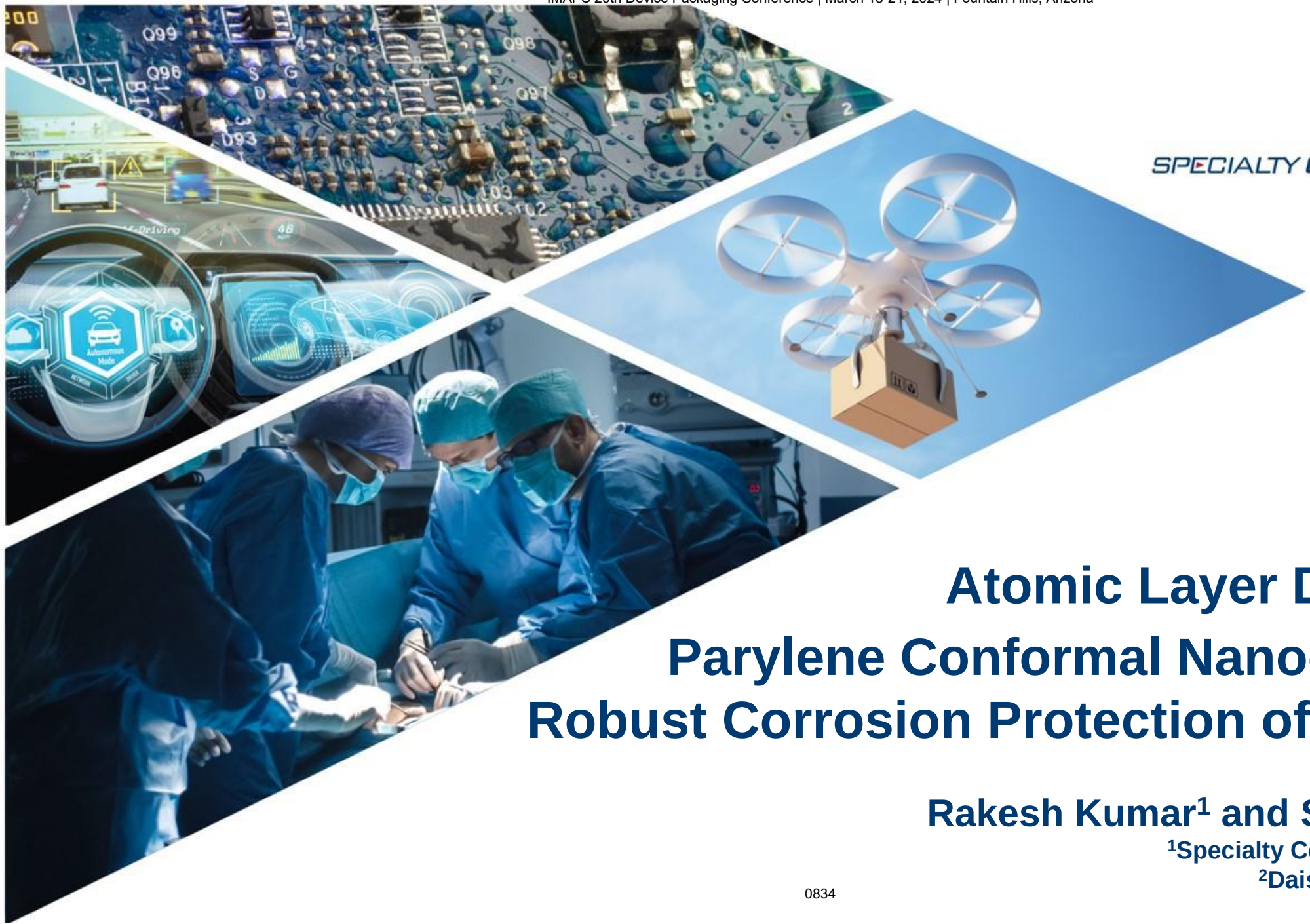

50 SCS YEARS
SPECIALTY COATING SYSTEMS™
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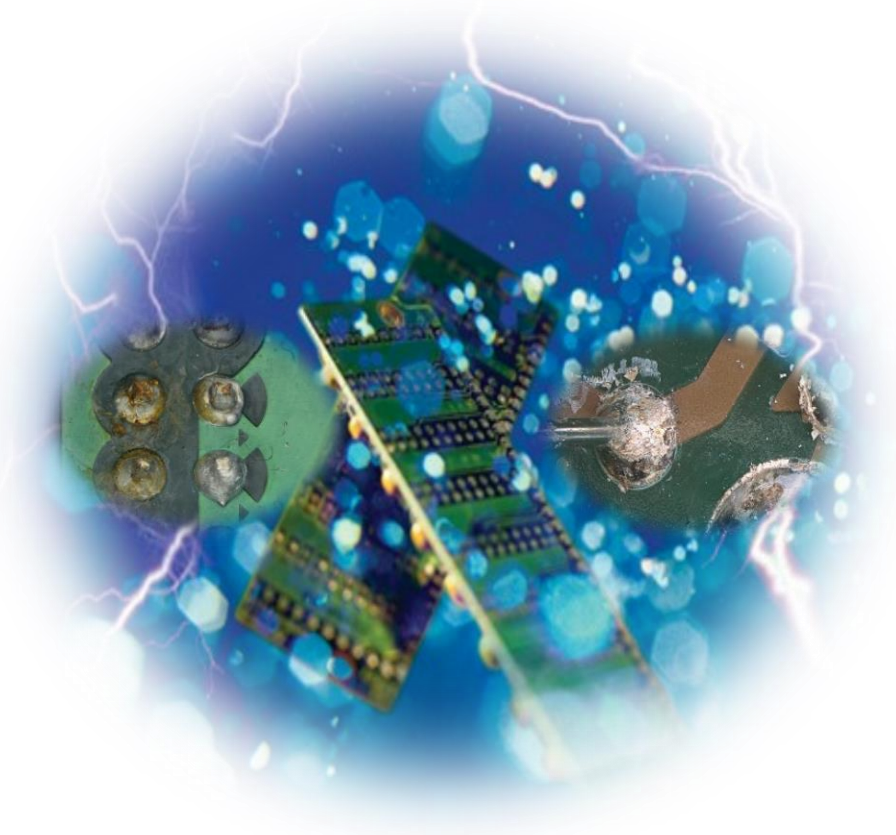
Atomic Layer Deposition + Parylene Conformal Nanocoatings for Robust Corrosion Protection of Electronics

Rakesh Kumar[1] and Shuichi Sawada[2]
[1]Specialty Coating Systems, Inc., USA
[2]Daisan Kasei Co., Ltd., Japan

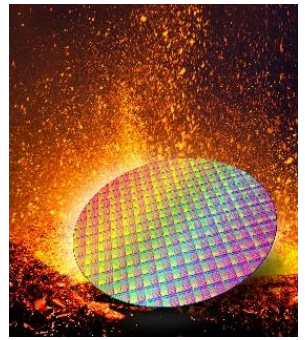
Outline

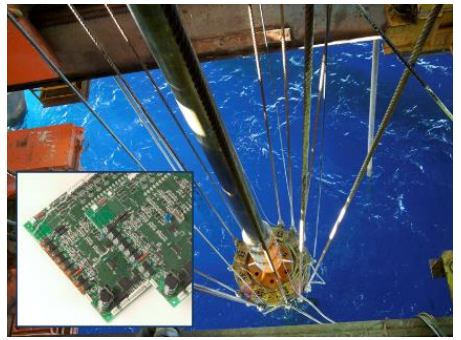
- Challenges of electronics
  - Protection and reliability
- ALD conformal coating
  - A nanoscale precision coating
  - ALD-Parylene for best protection
- Protection performance evaluation
  - High performance, protection and reliability enhancement
- Conclusion



Challenges of Electronics

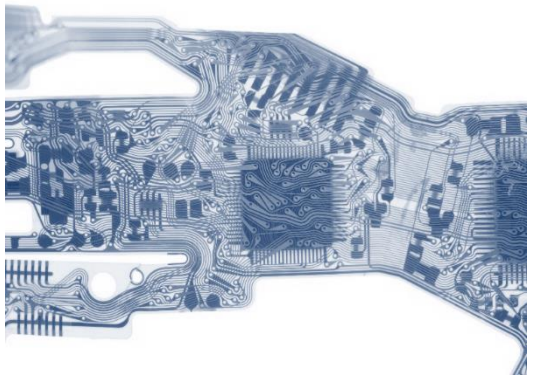
- Design oversights
  - Insufficient clearances or incorrect measurements
- Manufacturing/assembly process
  - Bad soldering, loose components, flux residues, traces and pathways
- Protection and reliability
  - Environmental: Moisture, temperature, dirt & debris, corrosive chemicals
  - Higher operating temperatures, higher frequency operations
  - Electromigration/short circuit
  - Transient electrical stresses/failure
  - Mechanical shock and vibration
  - Metallic whiskers
  - Controlling degradation due to time, physical and chemical attack
  - Industry and government regulatory compliance

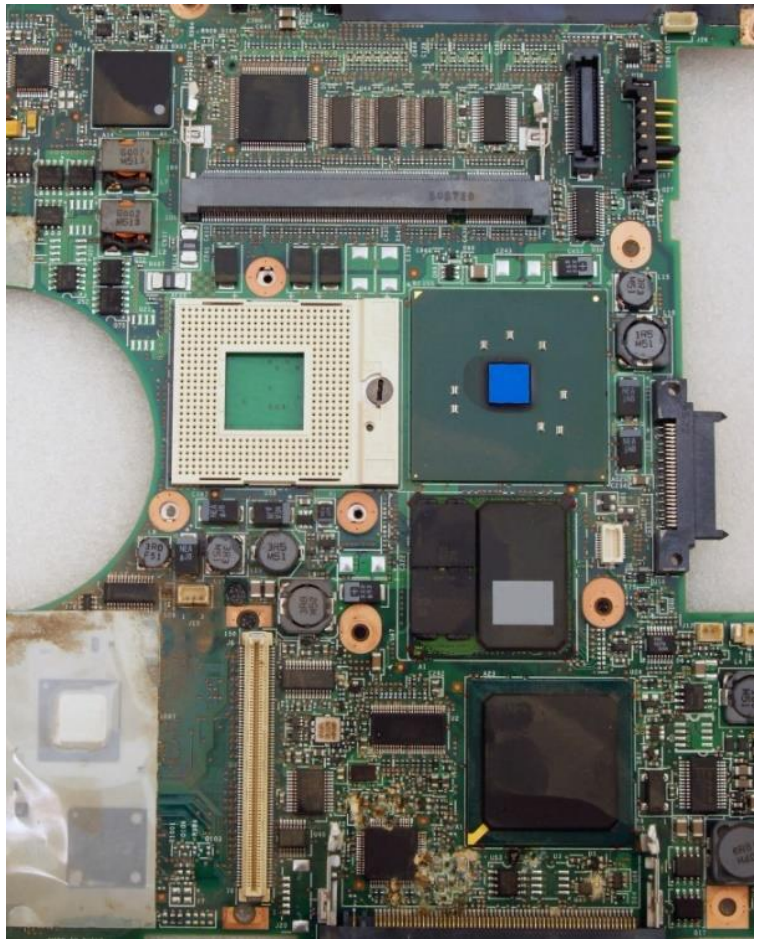


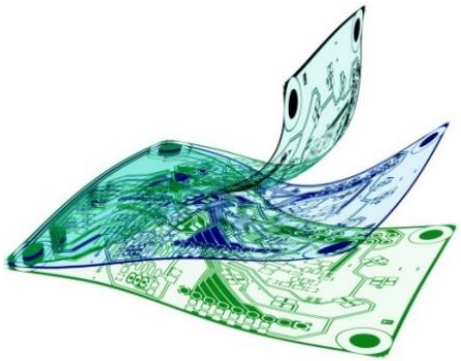


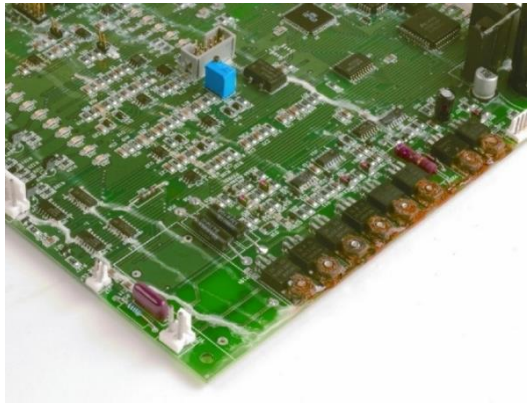
Environmental Challenges: Moisture, temperature, dirt & debris, corrosive chemicals

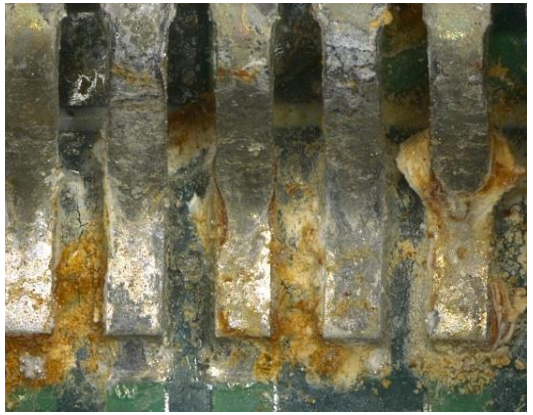
- Environmental
  - Water
  - Other corrosive environments











SCS Sustainable Conformal Coating Technologies

Chemical Vapor Deposition Parylene Coatings	PE Chemical Vapor Deposition Plasma Coatings	Atomic layer deposition(ALD) ALD+Parylene Coatings
Molecular level deposition (0.5 - 50 microns)	**Atomic/molecular level deposition** (10 nm – 3 microns)	**Atomic/molecular level deposition** (1 - 100 nanometer)
• Moisture & chemical barrier • Corrosion protection in harsh environment • Biocompatible • High dielectric strength • Chemically inert	• Water repellent • Hydrophobic • Low power insulating organic coating • Corrosion protection	• Dense • Smooth • Dielectric and insulating • Inorganic nanocoating • Corrosion protection in harsh Environment
• 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)

Atomic Layer Deposition (ALD) Coating

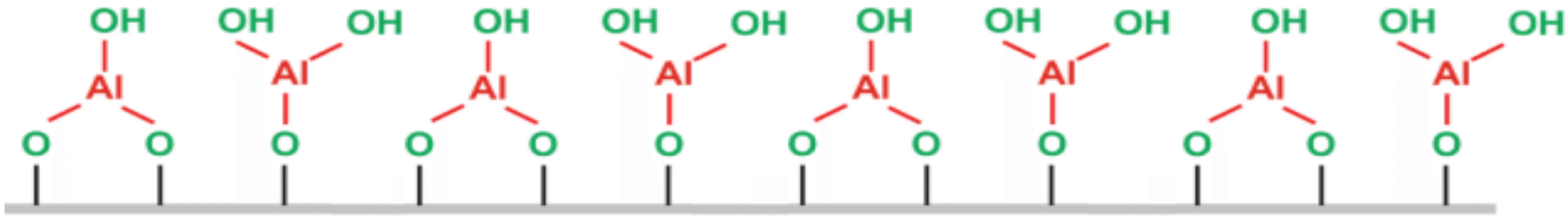
- Ultra-thin, highly conformal coating at the nanometer and sub-nanometer level
- Vapor-phase technique where coating formation is via sequential cycling of self-limiting chemical half-reactions on the substrate surface, resulting in a nanoscale precision coating
- Key Advantages of ALD
  - High-quality films
  - Conformality
  - Gentle deposition process for sensitive substrates
  - Inherent film quality associated with self-limiting
  - Self-assembled nature of the ALD mechanism

ALD Types

- 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

Why ALD-Parylene for Protection?

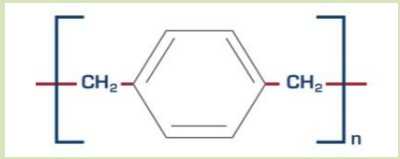
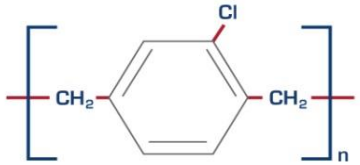
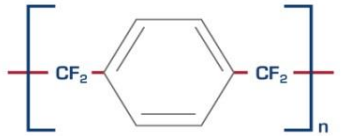
- ALD advantages for electronics
  - The coating thickness is homogeneous, controllable to sub-nanometer level
  - 3D conformality, high film density
  - Atomically flat and smooth surface coating
  - Organic and inorganic film can be formed
  - Coating can be formed at room to very low temperatures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



Why ALD-Parylene for Protection?

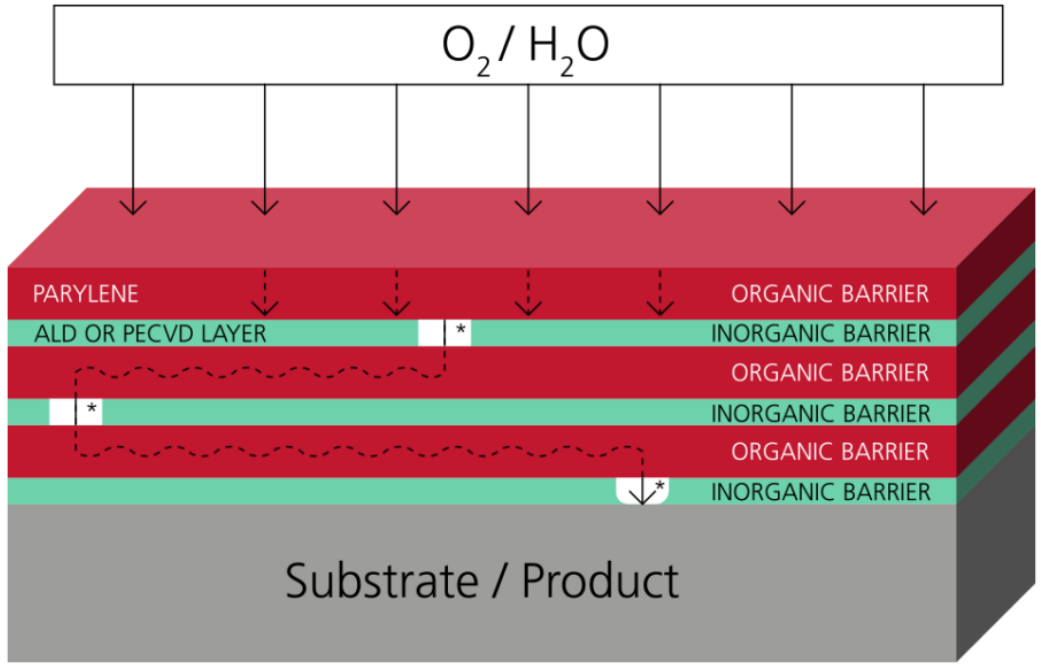
- Parylenes are known to provide better protection and reliability to electronics compared to liquid conformal coatings
- Parylene advantages for electronics
  - Vapor-phase deposition results in complete coverage, even beneath and around closely-spaced wires and chips
  - Envelops and reinforces fragile wire bonds, strong mechanical strength
  - Among the best coatings for moisture impermeability
  - Coating process at room temperature
  - No by-products are released during polymerization
  - Parylenes have low dielectric constant, low dissipation factor and high electrical insulation resistance
  - Biocompatible and biostable

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**

Why ALD-Parylene for Protection?

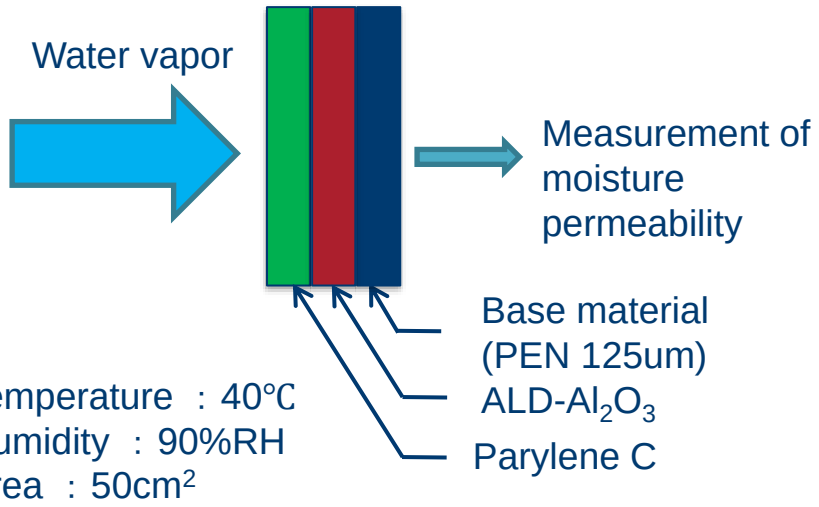
- Considering the unique properties of both ALD and Parylene, a combination of both at ultra-thin levels can provide better and enhanced protection and reliability to various electronics and components
- Defects or pinholes are decoupled leading to increased barrier performances



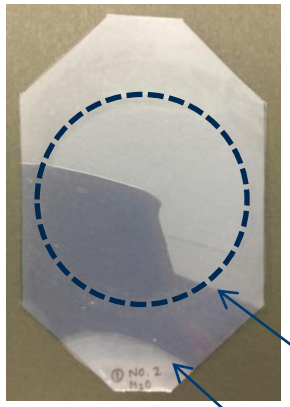
Protection Performance Evaluation

Protection Performance Evaluation

- Study of Water Vapor Transmission Rate (WVTR)



Sample shape



The measurement point is the center of the sample. The sample is placed at the center on the stage in ALD equipment.

Area ：50cm^2

Base material:
Teijin DuPont films
Teonex® PEN film
polyethylene naphthalate film
Q65FA 125um

Measuring device: MOCON PERMATRAN-W 3/33
Measurement standard: JIS K 7129：2008 (Infrared sensor method)
Device measurement lower limit value: 0.02g/(m^2・24h)

WVTR: ALD-Al2O3 + diX C Multi-layer film

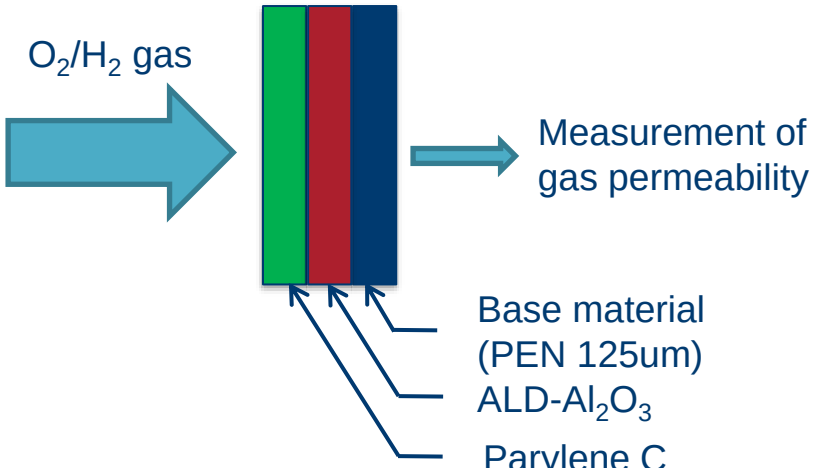
- WVTR of Parylene C improves 63 times due to ALD layer

Deposition Condition	WVTR [g.mm/(m^2.24h)] 40°C/90%RH
Reference (PEN film)	0.21
Parylene C 25 µm	0.17
Parylene C 10 µm	0.19
Parylene C 5 µm	0.18
Parylene C 0.5 µm	0.19
Parylene N 10 µm	0.22
1st layer Al_2O_3 10nm + 2nd layer Parylene C 10 µm	0.009
1st layer Al_2O_3 10nm + 2nd layer Parylene C 0.5 µm	0.004
1st layer Parylene C 10 µm + 2nd layer Al_2O_3 10nm	0.026
1st layer Al_2O_3 18nm + 2nd layer Parylene C 0.5 µm	0.003
1st layer Al_2O_3/10 nm + 2nd layer Parylene N 10 µm	0.010

Measuring device: MOCON PERMATRAN-W 3/33. Measurement standard: JIS K 7129：2008
Device measurement lower limit value: 0.02g/(m^2・24h)

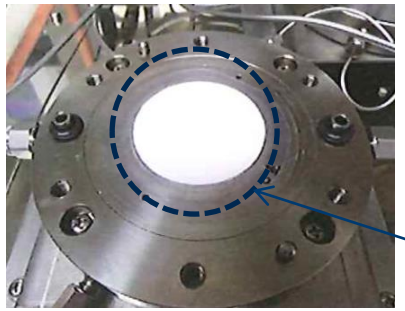
Protection Performance Evaluation

- Study of Gas Barrier



Temperature： 23±2℃
Test differential pressure：1atm
Area：15.2cm^2

Sample shape



Base material:
Teijin DuPont films
Teonex® PEN film
polyethylene naphthalate film
Q65FA 125um

Measuring device: Differential pressure gas measurement device GTR Tec Corporation GTR—30XAD2
:Vapor transmission measurement device yanako G2700T・F
Measurement standard: JIS K7126−1：2006 (Differential pressure method)
Device measurement lower limit value: 0.05 (cm^3/m^2・24h・atm)

Gas Barrier: ALD/Parylene Coating

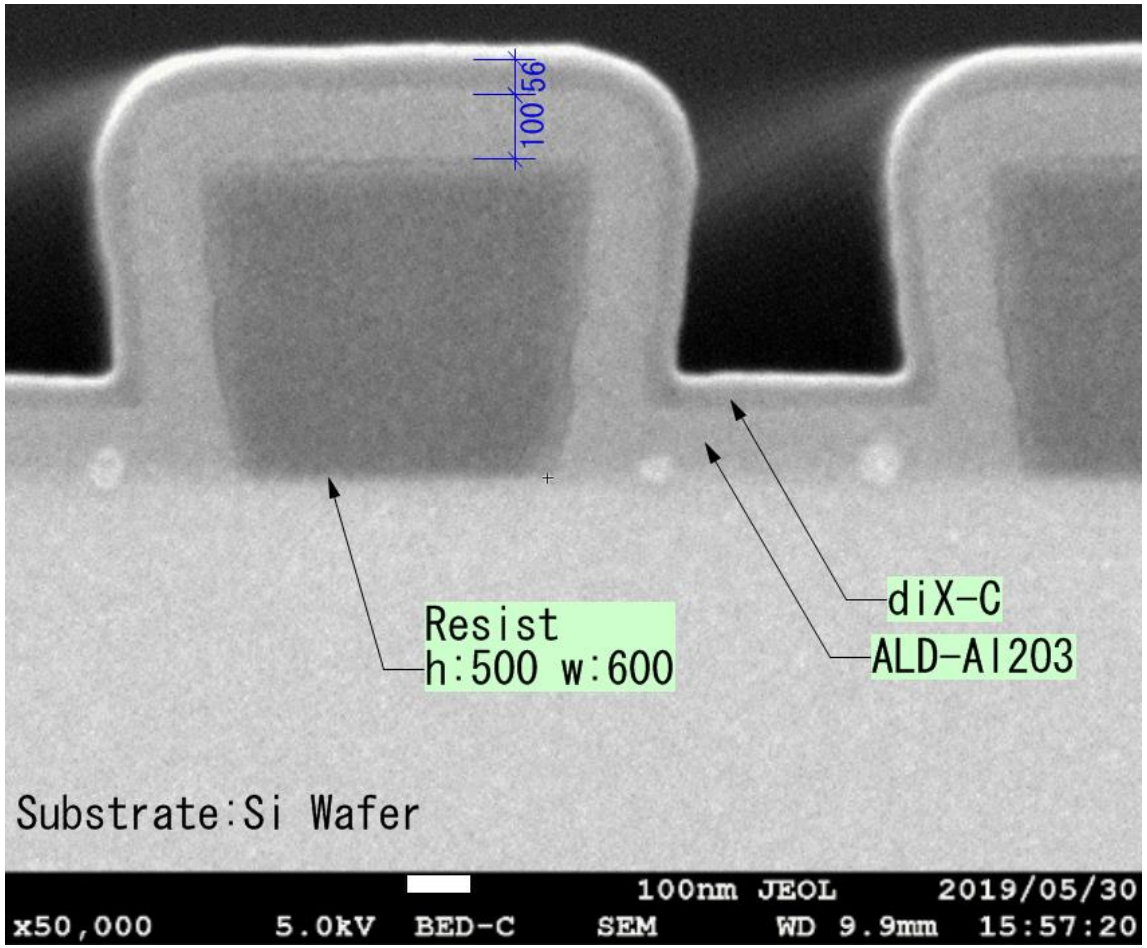
- Results of Gas Barrier
  - The gas barrier property of Parylene-C was greatly improved adding ALD-Al2O3 film (10 nm)

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

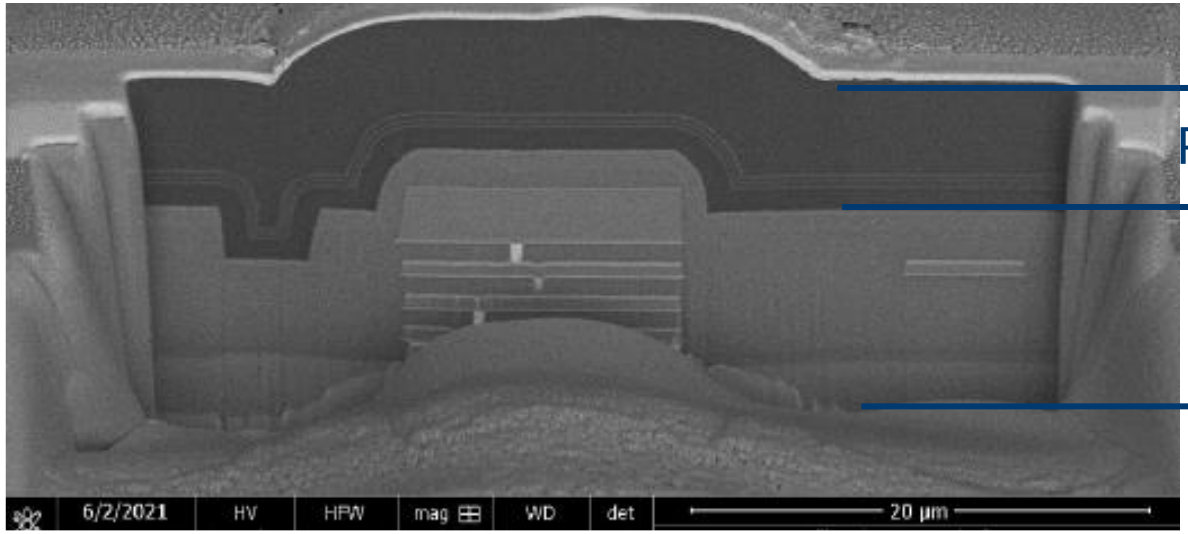
Protection Performance Evaluation

- Study and result of step coverage
  - The resist film on the wafer was processed into a reverse tapered structure by etching to form ALD-Al2O3 100 nm + diX-C 56 nm, and the coverage was confirmed by SEM
  - Step coverage with good isotropy was confirmed from SEM photo



Protection Performance Evaluation

- Study and result of step coverage
  - Step coverage with good isotropy was confirmed from FIB-SEM



Parylene – ALD multilayer

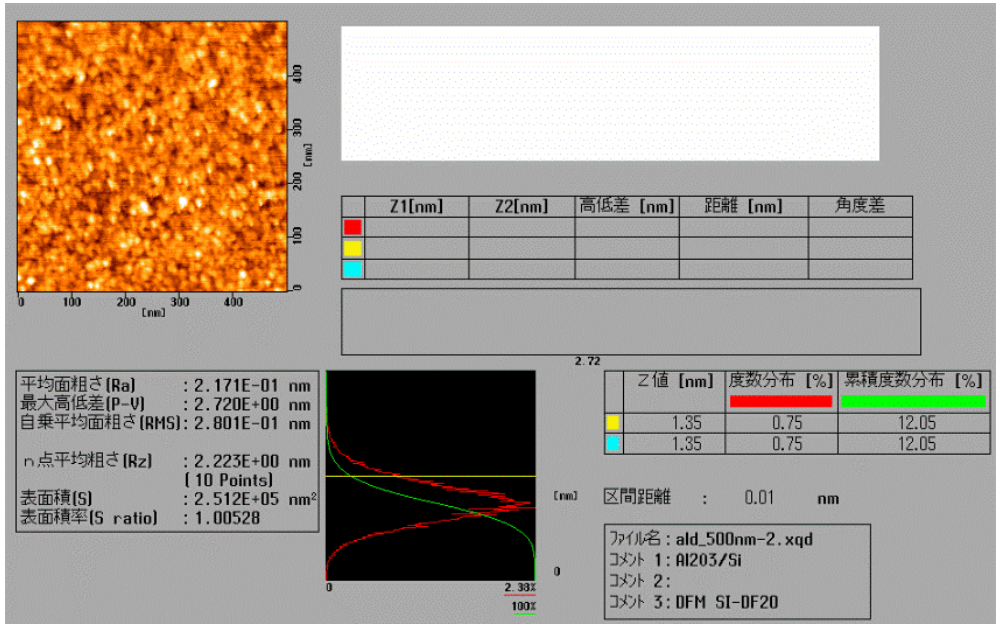
Substrate

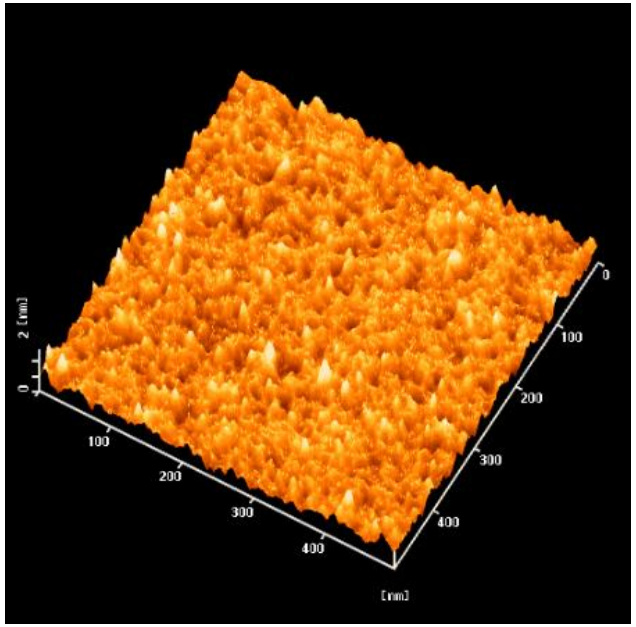
SEM-FIB micrograph of a chip coated with a Parylene-C – ALD (TiO_2-Al_2O_3) multilayer

} 3 ALD layers

Protection Performance Evaluation

- Study of surface flatness and pinhole-free
  - It was confirmed that the film was very flat, RMS: 0.28 nm
  - Per value of Ra: 0.22 nm, the film was a very dense
  - AFM images show neither cracks nor pin-holes

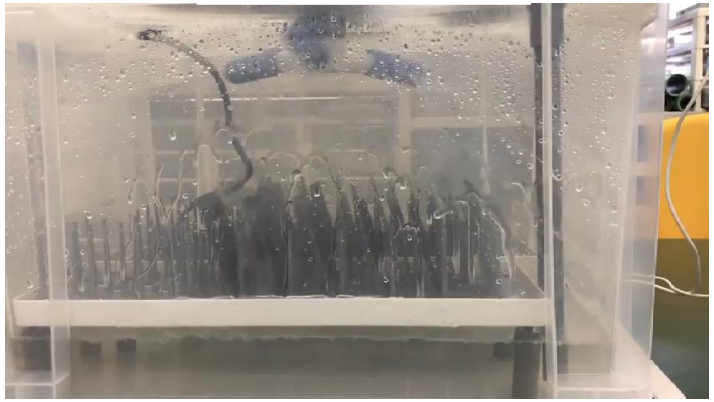




Corrosion Resistance: Salt Solution Spray

- ALD/Parylene Coating

Salt Spray Tester

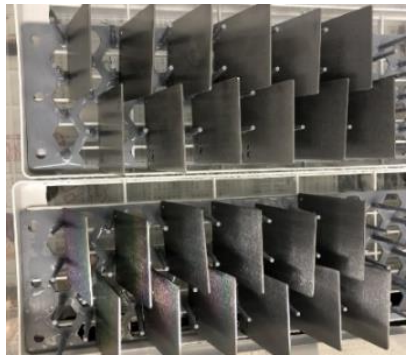


Substrate	1st layer	2nd layer
Based Material (Fe plate SPCC-SB)		Parylene C/0.5um
		Parylene C/1um
		Parylene C/3um
		Parylene C/5um
	ALD-Al_2O_3 10nm	Parylene C/0.5um
	ALD-Al_2O_3 10nm	Parylene C/1um
	ALD-Al_2O_3 10nm	Parylene C/3um
	ALD-Al_2O_3 10nm	Parylene C/5um

*n=3

Experimental conditions

Based material: Fe plate SPCC-SB (JIS K2246B 1.2* 60 * 80)
Test solution : 50 ± 5 g/L NaCl solution (pH 6.5 ~ 7.2), 35±2℃
Flow rate is 5 L/min.



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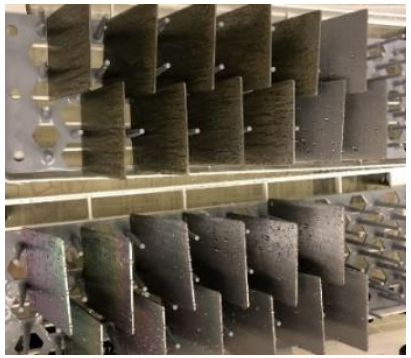


+15 min

+24 hours

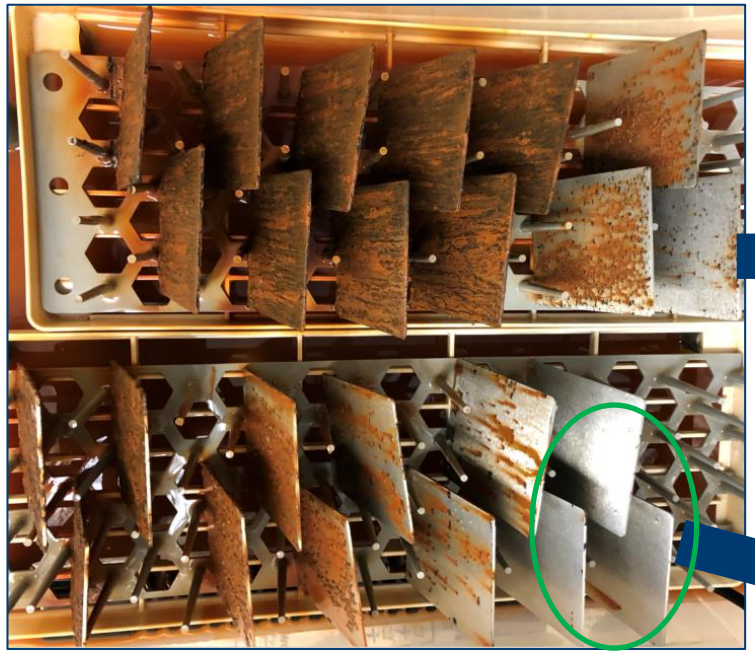
+500 hours

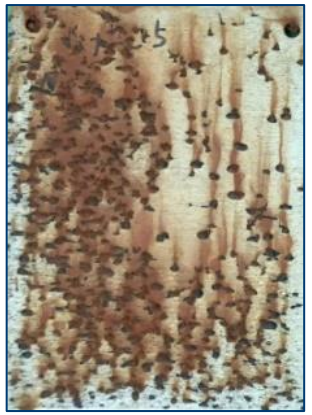
Parylene C

ALD+Parylene C

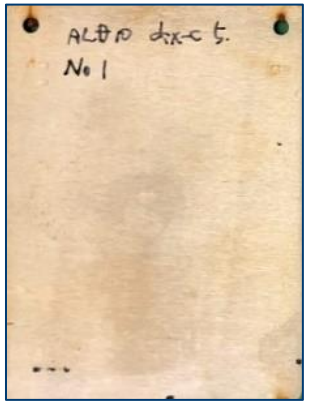
Corrosion Resistance: Salt Solution Spray

- ALD/Parylene Coating





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

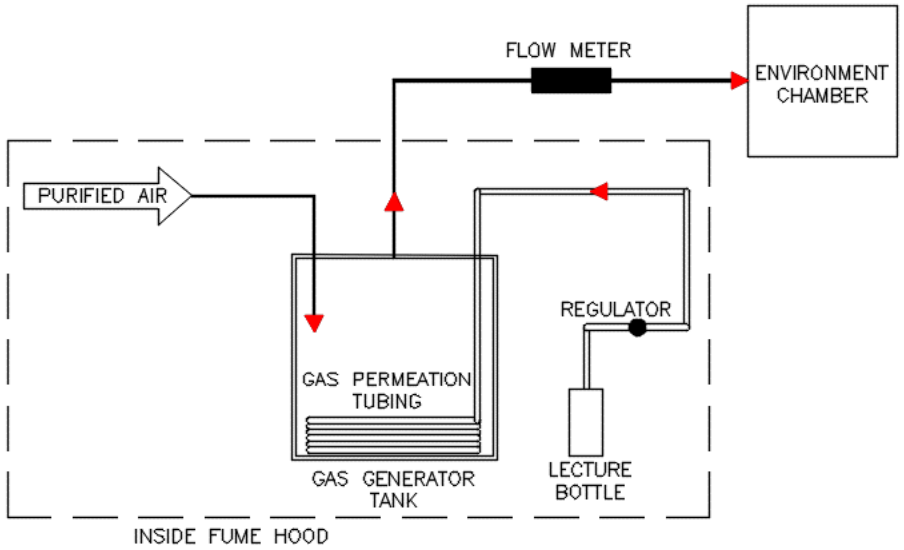
The above photo shows the status of sample after 500 hours. The film thickness is Parylene C 0.5, 1, 3, 5 μm, from left to right.（Sample : n=3）

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.

Mixed Flow Gas Testing

- Testing Parameters

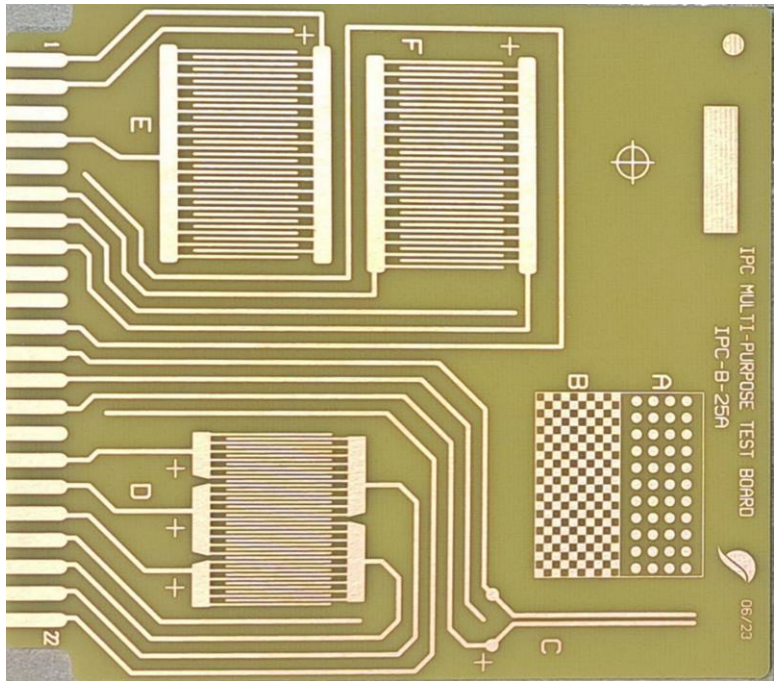
ASTM B845 Class IIIA MFG Test Parameters			
Cl_2:	20±5 ppb	Relative Humidity:	70%±2%
NO_2:	200±5 ppb	Temperature:	30°C±1°C
H_2S:	100±5 ppb	Duration:	21
SO_2:	200±5 ppb		



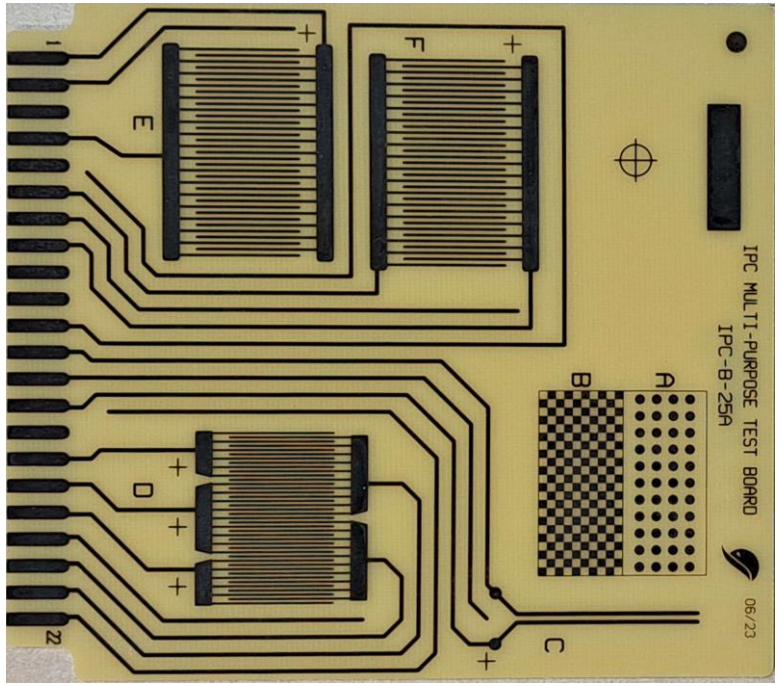
- Testing Lab: Battelle Advanced Materials

MFG Testing – Control (Uncoated)

Day 0 (Before testing)

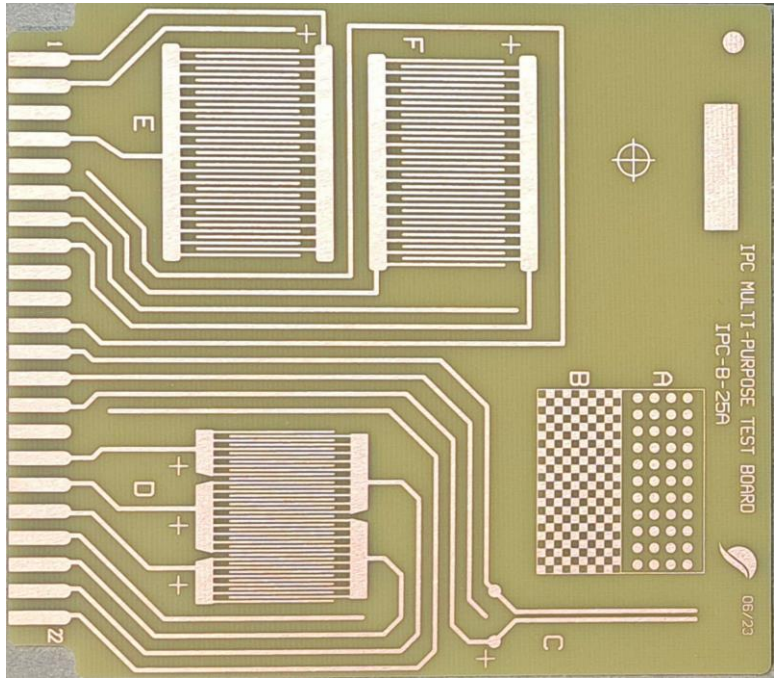


Day 21

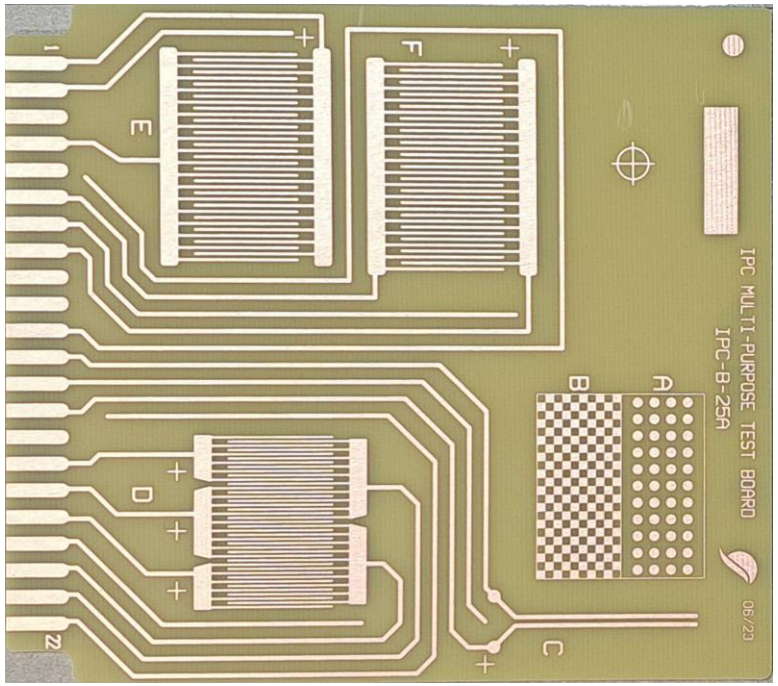


MFG Testing: ALD + Parylene C 5um

Day 0 (Before testing)

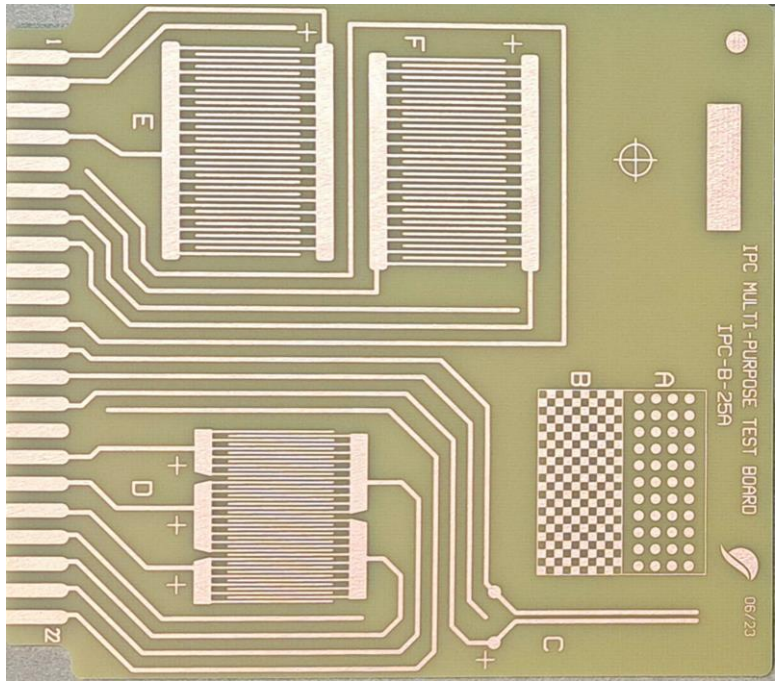


Day 21

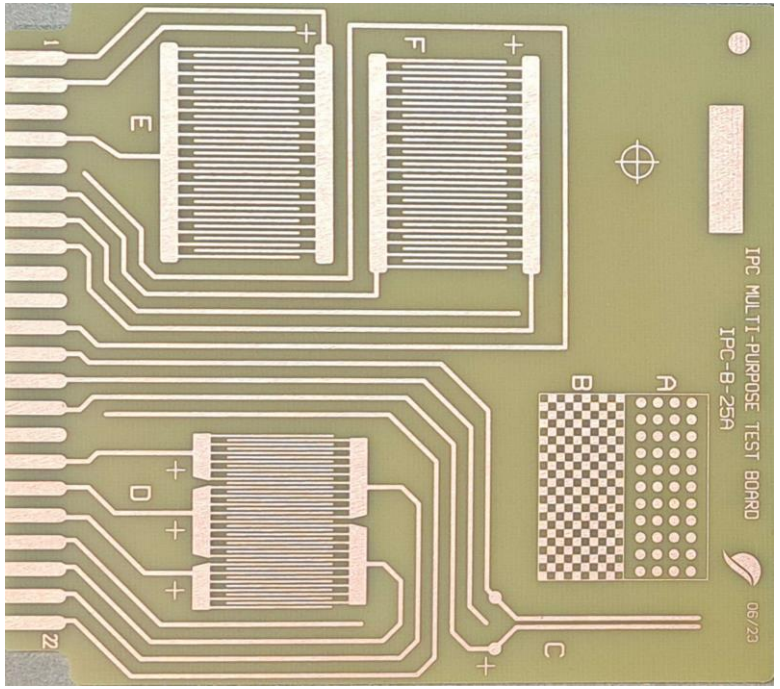


MFG Testing –ALD + Parylene C 10um

Day 0 (Before testing)



Day 21



Protection Performance Evaluation

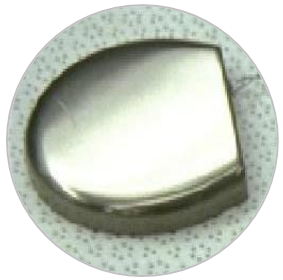
- Real Life Application: PCBA coating with ALD-Parylene
  - Several PCBA were coated at one time (high volume capability)
  - 1st layer was ALD-Al2O3, 10 nm
  - 2nd layer : Parylene-C, 15 μm

Photo Courtesy: Dr. Thomas Finocchiaro, ReinHeart TAH GmbH, Germany

The diameter of the PCBA is 70 mm
The thickness is 5mm

Conclusion

- Combining a thin layer of ALD with Parylene coating offers better protection of electronics, particularly against corrosion due to salt and other chemicals in harsh environments
- Excellent barrier properties at ultra-thin level
  - WVTR could be improved up to 100 times
  - In addition, parts coated with ALD-Parylene benefit from all key attributes of Parylene
  - Protects electronics and other devices against water splash and water immersion, IPX7 & IPX8 designations
  - Suitable for high frequency devices
  - Completely halogen-free when used with ParyFree, a new halogen-free variant of Parylene
  - Meets industry standards and regulatory compliances



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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