Outline

- Challenges of Harsh Environments
  - Protection and reliability

- Advanced Coatings
  - A nanoscale precision ALD coating
  - ALD-Parylene for best protection

- Protection Performance Evaluation
  - High performance, protection and reliability enhancement

- Conclusion
Challenges of Electronics in Harsh Environments

- Environmental: Moisture, temperature, dirt and 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
Protection Challenges of Electronics in Harsh Environments

- Environmental
  - Water
  - Other corrosive environments
Challenges of Electronics in High Temperature Environments

- Temperature of engine compartments: -40°C to 200°C
- Temperature on engine/transmission: -40°C to 250°C
  - Driver interior: -40°C to + 80°C
  - Under hood: -40°C to + 200°C
  - On engine: -40°C to + 250°C
  - In the exhaust & combustion: -40°C to + 200-600°C

- Select companies high-temperature electronics requirements
  - On engine: -150°C to + 200°C
  - In-transmission: -150°C to + 200°C
  - On wheel-ABS sensors: -150°C to + 250°C
  - Cylinder pressure: -200°C to + 300°C

Reference:
1. A. Craig and S. Martin, Automotive Packaging is a powerful, problem-solving tool, *Advanced Packaging*, June 2005
Challenges of Medical Devices in Harsh Environments

- Effective moisture, gas, chemical, fluid barrier
- Higher operating temperature
- Higher frequency operations
- Improved processing methods
- Chemical resistance
- Stabilization of delicate structures
- Electrical insulation
- Biocompatibility and biostability
- Reliability of the components in corrosive/harsh environments
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
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
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?

- 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.
- Study approach to achieve better protection from corrosion and various gases.
## Protection Performance Evaluation

- **Study of Water Vapor Transmission Rate (WVTR)**
  - WVTR of diX-C improves 63 times due to ALD layer deposition

<table>
<thead>
<tr>
<th>Deposition Condition</th>
<th>WVTR [g • mm/(m² • 24h)] 40℃/90%RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference (PEN film)</td>
<td>0.21</td>
</tr>
<tr>
<td>diX-C 25um</td>
<td>0.17</td>
</tr>
<tr>
<td>diX-C 10um</td>
<td>0.19</td>
</tr>
<tr>
<td>diX-C 5um</td>
<td>0.18</td>
</tr>
<tr>
<td>diX-C 0.5um</td>
<td>0.19</td>
</tr>
<tr>
<td>diX-N 10um</td>
<td>0.22</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; layer: Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; 10nm + 2&lt;sup&gt;nd&lt;/sup&gt; layer: diX-C 10um</td>
<td>0.009</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; layer: Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; 10nm + 2&lt;sup&gt;nd&lt;/sup&gt; layer: diX-C 0.5um</td>
<td>0.004</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; layer: diX-C 10um + 2&lt;sup&gt;nd&lt;/sup&gt; layer: Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; 10nm</td>
<td>0.026</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; layer: Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; 18nm + 2&lt;sup&gt;nd&lt;/sup&gt; layer: diX-C 0.5um</td>
<td>0.003</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; layer: Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt; 10nm + 2&lt;sup&gt;nd&lt;/sup&gt; layer: diX-N 10um</td>
<td>0.010</td>
</tr>
</tbody>
</table>
Study of Gas Barrier

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

<table>
<thead>
<tr>
<th>Deposition Condition</th>
<th>Gas Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(cm³/m² • 24h • atm)</td>
</tr>
<tr>
<td></td>
<td>O₂</td>
</tr>
<tr>
<td>diX-C film (10um)</td>
<td>3.84</td>
</tr>
<tr>
<td>ALD-Al₂O₃ (10nm)</td>
<td>0.45</td>
</tr>
<tr>
<td>1st layer ALD-Al₂O₃ (10nm) + 2nd layer diX-C (10um)</td>
<td>&lt; 0.05*</td>
</tr>
</tbody>
</table>

*Regarding gas transmission, the oxygen/hydrogen gas data is lower than the detection limit of the measuring equipment.

**Base material: PEN 125um
Protection Performance Evaluation

- Conformal nature ALD/Parylene coating

<table>
<thead>
<tr>
<th>The wafer condition</th>
<th>In a standing bottle</th>
<th>In the sideways bottle</th>
<th>On the stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Film thickness (nm)</td>
<td>98.8</td>
<td>99.5</td>
<td>102.0</td>
</tr>
</tbody>
</table>

Al$_2$O$_3$ can be deposited in any shape.
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 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
Protection Performance Evaluation

**Corrosion Resistance Study**

![Salt Spray Tester](image)

<table>
<thead>
<tr>
<th>Substrate</th>
<th>1st layer</th>
<th>2nd layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALD-Al₂O₃ 10nm</td>
<td>diX-C/0.5um</td>
<td>diX-C/0.5um</td>
</tr>
<tr>
<td>ALD-Al₂O₃ 10nm</td>
<td>diX-C/1um</td>
<td>diX-C/1um</td>
</tr>
<tr>
<td>ALD-Al₂O₃ 10nm</td>
<td>diX-C/3um</td>
<td>diX-C/3um</td>
</tr>
<tr>
<td>ALD-Al₂O₃ 10nm</td>
<td>diX-C/5um</td>
<td>diX-C/5um</td>
</tr>
</tbody>
</table>

**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°C
Flow rate is 5 L/min.

* Salt Spray Tester

Reference images:
- Ref
- +15 min
- +24 hours
- +500 hours
Protection Performance Evaluation

Corrosion Resistance Results

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

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

Sample of diX-C 5 μm corrosion occurred after 500 hours test.

Sample of diX-C 5 μm + ALD Al₂O₃ 10nm have no corrosion after 500 hours test.
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-$\text{Al}_2\text{O}_3$, 10 nm
  - 2nd layer: diX-C, 15 μm

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

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

- Combining a thin layer of ALD with Parylene coating offers better robust of electronics and medical devices, 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 sixty-three 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 (SCS) is the industry leader in Parylene conformal coating service and technologies for our global customers

- 19 worldwide centers
  - Americas: US, Costa Rica, Brazil
  - Europe: United Kingdom, Ireland, Czech Republic, Germany
  - Asia: Japan, Singapore, Thailand, China

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