High Performance Light and Moisture Dual Curable Encapsulant

Dr. Aysegul Kascatan Nebioglu, Chris Morrissey
Dymax Corporation, Torrington, CT

Abstract
Light-curable materials can provide significant benefits over conventional technologies, including very fast tack free curing, lower operating costs driven by lower labor needs, space savings, lower energy demand, and higher throughput. Encapsulants are often required to protect PCB components against moisture, chemicals, and rapid and extreme temperature changes while providing mechanical support and electrical insulation. We have developed a light and moisture dual curable 100% solids encapsulant that exhibits an excellent balance of properties. While the key advantage to light-curable encapsulant is the ability to use a non-solvated "green" (100% solids) material, secondary moisture curing allows curing of the material in shadow areas – areas not available to UV light. And, the secondary moisture curing material can be shipped and stored at ambient conditions, does not requiring cold shipping/storage. We will discuss the performance of this material against other light-curable materials as well as other types of encapsulants in reliability tests such as heat and humidity resistance (85 ºC / 85 % RH), thermal shock resistance (-55ºC to +125ºC) and corrosion resistance against salt spray and chemicals.

Introduction

Components on circuit boards or electronic modules are often required to be covered with polymeric encapsulants to protect them against environmental conditions (heat, humidity, chemicals etc.) and mechanically induced damages. [1,2] Several types of encapsulants are used to protect circuit boards such as conformal coatings, glob tops, underfills and molding compounds.[3] This study is focused on liquid glop top encapsulants that are placed over the PCB components and wire bonds as a protective layer.

It is crucial for encapsulants to induce minimal stress on chips, wires, and other components for the reliability of the electronic assemblies. Liquid encapsulants are typically based on epoxies, silicones or light-curable materials. Epoxy formulations are rigid and utilize high loads of mineral fillers to lower bulk coefficient of thermal expansion (CTE) to match CTE of the substrates. However, since the organic epoxy has a higher CTE than the mineral fillers, it can move filler particles against the wires and create an abrasive effect on the wires, reducing the reliability of the parts. Silicones and light-curable encapsulants are typically more flexible and have low modulus than epoxies and therefore create less stress on the components, wire bonds and solder connections.[4] Light-curable encapsulants do not require mixing of two parts as with the silicones and they can be cured tack-free within seconds which enables faster processing, greater output, and lower processing costs.[5]

Typical ingredients of light-curable formulations and their functions are represented in Figure 1. Photoinitiators convert light energy to chemical energy by absorbing the photons and generating polymerization initiating molecules. Rate of initiation and penetration of the incident light depend on the type, quantity, absorption wavelength, and efficiency of the photoinitiator. The performance properties of the light-curing materials depend mostly on the oligomers and monomers used in the formulations. Monomers are usually introduced as a reactive diluent to adjust viscosity and crosslink density. Low modulus, higher elasticity materials can be obtained by choosing the appropriate combination of monomers and oligomers.[6]

A limitation of light-curing is the curing of shadow areas where light cannot penetrate. Light-curable encapsulants are typically thixotropic to form a dome shape protection over the components and wire bonds and minimize the amount of material going under the shadow areas. A two step, two material approach is also used to address shadow areas. This is where a high viscosity and thixotropic dam is applied to the surrounding area and then a low viscosity encapsulant fills the cavity. Often referred to as dam and fill. Alternatively, light/heat dual curing and light/ moisture dual curing encapsulants have been developed to eliminate the need for a two-step process and allow for curing in shadow areas.[7] Light and moisture dual curing enable cure of liquid encapsulant in shadow areas over time with moisture, which eliminates the need for a secondary heat curing or a two-step dam/cavity fill process.
One of the challenges of the high-performance encapsulants has been their relative instability and hence their required cold or frozen storage and shipping. For light and moisture, curable encapsulants, this is due to the inherent moisture adsorbed in the fillers used to provide thixotropy to the encapsulant formulations. We developed a technology that enables formulating a high-performance light and moisture curable encapsulant with room temperature storage and shipping stability.

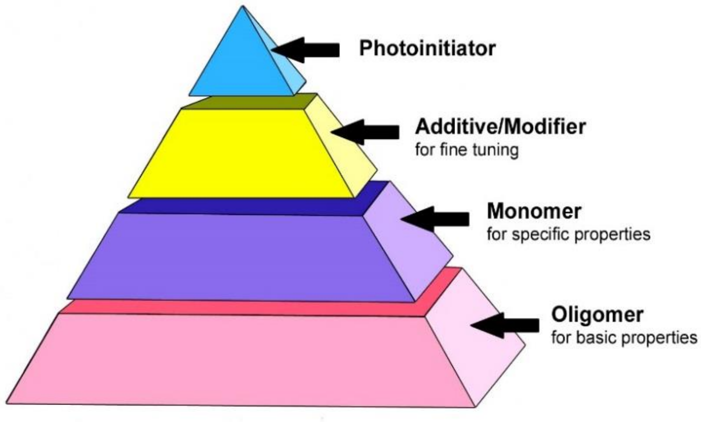


Figure 1. Ingredients of a Typical Light-Curable Product

Experimental

Heat-humidity and thermal shock resistance of the encapsulants were tested on solder masked populated test boards (Figure 2). Different locations on each board were encapsulated using a digital fluid dispenser to obtain a dome shape coverage at 2-2.5 mm thickness. Samples were cured with mercury-based UV light (2,500 mW/cm^2 light intensity at 1.5 m/min conveyor belt speed). After the UV curing, secondary moisture curing encapsulants were kept at 25ºC, 50% relative humidity(RH) for 7 days to complete moisture cure. Alternatively, moisture cure can be accelerated at 40ºC, 50% RH. Secondary heat cure encapsulant was exposed to 120ºC for 30 minutes for heat curing. A humidity chamber was set to 85ºC, 85% RH for 500 hours to evaluate heat and humidity resistance. Thermal shock resistance was tested by exposing test boards to -55ºC and +125ºC with 30 minutes dwell time at each temperature and 15 second transition time between lowest and highest temperatures. The boards were tested under these conditions for 500 cycles. Any cracks or delamination of encapsulants on and around the components were inspected with magnification.

Custom designed multi-pattern FR4 boards as shown in Figure 2 were used to test salt spray corrosion resistance by utilizing ASTM B117. Encapsulants were applied at 2 mm thickness to the entire board with a drawdown bar and UV cured. Encapsulated boards were exposed to 5% sodium chloride solution at 35ºC for 500 hours in a salt spray chamber. Upon completion of the test, samples were maintained at 25 ºC, 50% RH for a 24-hour stabilization period and visually inspected for the appearance, crack or delamination and corrosion on the copper by a microscope camera. Encapsulated boards were subjected to a modified voltage transient test before and after reliability tests according to UL-746E.[8] Ten pulses of 6kV voltage were applied to the boards over 2 minutes. There should be no disruptive charge formation evidenced by spark-over or flash during the voltage transient test.

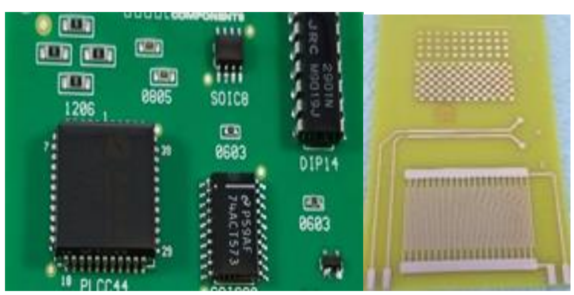


Figure 2. Populated test board and multi-pattern FR4 test coupon

Viscosities of the encapsulants were measured per ASTM D2556. Cured mechanical properties were measured per ASTM D638 and ASTM D2240. Glass transition temperature (Tg) values were determined utilizing dynamic mechanical analyzer (DMA). Coefficient of thermal expansion (CTE) values were determined by using a thermomechanical analyzer (TMA).

Results and Discussion

We have developed a light and moisture dual curable (LM) 100% solids encapsulant (LME1) that exhibits an excellent balance of properties. For manufacturers involved with chip-on-board, chip-on-flex, chip-on-glass, and wire bonding assembly, this material features excellent flexibility and increased durability on PCBs. Two different commercially available light and moisture dual curing encapsulants (LME2 and LME3) and a light and heat dual curing encapsulant (LHE) were tested as benchmarks against LME1. Description of the encapsulants tested and their nominal viscosities are given in Table 1.

Table 1. Description of the encapsulants tested

	Chemical Classification	Curing Mechanism	Viscosity (cP)
LME1	Urethane Acrylate	Light + Moisture	14,000
LME2	Urethane Acrylate	Light + Moisture	17,000
LME3	Urethane Acrylate	Light + Moisture	18,000
LHE	Urethane Acrylate	Light + Heat	50,000

Physical properties of the encapsulants are given in Table 2. LME1 has the lowest modulus and highest elongation among the LM encapsulants. Therefore, it is expected that it will cause the least stress on the components and wire bonds although its CTE values are slightly higher than LME2 and LME3. LHE3 was chosen as an out-of-kind benchmark, since it has a higher elongation and similar modulus when compared to LME1.

Table 2. Physical properties of the encapsulants tested

	Tensile Strength (psi)	Elongation (%)	Young's Modulus (psi)	Shore Hardness (D)	Tg (ºC)	CTE, <Tg (µm/m/ ºC)
LME1	620	46	1600	33	53	90
LME2	430	29	2300	30	83	74
LME3	1640	15	34300	60	86	79
LHE	1100	127	1900	40	63	128

Secondary moisture curing of the light-cured encapsulants enable the curing of material in shadow areas on PCBs over time, with moisture. Rate of moisture cure is important for faster processing of the parts. Table 3 lists tack free time of the encapsulants cured just with moisture under dark conditions. Both LME1 and LME3 were cured within 3 days, whereas it took more than a week for LM3 to become tack free with only moisture curing.

Table 3. Tack-free time of the encapsulants cured only with moisture

	LME1	LME2	LME3
Tack Free Time at 25ºC, 50% RH	3 days	3 days	> 7 days

Representative pictures of the boards with encapsulants after they are tested for 85ºC, 85% RH damp heat reliability are shown in Table 4. Several boards were used for each encapsulant and different locations on each printed circuit board were encapsulated. LME1 showed no delamination or cracking whereas all other encapsulants had delamination and/or cracking issues. Among the light and moisture curing encapsulants, materials with lower modulus and higher elongation performed better potentially since they have the least amount of internal stress. LME3 performed the worst, likely due to its significantly higher modulus value which is an indicative of internal stress build-up. Furthermore, LME2 and LHE showed significant yellowing, which is indicative of oxidation of the encapsulants. After the test LME3 was hazy, which might be due entrapment of the absorbed water during the test.

Table 4. Damp Heat Reliability Test

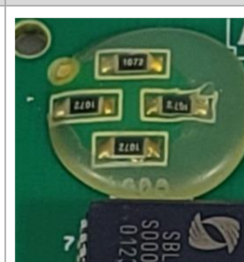
	LME1	**LME2**	**LME3**	**LHE**
After 500 h				

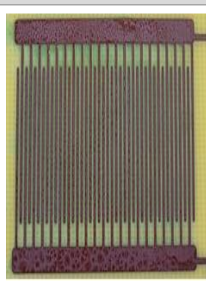
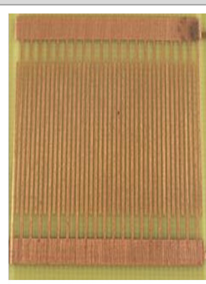
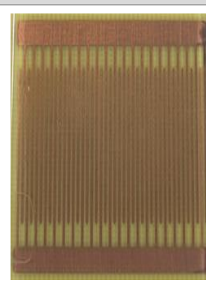
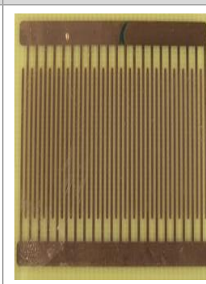
Table 5 shows the representative pictures of the boards with encapsulants after they are tested for 500 cycles of thermal shock. LME1 performed the best without any failures. LHE performed the second-best only with discoloration (yellowing) and without any cracks. LME3 performed the worst in thermal shock test with many severe cracks formed. This is most likely due to the material getting brittle at low temperatures, due to its limited flexibility (low elongation value). LME2 had also shown cracks, but not in as many locations as LME3. All the encapsulants had yellowing issues except LME1. Yellowing is often caused by oxidation and hence formation of colored chromophores.

Table 5. Thermal shock test

	LME1	LME2	LME3	LHE
After 500 cycles				

Magnified pictures of custom designed bare FR4 board and coated with encapsulants after they are tested for salt spray corrosion resistance are given in Table 6. The salt spray corrosion resistance test is correlated with permeability of the coating against salty water and not allowing it to reach the copper finish on the boards. As expected, copper on the board without encapsulant had severe corrosion. LME1 did not show any sign of severe corrosion, whereas copper coated with LME3 and LHE showed severe corrosion. Furthermore, LME3 lost its transparency. LME2 performed better compared to LME3 and LHE, but not as good as LME1. High elongation and low modulus materials are normally expected to perform worst in salt spray corrosion resistance testing due to their lower crosslink density. We did not see this correlation among the LM encapsulants which might be due to repellency of the encapsulants against salty water.

Table 6. Salt spray corrosion resistance test

	No Encapsulant	LME1	LME2	LME3	LHE
After 500 h					

Encapsulants coated on bare FR4 boards were dipped into several automotive fluids (ethanol, transmission fluid, antifreeze, motor oil and windshield cleaner) for 8 days to test chemical resistance. None of the encapsulants showed any sign of delamination or cracking after the chemical resistance test. Absorption of the chemicals by the encapsulants was also tested to understand permeability and affinity of the materials against the chemicals. In all the chemicals, LHE had the highest absorption values whereas LME3 showed the least chemical absorption values in three of the chemicals (ethanol, antifreeze and windshield cleaner). LME1 had the third highest absorption values in most of the chemicals.

Table 7. % Absorption of chemicals

	Ethanol	Transmission Fluid	Antifreeze	Motor Oil	Windshield Cleaner
LME1	19.97	0.14	1.61	0.74	6.59
LME2	17.77	0.15	1.41	0.73	4.04
LME3	12.10	0.14	1.22	0.76	2.66
LHE	31.23	0.17	2.55	2.08	7.56

Conclusions

Encapsulants are used to protect PCB components against mechanically induced damages and environmental effects such as heat, humidity and chemicals. The new light and moisture curing encapsulant (LME1), provided an excellent balance of properties when compared with other commercially available encapsulants. LME1 cures tack-free in seconds with UV light which allows faster processing of the parts. Additionally, it cures tack-free in shadow areas relatively fast and it does not require cold or frozen storage and shipping. This material does not require heating to cure which makes it ideal choice for heat sensitive substrates. LME1 demonstrated excellent performance when tested against high temperature and humidity, thermal shock and salt spray corrosion.

Acknowledgement
The authors would like to thank Boun Phengkaen (at Dymax) for the application and testing of the materials.

References:

1) Le, B. Q.; Maurer, R. H.; Nhan, E.; Lew, A. Design, Fabrication, and Qualification of Chip-On-Board Technology for Space Electronics. The International Journal of Microcircuits and Electronic Packaging, 1999, 22(2), 104-114.
2) Wunderle, B.; Becker, K. F.; Sinning, R.; Wittler, O.; Schacht, R.; Walter, H.; Schneider-Ramelow, M.; Halser, K.; Simper, N.; Michel, B.; Reichl, H. Thermomechanical Reliability During Technology Development of Power Chip-on-Board Assemblies with Encapsulation. Microsystem Technologies, 2009, 15(9), 1467–1478.
3) Benson, R.C.; Farrar, D.; Miragliotta, J.A. Polymer Adhesives and Encapsulants for Microelectronic Applications. Johns Hopkins APL Technical Digest, 2008, 28(1), 58-71.
4) Company Literature, “Choosing an Encapsulant to Minimize Stress”.
5) Wicks, Z.W.; Jones, F.N.; Pappas, S. P. Organic Coatings Science and Technology, Third Edition; John Wiley and Sons: New York, 2007, 591-593.
6) Company Literature, “Why Choose UV?”.
7) Company Literature, “Chip Encapsulants for Superior Protection on Flexible and Rigid Platforms” .
8) UL 746E, Standard for Safety Polymeric Material- Industrial Laminates, Filament Wound Tubing, Vulcanized Fiber, and Materials Used in Printed- Wiring Boards.