Solving conformal coating problems in the application process

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Introduction

Normally, problems relating to conformal coating can be broken down into two areas.

Those areas are problems associated with conformal coating processing and problems in the short, medium and long-term reliability of the circuit board or product coated.

Ultimately, there are many factors that can affect the short, medium and long-term reliability of a circuit board that are not associated with conformal coating and are not considered here.

The scope of this paper is really to focus on troubleshooting the problems associated with conformal coating processing and production.

Defining a conformal coating failure in process

Conformal coating failures due to the process come from many different areas.

However, they can usually be divided into three main types.

These are:

• Failures due to the incorrect selection of the material and, or the application method at the beginning.
• Failures in the conformal coating masking process during production
• Failure in the conformal coating production process itself.

The first area, selection of material and application method, relates to the holistic approach to conformal coating and is studied elsewhere.

Also, the conformal coating masking is considered as a separate problem and help can be found here.

This leaves the final section that relates to failures to use the conformal coating material and the application processes correctly that we will focus on.
Typical failure mechanisms in conformal coating processing

Typical failure mechanisms are listed below.

- Blistering
- Blushing
- Bubbles, pinholes and foam
- Capillary flow (Scavenging)
- Contamination
- Corrosion
- Cracking
- De-wetting
- Delamination
- Discoloration
- Fish Eyes
- Layering
- Mealing
- Orange Peel
- Shadowing
- Uneven coating

It isn’t exhaustive but covers all of the points raised in the IPC standards such as the IPC HDBK-830 and IPC-A-610 documents.
Blistering

Blistering is the formation of dome- or circular-shaped bubbles of the conformal coating film held away from the substrate.

Blistering can be the start of conformal coating delaminating.

However, it can also happen within the conformal coating itself and not just the interface of the conformal coating and the laminate surface.

Examples

Causes

Poor cleanliness
The cleanliness of the surface is critical for good adhesion. If the surface is contaminated across a wide area then blistering can occur due to the poor adhesion of the coating to the laminate as the coating peels away.

This could also be made worse by high permeability (see below).

Poor compatibility
For the conformal coating to adhere to the surface, both need to be compatible to bond together. If they are incompatible then they will not bond. This incompatibility may by due to surface energies mismatch.

If the conformal coating is not matched to the laminate then blistering can occur.
High coating permeability to moisture
If the coating allows the moisture to permeate into the region between the coating and the laminate, then a difference in vapor pressure occurs. This could lead to osmotic pressures building due to a change in temperature and pressure, which lift the coating away from the laminate and cause a blister.

Incorrect degree of coating cure
If the conformal coating is not cured correctly then this can lead to adhesion problems.

Prevention

Improve cleanliness
Clean the surface of the board to improve the adhesion of the coating. Remove contamination such as mold release agents on components before application.

Check compatibility
Match the conformal coating to the solder resist and laminate so that good adhesion is achieved. Change the coating and / or surface finish so the surface energies are more favorable.

Reduce permeability to moisture
Choose a less permeable conformal coating to limit moisture penetration to the surface of the laminate.

Reduce the coating thickness
Reducing the coating thickness reduces the problems associated with coefficient of thermal expansion (CTE) mismatch with the components and the laminate that lead to flexing of the coating.

Lower the cure temperature
Reduce force drying (thermal profile) during curing to avoid excess stress and strains on the conformal coating.

Prime the surface
Apply a primer to treat the board surface. This will increase the bonding of the conformal coating to the substrate.
Blushing

Blushing is where the conformal coating, once applied to the circuit, will appear to be blotchy, milky, or cloudy.

Some of the problems can include surface tackiness or greasiness, incomplete cure, poor adhesion, poor adhesion on over-coating, coating discoloration over time and poor gloss retention (matt finish).

Examples

Causes

Environmental conditions
If the conformal coating is dried or cured during conditions of cool ambient temperatures, dropping temperatures, or high humidity, some conformal coatings can develop blushing. This can be caused by the absorption of carbon dioxide and water into the conformal coating film.

Prevention

Environmental control
Control the temperature and humidity in the environment during processing and this could reduce the blushing effect in the conformal coating.
Bubbles, pinholes and foam

Bubbles, pinholes and foam are similar defects. Bubbles are trapped pockets of air within the conformal coating. Pinholes are burst bubbles that reach to the surface of the PCB from the substrate. Foam is extreme bubbling.

Examples

![Bubbles and pinholes]

Causes

**Premature drying**
When applying the conformal coating the wet film surface can skin over, entrapping solvents under the surface that can prevent the bubbles escaping.

**Coating layers applied too quickly**
Applying multiple layers of coating can entrap solvent.

Solvent popping is an application phenomenon that occurs when a second coat is applied without sufficient flash time of the first. Solvent, which is still trying to outgas, is trapped underneath the second coat, and as it migrates to the top it bursts, leaving a small crater.

If the conformal coating is applied too thick or too viscous any bubbles that are created in the process of application can become entrapped in the coating before they settle out.

**Air entrapment**
Air entrapped under components by the coating process can be forced out during the drying & curing process and cause bubbles.
Champagne effects
Pressure pots with conformal coating inside can absorb air that can manifest as champagne bubbles when applied.

Wrong viscosity
Brush coating with too viscous a material or working the coating can cause bubbles during application.

Too much spray pressure
Incorrect spray equipment or pressures can cause excessive bubbles & foam.

Prevention

Apply the correct film thickness
When applying the conformal coating ensure the wet film surface is not too thick. This is particularly important when spray coating. It is better to apply multiple thin layers than one thick layer.

Use the correct drying process
Ensure the individual coating layers are sufficiently dry before applying the next coating layer. This will avoid solvent popping.

Change the dip process settings
To avoid air entrapment under PCB components try dipping slower into the conformal coating dip tank, adding a dwell time to allow penetration of the coating and, or using a lower viscosity version of the conformal coating to under fill the area more effectively.

Turn off pressure in pots when not used
When using pressure pots with conformal coating inside try to avoid leaving the pots pressurised for long periods of time when not being used in the process.

Also, avoid running the pressure pots less than 50% full and letting them stand. This will minimise the champagne effect in the coating.

Brush the coating correctly
When brush coating try to blend the viscosity of the conformal coating so it flows easily and “flow” the material onto the PCB. Do not work the coating into the PCB as it creates bubbles.

Adjust the pressure during spraying
Reducing the pressure on spraying reduces the mechanical agitation and reduces bubbles.
Capillary flow (scavenging)

Capillary flow in conformal coating is where the coating pulls or runs away from certain areas of a PCB. Or it can move underneath devices.

The coating moves to a more favorable area of the board due to a combination of effects. This leaves a patchy finish on the surface of the board.

Examples

Causes

Low viscosity of coating
If the conformal coating has a very low viscosity it will penetrate into devices much easier and more scavenging will occur.

Volume of coating
An abnormally high amount of wet conformal coating applied during the application process can mean the excess material can wick into components before “gelling” of the material is achieved.

Substrate cleanliness
If the circuit board is not clean or has a low surface energy then the conformal coating will not bond to the substrate.

High surface tension
If the conformal coating has a high surface tension then it will also like to energetically penetrate under components leaving uncoated areas behind.
Prevention

**Increase the viscosity**
Increasing the viscosity of the conformal coating will lower the mobility of the coating and aid the adhesion to the right areas of the board.

**Reduce the volume of coating**
Reducing the amount of conformal coating applied in each application will reduce the amount of free material to capillary.

**Substrate cleanliness**
Cleaning the board before processing will aid the bonding of the coating during the application.

**Lower the surface tension**
Use a solvent based material rather than water based or 100% solid conformal coating.

**Heat the board**
Prior to coating the board raising the core temperature of the circuit can allow the coating to dry quicker and be less mobile on the circuit board.
Contamination

Contamination is debris found under, trapped in or on top of the conformal coating on the circuit board. This contamination may be detrimental to the long-term reliability of the circuit.

Examples

Causes

Contamination can come from a variety of areas. This includes pre-production stages of laminate and component manufacture, the process stages during application and the drying & curing stages.

Prevention

Improve cleanliness
Before production starts, all parts of the circuit should be fit for purpose in terms of cleanliness.

Change process materials
Use less contaminating process materials such as flux.

Clean the production and application line
Once ready for assembly, the board production process should not add unwanted contamination to a circuit board.

The conformal coating application process should not add contamination. This includes all the stages after cleaning including masking. The areas should be contamination free to a level that does not produce significant defects.
Corrosion

Corrosion is the chemical or electrochemical reaction between a circuit board, usually a metal, and its environment, that produces a deterioration of the circuit and its properties.

Corrosion can occur without a conformal coating being present. A conformal coating could help prevent or slow down corrosion as a complete process.

Examples

Causes

Factors that influence corrosion and, or electrochemical migration, usually revolve around ionic contamination and the cleanliness of a circuit. These contaminants come from electronic processes such as:

Board fabrication
The laminate goes through a lot of chemical processes. The cleaning of the chemicals on the circuit is crucial to ensure the contaminants are removed.

Components
Components also can get contaminated. Again, cleanliness is critical.

Assembly equipment
The equipment used to make the circuit board may add contamination.
**Soldering process**
The flux residues can have a major influence on the long-term reliability of the circuit.

**Operator handling**
People can add contamination in a variety of ways due to dirty hands, hair loss etc.

**Incorrect cleaning**
The cleaning process may not clean the boards correctly or leave cleaning fluid residues on the circuit due to a failure to rinse the board.

**Prevention**

**Introduce incoming inspection**
A full inspection of incoming boards and components, for solderability and cleanliness, can help.

**Improve the process control**
If you are using a no clean process then tightening up the production process is critical. Adjust the soldering window and fine-tune to ensure the minimum of flux is used and is below or equal to the recommended amount.

**Improve operator cleanliness**
All operators wear gloves and other suitable clothing to minimise contamination.

**Select the right manufacturing materials**
Use “low residue” no clean flux/paste that is less harmful to the circuit. Use the minimum amount.

**Clean the circuit board**
It is possible to minimise the majority of corrosion effects by using an effective cleaning process before conformal coating.

**Control the solder rework process**
Low residue wire/flux used for rework.
Cracking

Cracking in conformal coating is where the smooth surface of the coating fractures into sections. This can occur in the short, medium and long term.

The cracks in the conformal coating leave the surface area below exposed to potential contamination penetration. This allows moisture, water and debris to reach the board level where other defects could then occur such as corrosion.

Examples

![Example Image]

Causes

**Cure temperature too high**
When the conformal coating is accelerated cured within an oven for example the temperature of cure can lead to premature drying of the top surface before the remainder of the coating is dry. Cracking can occur.

**Cure temperature too quick**
Heating the coating too quickly without allowing enough time for room temperature (RT) drying can cause cracking.

**Film thickness too great**
If the dry conformal coating is too thick on the circuit board then this can cause coefficient of thermal expansion (CTE) mismatch and cracks occurring in the coating.
Environment extremes
If the operating temperature of the circuit board is too high or too low, then this can cause the conformal coating to flex too much and crack in the field due to thermal stresses and shock.

Prevention

Reduce the cure temperature
Lowering the initial cure temperature of the oven can reduce the cracking effect.

Slow the cure process
Allow an initial drying time at room temperature before exposure to elevated temperature. This can help minimise the cracking of the coating.

Lower coating thickness
Reduce the coating thickness to avoid CTE mismatch issues and thermal shock effects.

Improve material selection
Select a coating with a wider temperature range performance can help. Also, select a more flexible conformal coating and that matches closer to the other components for less CTE mismatch problems.
Delamination

Delamination in conformal coating is where the conformal coating lifts from the surface of the PCB. This leaves the circuit board area below exposed.

The lifting can be partial or complete. It can occur naturally due to a reaction in the materials. It can occur during the production process such as de-masking.

Examples

![Image of delaminated circuit board]

Causes

**Poor cleanliness**
The cleanliness of the surface is important for good adhesion. If the surface is contaminated across a wide area then delamination can occur due to the poor adhesion of the coating to the laminate.

**Incorrect compatibility**
The conformal coating and the surface have to bond together. If they are incompatible then they will not bond. This incompatibility may be due to surface energies mismatch. If the conformal coating is not matched to the laminate then delamination can occur.

**High permeability to moisture**
If the conformal coating allows the moisture to permeate into the region between the coating and the laminate, then a difference in vapor pressure occurs. This could lead to osmotic pressures building due to a change in temperature and pressure, which lift the coating away from the laminate.
Degree of coating cure
If the conformal coating is not cured correctly then this can lead to adhesion problems and mismatch of Coefficient of Thermal Expansion (CTE).

Thickness and cure level of conformal coating during de-masking
If the conformal coating is too thick and well cured, the coating may lift off the board before tearing when de-masking with tape and dots.

Prevention

Improve cleanliness
Clean the surface of the board to improve the adhesion of the coating. Remove contamination such as mold release agents on components before application.

Check compatibility
Match the conformal coating to the solder resist and laminate so that good adhesion is achieved. Change the coating and / or surface finish so the surface energies are more favorable.

Lower permeability to moisture
Choose a less permeable conformal coating. There are several options available.

Reduce the coating thickness
This reduces the problems associated with CTE mismatch with the components and laminate that lead to flexing of the coating.

Lower the cure temperature
Reduce force drying (thermal profile) during curing to avoid excess stress and strains on the coating.

Prime the surface
Apply a primer to treat the board surface. This will increase the bonding of the conformal coating to the substrate. This occurs all the time for Parylene and other vapor deposition coatings.

Reduce thickness and de-mask quickly
If the coating is thin enough then it will tear easily. Also, de-mask before fully the conformal coating is completely dry or cured also helps.
De-wetting

De-wetting is the tendency of the conformal coating material to refuse to wet the surface that it has been applied to evenly.

The effect can act locally due to local contamination. It can be a global effect right across the board.

Examples

Causes

Board manufacturing process
Residues from board manufacture including silicone surfactants from solder resist & HASL rinse contamination can cause de-wetting.

Component residues
Materials like mold-release agents used to allow easy release of components from their molds when fabricated could cause conformal coatings to de-wet.

Silicone oil
Oils from adhesives in production and from maintenance processes can be lethal to circuit boards. Also, silicone residues from RTV anti vibration and staking compounds can also cause problems.

Soldering processes
The residues from the soldering production line and process can cause de-wetting issues.
Cleaning bath contamination
Some cleaning solvents may cause de-wetting as can any contaminants picked up in the cleaning process. Where rinsing has failed then these residues can be present on the board.

Operator handling
People on the line can add contaminants from barrier creams, food and other materials.

Prevention

Control the process
Minimise the contaminants that are on the component parts before assembly. This includes laminate & component cleanliness control before assembly and selection of low residue process materials including fluxes and pastes during assembly

Clean the boards
Improving the cleanliness of the boards before conformal coating could minimise de-wetting defects.

Compatibility of solder resist
Ensure the solder resist is compatible with the conformal coating or it may not wet correctly.

Repair while processing
After applying the coating, locally strip the de-wetted area and re-apply the coating to the correct specification.
Discoloration
A change in the colour or loss of transparency of the conformal coating that adversely affects the performance or the identification of the components below the coating.

Causes

**UV light exposure**
Damage from UV radiation, like sunlight, from prolonged exposure can change the colour of a coating.

**Contamination**
Prolonged exposure to particulates and dust that stick to a tacky surface can cause changes in colour.

Prevention

**Eliminate the UV light**
Don’t expose the conformal coating to prolonged UV light radiation.

**Correct conformal coating**
Use a UV stable conformal coating.

**Clean Environment**
Prevent the circuit from getting covered in contamination.
Fish Eyes

A fish eye is a localised de-wetting defect that looks like a fish eye crater on the surface of the conformal coating.

Examples

![Fish Eye Examples](image1.png)

Causes

Fish eyes are normally caused by a contaminant on the surface prior to application of the conformal coating. Typically, that contaminant is a substance like a silicon particle.

When conformal coating is applied on top of the contaminant, the conformal coating is unable to adhere to the oily surface and a “fish eye” is caused.

Prevention

**Improve the cleanliness of the surface**

Thoroughly clean the surface of the board before coating. Fish eyes are a surface preparation defect. If the surface of the circuit board has been properly cleaned and degreased, fish eye can usually be prevented completely.
Layering

Layering is where multiple layers of conformal coating are applied to a circuit board and do not adhere to each other or cause incorrect curing of the individual layers.

Causes

Coating adhesion
Some conformal coatings do not stick to themselves. For example you cannot apply multiple layers of Parylene to a circuit board, as they will not adhere to each other.

Inadequate level of coating cure
Some coatings must be fully cured before you apply a second layer. Otherwise, incorrect curing can occur due to the second layer inhibiting the first.

Ineffective coating keying
Finally, some coatings must not be fully cured before the second coating layer is applied to ensure good adhesion. This can be the case with many solvent based coating processes which require multiple layers of coating to achieve the film thickness defined. The second layer bonds (keys) into the first layer.

Prevention

Apply the conformal coating correctly
It is possible to minimise the majority of layer problems by following the manufacturers guidelines.

Get it right first time
For Parylene, ensure the correct film thickness is achieved in one coat application. This is achieved through trials and calculations. If repair of Parylene is required, then normal practice is to use a solvent or water based film-forming coating as a “patch” over the repaired area.

Make the coating adhere
To avoid coating inhibition, follow the manufacturers cure schedules. Also, use adhesion promotion and surface preparation techniques to help.
**Time the coating application layers correctly**

To avoid lamination of coating in solvent-based coatings, ensure that the optimum time between coating layers is selected.

This time is dependent on several factors including the solvent flash off time, the temperature and humidity in the area, the extraction rate and the chemical nature of the material.

The key to success is to dry the coating enough where the second layer bonds to the surface of the first layer but does not trap excessive solvent in the lower layer. This trapping can lead to excessive bubbles.
Mealing

Mealing is a form of delamination of the conformal coating that occurs across the circuit board. It is a blistering (vessication) affect.

Examples

Causes

**Surface cleanliness**
Poor cleanliness of the surface reduces adhesion. If the surface is contaminated across a wide area then mealing can occur due to the poor adhesion of the coating to the laminate.

**Materials compatibility**
Compatibility between the conformal coating and the surface adhered to due to surface energies mismatch is important. If the conformal coating is not matched to the laminate then mealing can occur.

**Permeability to moisture of the coating**
If the conformal coating allows the moisture to permeate into the region between the coating and the laminate, then a difference in vapour pressure could occur. This could lead to osmotic pressures building due to a change in temperature and pressure, which could lift the coating away from the laminate.

**Degree of coating cure**
If the coating is not cured correctly then this can lead to adhesion problems.
Prevention

Clean the board
Clean the surface of the board to improve the adhesion of the coating. Remove contamination such as mold release agents on components before application.

Material compatibility
Match the conformal coating to the solder resist and laminate so that good adhesion is achieved. Change the coating and/or surface finish so the surface energies are more favorable.

Coating thickness
Reduce the conformal coating thickness. This reduces the problems associated with CTE mismatch with the components and laminate that lead to flexing of the coating.

Lower curing heat
Reduce force drying of the conformal coating after application (change the thermal profile) to avoid excess stress and strains on the coating.

Prime the substrate
Apply a primer to treat the board surface. This will increase the bonding of the conformal coating to the substrate.
Orange Peel

This defect is an uneven textured surface formed on the conformal coating, often appearing dull, which looks like the skin of the orange or a golf ball with small craters and dimples.

Example

![Image of PCB with orange peel]

Causes

**Spray setup**
Orange peel is often caused because of poor gun adjustment as the conformal coating is being applied.

**Application incorrect**
An incorrect application technique can produce the orange peel effect. This manifests in aerosol or spray gun application where the coating is applied too far away from the PCB and the coating is too “dry” on the surface to level out.

**Incorrect viscosity**
An incorrect viscosity of the conformal coating before application can cause orange peel.

**Coating thickness**
The incorrect thickness of the coating is deposited so that there is insufficient conformal coating to self-level.
Curing
The incorrect cure profile when using an accelerated curing mechanism. This could be that the flash off zone before heat curing is inadequate or the oven profile is incorrect.

Prevention
Gun setup
Set the spray gun up correctly. Gun setup and adjustment are critical to a smooth and flat appearance of a conformal coating.

If the needle/nozzle combination is not specifically matched to the coating being applied, the air pressure (especially when using an high volume low pressure (HVLP) gun may not be sufficient to correctly atomise the conformal coating.

Viscosity
Reduce the viscosity of the conformal coating. If a coating is mixed at the wrong viscosity and it is too thick (too high a viscosity), orange peel is likely.

Spraying technique
Optimise the distance for spray application to the manufacturer specification when applying the conformal coating.

Material volume applied
Ensure enough layers of coating are applied to form a level coating. This is especially true for aerosols that are susceptible to this issue.

Drying
Increase the flash off time for the solvents to evaporate before increasing the temperature for elevated curing of the conformal coating. Re-profile the curing oven using the conformal coating material suppliers recommended profile.
Shadowing

Shadowing is where correct conformal coating coverage is not achieved on a section of a board due to a component or part of the board is blocking another area of the circuit board.

This can occur when coating is applied by spray method to a circuit board. This can easily occur with 3D components and tall components.

Causes

If the circuit board has an architecture structure that is 3D in nature with large components such as heat sinks, capacitors and through-hole components on the circuit then this is more likely to occur.

Prevention

Avoiding shadowing can be easily done if you use the correct spray application method for conformal coating.

The method that should be adopted for most cases is as follows:

1. Angle the spray gun at 45 degrees so the conformal coating can penetrate easier onto the circuit board.
2. Spray the PCB in a light coating in a rastered pattern.
3. DO NOT apply the full film thickness on this first pass. A thin layer is appropriate.
4. Rotate the circuit board by 90 degrees
5. Repeat the rastered pattern across the circuit.
6. Rotate again and repeat until 4 coats have been applied to the circuit.
7. Examine the PCB for coverage. If the coating coverage is good then the board is coated. If the coating is patchy or too thin then repeat the process after the correct time for the coating to dry enough (to avoid layering issues).
Uneven conformal coating as a defect is where the thickness of the material is outside the range of the specified requirement.

When the coating is too thin this will give inadequate protection. When the coating is too thick the coating can lead to other defects such as bubbles, cracking and delamination.

Examples

Causes

**Capillary effects**
Wicking can pull the coating under components, filling the area underneath the device with very thick material and leaving other areas clear of coating. This can also lead to large fillets of coating between leads and bridging effects, which can lead to CTE mismatch problems in the long term.

**Effects of Gravity**
Gravity can lead to coating running down the sides of components and pooling at the base. It can also lead to poor tip coverage of sharp edges. This can also be a factor with surface tension effects of conformal coating that can move the liquid around the circuit.

**Overlapping material layers**
An automatic spray pattern from a robot may inadvertently apply some areas with thicker amounts of coating by overlapping the spray stripes.
Shadowing
A manual spray process may be poorly applied, leading to shadowing and areas of thick coating.

Entrapped coating
A circuit board when withdrawn from a dip tank in a dip process may have entrapped conformal coating in pockets of the components or board itself that can lead to very thick areas of coating.

Drying too quick
A conformal coating may not level out correctly when applied may be prematurely “gelling” too quickly.

Prevention

Capillary effects
Avoid wicking (scavenging) and the problems associated with it.

Effects of gravity
Ensure the coating technique takes into account the effects of gravity. For example when spraying, use multiple thin layers of coating. This reduces the amount of free liquid to flow on the vertical walls and ensures the coating sticks where applied.

Overlapping material layers
Program the selective robot to avoid crossing the flow stripes where possible.

Shadowing
Avoid shadowing effect problems with conformal coating.

Entrapped coating
Ensure the optimum drain angle when dipping to ensure minimal coating is trapped. Other options including building in a tilt or rotate mechanism into the fixtures of the dip process so that the drain can be more effective. Finally, design the circuit with drain holes and flow paths to achieve good coating coverage.

Drying too quick
Use a lower viscosity mix of the coating if the coating is prematurely drying and not leveling. Also, reduce the extraction rate and increase the ambient temperature for better flow.