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Silicones for Circuit Board Conformal Coating

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Silicones for Circuit Board Conformal Coating

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Despite the higher gas permeability of silicone relative to other polymers, it was found that formulation design approaches and improvements in adhesion can allow silicone to mitigate gas permeability concerns, and help deliver corrosion resistance performance that meets emerging expectations for conformal coating materials in electronic applications. The following is a translation (with revisions) from the original Japanese language article published in the Japan Energy & Technology Intelligence journal, Vol. 64, No. 12, November 2016.

Introduction

Recent trends in the electronics industry, that call for higher functionality and miniaturization, are resulting in increasingly greater demand for improved reliability of printed circuit boards (PCBs). Various conformal coating materials are used to provide moisture resistance and insulation performance, and are typically organic polymers containing solvents that form a coating layer as the solvent evaporates. While the use of solvents allows for easy achievement of lower viscosity, there may be concerns associated with various regulations applicable to the solvent, environmental impact, and its potential effect on operator health.

Compared to organic polymers, silicone conformal coating materials have insulation, heat resistance, and cold temperature resistance advantages, and due to their softer properties, excel in their ability to absorb stress. Silicone is also more conducive to formulation designs that do not include solvents. It is for these reasons that low viscosity, solvent-less, silicone conformal coating materials are increasingly being sought.

Conformal Coating Material Requirements

Performance requirements for conformal coatings include:

- **Durability:** The ability to provide long-term dielectric property stability (maintain PCB insulation) under high temperature and high humidity environments.
- **Adhesion:** Good adhesion to PCB and component surfaces, and prevention of moisture ingress
- **Corrosion Prevention:** Protection again corrosion of devices, bonding wires, etc.
- **Flexibility:** Elasticity of the coating layer to absorb stress associated with expansion and contraction of components during temperature cycles.
- **Chemical Resistance:** Resistance to solvents and oil
- **Fast Cure:** Fast cure under temperatures that do not damage PCBs or components
- **Processability:** Ease of application and curing using readily available equipment
- **Toxicity:** Minimize harmful effects on operators and the environment. (Formulations without solvents are preferred)
- **Optical Clarity:** Transparency or translucence to enable visual observation of PCB components.

Organic conformal coating materials such as acrylics, polyurethane and epoxy are known to have inherent disadvantages associated with temperature resistance, cure shrinkage and toxicity. Silicone conformal coating materials consist of silicone resin that typically is solvent borne, or silicone rubber that is formulated without solvents and cures by either heat (addition) cure or room temperature (moisture) cure.

Based on the performance requirements of conformal coating materials, as long as cure time can be shortened, room temperature cure silicone rubber materials are considered good candidates due to their ease of use and ability to eliminate curing equipment from manufacturing processes.

Over the years, Momentive Performance Materials has developed a line-up of silicone coating materials that exhibit the inherent characteristic of silicone for temperature resistance in low viscosity, solvent-less room temperature (moisture) cure formulations. The typical properties of these conventional coating materials are depicted in Table 1. Based on end-use application requirements, products are available in an array of moderate to low viscosities and used widely in the electronics industry.

Typical Properties		Conventional Momentive Coating Grade Names						
		TSE399 Encapsulant	TSE3995 Encapsulant	TSE3991 Encapsulant	TSE3996 Encapsulant	TN3705 Encapsulant	ECC3010 Encapsulant	ECC3050S Encapsulant
Appearance		translucent	translucent	translucent	translucent	translucent	transparent~t ranslucent	transparent~t ranslucent
Viscosity (23°C)	Pa.S	2.5	2.5	1.5	1.5	1.5	0.11	0.55
Tack Free Time*1	Min	10	10	10	10	7	3**	5**
Corrosiveness*2		none	none	none	none	none	none	none
Density (23°C)	g/cm³	1.04	1.04	1.03	1.03	1.01	0.99	0.98
Hardness	Type A	28	25	19	23	13	35	22
Volume Resistivity	MΩ.m	2.0×10^7	2.0×10^7	2.0×10^7	2.0×10^7	2.0×10^7	1.0×10^7	1.0×10^7
Dielectric Strength	KV/mm	20	23	18	23	26	20	20
Dielectric Constant (60 Hz)		2.9	2.9	2.9	2.9	2.7	2.8	2.6
Dissipation Factor (60 Hz)		0.005	0.005	0.005	0.005	0.00	0.001	0.001
UL Flammability Class		HB	HB	HB	HB	HB	V-0 (746E)	V-0 (746E)
RTI Rating	°C	105	105	105	105	105	105	130

*1 23C, 50%RH *2MIL -A-46146B **100µm Typical properties are average data and are not to be used as or to develop specifications.

Table 1: Typical Properties of Coating Materials

Corrosion Prevention

As described in section 1, corrosion prevention is a critical performance requirement for conformal coating materials. A variety of materials including ITO, silver, and chromium are currently used in applications such as electrodes for flat panel displays, where moisture protection of these materials is required. Protecting against electrode corrosion and migration under impressed voltage and high temperature / high humidity environments is essential for these applications.

Furthermore, in applications such as automotive electronics, air conditioners and power tools, the PCB can be exposed to outdoor conditions where protection against dust, temperature changes and corrosive gases becomes increasingly important.

As depicted in Table 2, silicones inherently have a higher level of gas permeability when compared to organic polymers, and this difference is often associated with a higher level of water vapor and corrosive gas permeability of silicones. In addition, silicone resin exhibits approximately half the gas permeability of a silicone rubber but still has higher gas permeability than organic polymers in the order of 1~2 units.

Table 2: Oxygen Permeability of Various Materials and Permeability of Silicone (dimethyl silicone) to Various Gases

Oxygen Permeability of Various Materials	
Material Type	Permeability
Dimethyl Silicone	60
Natural Rubber	2.4
Low Density Polyethylene	0.8
High Density Polyethylene	0.1
Butyl Rubber	0.14
High Density Polystyrene	0.12
Nylon 6	0.004

$1x10^{-9}$ (cc·cm/sec·cm²·cmHg)

Silicone Permeability to Various Gases	
Gas	Permeability
H_2	65
N_2	28
O_2	60
H_2O	3600
NH_3	590
CO	34
CO2	325
H_2S	1000
CS_2	9000
NO	60
NO_2	1500

$1x10^{-9}$ (cc·cm/sec·cm²·cmHg)

Polymer Permeability (1 mm)	
Polymer Type	Permeability
Polyolefin	2
Polyurethane	25
Acrylic	16
Silicone (resin)	47
Silicone (rubber)	100

g/m²·25h (JIS Z 0208)

When electrodes containing silver are exposed to environments containing sulfur or hydrogen sulfide, sulfuration and conduction failure may occur. This is often cited as a problem in applications such as air conditioning outside units and power tools.

Corrosion Resistance Improved Products:
ECC3011 and ECC3051S Conformal Coatings

As described, silicone exhibits higher gas permeability than organic polymers and is inherently less able to block sulfur vapor compared to other polymers. However, it is possible to mitigate corrosion on substrates such as silver, even in sulfur vapor rich environments, through improved adhesion. The approach to improving adhesion and mitigating corrosion concerns involves silicone polymer selection, formulation adjustments for adhesion improvement, and consideration of various additives such as catalysts.

Momentive's ECC3011 and ECC3051S conformal coatings are room temperature (moisture) cure silicone rubber conformal coating products that offer corrosion resistance, and employ the product design approaches described above. Typical properties of ECC3011 and ECC3051S conformal coatings are provided in Table 3.

Table 3: Typical Properties of Corrosion Resistant ECC3011 and ECC3051S Conformal Coatings

Typical Properties		Corrosion Resistant Coating Grade Names	
		ECC3011 Conformal Coating	ECC3051S Conformal Coating
Appearance		Transparent ~ Translucent	Transparent ~ Translucent
Viscosity (23°C)	Pa.S	0.11	0.55
Tack Free Time *1	Min	3**	5**
Cure Time (23°C, 50% RH)	Min	10**	30**
Cure Time (60°C, 15% RH)		2**	2**
Density (23°C)	g/cm^3	0.99	0.98
Hardness	Type A	35	22
Volume Resistivity	MΩ.m	1.0 x 10^7	1.0 x 10^7
Dielectric Strength	KV/mm	20	20
Dielectric Constant (60Hz)		2.8	2.6
Dissipation Factor (6-Hz)		0.001	0.001

1* 23C, 50%RH   ** 100µm

Typical Properties are average data and are not to be used as or to develop specifications.

Sulfur Resistance

Sulfur resistance of ECC3011 and ECC3051S conformal coatings was tested according to the method described in Diagram 1. As reference, uncoated specimens and specimens coated with silicone without the corrosion countermeasure were included. The results are provided in Diagram 2.

Diagram 1: Sulfur Resistance Test

- Place a silver sheet (90µm) on glass-epoxy board (2 x 25 x 80mm)
- Apply conformal coating (100µm thickness)
- Place sulfur powder and the specimen inside a 100c glass jar
- Store at 70°C and observe the surface condition of the silver

Diagram 2: Sulfur Resistance Test

Before Test	Uncoated 1 day	Silicone (resin) 2 days	ECC (untreated) 7 days	ECC3011 7 days	ECC3051S 7 days

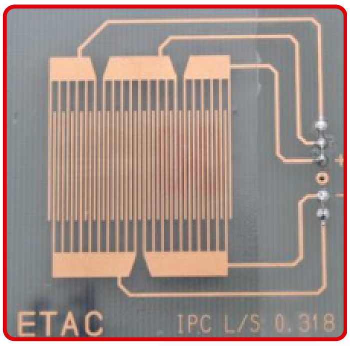
Note: Test results. Actual results may vary.

The uncoated specimen turned black in 1 day, while the results for ECC3011 and ECC3051S conformal coatings after 7 days confirmed a sulfur corrosion benefit from the improvement countermeasures. Silicone resin resulted in brownish discoloration, and upon completion of the test, the sliver sheet and its contact interface with glass epoxy was observed. Some delamination from the glass epoxy board was observed with the silicone resin specimen, while ECC3011 and ECC3051S conformal coatings exhibited no delamination. Good adhesion to the silver surface and no sulfur corrosion was observed for ECC3011 and ECC3051S conformal coatings.

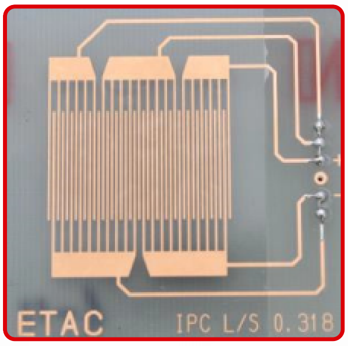
Corrosive Gas Resistance

Many actual-use environments require protection against corrosive gases (NOx, SOx H2S, etc). To verify performance against corrosive gases, a mixed gas corrosion test was performed using comb shaped electrodes according to the conditions described in Diagram 3.

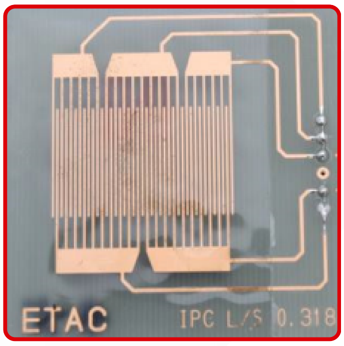
Diagram 3: Mixed Gas Corrosion Test (IEC60068-2 Method 4)



ECC3011 (no corrosion)



ECC3051S (no corrosion)



Resin Type (localized corrosion)

Note: Test results. Actual results may vary.

Despite its lower gas permeability, the silicone resin type coating material resulted in some localized corrosion, while ECC3011 and ECC3051S conformal coatings exhibited no corrosion. These results confirm that the formulation approach used in ECC3011 and ECC3051S conformal coatings can have a positive benefit in preventing corrosion associated with mixed gas exposure.

Gas	Concentration (ppm)
H2S	10 ± 5
NO2	200 ± 20
Cl2	10 ± 5
CO2	200 ± 20

25°C, 75% RH, 21 days

Salt Spray Resistance

Resistance to salt mist is a common concern with electronic components and appliances. A salt spray corrosion test was performed using comb shaped electrodes according to the conditions described in Diagram 4.

Diagram 4: Salt Spray Test (IEC60068-2-52, Severity 5)

- **Salt Spray Cycle:**

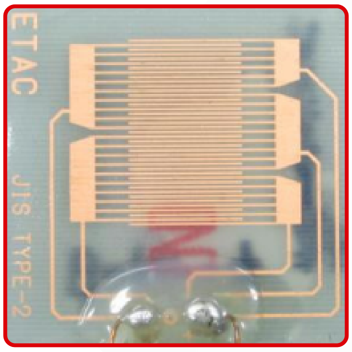
[(Salt Spray at 35 °C x 2 hours) + (40C, 95% RH x 22 hours)] x 4 cycles (96 hours total)

- **Conditioning Cycle:**

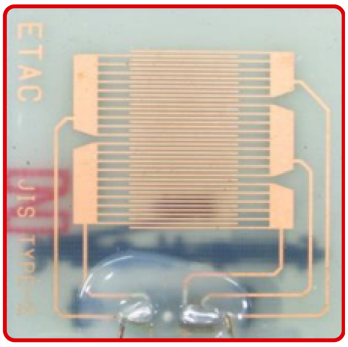
After each Salt Spray Cycle, dwell at 23 °C, 50% RH x 72 hours (168 hours total)

- **Cycle Repetition:**

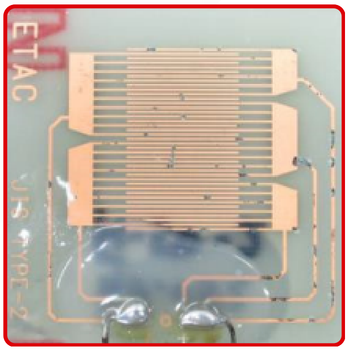
Repeat above process 4 times (672 hours, 28 days)



ECC3011 (no corrosion)



ECC3051S (no corrosion)



Resin Type (localized corrosion)

Note: Test results. Actual results may vary.

Despite its lower gas permeability, testing of the silicone resin type coating material resulted in black colored corrosion, while ECC3011 and ECC3051S conformal coatings resulted in no corrosion. These results confirm that the formulation approach used in ECC3011 and ECC3051S conformal coatings can have a positive benefit in preventing corrosion associated with salt spray exposure.

Conclusion

Conformal coating materials are used throughout the electronics industry. As the industry progresses and requirements continue to evolve, it can be expected that the inherent benefits of silicone conformal coating will increasingly be required to satisfy industry needs, and that through continued incremental efforts such as those described in this study, silicone can continue to expand into applications where organic conformal coating materials are presently used.

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Product Safety, Handling and Storage

Customers should review the latest Safety Data Sheet (SDS) and label for product safety information, safe handling instructions, personal protective equipment if necessary, emergency service contact information, and any special storage conditions required for safety. Momentive Performance Materials (MPM) maintains an around-the-clock emergency service for its products. SDS are available at www.momentive.com or, upon request, from any MPM representative. For product storage and handling procedures to maintain the product quality within our stated specifications, please review Certificates of Analysis, which are available in the Order Center. Use of other materials in conjunction with MPM products (for example, primers) may require additional precautions. Please review and follow the safety information provided by the manufacturer of such other materials.

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