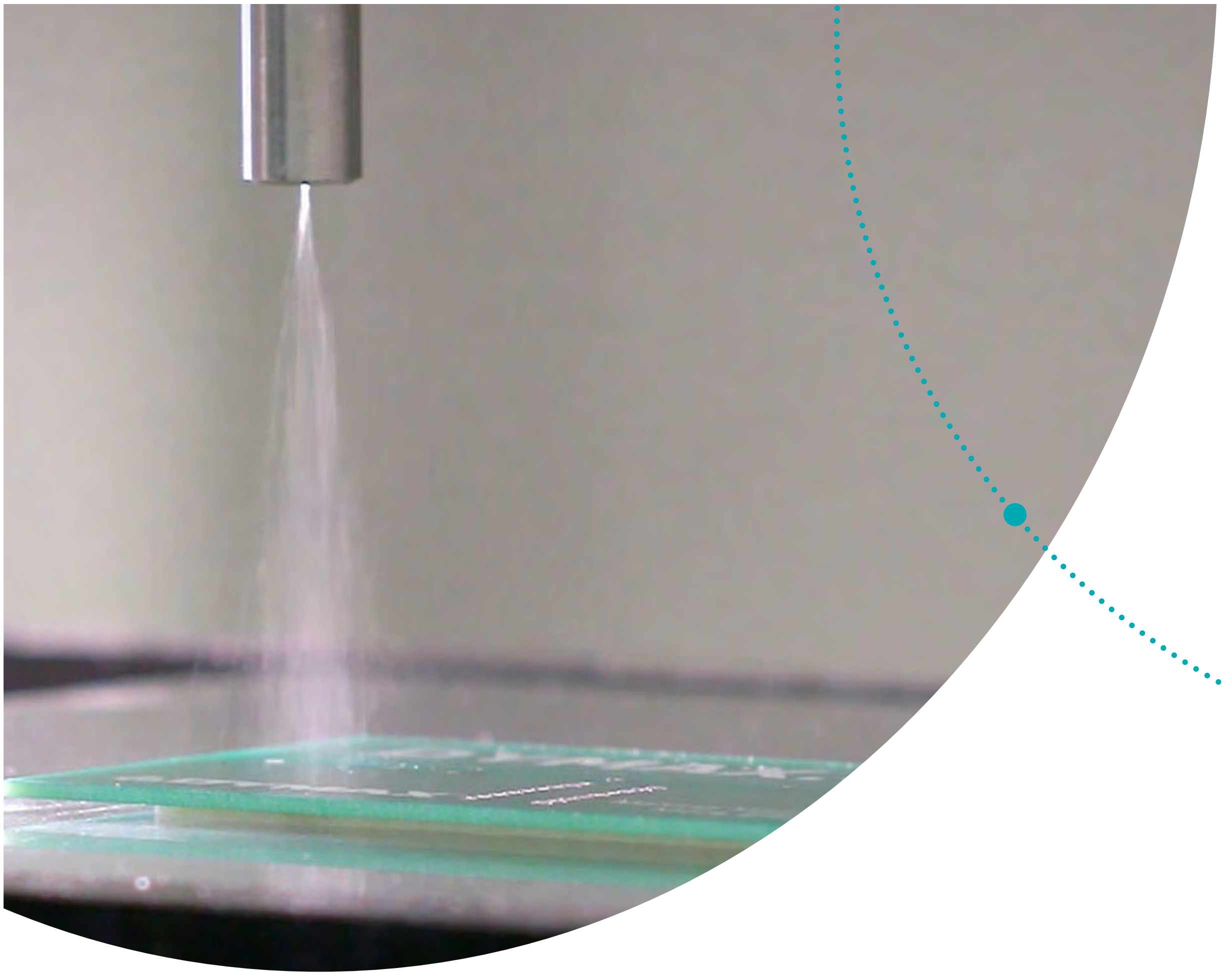

UV Broad-Spectrum & LED-Curable, 100% Solids, Very Low Viscosity Conformal Coating

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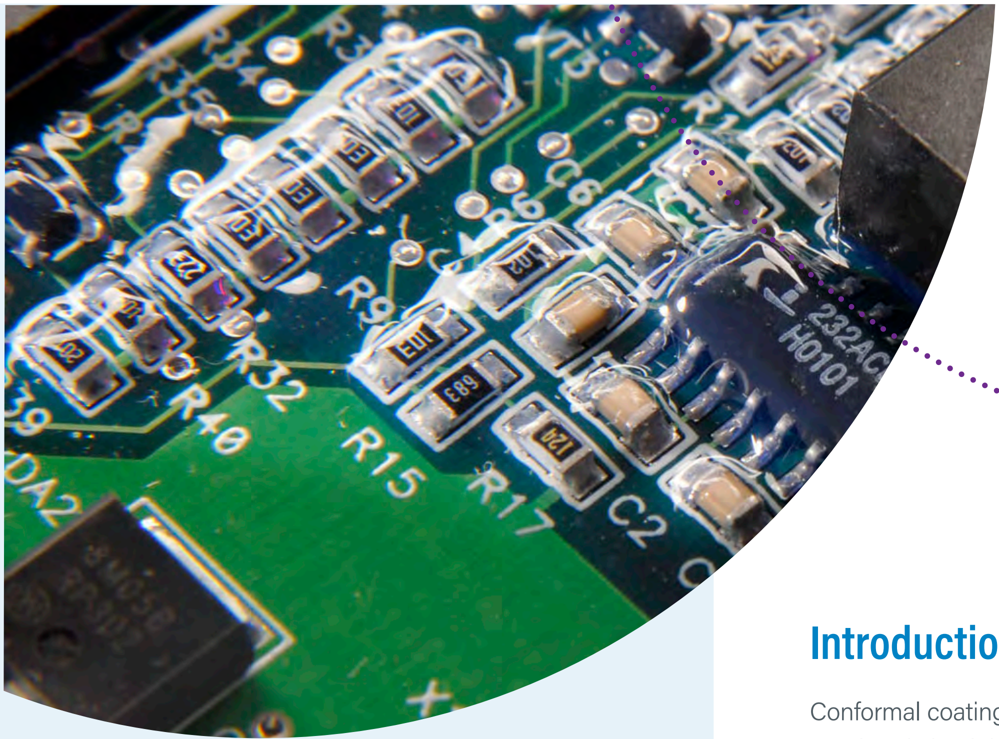

Abstract

Very low viscosity formulations are often required for very thin conformal coating applications. Solvents are used to reduce viscosity of the formulations and accommodate dispensing needs. Solvent-free coatings are attractive due to their environmental friendliness and ability to allow faster processing for coating lines. Until recently, efforts in developing very low viscosity, 100% solids coatings were not successful due to performance requirements such as chemical, heat, and humidity resistance. We have developed a technology that results in 20-30 cP viscosity 100% solids UV-curable coatings. We will discuss the performance in reliability tests such as heat and humidity resistance (500 hours at 85°C / 85% relative humidity) and corrosion resistance (flowers of sulfur resistance and salt spray resistance). Any change in physical appearance, formation of oxidation spots, and insulation performance were checked after reliability tests. The new coatings can also be cured with long wavelength LED light and secondary heat.

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Introduction

Conformal coatings are thin coatings that are applied to printed circuit boards (PCBs) to protect against environmental conditions and electrically insulate the components. A typical thickness of the conformal coatings (CCs) are in between 25µm to 150µ. Due to CCs insulation properties, space needed between conductors on a PCB might be reduced. Also, there are no additional enclosures needed. Therefore, CCs enable design of smaller electrical assemblies. CCs also increase mechanical support for components and improve the fatigue life of solder joints[1,2]

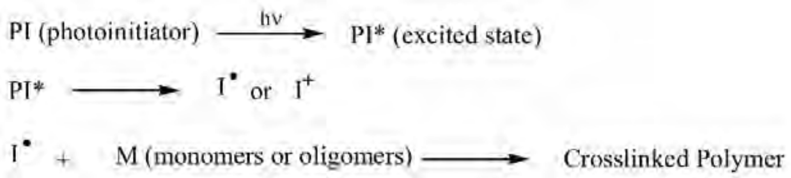
Different industries have different requirements from CCs. In the automotive industry, CCs are expected to protect PCBs from gasoline, salt, sulfur, and brake fluid. Conformal coatings are required for long-term reliability of automotive electronic parts. The CC market is gradually growing as the usage of electronic components in both under the hood and passenger compartments are increasing. 3 Usage of conformal coatings is also increasing in consumer electronics as the devices become smaller and as the consumers demand more water-proof devices.

Various types of conformal coatings are available including silicones, acrylics, polyurethanes, epoxies, poly-para-xylylenes, and light curable. Acrylics and polyurethanes often require use of solvents. Acrylics are easy to rework but have poor chemical resistance. Polyurethanes provide good chemical and moisture resistance but are often hard to rework and create problems during application in humid environments. Silicone CCs are often used for very high and low temperature environments. They require thermal curing and have short pot lives. Epoxy based CCs are two-part systems with limited pot life. Similar to polyurethanes they provide good moisture and chemical resistance. Poly-para-xylylenes are applied at very high temperature with a vacuum coating process. Therefore, they cost significantly more compared to other technologies.[4]

Light-curable coatings' usage and application areas have steadily increased over the last three decades because of the regulations against solvent emissions, low energy usage, and their ability to allow instant cure and therefore improve productivity. In addition to saving time, light-cure technology also saves space on the manufacturing floor and increases efficiency overall. Light curing is ideal technology for heat-sensitive substrates. There is no need for mixing, as with two-part epoxies; no need for explosion-proofing, as with solvent-based coatings; and typically fewer steps and fewer operators are required for each processing step. In addition, no extra shipping charges are required as may be the case with hazardous materials.[5,6]

Two types of polymerization mechanisms are used in light curing: free radical and cationic polymerizations. Photopolymerization mechanism steps are depicted in Figure 1. Photoinitiators convert light energy to chemical energy by absorbing the photons and generating radicals or cations. Rate of initiation and penetration of the incident light depend on the type, absorption wavelength, and efficiency of the photoinitiator. During this process the excited state may be quenched by atmospheric oxygen or water depending on the type of polymerization mechanism. Polymerization rate can be adjusted by changing the light intensity. The polymerization rate is directly related to amount of initiator radicals or cations. This does not mean that polymerization rate increases with the photoinitiator concentration. Since photoinitiators absorb the light, they also block the penetration of the light to lower parts. Therefore, in order to optimize the cure rate photoinitiator concentration needs to be optimized.[7]

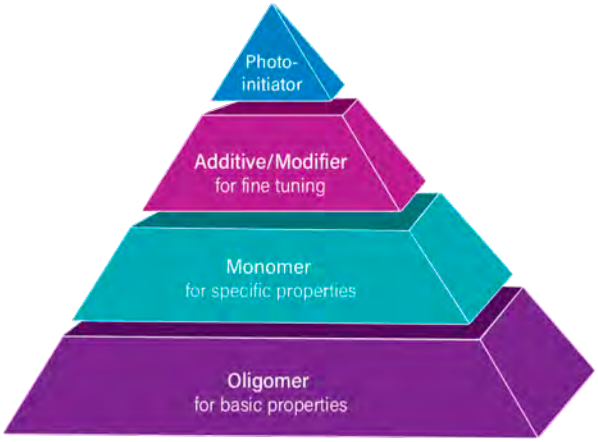
Figure 1. Polymerization Steps in Light Curing



The overwhelming majority of the current light-curable CCs are cured with UV light generated by mercury-based bulbs. Over the past decade, light emitting diode (LED) based curing has become an increasingly popular method of curing due to improved efficiency, reduced operating costs, and less substrate heating.[8]

The most frequently used resins used in light-curable coatings are (meth)acrylated monomers and oligomers. Figure 2 represents a typical light-curable formulation's ingredients and their functions. In early light-curing systems, unsaturated polyesters dissolved in styrene were used. The volatility of styrene and relatively slow curing rates has restricted the wide usage of these resins. Current light-curable coatings are mostly based on acrylated oligomers due to their relatively higher reactivity and lower volatility. The main types of acrylate oligomers are: epoxy acrylates, polyether acrylates, urethane acrylates, polyester acrylates, and silicone acrylates. Acrylate monomers are usually introduced as a reactive diluent to reduce viscosity and increase crosslink density. Low modulus, higher elasticity films are generally obtained with aliphatic monomers whereas aromatic ones results in hard and glassy networks.

Figure 2. Ingredients of a Typical Light-Curable Product

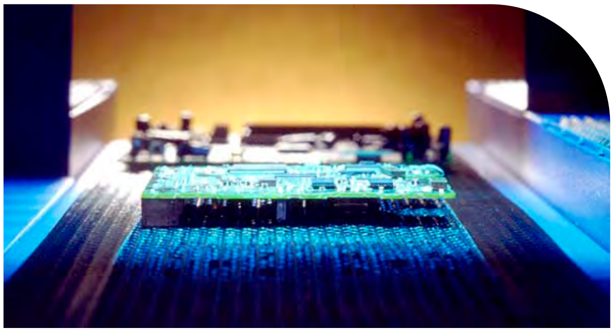


Very thin conformal coating applications require 20-30 cP viscosity formulations. Solvents or reactive diluents are used to reduce viscosity of the formulations and accommodate dispensing needs. Solvent-free coatings are attractive due to their environmental friendliness and ability to allow faster processing for coating lines. Efforts in developing very low viscosity, 100% solids, light-curable coatings by using more reactive diluents were not successful due to performance requirements such as chemical, heat, and humidity resistance. The company recently developed a technology that enables solvent-free, 100% solids, light and heat dual-curable formulations that provides good insulation properties and also good humidity, thermal shock, and corrosion resistance.

Experimental

Conformal coatings were applied by precision spraying to obtain 2 mil (0.054 mm) dry film thickness on to custom designed boards. Light-curable formulations were cured with either LED light (405 nm wavelength with 300 mW/cm^2 light intensity on the substrate surface) or mercury-based UV light (with 2,500 mW/cm^2 light intensity). Figure 3 shows curing of the conformal coatings in a UV conveyor. Adhesion of the coatings was tested by using the crosshatch adhesion test method in accordance with ASTM B2197. 85°C/85% relative humidity damp heat test was used to evaluate heat and humidity resistance of the coatings. Coatings were left in 85°C/85% relative humidity conditions for 580 hours and then inspected against any delamination, corrosion or voltage transient failure. Thermal shock resistance was tested by exposing coated test boards to -55°C and +125°C with 30 minutes dwell time at each temperature and 15 second transition time between lowest and highest temperatures. After 300 thermal cycles, coatings were evaluated against any delamination, corrosion or voltage transient failure.

Figure 3. Light Curing of Coatings in a UV Conveyor



Salt spray corrosion resistance was evaluated using ASTM B117. The appearance, spreading of corrosion, and voltage transient of the boards after exposing them to 5% salt solution at 35°C, for 280 hours were evaluated.

Flowers of sulfur corrosion resistance was also tested using ASTM B809 where coated PCBs were suspended over powdered sulfur in a vented container (Figure 4) at around 90% relative humidity and 50oC temperature for 265 hours. Forced air was used to circulate sulfur vapor. Elemental sulfur vapor attacks copper on the PCB. Formation of brown or black tarnish spots indicate oxidation and corrosion of copper.

Figure 4. Representation of a Flowers of Sulfur Test Chamber

IPC-TM-650.2.3.3a standard was used to test chemical resistance of conformal coatings. Test specimens with 75 mm x 25 mm x 0.12 mm thickness were prepared and immersed into separate 10% Hydrochloric acid (HCl), 10% Sodium Hydroxide (NaOH), 50% Ethanol (EtOH), and 3% Hydroperoxide (HPO) solutions for 7 days. Weight and dimensional change of the test specimens were reported.

Wetting of substrate with different CCs were evaluated based on ASTM D724 utilizing a Goniometer. Contact angle formed between a drop of CC and each substrate were reported. All the coated boards were subjected to a modified voltage transient test before and after reliability tests according to UL-746E. 10 pulses of 6kV voltage were given over 2 minutes. There should be no dielectric breakdown or damage to the coating during the voltage transient test.

Results and Discussion

Very low viscosity conformal coating formulations are needed to obtain very thin coatings. Two different types of commercial conformal coatings (PUA1 and PU2) were tested against a recently developed very low viscosity conformal coating (VLV1). PUA1 is a commercial polyurethane acrylate based, light and heat curable conformal coating. It was diluted to 80% solids with butyl acetate to reduce its viscosity to 20 cP. PU2 is a commercial 50% solids, solvent-borne, two-part polyurethane conformal coating. VLV1 is a 100% solids, both light and heat dual-curable, conformal coating with viscosity around 20 cP. PUA1 was cured with a mercury-based UV lamp and VLV1 was cured with a 405 nm LED light.

Solvents are often used not only to reduce viscosity but also improve wetting of the substrate. Coatings that do not efficiently wet a substrate often show adhesion failure such as delamination or appearance failure such as the orange peel effect. Therefore, the first step to check feasibility of very low viscosity, 100% solids coating was to compare its wetting property. Wetting of a substrate by a liquid is often quantified by measuring contact angle of the liquid droplet on the substrate. Lower contact angle indicates better wetting of the substrate.

Table 1 lists contact angles of PU2, PUA1, and VLV1 on different solder masks and chip components. Contact angles were measured on 5 different solder masks and 5 different chips. On all solder masks and chips VLV1 had resulted in a lower contact angle than PU2. This was very encouraging since this wetting was achieved without any solvent, and PU2 contains about 50% solvent. VLV1 had also better wetting on most chip components and similar wetting on solder masks compared to PUA1.

VLV1 and PU2 had shown excellent adhesion to the boards according to crosshatch adhesion testing. PUA1 had about 5% failure in crosshatch test.

Pictures of boards before and after 265 hours flowers of sulfur (FoS) testing are given in Table 2. The FoS test is correlated with porosity of the coating and its ability to avoid sulfur vapor to reach the copper finish on the boards. All coatings had shown significant protection against sulfur vapor compared to uncoated boards. VLV1 had the least amount of change after the FoS test. No oxidation spots were observed. Boards with PU2 had visible oxidation spots but as with the other coated boards it also passed the voltage transient test.

Table 1. Contact Angle of CCs on Different Solder Masks and Chips

Substrate	PU2	PUA1	VLV1
SM #1	26	9	21
SM #2	27	13	7
SM #3	23	20	10
SM #4	25	14	17
SM #5	19	14	12
Average on SMs	**24**	**14**	**13**
Chip #1	49	16	24
Chip #2	48	48	31
Chip #3	50	31	6
Chip #4	37	24	9
Chip #5	50	23	11
Average on Chips	**47**	**28**	**16**

Table 2. Flowers of Sulfur Corrosion Resistance

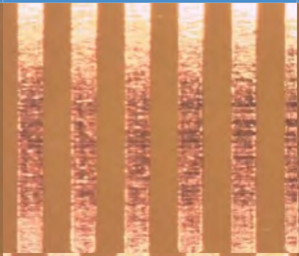
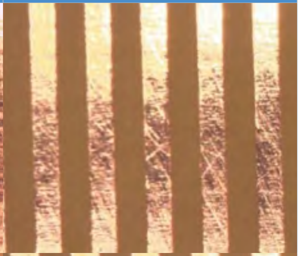
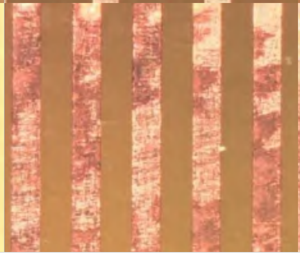
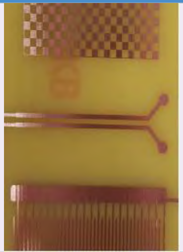
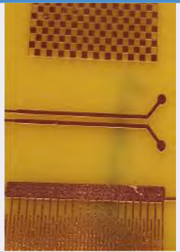
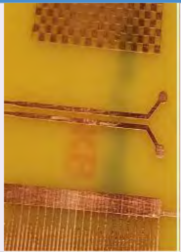
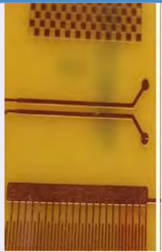
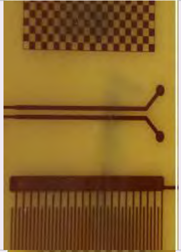
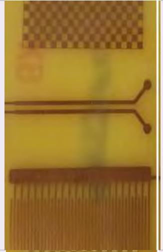
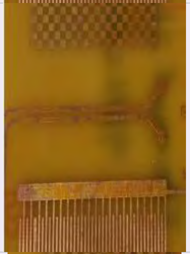
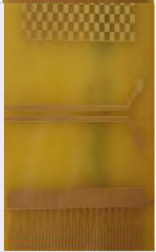
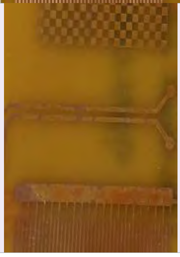
	No Coating	PU2	PUA1	VLV1
Initial				
After FoS Test				

Table 3. Damp Heat, Thermal Shock, Salt Spray Corrosion Test

	No Coating	PU2	PUA1	VLV1
Initial				
After 85°C /85% R.H.				
After Thermal Shock	Not Tested			
After Salt Spray				

Appearance of test boards before and after 85oC / 85% R.H. damp heat, thermal shock, and salt spray corrosion resistance accelerated reliability tests are shown in Table 3. After each reliability test, boards were investigated for oxidation spots or delamination of the coatings. Voltage transient testing was also performed to check if the boards were still functioning. In all cases, severe oxidation was seen on non-coated boards. Thermal shock testing was not done on uncoated boards since thermal shock is often done to test if the coating will delaminate or not during rapid temperature changes. After damp heat testing, copper on the board coated with PU2 had turned dark brown but still was able to pass the voltage transient test. PUA1 and VLV1 had shown minimal change in the color of copper on the board.

VLV1 performed the best in thermal shock testing, with copper on the board coated with VLV1 having the least darkening. The color of the copper on the boards coated with PUA1 and PU2 were uneven which are often indications of formation of oxidation spots. VLV1 performed very well in salt spray testing along with PU2. Whereas, the board with PUA1 had uneven colored copper after the salt spray test. All the coated boards passed the voltage transient test after the reliability tests.

Chemical resistance results according to IPC-TM-650.2.2.3a are listed in Table 4. VLV1 films disintegrated in NaOH solution indicating very poor resistance. VLV1 is absorbing more HCL, NaOH, and HPO solutions than the other two coatings according to the weight change results in Table 4. This might be the reason for the dimensional increase. It is important to note that the IPC-TM-650.2.3.3a is done on free standing films and not coatings. It might be worthwhile to do a chemical resistance test on coated boards to see if the absorbed chemicals goes through the coating and does damage to the boards or not.

Conclusions

Very low viscosity conformal coatings are needed for very thin, precisely applied coatings. Existing conformal coatings exclusively use solvents to obtain low viscosity while meeting the performance requirements. We have demonstrated that it is possible to obtain about 20 cP viscosity in a light- and heat-curable, 100% solids coating. The new coating outperformed or matched properties of commercially used polyurethane acrylate based light- and heat-curable conformal coating and a two-part solvent-borne polyurethane conformal coating. Furthermore, the new very low viscosity conformal coating can also be cured with LED light, which will help improve efficiency of the coating process. Chemical resistance of the new coating needs to be further investigated with various different chemicals.

Table 4. Chemical Resistance Testing (IPC-TM-650.2.2.3a)

	PU2		PUA1		VLV1	
	Dimension Change	Weight Change	Dimension Change	Weight Change	Dimension Change	Weight Change
HCl	1.52%	1%	-0.34%	1%	1.89%	6%
NaOH	0.42%	1%	0.68%	1%	Disintegrated	Disintegrated
EtOH	2.29%	3%	-0.10%	2%	0.07%	6%
HPO	-1.01%	2%	1.14%	2%	3.20%	5%

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