PERFORMANCE SILICONES

Working under stress: Thermal interface materials

Stephanie A. Valenzuela, Andrés Becerra, Joe Sootsman

Electronics are becoming smaller, more powerful, and more essential to our everyday lives. This is highlighting the need for more advanced thermal interface materials (TIMs) with the ability to perform under extreme environments. Superior TIMs must have resiliency towards high power environments, and adaptability towards stresses related to the increasingly harsh dynamic operating conditions of electronic systems. Without improved TIMs, electronic devices would face failure while undergoing thermal cycling processes. However, progress is being made in advanced thermal interface material development.

An example of such a high-performance material is DOWSIL™ TC-4060 Thermal Gel. DOWSIL™ TC-4060 Thermal Gel is a two-part highly thermally conductive gap filler (>6 W/m·K) that is soft and provides stress relief. In addition, it has long-term stability in high-temperature and high-power environments. This material has proven to be well suited for automotive, telecommunication, and aerospace applications. DOWSIL™ TC-4060 Thermal Gel is part of Dow's portfolio of advanced TIMs that exhibit resilience and superior performance in applications with demanding conditions and extreme environments.

In order to better study the extreme conditions encountered by new TIM materials, scientists at Dow have developed novel test methods to evaluate their reliability. In addition to static test methods under accelerated aging, new dynamic test methods that combine multiple stresses to mimic the end-use geometries and operating conditions have been developed. While aging processes in environmental chambers are valuable for understanding how the physical properties of a material may evolve upon exposure to harsh conditions, there is also an ever-growing need to characterize materials under dynamic systems with in-situ monitoring.

To achieve this, the Thermal Interface Material Analyzer (TIMA, produced by Nanotest) is used to subject TIMs to a thermal gradient while undergoing controlled mechanical deformations. The TIMA follows the ASTM D5470 standard test method which is used to determine the thermal transport properties of thermally conductive materials. The TIMA is an all-in-one fully automated test system that can evaluate a wide range of materials including greases, pastes, gap fillers, adhesives, anisotropic composites, and phase change materials. The TIMA can determine a wide range of properties such as the thermal resistance, effective thermal conductivity, bulk thermal conductivity, and thermal contact resistance. Unlike other ASTM D5470 tools, the TIMA boasts a modular design with interchangeable reference bars of various materials, shapes, and sizes. The TIMA can evaluate materials under combined thermal and mechanical loads with in-situ monitoring; the strain input can include a combination of compression and tension cycling that best replicates the observed in-application stresses on the thermal interface material. These key features and capabilities render the TIMA ideal for emulating end-use application and evaluating the next generation of advanced thermal interface materials.

The ASTM D5470 geometry consists of a layer of the test material between a heated reference bar and a cooled reference bar of equal cross-sectional area, *A*. At thermal equilibrium, a steady-state heat flow, *Q*, is achieved with a measured temperature drop, ΔT, across the TIM. The thermal resistance across the TIM, R_{th}, is the measurement of the linear heat transfer between the heated and cooled reference bars:

$$R_{th} = \frac{\Delta T}{Q}$$

The thermal resistance is the summation of the TIM's bulk thermal resistance, R_{th}^{bulk}, and the interfacial contact resistances:

$$R_{th} = R_{th}^{bulk} + (R_{th}^{int0} + R_{th}^{int1})$$

Only the bulk thermal resistance is dependent on the bond line thickness, *d*:

$$R_{th}^{bulk} = \frac{d}{k_{bulk} \cdot A}$$

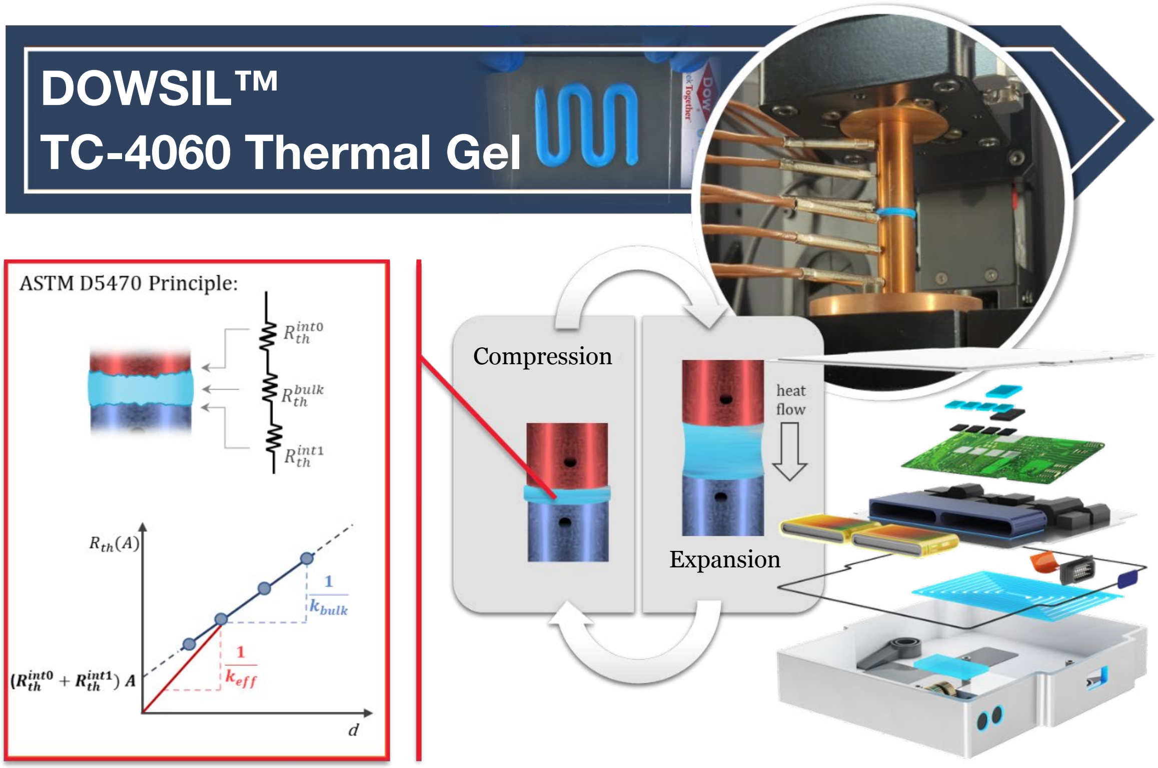
Measuring at different bond line thicknesses enables the determination of the TIM's intrinsic bulk thermal conductivity, k_{bulk}, assuming the bulk microstructure is unchanged across measurements (i.e. zero residual stresses). k_{bulk} is extracted from the inverse slope of the linear fit of the resistance vs. thickness plot.

A useful construct is the effective thermal conductivity, k_{eff}, which is related to the thermal resistance and (unlike the bulk thermal conductivity) is dependent on the geometry:

$$k_{eff} = \frac{d}{R_{th} \cdot A} = \frac{d \cdot Q}{\Delta T \cdot A}$$

The effective conductivity, k_{eff}, will be close to k_{bulk} in zero-stress geometries (especially at thick bond lines), but it incorporates the impact of the contact resistances. Moreover, k_{eff} can be used to describe (with familiar units) the TIM's performance in nonzero-stress situations, so it provides researchers with freedom to flexibly design tests with dynamic thermomechanical loads to study the response and reliability of advanced TIMs.

DOWSIL™ TC-4060 Thermal Gel



Dow collaborates closely with customers to develop custom product testing to meet the specific criteria of an application. The addition of dynamic test methods with instruments like the TIMA has become invaluable for assessing the resiliency of a product towards a targeted application. To provide an example, scientists at Dow worked closely with a customer to find the ideal material for an application that requires exposure to extreme temperatures with varied time frames of thermal cycling. The scientists at Dow suggested DOWSIL™ TC-4060 Thermal Gel due to its elastomeric properties and stability in extreme conditions. In collaboration with the customer, Dow scientists developed a series of protocols on the TIMA to mimic the application. DOWSIL™ TC-4060 Thermal Gel's performance was examined under a series of varied mechanical strains and strain rates at elevated temperatures. To highlight one of the protocols, DOWSIL™ TC-4060 Thermal Gel was subjected to 9% mechanical strain cycling at high temperatures for 200 cycles. In addition, key features such as surface roughness were determined to have a significant impact on the material's performance for the specified application. The effective thermal conductivity was monitored and the specified 6 W/m·K was preserved throughout the test. Upon completion, the specimen was inspected and there were no visible signs of degradation. The series of procedural protocols developed helped to assess and validate DOWSIL™ TC-4060 Thermal Gel's overall ability to deliver stable performance and provided substantial evidence that the material will meet the application requirements.

Today's demand for superior thermal management warrants the need to test thermal interface materials not only under static conditions but also with dynamic test methods that subject the material to multiple stresses to monitor the overall performance. Dynamic testing gives insight into how a material will function in a real-life application by mimicking the end-use conditions for the automotive, aerospace, and energy storage industry. Dow has proactively adopted and implemented additional testing systems that help both the scientists and customers determine the optimal thermal interface material for a given application. Dow is dedicated to developing the next generation of high-performance materials as the needs of electronic devices continue to evolve.
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