SPECIALTY COATING SYSTEMS™
A KISCO Company

Advances in Sustainable Nanocoating Technologies for Electronics and Medical Applications

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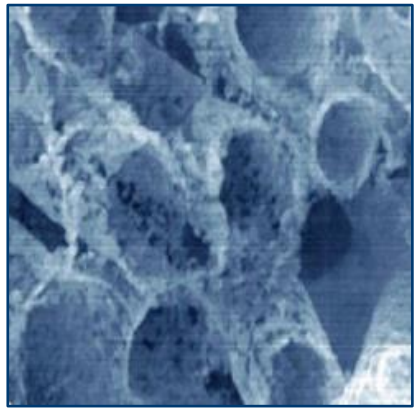
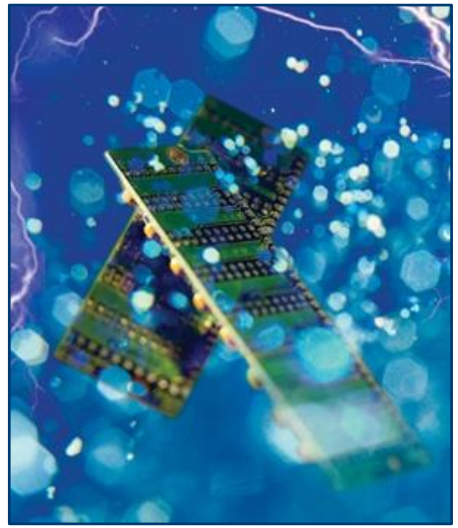
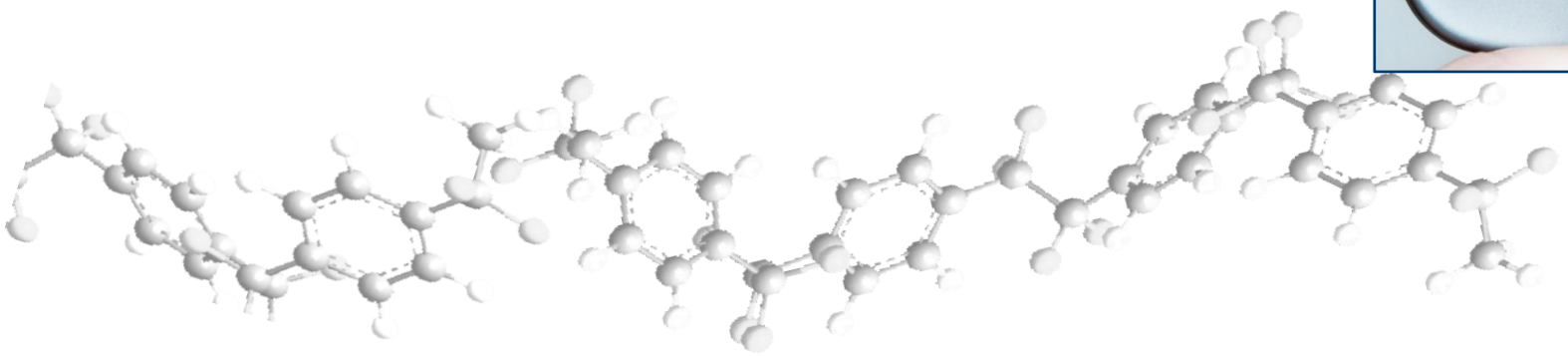
Outline

- Introduction
- Sustainable Nanocoating Technologies
  - Chemical vapor deposition coatings
  - Plasma polymerized coatings
  - Atomic layer deposition coatings
- Electronics and Medical Applications
  - Corrosion protection and reliability enhancement
  - Surface modifications
- Conclusion



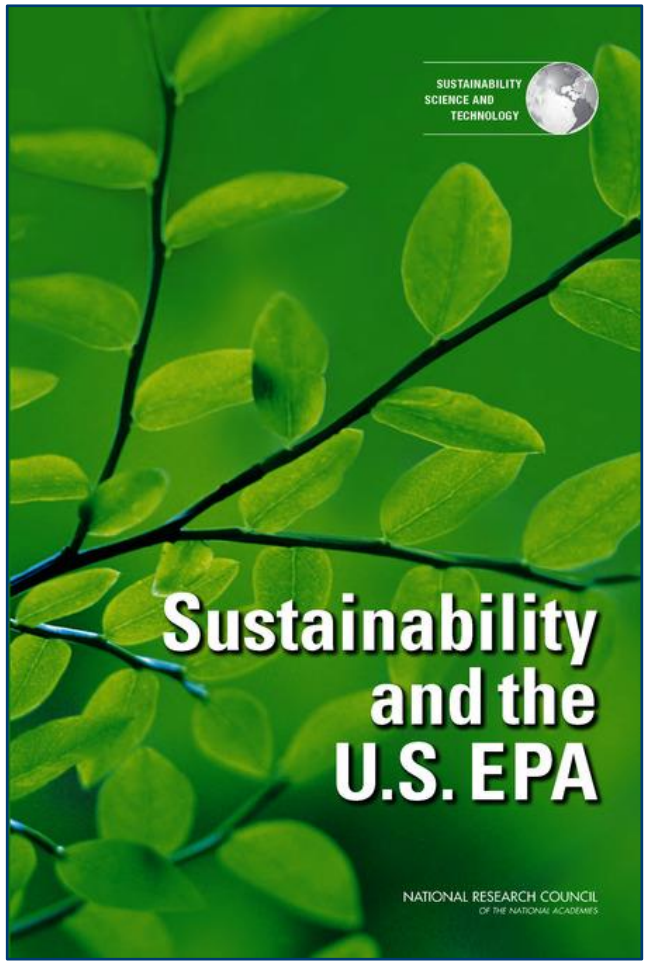




Introduction

- What is Sustainability
  - Sustainability is based on a simple principle: Everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. To pursue sustainability is to create and maintain the conditions under which humans and nature can exist in productive harmony to support present and future generations.

- What is Sustainable Manufacturing
  - Sustainable manufacturing is the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable manufacturing also enhances employee, community and product safety.



Reference: https://www.epa.gov/sustainability

Introduction: Sustainable Nanocoatings

- What are Nanocoatings?
  - Nanocoatings are ultra-thin layers or chemical structures that are built upon surfaces by a variety of methods. Some Nanocoatings are polymers, either polymerized in-situ or prior to application.
  - The term Nanocoating refers to nanoscale (i.e. with a thickness of a few tens to a few hundreds of nanometers) thin-films that are applied to surfaces in order create or improve a material's functionalities such as corrosion protection, water and moisture protection, friction reduction, antifouling and antibacterial properties, self-cleaning, heat and radiation resistance, and thermal management.
- What makes SCS Nanocoatings sustainable?
  - Greener alternative to solvent-based coatings
  - Made entirely from non-toxic martials
  - Less bulky in terms of packaging and delivery
  - Less energy-intensive than thermal drying ovens and contain no VOCs
  - RoHS, California Proposition 65, and REACH/SVHC Compliant
  - Eco-friendly manufacturing, low carbon foot print

Why Nanocoatings for Electronics & Medical Applications?

- Key Functions
  - Environmental protection
    - Corrosion, moisture, water, chemicals, contamination, handling and abrasion, temperatures, and radiation
  - Electrical insulation or isolation
    - Dielectric strength
    - Surface insulation resistance
  - Surface modifications
    - Splash proof
    - Biocompatible
    - Anti-stiction, low friction, abrasion resistance
  - Others
    - Electromagnetic Interference/Radio Frequency Interference shielding, ESD protection, stabilizing components and structures etc.

Adhesion of the coatings is critical to achieve these functions

SCS Sustainable Nanocoating Technologies

Chemical Vapor Deposition Parylene Coatings	PE Chemical Vapor Deposition Plasma Coatings	Atomic layer deposition(ALD) ALD+Parylene Coatings
Molecular level deposition	**Atomic level deposition**	**Atomic/molecular level deposition**
• Moisture & chemical barrier • Biocompatible • High dielectric strength • Chemically inert	• Water repellent • Hydrophobic • Low power insulating organic coating	• Dense • Smooth • Dielectric and insulating • Inorganic nanocoating
• Unique combination of performance, protection & durability characteristics	• Low cost, nanocoating for protection of consumer electronics and medical devices	• Improved corrosion resistance / barrier performance against water vapor and gases
Applications: Electronics, medical and other substrates for high reliability & protection	**Applications:** Consumer products (electronics, medical devices, flexible devices)	**Applications:** Consumer products (electronics, medical devices, flexible devices)

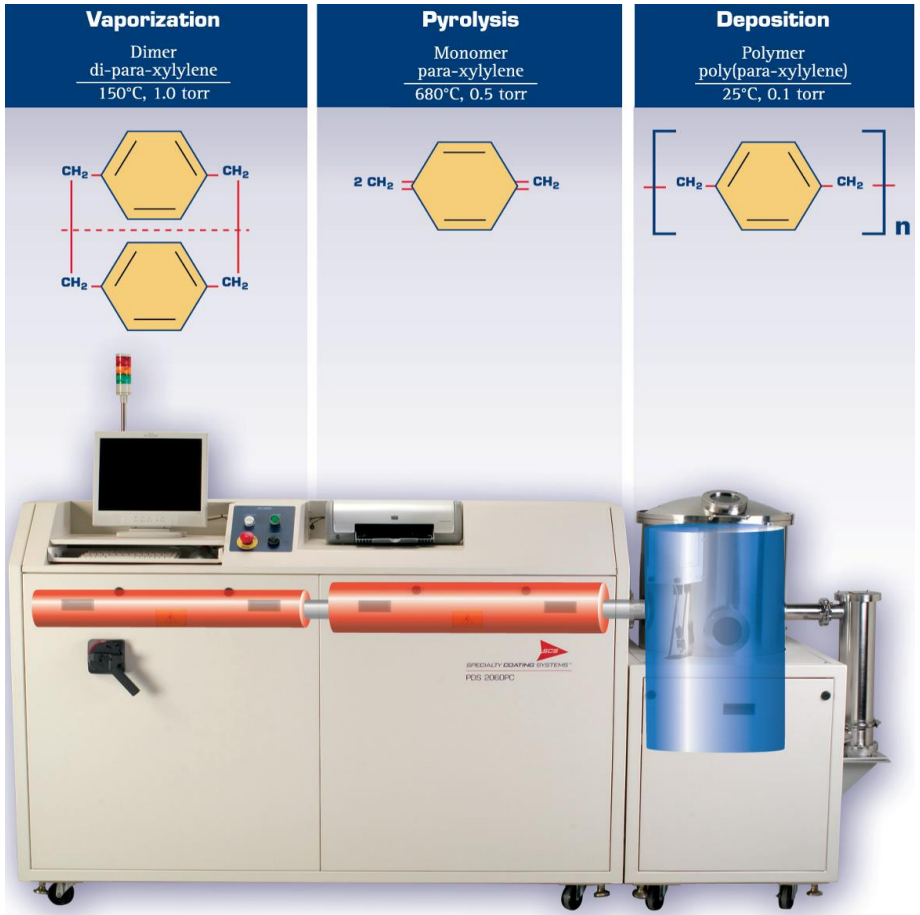
Chemical Vapor Deposition Coatings
Parylene Coatings

What is Parylene?

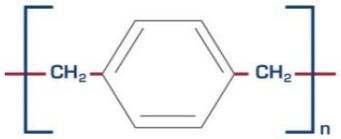
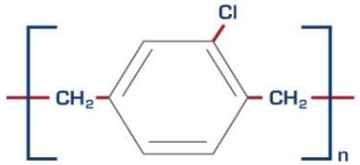
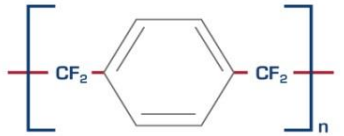
- A name that refers to a polymer series based on p-Xylylene

  POLY(PARA-XYLYLENE)

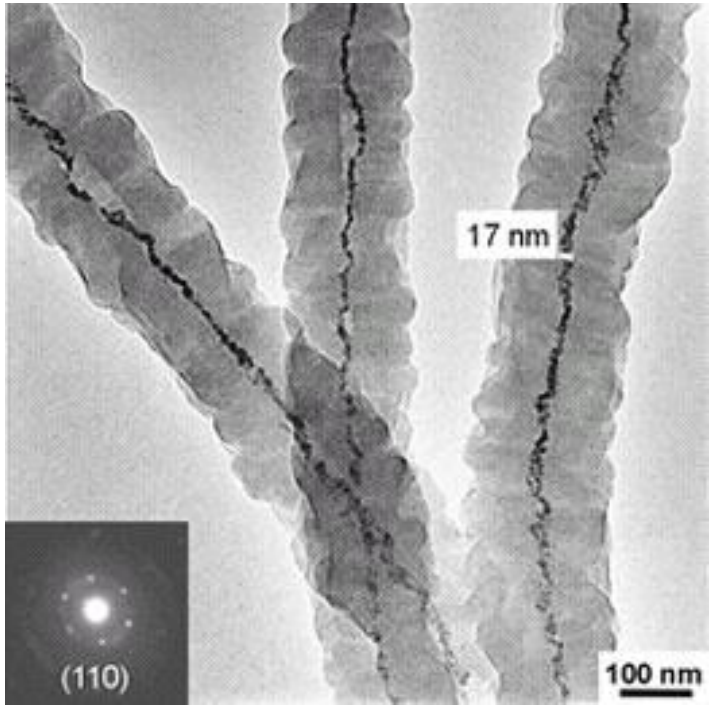
- A truly conformal, thin, optically clear, inert coating applied in a vacuum chamber at room temperature
- A non-line-of-sight coating that follows a molecular-level deposition process
- A chemically pure coating that does not use any catalysts or leachable materials



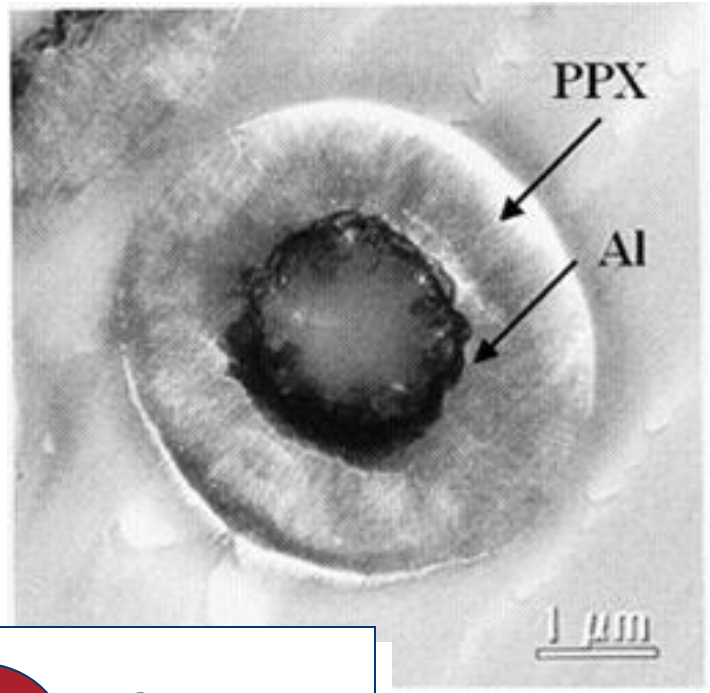
WW Commercially Available Sustainable Parylene Types

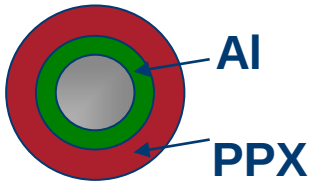
Parylene N	Parylene C	ParyFree	Parylene HT
		ParyFree® SCS Proprietary	
Dielectric strength: 7,000V @ 25µm Continuous service temp.: 60°C Short term (≤24 hrs.): 80°C Crevice penetration: 40X COF: 0.25 Certifications: • IPC-CC-830, MIL-I-46058C and listed on the QPL • **USP Class VI** • **ISO-10993 biological evaluation**	Dielectric strength: 5,600V @ 25µm Continuous service temp.: 80°C Short term (≤24 hrs.): 100°C Crevice penetration: 5X COF: 0.29 Excellent chemical resistance Lowest permeability to moisture and gases Certifications: • IPC-CC-830, MIL-I-46058C and listed on the QPL • **USP Class VI** • **ISO-10993 biological evaluation.**	Dielectric strength: 6900V @ 25µm Continuous service temp.: 60°C Short term (≤24 hrs.): 80°C Crevice penetration: 10X COF: 0.23 Excellent chemical resistance Lowest permeability to moisture and gases High Thermal Conductivity Certifications: • IPC-CC-830, MIL-I-46058C and listed on the QPL • **USP Class VI** • **ISO-10993 biological evaluation**	Dielectric strength: 5,400V @ 25µm Highest continuous service temp.: 350°C Short term (≤24 hrs.): 450°C Crevice penetration: 50X COF: 0.13 UV stable Lowest dielectric constant & dissipation factor Certifications: • IPC-CC-830, MIL-I-46058C and listed on the QPL • **USP Class VI** • **ISO-10993 biological evaluation**

Parylene Nanotubes



Palladium-Nanowire

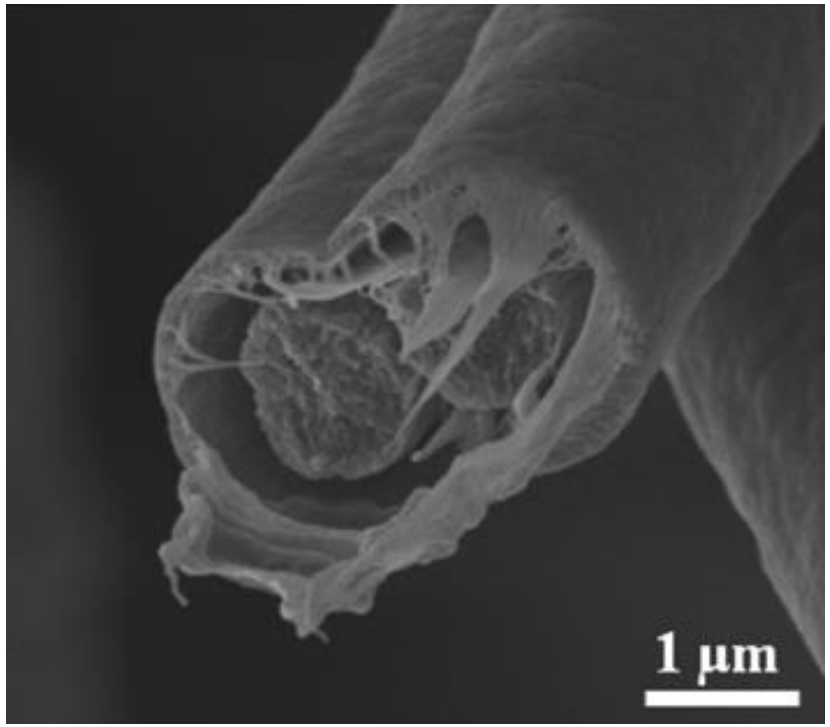


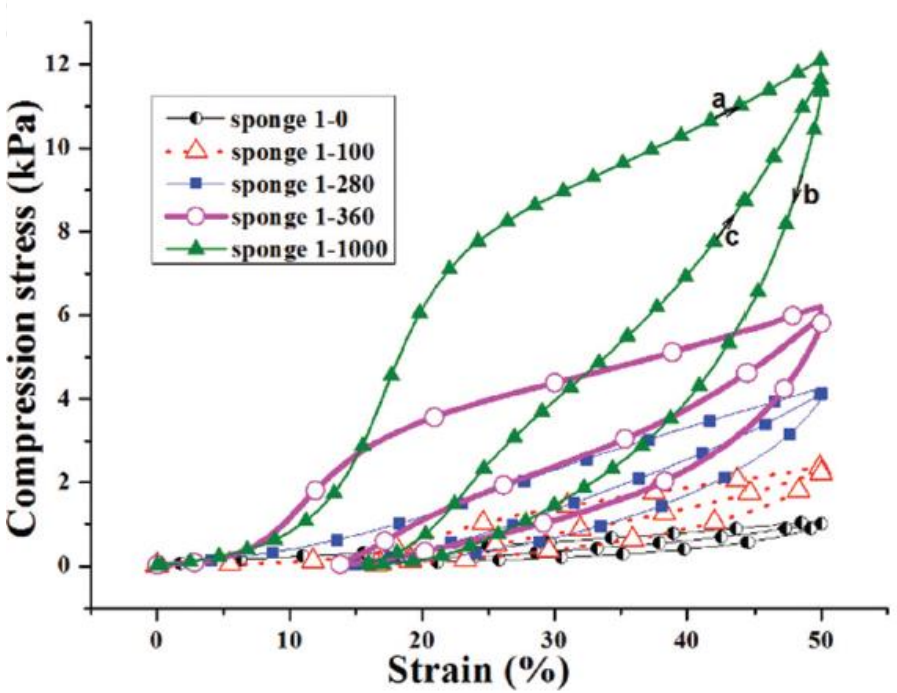


1. PLA template
2. PVD of Al
3. CVD of PPX
4. Degradation of PLA

Coating of Sponges by Paryelene

- Gain in mechanical and chemical stability by Parylene coating

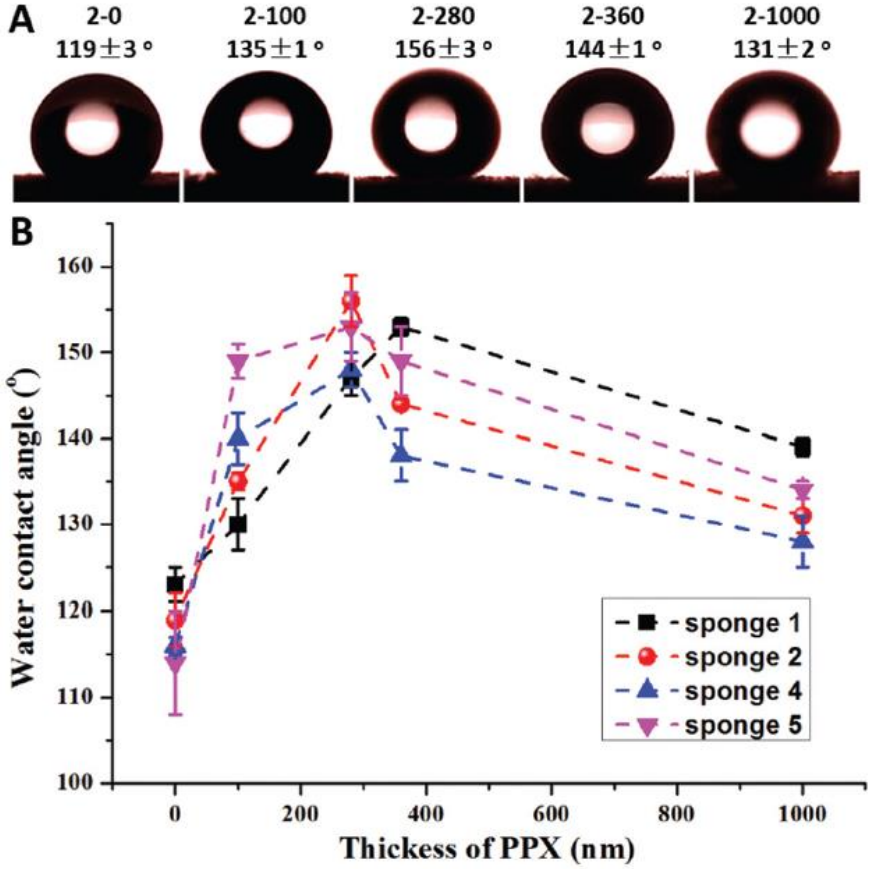




Reference: G. Duan et al. Polym. Chem., 2016, 7, 2759–2764

Coating of Sponges by Paryelene

- Super hydrophobic and excellent heat insulation



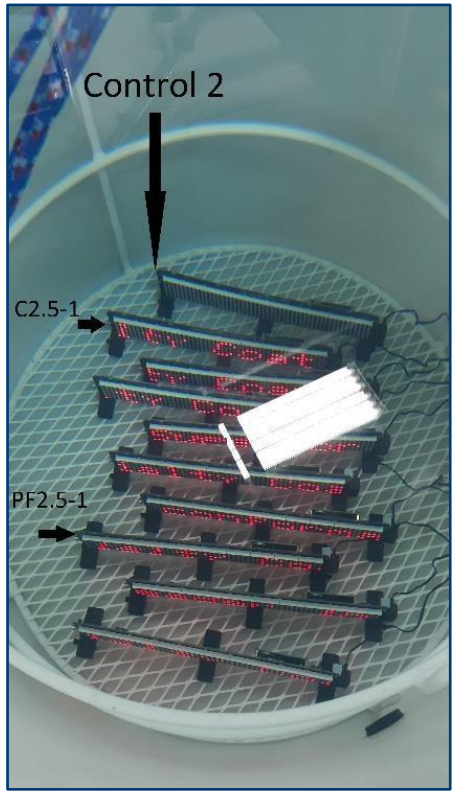
Thermal conductivity: 0.05 W (K m)$^{-1}$

Dry ice on human skin protected by sponge

Reference: G. Duan et al. Polym. Chem., 2016, 7, 2759–2764

IPX7 and IPX8 Designations: Water Immersion Test

- IPX7 and IPX8 designations
  - Per IEC 60529, test conditions 14.2.7 and 14.2.8 (independent lab)
  - IPX7 : 1.0 m deep, 30 min
  - IPX8 : 1.5 m deep, 30 min or defined by customer
- ParyFree-coated LED board

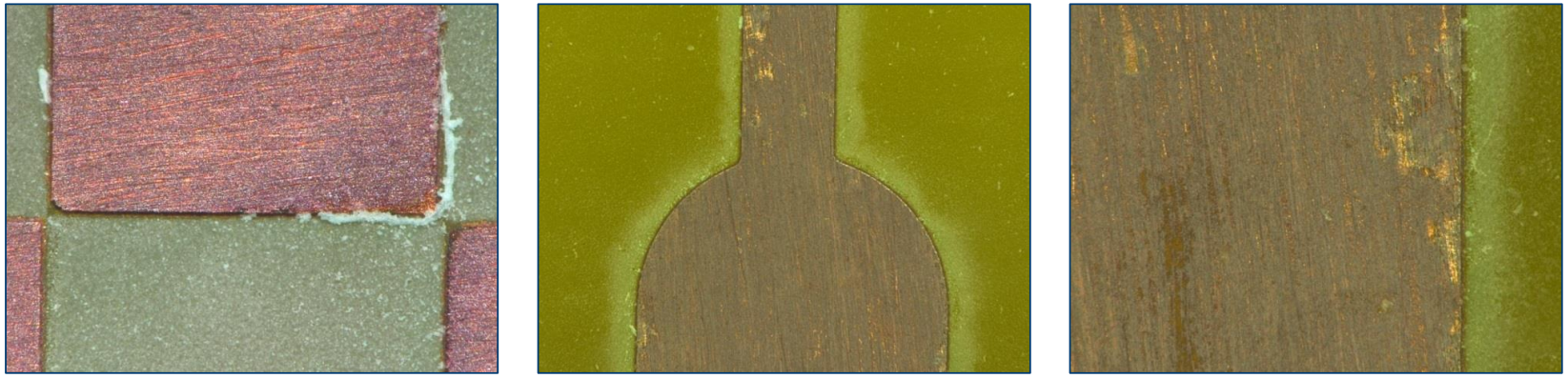


IPX8 :Submerged
1.5 m deep, 30 minutes

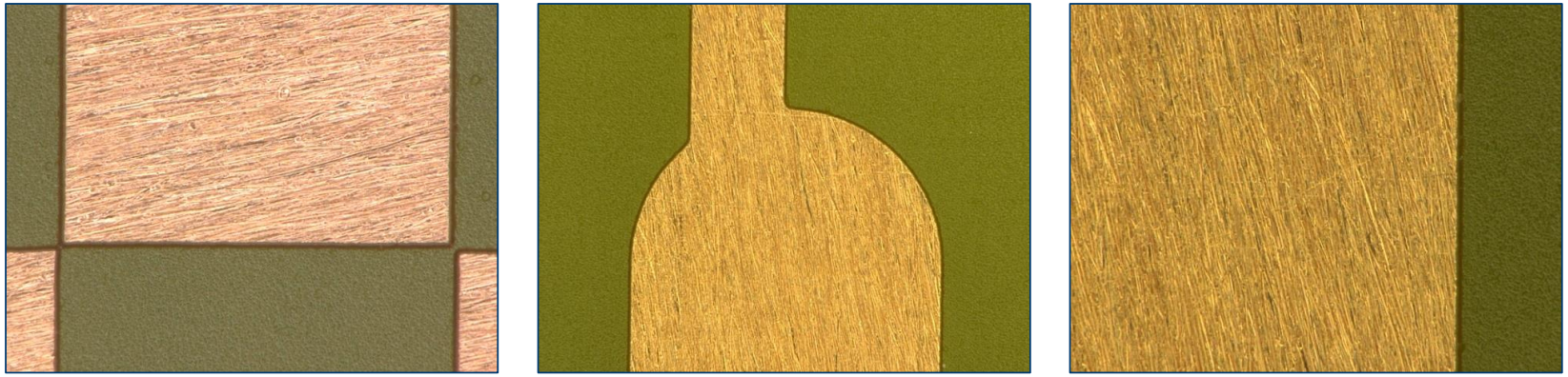
IPX8 : Post test
1.5 m deep, 30 minutes

Corrosion Resistance Test

- Salt Fog Exposure: 144 Hours – B25A



Uncoated (After)



ParyFree Coated (After)

Chemical Resistance Test

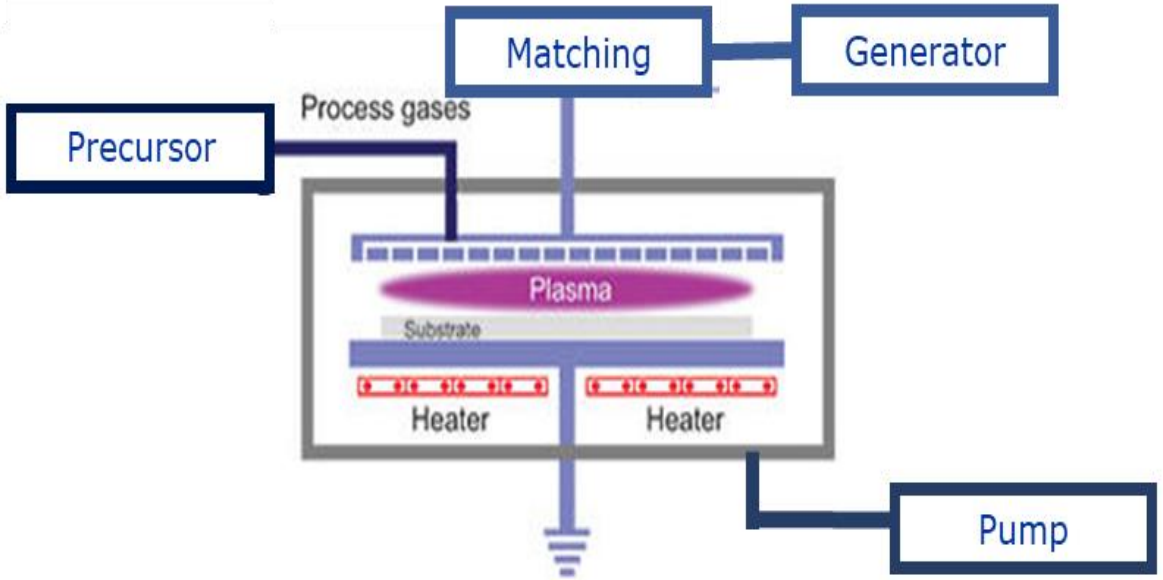
% Change in Thickness - 120 min (Ambient)				
Reagent	**Parylene C**	**ParyFree**	**Parylene N**	**Parylene HT**
Antifreeze	0.6	0.0	NT	2.5
Brake Fluid	0.8	0.0	NT	-0.5
Motor Oil	1.2	3.3	NT	1.2
Power Steering Fluid	1.0	0.0	NT	2.1
Transmission Fluid	2.0	2.3	NT	1.3
Windshield Washer Fluid	0.3	0.0	NT	1.3
Unleaded Gasoline	1.3	1.4	NT	1.1
Diesel Fuel	1.2	1.4	NT	2.8
10% Nitric Acid	-0.6	0.5	0.1	0.0
70% Nitric Acid	0.0	0.5	0.2	0.0
10% Sulfuric Acid	-0.5	-0.5	0.1	-0.6
95-98% Sulfuric Acid	0.0	0.0	0.2	0.6

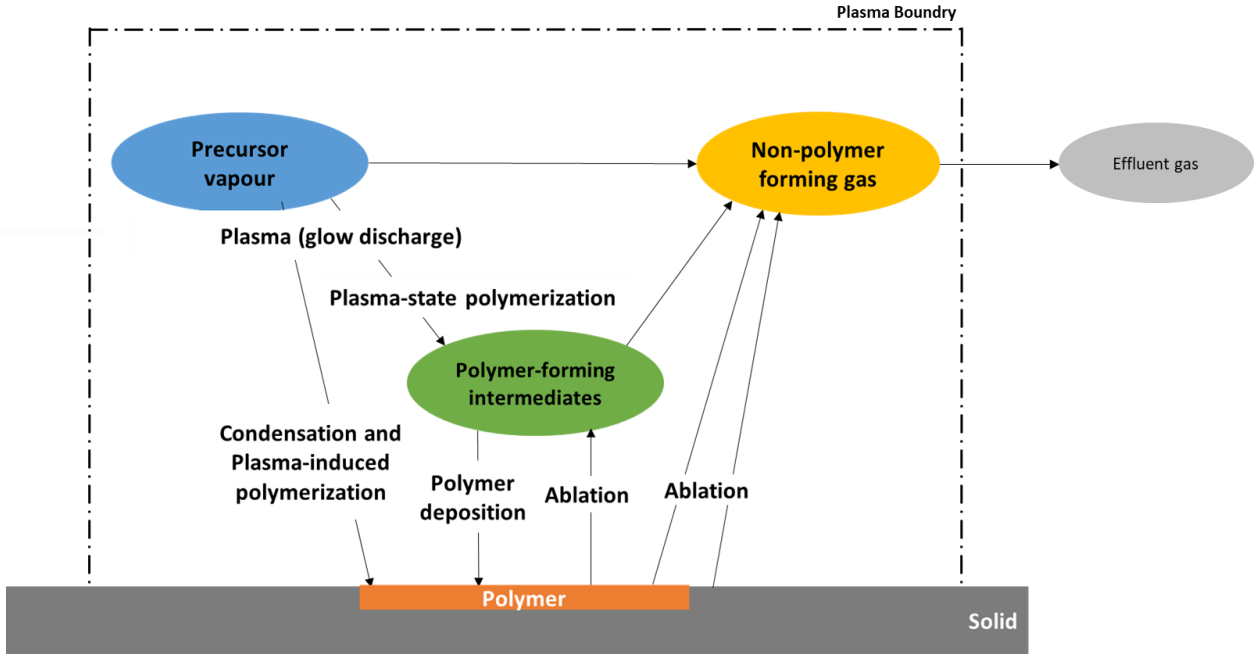
% Change in Thickness - 120 min (75°C)				
Reagent	**Parylene C**	**ParyFree**	**Parylene N**	**Parylene HT**
10% Nitric Acid	2.3	-0.9	0.2	-0.5
70% Nitric Acid	0.0	0.5	Brittle	-0.6
10% Sulfuric Acid	0.0	-0.5	0.2	-0.5
95-98% Sulfuric Acid	0.0	-0.5	5.3	0.0

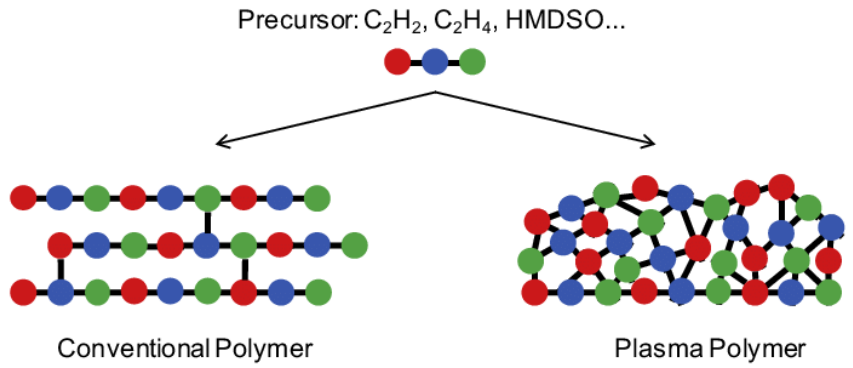
% Change in Thickness - 120 min (90°C)				
Reagent	**Parylene C**	**ParyFree**	**Parylene N**	**Parylene HT**
Antifreeze	-0.2	-0.9	NT	1.0
Motor Oil	0.2	0.0	NT	4.2
Transmission Fluid	0.9	0.0	NT	3.0

Plasma Polymerized Coatings

Plasma Coating Process







Reference:

https://www.samco.co.jp/en/technews/2020/stress-control-in-dual-frequency-pecvd.php

Yasuda, H. Plasma polymerization

Plasma Nanocoatings

Splash Proof Coating

- High water contact angle (>120°)
- Significantly reduces water ingress
- Z-axis conductive
- Excellent membrane breathability
- No audible impact on acoustics
- Biocompatible per ISO 10993-5
- Not hypersensitive per ISO 10993-10
- RoHS & REACH compliant
- Abrasion Resistant

Barrier Coating

- Exceeds IPX7 and IPX8 requirements
- Excellent dielectric properties
- Excellent chemical and moisture barrier
- Excellent sweat and salt water barrier
- Pinhole free
- Excellent wettability and adhesion
- Biocompatible per ISO 10993-5
- Not hypersensitive per ISO 10993-10
- RoHS & REACH compliant
- Abrasion Resistant

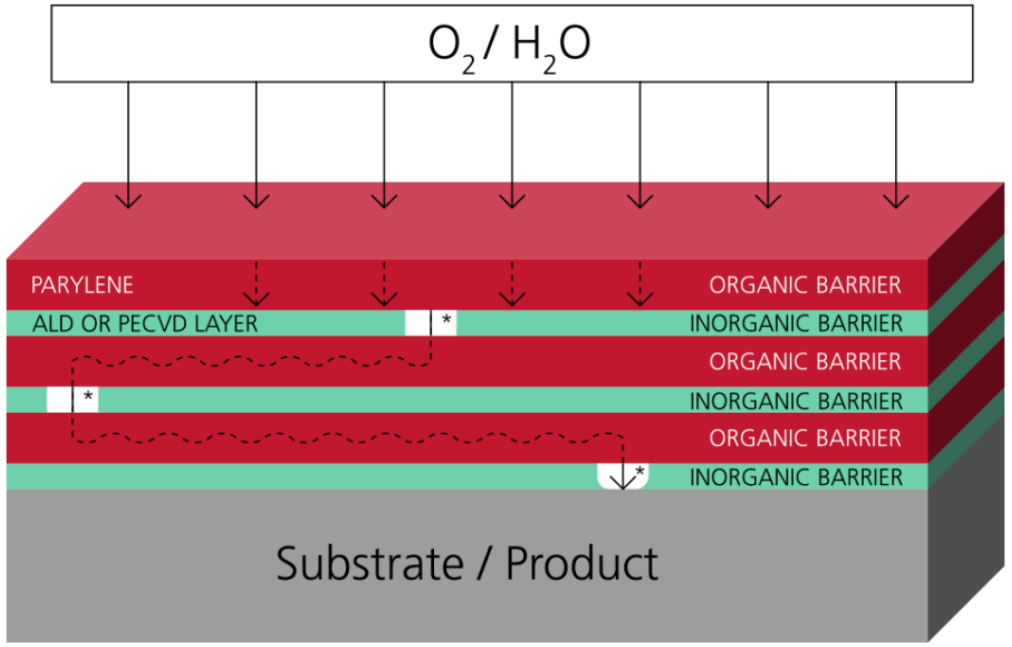
Atomic Layer Deposition Coatings

Atomic Layer Deposition (ALD) Coatings

- Ultra-thin, highly conformal coating at the nanometer and sub-nanometer level
- Vapor-phase technique where coating formation is via sequential cycling of self-limiting chemical half-reactions on the substrate surface, resulting in a nanoscale precision coating
- Key Advantages of ALD
  - High-quality films
  - Conformality
  - Gentle deposition process for sensitive substrates
  - Inherent film quality associated with self-limiting
  - Self-assembled nature of the ALD mechanism
- Thermal ALD
  - Requires temperature more than 100°C and can go up to 350°C
  - Many sub-types that use thermal or classical ALD
    - Metal ALD
    - Particle ALD
- Plasma-enhanced ALD (PE-ALD)
  - Processing at temperature below100 °C
- Electron-enhanced ALD (EE-ALD)
  - Processing at 25-100°C
- Photo-assisted ALD

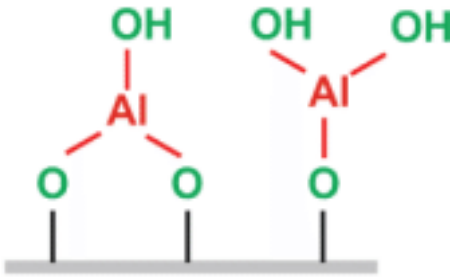
ALD (Atomic Layer Deposition)

- ALD technology deposits Al_2O_3, TiO_2, SiO_2 and other inorganic materials at the atomic level.
- Multi-layer coatings by combination with organic Parylene film and inorganic ALDs can improve the level of a wide range of properties.
- ALD can be formed at room temperature in the same way as Parylene coatings.
- High barrier properties (water vapor and oxygen transmission rates, WVTR / OTR):
  - ✓ WVTR <10-3 g / m^2 / day, 38°C / 50%RH
  - ✓ OTR <10-2 cm^3 / m^2 / day, 38°C / 90%RH
  - ✓ Supports 100 to 1000 times barrier improvement compared to conventional Parylene coatings

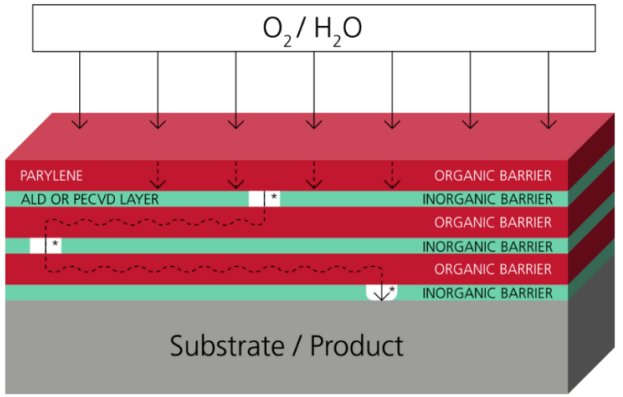


Why ALD+Parylene for Protection?

- ALD advantages
  - The coating thickness is homogeneous, controllable to sub-nanometer level
  - 3D conformality, high film density
  - Atomically flat and smooth surface coating
  - Organic and inorganic film can be formed
  - Coating can be formed at room to very low temperatures
  - Excellent barrier properties at ultra-thin (Angstrom) level



- Considering the unique properties of both ALD and Parylene, a combination of both at ultra-thin levels can provide better and enhanced protection and reliability to various electronics and components



Protection Performance Evaluation

- Results of Water Vapor Transmission Rate (WVTR)
  - WVTR of Parylene C improves 63 times due to ALD layer

Deposition Condition	WVTR [g・mm/(m2・24h)] 40℃/90%RH
Reference (PEN film)	0.21
Parylene C 25um	0.17
Parylene C 10um	0.19
Parylene C 5um	0.18
Parylene C 0.5um	0.19
Parylene N 10um	0.22
1st layer: Al_2O_3 10nm + 2nd layer: Parylene C 10um	0.009
1st layer: Al_2O_3 10nm + 2nd layer: Parylene C 0.5um	0.004
1st layer: Parylene C 10um + 2nd layer Al_2O_3 10nm	0.026
1st layer: Al_2O_3 18nm + 2nd layer: Parylene C 0.5um	0.003
1st layer: Al_2O_3 10nm + 2nd layer: Parylene N 10um	0.010

Protection Performance Evaluation

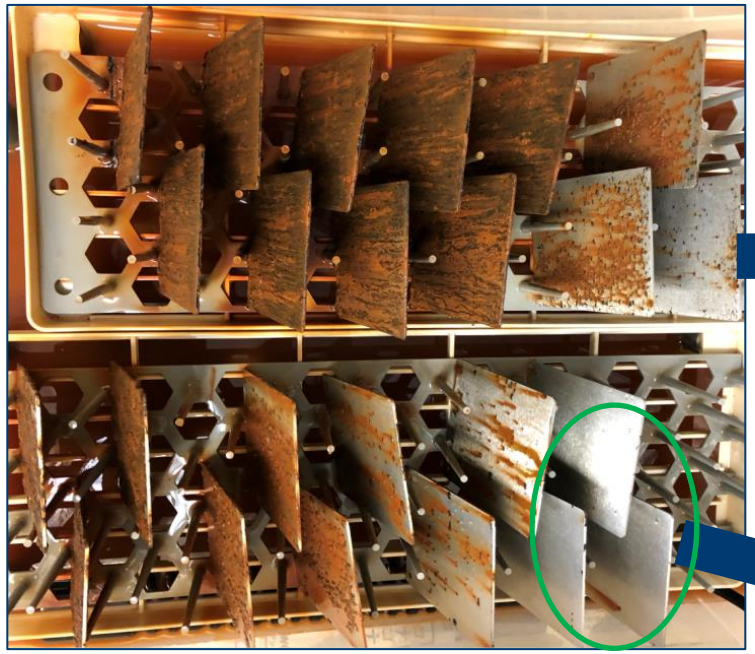
- Results of Gas Barrier
  - The gas barrier property of Parylene-C was greatly improved adding ALD-Al_2O_3 film (10 nm)

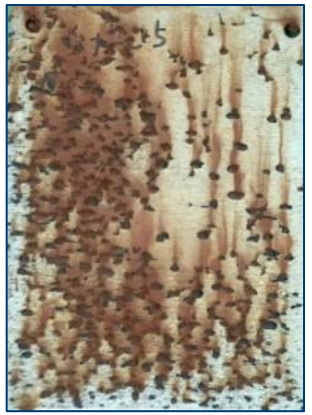
Deposition Condition	Gas Transmission			
	($cm^3/m^2 \cdot 24h \cdot atm$)		($mol/m^2 \cdot s \cdot Pa$)	
	O_2	H_2	O_2	H_2
Parylene C film (10um)	3.84	198	1.96E-12	1.01E-14
ALD-Al_2O_3 (10nm)	0.45	27.8	1.42E-16	2.76E-18
1^{st} layer ALD-Al_2O_3 (10nm) + 2^{nd} layer Parylene C (10um)	< 0.05*	< 0.05*	< 5.00E-16*	< 5.00E-16*

*Regarding gas transmission, the oxygen/hydrogen gas data is lower than the detection limit of the measuring equipment.
**Base material: Polyethylene naphthalate (PEN) 125um

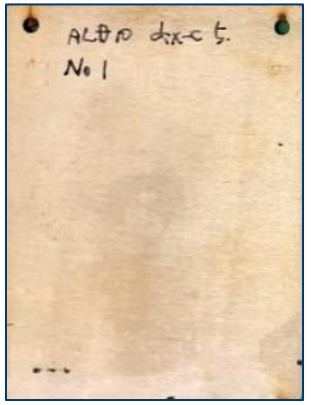
ALD+Parylene: Protection Performance Evaluation

- Corrosion resistance results





Sample of Parylene C 5 μm corrosion occurred after 500 hours test



Sample of Parylene C 5 μm + ALD Al_2O_3 10nm has no corrosion after 500 hours test

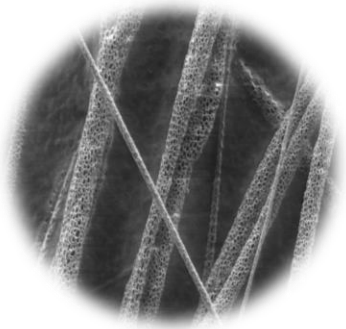
The above photo shows the status of sample after 500 hours. The film thickness is Parylene C 0.5, 1, 3, 5 μm, from left to right.（Sample : n=3）

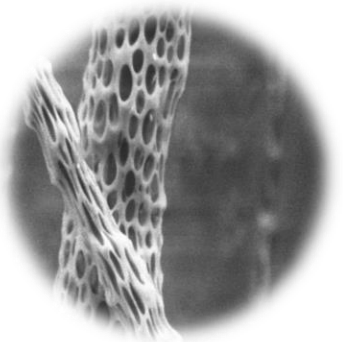
The upper right photo shows Parylene single layer on Fe plate; the lower photo shows ALD 10 nm in 1st layer and Parylene film in 2nd layer on Fe plate.

Electronics and Medical Applications

Parylene Nanocoating Applications

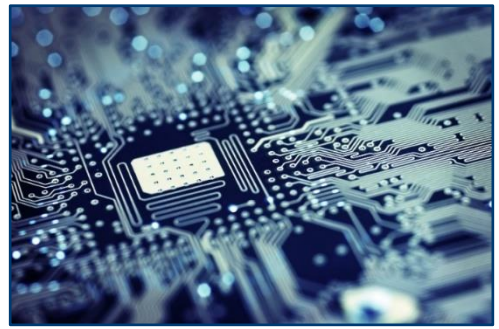
- High frequency electronics
- NEMS & MEMS
- Pressure and temperature sensors
- Nano-electronic parts
- Hybrid fuel system electronics
- Fuel cell components
- Optoelectronic devices
- Biochips & other medical electronics devices
- Flexible electronics

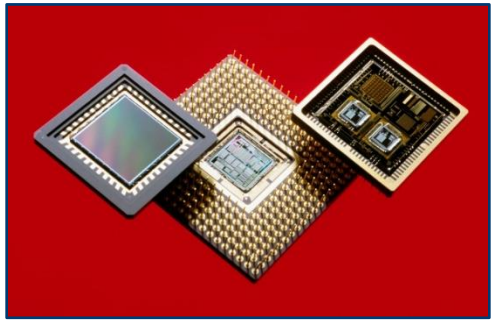


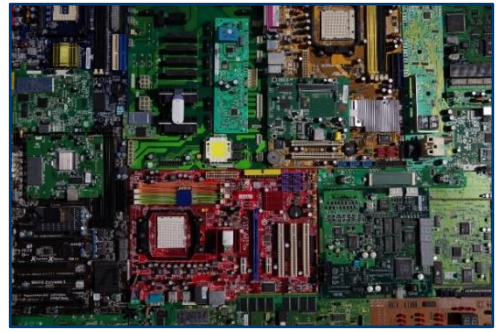


Electronics Coating Applications

- Printed circuit boards
  - applications include high-reliability hybrid microcircuits and multi-chip modules, sensors, electric motors, etc
- MEMS wafers
- Probes/pins
- Rotors/stators
- Components
  - Metal
  - Brackets
- Cables
- Ferrite Cores
- Telecommunication devices



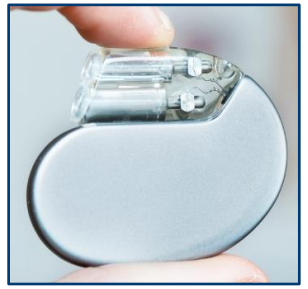


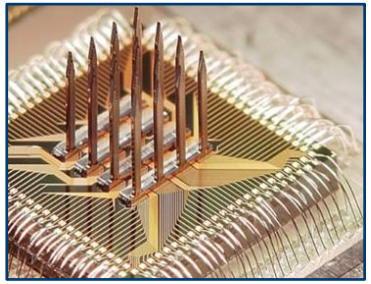


Medical Coating Applications

- Mandrels, molds, core pins
- Seals: O-rings, endoscopic port seals, valves
- Needles: Hypodermic, acupuncture, epidural
- Catheters: CV, IV, urology, biliary, etc.
- Ultrasonic transducers and sensors
- Guide wires
- Gastric balloons and cuffs
- Surgical tools
  - Electrocautery devices
  - Energized surgical tools (motors, jaws)
- Pharmaceutical containers
  - Syringe components, stoppers, caps
  - Capsules, containers

- Cardiac assist devices and components
  - ICDs, VADs, pacemakers
  - Stents: coronary, cerebral, ocular
- Neurostimulators
- Electrosurgical tools
- Cochlear and ocular implants
- Drug delivery devices
  - Inhalers (metered dose, dry powder, nasal)
  - Needles, syringes and other infusion devices
  - Blood glucose monitors and insulin pumps
  - Pharma ampoules and containers

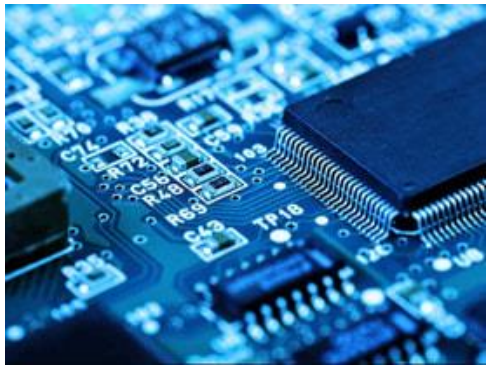




Courtesy of IMEC

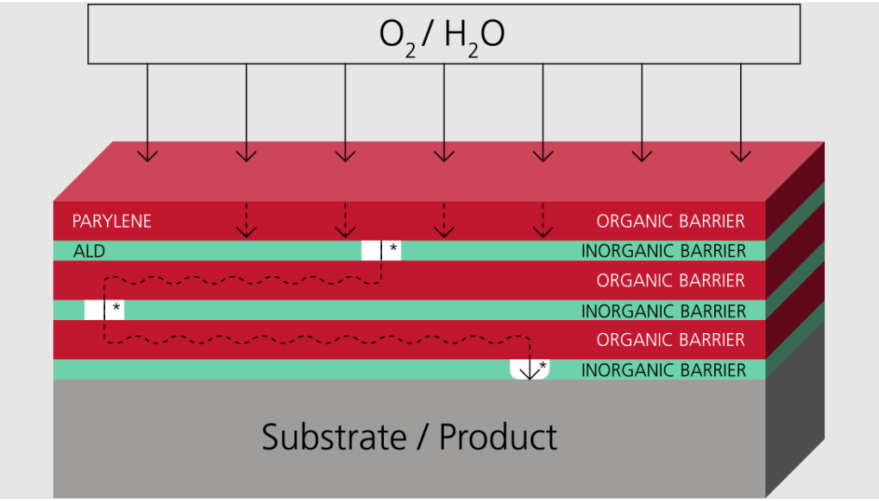
Plasma Nanocoating Applications

- Electronics market
  - Hydrophobic and oleophobic coatings
  - Focus on consumer electronics
    - Speakers, headphones, wearables (see appendix for details)
- Medical products
  - Hydrophilic coatings
    - Hearing aids, catheters, guide wires, and stents
    - Also used on textile to wrap organs for transplants/implants to reduce rejection
  - Hydrophobic
    - Water-repelling, antifouling and anticorrosion
    - Hearing Aids



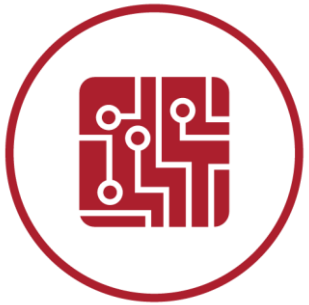
ALD/Parylene Coating Applications

- ALD/Parylene is an ideal solution for devices and systems across the medical, electronics, transportation and aerospace markets that must operate without failure in harsh or extreme environments for extended periods of time.
- Printed circuit boards
- Flexible electronics
- MEMS
- Fuel cells
- Solar cells
- Transistors
- Drug Delivery
- Tissue Engineering
- Implants



Conclusion

- SCS sustainable Nanocoatings offer excellent corrosion protection, reliability enhancement and surface modifications of various electronics and medical devices.
- Depending on specific needs, SCS coating solutions are able to protect devices and components, enhancing the reliability of today's and tomorrow's innovative medical technologies.
- Excellent attributes at ultra-thin level
  - WVTR could be improved to provide almost hermetic sealing
  - Suitable for high frequency devices
  - Completely halogen-free, made entirely from non-toxic martials
  - Meets medical industry standards and regulatory compliances
  - Complemented by advanced adhesion technologies
  - Less energy-intensive than thermal drying ovens and contain no VOCs
  - RoHS, California Proposition 65, and REACH/SVHC Compliant
  - Eco-friendly manufacturing, low carbon foot print



Thank you for your attention

- Specialty Coating Systems is the industry leader in conformal coating services and technologies for our global customers
- 21 coating facilities
  - Americas: US (8), Costa Rica
  - Europe: United Kingdom, Ireland, Czech Republic, Germany, Switzerland
  - Asia: China (2), Japan (2), Singapore, Thailand, Vietnam
- Manufacturing Standard Procedures (MSPs) to meet customer requirements
- Multiple locations to react to changes in requirements, volume ramp-up, natural disasters, etc.

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