# Challenges in Testing

## Thermal Interface Materials

When choosing a thermal interface material (TIM), most of the time we look at the datasheet and find the thermal impedance if it is a solid material, or the thermal conductivity if it is a grease. Then, we calculate the thermal resistance and temperature rise with those numbers. But, how do we know that a TIM is performing as advertised? Can we really tell if one TIM will perform better than another, based on their specs?

To choose a TIM, we often start by comparing the TIM datasheets to each other. For this reason, it is obviously important that all of the data is generated in the same way, under the same test conditions. We may also want to verify the performance of a batch of TIM we have just received, in which case our test should also follow the same conditions that the manufacturer used. But this is much easier said than done.

There are a number of problems that can make it difficult to evaluate TIM performance, and most of these boil down to the fact that everybody who is testing TIMs does it a little differently. Standards such as the ASTM D-5470 exist, but the test pressures called for in the standard do not reflect the pressures typically seen in applications of electronics thermal management. Moreover, differences can exist between test rigs that adhere to the D-5470 standard.

The standard dictates a test rig that is some kind of stack, with a heater on one side to provide power, and a cooler on the other side to dissipate the heat. In between the two sides is the TIM test sample (See Figure 1). The standard dictates that the two surfaces that contact the TIM be parallel, with smooth surface finish. Even so, different contact resistances can still occur from one test rig to the next.

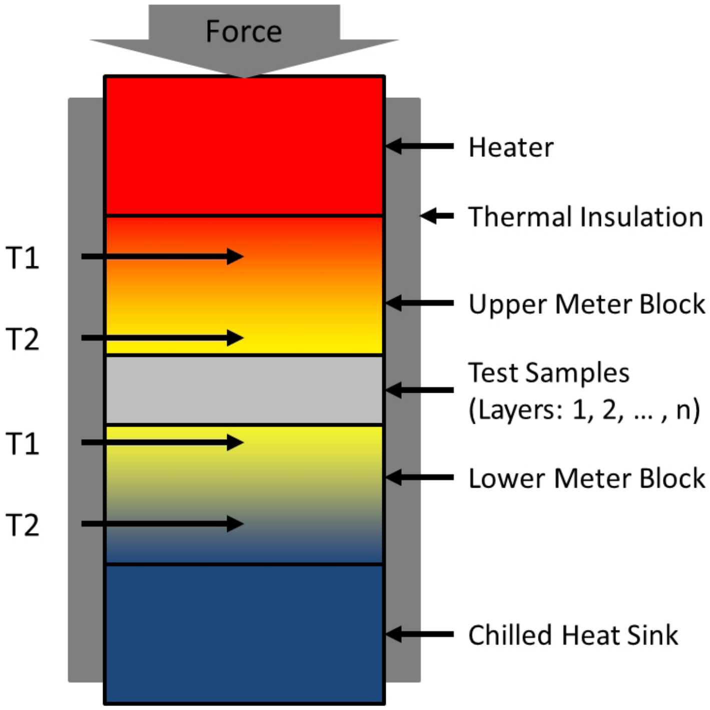


*Figure 1. Typical ASTM D-5470 Test Fixture [1]*

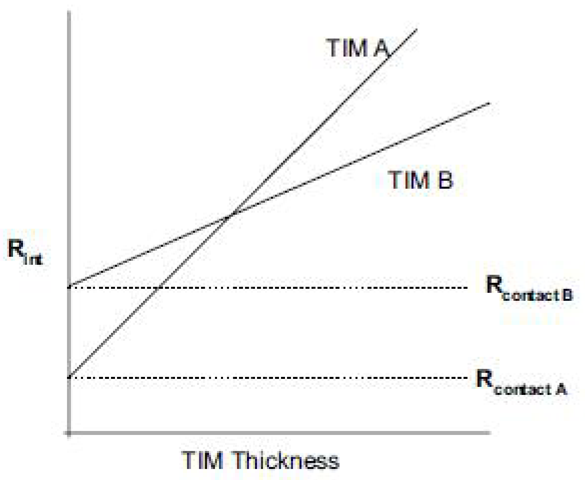


*Figure 2. Typical $R_{TIM}$ vs TIM Thickness [2]*

ASTM D-5470 solves the problem of different contact resistances by testing TIM samples of the same material in different thicknesses. This way, a plot of TIM thickness vs $R_{TIM}$ can be plotted, and at the y intercept where the thickness would be 0, the total contact resistance (on both sides) of the test sample can be obtained. See Figure 2 below. The standard then recommends reporting the thermal conductivity or resistance of the TIM while excluding contact resistance.

The problem posed to end users by this method is that the contact resistance is not listed on TIM datasheets, because it is impossible for the TIM manufacturer to know what it will be in a given application. Ideally, a TIM would be tested in conditions that are as close as possible to its real application, but this is not always possible. This does highlight the importance of having good flatness and finish specifications for TIM mating surfaces, in order to minimize contact resistance. In fact, in cases of thermal greases with very thin bond lines, the contact resistance can become a significant, and even a majority, portion of the total interface resistance [3].

In the D-5470 test rig, other sources of inaccuracy involve temperature measurement. The rig measures temperature at a minimum of 4 points, so these sensors all need to be carefully calibrated in order to measure the temperature gradient along the bars. The position of the sensors themselves also needs to be known very accurately, in order to extrapolate the temperature gradient to the surfaces which contact the TIM.

Even if we can assume that these inaccuracies are small, and the test uncertainty is acceptable, we still face many variables with regards to how the TIM is going to be used in its final application, and all of these variables will affect the actual TIM performance. When considering thermal grease, for example, this falls into the first type of material defined in D-5470, a "liquid material". These materials are tested at a controlled thickness, and pressure is disregarded.

Right away, we can see a discrepancy between the standard and actual applications. In most cases, heat sinks are mounted on a component with springs applying constant pressure. This is done to conform to variations in component height, heat sink dimensional tolerances, and in parallelism between the heat sink and component. But it is important to note that the TIM is loaded with a certain pressure. In the case of grease, materials with different viscosities will have different thicknesses in a given application. In addition, the same grease layer may change in thickness with time and temperature, or possibly even "pump out" of the interface, leaving it with very little TIM [4].

These changes are evidenced by testing conducted by Pang, et al. [4]. Grease samples were tested between a simulated CPU and an active heat sink. A mounting pressure of 35 psi was applied to the grease, and testing was run at 90ºC for 24 hours. The total resistance from the CPU to ambient air was measured at the beginning and end of the test cycle, and the difference, if any, is attributable solely to resistance changes in the TIM. Results can be seen in Figure 3 below, for several different greases.

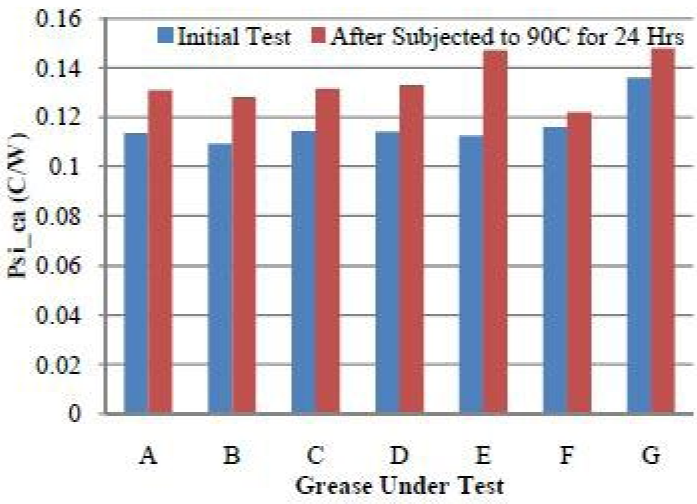


*Figure 3. Changes in $R_{TIM}$ After 24 Hours at 90ºC [4]*

In this case, the $R_{TIM}$ was not affected so much by the bond line changing (which probably would have decreased, lowering the resistance), but by another phenomenon that affects grease, which is dry-out. Over a period of time, the carrier in thermal grease may evaporate or otherwise leave the interface, increasing the thermal resistance.

One type of TIM testing that can do away with some of the uncertainties of the D-5470 test is transient testing. While the standard D-5470 test evaluates TIMs at steady state conditions, by calculating the temperature at each side of the TIM, transient methods can measure temperature at a single point, and do not have to wait for the test rig to reach steady state. Instead, a "structure function" is generated based on the temperature response to a stepped power input [5].

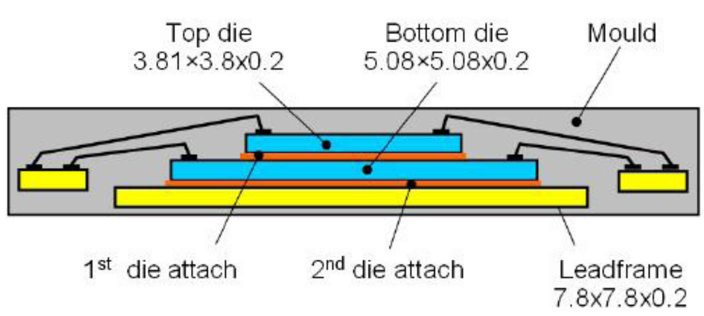


*Figure 4. Cross Section of a Stacked Die Component [5]*

Rencz et al. [5] performed a transient thermal test on a component with a stacked die configuration, shown above in Figure 4. The top die was used as the heat source, and also incorporated a temperature sensor. Because all of the measurement was done at one point, the problems with having multiple temperature sensors were eliminated. The position of the sensor does not have to be precisely measured, and the sensor does not have to be calibrated, so long as it has a linear response. The test can also be performed in a setup which is nearly the same as an in-situ application, rather than a test rig that has no similarity to an end use application.

Using commercially available thermal analysis software, Rencz et al. [5] were able to generate the structure function for the stacked die, shown in Figure 5. This plot is based on the temperature response of the entire system, from the top die where the heat is generated, to the lead frame and cold plate where the heat is ultimately dissipated. As we move through the parts of the system, the observed thermal resistance rises, and so does the thermal capacitance. Where the plot rises more sharply, it indicates the presence of a mass, which contributes to the thermal capacitance.

In between those sharp rises, where the resistance increases and the capacitance does not increase much, are regions that indicate the thermal interfaces. By measuring the distance of these areas on the plot, the thermal resistance of the interface can be calculated, as indicated on the plot. Another way to read this plot is to look at the derivative of the structure function with respect to $R_{th}$. Then, peak-to-peak measurements indicate TIM resistance, and this may be clearer for measurement purposes.

The material presented here suggests that the data printed in TIM datasheets should be evaluated carefully to ensure that the testing procedures

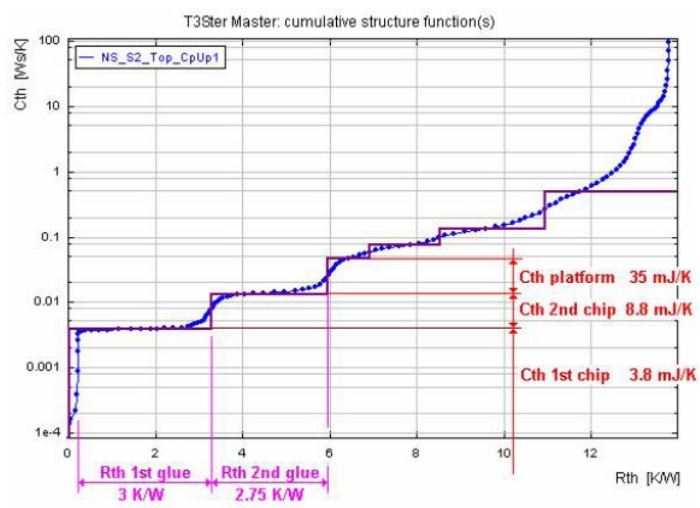


*Figure 5. Structure Function for the Stacked Die Component [5]*

are similar to the actual application. Furthermore, even with the existing standards, many variables still exist. In choosing TIMs, it is helpful to be familiar with the conditions that are specified by the standard; and in critical applications, it is best practice to evaluate TIMs under the actual use conditions. Using a transient technique, there is at least one way to perform that test which is easy to implement and may be quicker than conventional steady state tests. This may prove more important, if many samples are to be tested.

**References:**


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2. **Chu, C. P., Solbrekken, G. L., and Chung, Y. D., Thermal Modeling of Grease-Type Interface Material in PPGA Application, Semi-Therm 1997.**

3. **"Thermal Conductivity Measurement", http://www.analysistech.com/material-faq.htm, [Sept. 10, 2013].**

4. **Pang, Y. F., Mohammed, R. K., Sahan, R. A., Xia, Y., and Prabhugoud, M., "TIM Selection Criteria for Silicon Validation Environment", Intel Corporation, Santa Clara, CA, 2010.**

5. **Rencz, M., Szekely, V., Courtois, B., Zhang, L., Howard, N., and Nguyen, L., "Die Attach Quality Control of 3D Stacked Dies", Proceeding of the IEMT Symposium of SEMICON West, Jul 12-16, San Jose, CA, 2004, Proceedings pp 78-84.**