# High Temperature Silicone Gels for Power Module Protection

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## Why High Temperature Silicone Gels are Required

Silicone gels have already been used in the power electronics industry for decades. The main purpose of these materials is to protect the power chips from harsh environmental conditions (moisture, in particular) and to provide electrical insulation for high voltage operations. The majority of today's power modules are specified for junction operating temperatures up to 150°C. Slowly becoming more widely used are power modules rated at 175°C. Increasing the junction temperature allows a higher power density, allowing size and weight reduction. This increase in junction temperature is also driven by the spread of new devices based on SiC and GaN technologies which can intrinsically tolerate a higher operating temperature compared to the Si counterparts.

In order to pass reliability requirements at higher temperatures, accelerated tests are performed by power module manufacturers in order to simulate the 20 years or longer lifetime of power modules. These tests consist of storing the modules at higher temperatures than the operating temperatures (typically 25°C higher according to UL1557) and measuring the mechanical and electrical performances after the required hours of aging. The higher the aging temperature, the shorter the time of aging can be.

## Dow: A Leader in the Silicone Gel Industry

Dow has been a key player in the silicone gel industry for decades. We developed a broad range of silicone-based solutions covering operating temperatures from -40°C to +175°C. In order to meet industry requirements of higher temperatures of operation, development of silicone gels with resistance up to +200°C is required to simulate the aging conditions of power modules operated at +175°C. Moreover, low temperature resistance for particular areas of the world is required. Chemistry suitable for operations as low as -60°C was also investigated. As a result, Dow has developed two new materials to be added to its extensive portfolio: DOWSIL™ EG-3810 Dielectric Gel for operating temperatures between -60°C and +200°C, and DOWSIL™ EG-3896 Dielectric Gel for operating temperatures between -40°C and +185°C.

## DOWSIL™ EG-3810 Dielectric Gel and DOWSIL™ EG-3896 Dielectric Gel: High Temperature Stable Silicone Gels

Two different polydimethyl-based formulations were developed in order to meet the temperature requirements of next-generation power modules: DOWSIL™ EG-3810 Dielectric Gel (using highly cross-linked polymers) and DOWSIL™ EG-3896 Dielectric Gel (using a lower density of cross-linking). These materials have a low viscosity (< 700 cP) in order to ensure proper filling of cavities within the power module architecture and high dielectric strength (> 20 kV/mm) to ensure the required dielectric insulation properties.

DOWSIL™ EG-3810 Dielectric Gel was specifically formulated to cover a broad range of temperatures from -60°C to +200°C, whereas DOWSIL™ EG-3896 Dielectric Gel was formulated to cover a smaller temperature range (-40°C to +185°C) but with a reinforced resistance to cracking required in particular applications with very stringent design.

The temperature resistance of these two materials was bench-marked against a high runner in the DOWSIL™ product portfolio (SYLGARD™ 527 Silicone Dielectric Gel – specified for operations between -40°C and +175°C). Aging in ovens set at different temperatures was conducted and the hardness of the gel was periodically measured using a texture analyzer in order to study the increase in hardness.

This hardness increase is explained by reaction mechanisms between oxygen in the air and the silicone PDMS material:

- Even though silicone is based on non-carbon chemistry, it contains a set of carbon-containing units such as $CH_3$ (methyl), $CH=CH_2$ (vinyl) and $CH_2$-$CH_2$ (post-reacted vinyl), that are most sensitive to oxidative degradation.
- Crosslinking between polymer chains occurs via thermally-catalyzed complex reactions fueled by the formation of free radicals reacting with oxygen.

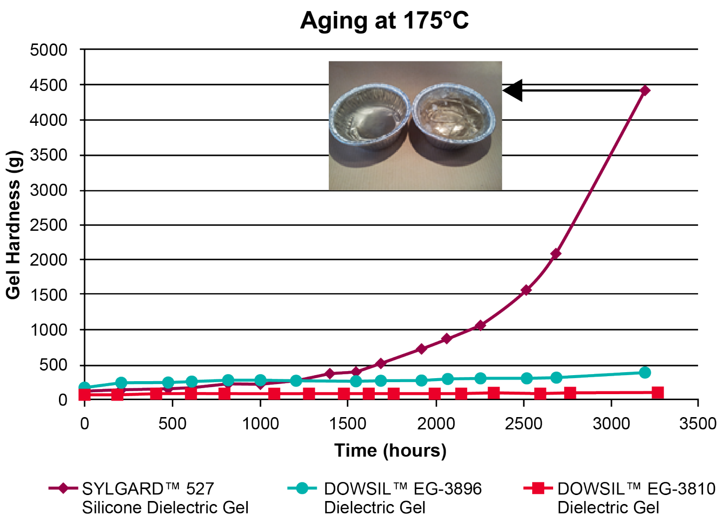


**Figure 1:** Hardness increase of SYLGARD™ 527 Silicone Dielectric Gel, DOWSIL™ EG-3896 Dielectric Gel, and DOWSIL™ EG-3810 Dielectric Gel after aging at 175°C for 3200 hours

Both effects lead to an increased cross-linking within the silicone gel, generating increased hardness and a fragile surface subject to cracking when mechanical stress is applied. Differences in the formulations in terms of density of dielectric gel at elevated temperatures compared to SYLGARD™ 527 Silicone Dielectric Gel are explained by the cross-linking and reactive sites, retarding the degradation mechanisms. The comparison of these three materials is presented in Figure 1 where a dramatic increase in hardness of the SYLGARD™ 527 Silicone Dielectric Gel is observed after prolonged exposure at 175°C, whereas the DOWSIL™ EG-3896 Dielectric Gel and DOWSIL™ EG-3810 Dielectric Gel remain stable.

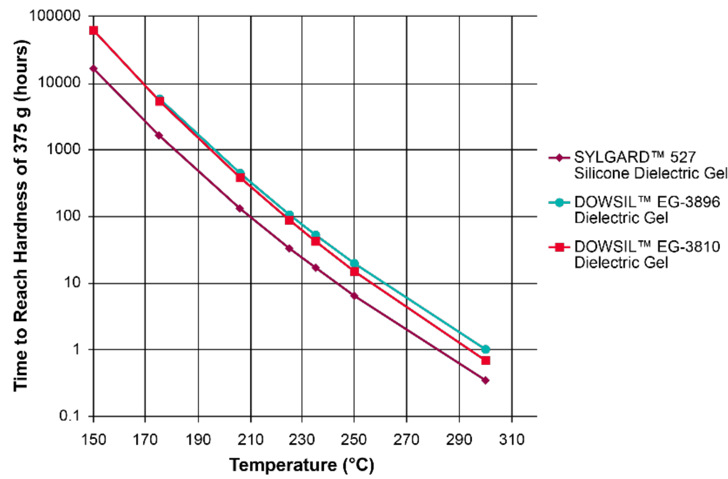


**Figure 2:** Failure prediction tool

A prediction tool has been developed in order to estimate by extrapolation the expected time to failure over a broader range of temperatures. Results are shown in Figure 2. This test was interrupted once a hardness threshold of 375 grams was measured.

Note that only gel hardness is evaluated and that other effects related to the real application (packaging effects) could also alter the lifetime of the silicone gel.

## Dow: Your Technology Leader for the Future

In order to meet the requirements of the future, Dow is still actively working on the development of silicone gels with a stability in temperatures up to 225°C and higher. These challenging targets will be required in order to operate next-generation power modules at temperatures up to 200°C and beyond, leveraging all of the benefits offered by new SiC and GaN semiconductor devices.




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