Coatings and Potting - Issues and Challenges

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Conformal Coating Options

- Conformal Coating Overview:
  - Conformal coating is applied to circuit cards to provide a dielectric layer on an electronic board.
  - This layer functions as a membrane between the board and the environment.
  - With this coating in place, the circuit card can withstand more moisture by increasing the surface resistance or surface insulation resistance (SIR).
  - With a higher SIR board, the risk of problems such as cross talk, electrical leakage, intermittent signal losses, and shorting is reduced.

- This reduction in moisture will also help to reduce metallic growth called dendrites and corrosion or oxidation. Conformal coating will also serve to shield a circuit card from dust, dirt and pollutants that can carry moisture and may be acidic or alkaline.
# Summary of Conventional Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Properties</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>Good adhesion&lt;br&gt;Excellent chemical resistance&lt;br&gt;Acceptable moisture barrier</td>
<td>Difficult to rework&lt;br&gt;Needs compliant buffer&lt;br&gt;Not widely used</td>
</tr>
<tr>
<td>Urethane</td>
<td>Good adhesion&lt;br&gt;High chemical resistance&lt;br&gt;Acceptable moisture barrier</td>
<td>Difficult to rework&lt;br&gt;Widely used&lt;br&gt;Low cost</td>
</tr>
<tr>
<td>Acrylic</td>
<td>Acceptable adhesion&lt;br&gt;Poor chemical resistance&lt;br&gt;High moisture resistance</td>
<td>Easy to rework&lt;br&gt;Widely used&lt;br&gt;Moderate cost</td>
</tr>
<tr>
<td>Silicone</td>
<td>Poor adhesion&lt;br&gt;Low chemical resistance&lt;br&gt;Excellent moisture resistance</td>
<td>Possibility of rework&lt;br&gt;Moderate usage&lt;br&gt;High cost</td>
</tr>
<tr>
<td>Paralyne</td>
<td>Excellent adhesion&lt;br&gt;Excellent chemical resistance&lt;br&gt;Excellent moisture resistance</td>
<td>Impossible to rework&lt;br&gt;Rarely used&lt;br&gt;Extremely high cost</td>
</tr>
</tbody>
</table>
Applications

- **Automotive:** exposure to gasoline vapor, salt spray and brake fluid, both under the hood (e.g. engine management systems), and in passenger compartments (e.g. onboard computers).

- **Aerospace:** high reliability requirements, rapid compression and decompression, pressurized and depressurized areas.

- **Marine:** both fresh and salt water environments will attack electronic circuitry, under the dash of high performance boats, to exterior equipment used on larger maritime systems.

- **Medical:** Tool protection while in storage to prevent corrosion; pacemakers, where it is vital to ensure continuous performance and even food carts in hospitals.
How is Conformal Coating Applied?

- The conformal coating material can be applied by:
  - brushing
  - spraying
  - dipping
  - Or, due to the increasing complexities of electronic circuit board assemblies being designed and with the 'process window' becoming smaller and smaller, by selectively coating via robot.
Inspection

- Inspection of the coating is easily accomplished using “Black Light” to expose the surface to be inspected. The conformal coating will fluoresce. Areas that are coated will look like snow on the surface of the PWB, while uncoated areas look dark. This allows touch up to be performed to assure full coverage of the product.

- Inspection Requirements are usually to IPC-610 for commercial applications and MIL-I-45608 for military.
Selecting the appropriate coating based on the application will reduce the risk of failure.

- Acrylic coating would not be the ideal choice for an automotive application, because this coating type tends to soften (low glass transition temperature, Tg) with the high temperatures and exposure to moisture or petroleum residues.
- A better choice might be a silicone coating, which has a usable operating range of -55°C to +200°C and offers resistance to high humidity environments. (watch out for sulfur)
- An ultraviolet (UV) cured coating may not be the best choice if the assembly in question has high-profile components. Shadowing can leave uncured coating which compromises the reliability of the PWB.
Proper Curing

- Methods include air, UV, thermal and moisture laden atmospheres
- Time to cure is a function of the type of coating and the application method
  - Tack free, Time required, Optimum properties
- Know the Difference!!!
- If using UV curable coating you may have to have a secondary cure for material not exposed to the UV
- Max temperature during curing should be <100°C
- If thermal curing is used — may require several hours of air curing to permit outgassing before entering a chamber
- Must be cured to optimum properties before any other environmental exposure
CTE Mismatch/Thickness

- Breaking Components
  - Primary concern is stress due to CTE mismatch
  - Very sensitive to thickness

Table 1: Conformal Coating Thickness tolerances from NASA Technical Standard NASA-STD-8739.1

<table>
<thead>
<tr>
<th>Type of Coating</th>
<th>Cured Coating Thickness (in)</th>
</tr>
</thead>
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<tr>
<td>Acrylic</td>
<td>0.001 to 0.005</td>
</tr>
<tr>
<td>Urethane</td>
<td>0.001 to 0.005</td>
</tr>
<tr>
<td>Epoxy</td>
<td>0.001 to 0.005</td>
</tr>
<tr>
<td>Silicone</td>
<td>0.002 to 0.008</td>
</tr>
</tbody>
</table>

Similar specs in IPC2221, J-STD-001, and IPC-HDBK-830
Problems

- **Problem 1: Does Not Consider Low Standoff Components**
  - QFN standoff can be less than five mil (125 microns)

- **Problem 2: Does Not Consider Glass Transition Temperature (Tg)**
Conformal Coating and QFN

- Care must be taken when using conformal coating over QFN
  - Coating can infiltrate under the QFN
  - Small standoff height allows coating to cause lift

- Hamilton Sundstrand found a significant reduction in time to failure (-55 / 125C)
  - Uncoated: 2000 to 2500 cycles
  - Coated: 300 to 700 cycles

- Also driven by solder joint sensitivity to tensile stresses
  - Damage evolution is far higher than for shear stresses

Wrightson, SMTA Pan Pac 2007
Solder Fracture – Why?

- Dip coated assembly with BGA technology
- Passed ALT (-40C / 100C)
- Failing quickly in the field
Coating Under Component – Causing Lifting
All amorphous materials have a glass transition temperature (Tg)

Breaking Components – Glass Transition Temperature

Hard/Brittle ⇔ Soft/Rubbery

-65°C 125°C

Silicone Acrylic Urethane
Near the glass transition temperature (Tg), CTE changes more rapidly than modulus
- Changes in the CTE in polymers tend to be driven by changes in the free volume
- Changes in modulus tend to be driven by increases in translational / rotational movement of the polymer chains

Increases in CTE tend to initiate before decreases in modulus because lower levels of energy (temperature) are required to increase free volume compared to increases in movement along the polymer chains.

High stresses generated due to CTE increase before modulus decrease.

Polymer Science and Technology, Chapter 4: Thermal Transitions in Polymers, Robert Oboigbaotor Ebewele, CRC Press, 2000
Concentrate Contaminants

- Traditional Conformal Coatings are NOT hermetic
  - Moisture will diffuse through

- Requires good adhesion to the circuit board
  - Bubbles/Voids/Delam can drive micro-condensation
  - Can make it electrochemical migration MORE likely
Sulfur Corrosion Sites on Coated Hybrid

- Silicone coating, ceramic hybrid
- Used in industrial controls
- Customer reported failures after 12 to 36 months in the field
- X-ray identified several separations
Sulfur attack of silver occurs at the abutment of the glass passivation layer and the resistor termination
- Cracks or openings can allow the ingress of corrosive gases,
- Reaction with the silver to form silver sulfide (Ag2S)

Large change in resistance
- $\rho_{Ag} = 10^{-8}$ ohm-m;
  $\rho_{Ag2S} = 10$ ohm-m
- Up 20K ohms (0.01 x 0.01 x 0.5mm)

Manufacturers’ solutions
- Sulfur tolerant – silver alloys
- Sulfur resistant – silver replacement
I Feel the Need for Clean!!!!

- Selecting the Correct Cleaning Procedure
  - Ensure a high surface cleanliness – aiding adhesion

<table>
<thead>
<tr>
<th>Cleaning Medium</th>
<th>Benefits</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic solvents</td>
<td>- Can remove a wide range of different residues</td>
<td>- High VOC (volatile organic compound) content</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Flammable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Explosion-protected systems are necessary</td>
</tr>
<tr>
<td>Aqueous-alkaline cleaners</td>
<td>- Little to no VOC content</td>
<td>- Short bath life</td>
</tr>
<tr>
<td>(surfactant cleaners)</td>
<td>- Non-flammable</td>
<td>- Large amounts of cleaner must be disposed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Residue-free drying is difficult</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- possible problems with coating adhesion</td>
</tr>
<tr>
<td>Water-based Microphase Cleaners</td>
<td>- Little to no VOC content</td>
<td>- Agitation of the cleaner must be adapted to the process</td>
</tr>
<tr>
<td>(MPC8)</td>
<td>- Can remove a wide range of residues</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Non-flammable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Residue-free drying</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Long bath life</td>
<td></td>
</tr>
</tbody>
</table>

Reference: Conformal Coating Issues: When Reliability Goes Astray, Dr. Helmut Schweigart, Zestron Europe.
Conformal Coating and No-Clean

- Concerns about applying conformal coating over no-clean flux residues
  - Conformal coating suppliers tend to not recommend
  - Some have compatibility docs

- Residues can reduce adhesion, potentially resulting in delamination
  - Creates micro-condensation conditions; more detrimental than no conformal coating

- Has not stopped the practice
  - Current industry standards create relatively benign conditions
  - Allows products to pass qualification
Potting Materials
Potting Materials

- Very similar behavior to that of conformal coatings
  - Potting materials are also designed to protect electronics from environmental, chemical, mechanical, thermal, and electrical conditions that could damage the product.
  - Selection of the wrong potting for your application could result in damage from the potting due to unwanted stresses or heat.
  - Though there are potting materials made from polyurethane, silicone and UV cured acrylic, most potting applications use epoxy compounds due to their balance of mechanical, thermal, electrical and adhesion properties.
Why Use Potting Materials?

Questions to ask yourself.

- Does the potting compound perform a thermal function?
- Does it need to protect from aggressive chemicals or moisture?
- Does it need to protect from shock loads?
- Will the potting see high temperatures during manufacturing?
- Are issues such as outgassing, cryogenic operation, or medical compatibility involved?

- Ask the right questions during the design cycle to keep problems to a minimum.
One of the most common issues with selecting the right potting material is understanding your thermal requirements. Typically selected based on min and max temperatures. Maybe OK, but does not take ramp times and dwells into consideration. Failing to consider dwell and ramp times often can lead to over specifying the materials. For example, if you select a material with a 200°C continuous rating, it would be able to withstand a short burst at 250°C during a soldering operation. Ignoring the short dwell time could result in selecting a much more expensive material than you actually require.
Typically, manufacturers will select the potting material with the fastest cure cycle.

- A risk is that the fast cure can result in a larger exothermic reaction which could possibly cause damage (potential >200°C).
- Fast cures also have the potential for entrapped bubbles, which can impact the materials electrical and mechanical properties.
- The selection of a 1 or 2 part material also can have an impact – selecting the easiest approach may not be the best.
- The more potting material involved the higher risk associated with the exothermic reaction during curing especially in thicknesses greater than ¼ to ½ inch.
Think About Shrinkage/Adhesion

- **Shrinkage:** Potting materials will shrink, sometimes as much as 2.3% for an unfilled epoxy
  - If not accounted for this shrinkage can increase stress levels on electronic components, crate leak paths, and create visual defects
  - Good news – shrinkage can be controlled by selecting the right material
    - Filled potting and slower curing materials will incur less shrinkage

- **Adhesion:** Some potting materials have low surface energy and do not bond easily
  - Substrate materials can be treated with surface treatments or primers
  - Undercuts in the housing can be used to let the cured potting “lock” itself into the housing
Ideally the CTE of the potting should be as close to the CCA as possible

- Usually in the 20 to 30 ppm/°C
- The larger the CTE, the more compliant the potting must be to limit the stresses imparted to the CCA
- Potting should generate hydrostatic pressure (equal on all sides) of the circuit card
  - This prevents warping of the CCA as the potting expands
  - Excessive warping will greatly reduce time to failure
  - May cause overstress failures.
- This may require modification to the housing
- Housing may need to be relatively stiff
**Solder Stresses**

- Very high stresses during cold dwell of thermal cycle
Creep Strains

- The higher the creep strains, the shorter the time to failure

![Graph showing Unpotted and Potted creep strains](image)

- Excessive creep occurring at cold temperature
- More energy required to cause cold temperature creep (more damaging)
Potting Conclusions

- **Mechanical properties of the potting material**
  - Glass transition temperature (Tg) – should be specified outside the operational range
  - Modulus should be specified above and below the Tg
  - CTE should be specified above and below the Tg

- **The design of the housing**
  - May provide a surface to which the potting material can pull against when shrinking causing PCB warpage
  - Should be designed to provide as close to a hydrostatic pressure as possible (equal pressure on all sides)
New Superhydrophobic Nanocoating Materials

- Explosion in new coating technologies over the past 24 months
- Reached an apex at Consumer Electronics Show in Jan. 2012
- Drivers
  - Moisture proofing
  - Oxygen barrier (hermeticity)
  - Tin whiskers
Super Hydrophobicity

- **Definition**: Wetting angle far greater than the 90 degrees typically defined as hydrophobic
- Can create barriers far more resistant to humidity and condensation than standard conformal coatings
Risks?

- Voltage Breakdown
  - Levels tend to be lower compared to existing coatings (acrylic, urethane, silicone)
  - Can be an issue in terms of MIL and IPC specifications

- Optically Transparent
  - Inspection is challenging

- Cost
  - Likely more expensive than common wet coatings
  - However, major cell phone manufacturer claims significant ROI based on drop in warranty costs

- Throughput
  - Batch process. Coating times tend to be 10 to 30 minutes, depending upon desired thickness
  - However, being used in high volume manufacturing
There is significant opportunity for field performance improvement and cost reduction through the use of nanocoatings.

Requires a knowledge of the materials and processes on the market.

Benefits vs. Risks

With any new technology, do not rely on standard qualification tests!

A physics-based test plan provides the most robust mitigation.
THANKS

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