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Coatings and Pottings: A Critical Update

Webinar – February 16, 2017

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Abstract

- Conformal coatings and potting materials continue to create issues for the electronics industry. This webinar will dig deeper into the failure modes of these materials, specifically issues with Coefficient of Thermal Expansion (CTE), delamination, cracking, de-wetting, pinholes/bubbles and orange peel issues with conformal coatings and what mitigation techniques are available. Similarly, this webinar will look at the failure modes of potting materials, (e.g Glass Transition Temperature (Tg), PCB warpage, the effects of improper curing and potential methods for correcting these situations.
- Finally, advances in superhydrophobic materials will be addressed to demonstrate the direction the industry is taking with respect to this topic.

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The Need for Cleaning Before Coating or Potting

Contamination

- Two concerns
  - Hygroscopic contaminants (discussed)
  - Ionisable contaminants that are soluble in water (e.g., acids, salts)

- Ionic contaminants of greatest concern
  - Primarily anions; especially halides (chlorides and bromides)
    - Chemically aggressive due to chemical structure
    - Very common in electronics manufacturing process
    - Decreases pH; few metal ions found in dendrites are soluble at mid to high pH. Cu dendrites require pH less than 5 to form.
    - Silver(I) ions are soluble at higher pH; reason it is one of easiest to form dendrites.
  - Cations primarily assist in the identifying the source of anions
    - Example: Cl with K suggests KCl (salt from human sweat)

Sources of Contaminants

Ion	Possible Sources
Cl	Board Fab, Solder Flux, Rinse Water, Handling
Br	Printed Board (flame retardants), HASL Flux
Fl	Teflon, Kapton
PO_4	Cleaners, Red Phosphorus
SO_4	Rinse Water, Air Pollution, Papers/ Plastics
NO_4	Rinse Water
Weak Organic Acids	Solder Flux

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PCB Contaminants (examples)

- Etching
  - Chloride-based: Alkaline ammonia (ammonium chloride), cupric chloride, ferric chloride, persulfates (sometimes formulated with mercuric chloride)
  - Other: Peroxide-sulfuric acid
- Neutralizer
  - Hydrochloric acid
- Cleaning and degreasing
  - Hydrochloric acid, chlorinated solvents (rare)
- Photoresist stripping
  - methylene chloride as a solvent
- Oxide
  - Sodium chlorite
- Electroless plating
  - Sodium hypochlorite (in potassium permanganate)
  - Palladium chlorides (catalyst)

Source of Contaminants: Fluxes

- Chemicals used for preparing metal surfaces for soldering
  - High molecular weight chemistries
  - Slightly acidic

- Optimum behavior
  - Maximum activity during reflow; minimum activity after reflow
  - Difficult balancing act

- Flux nomenclature
  - Rosin only (RO)
  - Rosin, mildly activated (RMA)
  - Rosin activated
  - Water soluble
  - Low residue (no-clean)

J-STD-004 Flux Classification

Materials of Composition[2]	Flux/Flux Residue Activity Levels	% Halide[3] (by weight)	Flux Type[3]	Flux Designator
Rosin (RO)	Low	0.0%	L0	ROL0
		<0.5%	L1	ROL1
	Moderate	0.0%	M0	ROM0
		0.5-2.0%	M1	ROM1
	High	0.0%	H0	ROH0
		>2.0%	H1	ROH1
Resin (RE)	Low	0.0%	L0	REL0
		<0.5%	L1	REL1
	Moderate	0.0%	M0	REM0
		0.5-2.0%	M1	REM1
	High	0.0%	H0	REH0
		>2.0%	H1	REH1
Organic (OR)	Low	0.0%	L0	ORL0
		<0.5%	L1	ORL1
	Moderate	0.0%	M0	ORM0
		0.5-2.0%	M1	ORM1
	High	0.0%	H0	ORH0
		>2.0%	H1	ORH1
Inorganic (IN)	Low	0.0%	L0	INL0
		<0.5%	L1	INL1
	Moderate	0.0%	M0	INM0
		0.5-2.0%	M1	INM1
	High	0.0%	H0	INH0
		>2.0%	H1	INH1

Handling / Storage / Environment

- Handling
  - Salts from human contact (KCl and NaCl)

- Storage
  - Cleaning chemicals
  - Outgassing
  - Polymeric materials

- Use Environment
  - Dust
  - Evaporated sea water
  - Industrial pollutants

Handling / Sweat

- Composition of dissolved salts in water
  - Can include other biological molecules.
- Main constituents, after the solvent (water),
  - Chloride, sodium, potassium, calcium, magnesium, lactate, and urea.
- Chloride and sodium dominate.
  - To a lesser but highly variable extent, iron, copper, urocanate (and the parent molecule histidine), and other metals, proteins, and enzymes are also present.
- The main concern regarding sweat is as a source of chloride

Conformal Coating

- 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.

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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

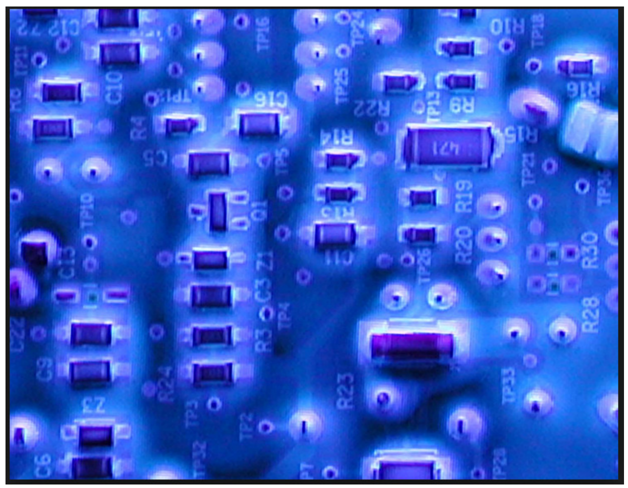
- Rework procedures for Paralyne now exist

Theoretical Information

- 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.

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

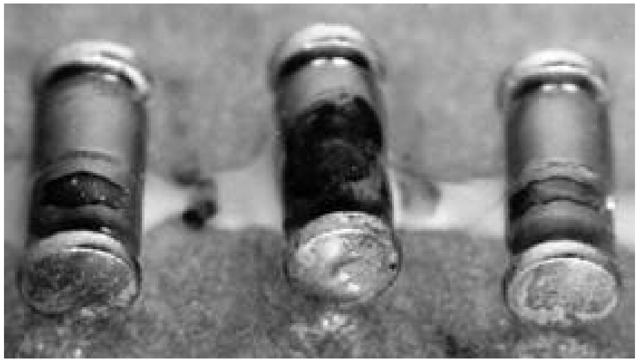
Table 1: Conformal Coating Thickness tolerances from NASA Technical Standard NASA-STD-8739.1

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

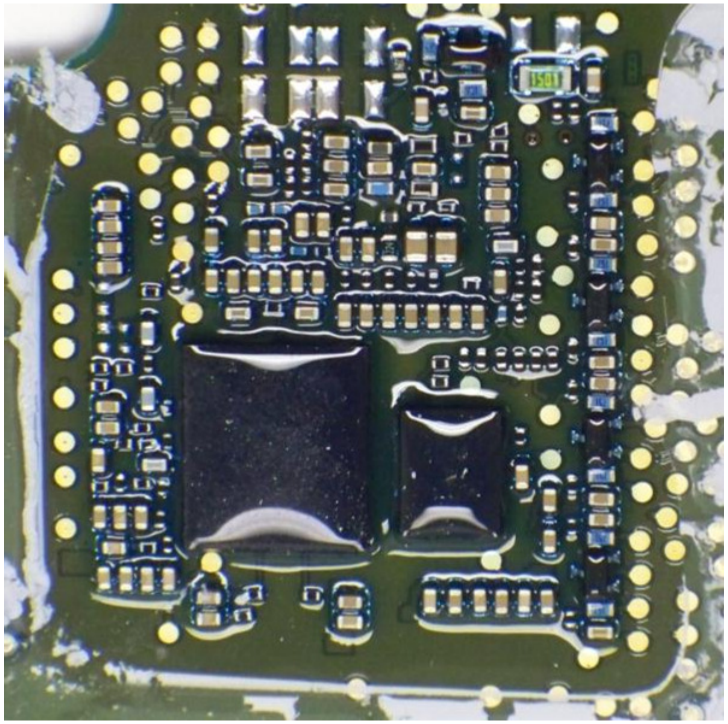
Failure Modes

- Cracked Components
  - Especially glass MELF Diodes

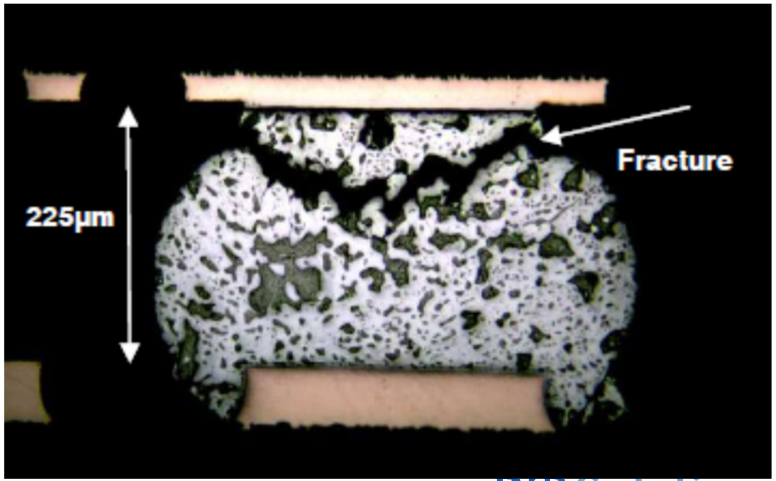


- Cracked Solder Joints
  - Primarily cylindrical components

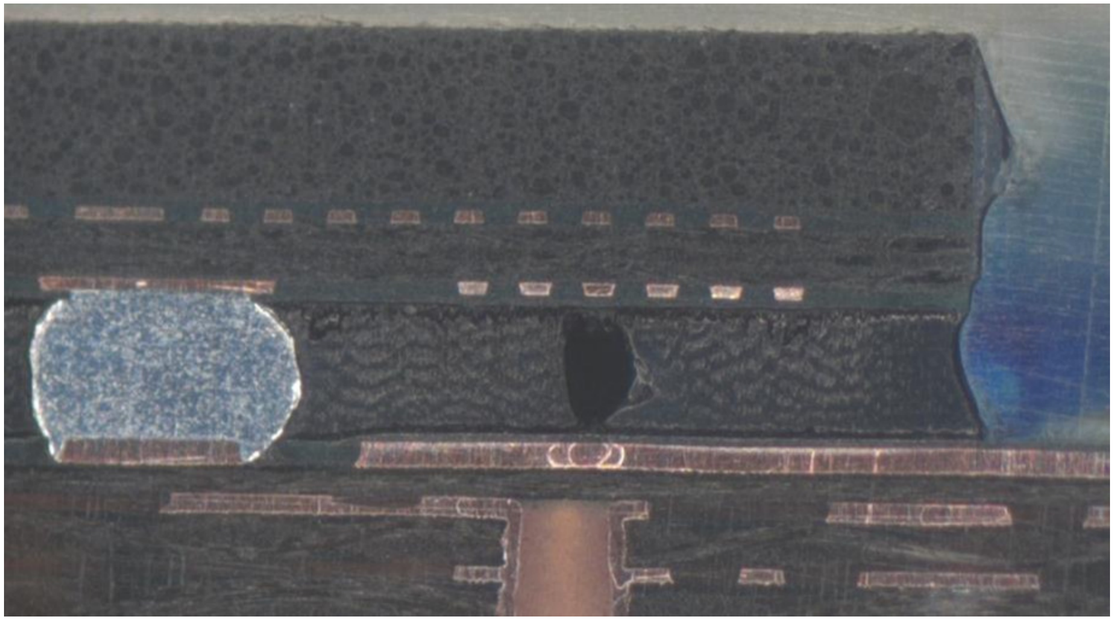
Solder Fracture –Why?



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

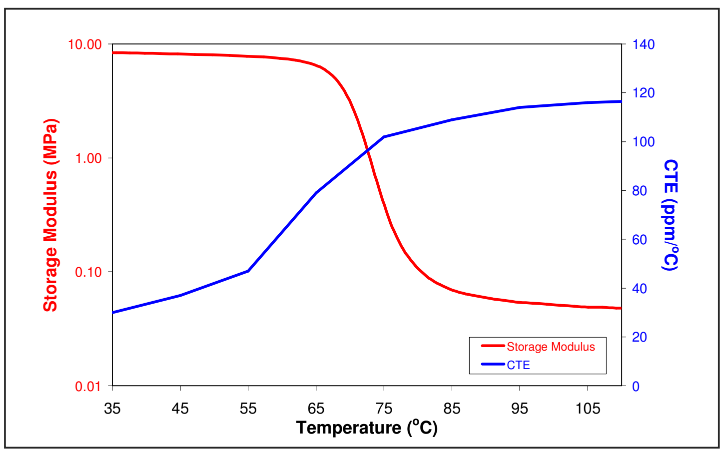


Coating Under Component –Causing Lifting

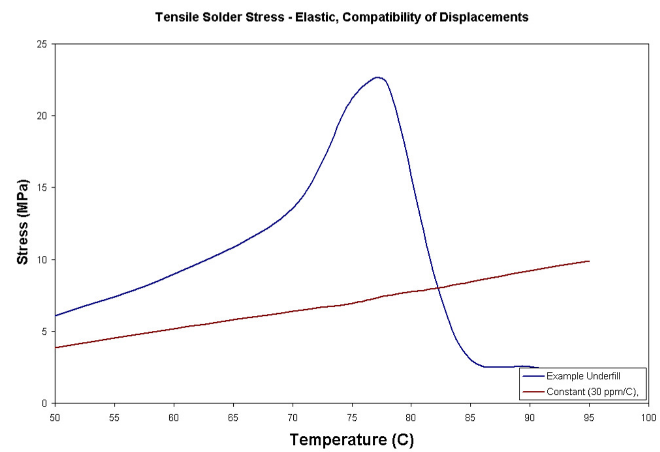


Tg Behavior

- 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



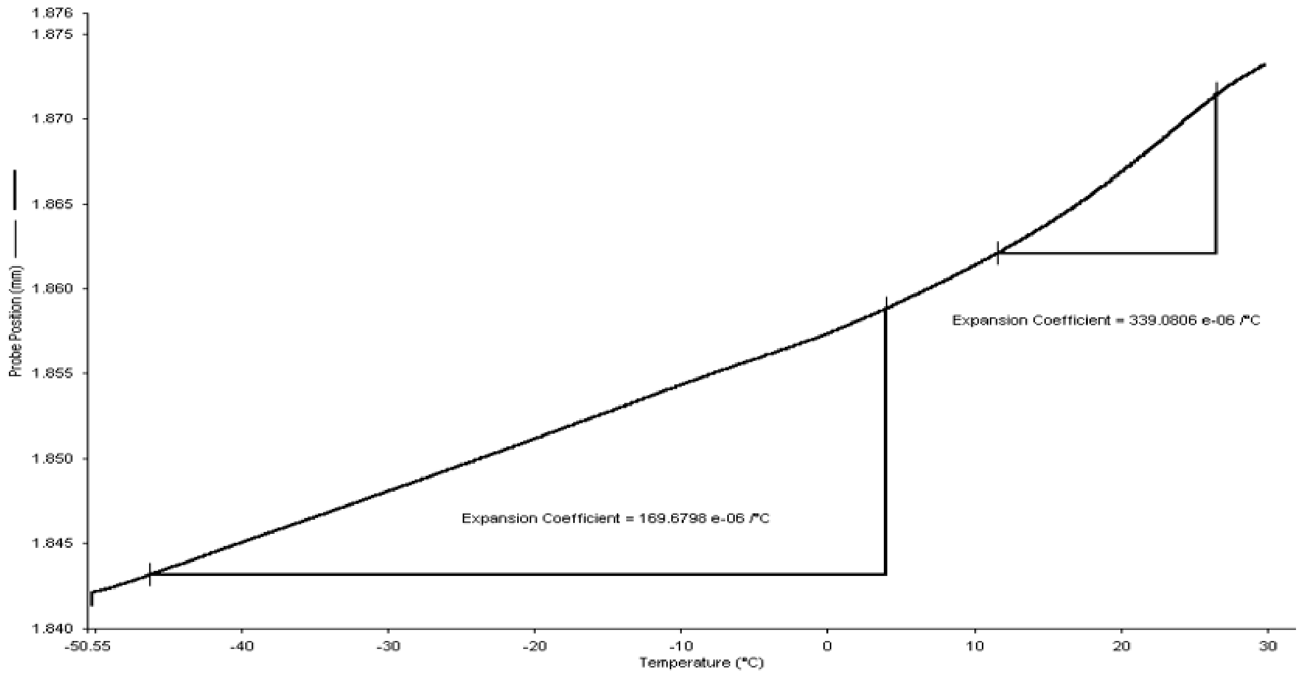
High stresses generated due to CTE increase before modulus decrease



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

Coefficient of Thermal Expansion - TMA

Acrylic conformal coating

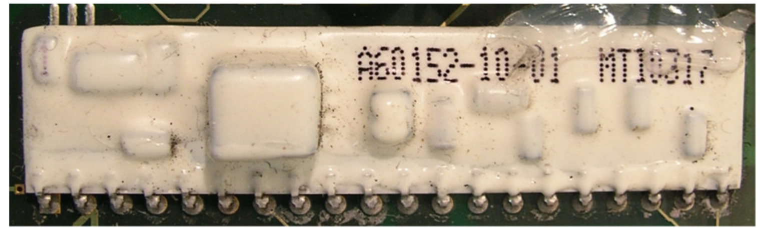


Below Tg CTE – 170 ppm/°C
Above Tg : CTE – 340 ppm/°C

Glass Transition Temperature
Tg ≈ 5 to 15°C

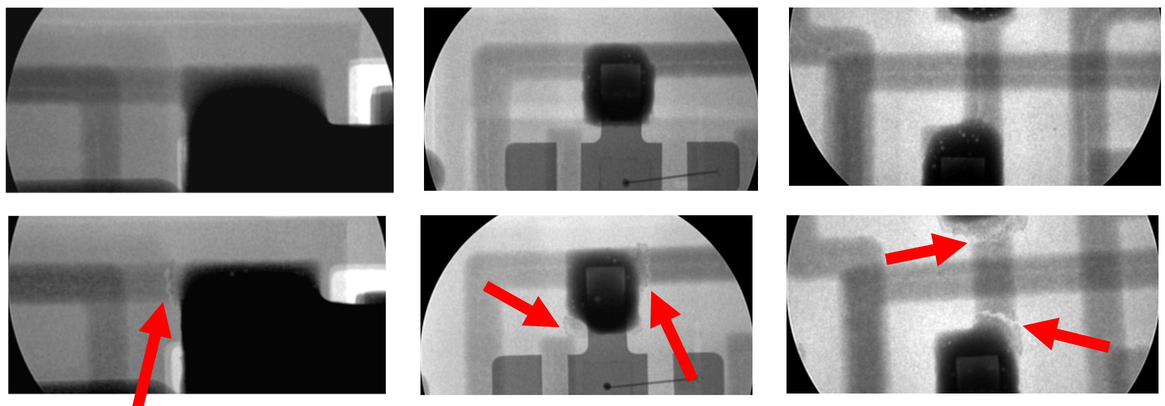
Sulfur Attack of Coated Hybrid

- 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

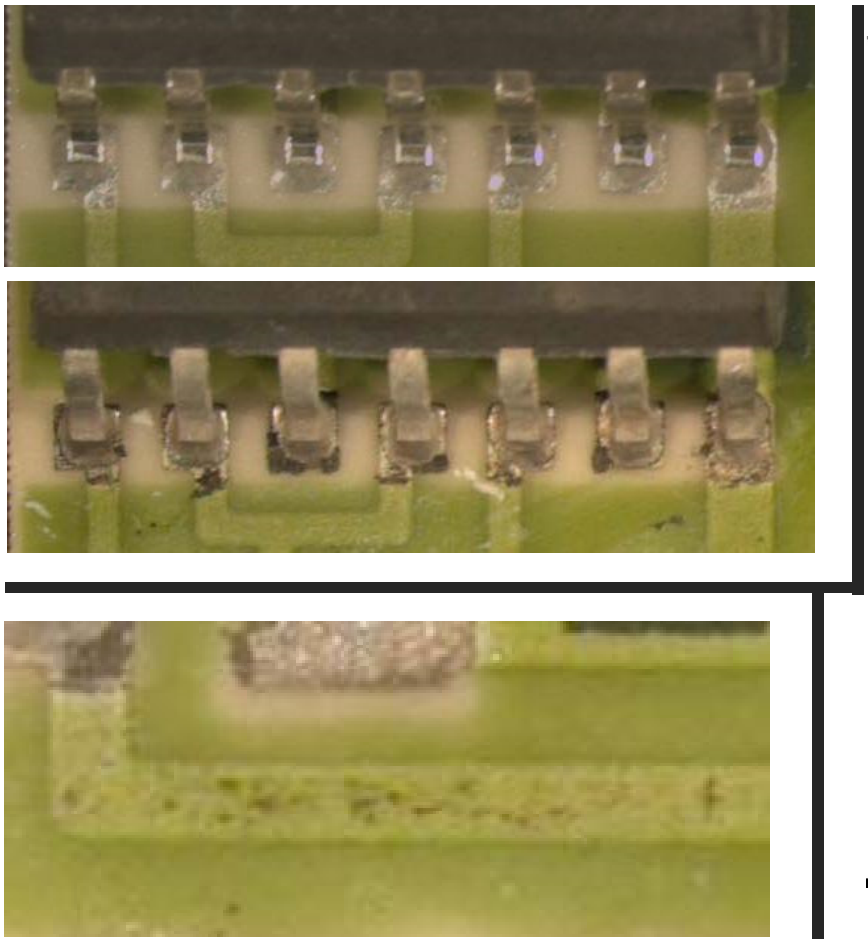
‘Bad’ hybrid

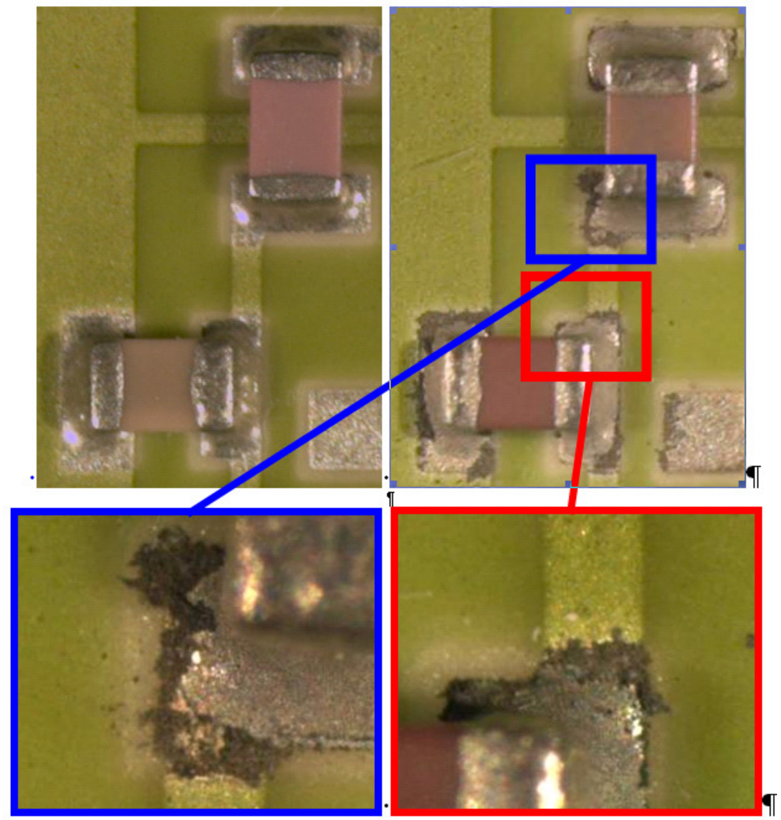


Visual inspection revealed black corrosion product throughout the hybrid

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

Sulfur Corrosion Sites



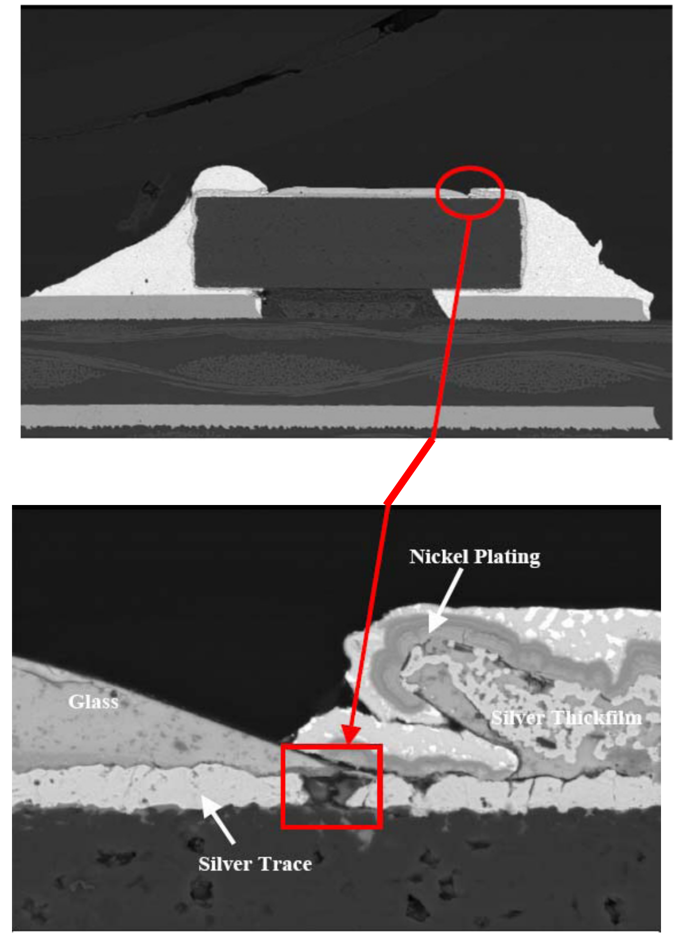


SMT Resistors

- 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



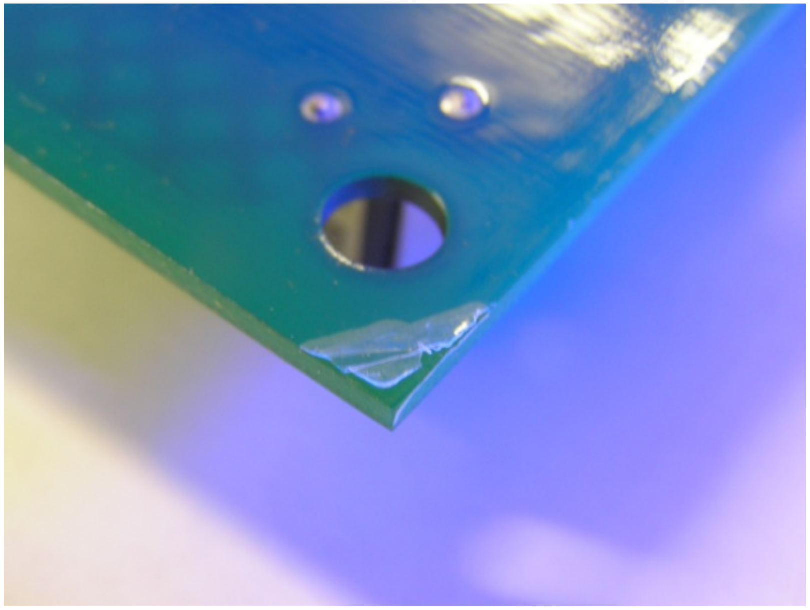
Conformal Coating Failure Modes

- Capillary Flow is when the conformal coating runs away from some areas to more favorable areas, possibly even under BGAs
  - Low viscosity of the coating could cause this
  - Too much coating applied
  - High surface tension of the coating

From SCH Technologies – Aug 08 Technical bulletin

Conformal Coating Failure Modes

- Delamination is when the conformal coating lifts from the board surface
  - Cleanliness
  - Cure cycle for coating



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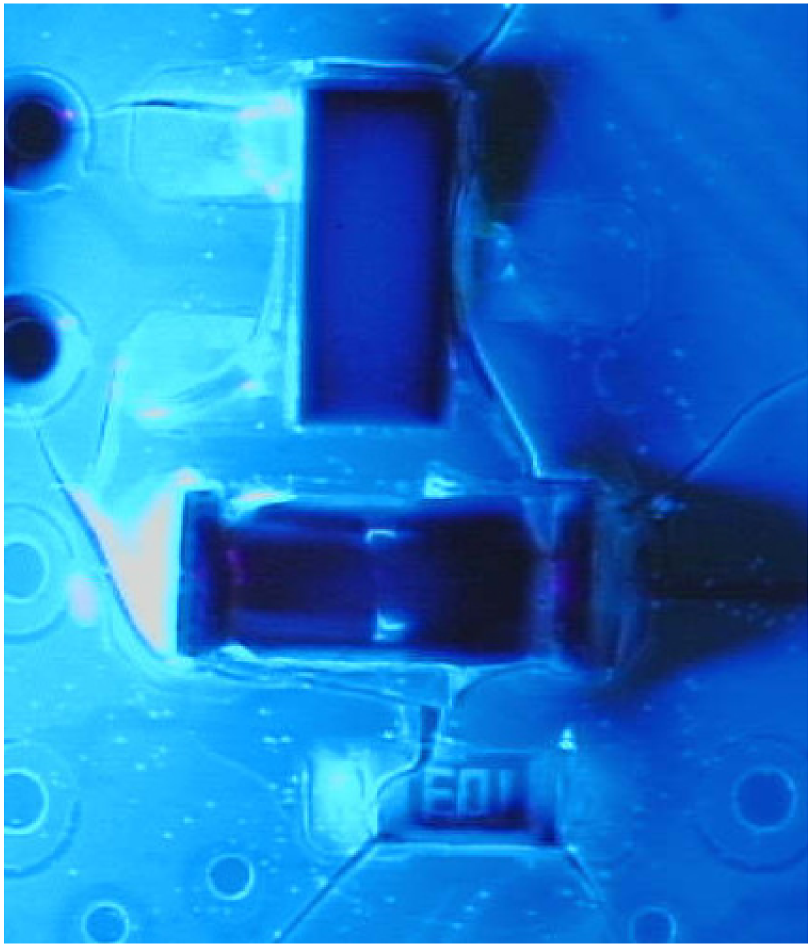
Conformal Coating Failure Modes

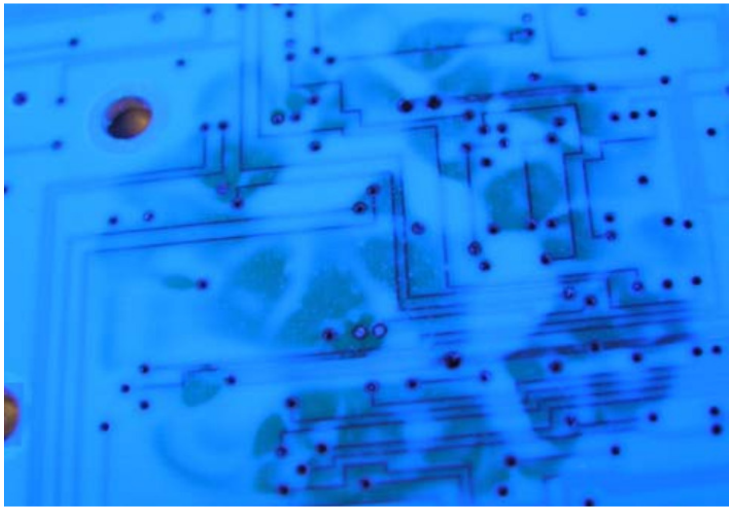
- Cracking of the coating can be due to a cure temperature that was too high or the cure cycle was too fast.
- Also if the conformal coating is applied too thick (>5 mils) its CTE mismatch can drive the cracks.
- Or, the operating environment is too hot or too low causing the coating to flex too much and crack



From SCH Technologies – Oct 08 Technical bulletin

Conformal Coating Failure Modes

- Dewetting – is when the conformal coating refuses to adhere to the surface that is has been applied to.
  - Causes can be flux residue due to no-clean flux being used.
  - HASL rinse operation not cleaning completely
  - Silicone oils
  - Mold release agents
  - Soldering processes
  - Cleaning bath contamination



From SCH Technologies – Nov 08 Technical bulletin

Conformal Coating Failure Modes

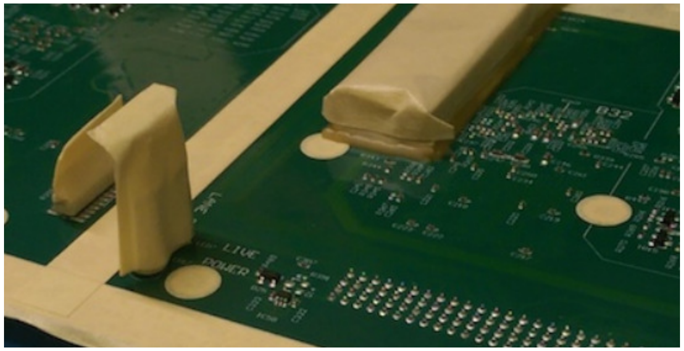
- Pinholes/Bubbles – trapped air under conformal coating
  - Possible causes – skin over surface trapping solvents under surface
  - If coating is too thick then bubbles can get trapped during application
- Requires good adhesion to the circuit board
  - Bubbles/Voids/Delam can drive micro-condensation
  - Can make it electrochemical migration MORE likely

Conformal Coating Failure Modes

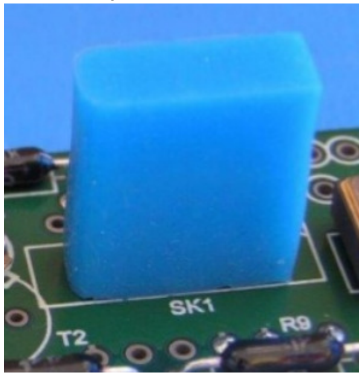
- Orange Peel - appears as an uneven textured surface resembling the skin of an orange
  - Can occur is spray application if nozzle is held too far away from the PCB surface.
  - Insufficient coverage so coating can’t level on surface
  - Incorrect cure profile-especially when a fast profile is used.

Masking Approaches

- Masking is performed to assure components or areas that are not to be coated do not get coated.
  - Liquid latex
  - Masking boots
  - Kapton tape
- Parts not typically coated
  - Electromechanical devices/switches
  - Batteries
  - Connectors/sockets
  - Glass bodied diodes
  - Optical devices
  - Potentiometers



Courtesy – Thin Film Partners



Courtesy SCH Technologies

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.

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

Know Your Thermal Situation

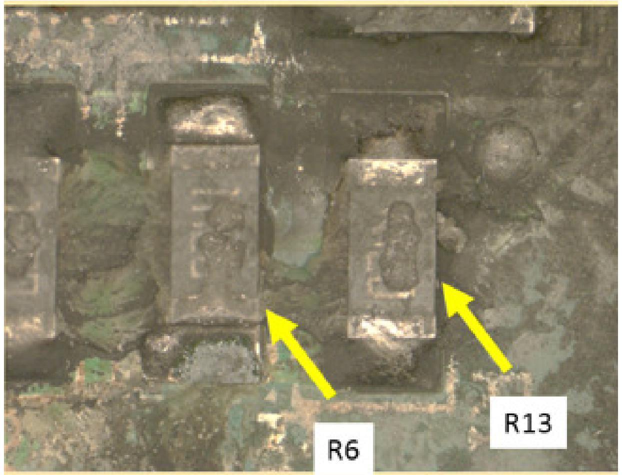
- One of the most common issues with selecting the right potting material is understanding your thermal requirements
  - Typically selected based on min and max temperatures
    - Maybe OK, but does not take ramp times and dwells into consideration
    - Failing to consider dwell and ramp times often 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.

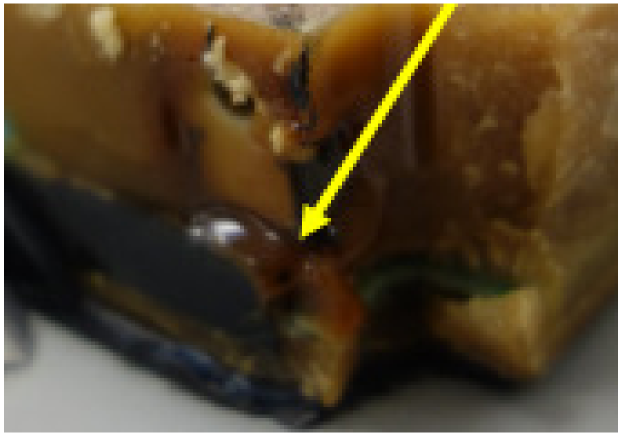
The Curing Process

- 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

What Happens if Cure Cycle is Wrong

- DfR had a situation where components were being damaged by a breakdown of the potting material
- Testing showed that the Tg for the material was -22C and not -40C as advertised.
- DfR looked at failure and observed that the potting material seemed very viscous rather than fully cured.
- DfR performed an analysis of the uncured potting material and demonstrated that the uncured potting material could carry a current and then result in a breakdown failure. The uncured material carries a significant and growing level of current with only 20V applied





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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

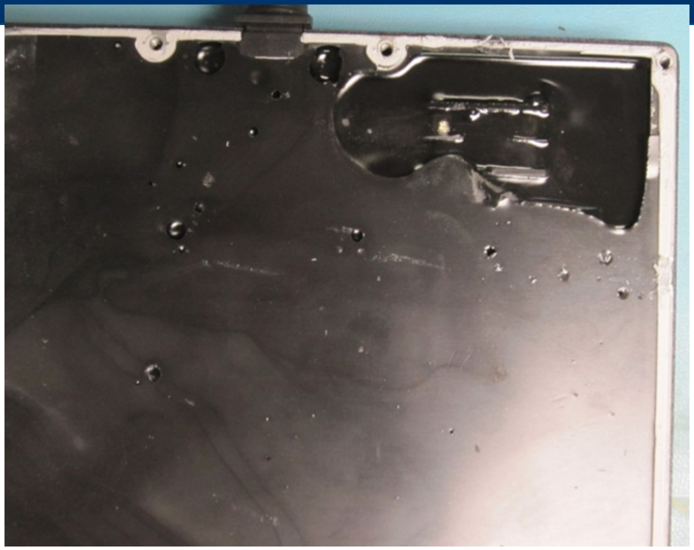
- Cleanliness is paramount

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

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

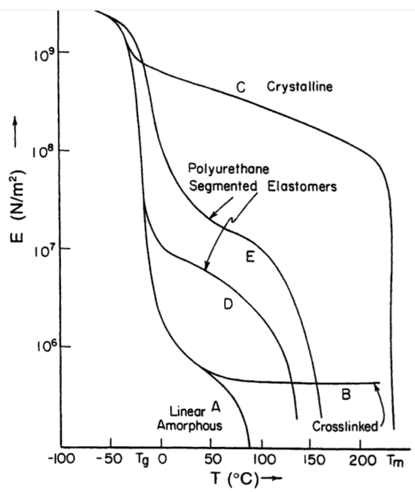
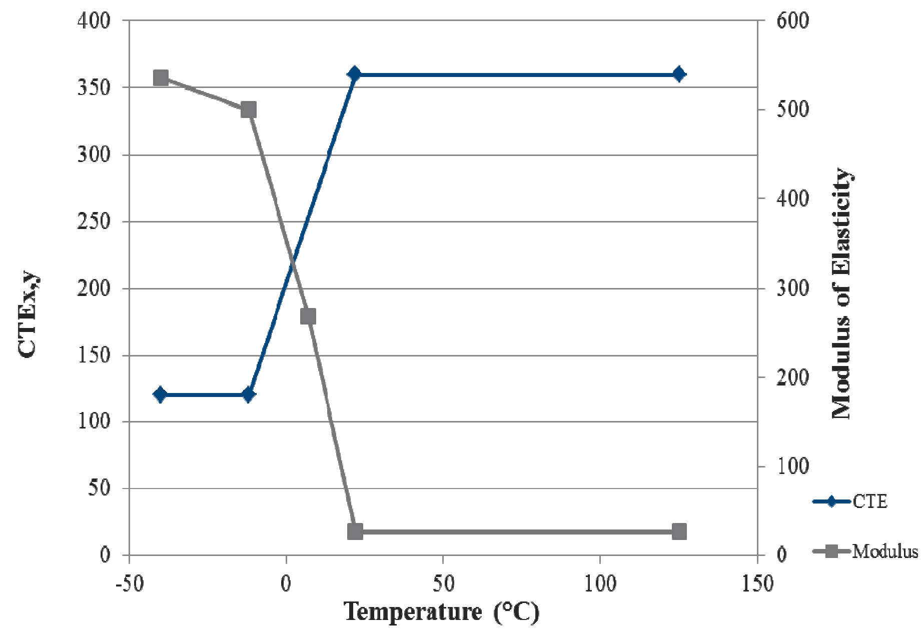
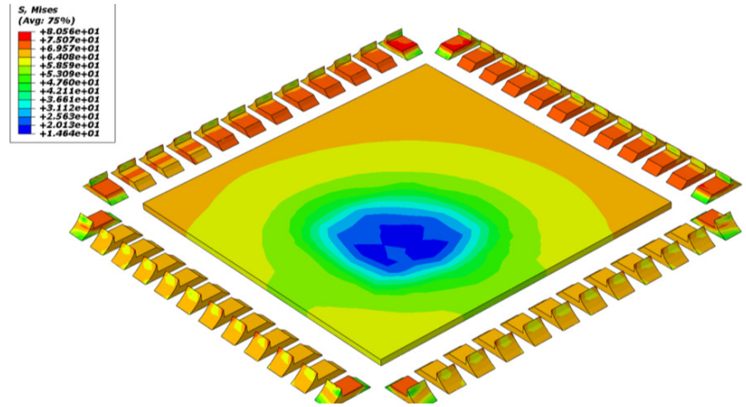


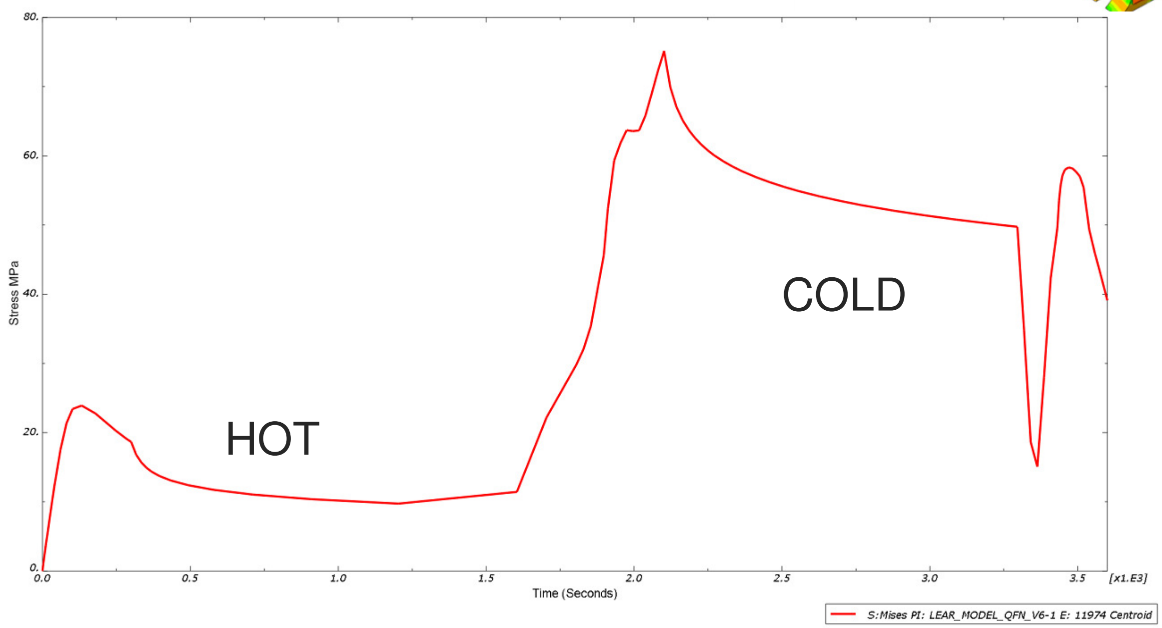
FIGURE 22 Storage modulus v temperature curves for (A) linear amorphous polymer, (B) crosslinked polymer, (C) semicrystalline polymer, (D) MDI/BD/PTMA segmented polyurethane (32% MDI by weight), (E) MDI/BD/PTMA segmented polyurethane (38% MDI by weight). From Cooper S.L. and Tobolsky A.V. *J. Appl. Polym.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



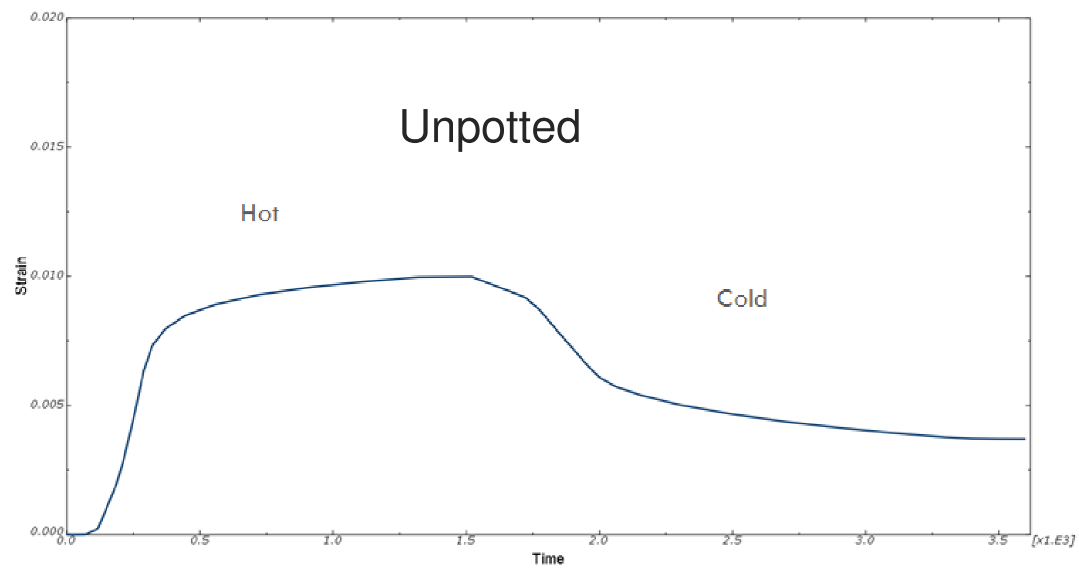
Solder Stresses

- Very high stresses during cold dwell of thermal cycle

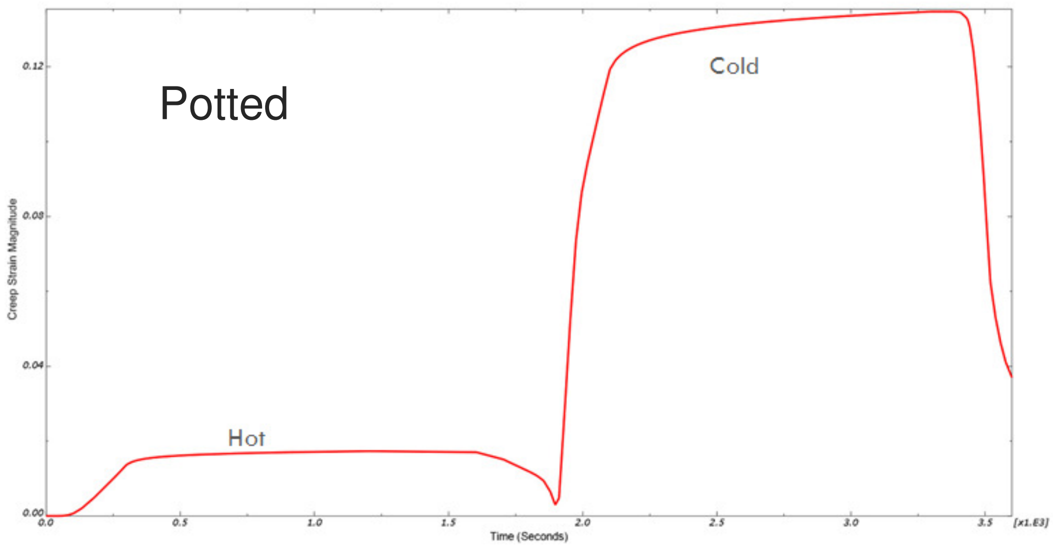




Creep Strains



- 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

Need to Pay Attention To

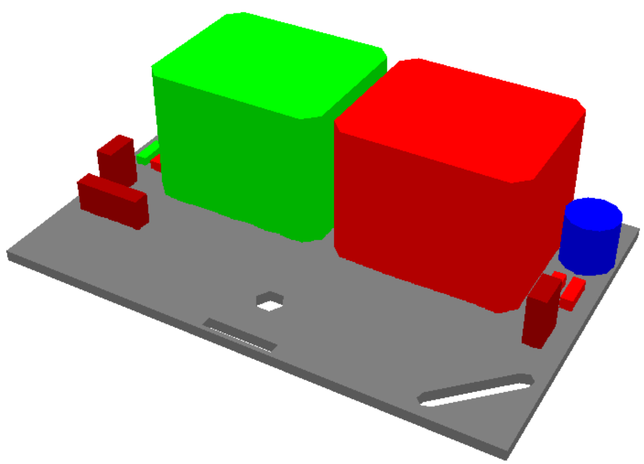
- Mechanical properties of the potting material
  - Glass transition temperature (Tg)
  - Modulus should be specified above and below the Tg
  - CTE should be specified above and below the Tg
- The design of the housing
  - May provide a surface to which the potting material can pull against when shrinking causing PCB warpage
  - Should be designed to provide as close to a hydrostatic pressure as possible (equal pressure on all sides)

Natural Frequencies

Without Potting

Natural Frequencies

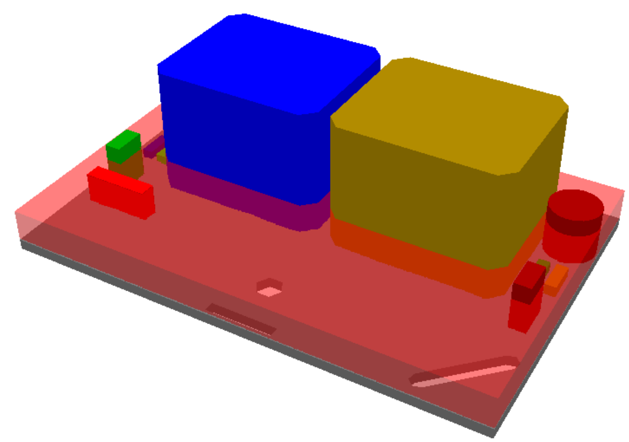
Natural Freq #1:	623.46 Hz
Natural Freq #2:	1,029.80 Hz
Natural Freq #3:	2,375.60 Hz
Natural Freq #4:	2,986.40 Hz
Natural Freq #5:	4,006.10 Hz



With 5 mm potting covering entire board surface

Natural Frequencies

Natural Freq #1:	1,727.90 Hz
Natural Freq #2:	2,868.20 Hz
Natural Freq #3:	4,169.70 Hz
Natural Freq #4:	4,881.20 Hz
Natural Freq #5:	

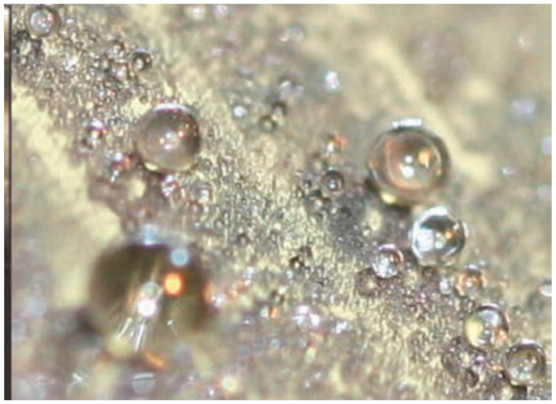


New Superhydrophobic Nanocoating Materials

- Explosion in new coating technologies over the past several years
- 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



Nanodeposition of High Surface Tension Materials

- Many companies currently focused on the electronics market

BARRIAN

NEI Corporation
NanoMyte

ACT
ACTivate nanotechnology

P2i perform protect improve

GVD

NeverWet

Semblant

NanoSlic

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

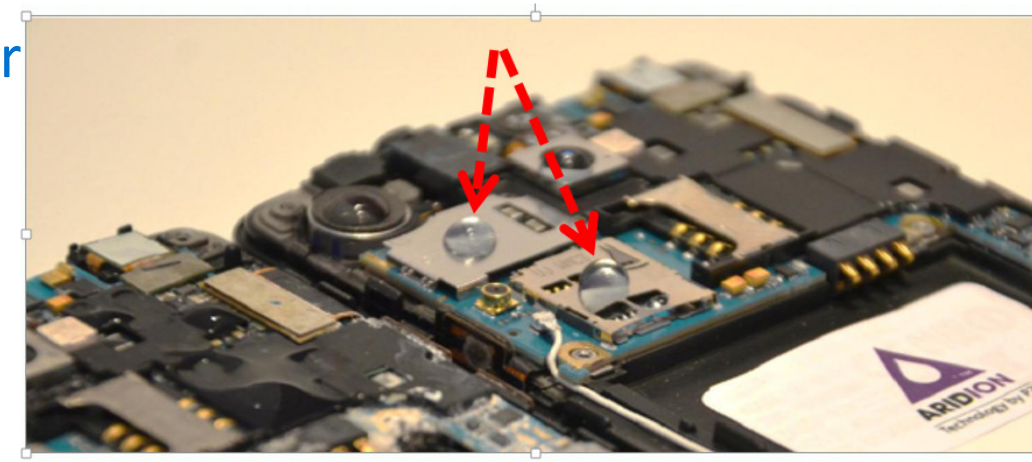
Process Technology

- 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:
  - Some are chemical vapor deposition (CVD) processes, with low vacuum requirements, Room Temperature Deposition Process
  - Variety of Potential Coating Materials (with primary focus on fluorocarbons)
  - Some incorporate nano-particles into a conventional conformal coating

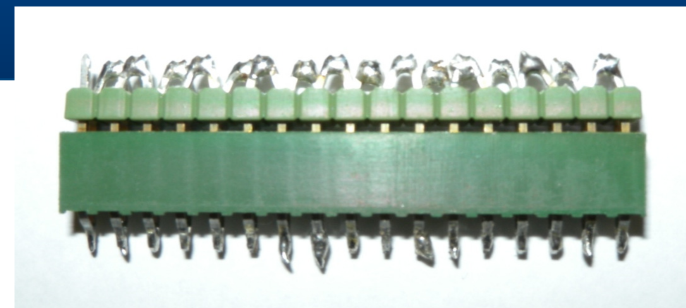
Benefits (especially compared to Parylene)

- 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

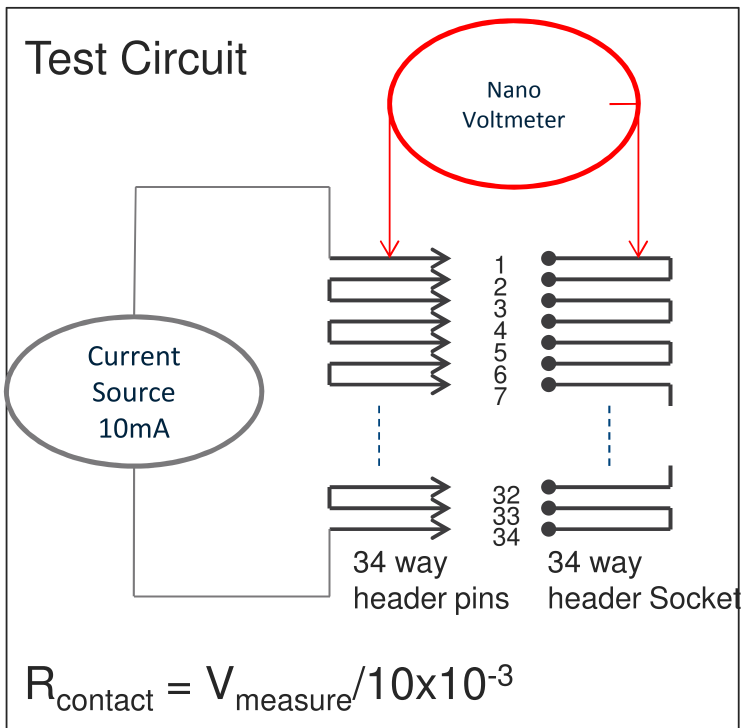
- Nanocoating allows for
  - Optical Transparency
  - RF Transparency
  - Reworkability
  - Elimination of masking

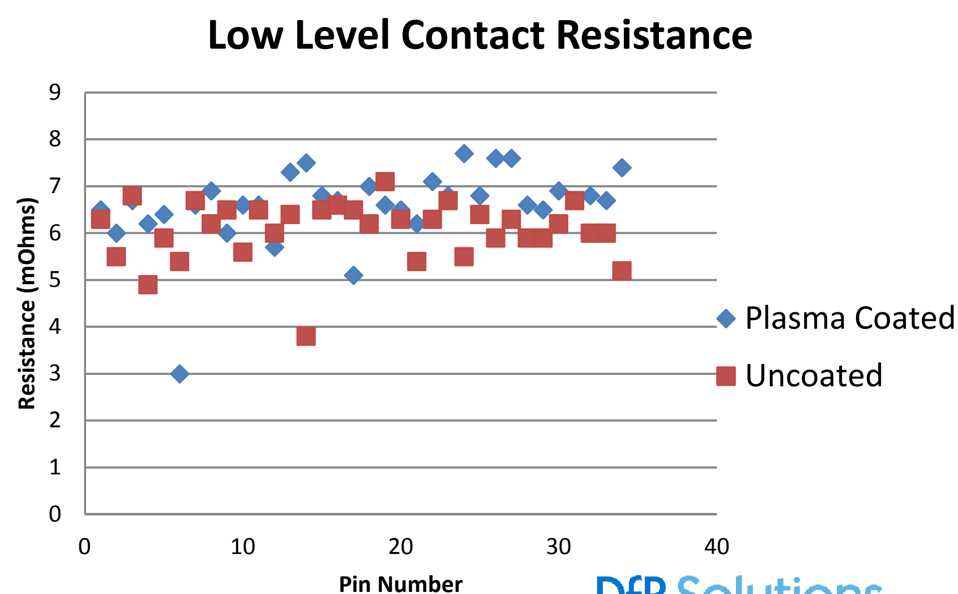


Benefits: No Masking



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)





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

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Conclusions

- There is significant opportunity for field performance improvement and cost reduction through the proper use of coatings and pottings

- Requires a knowledge of the materials and processes on the market
  - Benefits vs. Risks

- With any technology, do not rely on standard qualification tests!
  - A physics-based test plan provides the most robust mitigation

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