Conformal Coatings For Electronic Assemblies

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A flat pack with all components assembled is only appropriate when it guarantees safe operation for a defined period of time. While a large number of flat packs are installed in end units unprotected and operate trouble-free for their entire service life, long-lasting functionality in certain applications can only be ensured if the assembled printed circuit board is provided with a protective coating or encapsulation.

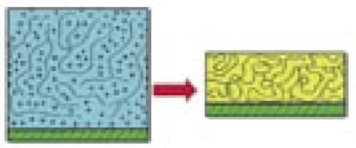

Figure 1 - Physical drying

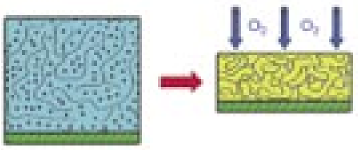

Figure 2 - Film formation during oxidative drying

Protective coatings are used in many applications in the electronics industry. One example is assemblies where long-lasting functionality is required in particular for those destined for aerospace, military, medical and especially automotive applications (for instance central locking, airbag electronics, etc).

In many cases, the worldwide distribution of an electronic component can only be accomplished by means of a protective coating or encapsulation. Depending on the lacquer system employed, these protective lacquers offer protection from attack by mechanical abrasion, vibration, impact, atmospheric humidity, sweat, various chemicals, and mould when used in tropical environments.

As far as miniaturisation of printed circuit boards (PCBs) is concerned, progress has been made possible also by the dielectric properties of protective lacquers, which permit a reduction in the minimum spacing of current-carrying conductors. In fact, as a rule, protective lacquers usually have tracking resistances with a CTI value greater than 600, significantly higher than the base material and the applied solder resists. In the case of loads that exceed this value, especially in aggressive industrial environments or in the case of exposure to solvents or other conditions to which a conventional 1-pack protective lacquer is no longer resistant, 2-pack conformal coatings, thick film lacquers or casting compounds/resins are used to protect the electronics.

How to select a suitable coating material

Table 1 shows the material properties that should be considered when selecting a suitable coating material, as a function of the application. The following aspects could or should also be of interest: easy processing; minimum embrittlement also at temperatures far below freezing point; self extinguishing properties according to UL 94 V-0; reliable visual cover in order to protect valuable know-how by means of casting compounds; high transparency and translucence when used in optoelectronics.

Types of protective lacquers

Generally, protective lacquers are subdivided according to their drying or cross-linking mechanism: physically drying lacquers; oxidatively drying lacquers; chemical curing lacquers; radiation-curing lacquers.

Physically drying lacquers

Physically drying protective lacquers contain highly molecular materials as binding agents in order to meet requirements regarding the flexibility and resistance of the coating. These protective lacquers dry through the evaporation of the solvents. Figure 1 illustrates the drying process.

These conformal/permanent coatings dry very quickly thanks to the careful selection of the solvents. A great advantage of many purely physically drying lacquer systems is that, for repair purposes, the cured lacquer film can not only be soldered-through at soldering iron temperature, but can also be removed with the product-specific thinner without the risk of incipient dissolution of components and marking inks.

After the repair work is completed and the surface cleaned, the lacquer coating can be reapplied. However, chemical resistance is inferior in comparison to other systems, as described in Table 2.

Physically drying, water-borne protective lacquers

Due to their considerably better resistance to chemicals than most conventional solvent-containing 1-pack lacquer systems, these types of lacquers are dealt with separately at this point. Figure 3 shows the different stages of the film formation of aqueous systems consisting of polymer dispersions.

There are 1-pack insulating and conformal coatings with special water-borne binding agents that are

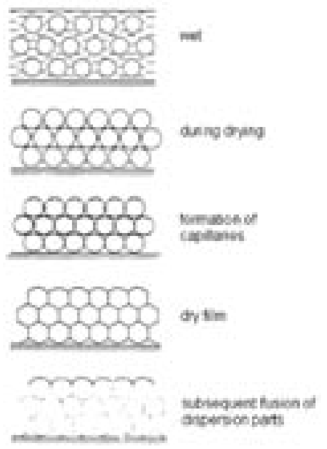

Figure 3 - Film formation from polymer dispersions

dispersed exclusively in water. These contain just a small portion of organic solvent (less than 10%) required for the film formation of the protective lacquer coat. Unlike conventional physically drying lacquers, the cured lacquer coat is not susceptible to the original solvent.

Among the advantages of typical water-borne protective lacquers are neutral smell during and after processing, minimum solvent emission, and extremely fast drying at room temperature. The demand for these lacquer systems is increasing substantially.

Oxidatively drying lacquer systems

These lacquer systems consist of weakly cross-linked binding agents dissolved in suitable solvents. Modified alkyd resins are often used as binding agents for these lacquers. With this type of resin, one has to differentiate between polyurethane (PUR) modified, epoxy (EP) modified, and acrylic modified versions.

All binding agents have the same drying sequence however: after application of the lacquer coat, the solvents evaporate first. The remaining film begins to gel under the influence of the atmospheric Oxygen. As the Oxygen supply continues, the state of the film passes from a gel to a solid, dust-dry condition and finally ends in the complete cross-linking and curing. Because of the involvement of atmospheric Oxygen, this method of lacquer curing is called oxidative curing or oxidative cross-linking (Figure 2).

It must be noted that this curing process takes several days and therefore some of the final lacquer properties, such as resistance and dielectric strength, cannot be measured for 96 hours or even 2 weeks.
When taking the different resin bases, protective lacquers can be assigned characteristic properties (see also Table 2). Polyurethane resins, for example, are generally much more elastic and resistant in thermal shock tests while epoxy resins are distinguished by their comparatively high thermal resistance and hardness, and acrylic resins by their excellent adhesion.

Chemically curing lacquer systems

All two-pack or multi-pack lacquers on polyurethane and epoxy resin basis are included in this group. These lacquer systems are usually distinguished by excellent resistance to many chemicals.

The biggest disadvantage of chemically curing multi-pack lacquer systems is the limited processing time: after termination of the pot life, the reaction of the components with each other has proceeded so far that the lacquer can no longer be applied because its viscosity is too high. For near continuous and economical coating with multi-pack lacquers, ink systems with very long pot lives should be used.

Easier to handle are the humidity-curing 1-pack protective lacquers based on polyurethane resin (PUR). They react with air humidity from the ambient atmosphere and form coatings with the resistance of a 2-pack system that offer optimum protection from climatic influences at high temperatures and high humidities. Their electrical properties also meet the toughest requirements but they have the drawback of considerably reduced storage stability, especially when containers are opened frequently.

Humidity-curing silicone lacquers represent a very interesting group of coating materials. They comprise condensation cross-linking silicone resins that chemically cross-link under the absorption of moisture from their surroundings and simultaneously split off, for example, an alcohol that diffuses from the film. Silicone

Table 1 – Material properties

Electrical properties	Thermal properties	Mechanical properties	Chemical and physical properties
Specific resistivity	Coefficient of expansion	Mechanical stability	Water absorption
Surface resistance	Thermal conductivity	Tensile strength	Humidity resistance
Tracking resistance	Dimensional stability	Compressive strength	Chemical resistance
Dielectric breakdown		Flexural strength	Tropical resistance
Loss factor		Impact strength	Electrolytical corrosion resistance
Dielectric constant		Hardness/elasticity	Solvent resistance
		Impact strength when notched	

Table 2 - Comparison of typical properties of 1-pack conformal/permanent coatings

	physical drying		oxidative curing			chemical curing	
	solvent containing, based on polyacrylic resin	water-borne, based on polyurethane resin	based on modified poly-urethane resin	based on modified epoxy resin	based on modified acrylic resin	humidity curing, based on polyurethane resin	humidity curing, based on poly-organo-siloxane
Drying speed	+++	++	+	+	+	++	+++
Through-drying speed	+++	+++	++	+	+	+++	+++
Adhesion	+	++	+	++	+++	+++	+
Permanent elasticity	++	+++	+++	+	+	+++	+++
Hardness +++ = hard + = soft	+++	++	++	+++	+++	++	+
Moisture resistance	+++	+++	++	++	++	+++	+++
Dewing resistance	+	++	+	+	+	+++	+++
Chemical resistance	+	+++	+++	+++	+++	+++	+++
Weather resistance	++	++	++	+	++	++	+++
Temperature resistance	+	++	++	+++	++	++	+++
Thermal shock resistance	++	+++	+++	+	+	+++	+++

lacquers with such a cross-linking mechanism can also be formulated without solvents and thus count as being particularly environmentally friendly owing to their minimal emission of volatile organic compounds (VOCs).

Likewise, the 1-pack addition cross-linking silicone lacquers belong to the chemically reactive protective lacquers that cure by means of heat. They can also be formulated without solvents and cure at temperatures of 100 to 120 °C. Addition cross-linking silicone lacquers are particularly suitable for encapsulating applications as their is no risk of reversion (reverse reaction) unlike with condensation cross-linking silicone resins. However, it must be considered that with addition cross-linking lacquer systems inhibitory effects may occur, e.g. caused by sulphur, polysulphides, polysulphones and other sulphur-containing materials as well as organo-tin compounds, amines, amides and urethanes.

The decisive advantage of silicone lacquers is their outstanding temperature stability in comparison with the other protective lacquers.

Properties of lacquer systems

Table 2 gives an overview of the various properties and applications of typical products of the lacquer systems mentioned above. In every case, when choosing a lacquer system, it is necessary to keep an eye on the field of use and the required properties of the protective lacquer.

Radiation-curing lacquer systems

These lacquers consist of radiation-curable monomers/polymers, for instance unsaturated polyester resins dissolved in styrene or acrylated monomers/polymers, and do not contain any solvents. The film formation is accomplished as a result of the monomers and polymers completely polymerising and curing under the influence of UV rays or high-energy electron beams. This reaction takes place at room temperature; the lacquer contains so-called radical components that break down under the influence of suitable radiation and trigger the polymerisation. One decisive disadvantage of these systems is the varying degree of polymerisation after the UV curing of an assembled PCB caused by the shadowing effect of the components. For this reason, it is frequently recommended that they are thermally post-treated, mostly at temperatures exceeding 100 °C to initiate the film formation also in shadow areas. For this reason, the use of such systems is greatly restricted. This drawback of pure UV systems can be avoided if the polymer molecule owns a second cross-linking property that is independent from UV curing. The Twin-Cure system, a typical thick film lacquer, offers such a solution.

Thick film lacquer systems

Before introducing the special properties of the Twin-Cure thick film lacquer and other thick film lacquers, there is a question to be answered: "Why use thick film lacquers at all?"

Table 3 - Comparison of typical properties of thick film lacquers

	Twin-Cure, copolymerisate of polyurethane and polyacrylate UV + PUR curing	Addition cross-linking polyorgano-siloxane thermal curing	Condensation cross-linking polyorgano-siloxane humidity curing at room temperature
Drying speed	+++	++	++
Through-drying speed	++	+++	++
Adhesion	+++	++	+
Permanent elasticity	+	+++	+++
Hardness +++ = hard + = soft	+++	+	+
Moisture resistance	++	+++	+++
Dewing resistance	+++	+++	+++
Chemical resistance	+++	+++	+++
Weather resistance	+++	+++	+++
Temperature resistance	+	+++	+++
Thermal shock resistance	+	+++	+++

The climatic conditions to which components are exposed are becoming increasingly agressive and contaminated. In some cases, the protection offered by the conformal/permanent coatings used is inadequate, especially when dewing of the assembly occurs. This inadequacy is less due to poor performance or quality of the polymers or binding agents than to the thickness of the layer presently applied.

The solution to the problem seems to be simple: apply a thicker layer of lacquer so that protection is improved. But this presumption leads to the contrary effects: all common solvent-based conformal/permanent coatings applied in thick layers are susceptible to insufficient drying and solvent retention, which result in an inadequate protection down the line.

In compliance with IPC-2221, layer thicknesses of only 30 - 130 µm for conformal/permanent coatings based on acrylic, epoxy and polyurethane resin and 50 - 150 µm for silicone resins are recommended.

A sensible solution for the application of higher layer thicknesses from a technical as well as ecological point of view is of course solvent-free coating materials. These products offer an optimal solution with regard to the VOC guideline combined with a better protection of components.

Solvent-free 1-pack thick film lacquers with excellent wetting properties fill the gap between casting compounds and conventional conformal/permanent coatings both in terms of costs as well as protection offered.

In Table 3, three systems with user friendly processing and curing properties are presented. The Twin-Cure system is based on the principle that two different, complementary chemical curing mechanisms take place during drying. In the first step the 1-pack system Twin-Cure is UV-cured and thus dried (and handled) within a short time. In the second step, chemical cross-linking takes place with the help of the air humidity, particu-

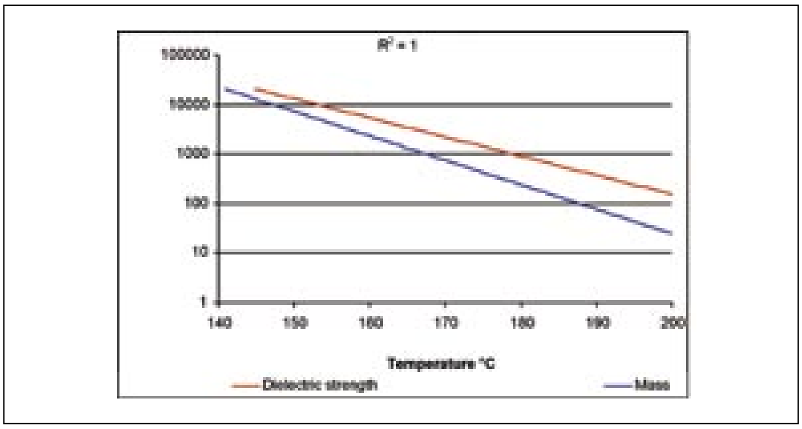

Figure 4 - Changes in the properties in relation to elapsed time

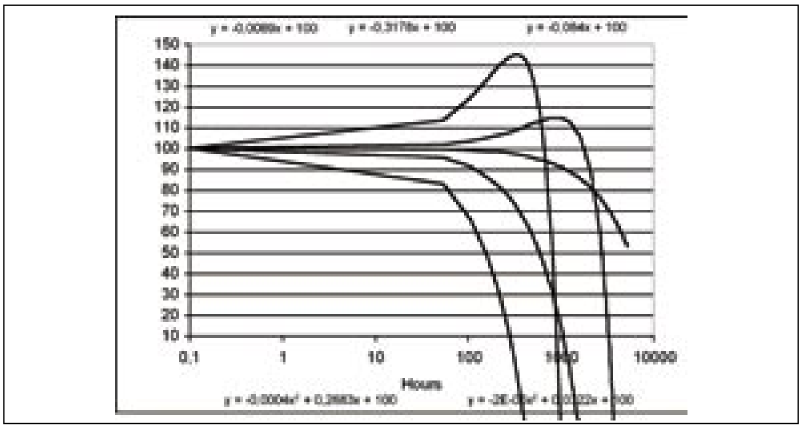

Figure 5 - Extrapolation of experimentally determined failure times for a failure period of 20,000 hours

larly in the shadow zones where no UV initiated cross-linking is possible. With this cross-linking mechanism, called polyurethane (PUR) curing, the moisture that diffuses into the polymer is "intercepted" and used for polymerisation, further curing the lacquer in the shadow zones. This double functionality warrants highest resistance owing to the fact that no uncross-linked binding agents remain in the film as a soft resin. Layer thicknesses are typically between 200 and 500 µm.

Further examples of thick film lacquer systems are solvent-free addition cross-linking (thermal curing) and condensation cross-linking (humidity curing) silicone thick film lacquers as already described in the section on chemically curing lacquer systems. The characteristic properties of typical representatives of these ink systems in comparison to the Twin-Cure thick film lacquer are illustrated in Table 3.

Long-term thermal behaviour

Thick film lacquers are often the solution to achieving a satisfactory protection against the increasingly aggressive operating conditions of electronic components. However, there is one aspect where higher layers are still of no help: the resistance at elevated operating temperatures.

In order to be able to evaluate the failure rate of electronic components within a reasonable space of time, it is necessary to perform accelerated ageing tests. If the ambient conditions are known (elevated temperatures, mechanical stress, chemical loads), the concentrated exposure to one of the stress factors can make sense for test purposes to shorten the time required to get meaningful results.

DIN EN 60216 attempts to simulate the changes in the characteristics of protective coating systems/casting compounds when stored at a certain temperature. The objective is to determine the so-called temperature index, describing the temperature at which one or several properties of a system fall below predefined threshold values, e.g. a mass loss of 25%, a drop in the electrical properties to 75%, etc.

The temperature index is indicated for 20,000 hours (833 days - long-term behaviour) and 5,000 hours (208 days - short-term behaviour). Since this is far too long, the storage temperatures are increased significantly, and the results are then extrapolated to 20,000 or 5,000 hours.

Three temperature ranges are selected that are partly well above the expected temperature index. The appropriate properties are then examined in cycles, e.g. 10 cycles of 7 days each. The measured values are depicted on a graph as changes in the properties as a function of time (Figure 4).

With the help of trend curves, the approximate mathematical functions can be determined. This allows the number of hours to be calculated at each test temperature where the properties fell below the threshold values. These are then illustrated in a second graph, time vs. temperature (Figure 5). By linking the individual "hours failed", it is possible to extrapolate the mathematical failure temperature for 20,000 hours.

Only silicone lacquers are suitable for permanent exposure to a temperature range in excess of 150°C. Typical temperature indices for the other systems previously described lie between 125°C and 150°C for the 20,000 hour test, with protective lacquers based on epoxy resin exhibiting the highest temperature resistance, followed by polyurethane resins. Protective lacquers based on (poly)acrylic resin exhibit the lowest temperature resistance.

Nevertheless these results show that protective lacquer systems all exhibit a high continuous temperature resistance.