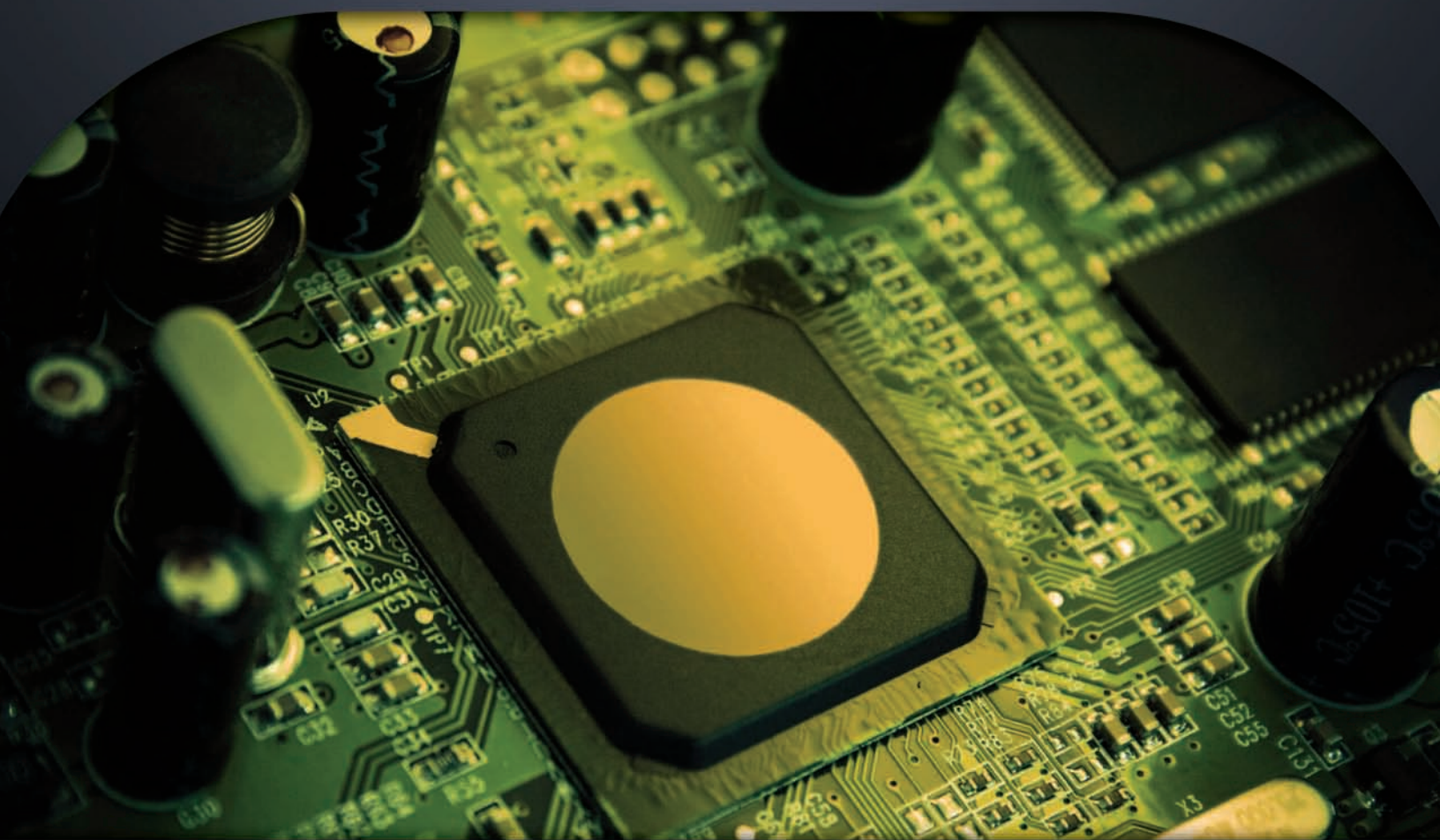




Conformal Coatings Facts & Data Handbook





Overview

Our popular, newly revised conformal coatings Facts & Data booklet, is designed to form a readily understandable, introductory guide focusing on the main issues of selecting a coating material and putting it into process.

Its objective is to present the salient facts in succinct style rather than attempting to take the reader into a long and detailed scientific explanation (numerous further reading references can be supplied for this purpose).

The need for such a guide has never been so great. The global shortage of electronics engineers is drawing a steady stream of newcomers into the field. In addition, the reliability-enhancing nature of conformal coatings (not to be confused with potting compounds or encapsulants) has become a highly effective way to combat the vast cost, not to mention reputation-damaging effects, of having to rectify field failures.

As such, the use of conformal coatings is becoming increasingly popular in many less traditional consumer and domestic applications - especially densely packaged portable electronics devices that can be susceptible to environmentally induced failures in the field.

Nonetheless, choosing the right coating material and application process can be very difficult and time-consuming for the uninitiated. Without a sound overview of the subject and familiarity with the relevant standards and specifications, expensive and irreversible errors can easily be made.

This booklet serves to help address this problem and we hope it will continue to be regarded as an invaluable and welcome guide to conformal coatings for many years to come.



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Selection

There is no shortage of conformal coating materials, and the first thing to appreciate when selecting a conformal coating is that no perfect solution exists. To be able to effectively resist a variety of environmental attacks, many different formulations with widely differing performance characteristics have emerged. (Over the last 50 years, the HumiSeal range has grown to currently include over 150 different coating formulations to meet specific performance and process application requirements.)

In reality, therefore, the performance of all conformal coatings should be regarded as a working trade-off. A gain in one parameter (for instance thermal resistance or thermal operating range) will inevitably be achieved at the expense of another (poorer salt or chemical resistance, for example).

Definition

A conformal coating is a 25-200 μ m (1-8 mils) thick (50 μ m(1-3 mils) typical) protective membrane (or-coating) that adheres to an assembled PCB by literally 'conforming' to its irregular profile. Electrically insulating with good dielectric resistance, it ensures the operational integrity of the assembly.

Its primary function is to protect PCBs used in hostile or harsh operating environments. This includes exposure to moisture, aggressive solvents, chemicals and vapours, salt sprays, temperature variations, mechanical vibration, and organic attack (for example from fungus).

No conformal coating, however, can be regarded as a totally impermeable shield. Although many modern formulations are engineered to offer high levels of environmental protection, none can withstand unreasonably prolonged exposure to, for example, an aggressive chemical attack or moisture (due, say, to full immersion). They should instead be viewed as highly efficient and effective filters to harmful environmental effects at a molecular scale.

The physical characteristics of any conformal coating must meet strict minimal standards. These currently include IPC-CC-830 MIL-I-46058 IEC-1086 specifications and UL746 approval.



Advantages

The particular advantages of conformal coatings can be summarised as follows:

- 1 Insulating properties allow a reduction in PCB conductor spacing of over 80%
- 2 Can help eliminate the need for complex, sophisticated enclosures
- 3 Light weight
- 4 Completely protect the assembly against chemical and corrosive attack
- 5 Eliminate potential performance degradation due to environmental hazards
- 6 Minimise environmental stress on a PCB assembly
- 7 Inherent flexibility conforms to varied component profiles

Ideally, conformal coatings should exhibit the following characteristics:

- 1 Simple application
- 2 Easy removal, repair and replacement
- 3 High flexibility
- 4 Protection against thermal and mechanical shock
- 5 Protection against environmental hazards including: moisture, chemicals and other corrosive elements

Design Application

If the decision to use conformal coating is made as part of an assembly's original product specification, the designer can take steps to ease the actual coating process in production, maximising the financial viability of their design.

Specifically, substantial process cost savings can be made if components that shouldn't be coated (such as connectors, IC sockets, trimmers, test pins, fuses and presets) are put at one edge of a board. This allows the assembly to be more easily dip or selectively spray coated using automated in-line methods, and eliminates the need for (and added expense of) masking (see section 4).

Dip or selective-spray coating also makes it relatively simple and inexpensive for a manufacturer or an EMS provider, to conformal coat in volume, which is why most volume automotive manufacturers use this approach.

It is also important for designers to determine, given the expected operating environment of an assembly, the optimum technical requirements that any potential coating should exhibit in order to ease selection for manufacturing.

Performance requirements:

- Electrical properties
- Moisture permeability
- Chemical compatibility
- Mechanical durability
- Thermal properties
- Chemical resistance
- Environmental hazard

Process criteria determined by materials:

- Solids content
- Type of carrier used (solvent, water or none)
- Viscosity
- Pot life
- Ultimate shelf life
- Curing temperature
- Curing time
- Method of application

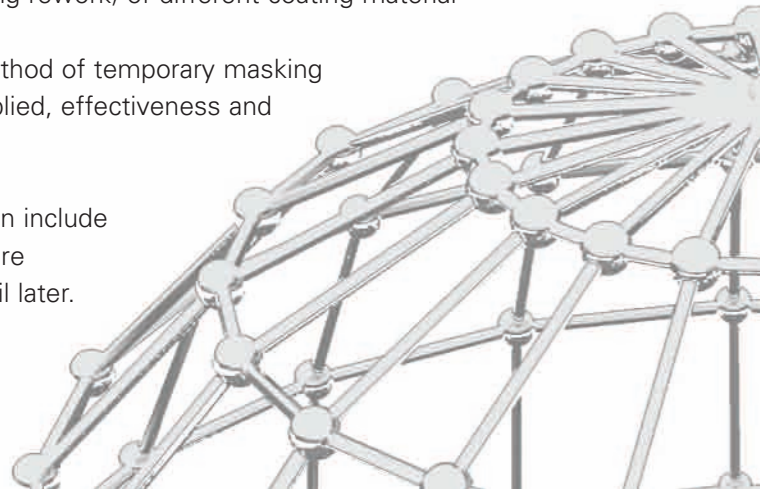


Criteria

The type of conformal coating material (see section 3), its viscosity and its solids content, broadly dictate the method of application (section 5). To avoid potential design-related process problems later on, however, it is necessary to carefully consider each of the following:

- 1 Larger clearances between components and substrates may prevent a meniscus forming around a component yet total penetration may not be achieved when spraying
- 2 If the coating is applied via manual hand spraying or brushing application methods, it is difficult to obtain a uniform, repeatable process except with highly skilled and experienced operators
- 3 Components that require temporary masking (i.e. that shouldn't be coated as listed above) should be grouped together in one location on a board
- 4 Avoid the use of silicone-based heat sinks, adhesives or greases that are known to be incompatible with standard conformal coating materials
- 5 Although the mechanical rigidity of a coating in its cured plastic state can aid component support and resistance to vibration, it is unwise to rely solely on the coating for this purpose. Instead consider staking (or mechanically pinning) components to the PCB
- 6 Volume PCBs in particular should be designed to be able to be coated as easily and therefore cost-effectively as possible
- 7 The curing time of some coatings can be very long unless elevated curing temperatures are used (see section 2)
- 8 The ease of reparability (ability to be removed during rework) of different coating material types can vary dramatically
- 9 The economic and technical implications of the method of temporary masking that will be required, ease with which it can be applied, effectiveness and cost of labour

Other characteristics that should be taken into consideration include processing and performance criteria requirements. These are summarised in the table below and explained in more detail later.



Material Characteristics

Pot Life

Pot life is the time period after preparation, during which the coating material can be effectively applied before it starts to cure. It is an important factor when planning coating operations and its impact on cost should be seriously taken into consideration in any volume application.

An acceptable pot life is considered to be between 30 minutes and 3 hours at room temperature. A short pot life will inevitably result in material waste during processing, but can also lead to non-uniformity in coating thickness and quality due to rapid thickening. Shortened pot life is a drawback of many older two-compound formulations. Modern single-component coatings, however, have an extended pot life that sometimes equates to shelf life. It is important not to confuse pot life with shelf life (see next).

Shelf Life

Shelf life is defined as the time a material can be stored at a predetermined temperature in unopened original containers without deterioration. For practical purposes, shelf life should be in the region of months rather than days.

Viscosity

Viscosity must be low enough (less than 3000 cps) to permit easy flowing of the liquid coating over, around and under components during application to ensure complete coverage. A relatively high viscosity, however, is desirable when coating core components with sharp corners and/or protruding leads. Viscosity should also be sufficient to provide a thicker meniscus around the edge of components where the underside gap is inadequate for complete penetration.

The viscosity of solvent-type coatings can easily be adjusted prior to coating application by the addition of a (dedicated) thinner to achieve optimum performance for a particular assembly configuration.

The coating should, however, be supplied from the coating vendor with a viscosity at or near that of intended use. This will minimise or even eliminate the need (and added labor cost) of thinning.



Solids Content

Solids content represents the proportion of a coating formulation (i.e. its pure coating content) that will cure into the final protective film upon application.

Coatings are usually supplied in liquid form using a carrier medium (which evaporates upon application) that has traditionally been solvent-based but is increasingly now water-based. The proportion of solids (pure coating material) contained within the solvent can be anywhere between 15 and 45%. (100% pure coating material is also available.)

Solids content affects coating thickness per application (therefore the number of applications and the amount of material required to achieve a desired coating thickness) and consequently has a cost impact on the coating operation.

When comparing costs one must consider the relative solids content between alternative suppliers' products. The best way to do this is to divide the unit litre cost of a given material by its percentage solids content for a "cost per percentage solids" figure. This ensures a comparison of 'like with like'.

To emphasise the point, compare a liter of 20% solids material to a liter of 40% solids material: Say the former apparently costs half of the latter, it's likely that two liters of the former will be required, compared to the one of the latter. Consequently the cost is the same, but the job takes twice as long with the apparently cheaper material, translating into a much more expensive process in reality. High quality solvent or water-based conformal coatings should have a minimum solids content of around 20%.

Cure Temperature

Cure temperature is an important factor for consideration, the higher the temperature, the faster the cure. Obviously, a room temperature cure will require less energy (and therefore less cost) than a high temperature cure. Ambient curing materials typically require up to 24 hours to cure completely. UV cure coatings may be cured in as short a time as 30 seconds. Fast-cure formulations, however, are usually two component systems. While the shortest cure time is desirable for volume production, high cure temperatures do run the risk of causing thermal damage to heat sensitive components on a board.

For practical purposes, a cure time for handling (i.e. the time it takes the coating to become dry to the touch) should not exceed 30 minutes at room temperature.

Electrical Properties

The ideal coating should exhibit high resistivity and dielectric strength to ensure electrical integrity. These characteristics should not deteriorate with changes in temperature and humidity. Equally, the electrical properties should not affect circuit performance. For example, some coatings work well at low frequencies but can cause circuit malfunctions above 100KHz. The dielectric constant and loss factor also begins to increase, while resistance and dielectric strength decrease.

Moisture Permeability/Absorption

Coatings should have low moisture absorption and permeability. Often, however, a coating with high absorption and low permeability will initially withstand high humidity, but then moisture will start to penetrate. Furthermore, this moisture takes a long time to evaporate when humidity drops.

Chemical Compatibility and Properties

The coating must be electrochemically compatible with the substrate and the components upon which it is applied. It must not soften plastic cases or remove (or blur) markings. Some materials can affect the bond between the coating and the assembly, inhibiting or extending the cure period. It is strongly recommended that the user run a series of compatibility tests with the pre-production assembly and the planned coating material.

In addition, it is a good idea to perform long-term accelerated life testing and modern Surface Insulation Resistance (SIR) analysis on the end product (assembled under factory conditions, conformally coated and de-masked). This will ensure there are no electrochemical compatibility issues between various assembly chemistries and materials (such as solder resist, flux, adhesives and cleaning agents) that could cause unexpected long-term product reliability problems.

In terms of chemical exposure, most coatings will supply a reasonable level of resistance within their pre-defined limits. But if an assembly is going to be subjected to harsh chemical attacks, such as prolonged exposure to

hydrocarbons, or some combination of corrosive chemistries, then a two-component Polyurethane or a UV curable Urethane (see section 3) formulation may be the only coating capable of delivering the level of protection required.

Mechanical Durability

The cured coating should be tough and abrasion-resistant (not easily removable by rubbing) to withstand subsequent handling during production and (potentially) in the field. Ideally, it should be flexible enough to 'move' with the board during final installation into its housing.

Repair

The coating should be easily re-workable (or repairable) so that solder touch-up can take place when components are replaced. The materials used for patching the coating should be of the same generic type as the original assembly coating itself. The affected area must be cleaned (or more precisely, pre-treated - see section 4) before re-coating.

Thermal Properties

The coating must be able to withstand localized thermal 'hot spots' generated by components. High temperatures can cause short-term changes in coating characteristics, such as softening and lowered electrical resistance. Long-term effects of high temperature operation include discoloration, brittleness, cracking, and shrinkage and could result in lower dielectric strength, along with possible reduction in moisture and insulation resistance.



Fungus Resistance

Conformal coating materials are generally not nutrients for fungus, but some organics do support fungus growth and require a fungicide additive. It should be verified between the end user and conformal coating supplier as to the exact anti-fungal properties required of the conformal coating material.

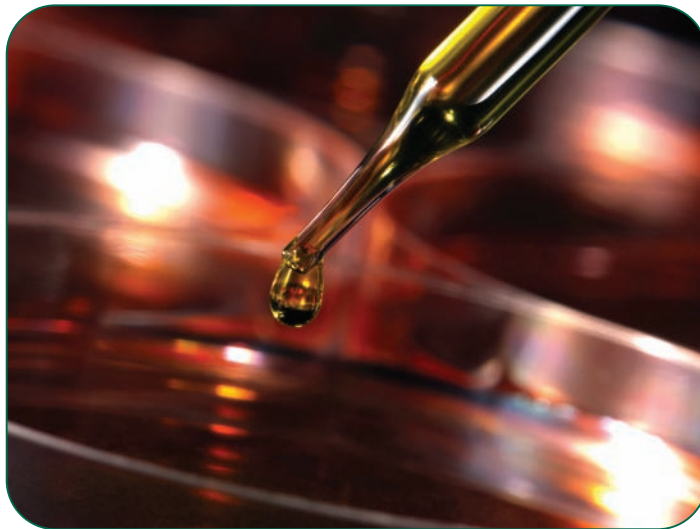
Curing and Setting

The liquid coating should thoroughly wet all surfaces and cure without leaving surface defects. Epoxies (see section three) are especially sensitive to surface defects. Epoxies and UV curable material can also shrink while setting and may lose adhesion as a result. In addition; excessive shrinking during cure can place severe mechanical stresses upon circuit components.

The supplier, to create the special formulation required for a particular application, should be able to modify all of these properties. Other characteristics can also be enhanced. For example, fillers can be added to achieve improved flame retardance or to meet UL specifications, as well as extra-high temperature resistance and high or low thermal conductivity.

Accessory chemicals and solvents should only be blended with base polymer resins by the coating manufacturer.

Plasticizers can also improve mechanical flexibility, and selected solvents in conventional coating formulations can improve adhesion of the cured film.



TYPICAL CHARACTERISTICS OF VARIOUS CURED COATING MATERIALS

Properties	Acrylic	Urethane	Epoxy	Silicone
Volume resistivity, ohm/cm (50% RH, 23°C (73°F))	10 ¹⁵	2 x 10 ¹¹ 11 x 10 ¹⁴	10 ¹² -10 ¹⁷	2 x 10 ¹⁵
Dielectric constant, 60 cycles	3-4	5.4-7.6	3.5-5.0	2.7-3.1
Dielectric constant, 10 ³ cycles	2.5-3.5	5.5-7.6	3.5-4.5	-
Dielectric constant, 10 ⁶ cycles	2.2-3.2	4.2-5.1	3.3-4.0	2.6-2.7
Dissipation (power) factor, 60 cycles	.02-.04	.015-.048	.002-2.7	.007-.001
Dissipation (power) factor, 10 ³ cycles	.02-.04	.043-.060	.002-.02	-
Dissipation (power) factor, 10 ⁶ cycles	2.5-3.5	.05-.07	.030-.050	.001-.002
Thermal conductivity, 10 ⁻⁴ cal/sec/sq.cm/1°C/CM	3-6	1.7-7.4	4-5	3.5-7.5
Thermal expansion 10 ⁻⁵ /°C	5-9	10-20	4.5-6.5	6-9
Resistance to heat °C (°F) continuous	120 (250)	120 (250)	120 (250)	204 (400)
Effect of weak acids	None	Slight dissolve	None	Little or none
Effect of weak alkalis	None	Slight dissolve	None	Little or none
Effect of organic solvents	Attacked by ketones, aromatics & chlorinated solvents	Resists most	Generally resistant	Attacked by some

IMPORTANT!

It should be noted that the introduction of any additives by the end user will materially affect the ultimate performance of the coating and will likely result in totally unpredictable, even catastrophic long-term electrochemical side effects and reactions. As a result of this, any assembly that has been coated with a material to which an additive has been applied will totally destroy any qualification to international standards.

The addition of coloring agents to a coating (for instance to hide components on the coated assembly from view), will generally reduce its dielectric efficiency. It will also greatly impair its moisture resistance. If color is required, it is most safely achieved by applying a second layer of electrochemically-compatible colored coating over the original clear coating. A true conformal coating, however, is never opaque.

Coating Types

There are five main types of conformal coating used in assembly, categorized by the primary solids material they contain: acrylics, polyurethanes (or urethanes), epoxies, silicones and UV curables.

Each exhibits different strengths and weaknesses and the eventual operating environment of the assembly governs choice. (The table on page 13 summarizes the relative differences that are also discussed below.) It is important to note, however, that comments on all aspects of performance are relative in comparison with other material types and should not be taken as absolute characteristics. In addition, recent advances in coating material and polymer technology are narrowing the performance gap between different coatings all the time.

Acrylics

Acrylics cure rapidly (reaching optimum physical properties in minutes), are fungus resistant and provide long pot life. Furthermore, during curing, acrylic coatings emit little or no heat (eliminating the risk of thermal damage to heat-sensitive components), and do not exhibit shrinkage (a phenomenon that places excessive mechanical stress upon components and joints).

Of the various types of conformal coatings on offer, acrylics offer the highest humidity resistance of all. They also have a relatively high dielectric characteristic (i.e. impedance), fair chemical resistance and good temperature resistance. In production they are easy to apply and can be quickly removed during rework with either glycol based stripping solvents or fluorinated solvents, or by soldering directly through them for spot repairs.

Polyurethanes

Polyurethane (commonly shortened to urethane) coatings offer excellent chemical resistance combined with good moisture, temperature and dielectric characteristics. Their high level of chemical resistance, however, can be a major drawback since their re-work can prove difficult and costly. To repair or replace a component, a special stripper compound must be used, but since its residues can introduce contaminants, the stripper compound may affect longer-term circuit performance and reliability, and inhibit adhesion of the new coating, if not properly cleaned.

While polyurethanes can be soldered through during rework, there is usually a brownish residue that only affects the aesthetics of the coating.

Urethanes are available as either single or two-component formulations. Single component polyurethanes, however, whilst easy to apply, sometimes require 3-10 days at room temperature for final cure. Two-component formulations, on the other hand, reach optimum properties at elevated temperatures within 1-3 hours, but have pot life range of 30 minutes to 3 hours.

Epoxies

Epoxy coatings provide excellent abrasion resistance (i.e. the ability to withstand rubbing) and chemical resistance, but poorer moisture and dielectric performance.

Cure time is average but epoxies are virtually impossible to remove for rework, due to the other epoxy-based materials on a board (epoxy glass substrate and epoxy-based plastics in component housings), which could be vigorously attacked by the application of any epoxy dissolving stripping material. The only effective way to repair a board or replace a component is to burn through the epoxy coating with a hot knife or soldering iron.

When most epoxies are applied, a 'buffer' material must be used around fragile components to prevent their damage due to film shrinkage during polymerisation. What buffer materials are we talking about?

Curing of epoxy systems takes place in 1-3 hours at an elevated temperature or in 4-7 days at room temperature. Short Pot Life creates a limitation on their effective use.

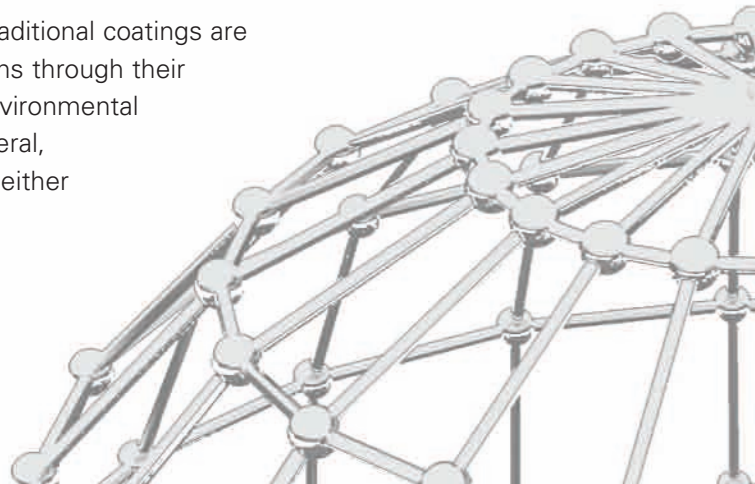
Epoxy-based coatings are usually supplied as two component compounds, but single part vinyl-modified epoxies are available for special applications.

Water-based and Low VOC

A major recent development in the field of conformal coatings is the introduction of water-based coatings (acrylic, urethane, epoxy and silicone types are all now available) that replace solvent as the carrier medium with water.

Their development has been driven by the fact that most traditional coatings are solvent-based, producing harmful solvent and VOC emissions through their industrial application. This has created a large amount of environmental concern over the use of conformal coating materials in general, encouraging the development of 'greener' alternatives that either use VOC exempt solvents or water as the main carrier.

The most notable are solventless silicone and UV curable types that are both available in "100% solids" format.



However, the absence of a cheaper carrier material (users pay for the proportionately vastly more expensive but small solids content) can make their cost appear formidable.

In addition to being extremely environment friendly, water-based coatings are also non-flammable, as they do not use solvents. They are therefore safer than most conventional coating ingredients, by reducing Health and Safety demands for fume extraction and handling of hazardous chemicals.

Furthermore, unlike traditional solvent-based coatings, water-based types can be delivered 'ready-to-use' and as such they do not require any on-site handling and mixing, or packaging disposal.

On the downside, switching to a water-based coating from a conventional solvent based formulation isn't straightforward and should in no way be considered as 'drop-in' replacements for traditional materials. There are a number of processing issues that have to be addressed.

It is also important to note that the performance of existing water-based products can vary enormously from supplier to supplier,

Silicones

Silicone coatings offer high temperature, moisture and dielectric resistance, but limited chemical resilience. A very low surface tension aids their ability to penetrate into every part of an assembly, although due to their high solids content and high Co-efficient of Thermal Expansion (CTE) care must be taken to ensure that this is not counterproductive.

Their primary use is in high temperature applications up to a maximum of 200°C, making them desirable for assemblies with, for instance, large heat dissipating devices such as power resistors.

Like epoxies, silicone coatings can be difficult to rework, and they are relatively expensive compared to other coating material types. In addition, silicone materials tend to be 2-3 times more permeable to moisture vapour than other coating chemistries, resulting in the requirement to apply thicker films to achieve the same level of protection.

In addition, the CTE of silicones are large (e.g. 300-350 ppm/°K) compared with solder (c. 16 ppm/°K) or other coating types.

Furthermore, silicones have a unique property that, however soft they may feel under the thumb, they are rock-hard when subjected to a shock.

This combination could result in a squashed silicone at slightly elevated temperatures which would place a tension on a BGA-ball-pad combination, which could increase by orders of magnitude should it be subjected to a small shock at the same time.

UV Curable Coatings

Ultraviolet (UV) light curable conformal coatings offer extremely fast cure speed and low VOC content as well as providing excellent moisture, dielectric and temperature resistance and high chemical resistance. UV curable materials are especially suited to high volume, selective coating applications and due to the extremely low footprint of the curing equipment can free up valuable floor space.

Most commercial formulations incorporate a secondary cure mechanism to help overcome any shadowing issues or to help cure material which flows under components and does not see the UV light source. This can be either heat activated or moisture activated. The advantage of the moisture cure is that it does not require any additional process steps.

Due to their extremely good chemical resistance, most UV curable materials are difficult to rework, although modern formulations can be successfully repaired using a soldering iron or micro-bead blasting equipment.

COATING SELECTION CHART

Properties	Acrylic	Urethane	Epoxy	Silicone
Ease of application	A	B	C	C
Ease of rework removal (chemically)	A	B	-	C
Ease of rework removal (burn through with soldering iron for spot rework)	A	B	C	-
Abrasion resistance (rubbing)	C	B	A	C
Mechanical strength	C	B	A	B
Temperature resistance	D	B	D	A
Humidity resistance (moisture)	A	A	B	A
Humidity resistance (extended periods)	A	A	C	B
Pot Life	A	B	D	D
Optimum cure	A	B	B	C
Room-temperature cure time	A	B	B	C
Elevated-temperature cure time	A	B	B	C
Cost	A	A	A	D

Property ratings (A-D) are in descending order - A being optimum

Long Term Reliability Testing

As previously mentioned no coating forms a totally impermeable barrier, and all, in fact, 'breathe' in the sense that they permit air (which may contain moisture) to migrate in and out through their protective membrane coating.

Moreover, the conformal coating, while acting as a barrier against external contaminants, will also seal in contaminants that are on the board at the time of coating.

This can create a problem, because after assembly, a whole host of residues can be present on a board, especially during a no-clean process. This reinforces the need for SIR testing as described previously in Section 2.

If the contaminant on the board prior to coating is soluble, it can repetitively dissolve and crystallise after coating (between the coating and the substrate) as moist air penetrates and then dries out over time. The contaminant is usually a salt and will induce an osmotic 'pumping action' pressure which can compromise the protective abilities of the coating, promote poor coating adhesion and/or dewetting, and in the most extreme cases cause voids and bubbles that permeate the surface of the coating. This condition is known as vespigation or measling.

This degradation can be made worse if moisture penetration reacts in unpredictable ways with assembly materials and residues left on the board after production (including oily organic particulates left by any form of manual handling). Ionic contaminants on insulation surfaces are particularly damaging, since they can compromise electrical contact of in-circuit test probes, cause electrical leakage and corrosive degradation of the circuit elements, and ultimately lead to failure of the assembly.

Ionic contamination will also cause 'measling' of conformal coatings that is not only cosmetically unattractive, but will also result in rejection of the completed assembly under most supply contracts. Prime sources of ionic contaminants include rosin flux residues, acidic soils in the form of perspiration and fingerprint residues from manual handling and previous chemical processing steps such as etching or plating. Whilst rosin itself is non-ionic, it too should be removed since it partially encapsulates ionic residues from flux activators.

Ionic contamination can be measured using a range of test methods.. These can determine the amount of ionic contamination remaining on an assembly after various manufacturing procedures.

Cleaning

If cleaning is warranted as a result of SIR and/or ionic extract testing, then its ultimate objective is to produce a completely clean assembly, free of contaminants, without inflicting any damage either on the substrate or its mounted components.

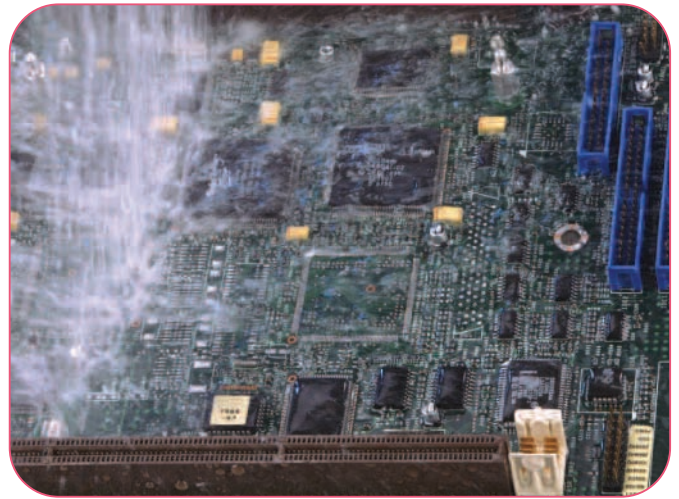
Establishing an in-line cleaning process, however, is far more challenging than introducing, for example, a wave-soldering or reflow operation. Water and chemicals used for industrial cleaning are subject to strict environmental regulations. The best solution is to avoid the need for cleaning by soldering in an inert atmosphere or using low solids or no-clean fluxes that safely remain on a board during its working life.

All cleaning processes can be categorized into three broad groups: aqueous, semi-aqueous and solvent.

Pure aqueous cleaning uses water to remove flux residues from a board. For the procedure to be effective, the fluxes used during manufacture must be formulated to be water-washable.

If no-clean or rosin-based fluxes are used, their removal will require some form of detergent or saponifier. These are alkaline additives added to the cleaning media to render flux residues soluble, or surfactants to help lift residues from the surface and solubilise them. Most modern cleaning formulations use a combination of both methods to provide as wide a process window as possible.

Both semi-aqueous and solvent processes use such detergents to remove non-soluble residues through three separate stages; wash, primary rinse and final stages. Semi aqueous cleaning is the more popular option, as it uses fewer solvents, but will demand a dedicated water cleaner if it is to be used in a closed loop configuration.



It is important to note that a thorough drying cycle of the assembly must be undertaken prior to the application of conformal coating. If the cleaned assemblies are not to be coated immediately, they should be stored in a desiccation cabinet or a sealed non-contaminating bag, such as Kapak.

A typical drying schedule after a batch type aqueous cleaning would be one hour at 75°C (167°F), as compared to 4-5 minutes with in-line systems, although how dry the boards are after in-line drying depends on the specific equipment and assembly.

Ionic Cleanliness Testing:

Often referred to as ROSE (Resistivity of Solvent Extract) testing or SEC (Solvent Extract Conductivity) testing. These methods were developed in the 1970s to help monitor the ionic cleanliness of PCB assemblies.

Most ROSE test machines operate on a similar principle. Ionic extract testing is accomplished by applying a computed amount of isopropyl alcohol and de-ionized water to an assembly.

By observing the decline in resistance of the test solution (since ionic materials are conductive, the lower the resistivity the greater the amounts of original contamination extracted) the cleanliness level of the assembly can be accurately determined. By measuring the amount of ionic material extracted and knowing the surface area of the PCB under test, it is possible to derive a unit of cleanliness, often reported as g NaCl (Table salt) equivalent per cm².

The military, IPC and many companies all have a maximum level of permitted NaCl equivalence, but for a well-controlled no-clean SMT process, you should aim for a value as low as possible but certainly between 0.5 and 1.0 g NaCl equivalence per cm².

Modern techniques, such as ion chromatography are more accurate in determining both the identities of and concentrations of ionic species, which may be detrimental to circuit board reliability and assist with determining the source of these contaminants.

Surface Preparation

Having achieved the desired cleanliness levels, assemblies must be handled with gloves, to avoid further contamination.

Be aware that nearly all hand creams and cosmetics, deodorants etc contain silicone materials, which pose a severe risk of de-wetting and other process issues during the coating process, such as loss of adhesion.

Components on the assemblies that are not to be coated should now be masked.

Masking

A mask is a temporary, protective material (or pre-formed cover called a masking 'boot') that is placed over devices that are not to be coated scattered upon a board's surface, prior to, and during the application of a conformal coating.



When selecting a masking material, it pays to make sure that the masking material itself is easily removable after the conformal coating application. These materials can simply be peeled away by hand or by the use of tweezers. It is important, however, for this to be done in a single, non-flaking peel away movement in which the masking material does not break-up into small fragments.

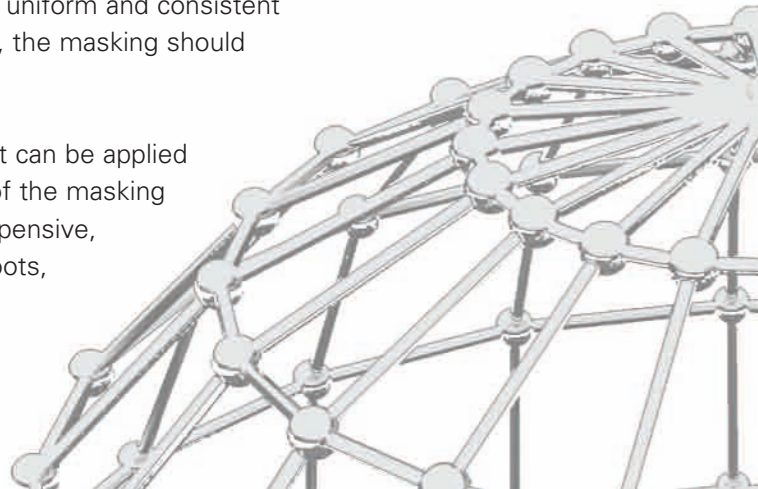
Tiny amounts of masking residue that do remain on a board's surface should ideally be completely inert and not introduce contamination of the sort that could potentially lead to long term product reliability issues as described previously.

It is preferable that masking be conducted after cleaning, as many masking materials are unable to withstand the cleaning process itself.

For spray applications, the masking of connectors and other lead components can be achieved by using sleeves or boots. For dipping, such components must be masked more thoroughly. Purpose made masking tape should be adopted in conjunction with a peelable liquid latex-type compound to seal the edges and edge-to-substrate contact. The tape's adhesive backing must be of a non-silicone type.

For other small components, the use of liquid latex masking can be adopted. A pneumatic dispenser is often useful, to help apply these materials in a uniform and consistent fashion. After the conformal coating has become tack free, the masking should be easy to pull off.

It is possible to buy a range of re-usable masking boots that can be applied and removed in seconds, keeping the time and labor cost of the masking process to a minimum. Tooling costs for boot molds are expensive, but many suppliers have an extensive selection of these boots, forming an economic ex-stock service facility.



Methods of Application

To be effective, a conformal coating should completely cover the assembly and provide good coverage of sharp edges (components and component leads) and other contours (solder joints for example).

It may even be essential to coat the edges of the board, as these will not even have any solder resist present. The effectiveness of the coating is to some degree influenced by the efficiency of the application method, which also governs the type of coating used (some suppliers offer dedicated versions of the same coating product to suit different application methods).

There are essentially four main ways of applying a conformal coating: dipping, selective robotic coating, spraying and brushing. However, brushing, requires extremely proficient and skilled operators in order to be suitable for production purposes.

Dipping

Dipping an assembly into a bath of coating material is the most efficient way to apply a conformal coating, but demands that a board is designed from the outset to be conformally coated in this manner (as explained in Section 1).

Dipping promotes full and simultaneous penetration under and around components on both sides of the assembly and can totally eliminate the need for (and added cost of) any form of masking. Although, whether having coating penetrating underneath devices such as BGAs may not be such a good idea, due to CTE mismatches, is a question that can only be answered based on the chemistry of the material and through extensive reliability testing.

A range of dedicated, automated machinery is available for this purpose, which at the top end typically achieve throughput rates of between 350 to 700 boards per hour. Assemblies should be dipped vertically (but some designs lend themselves to horizontal dipping, although typically the boards will be dried in a vertical fashion) to ensure coating uniformity.

The most important factor influencing the results of dip coating is the speed of the assembly's immersion

(insertion into bath) and withdrawal. Typical recommended immersion speeds are between 15 to 30 cm/minute to allow sufficient time for the coating to displace the air surrounding components and to avoid air bubble entrapment.

This is of particular importance when coating surface mount devices. The assembly should be left in the bath until all bubbling has stopped. The withdrawal speed must be slower than the cascade effect of the coating material being used (typically 2.5 to 15cm/minute), allowing a homogenous film to cover the entire assembly. However, the slower the withdrawal speed, the thinner the coating, although a single dip application is normally sufficient to achieve desired coating thickness.

For best results, coating bath temperature should be maintained between 20-30°C. When dipping, the RH level should not exceed 65% otherwise there is a greatly increased chance of pin holing, blooming and poor surface texture.

When dipping, the evaporation of solvents (if used) will increase the viscosity of the material so it must be monitored and thinners added as required in order to maintain the correct viscosity. It is always a good idea to keep the ratio of the area of the dip-tank to its volume as low as possible to minimise the evaporation of solvent (and subsequent viscosity increase) to a minimum.

Moisture cure, and UV cure materials are generally less well suited to dip-application processes, due to their continual exposure to moisture and light, and the difficulty of ensuring complete cure. Extremely elaborate, custom engineered equipment is required to make these processes work in production, without high levels of material wastage.

Finally, over time, accumulation of contamination from the circuit board and factory floor will be experienced in the coating material in a dip tank, resulting in less than optimal coating performance. Good housekeeping would require complete material exchange and thorough cleaning of the drained dip tank on at least an annual basis.



Selective Robotic Coating

The most popular contemporary method of conformal coating application is via selective robotic coating. This exploits high precision automated machinery to selectively apply a coating to assemblies, which are either loaded manually or fed into the machine via dedicated conveyors for in-line processing.

The benefits of selective robotic coating machines are that they provide consistent, automated application of material, a high throughput, material savings and can exploit closed fluid systems to help prevent material contamination.

In addition, if a PCB is designed to be coated via a selective robotic coating machine (components that are not to be coated are kept well away from those that are) the need for custom tooling and/or board masking is minimized.

Selective spraying does not, however, eliminate the need for masking but does help minimise it. (Note: vias on double sided boards, for instance, may lead to coating of underside components that need to be protected and therefore must be masked prior to spraying.)

Most selective robotic coating machines use a combination of dispense needle/nozzle to deposit a bead or film of coating in and around components and PCB features and/or an airless-dispensing technology or air-spray to 'fill-in' larger areas. These are mounted on a robot programmed to move and dispense material in designated locations on the assembly.

Coating deposition can be classified as either atomised (breaking the coating material into fine particles during application) or non-atomised (dispensing the coating in liquid form).

In needle dispensing (non-atomised), the coating material is dispensed as a bead. These are placed at different locations on the board, and through capillary action produce the desired coverage. However, this process is slow and its robustness can be questionable in certain applications. This is because most needle dispensers have a tendency to drip because their shut-off valves are positioned far from the tip. Since dripping is an uncontrollable event, there is a risk they could fall into a 'not-to-be-coated' area on the PCB (such as a connector) or on the system conveyor, leading to poor quality and board rejects.

Air-spray dispensing is an atomized process and as such suffers from an inherent tendency to overspray. During atomization, some droplets will drift. Most particles in the centre of a pattern will land in the desired area, but a certain percentage of particles land outside. The result is a non-uniform or ragged edge, which may not be acceptable in certain applications. If a sharp edge is required a secondary pass with a bead dispense may be necessary.

Non-atomized dispensing tends to produce very good edge definition, but can suffer from the volume of material applied, especially with 100% solids materials, and is much more suited to solvent-based formulations due to their inherently lower viscosities.

Spraying

Spraying is used to coat those assemblies not designed for dip coating. These typically have devices that must not be coated distributed randomly across the board. Spraying is therefore more time consuming and expensive and demand masking. Nonetheless, it is probably the most common application method in use today.

Compared to dip coating, it is relatively slow, requires complete masking of all keep-out areas, demands full fume extraction and can suffer from shadowing effects and lack of penetration under components

Spray coating can be subdivided into two alternative methods:

- 1 Hand Spraying
- 2 Aerosol Spraying

Hand Spraying

For aerosol or hand spraying techniques, the substrate should be turned through 360° (i.e. 4 x 90°) for each of four applications per coat to ensure total, uniform coverage.

Although a popular method of application, probably attributed to the historic need to coat with two-part material systems rather than the newer generation one-part systems, hand spraying has the following disadvantages:

- 1 A minimum of two - preferably three - applications are necessary to achieve correct coverage
- 2 100% repeatability of total coverage cannot be guaranteed
- 3 Shadow effect or lack of penetration under components where a meniscus has not formed may occur



- 4 Operators' health protection and fire safety precautions must be of a very high standard
- 5 Flameproof electrical components must be installed
- 6 Adequate ventilation to atmosphere must be provided
- 7 Vertical spraying onto a horizontal surface is difficult and not recommended
- 8 The process is very slow and labor intensive

Due to the thinning ratios necessitated by hand spraying, the material solids content is normally reduced to between 15 and 20%, and two or three separate coats should be applied to each side of the board to ensure adequate coating thickness has been achieved (25-75 μm).

Numerous companies manufacture batch spray booths, ergonomically designed to minimise operator fatigue, provide greater control of the spray gun position and direction (limiting overspray and material wastage), and have built-in fume extraction to minimize operator exposure to any solvent vapour. It is also strongly recommended that operators wear respiratory equipment.



Aerosol Spraying

Aerosols are the easiest way to spray-coat small volume prototypes and field repairs, but their suitability for production is limited as they have a much lower solids content (less than 15%) than hand or automated spray techniques and ventilation is even more important.

Due to their low solids content, to achieve an adequate coating, up to 3 coats will often have to be applied.

Brushing

Brushing can be used to coat small quantities of printed circuit assemblies, but it is neither a practical nor efficient method for mass production. Obtaining uniform coverage whilst controlling bubble formation, for example can be difficult.

It is important to note that the thicker the coating, the greater the likelihood of insulation failure due to gas bubbles forming from solvent entrapment. The dielectric properties of the PCB may also be impaired. Brushing can, however, be useful for field repair/rework and test or R & D evaluations.

Vapor/ Vacuum Deposition

Another application technique is vacuum deposition or Paraxylylene type coatings. While this method ensures an excellent, and completely uniform coating to the entire assembly, it has too many drawbacks to be a viable production method, namely:

- 1 Materials for vacuum deposition can only be used within a purpose-built equipment
- 2 The material itself is very expensive
- 3 Reworking is extremely difficult
- 4 The material is not flexible
- 5 As a batch process, process is both lengthy and expensive

Humidity

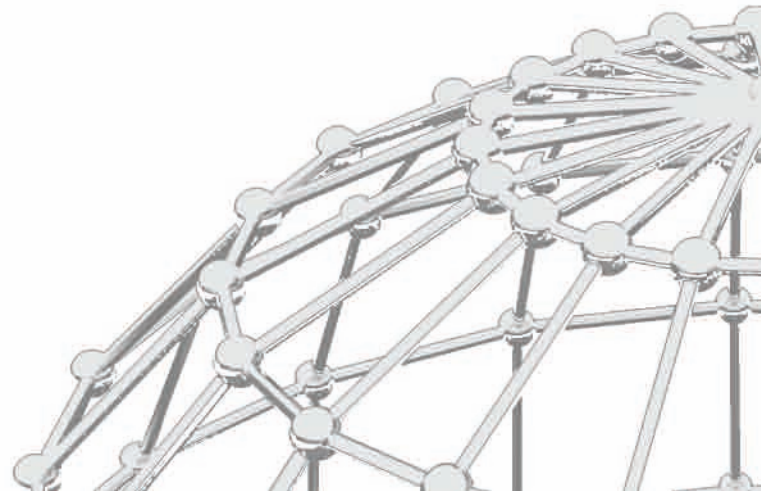
It is recommended that dehumidifiers be incorporated within the coating application area, as it is probable that RH levels above 60% or below 40% will cause coating defects such as 'cobwebbing', 'milking' or 'blooming'

Inspection

Any conformal coating production process should be visually inspected in production under a UV light. All approved coatings contain a UV trace that glows with a bright blue luminescence under UV light to make coated and uncoated areas easily detectable. With experience, operators can use the degree of luminescence as a measure of both presence and volume of coating at different locations across a board's surface.

The necessity for inspection becomes evident when one realizes that voids or bubbles can potentially provide a path for moisture to penetrate to the substrate. With automatic coating, a random or pre-selected interval test may be adequate, but 100% inspection is always recommended, and is mandatory in high reliability and safety critical applications. There is a range of dedicated products available for this purpose.

It is also important to inspect boards after rework to ensure any re-application of coating material doesn't end up on the inside or underside of devices that should not be coated e.g. Connectors.



Conclusion

As modern electronics assemblies continue to use ever greater packaging densities and reduced conductor widths and spacing, and are subjected to increasingly hostile operating conditions; the use of high performance conformal coating materials will become increasingly commonplace for virtually all manufacturers.

Choosing the right conformal coating and application process isn't easy. It therefore pays to work with a supplier that has the experience of solving hundreds of specific coating problems and can give advice on relevant reliability standards and specifications.

Time and effort invested into getting it right will be amply rewarded by the near elimination of end-product failures in the field. These can be the most expensive, and in safety critical applications, life-threatening, problems a company will ever experience. In short, if you need to apply conformal coating to your boards, you must get it right. When you do this, you protect both your customers and your profits.

Other reference documents, recommended to the reader:

IPC-JSTD-001
IPC-TM-650 - Test Methods Manual
IPC-A-610 - Inspection Criteria
IPC-CC-830 - Conformal Coatings

For further information on appropriate specifications and standards contact:

www.ipc.org

Glossary (Terms & Definitions)

Adhesion promotion

Either a chemical process of preparing a surface to enhance its ability for a coating to adhere to it (eg. Plasma) or an internal modification to the conformal coating material to help ensure it adheres to the intended, or difficult to adhere to substrate.

Adhesion failure

The rupture of an adhesive bond such that the separation appears to be at the adhesive-adherent interface.

AR/UR

Abbreviation standing for acrylic resin and urethane resin combination chemistries.

Bridging

Fillet or meniscus formation of coating around the leads of a component caused by capillary action.

Creep

Strain, deformation, or movement of coatings caused by time and/or temperature.

Cross-linking

The formation of chemical bonds between molecules in a thermosetting resin during a polymerization reaction.

CTE

Coefficient of Thermal Expansion - linear dimensional change with respect to an original dimension due to a change in temperature. Generally, the greater the value, the more mismatch there is between the coating and substrate during thermal excursions, which can result in stress-cracking.

Cure

A change in the physical properties of a polymer by a chemical reaction.

Degradation

Decrease in quality or integrity. Loss of desired physical, chemical or electrical properties.

Delamination

A separation between a conformal coating layer and the surface it is adhering to.

De-wetting

The propensity of the coating material to refuse to wet the surface evenly. This phenomenon is generally a sign of localized contamination, or that the surface energy of the substrate was too low to start with.

Dielectric constant

The ratio of the capacitance of a configuration of electrodes with a specific material as the dielectric between them to the capacitance of the same electrode configuration with a vacuum or air as the dielectric.

Dielectric strength

The maximum voltage that a dielectric can withstand under specified conditions without resulting in a voltage breakdown, usually expressed as volts per unit dimension.

SECTION 6

Dilution

Reduction in viscosity. Can be achieved by mixing a non-reacting, soluble agent (solvent) into the material.

Dissipation factor

A value that represents the tendency of insulating or dielectric materials to absorb some of the energy in an alternating-current signal.

Durometer

A measure of the degree of hardness or the resistance to be deformed or fractured.

Filler

A substance that is added to a material to modify its solidity, bulk, or other properties.

Fish eyes

A surface defect to the conformal coating that resembles the eyes of a fish, usually resulting from localized surface contamination.

Gel time

Time taken for a liquid polymer to begin to exhibit pseudo-elastic properties or to be immobilized.

Glass transition temperature T_g

The temperature at which an amorphous polymer, or the amorphous regions in a partially-crystalline polymer, changes from behaving more like a glass to more like a rubber.

Hardness

A property that indicates the ability of a material to resist penetration of a specific type of indenter when forced into the material under specified conditions. Indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material.

Insulation resistance

A measure of the capability of a material to electrically insulate adjacent conductors from each other. Moisture Insulation Resistance (MIR) is the same measure made under hot and humid conditions, usually 65°C/95%RH.

Masking

The process of applying a temporary film, tape boot or plug that prevents the area covered from being coated.

Monomer

A chemical compound that can undergo polymerization.

MSDS

(Material Safety Data Sheet) Provided by the manufacturer, contains relevant properties of the material with regards to safety concerns.

Multi-layering

The process of applying more than one layer of coating to make up the desired thickness.

Orange peeling

Surface defects in the conformal coating that resembles the surface or skin of an orange. Orange peeling is generally caused by a combination of excessive drying speed resulting in wetting issues.

Outgassing

The gaseous emission from a processed coating layer when it is exposed to heat or reduced air pressure, or both.

Permeability

The ability of molecules of one material to flow through the matrix of another material. The degree of permeability is dependant on the molecular structure of both materials.

Polymerization

The formation of a matrix of cross-linked long chain molecular structure from short chain monomer molecules.

Pot life

The length of time a material, substance, or product can be left in an open package or dispenser, while it meets all applicable specification requirements and remains suitable for its intended use.

Rework

The act of reprocessing non-complying articles, through the use of original or alternate equivalent processing, in a manner that assures compliance of the article with applicable drawings or specifications.

RTV

(Room Temperature Vulcanizing) The development of desired dry film properties at room temperature..

Shelf life

The length of time a material, substance, or product can be stored, under specific environmental conditions, while it meets all applicable specification requirements and remains suitable for its intended use.

Shrinkage

Reduction in volume as a wet, freshly applied layer dries/cures into a coating film with desired properties.

Solids content

The ratio of the resin or polymer material to the solvent carrier. The percentage of material converted to solid coating during curing.

Stripping

The process of eroding a material by chemical reaction. Stripping agents can be used to remove certain types of conformal coating for the purpose of rework or repair.

Surface tension

The natural, inward, molecular-attraction force that inhibits the spread of a liquid at its interface with a solid material.

Viscosity

The property of a polymer to frictionally resist internal flow in the liquid state that is directly proportional to the applied force. High viscosity materials generally resist flowing and levelling.

VOC

(Volatile organic compound) Regulated compounds containing at least one carbon atom and having a measurable vapor pressure.

Wetting

The formation of a relatively uniform, and adherent film of materials on a surface. Surface tension of the applied material must be lower than the surface energy of the substrate to enable this. Inability of a coating to wet a substrate is usually indicative of surface contamination or an inherently low surface energy substrate (eg Teflon).



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