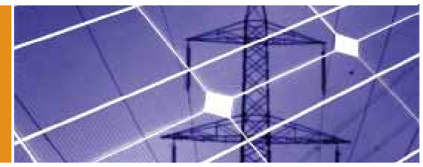
Marketing Bulletin

SilTRUST* E110 Transparent Encapsulant for Photovoltaic Modules

ENGINEERED MATERIALS - ECO ENERGY





Excellent Optical Properties

SilTRUST* encapsulant for photovoltaic cells has optical properties favorable for a higher light-to-electricity conversion yield. It also presents excellent mechanical properties that have been shown to withstand extreme exposure conditions during the photovoltaic panel life cycle.

Key Features and Typical Benefits

- Significant increase in the efficiency and durability of photovoltaic modules compared to traditional modules
- Potentially longer life span of PV projects, which may offer longer-term return on investment
- Extended durability in terms of reduced cell breakage, corrosion protection, damp heat resistance, mitigation of potential induced degradation and thermal cycling robustness

Potential Applications

- Encapsulation of crystalline silicon photovoltaic cells in solar modules

Typical Physical Properties

Uncured Properties

		SilTRUST E110 A encapsulant	SilTRUST E110 B encapsulant
Appearance		Translucent or White	Translucent
Density	g/cm^3	1.01	1.01
Viscosity(1)	Pa•s	34	28
Mix Ratio by Weight		1:1	
Viscosity after Mixing(1)	Pa•s	32	
Pot Life	hr	>12	

(1) Shear rate 10/s

Cured Properties

Mechanical

		SilTRUST E110 encapsulant
Cured Properties after 10 min at 80 °C.		Mix ratio A:B = 1:1 by weight
Appearance		Translucent rubber
Density	g/cm^3	1.036
Hardness	Shore A	20
Tensile Strength	N/mm^2	2.0
Elongation	%	400
Optical Transmission(2)	%	98.8
Refractive Index(2)		1.446

(2) AM 1.5 G, obtained on 0.5 mm sheet

Electrical

Volume Resistivity	Ω•m	$3.6 \cdot 10^{12}$
Dielectric Strength(3)	kV/mm	37

(3) Obtained on 0.4 mm sheet

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

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Performance Test Data

Photovoltaic cell encapsulation imposes many requirements on the materials being used. Physical-chemical properties of silicones make them excellent candidates to consider for this application, as evidenced by typical silicone performance test data.

- Silicones by themselves do not absorb UV-light, which thus becomes available for conversion to electricity when reaching the surface of a solar cell. The overall transmission of wavelengths present in the AM 1.5 daylight spectrum is typically higher than for today's incumbent material EVA, which needs to be protected from the harmful UV-rays that will damage this organic material.
- An encapsulant needs to electrically insulate current carrying components like ribbons, bus bars and the cells themselves from each other. Silicones can have a higher dielectric strength than EVA. In combination with an almost equally high volume resistivity, this insulating property results in excellent electrical performance.
- SilTRUST encapsulant material has a low modulus compared to EVA. Therefore, in combination with appropriate tensile strength and elongation values, SilTRUST encapsulant surrounds the fragile solar cells with a very flexible, stress dissipating matrix that adheres well, yet does not pass on much mechanical stress resulting from exterior forces to the cell. This can provide an advantage in module handling and transportation, as well as in modules carrying a mechanical load.
- Physical cell protection is also provided by the cushioning effect of SilTRUST silicone's softness, which is temperature independent, as opposed to that of EVA. Moreover, SilTRUST silicone can do an excellent job in keeping water away from corrosion sensitive parts due its much lower water equilibrium content.

Crystalline PV Cell Encapsulation

Application Function: PV Cell Encapsulation	Material Requirement	SilTRUST Encapsulant[(a)]	EVA[(a)]
Optical coupling of light from glass to cell surface	High light transmission [%][(b)] Matching refractive index	**0.988** 1.446	0.980 1.461
Electrical insulation of cells, ribbons, bus bars	High dielectric strength [kV/mm] High volume resistivity [µm]	**37[(d)]** $3.6\text{-}10^{12}$	25-35[(c)] $10^{13}\text{-}10^{15}$
Mechanical support of cells; Physical separation of components	Cohesive adhesion failure Low modulus [N/mm^2] Adequate tensile strength [N/mm^2] High elongation at break [%]	**Cohesive** **0.4** 1.9 414	Adhesive 2.2 19 566
Physical protection of cells and components	Low hardness [Shore A] Low moisture content [%]	**20** **0.03**	64 0.3
Thermal conduction	High thermal conductivity [W/mK]	0.2	0.2

(a) Standard conditions: RT, 50%RH
(b) Fraunhofer data, AM 1.5 weighted
(c) Thickness range 0.5-0.25 mm
(d) Thickness 0.4 mm

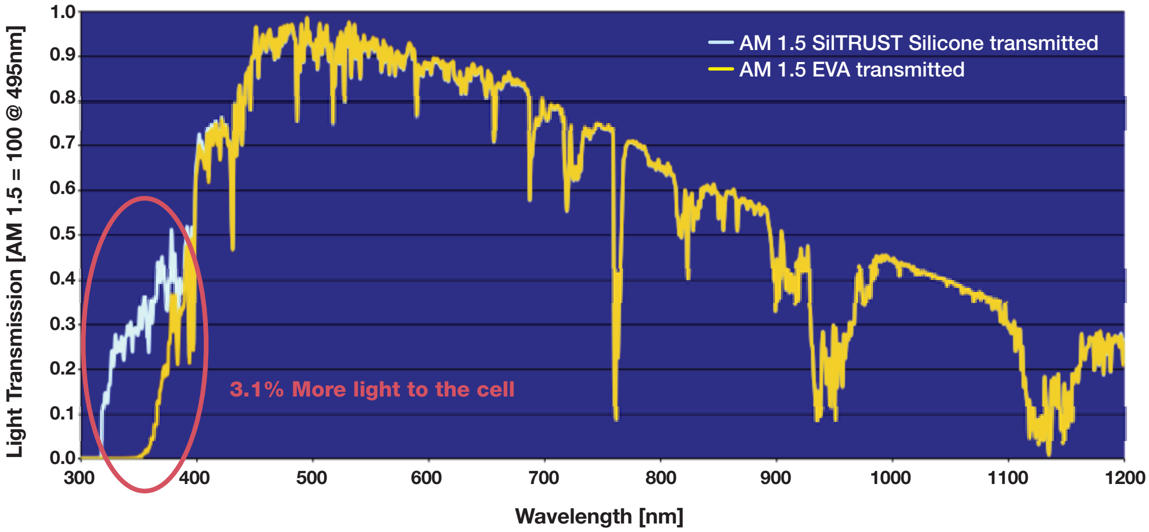
Note: Test data. Actual results may vary.

Efficiency

A - Enhanced Light Transmission of Silicone vs. EVA

UV radiation with a wavelength below 380 nm is blocked by typical EVA formulations due to UV absorbers. Silicones, on the other hand, are transparent throughout the AM 1.5 spectrum, and can transmit about 3.1% more light to the photovoltaic cells' surface. Depending on the spectral response curve of the encapsulated cell, a certain portion of this 3.1% is immediately available to increase electrical output in SilTRUST silicone encapsulated cells versus EVA encapsulated cells.

SilTRUST Silicone Transmits More Light Than EVA



Note: Test results. Actual results may vary.

SilTRUST silicone encapsulant is fully transparent for UV-light <380 nm: 3.1% more light can reach the cell's surface.

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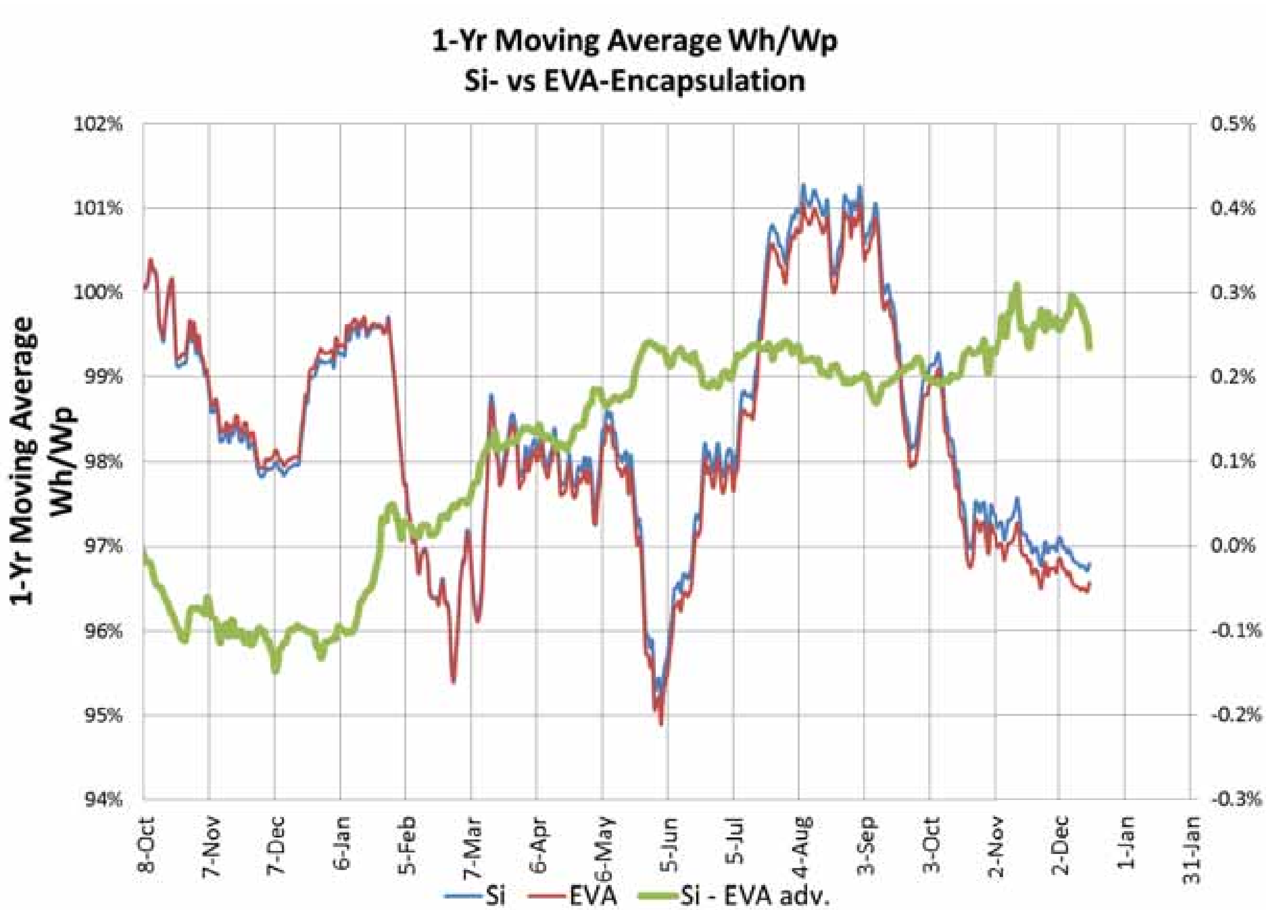
Efficiency (continued)

B - Module Efficiency Enhancement – Outdoors

The ultimate benefit to the end-user of a photovoltaic module is a larger amount of Watt-hours (Wh) output of a module versus its price per Watt peak (Wp). Due to the enhanced UV-transparency of silicone versus EVA and the excellent durability of SilTRUST E110 encapsulant, the efficiency advantage can actually increase over time. This can make the accumulated Wh/Wp output enhancement very significant for a PV-installation as a whole. As shown in the graph below, already two years after outdoor operation of a silicone encapsulated module, the annual Wh/Wp yield difference was trending upwards by about 0.3 percent per year, compared to commercially available EVA encapsulated modules. Over the anticipated lifetime of a PV installation, therefore, the overall return on investment can be five percent or more due to silicone encapsulation alone.



Increasing efficiency benefit over time is shown after two years of outdoor operation. Plotted are the 365-day moving averages of Wh/Wp for EVA-encapsulated modules (red line) and the SilTRUST E110 encapsulated modules (blue line), as well as the increasing relative difference between them (green line).

Data Source: SITEC, Neuruppin, Germany, 8-Oct-2011 – 16-Dec-2013.

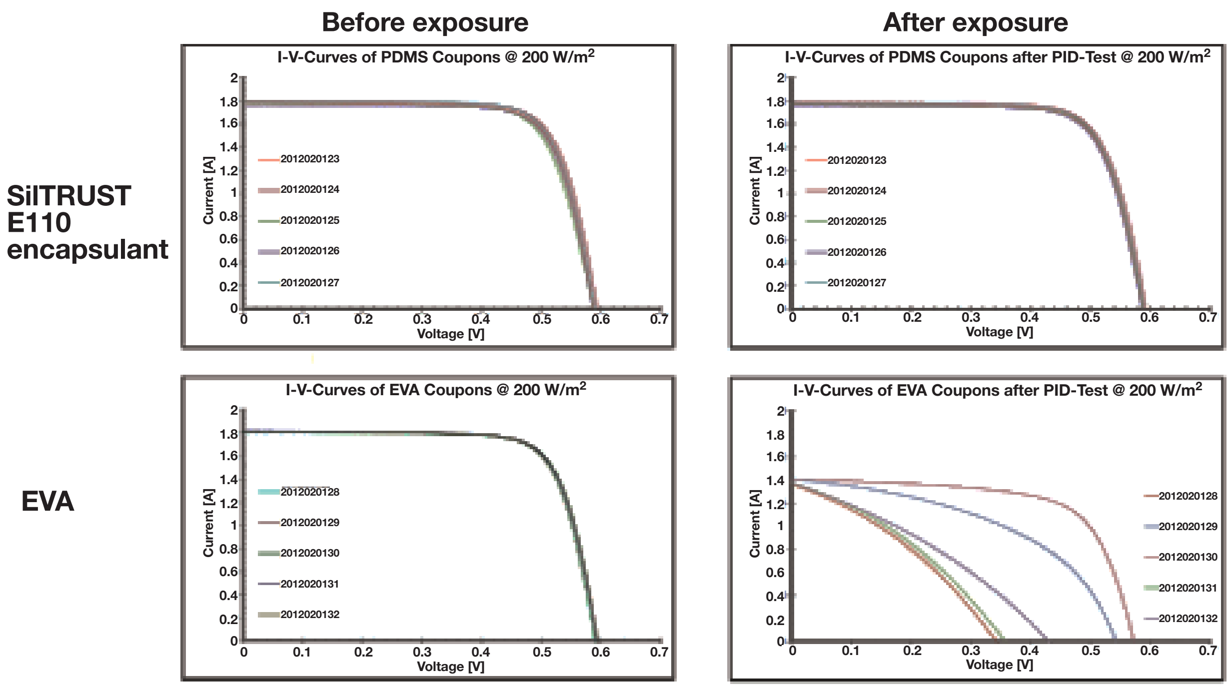
Note: Test results. Actual results may vary.

Annual power output decay rates of EVA and SilTRUST E110 encapsulant can differ by 0.3 percent.

Efficiency (continued)

C - Module Efficiency Enhancement – PID Mitigation

Potential Induced Degradation (PID) is a phenomenon by which high temperature and humidity can cause leakage currents through the EVA encapsulant at high operating voltages. It is assumed that ionic species migrate from the glass surface through the encapsulant to the cell surface where they interfere with the p-n junction of the photovoltaic cell. Our lab data indicate that, as expected, a cured silicone matrix is highly impermeable to ionic species because it contains very low amounts of moisture and no aggressive degradation products like for example acetic acid in the case of EVA. Hence PID effects can be very effectively mitigated by using SilTRUST E110 silicone as the encapsulant.



IV-curves before and after 48 hours @ 85 °C/85%RH with –600V (single cells) @ 200 W/m² irradiation.

Note: Test results. Actual results may vary.

PID can be mitigated by using low moisture, high dielectric strength silicone.

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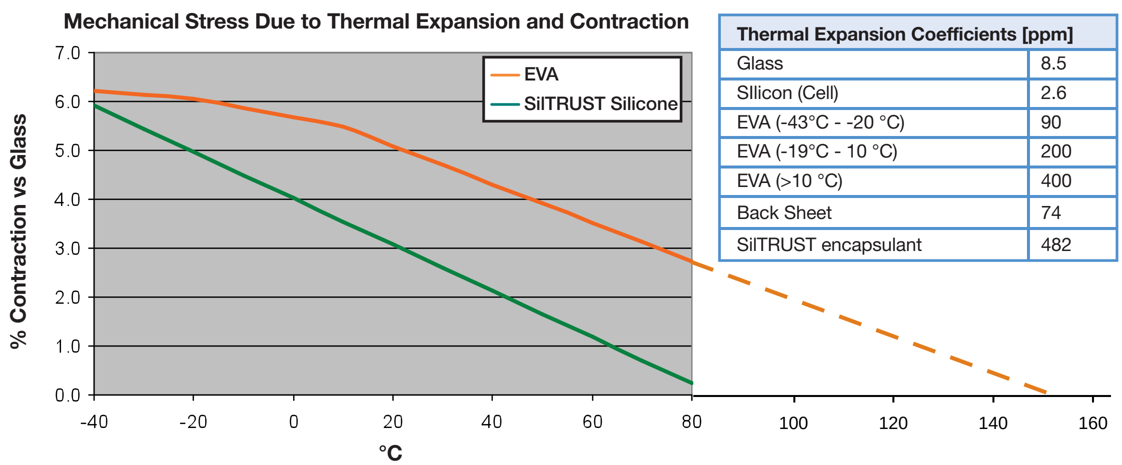
Durability

A - Mechanical Stress Due to Thermal Manufacturing History

Mechanical stresses in a module are an important cause of electrical connection failures over time. Modules built with SilTRUST silicone encapsulation, however, may be less prone to suffer from such failures not only because of the more favorable mechanical properties of silicone, but also because of the much lower module manufacturing temperature of 85 °C compared to higher than 140 °C for EVA. Upon cooling, stress builds in the module because encapsulation materials shrink more than the connectors, cells, glass and back sheet due to differences in thermal expansion coefficients. The graph below shows that at 80 °C, which is about the maximum operating temperature for a PV module, a SilTRUST silicone module theoretically should be virtually stress-free, whereas the EVA encapsulated module theoretically should show significant stress. At roughly 30 °C, the thermal stress in an EVA module theoretically should be approximately double that of a SilTRUST silicone encapsulated module. This is likely one of the factors making silicones the material of choice for extraterrestrial photovoltaic panels, which see many extreme thermal cycles with severe thermal shocks during the course of a day, such as in satellites orbiting the earth.



Thermal Expansion Coefficients [ppm]	
Glass	8.5
SIlicon (Cell)	2.6
EVA (-43°C - -20 °C)	90
EVA (-19°C - 10 °C)	200
EVA (>10 °C)	400
Back Sheet	74
SilTRUST encapsulant	482

Note: Test results. Actual results may vary.

SilTRUST silicones can reduce permanent mechanical stress levels in PV modules vs EVA, due to lower manufacturing (curing) temperature and lower modulus.

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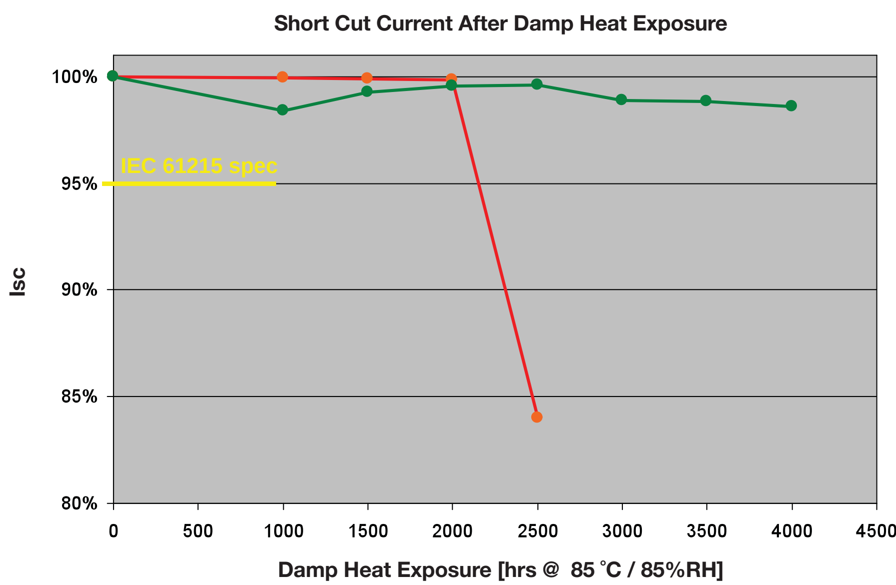
Durability (continued)

B - Single Cell Module Performance After Damp Heat Exposure

A key accelerated exposure test in the regulatory protocol for certifying modules is the damp heat test, in which the electrical output of a module must be at least 95 percent of its original value after 1,000 hours of exposure to 85 °C and 85 percent relative humidity. It is one of the toughest hurdles for passing the certification test protocol, causing a significant number of module designs to fail. High quality organic encapsulants typically last approximately 2,000 hours in this test, after which electrical connections start to fail and the output performance shows a steep decline below 95 percent. This was observed testing single cell modules encapsulated with EVA. However, single cell modules in which SilTRUST silicone was used as an encapsulant did not show significant power loss even after 4,000 hours, and they were likely to withstand many more hours.

In addition, when tested for potential induced degradation effects (PID), by applying 300V over a single cell module after high humidity exposure, there were no signs of output breakdown for SilTRUST silicone encapsulated cells. The EVA encapsulant, however, is believed to play a major role in the appearance of PID.



Single Cell Module

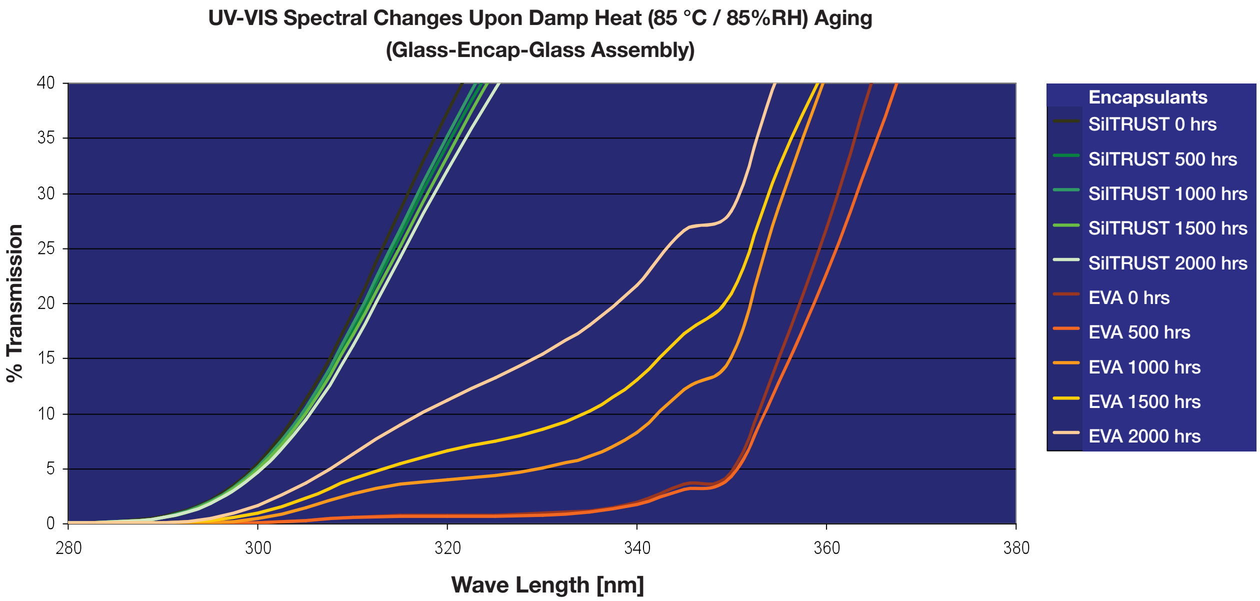
Note: Test results. Actual results may vary.

SilTRUST silicone encapsulant increased durability to >4,000 hours in damp heat.

Durability (continued)

C - Weathering Durability

Upon spectral analysis of glass-encapsulant test specimens after exposure to damp heat conditions, a very interesting feature was observed in the spectra of EVA. They tended to increase in UV transparency. This is symptomatic of the limited lifetime of UV absorbers in EVA under damp heat conditions. It is expected that the hydrolytic degradation of the UV absorbers will lead to radiation breakdown of the EVA backbone as well. The curves of a SilTRUST silicone encapsulated specimen remained largely unchanged. Any observable changes were more likely caused by corrosion effects at the outer glass surface.



Note: Test results. Actual results may vary.

EVA UV stabilizer degraded upon damp heat exposure.
SilTRUST silicone retained transparency.

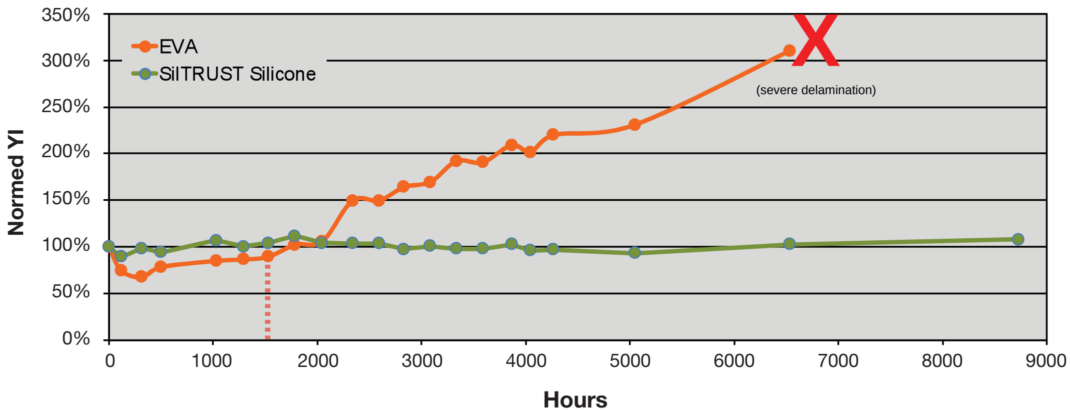
Durability (continued)

D - Weathering Durability

A major shortcoming of many accelerated tests is that they single out a specific stress factor, the damp heat test being a good example. In actual outdoor conditions, many stress factors are at work simultaneously, and interactions between these stress factors can cause additional acceleration towards failure over time, as shown by the effect of damp heat testing on stability of UV absorbers. As seen in accelerated testing in the automotive industry, it is possible to combine several stress factors into one test. For example, the Florida test protocol (a well-accepted accelerated weathering chamber setup used in the automotive industry) combines high humidity, high temperature and high irradiation into one test. The results of spectral analysis confirm the outcome of the electrical output tests on single cells shown earlier. A standard quality EVA degraded after roughly 2,000 hours of exposure to high humidity, high temperature and high irradiance, leading to yellowing, loss of transparency, and subsequent mechanical or catastrophic adhesion failures.

If delamination is not the ultimate failure mode after prolonged accelerated exposure, discoloration of organic encapsulants becomes apparent over time; this is an important failure when aesthetics are important. Under those test conditions, SilTRUST encapsulant material maintained its original yellowness index, adhesion performance and transparency.

Yellowness Index Stability
[“Florida” Test Protocol, VW PV3930]



Test Conditions:

Xenon-arc weatherometer (XAW) with 0.55 W/m^2 at 340 nm (Volkswagen PV3930, ***1,600 hours corresponds to approximately one year real Florida outdoor weathering).*** Measurement of Yellowing Index according to ASTM E313.

Note: Test results. Actual results may vary.

UV-stabilized EVA will typically yellow over time — SilTRUST silicone is essentially color stable.

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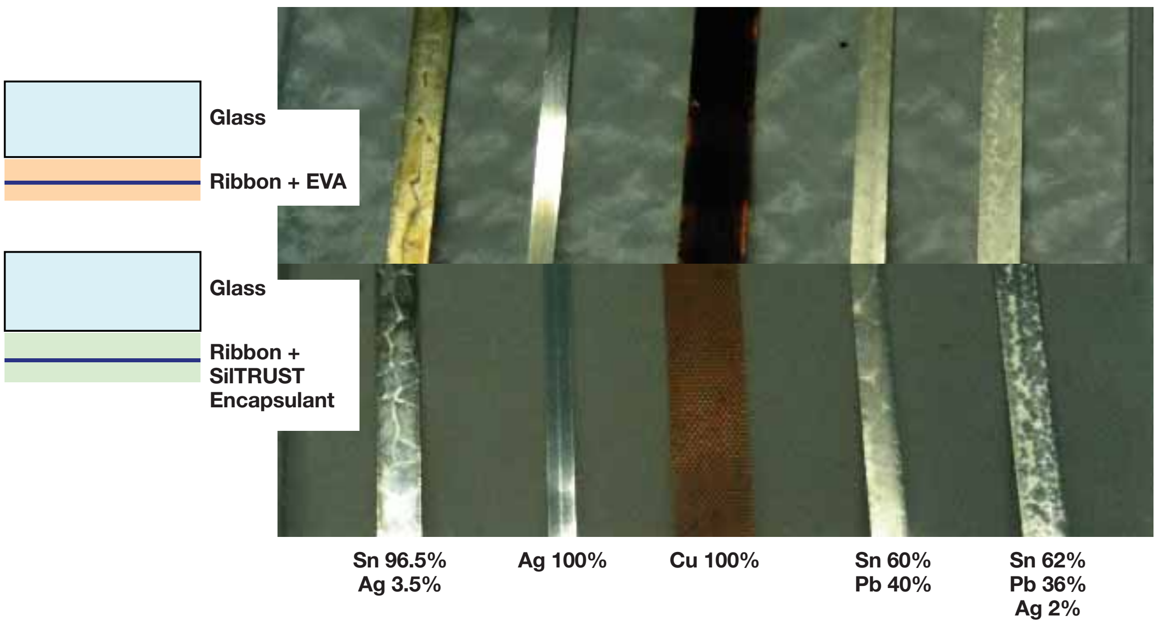
Durability (continued)

E - Corrosion Protection

Since water and silicones generally are incompatible, electrical conductors encapsulated in SilTRUST encapsulant can be well protected against the corrosive effects of moisture. It is theorized that the water vapor transmission rate of an effective encapsulant must be very low to prevent moisture from entering a PV module assembly. However, the maximum moisture uptake by the encapsulant is as important, or even more important, as shown in the image below. Typical ribbon and bus bar metal materials were exposed to damp heat conditions, while freely accessible to moisture diffusing through the encapsulant materials. The metals embedded in the SilTRUST silicone matrix showed no signs of corrosion, while the same metals embedded in EVA showed discoloration and onset of corrosion in the earliest stages of this test.

Corrosion Comparison of Silicone vs. EVA

500 hours Damp Heat (85 °C, 85% relative humidity)



Note: Test results. Actual results may vary.

SilTRUST silicone encapsulant can provide good protection against ribbon corrosion.

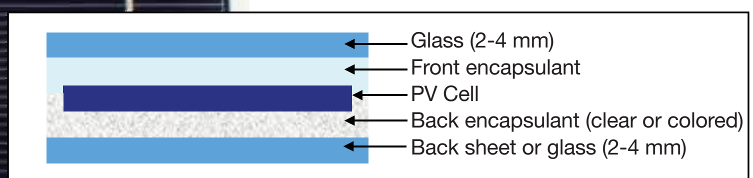
Manufacturing

A - Process Development

To support module development using new materials or cell technologies, a lab scale process was developed to easily manufacture single cell modules for various screening tests. These single cells can be used for first estimates of efficiency gain, to put them into accelerated testing protocols or to support process and material developments at lab scale.

Lab Scale Single Cell Module

- New material formulations
- Screening materials compatibility
- Screening processing options
- Efficiency gain estimations
- Durability testing



Momentive has developed lab expertise in support of process development and material selection.

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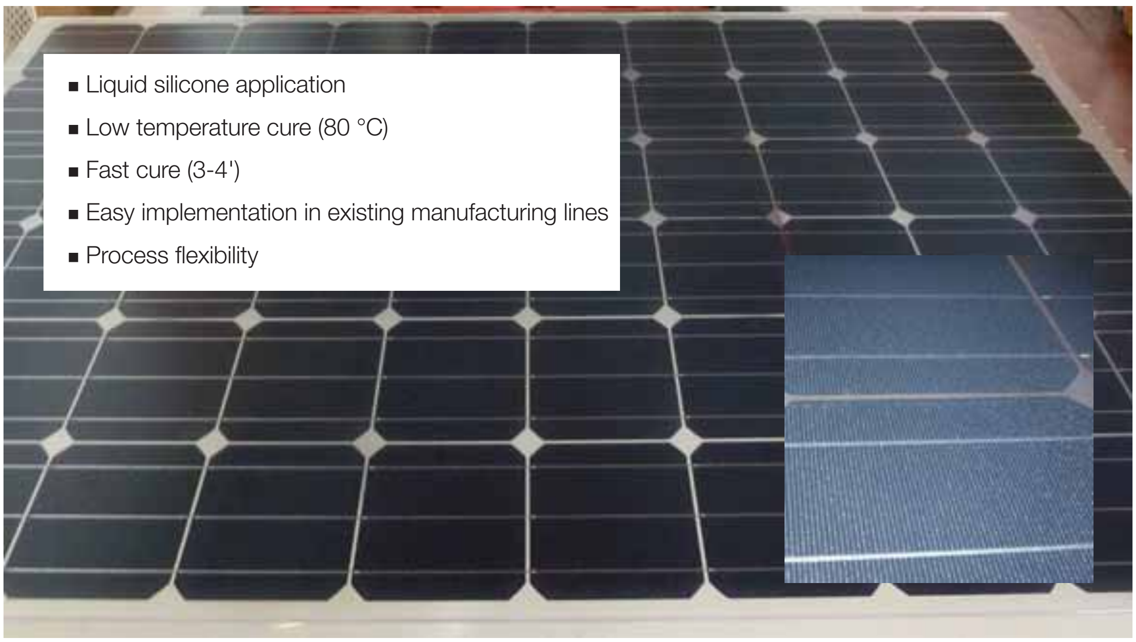
Manufacturing (continued)

B - Collaborative Process Development

Through collaboration with engineering and equipment manufacturers, a module manufacturing process that features many positive aspects has been developed. The SilTRUST silicone is applied as a liquid and cured at a low temperature of 80 °C. It is a fast process, typically requiring no more than four minutes for full cure into a solid film with excellent mechanical properties. The equipment can be integrated into existing manufacturing lines merely by changing the lamination section. The process is very flexible in meeting special needs of complicated connection schemes for new cell types. First manufacturing trials indicated that cell breakage could be reduced. At the same time, necessary rework is as easy, if not easier, than using EVA lamination.

Manufacturing Testing with SilTRUST Silicones



Momentive has collaborated with manufacturers and can offer flexibility in equipment and raw materials selection.

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Manufacturing (continued)

C - Certifiability[1] – UL 1703

Modules from the module pilot facility were submitted for regulatory testing according to the UL 1703 standard. Results were excellent; applicable requirements were met.

Canadian Standards Association Test Record
Test Location: 13799 Commerce Parkway, Richmond, British Columbia, Canada

Test	Result	Specification
21. Leakage Current	<0.4 µA	<1.0 mA
24. Cut	Complies	Comply
26. Dielectric Voltage Withstand	<0.2 µA	<50 µA
27. Wet Insulation Resistance	>3369 MΩ	>24.67 MΩ
36. Humidity	Complies	Comply
39. Hot Spot Endurance	Pass – 0.0 µA, 9999 MΩ	Comply
42. Wiring Compartment Securement	Complies	Comply

(1) Tests required for new laminates (without frame)

Note: Test data. Actual results may vary.

Liquid SilTRUST silicone encapsulation process can assist the production of certifiable modules.

Summary

Requirements for Encapsulants	Potential Benefits of SilTRUST Encapsulant
Module Reliability	
■ Mechanical protection of cells	■ Low modulus, low hardness, durable adhesion, chemically inert
■ Electrical insulation of cells and connections	■ Low moisture content, virtually no PID, high dielectric strength
■ Durability	■ UV stability, damp heat stability, low initial mechanical stress levels
Enhanced Module Efficiency	
■ High solar light transmittance	■ Up to 3.1 percent more light to the cell, color stability
■ Thermal management	■ Low thermal cycling stress, heat aging durability
Lowered Manufacturing Costs	
■ Fast and easy processing	■ Fast cure, flexible front/back encapsulation
■ Low investment	■ Low equipment cost, low heating cost, less floor space
	■ Potentially significant financial benefit for end-user

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Customer Service Centers

Email

4information@momentive.com

Telephone

Americas

+1 888 443 9466
+1 614 986 2497

Europe, Middle East, Africa and India

+00 800 836 43581
+40 212 534754

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MOMENTIVE™

260 Hudson River Road
Waterford, NY 12188 USA
momentive.com

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