NEW METHOD FOR CHARACTERIZING THERMAL INTERFACE MATERIALS IN AN IN SITU ENVIRONMENT

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WHITEPAPER

MECHANICAL ANALYSIS

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A new method based on existing measurement standards for a quick and repeatable thermal conductivity measurement of nanoparticle-based thermal greases and other compressible thermal interface materials (TIMs) has been created by Mentor Graphics in collaboration with researchers at the Budapest University of Technology and Economics.

The test approach is based on the thermal transient testing methodology, and test results clearly indicated that it can be applied well for the measurement of the bulk thermal conductivity of TIMs. Besides the measurement of the bulk thermal conductivity, after a proper calibration step, the proposed setup is also suitable for the measurement of the "effective" thermal conductivity of various TIM samples. For highly conductive samples, the characterization is done with exceptional accuracy and repeatability.

Designing a repeatable and reproducible method is of key importance in the power semiconductor industry because the inter-laboratory error for TIM measurements can be very significant. Designers need to be able to make a fair comparison for selecting TIM material out of the wide range of different market offerings.

After selecting the proper TIM, verifying the long-term stability of the material is necessary. The structure function approach can be applied to define a failure criterion that will verify the effect of standard reliability tests, such as temperature or power cycling and high-temperature storage.

Most of the research described in this paper took place after the group joined the European Nanopack consortium from 2007 to 2011. Nanopack was an FP7 project founded by the European Union with selected European companies, universities, and research institutes with a lot of experience in the field of TIM testing, led by Thales Research Institute. One of the goals of the project was the development of new TIM material solutions while other partners worked on the realization of enhanced, and, in some instances, highly scientific ASTM-type testers that are capable of measuring TIMs at 20 W/mK and beyond.

TIM CHARACTERIZATION IMPORTANT TO HIGH-POWER ELECTRONIC DESIGNS

The increasing power densities within electronic packages have become one of the major bottlenecks of today's electronics design. More power results in higher temperature in the chip that first modifies and eventually destroys the operation of the circuit if the excess heat is not removed from the chip. Heat transfer to the outside can be improved by better heatsinks, higher air velocities, and liquid cooling if the application for which it's being used allows it.

But the heat has to reach the surface of the package first. The efficiency of this heat transfer depends on the conductivity of the package and the thermal resistance (R_{th}) of the interface, which is defined as the sum of the thermal resistance of the interface material (TIM) plus the contact resistances.

Characterization of the thermal properties of TIMs is important because the relative percentage of overall semiconductor package material thermal resistance attributed to the TIMs has decreased. New TIM materials have resulted in very high performance and, in some cases, with very thin in situ application thickness, which provides very small thermal resistance values. As high power densities demand even better performing TIMs, soon the current technology will be unable to measure R_{th} values or at least not with such a high throughput that would allow the use of the methodology in manufacturing testing.

These trends have resulted in a focus on the methods for characterizing the thermal conductivity of TIM materials and in situ R_{th} values, for the development of characterization equipment and methods, and for verifying the accuracy and repeatability of results.

Thermal interface material is used at several layers in complex structures—stacked die packages contain as many TIM layers as the number of stacks—but TIM1 and TIM2 layers are usually distinguished even at single die processor packages (Figure 1) [1].

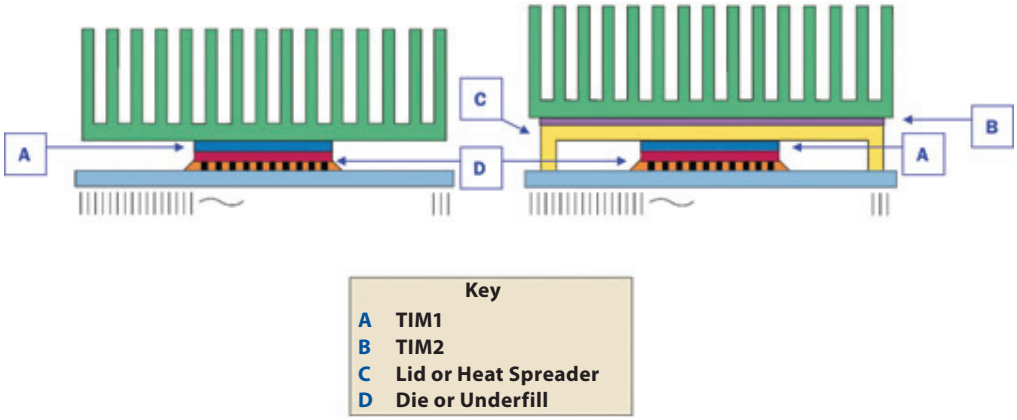

Figure 1: Typical TIM1 and TIM2 placement in a bare die package and a lidded package.

Mentor Graphics developed an in situ method, which mimics the application environment of the TIM, for the quick and repeatable thermal conductivity measurement of TIM2 materials used outside the package, mainly greases, gap pads, gap fillers, and phase-change materials.

Thermal resistance testing of interface layers within electronics products is critical for product performance, but the characterization of these thin, high-thermal conductivity materials under realistic conditions for their application is extremely challenging using current methods.

The major challenge in TIM testing is the significant difference between standardized lab test data and application-specific (or "in situ") test results in a given set of application conditions. Standardized test methodologies are necessary to make a fair comparison between various TIMs from different vendors [2].

THE CHALLENGE OF MEASURING TIM THERMAL CONDUCTIVITY

Measuring the thermal conductivity is not easy in general. The thermal conductivity (k or sometimes λ) is the intrinsic property of a material that indicates its ability to conduct heat. It is defined as the power P applied on a material having a thickness L, in a direction normal to a surface of area A, caused by a temperature difference ΔT, under steady state conditions and when heat transfer is dependent only on the temperature gradient.

$$k = P \cdot \frac{L}{A \cdot \Delta T} \qquad (1)$$

The exact values of the quantities in Equation 1 are needed, which is normally very problematic in TIMs, to measure thermal conductivity. For example, it is easy to understand that because of the roughness of the surfaces and the method of application, the thickness is never uniform; consequently, the temperature values along the interface will also be different and ensuring uniform heat flux along the sample is extremely difficult. In addition to this, many other factors influence the performance of a given TIM material (Figure 2), and a design of a measurement setup that ignores their effect is very difficult [3].

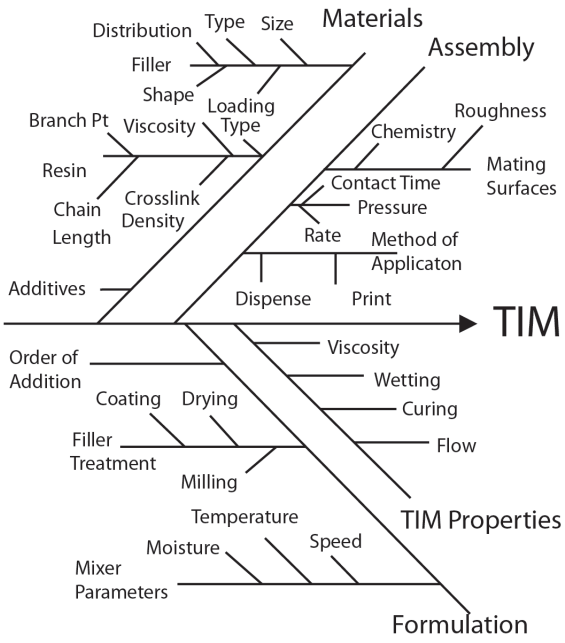

Figure 2: Factors that affect TIM performance.

First, the TIM material itself needs to be characterized, independently from the future applications. For this purpose, complex, very expensive, and slow techniques are acceptable because these measurements do not have to be done in high volumes. These experimental methods include transient thermo reflectance measurements [4] or 3ω testing [5].

Second, very fast in situ measurements with somewhat less demand for accuracy are needed to characterize the TIM performance in a given electronics application; for example, to find the R_{th} value of a TIM1 layer in a processor package during manufacturing testing. These industrial methods are either standardized methods that allow better comparison of the measured results, or they are application-specific (sometimes ad hoc) methods that ensure very fast measurement which allows in-line application for reliability assessment.

BACKGROUND ON THE PRIMARY STANDARDIZED STEADY-STATE TEST METHOD

The ASTM D-5470 test method [6] is a standard method for the measurement of thermal resistance and bulk conductivity for TIMs such as pads, tapes, greases, and phase-change materials (Figure 3). The sample is placed between a hot meter bar and a cold meter bar and a steady state of heat flux is established.

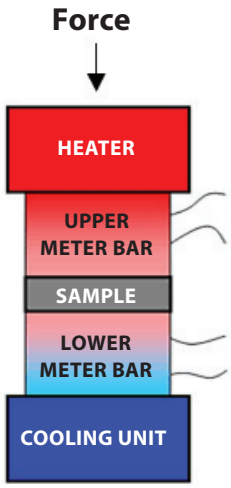

Figure 3: The measurement setup for the ASTM D5470-12 standard test method.

According to the ASTM test definition, the thermal resistance per unit area θ, includes the thermal resistance of the material ($\theta_{material}$) plus the interfacial contact resistance of the TIM to the substrates ($\theta_{contact}$):

$$\theta_{total} = \theta_{material} + \theta_{contact} \qquad (2)$$

Fourier's Law describing one-dimensional heat flow defines the thermal resistance per unit area of a material such that:

$$\theta_{material} = \Delta T \cdot A/Q = t/k_{bulk} \qquad (3)$$

where ΔT is the temperature difference across the TIM under test, A is the area of the meter bars, t is the thickness of the sample, and k_{bulk} is the material bulk conductivity. The heat flux Q is either measured from the temperature drop along the meter bars length (requiring multiple temperature sensors in each bar), or it is identified by carefully determining the power supplied to the hot bar and by using guarding and/or insulation of the bars to eliminate any heat loss. Combining Equations 2 and 3,

$$\theta_{total} = \theta_{contact} + t/k_{bulk} \qquad (4)$$

The ASTM method measures θ_{total} as a function of thickness of the TIM. This plot is linear, the slope of the line is proportional to $1/k_{bulk}$, and the intercept is a measure of $\theta_{contact}$ (Figure 4).

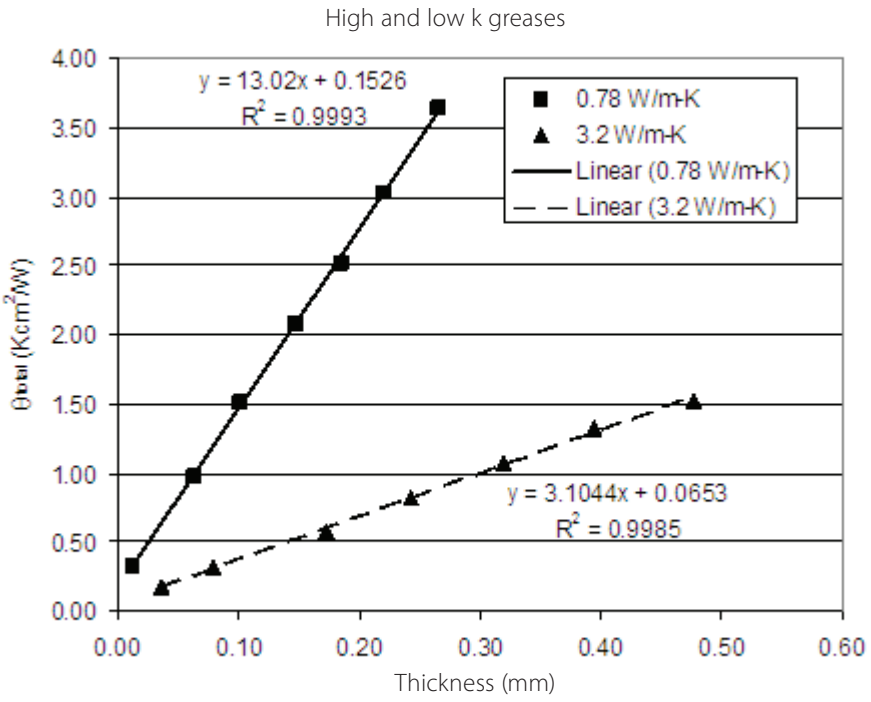

Figure 4: Thermal conductivity plots from the ASTM D5470-12 test method.

Because $\theta_{contact}$ is known to be sensitive to the testing surfaces (material type, flatness, roughness, and conditioning by previous samples, see Figure 2), the correlation of θ_{total} to thermal test vehicles has shown correct rank order but the ASTM test underpredicted the in situ thermal resistance [7, 8]. This difference in absolute value was attributed to the assemblies having different surface properties compared with the ASTM tester.

One advantage of the ASTM test is that Equation 3 allows one to obtain k_{bulk} independent of these interfacial effects, yielding a material property. The k_{bulk} along with θ_{total} measured at representative pressures and gaps can be useful in selecting candidate materials for in situ evaluation. Depending on the TIM under consideration, the gap in situ, and the nature of the in situ surfaces, the contact resistance, $\theta_{contact}$, may account for a large portion of the total resistance to the θ_{total} heat flow. Furthermore, the ASTM D5470-06 is only valid under the following assumptions:

- Truly one-dimensional heat flow,
- Constant thickness during measurement,
- Thickness independent contact resistance.

The 1D heat flow assumption has been investigated by modeling with the conclusion that the 1D heat flow can be ensured if the meter bars are long enough, the temperature sensing holes are far enough apart, and the position of these holes is known with high accuracy. The latest version of the ASTM test addresses methods to hold constant or measure the gap during the test. If the contact resistance is a function of thickness, a straight line is not obtained when plotting the data according to Equation 3, so this assumption can be tested.

The most important shortcoming of the ASTM method has been its use of high pressure during the test. This pressure is useful in coalescing elastomeric TIM material layers that are stacked to obtain the thickness variation required for analysis using Equation 3. In addition, the high pressure reduces the contact resistance between solid samples and the meter bars. With grease and phase-change TIMs, high pressure testing will result in lower gap settings than seen in most applications; and if the θ_{total} is only reported at this thinnest gap, the value of θ_{total} will be lower than seen in an actual application. Most TIM vendors address this issue by publishing θ_{total} as a function of pressure so designers can estimate the θ_{total} for their application.

Another disadvantage is that no commercial source of such testers is available that guarantee consistent quality. Each machine has been built uniquely for the specific design. Such a wide variety of instrumentation has led to the historic inter-laboratory error.

A final disadvantage to this method is that the problems associated with thermal conductivity measurements are often underestimated, even by experts, because the principle seems so easy. Design engineers should become familiar with recent papers [2, 9 -10] that discuss the issue and cover the technical difficulties of building reliable ASTM D5470-based equipment.

These problems are mainly TIM-vendor-related. But severe problems exist on the designers' side as well. When selecting the TIM, engineers tend to make their decision based on the bulk conductivity data provided by the vendor. Because of the reasons mentioned above, the datasheet values provided by vendors may be inaccurate, and they should always be confirmed. The candidate materials for a given application also should be tested in situ because they may perform differently between given surfaces and applied pressure or set bond line thickness (BLT). For safety-critical applications, it is also important to test the long-term behavior of the material with reliability tests. These problems in the industry were reported in 2003 [11], and unfortunately they are still valid today.

EXPERIMENTAL METHOD TO TEST THE TIM IN A SETUP THAT MIMICS THE APPLICATION ENVIRONMENT

As a first step, the group set out to eliminate the drawbacks of the ASTM standard. They created a test measurement that mimics the real application environment of the TIM. The test consisted of setting up the parallelism of the measuring surfaces as well as the distance between them. The newly developed fixture used a power diode as a heater/temperature sensor element. A measurement following the same principle can be done using any kind of semiconductor package with the appropriate cooling surface. The package of the diode is surrounded by a plastic thermal insulator; thus, the vast majority of the heat leaves the package through the exposed cooling tab. The heat-flow generated this way serves as probe for the TIM measurements.

The method described here is similar to the standard ASTM setup; however, the temperatures are not measured directly at the package boundary, but at the junction of the semiconductor itself. An advantage of this method is that the TIM can be tested in its application conditions, so besides thermal conductivity of the TIM, its direct effect on the junction temperature of the selected power package also can be derived.

The thermal interface material was put between the cooling surface of the selected package and an aluminum block that was directly mounted on a cold-plate. The distance between the cooling surface of the package and the metal block was adjusted manually with approximately 10 µm precision at the first experiments. A special clamp also could be used to apply constant force on the sample. Parallelism of the measuring surfaces is guaranteed by pressing the two surfaces to each other when setting up the zero distance point (Figure 5).

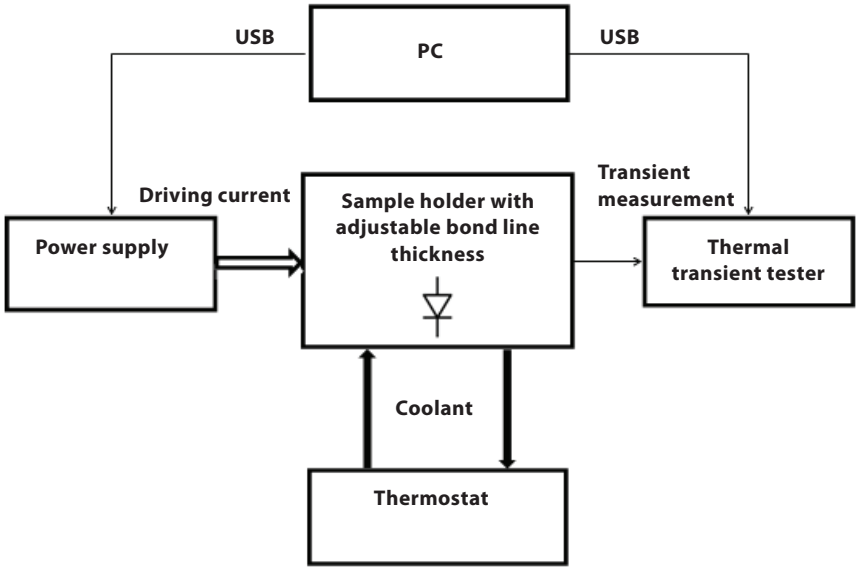

Figure 5: Arrangement of the TIM in the testing system.

The thermal conductivities of several metal-polymer and carbon-nanotube (CNT)-based TIMs were tested using this setup combined with the static thermal transient testing standard described in the JEDEC JESD 51-1.

T3Ster, a commercially available transient tester system, was used to determine the thermal resistance values required [12]. By making a power step on the junction of the diode, the cooling curve describing the thermal system could be captured with the transient tester. The cooling transients captured at different BLT values were turned into structure functions, which provided a map of the cumulative thermal capacitances of the heat flow path with respect to the thermal resistances measured from the location of the heating to the ambient.

Knowing the thermal resistance of the TIM, the distance between the surfaces, and the area of the cooling block, the thermal conductivity of the material was calculated. For an accurate calculation, however, the resistance of the TIM layer has to be known properly. Unfortunately, even with the high resolution of the existing transient testers and the help of the structure functions, determining it with the required accuracy based on the structure functions is extremely difficult.

However, the thermal resistance of the whole setup could be measured with high resolution, which is the sum of the θ_{total}, and a thermal resistance, which is characteristic to the measurement system. Extracting the resistance of the measurement system from the overall thermal resistance (R_{thJA}), and knowing θ_{total}, the effective thermal conductivity using Equation 1 was calculated.

A special "liquid metal" alloy was used between the grips of the tester consisting of 62.5 Ga/21.5 In/16.0 Sn having its eutectic point at 10.7 °C to measure the thermal resistance of the measurement system. This material has very high thermal conductivity, and it is highly corrosive. By placing it between the metal surfaces of the cold-plate and the diode package, a quasi-ideal thermal connection was achieved.

Figure 6 shows the R_{thJA} measured on the silicon diode of the TIM tester at minimum BLT level using the liquid metal. The value measured this way is 0.55 K/W.

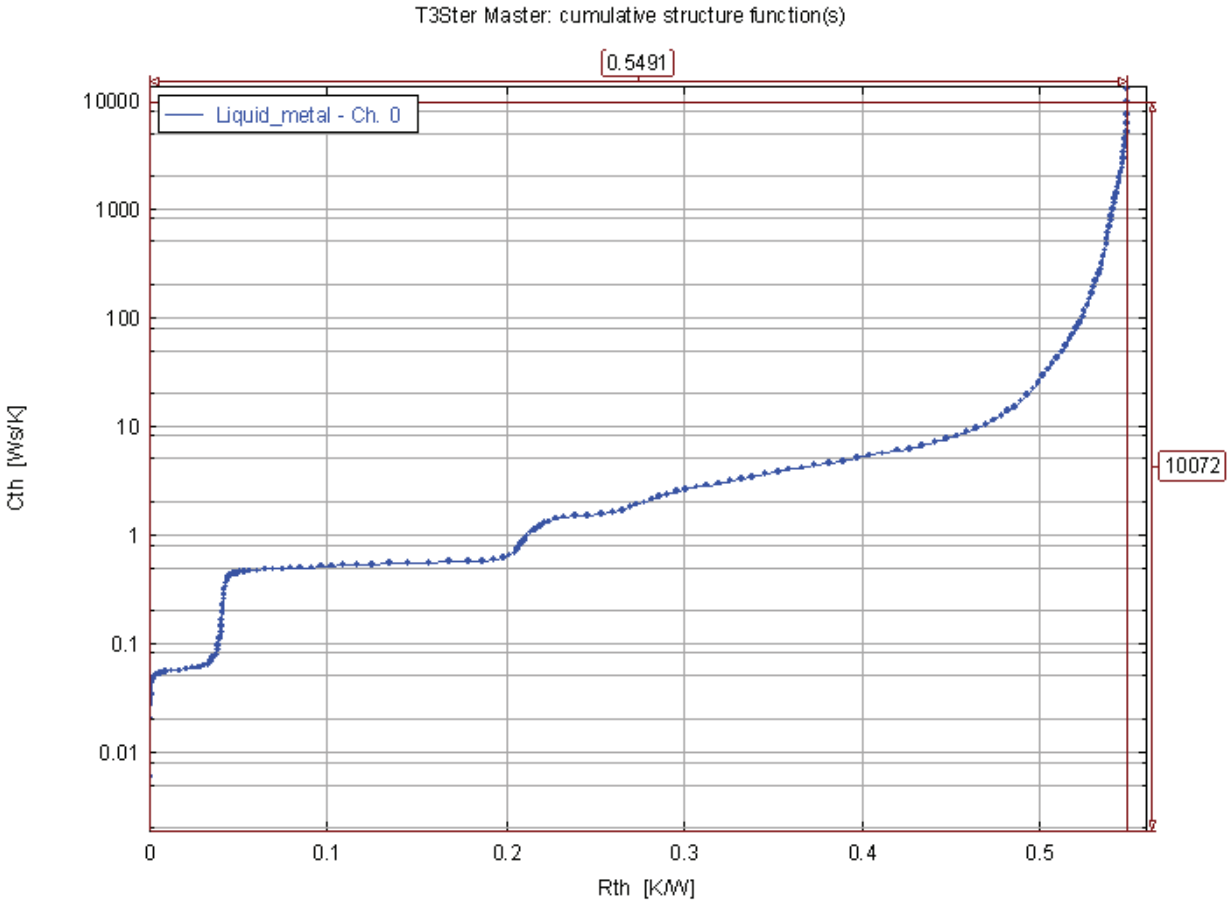

Figure 6: Junction-to-ambient thermal resistance (R_{thJA}) measured on the silicon diode of the TIM tester at minimum BLT level using the liquid metal connection.

This result was needed for the measurement of the effective conductivity of the TIM in the given environment based on one measurement point only. Even though the proposed setup was capable of doing so, the team focused on the measurement of the bulk thermal conductivity during the tests. TIM material producers in most of the cases have no information about the exact application because it is different at each customer site. Yet the group had to select the right comparison for others by reporting bulk thermal conductivity data of the materials used.

This test setup also allows the measurement of the bulk thermal conductivity by varying the thickness of the TIM. By plotting the resulting thermal resistance values as a function of the distance between the measurement surfaces, the thermal conductivity of the TIM is inversely proportional to the slope of the resulting curve based on the following equations:

$$k = \frac{\Delta L}{\Delta R_{th}} \cdot \frac{1}{A} = \frac{1}{m \cdot A} \qquad (5)$$

$$m = \frac{\Delta R_{th}}{\Delta L} \qquad (6)$$

By taking a look at the measured thermal impedance curves (Figure 7) and structure functions (Figure 8), useful information can be obtained on the thermal performance of the setup at first sight. While the heat flow is inside the diode, both types of functions fit each other perfectly. As it leaves the package boundary, the functions start to diverge. The change of the thermal resistance of the system is directly proportional to the change of the thickness of the grease layer.

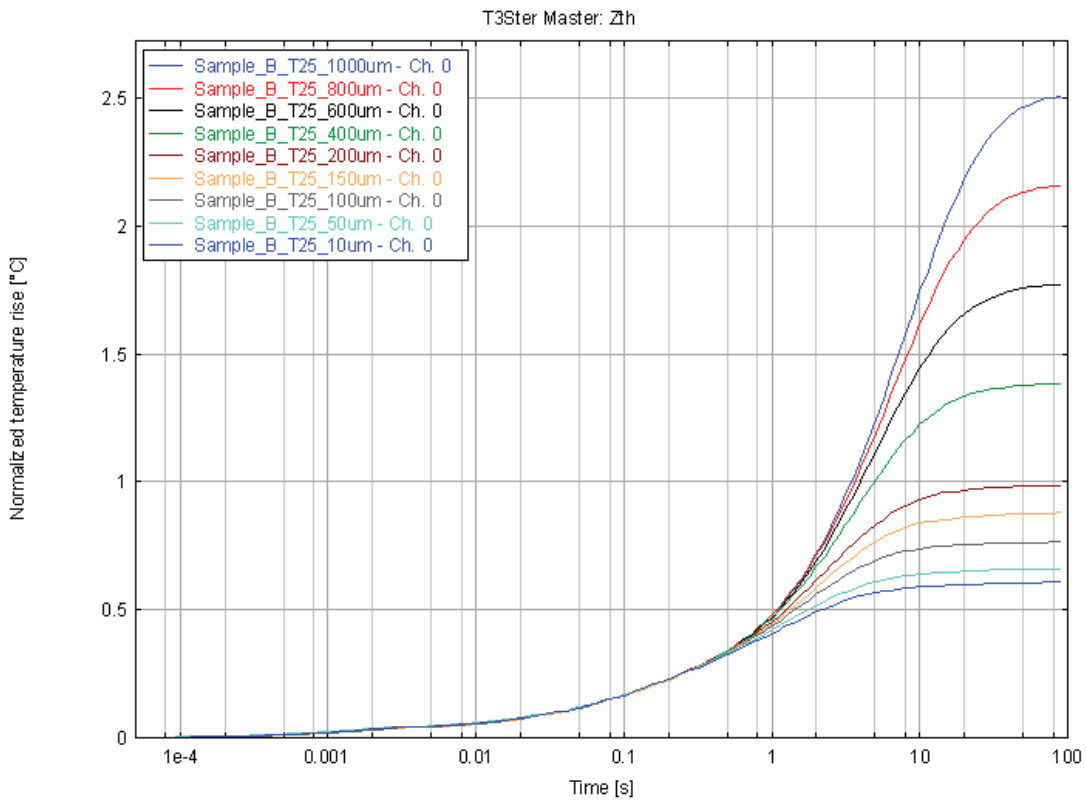

Figure 7: Thermal impedance curves captured at different BLT levels.

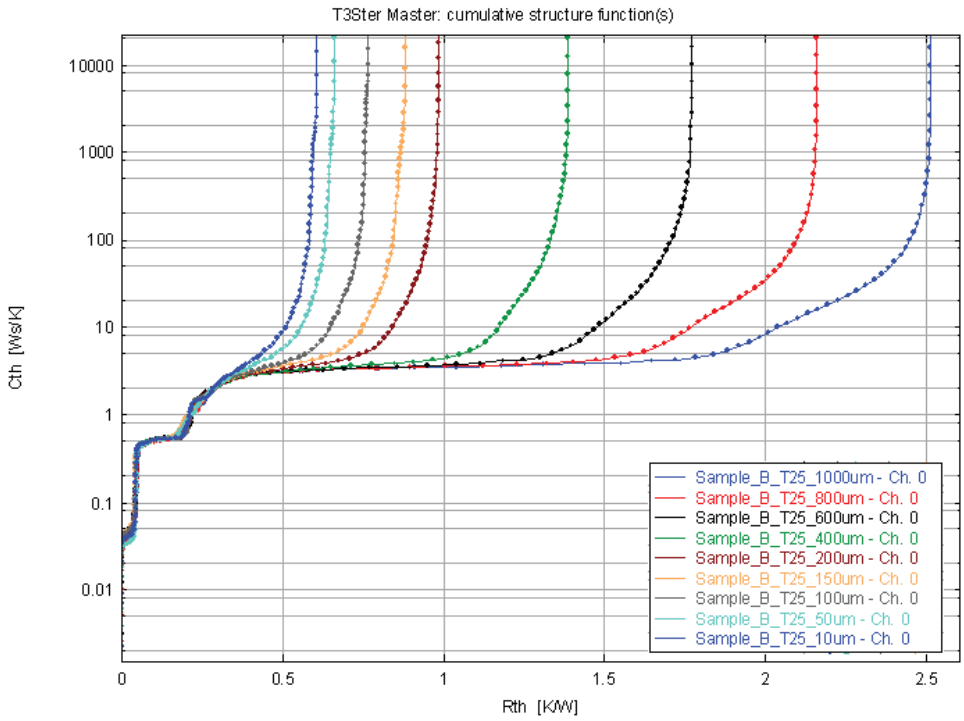

Figure 8: Structure functions derived from the thermal impedance at different BLT levels.

The junction-to-ambient thermal resistance is easy to read from the structure functions using the vertical part at the end of each curve. The thermal resistance value was measured and plotted at 10,000 Ws/K thermal capacitance value at each set BLT.

In case of the material shown in Figure 9, the minimum BLT value that could be set was 10 µm. Based on the slope of the curve, the measured thermal conductivity value was 4.1 W/mK in the case of this material.

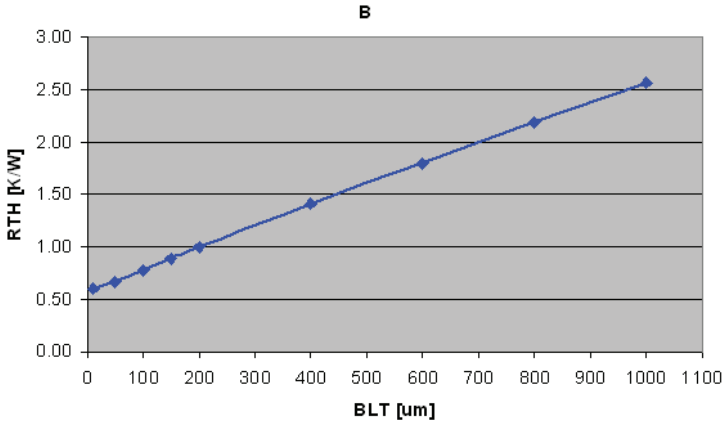

Figure 9: Thermal resistance values as a function of BLT.

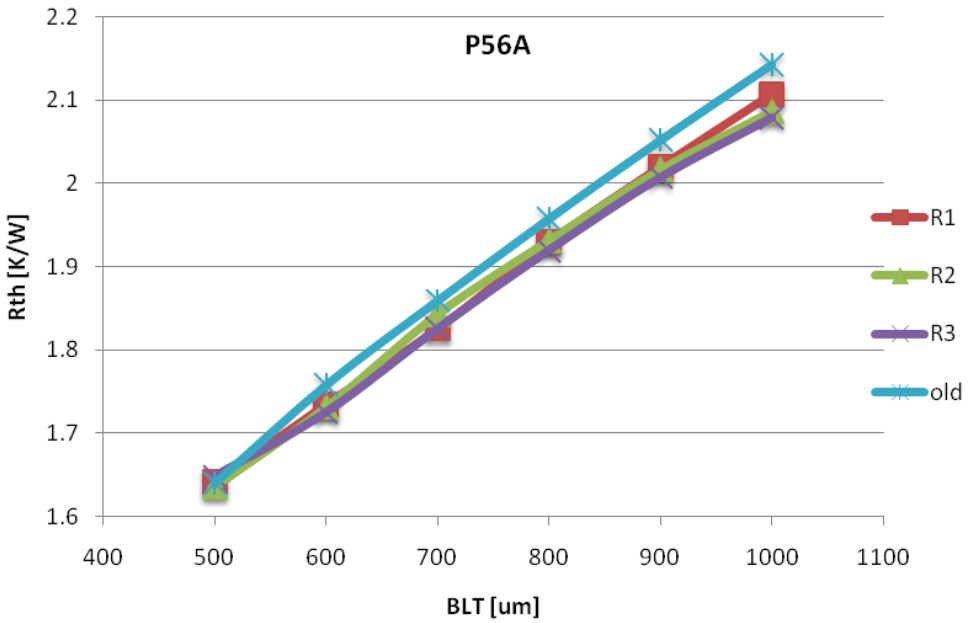

Figure 10: Results from repeatability measurements for the P56A material.

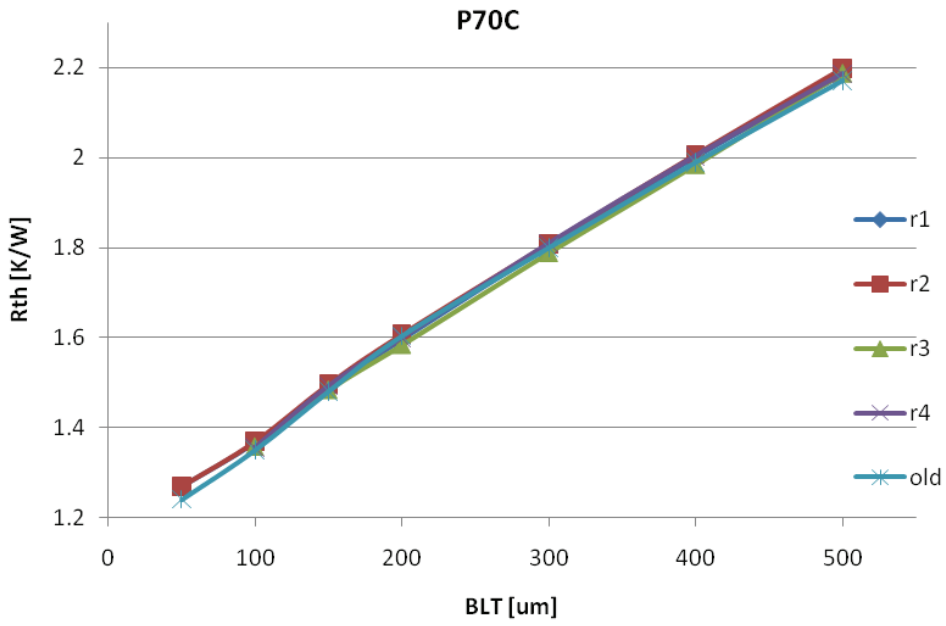

Figure 11: Results from repeatability measurements for the P70C material.

The repeatability of the measurements was also tested by applying the same type of grease several times. The results for materials with different viscosity are shown in Figures 10 and 11.

Each measurement was performed in similar conditions, after totally cleaning the grease from the surfaces and reapplying them from the same container. Sample P56A showed much higher viscosity than sample P70C, which resulted in higher standard deviation of the results (Table 1).

TABLE 1: THE RESULTS FROM SAMPLE P56A SHOWED MUCH HIGHER VISCOSITY THAN FROM SAMPLE P70C.

TIM	$\lambda_{average}$ [W/mK]	Standard Deviation
P56A	10.83	5.75 %
P70C	4.88	0.78%

The increase in the standard deviation of more viscous TIM materials originates from the phenomenon that the applicability of these materials was much more difficult and they wetted the surface less effectively than the other types.

Because TIM manufacturers need to provide reproducible bulk conductivity data, an automated test setup that eliminates the possibility of operator-specific measurement errors was designed.

AUTOMATED TEST SETUP FOR ACCURATE INDUSTRIAL EVALUATION

The team then designed automated measurement equipment to eliminate the errors originating from the manual settings and to demonstrate that the method is applicable for industrial use. The new TIM testing unit works together with T3Ster, which has high enough resolution to measure the temperature changes in the junction of a selected semiconductor at different BLT levels. The resolution and the accuracy of the automated system are also higher than the values of the experimental tester. The resolution of the set BLT is 0.1 µm, and the accuracy of the set BLT is 1 µm in case of the measurement of soft materials. The distance of the heater element and the cooling block can be set automatically with a servomotor that moves the semiconductor devices on a rail. An image of the measurement system is shown in Figure 12.

Figure 12: The DynTIM automated tester.

The first thermal resistance points were captured at higher BLT settings than in the real application. In this case, the system practically does not apply any pressure on the TIM material. It regulates to achieve the set BLT value, and the excess volume of TIM material is squeezed out of the system. The applied pressure increases at lower BLT settings only where the thickness of the TIM is close to the in situ thickness. At low BLT levels, the viscosity of the TIM materials may increase because of the congestion of the filler particles. The pressure range of the system is 1,060-3,600 kPa, and a pressure limit can be set where the measurement automatically stops. This BLT point can be defined as the minimum BLT value of the given TIM, which can be reported along with the corresponding effective thermal conductivity value.

The accuracy of the test setup depends on the accuracy and resolution of the TIM tester used and also on the accuracy and stiffness of the measurement stand. In the case of these measurements, the mechanics had an accuracy of 1 µm in terms of the set BLT for thermal greases. In the case of viscoelastic materials, the accuracy was typically better than 5 µm. The thermal transient tester used has a resolution of about 1/20th of the total thermal resistance of the system and approximately 3% accuracy, which is based on the ***k***-factor calibration of the semiconductor device [12].

An equivalent model of the tester's grips was prepared in FloTHERM (Figure 13) to demonstrate that the heat-flux generated at the junction of the power semiconductor device goes through the grips of the tester and "screens" the TIM material with sufficient efficiency, and then thermal simulations were made. The simulations demonstrated that the majority of the heat flows through the TIM—typically less than 3% of the heat-flux takes a different path. This percentage kept nearly constant through the test process; therefore, it can be considered as an offset error in the thermal resistance readings, but it does not influence the measured bulk thermal conductivity values at all.

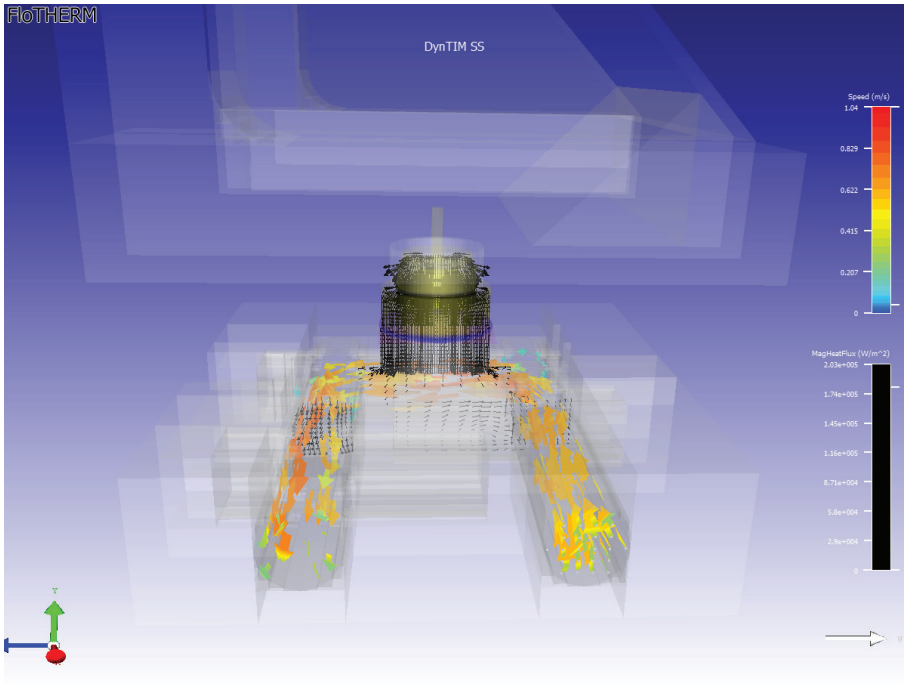

Figure 13: Thermal simulations demonstrated that less than 3% of the heat-flux takes a different path than through the TIM.

Also a crosscheck using the so-called "STATIM" high-precision TIM tester designed by Szekely, et al. [13] was performed to validate the results measured by the new methodology. Three different high-performance thermal greases from leading manufacturers were purchased. These materials are referred to here as A, B, and C. The measurements were performed with the in situ tester and the STATIM, and these results were compared to those reported by the TIM suppliers. Although both systems resemble the ASTM standard, the operation principle was different; while the team used the junction temperature measurement of packaged semiconductor devices to carry out the tests, the STATIM operates with silicon sensors on its grips capable of sensing the temperature and the heat-flux with high accuracy.

Figure 14 shows that the results measured by the STATIM and the in situ tester are very close to each other—within 10%—while, for example, in the case of material C, the difference between our measurement and the one reported by the manufacturer is approximately 900%! These results clearly point out that results reported in datasheets should be well-evaluated before making a decision on the TIM selection.

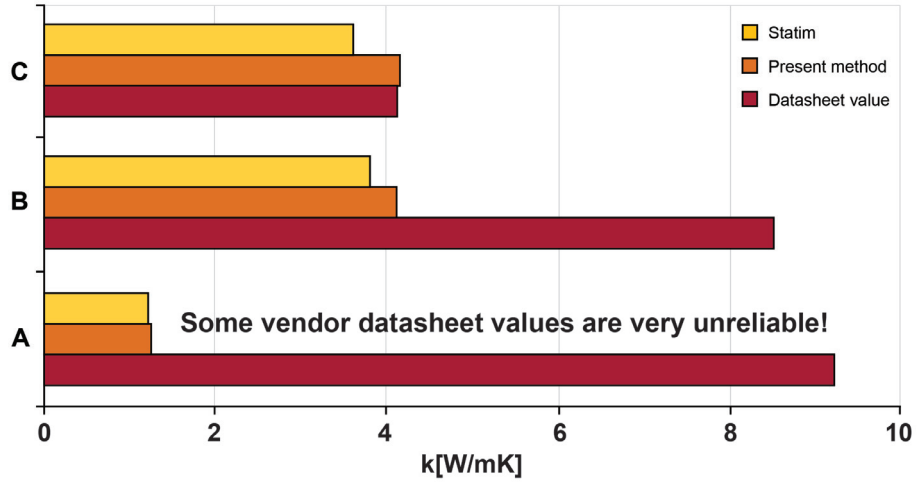

Figure 14: Comparable results on the industrial greases measured by the STATIM and the in situ tester.

Even though the current approach is mainly suitable for the measurement of greases and pastes, measurements on thermal adhesive TIM material which was prepared as sandwich-like samples between two thin silicon substrates were also conducted. The width of the material, that is, the distance between the silicon substrates, was maintained using small glass spheres with known diameters (38, 75, 106, and 250 µm) (see Figure 15).

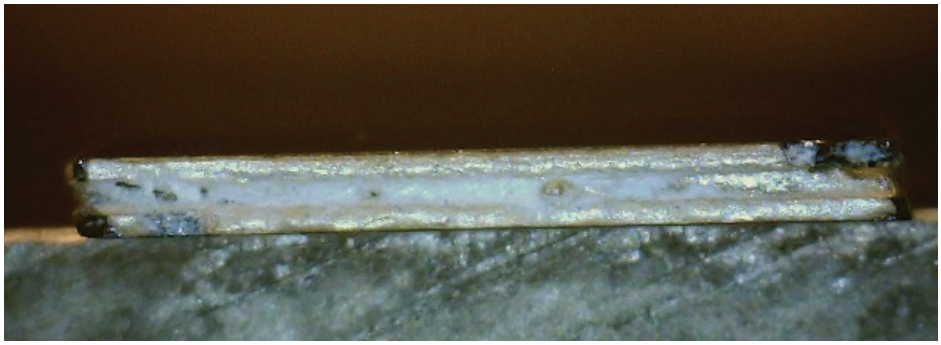

Figure 15: The TIM material inside a silicon diode.

Figure 16 shows that although the thermal resistances measured by both systems differ, there is only a constant offset between the resulting curves, with an absolute value of approximately 0.85 K/W. This value is realistic, and comes from the difference of the operating principle of the two testers. In the case of the STATIM, the temperature and heat-flux sensor chips are in the direct proximity of the measured samples; whereas, in the case of the current approach, the diode chip that acts both as a heater and as a sensor element is physically located farther from the TIM material under test. The 0.85 K/W resistance inherently contains the resistance of the package features and the spreading resistance in the cold-plate below the sample as well as the contact resistances at the grip surfaces.

This value is clearly lower than the distance between the two curves in Figure 16, and it can be assumed that the 0.85 K/W can be broken down to 0 BLT thermal resistance and the sum of the contact resistances.

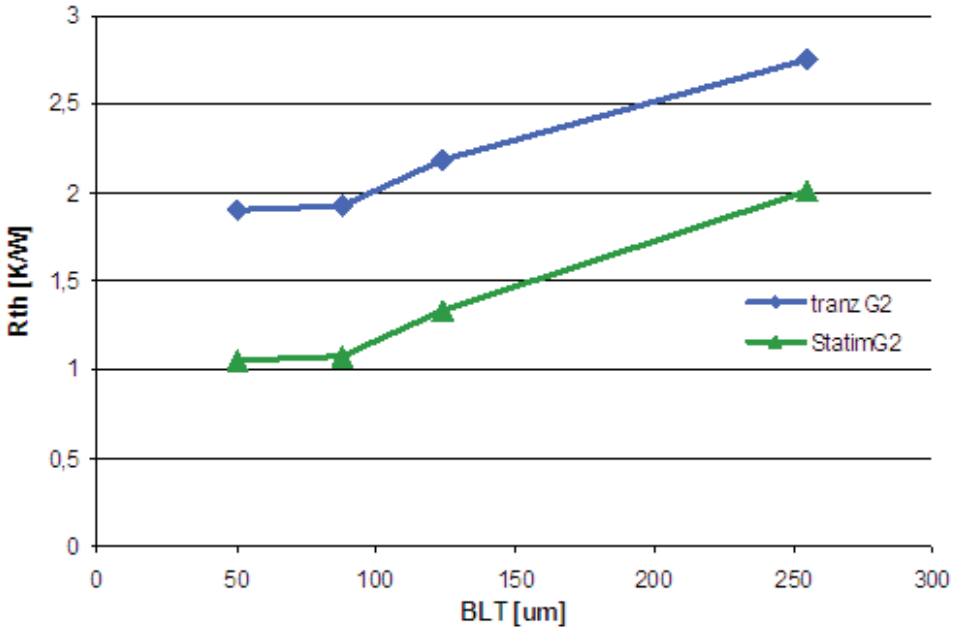

Figure 16: A comparison between the measurement results of the STATIM and the transient tester shows that they differ with an absolute value of approximately 0.85 K/W.

MEASUREMENTS OF DIFFERENT MATERIAL TYPES

Although determining the thermal conductivity based on the relationship between the thermal resistance and the varying bond line thickness is proven to be an accurate methodology, in reality, changing the material thickness is not always possible. For this reason, the ASTM standard differentiates three different material types. Based on the measurement experience gained, the following three measurement modes are recommended for these distinct groups.

For Type I materials, such as greases and pastes, strict BLT control is recommended, without maintaining any pressure on the sample. Assuming that because of its low viscosity, the excess material leaves the space between the grips as the BLT decreases during the test.

For Type II materials, that is, viscoelastic solids such as gap pads and gap fillers, BLT control with pressure limit is recommended, ensuring that the material is kept at the target thickness. Setting up a pressure limit is important so that the system can identify the minimum achievable BLT. Because this value influences the in situ Rth of the material, it should be listed in the datasheets.

For Type III materials (non-compressible solids), pressure control is advised. This way, the measurement of different samples at different thicknesses is possible, assuming that the contact resistances remain the same because of the comparable pressure at each thickness tested.

The use of a high conductivity thermal grease is recommended between the surfaces of the sample and the grips to reduce the contact resistances.

TYPE I MATERIALS

The measurement of Type I materials is the most straightforward task because the test system used in this study is capable of accurate BLT control. The BLT values used during the test should be selected such that they correspond to the BLT range set in the targeted application. In this study, the silicon-based thermal grease was tested five times, and the resulting test data can be viewed in Figure 17.

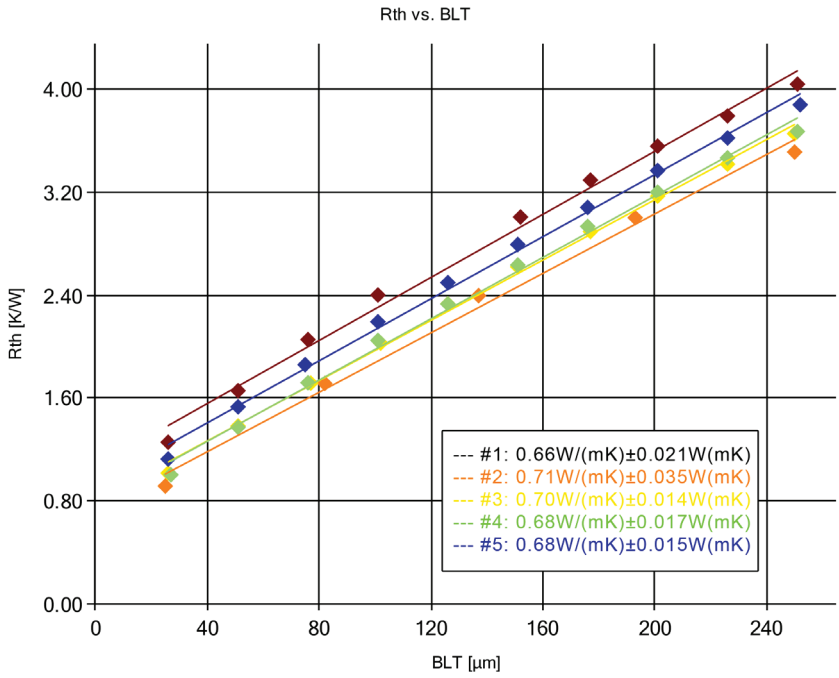

Figure 17: Measurement results on a silicon-based thermal grease.

The average conductivity value based on the five subsequent measurements resulted in 0.69 W/(mK) with a standard deviation of 0.02 W/(mK). The slight offset between the points corresponding to different measurements originates from the difference in the inherent thermal resistance of the different measurement systems. Because of the measured materials' low viscosity, the excess material gets squeezed out from the gap between the tester's grips, so the pressure remains 0 all through the test.

TYPE II MATERIALS

The measurement of viscoelastic materials is a more complex task because their viscosity is much higher than the thermal greases'. The materials get compressed because the BLT is reduced during testing. Typical results measured on a viscoelastic gap-pad are shown in Figure 18.

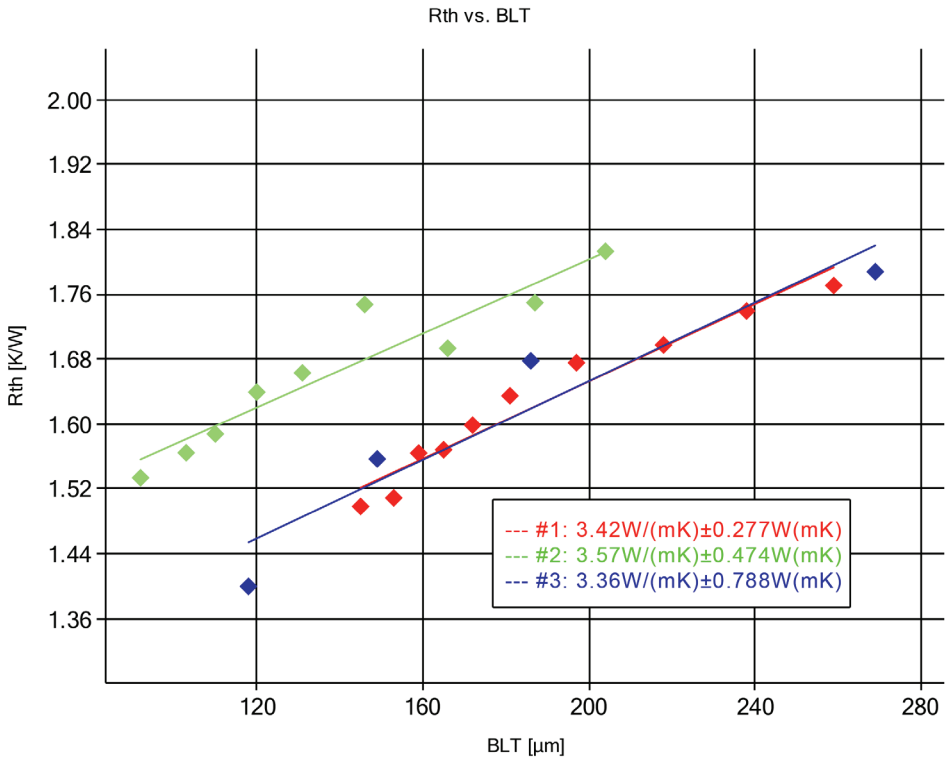

Figure 18: Measurement results on gap-pad samples.

The mean value of the test results shown in Figure 18 is 3.45 W/(mK) with a standard deviation of 0.108 W/(mK). The corresponding pressure values range varied between 1,060 and 1,800 kPa.

Beside the BLT-controlled operation, pressure-controlled measurement is also possible for the test of viscoelastic materials. This latter approach is widely used within the industry because controlling the pressure is a more straightforward task than controlling the BLT in an application environment.

The mechanical behavior of such viscoelastic polymer compounds is described by the "standard linear solid" model, where the springs represent the elastic behavior of the model, while the dashpot models the viscous element of the material's behavior.

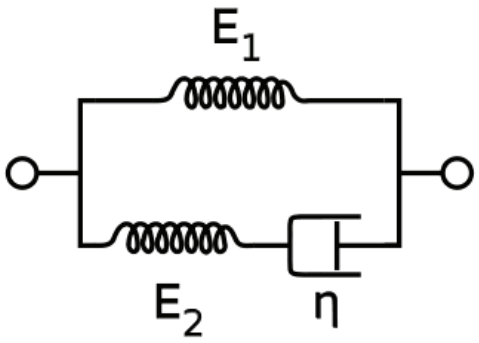

Figure 19: Standard linear solid model of polymer compounds [14].

The model denotes that the thickness may change in time while a constant pressure is applied on the modeled material because of its viscous behavior.

The error introduced by the relaxation effect explained above obviously depends on the mechanical parameters shown in the model in Figure 19. The more elastic and the more viscous the material is, the smaller the error will become. Figure 20 shows measurement data taken on a material where the error factor was not significant.

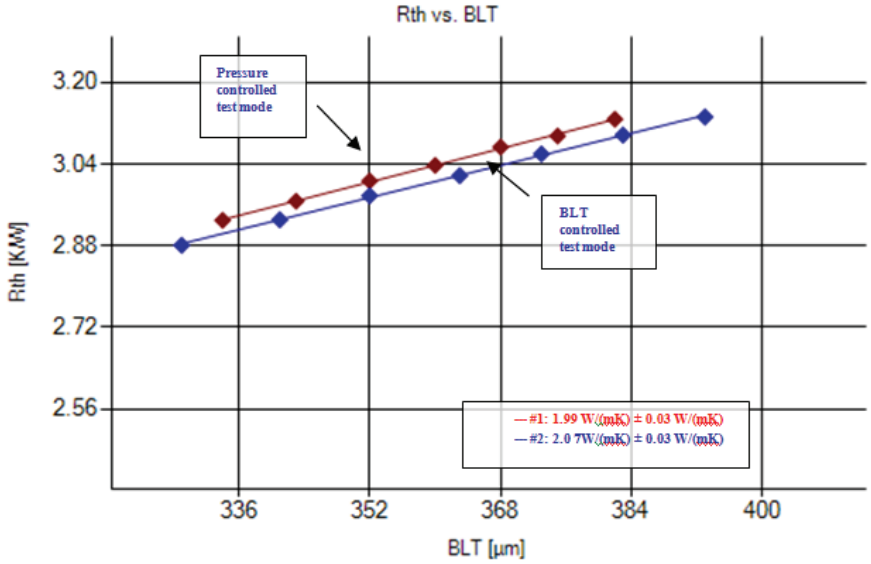

Figure 20: Comparison of test data taken at by pressure and BLT controlled methods.

Although this example shows that the difference is marginal, that is, close to the error limits of the individual measurements, the measurement mode in case of viscoelastic samples should be chosen carefully.

TYPE III MATERIALS

The measurement of solid materials may be important in a number of applications. Metals, plastics, even adhesive samples cured between a sandwich of conductive layers should be tested using this approach. The main difference to the previous two methods is that, in the case of Type III materials, even at higher pressures, no deformation should occur. For this reason, samples with different thickness values have to be prepared to maintain the ability to measure at different BLT levels. A measurement example on AISI 422-grade stainless steel samples, with a textbook conductivity of 23.9 W/mK, is shown in Figure 21.

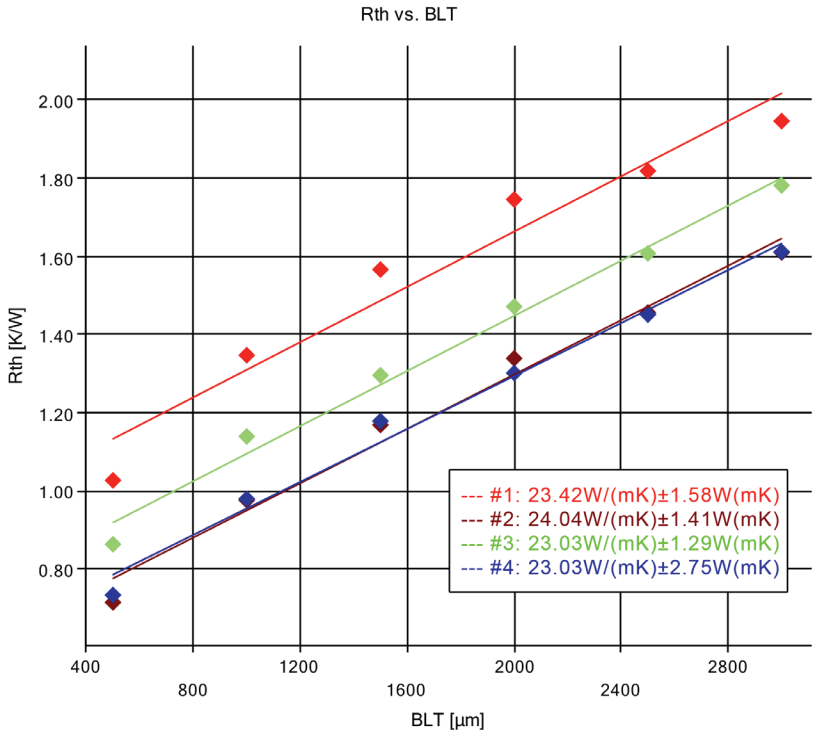

Figure 21: Measurement results on stainless steel samples.

The sample thicknesses were varied between 3 mm and 0.5 mm in 0.5 mm steps. The resulting average conductivity data based on the four measurements shown above was 23.39 W/mK, with a standard deviation of 0.46 W/mK.

The measurements were carried out such that thermal grease was applied between the grips and the sample's sides. The constant 3.6 MPa pressure ensured that the grease is squeezed to an acceptably short BLT; and as all measurements were conducted using the same boundary conditions, the thermal resistance added by the grease cancels out.

AUTOMATED TIM MEASUREMENT METHODOLOGY WITH THE DynTIM TESTER

The commercial outcome of this TIM testing methodology development is the DynTIM Tester equipment. Combined with the T3Ster test product, it provides the industry's most accurate method of measuring thermal resistance of TIMs on a variety of materials at different pre-set thickness levels, such as greases, pastes, phase-changing materials, and even specially prepared metallic samples. On average, the DynTIM tester provides TIM measurement accuracy by ±5% with the highest repeatability results, which the industry is currently lacking because most ASTM-based tests are conducted using in-house test systems.

Engineers who use DynTIM can test a large number of different TIMs to create a short-list of the best performing materials as possible candidates for the application. After the measurement of the material properties and narrowed selection of the TIMs, T3Ster is capable of testing these materials in situ, in their target environment, for the best possible design decision. This solution is ideal for the manufacturers of semiconductor, electric appliance, and materials markets where controlled manufacturing of materials performance is critical.

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