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Best Practices in Selecting Coatings and Pottings for Solar Panel Systems; Junction Boxes and Inverters

DfR Solutions, HB Fuller and Tonsan

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Introduction

- The solar industry has driven solutions that result in electronics systems that are required to perform in outside environments for over 25 years.

- This industry expectation has resulted in solutions to protect the electronics from failure that can result from interaction with moisture, and various chemicals leading to corrosion and shorting of the systems.

- Potting and encapsulation compounds can impart the very high level of protection from environmental, thermal, chemical, mechanical, and electrical conditions that the solar applications demand.

Coating and Potting Rules of Thumb

- The use of potting compounds and thick conformal coatings greatly influences the failure behavior under temperature cycling
  - Any time a material goes through its glass transition (Tg) temperature problems tend to occur
  - Potting materials can cause PCB warpage and tensile stresses on electronic packages that greatly reduce time to failure
  - Selection of the correct material for coating or potting is critical

Typical Solar Environment

- Extreme hot and cold locations (AZ to AK)
- Possible exposure to moisture/humidity
- Large diurnal thermal cycle events (daily)
- Largest temp swings occur in desert locations where it can reach 64C in the direct sun down to 23C at night (Δ41C)

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

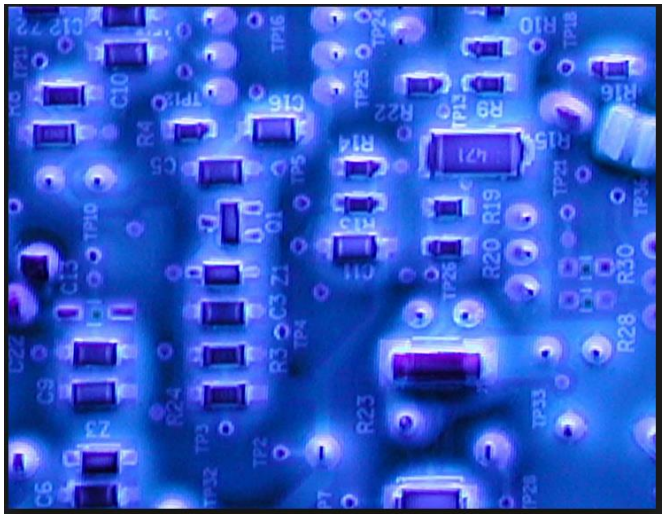
	Properties	Comments
Epoxy	Good adhesion Excellent chemical resistance Acceptable moisture barrier	Difficult to rework Needs compliant buffer Not widely used
Urethane	Good adhesion High chemical resistance Acceptable moisture barrier	Difficult to rework Widely used Low cost
Acrylic	Acceptable adhesion 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

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.

DfR Solutions

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.
- 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.

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)

CTE Mismatch/Thickness

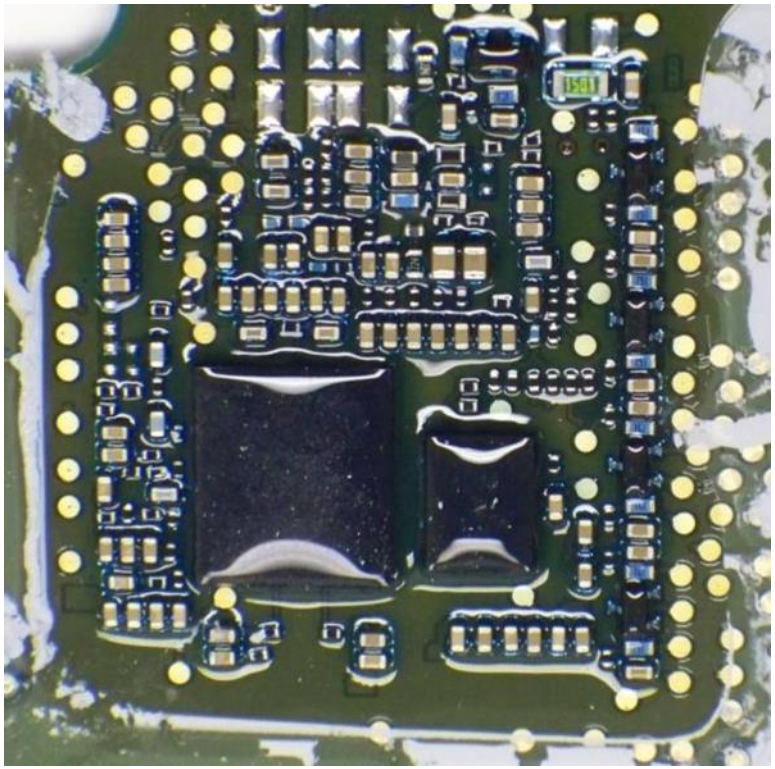
- Breaking Components
  - Primary concern is stress due to CTE mismatch
  - Very sensitive to thickness

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

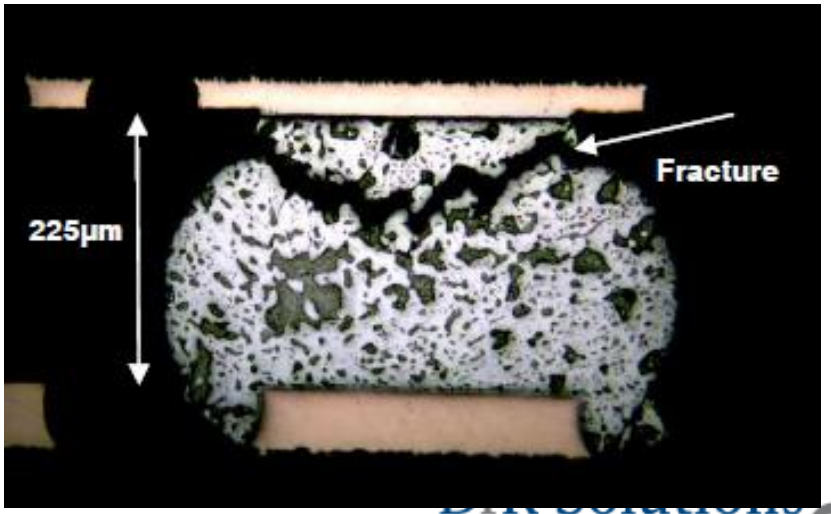
Type of Coating	Cured Coating Thickness (in)
Acrylic	0.001 to 0.005
Urethane	0.001 to 0.005
Epoxy	0.001 to 0.005
Silicone	0.002 to 0.008

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

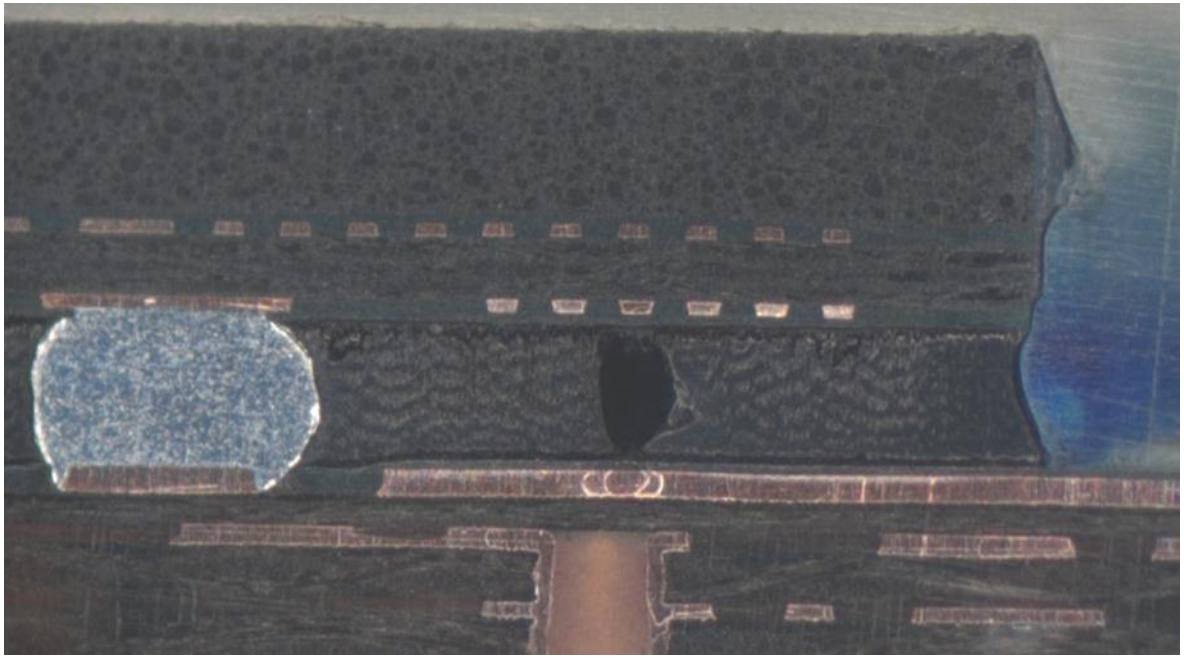
Solder Fracture –Why?



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



Coating Under Component –Causing Lifting



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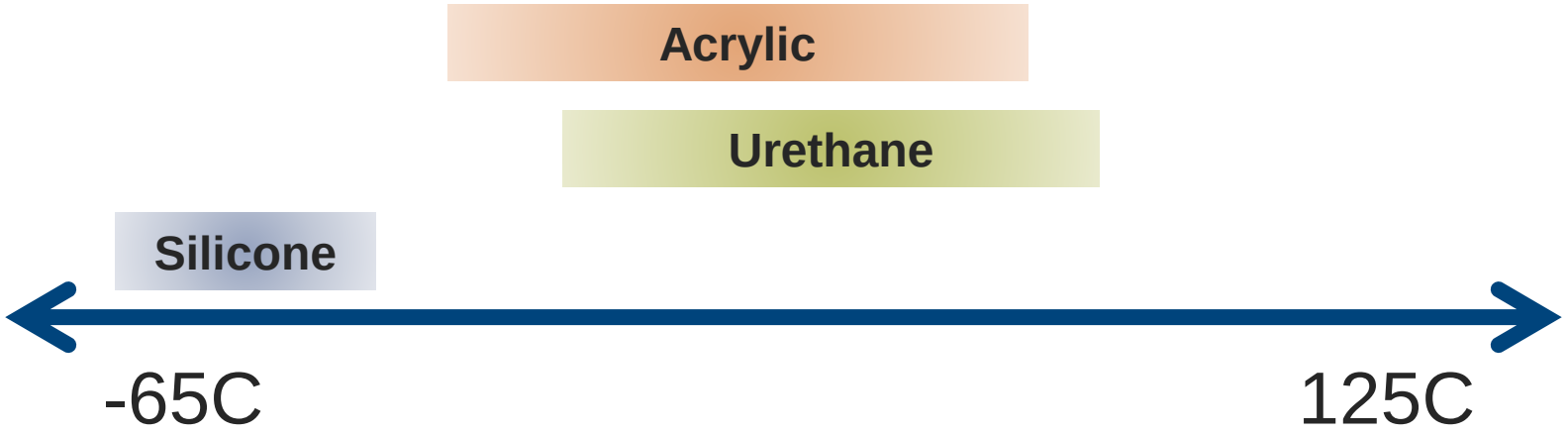
Breaking Components – Glass Transition Temperature

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

Hard/Brittle ⇔ Soft/Rubbery



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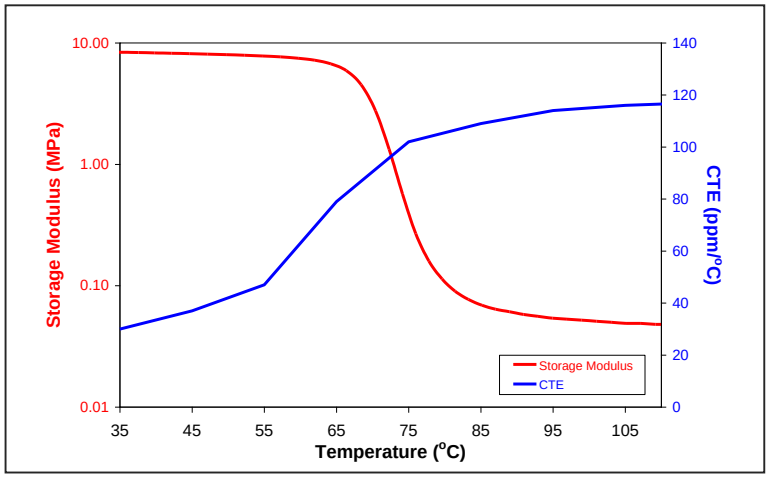
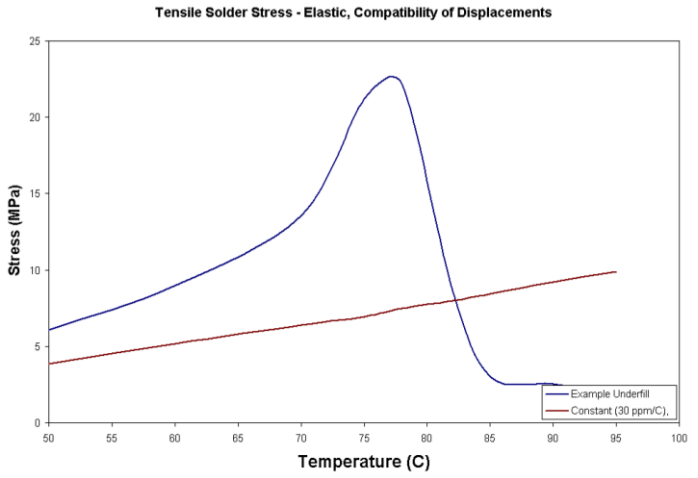
Tg Behavior

- 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

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.

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

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

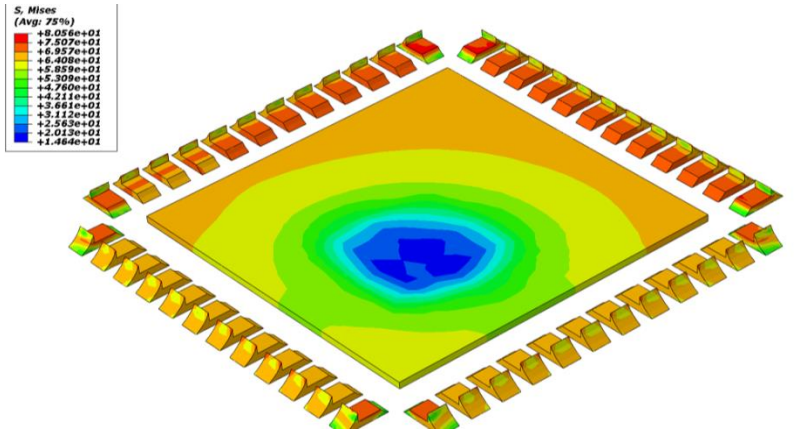
- Watch for large horizontal surfaces – when filled from the top, they can entrap moisture or air that can affect electronic components

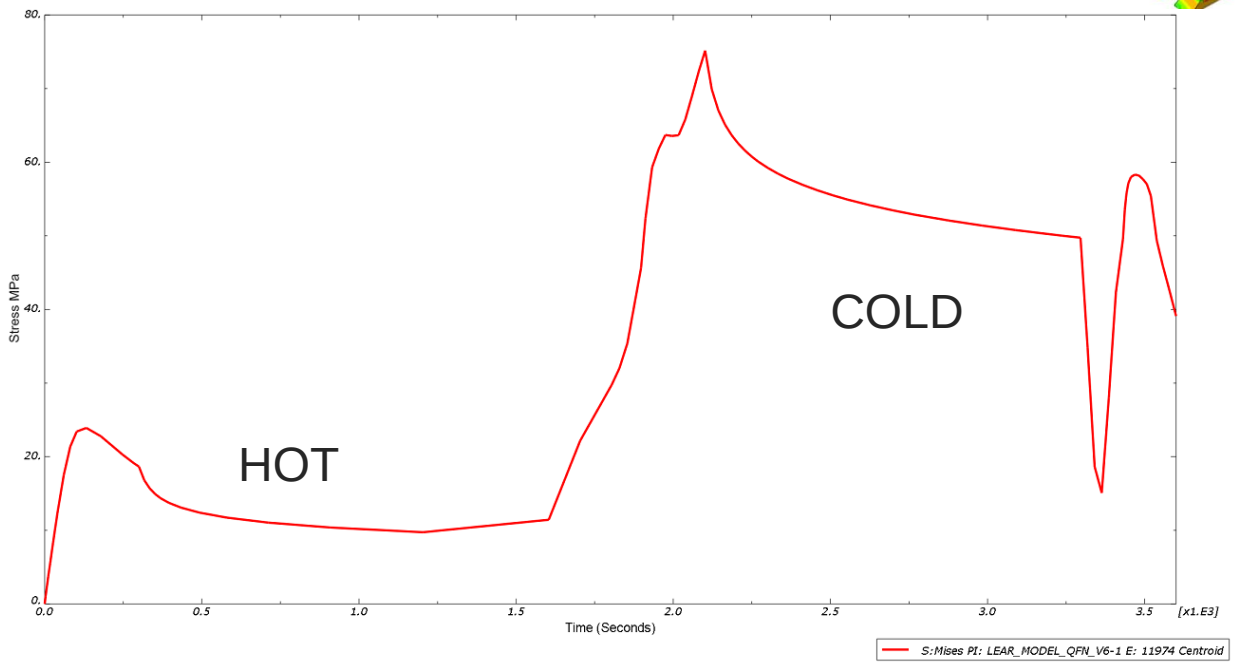
Potting

- 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

Solder Stresses

- Very high stresses during cold dwell of thermal cycle





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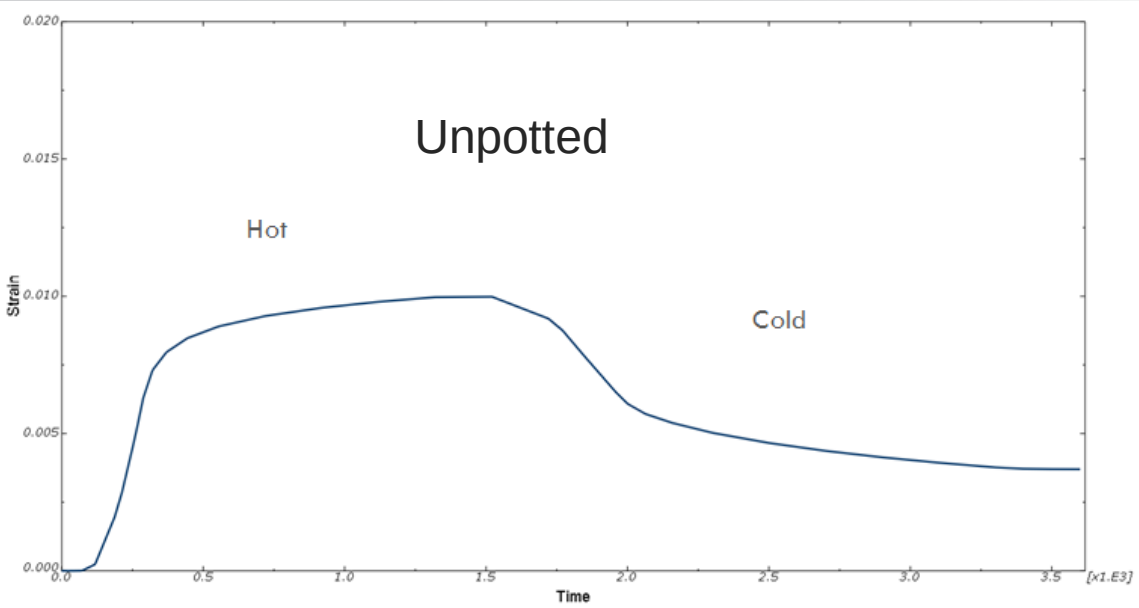
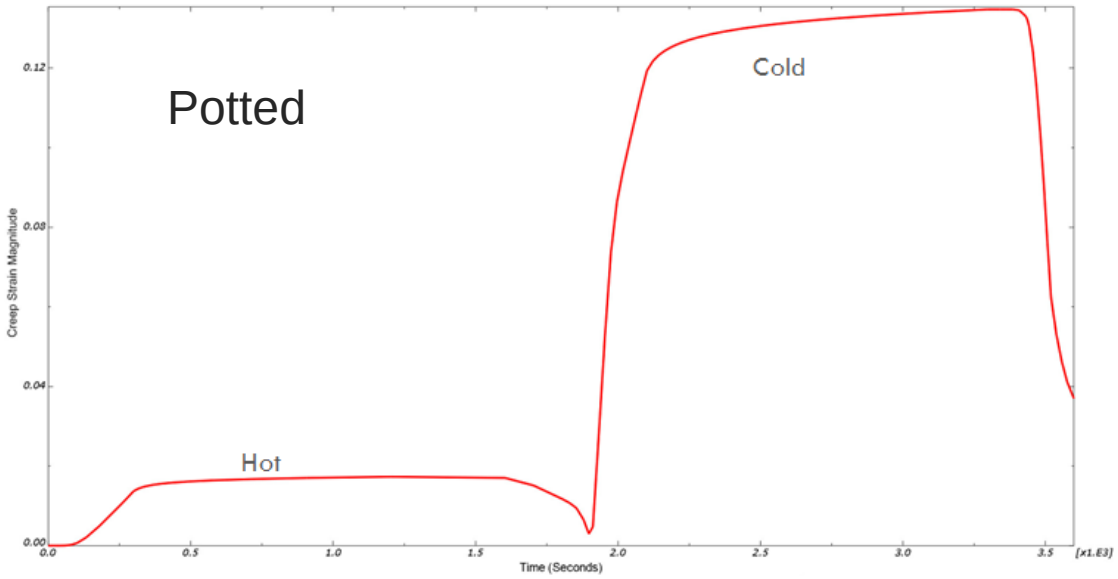
Creep Strains

- 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)

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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.

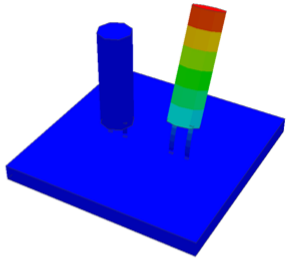
- Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Creep is a "time-dependent" deformation

Potting and Sherlock

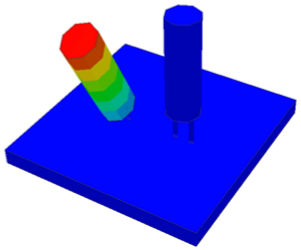
- DfR has added a module to our Sherlock software to assess the impact of the application of a coating or potting material

Two Components

- 5mm lead height : 206 Hz

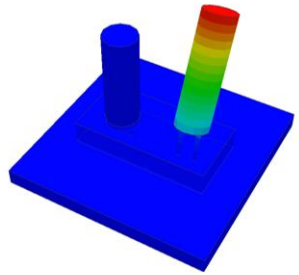


- 2.5 mm lead height: 285 Hz

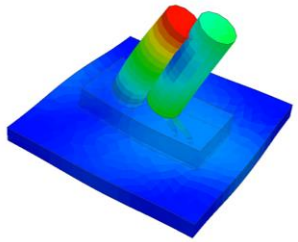


3.5 mm Potting

- 5mm lead height: 202 Hz



- 2.5 mm lead height:5486 Hz



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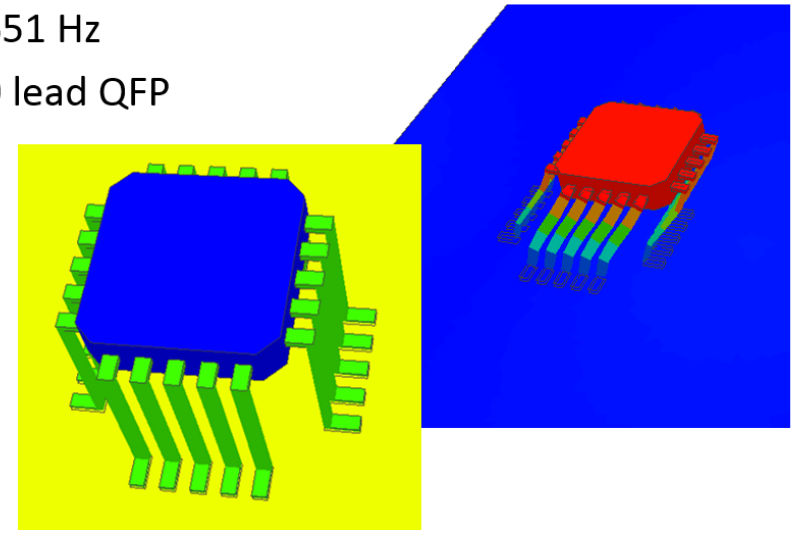
Potting and Sherlock

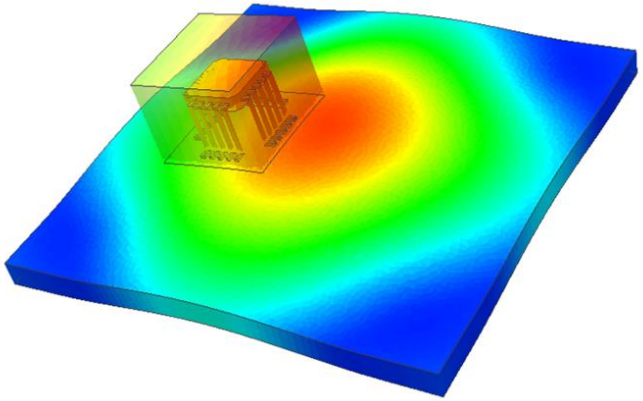
Gullwing Leads

- 4651 Hz
- 20 lead QFP



Gullwing: Fully Potted

- 5975Hz
- SMT Leads



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)

Electronic Protection for Junction Box

Date: 03.26.2015

TONSAN ADHESIVE, INC.
5 Shuangyuan Rd. Badachu High-Tech Zone, 100041, Beijing, China

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H.B. Fuller Company

- Over 127 years of success as a manufacturer of specialty chemical products:
  - Adhesives, sealants, coatings and polymers
- Headquartered in St. Paul, Minnesota
- Global with direct presence in:
  - 43 countries
  - Customers in more than 100 nations
- 2014 sales of ~$2 billion
- Public company listed on NYSE (FUL)

H.B. Fuller

TONSAN Solar Sealing and Bonding Solutions

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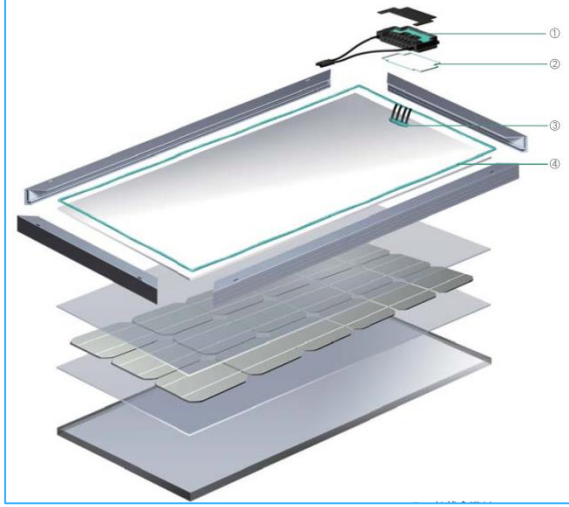
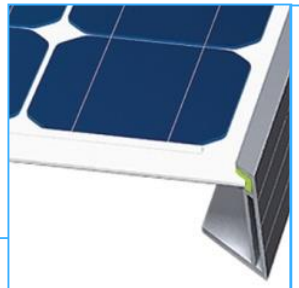
Connect the frames and the laminate;
Bond the junction box and the backsheet;
Increase the safety and reliability of the junction boxes;
Cost reduction and efficiency improvement.



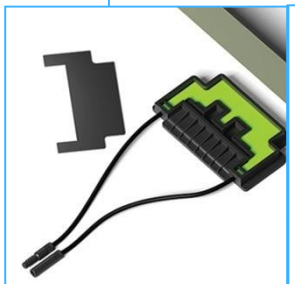


Frame Sealing

1527 Silicon Sealant for PV Modules

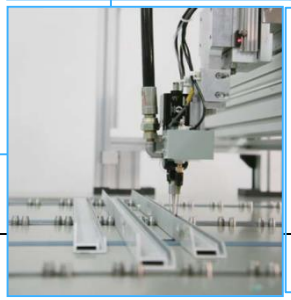
Junction Box Attaching

1527 Silicon Sealant for PV Modules



Junction Box Potting

1521 Potting Compound for PV Junction Box

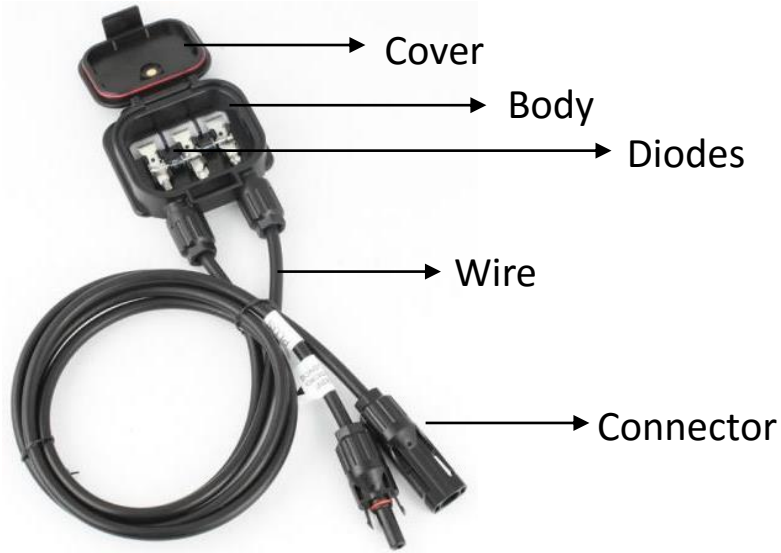


Automatic Dispensing Machine

DP-800-X220,used for frame sealing
DP-400,used for junction box attaching
LDP-700A,used for junction box potting

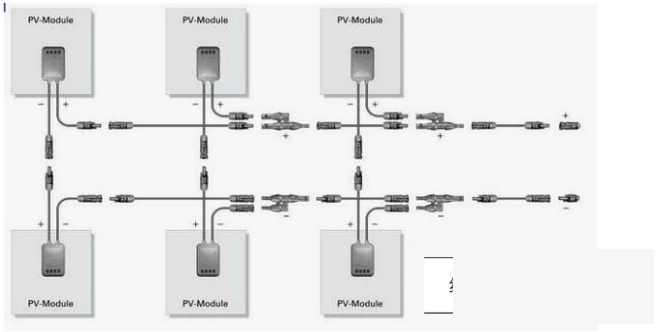
Sketch of J-box

Main component and function

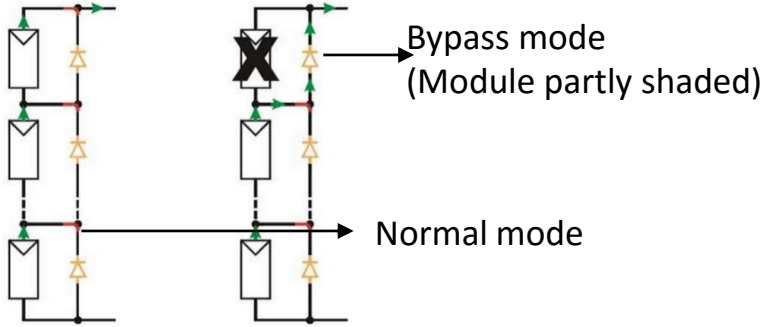


It's main function is connecting and protecting the PV modules, conducting the current generated by PV modules.

System connected by J-box



Working mode of diodes



Application

Application requirements

- Can be used in harsh environment;
- Excellent resistance to UV radiation and aging property;
- Have reasonable heat dissipation mode and inner cavity structure to help reduce the internal temperature and meet the electric requirements;
- Reliable sealing properties.
- Superior insulation and flame resistant properties.

Solutions for J-Box Sealing

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Junction Box Potting

1. Sealing Performance
2. Dielectric Properties
3. Thermal Conductivity

Why J-box need potting and how it works ?

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- **Seal invalidation of J-Box without potting**

Size tolerance

Rubber Strip aging

Seal invalidation → Corrosion, electrical resistance increase

Why J-box need potting and how it works ?

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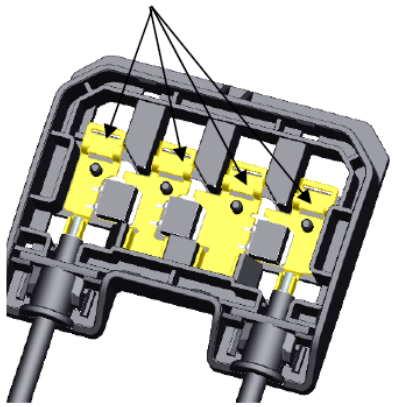
Solutions for J-box seal invalidation

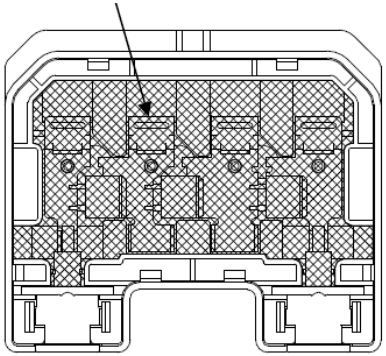
Junction Box Potting

Pot a certain amount of silicone compound in junction box. When it cured, a protective barrier will be constructed. As a result, the diodes and other components inside are isolated from the external environment.

Inner structure



Potting area



Why J-box need potting and how it works ?

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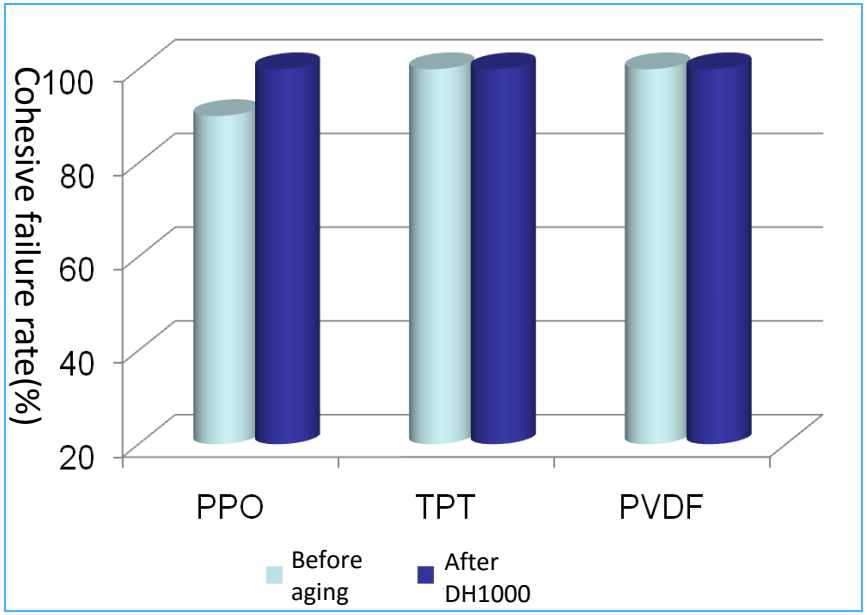
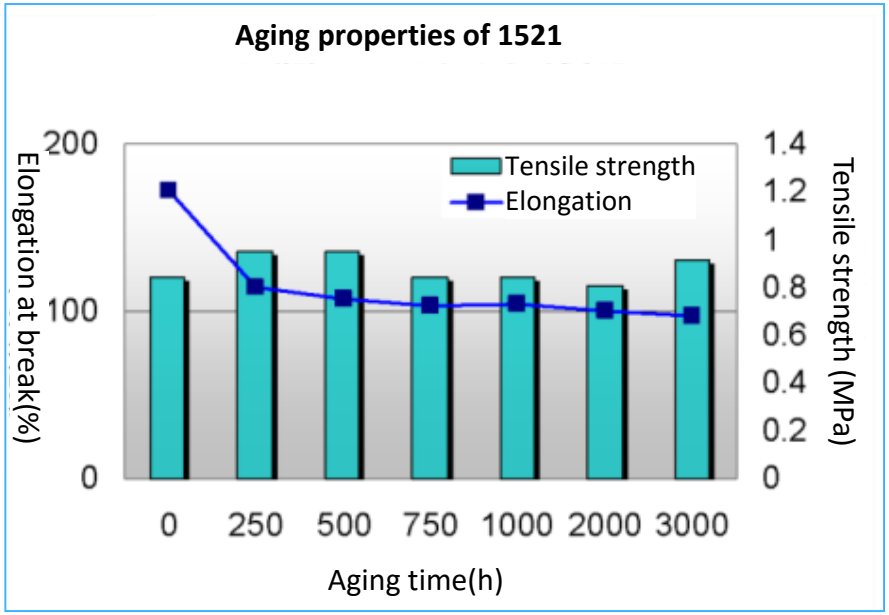
Solutions for J-box seal invalidation

Reliable sealing of 1521





Before and after aging, 1521 has excellent tensile properties and good adhesion to PPO, TPT and PVDF, etc.. It can provide long-term reliable protect for the junction box.

Why J-box need potting and how it works ?

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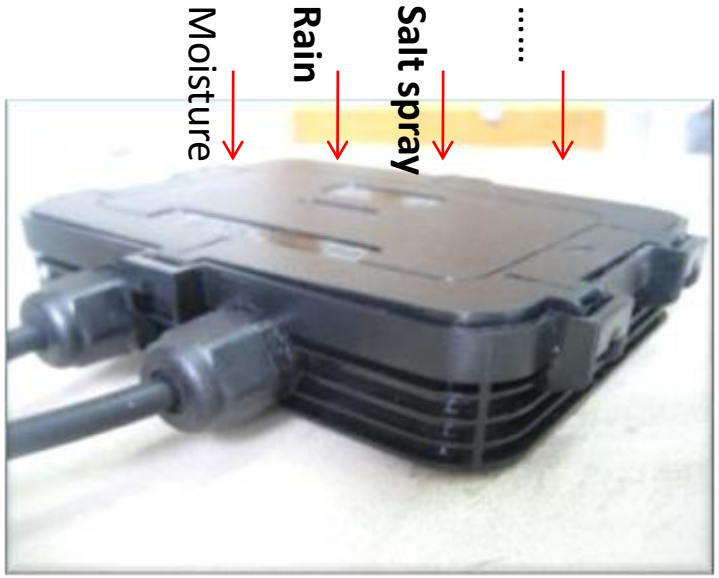
- **Potential insulation failure** of J-Box without potting



Short circuit, Breakdown

inside

outside

Get an electric shock

Why J-box need potting and how it works ?

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Solutions for J-Box insulation failure

Insulation Performance of 1521

Item	Unit	Test result	Test result after DH1000
Volume resistivity	Ω·cm	4.2×10^{15}	3.7×10^{15}
Breakdown voltage	KV/mm	23	21

With good insulation properties, TONSAN potting material can help to reduce the occurrence possibility of breakdown and electric leakage.

Why J-box need potting and how it works ?

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J-Box overheating failure

The working temperature of the bypass diodes will rise fast when the hot spot phenomenon occurs. In this condition, rapid heat dissipation is very important, in order to avoid fire caused by overheating.

Burnt junction box ⟶ Cause backsheet burnt ⟶ Module cracks

Why J-box need potting and how it works ?

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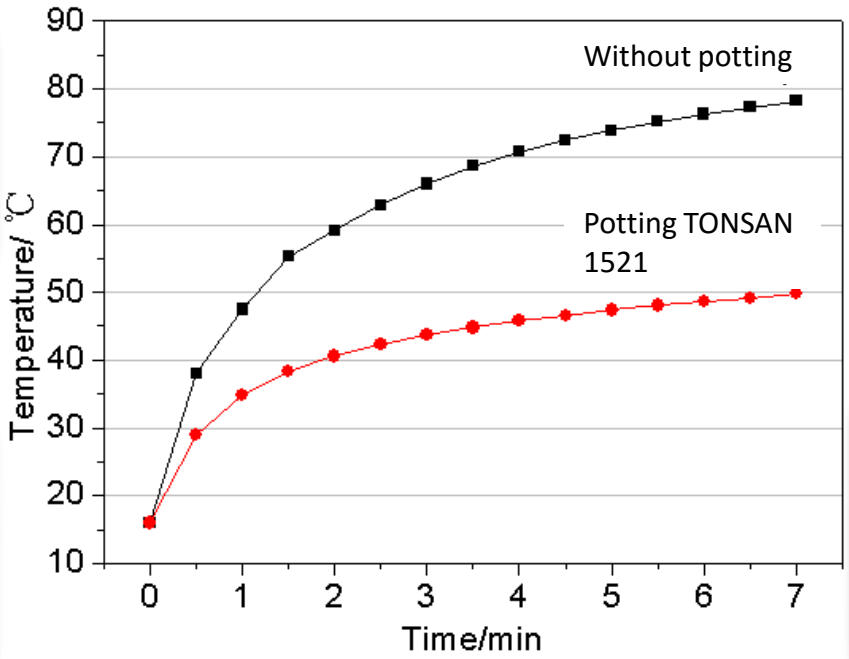
Solutions for J-box overheating failure

Heat dissipation comparison test



1521 can help to decrease the working temperature of diodes. Thus it avoids the risk of diode failure as a result of overheating. The amplitude can reach 30℃。

Why J-box need potting and how it works ?

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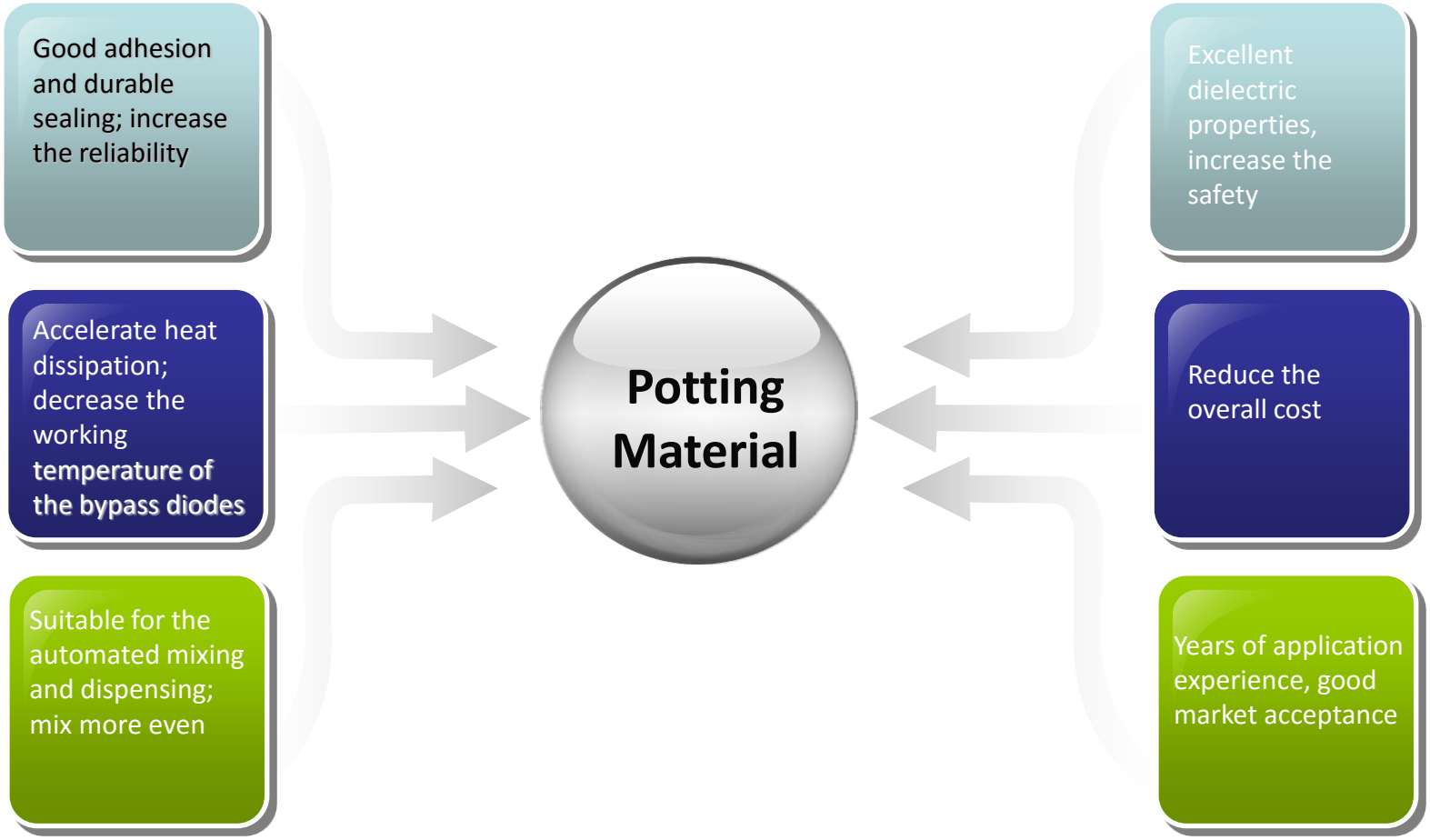
Summary

With good properties, our potting materials can help to improve the safety of J-box.



Automated solutions of potting

Our potting materials are suitable for the automated mixing and dispensing.

More than 200 sets machine made by TONSAN are being used steadily and successfully.

Application case

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More than 150 customers;

More than 60% market share in China.

Conformal Coating Introduction

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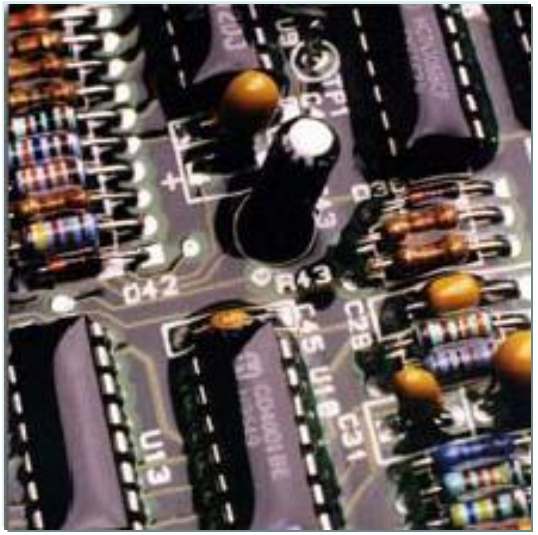
What is Conformal Coating?

"Conformal Coatings"—Specially formulated thin film materials that are applied directly to circuit boards or circuit card assemblies (CCAs). These provide environmental protection for the components and circuitry affixed atop these circuit cards. The material forms a dry resilient coating designed to protect against moisture, mold, dust, corrosion and other *extreme* environmental stresses.

Conformal Coatings

- Dust proof
- Moisture proof
- Mold Protection



Conformal Coating Introduction

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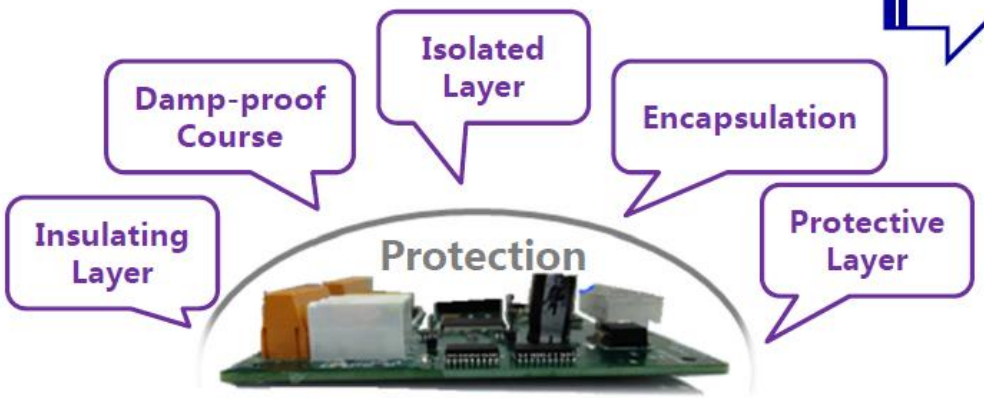

Why Conformal Coating

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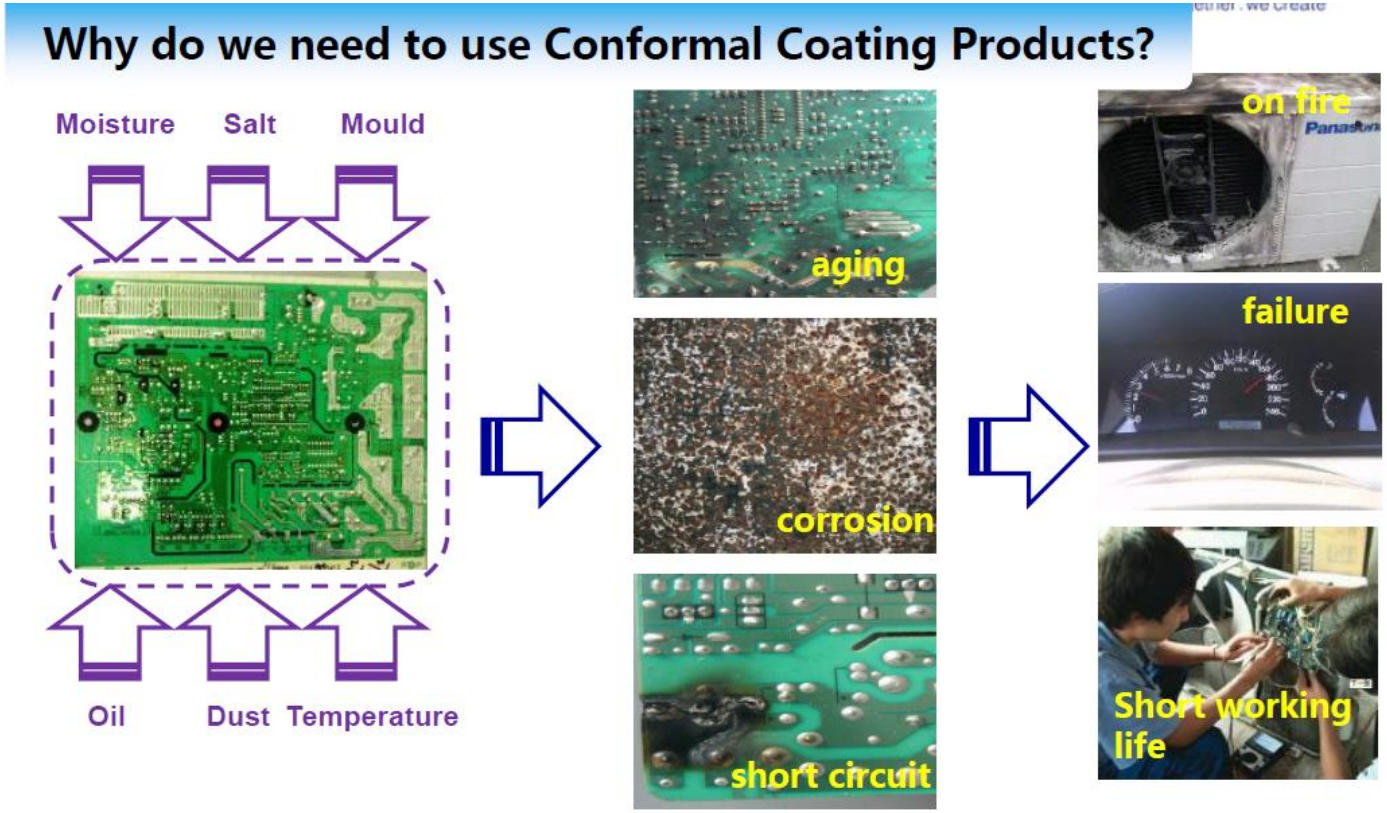

Conformal Coating Introduction

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Type

	Acrylic	Epoxy	Alkyd	PU	Silicone
Applicability	A	B	A	C	C
Repair	A	D	A	B	C
Curing Speed	A	C	B	B	C
Mechanical Strength	C	A	B	B	C
Heat Resistance	B	B	B	B	A
Humidity Resistance	A	B	B	A	C
Chemical Resistance	B	A	B	A	B
Insulativity	A	B	A	B	A

A-Excellent B-Good C-Normal D-Bad

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	UV Curing	Oxygen/ Humidity	Solvent Evaporation
Solid Content(%)	95~100	15~100	15~45
Curing Time(min)	10s~60s	10~60	10~60
Thickness(um)	30~120	10~80	10~35
VOC(%)	0~5	5~85	55~85
Mechanical Strength	A	B	A
Solvent Resistance	A	B	C
Insulating Property	A	B	A
Neutral Salt Fog，168h	A	A	A
Hot and Humid/85℃85%RH，240H	A	A	A
Heat and Cool/-40~85℃	A	A	A
Heat Resistant	A	B(Yellowing)	A

A-Excellent B-Good C-Normal D-Bad

Product Introduction

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Coatings

Product	Description	Type	Viscosity cps	Recommend Using Type	Recommend Curing Condition
EA6103	Environment Friendly, Fast Curing, Add Mildew Preventive, Suitable for Smarter Meter. Has a 60 Shore A hardness.	Acrylic	120	Spray, Dip, Brush	6min@25℃
EA6106	EA6106 is a dual UV-moisture cure material. The initial cure is made with UV light and a secondary moisture cure over time.	UV-Acrylate	150	Spray, Brush	800mJ/cm^2
FS3000	Alcohol Type Silicones, RTV	Silicone	2,000	Spray, Dip, Brush	10min@25℃
FH1280AB	FH1280 A/B is a two-component epoxy with high protection performance	Urethane	300	Spray, Dip, Brush	2 to 3 hours at 80oC

Fluorescent Indicator, Easy to Use.

Environment Friendly, Free From Benzene Solvent.

Frequent Problems

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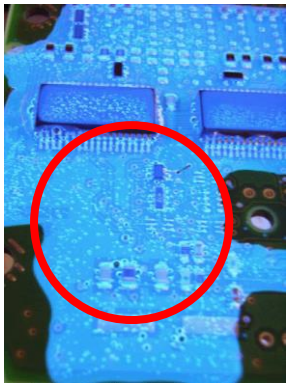
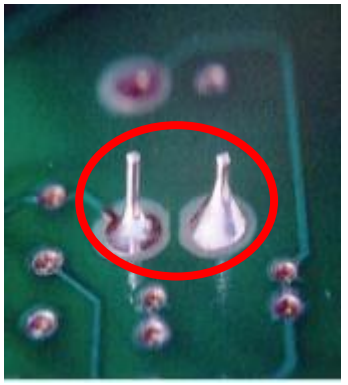
Frequent Problems

No-wetting

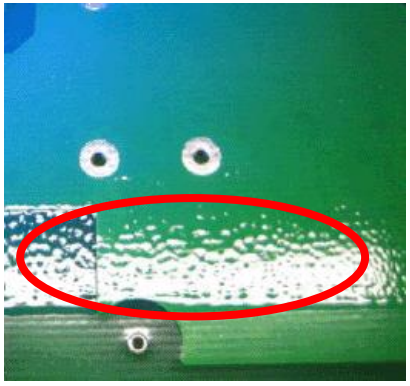


Bubble

Pinhole



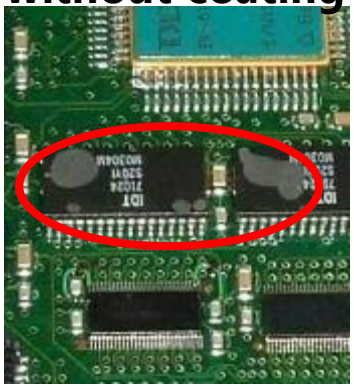
High welding spot without coating



Orange Peel

Crack

Capillarity



Delamination

THANK YOU

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