[a] *Handbook of Plastics, Elastomers, and Composites*, Chapter 6, "Plastics in Coatings and Finishes," 4th Edition, McGraw Hill, Inc., New York, 2002.
[b] *Conformal 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
	25ºC, 50% RH	25ºC, 90% RH	65ºC, 90% RH	65ºC, 90% RH	65ºC, 90% RH	25ºC, 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 25ºC, (cc·mm) / (m²·day·atm)[a] N_2	O_2	CO_2	H_2	Water Vapor Transmission Rate (g·mm) / (m²·day)
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]

[a] ASTM D 1434
[b] ASTM E 96 (at 90% RH, 37ºC)
[c] ASTM F 1249 (at 90% RH, 37ºC)
[d] ASTM F 1249 (at 100% RH, 38ºC)
[e] *Coating Materials for Electronic Applications*, Licari, J.J., Noyes Publications, New Jersey, 2003.

(International conversion chart on back cover.)

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