Coatings and Pottings – Issues and Challenges and the Reason for a Consortium

DfR Solutions Open House – March 17, 2014

Presented by:

Dr. Nathan Blattau – Senior Vice President
Greg Caswell – Sr. Member of the Technical Staff

Conformal Coating

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

	Properties	Comments
Epoxy	Good adhesion Excellent chemical resistance Acceptable moisture barrier	Difficult to rework Needs compliant buffer Not widely used
Urethane	Good adhesion High chemical resistance Acceptable moisture barrier	Difficult to rework Widely used Low cost
Acrylic	Acceptable adhesion Poor chemical resistance High moisture resistance	Easy to rework Widely used Moderate cost
Silicone	Poor adhesion Low chemical resistance Excellent moisture resistance	Possibility of rework Moderate usage High cost
Paralyne	Excellent adhesion Excellent chemical resistance Excellent moisture resistance	Impossible to rework Rarely used Extremely high cost

Applications

- The automotive industry specifies conformal coatings to protect circuitry from gasoline vapor, salt spray and brake fluid. The use of electronic systems in vehicles is growing rapidly, and as such, the use of conformal coatings is becoming vital to ensure long term reliability. Conformal coatings are used in applications both under the hood (e.g. engine management systems), and in passenger compartments (e.g. onboard computers).

- The aerospace industry with its high reliability requirements is also a viable application for conformal coatings. The environmental requirements of the aerospace industry where rapid compression and decompression can affect the performance of circuitry, necessitates the use of conformal coatings. The coatings are used in both pressurized and depressurized areas.

Applications

- Both fresh and salt water environments will attack electronic circuitry. Conformal coatings are ideal for the protection of equipment used for these applications, which can range from under the dash of high performance boats, to exterior equipment used on larger maritime systems.

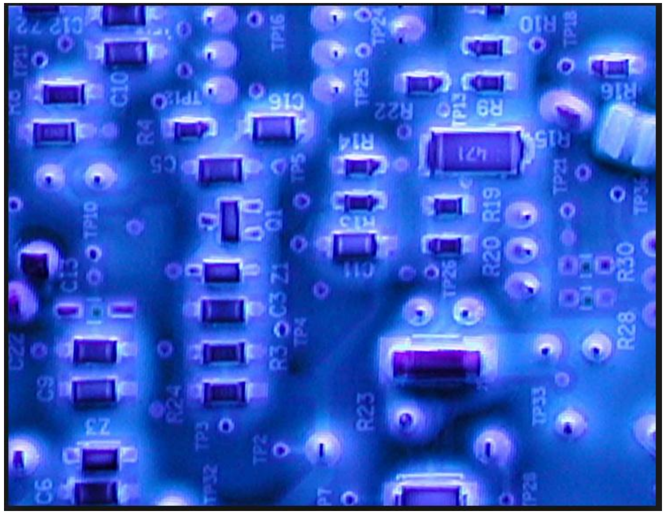
- Similarly, in the medical industry there are numerous areas where a conformal coating will be required for environmental protection: Tool protection while in storage to prevent corrosion; pacemakers, where it is vital to ensure continuous performance and even food carts in hospitals.

How is Conformal Coating Applied?

- The conformal coating material can be applied by brushing, spraying or 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 Right Material

- Selecting the appropriate coating based on the application will reduce the risk of failure.
  - For instance, an 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.

Selecting the Right Material

- 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. Some coating manufacturers address this issue by adding catalysts which act as a secondary cure mechanism.

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

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 <100C
- 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

Type of Coating	Cured Coating Thickness (in)
Acrylic	0.001 to 0.005
Urethane	0.001 to 0.005
Epoxy	0.001 to 0.005
Silicone	0.002 to 0.008

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

Failure Modes

- Cracked Components
  - Especially glass MELF Diodes

- Cracked Solder Joints
  - Primarily cylindrical components

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)

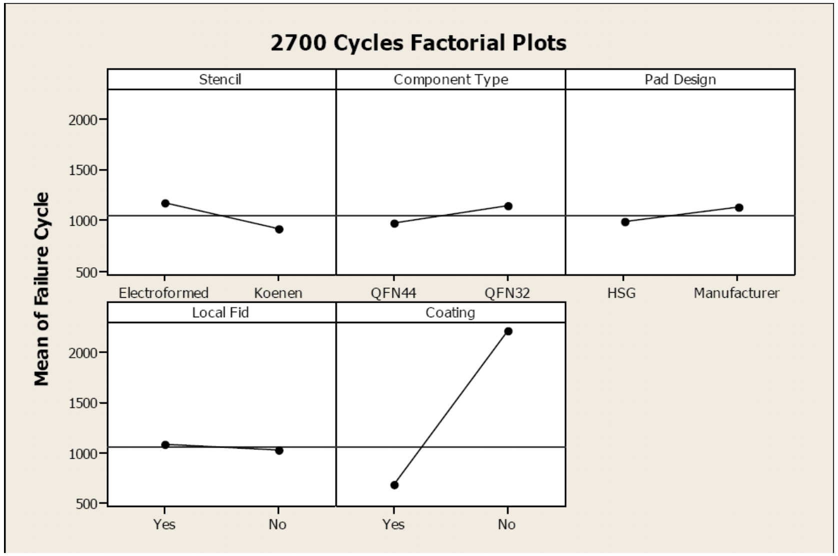
DfR Solutions

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

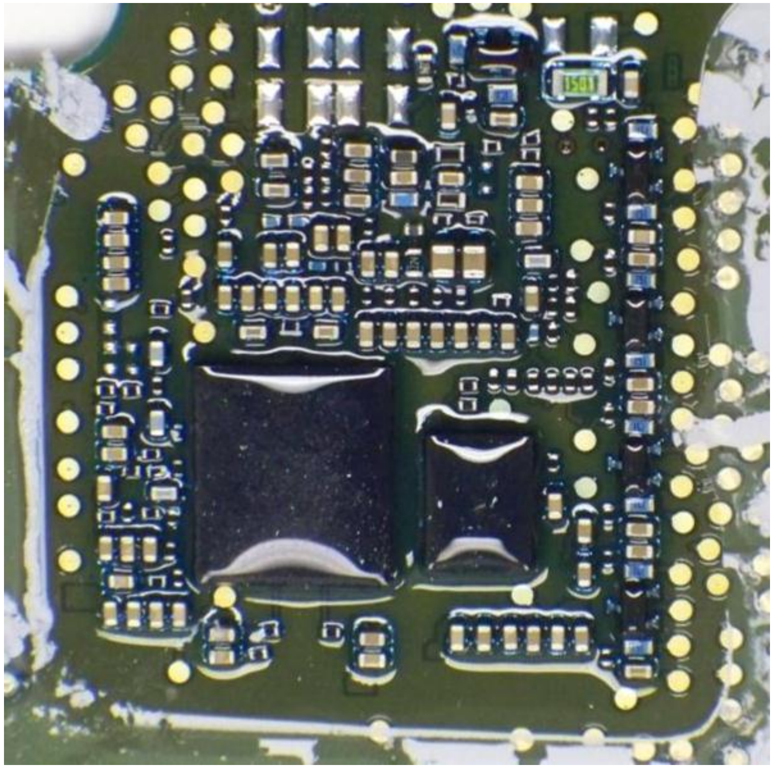


Wrightson, SMTA Pan Pac 2007

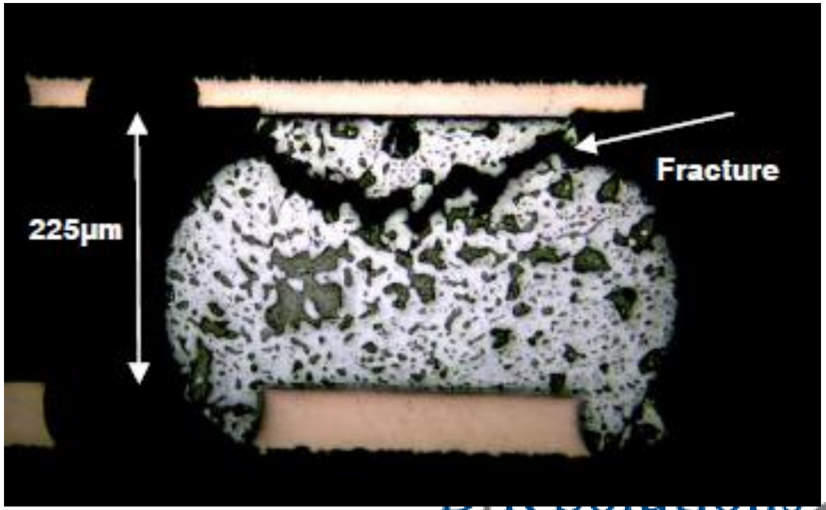
DfR Solutions

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

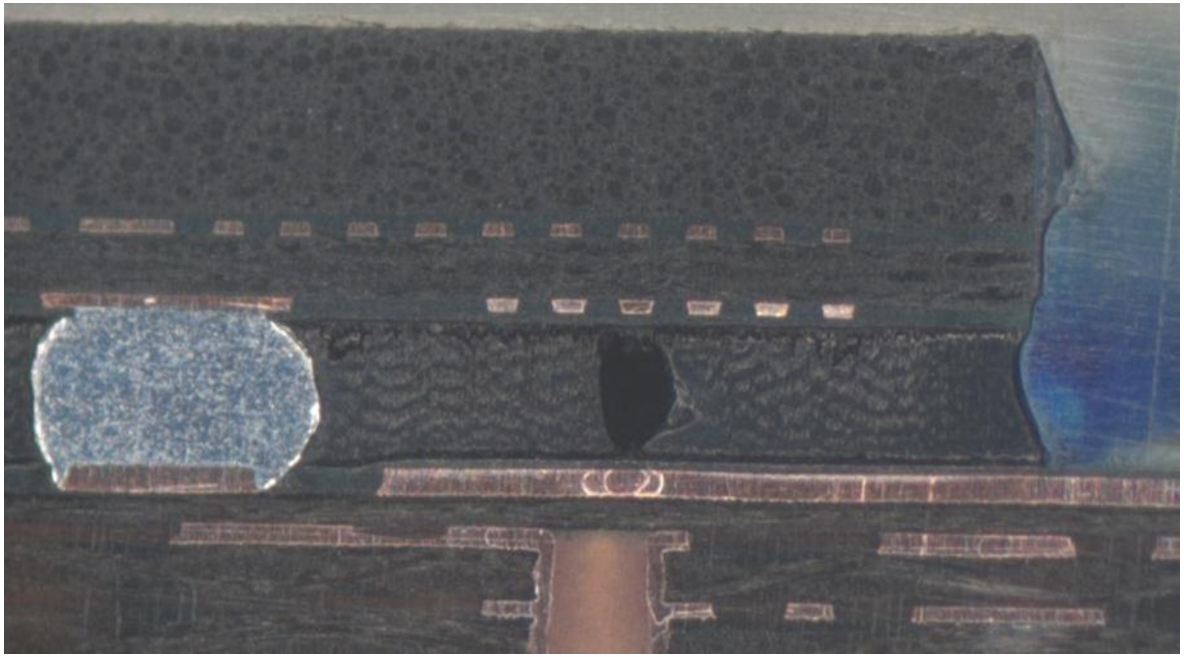
Solder Fracture –Why?



- Dip coated assembly with BGA technology
- Passed ALT (-40C / 100C)
- Failing quickly in the field



Coating Under Component –Causing Lifting

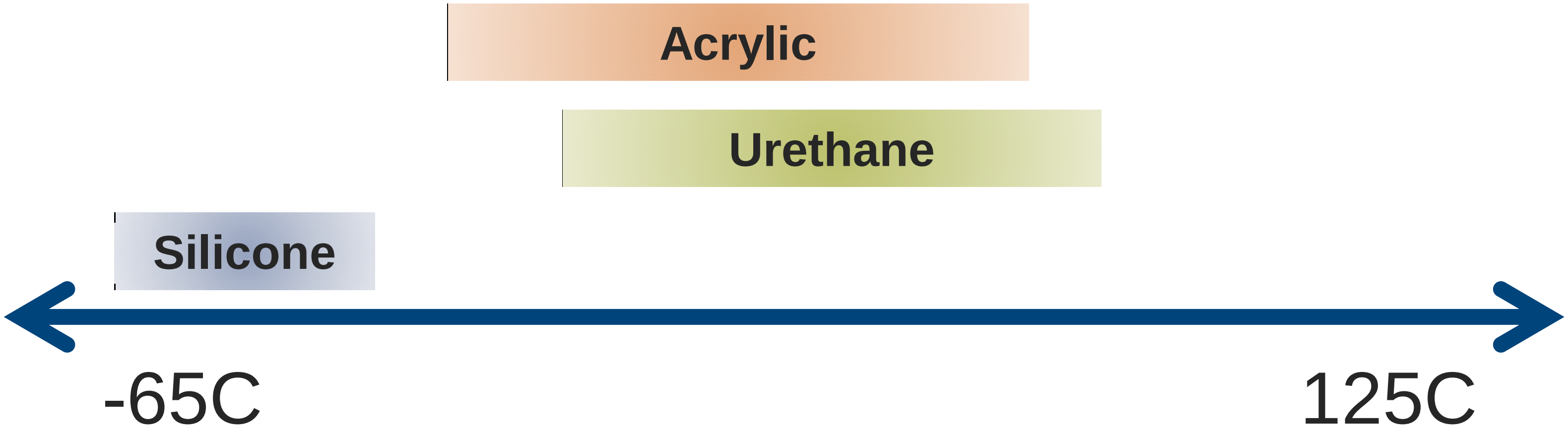


DfR Solutions

Breaking Components – Glass Transition Temperature

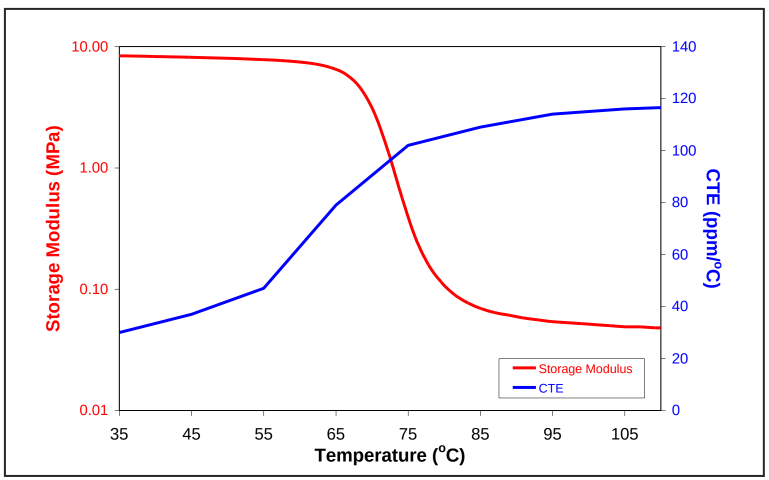
- All amorphous materials have a glass transition temperature (Tg)

Hard/Brittle ⇔ Soft/Rubbery

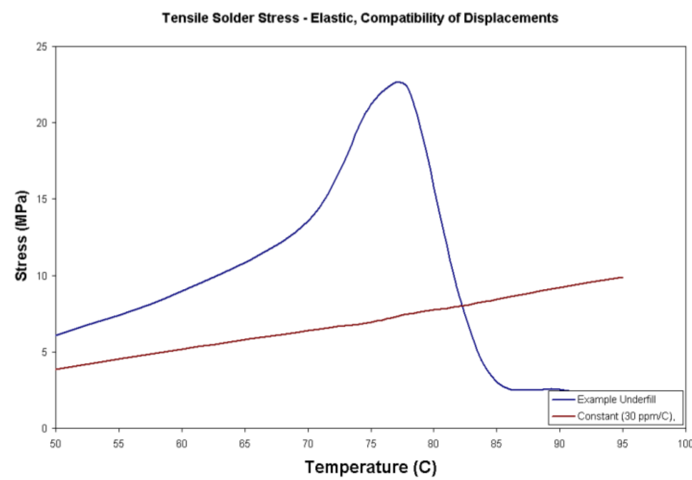


Tg Behavior

- 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



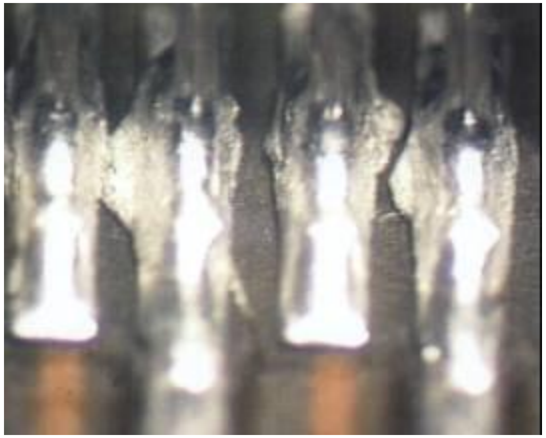
High stresses generated due to CTE increase before modulus decrease

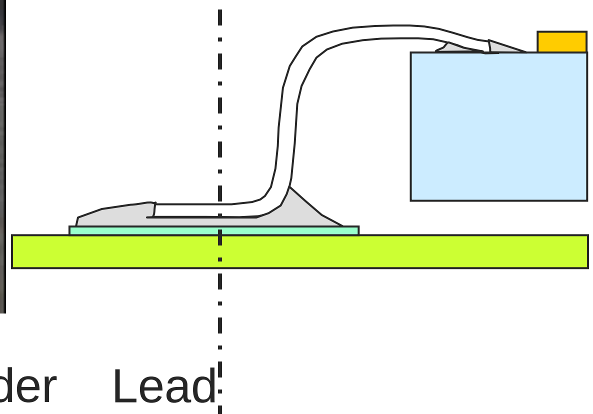


Polymer Science and Technology, Chapter 4: Thermal Transitions in Polymers, Robert Oboigbaotor Ebewele, CRC Press, 2000

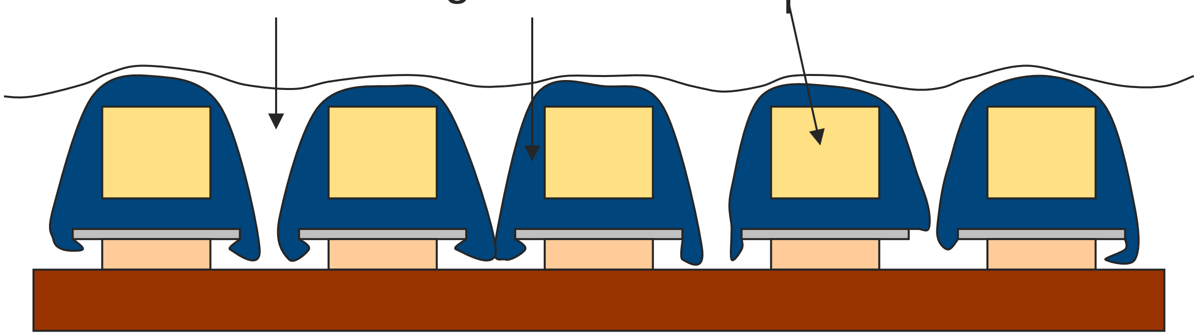
DfR Solutions

Case Study – Solder Spreading





During use, excessive solder deformation causes adjacent leads to short together. Failures only occur when excessive conformal coating is present



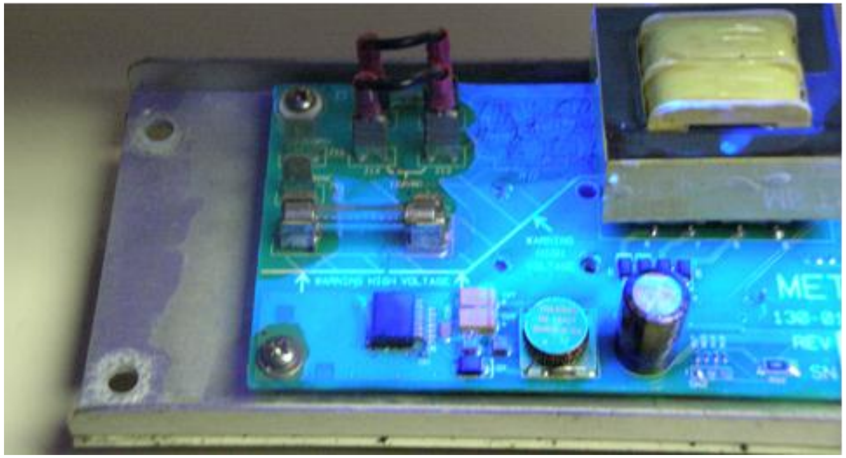
Field failures could not be duplicated using –55 to 125°C thermal cycling

DfR Solutions

Concentrate Contaminants

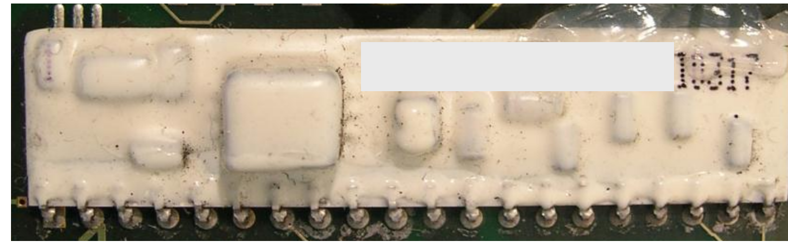
- Traditional Conformal Coatings are NOT hermetic
  - Moisture will diffuse through

- Requires good adhesion to the circuit board
  - Bubbles/Voids/Delam can drive micro-condensation
  - Can make it electrochemical migration MORE likely



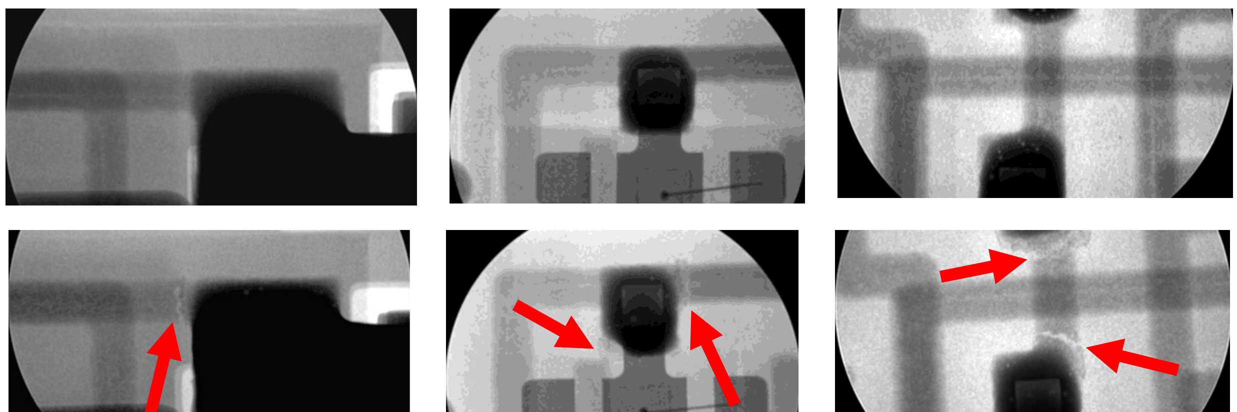
Sulfur Attack of Coated Hybrid

- Silicone coating, ceramic hybrid
- Used in industrial controls
- Customer reported failures after 12 to 36 months in the field
- X-ray identified several separations



‘Good’ hybrid

‘Bad’ hybrid

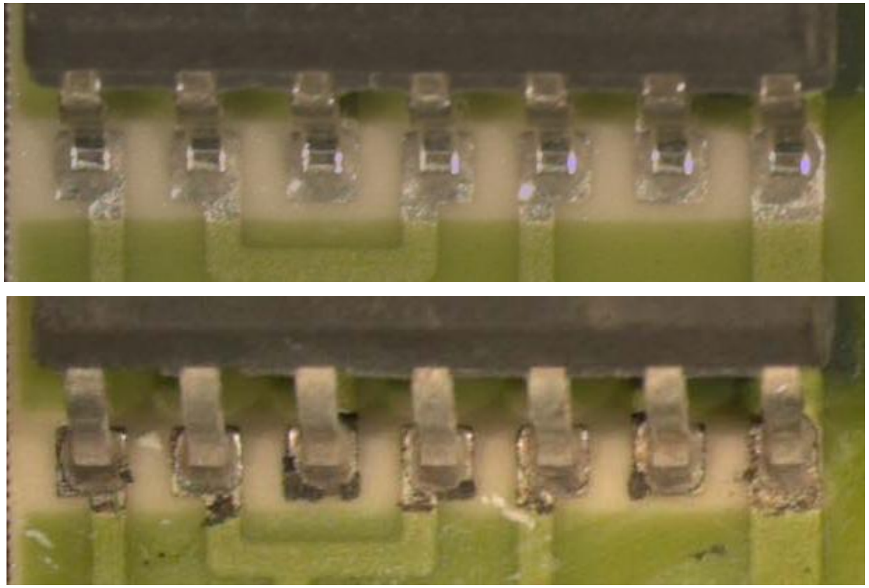


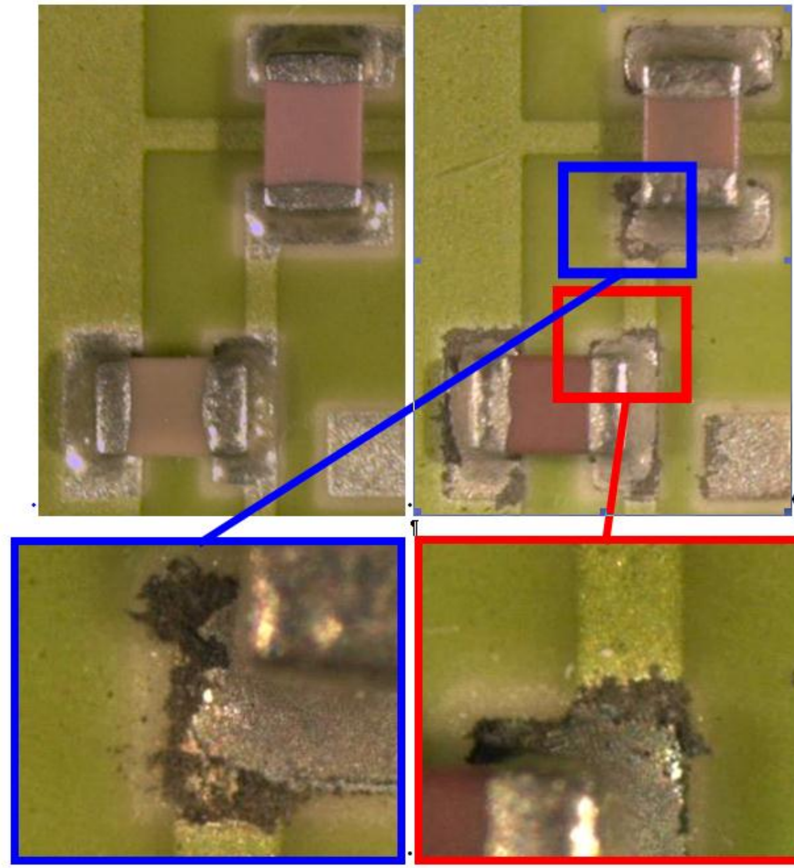
Visual inspection revealed black corrosion product throughout the hybrid

- Most severe in areas with no solder or solder mask covering silver thick film traces
- Attack through the solder mask in some locations

DfR Solutions

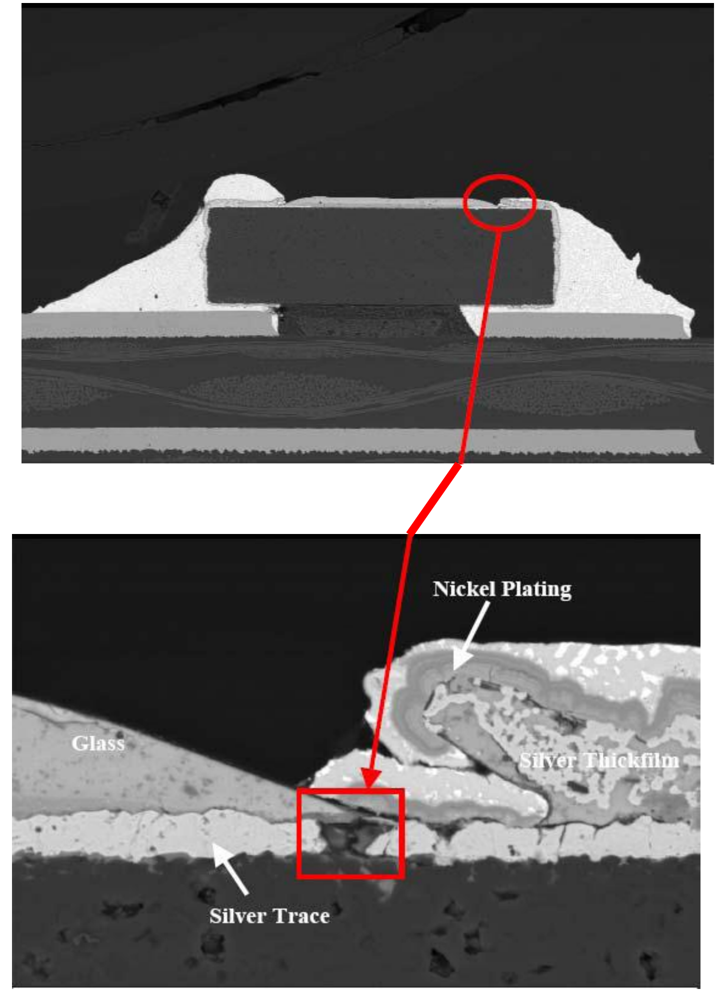
Sulfur Corrosion Sites





SMT Resistors

- 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
  - ρ_{Ag} = 10^{-8} ohm-m;
    ρ_{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



DfR Solutions

I Feel the Need for Clean!!!!

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

Table 1. Comparison of different cleaning systems.

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

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

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

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.

Know Your Thermal Situation

- 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 200C continuous rating, it would be able to withstand a short burst at 250C during a soldering operation
    - Ignoring the short dwell time could result in selecting a much more expensive material than you actually require.

The Curing Process

- 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 >200C)
  - 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

DfR Solutions

Think About 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

Think About 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

DfR Solutions

Think About the Flow and Think Small

- Viscosity is primary parameter
- Geometry of housing or shell in relation to the components on the PCB is also important

- Watch for large horizontal surfaces – when filled from the top, they can entrap moisture or air that can affect electronic components

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Potting

- 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 the 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

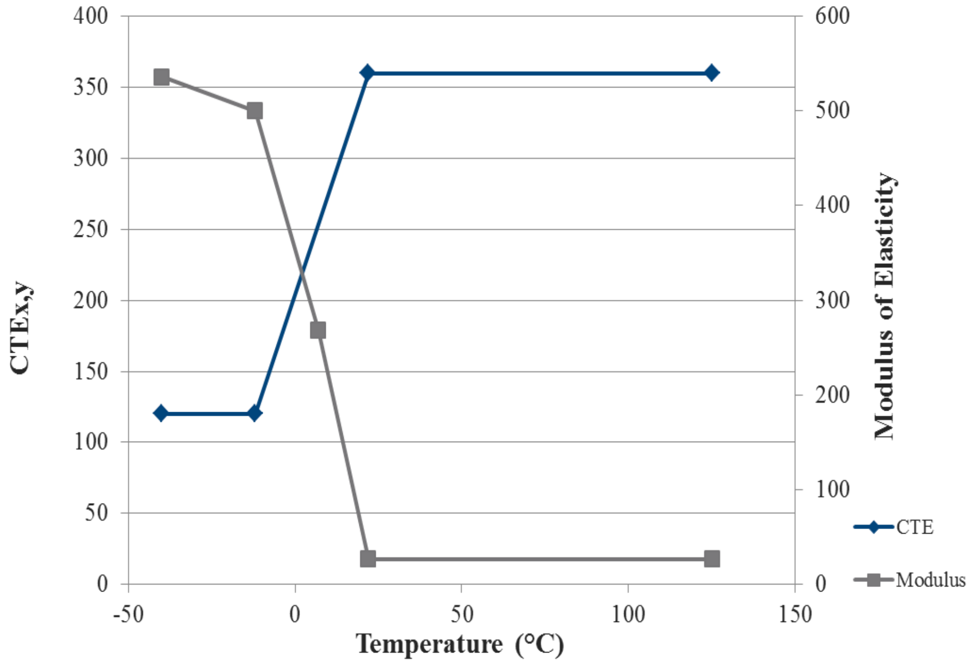
Material Properties

Potting Compound

Isotropic Material

$CTE_{x,y}$ = 120 ppm

Significant increase in modulus or stiffness below with high CTE



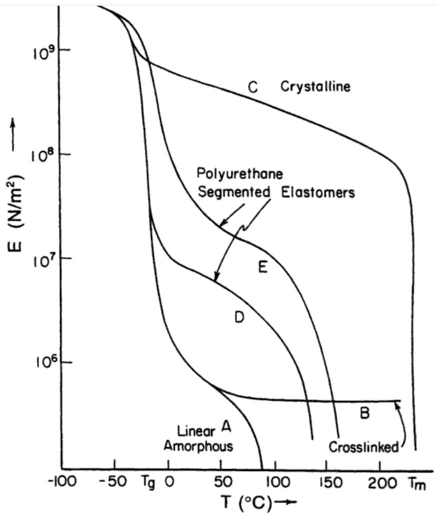
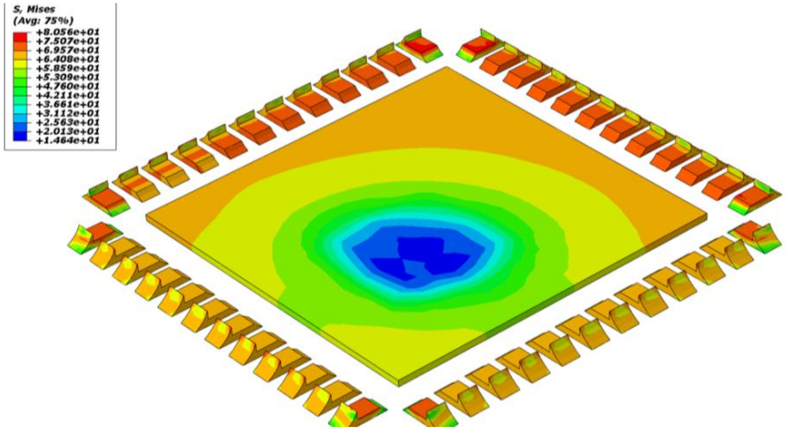


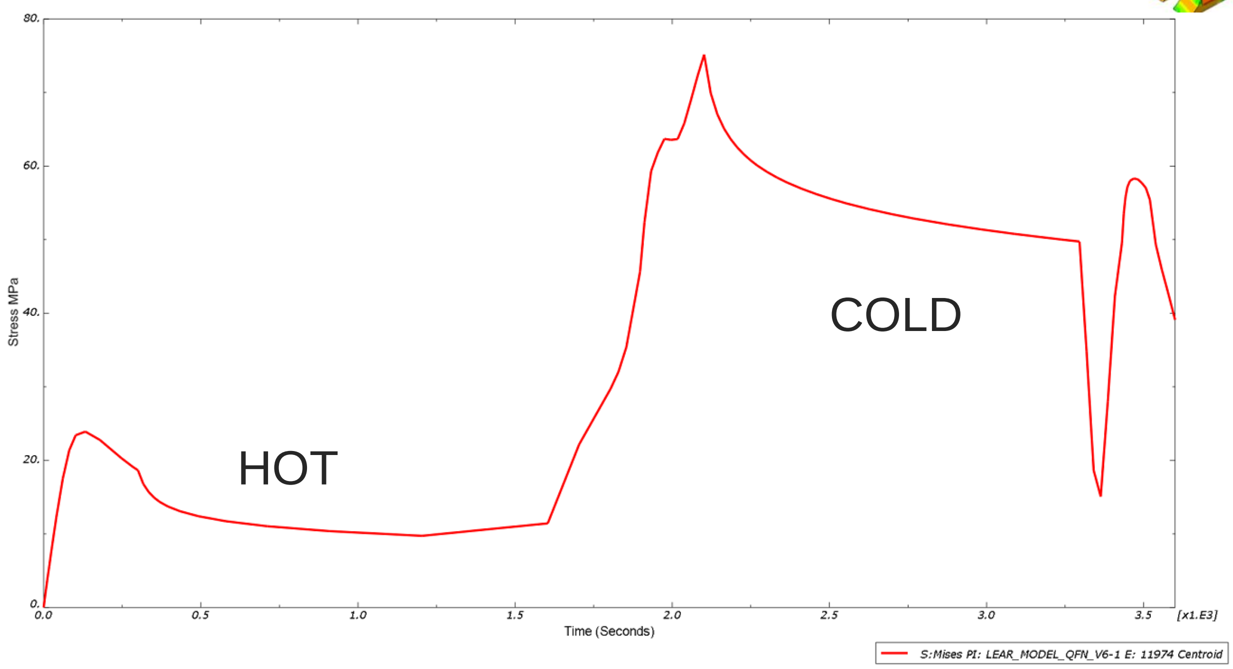
FIGURE 22 Storage modulus v temperature curves for (A) linear amorphous polymer, (B) crosslinked polymer, (C) semicrystalline polymer, (D) MDI/BD/PTMA segmented polyurethane (32% MDI by weight), (E) MDI/BD/PTMA segmented polyurethane (38% MDI by weight). From Cooper S.L. and Tobolsky A.V. *J. Appl. Polym. Sci.*, 10:1837, Copyright 1966. Reprinted with permission by John Wiley & Sons.

DfR Solutions

Solder Stresses

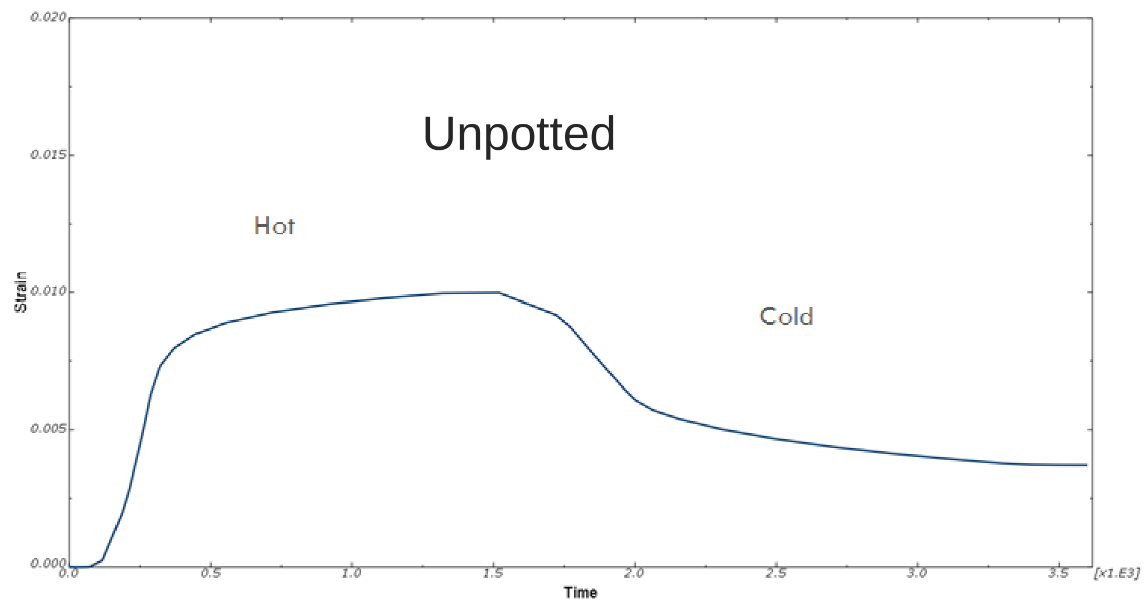
- Very high stresses during cold dwell of thermal cycle

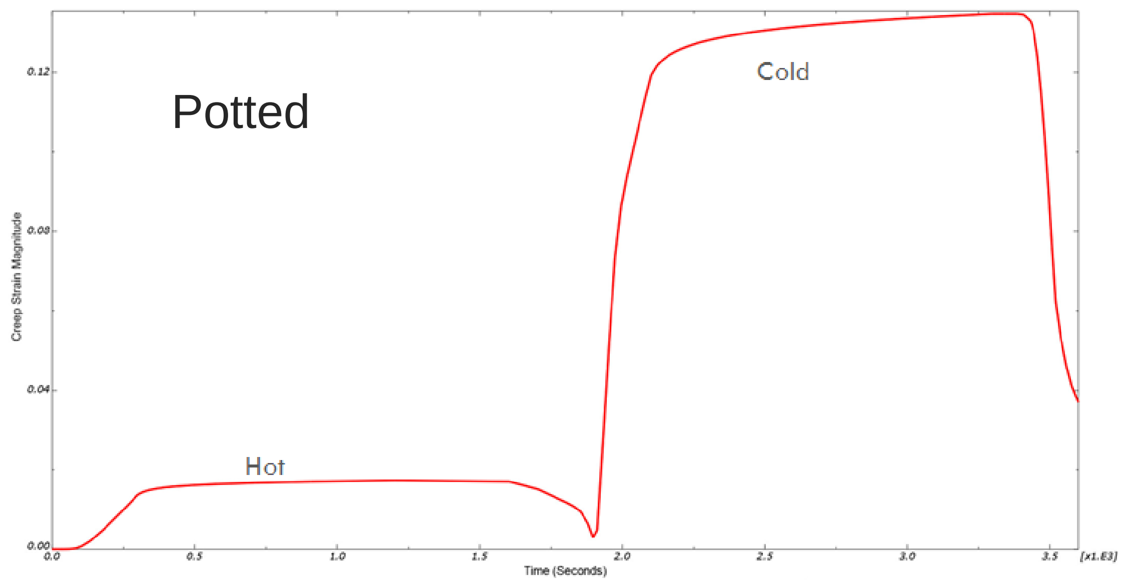




Creep Strains

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





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

Creep Strain

- In materials science, creep is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. It occurs as a result of long term exposure to high levels of stress that are below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and near melting point. Creep always increases with temperature.

- The rate of this deformation is a function of the material properties, exposure time, exposure temperature and the applied structural load. Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures. Creep is a deformation mechanism that may or may not constitute a failure mode. Moderate creep in concrete is sometimes welcomed because it relieves tensile stresses that might otherwise lead to cracking.

- Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Creep is a "time-dependent" deformation

Conclusions

- Mechanical properties of the potting material
  - Glass transition temperature (Tg)
  - 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 Materials

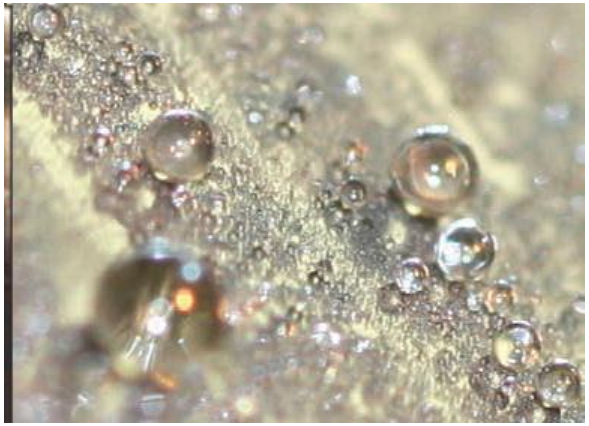
9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

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



DfR Solutions

Nanodeposition of High Surface Tension Materials

- Three companies currently focused on the electronics market

P2i perform protect improve

GVD

Semblant

- The key technology for each company is the process, not necessarily the materials

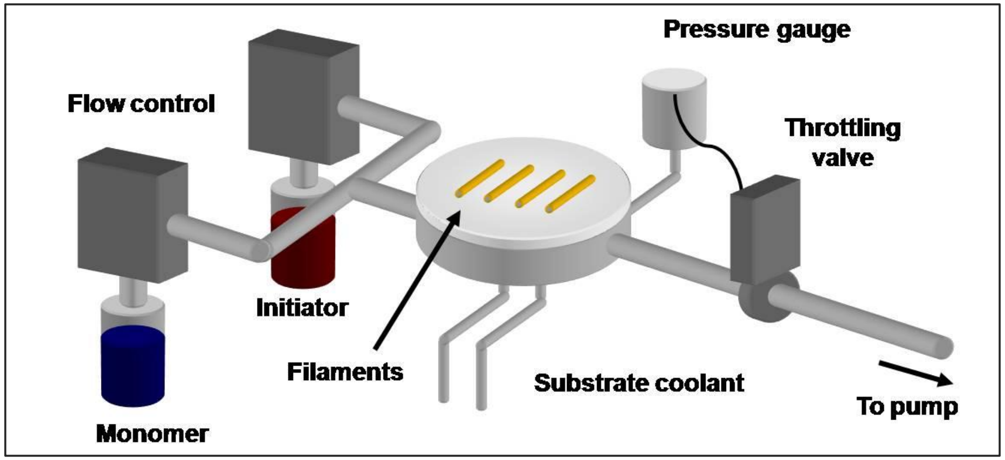
Process Technology

- Hydrophobicity tends to be driven by number and length of the fluorocarbon groups and the concentration of these groups on the surface

- The key points to each technology are similar
  - All assisted chemical vapor deposition (CVD) processes
  - Room Temperature Deposition Process
  - Low Vacuum Requirements
  - Variety of Potential Coating Materials (with primary focus on fluorocarbons)

- Differentiation is how they breakdown the monomer before deposition

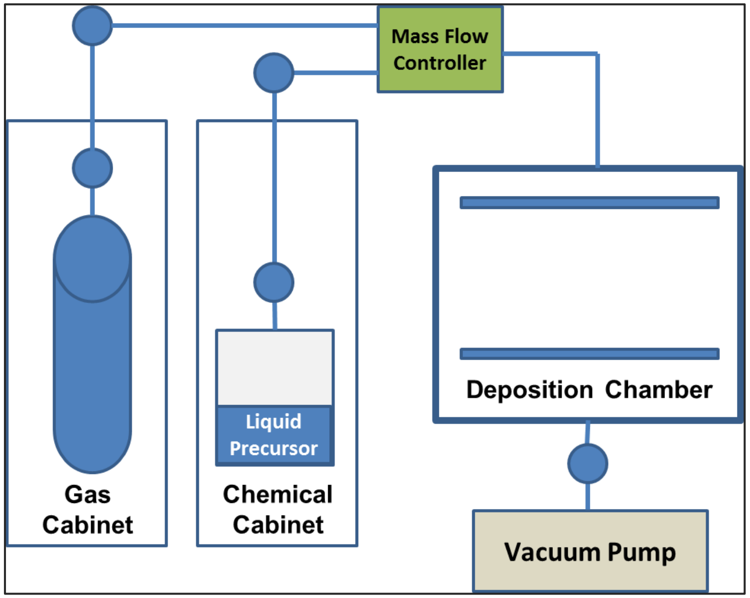
Process Differentiation



http://web.mit.edu/gleason-lab/research.htm

- iCVD uses a chemical initiator to breakdown the monomer

- Plasma-Enhanced CVD (PECVD) uses plasma to breakdown the monomer



Courtesy of Semblant Ltd.

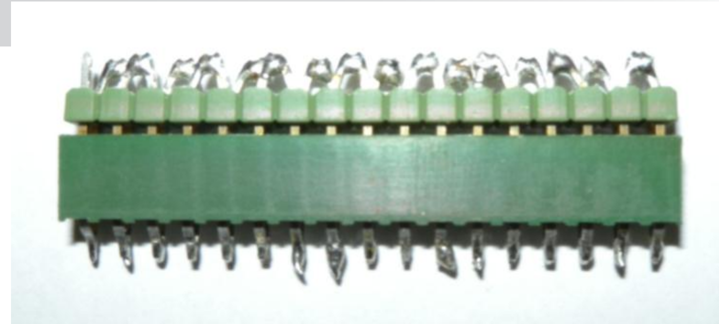
Benefits (especially compared to Parylene)

- These are truly nanocoatings
  - Minimum Parylene thickness tends to be above one micron (necessary to be pinhole free)
  - These coatings can be pinhole free at 100 nm or lower

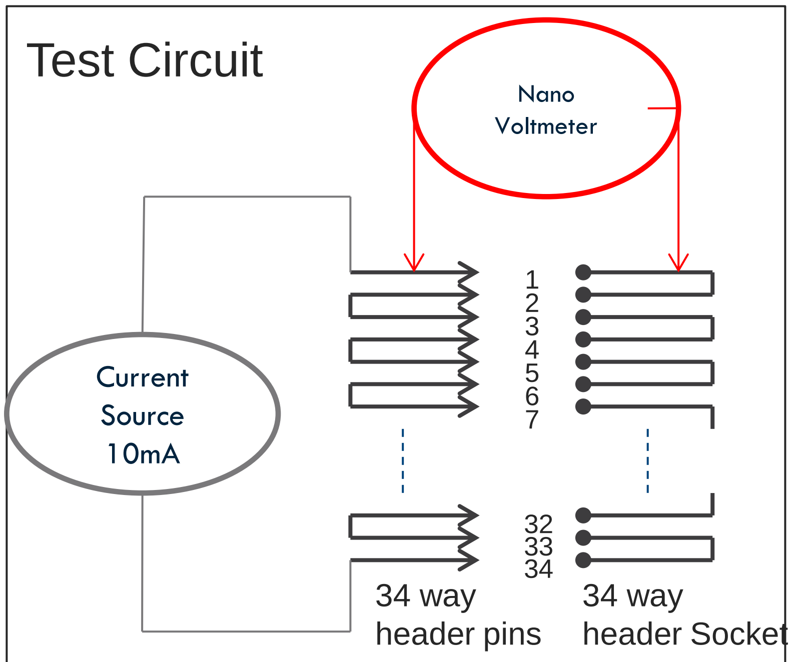
- Nanocoating allows for
  - Optical Transparency
  - RF Transparency
  - Reworkability
  - Elimination of masking

Optically Transparent

Benefits: No Masking

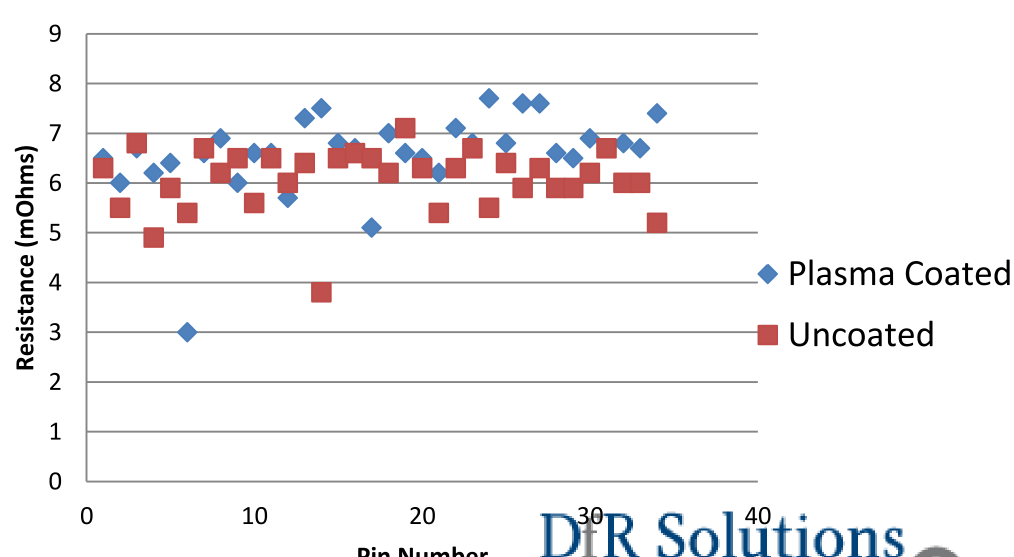


LLCR Measurements	
Current (A)	0.01
V comp (V)	0.1
Connector Male	34way Pin Header Au over nickel contact (TE Connectivity 1-215307-7)
Connector Female	34way Socket Header Au over nickel contact (TE Connectivity 1-826632-7)



$$R_{contact} = V_{measure}/10x10^{-3}$$

Low Level Contact Resistance



Courtesy of Semblant Ltd.

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

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Conclusion

- 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

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

DfR Consortium

- Quantifying Mitigation Strategies for Pb-free Assemblies: Effect of Potting and Coatings

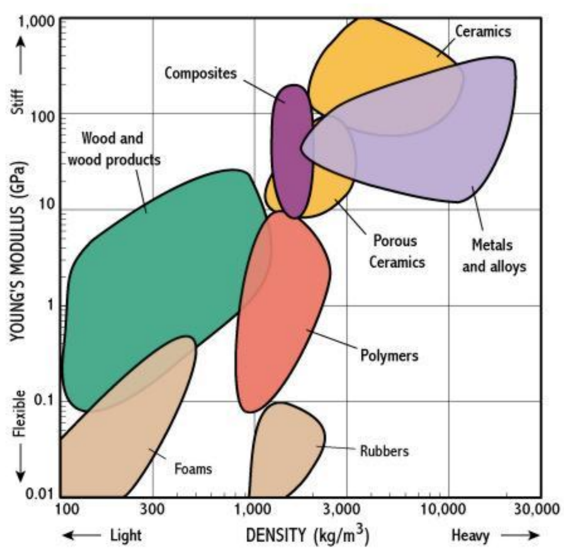
  - The use of pottings and coatings as protection against harsh environments is well known. Through the selection of the appropriate materials, electronic assemblies can be manufactured to operate under the most extreme conditions, including temperature, humidity, vibration, shock, and corrosive gases.

  - The one flaw in the electronics industry's current approach towards potting and coating mitigation is the lack of design rules and algorithms that would allow engineers to accurately select the right material and manufacturing process and accurately predict the performance of the potted or coated assembly. This is especially critical with the transition to Pb-free, as Pb-free product currently on the market is highly unlikely to be potted or coated and be expected to survive for long periods of time under harsh environments.

  - In addition, given some of the known risks of Pb-free electronics, including embrittlement and tin whiskers, several high reliability organizations are seriously considering the use of pottings and coatings for the first time as a mitigation technique. This approach may be successful, but without knowledge and data on behavior of Pb-free assemblies under these pottings and coatings, other failure mechanisms may result in field performance that is unacceptable to the customer.

Stage 1-Material Property Definition

- In Stage One of the Coating/Potting Activity, the DfR staff will gather information on polymers available for electronic potting/encapsulation and develop a realistic expectation of material properties. This range will not only define minimum and maximums, but also how material properties correlate with each other.



DfR Solutions

Stage 1

- When information on material properties is not available, DfR personnel will obtain coating/potting material and perform the necessary characterization over a range of temperatures using industry standard techniques.
  - CTE measurements will be performed using a thermo-mechanical analyzer in compliance with ASTM E831
  - Modulus measurements will be performed using a torsional approach on a dynamic material analyzer in compliance with ISO 6721
  - Hardness measurements will be performed
  - Moisture diffusion and saturation will be measured through weight gain measurements in compliance with ASTM D5229

DfR Solutions

Stage 2 – Modeling and Simulation

- Once the range and correlation of material properties is obtained, DfR will develop a three dimensional representation of an electronics assembly with a range of representative part and package technologies. Examples will include tall/large structures representative of power components (electrolytic capacitors, transformers, etc) and small low-profile components representative of leaded and leadless packages (SOIC, QFN, BGA).

- A parametric study using finite element analysis (FEA) will then be performed to investigate the effect of material properties, coating/potting thickness, and housing compliance on the stress and strain on the relevant solder joints under temperature cycling, vibration, and mechanical shock.

DfR Solutions

Stage 2 – Coatings Physical Testing

- To quantify and benchmark nanocoating performance against traditional coatings, DfR will use coupons designed to fail due to electrochemical migration, sulfur corrosion, and tin whisker formation. Each of these coupons will be assembled coated and uncoated and then evaluated for failure modes and time to failure.
- Samples selected for physical testing will either be based on IPC standard coupons, such as IPC-B-24 or IPC-B-52, or products provided by consortium members. Tin whisker coupons will be fabricated to evaluate this failure behavior.

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Stage 3 - Validation

- The predictions developed from the FEA parametric study will be validated through testing of coated/potted electronic assemblies. Specifically, the design and test conditions will be selected to induce failures and determine if the failure site, failure mode, and time to failure correlate to the FEA predictions. In addition, as appropriate, the validation testing will also assess the ability of the coating/potting compounds to eliminate whisker risks and corrosion behavior (e.g., electrochemical migration).

Stage 4 – Sherlock Upgrade

- DfR Solutions will use the data gathered from this activity to develop algorithms to accurately represent the influence of coating/potting on time to failure of a SnPb and Pb-free PCBA. This capability will be introduced after the completion of the consortium project and will be available to all license holders of Sherlock Automated Design Analysis software.

Value Proposition

- The value proposition to consortium members is clear. Members will obtain clear benchmarks to identify and select cost-appropriate potting and conformal coating materials and will have a strong understanding as to the quantifiable benefits of each mitigation.
- Benefits of Consortium Membership include
  - Invitation to monthly consortium meetings
  - Ability to directly engage with DfR potting and coating experts
  - Exclusive access to data and findings generated through the consortium
  - Ability to select potting and coating materials to analyze (requires a super-membership)
  - For existing Sherlock license holders, free access to the improvements in Sherlock
  - For other consortium members, 60 day trial of the Sherlock upgrade once it is released

THANKS

Nathan Blattau

Greg Caswell

gcaswell@dfrsolutions.com

301-640-5825 (office)

443-834-9284 (cell)

DfR Solutions