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# Thermal Interface Materials (TIM) for Power Electronics

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## Overview

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- EEMC is representing: Parker Hannifin Chomerics Division Europe
- Chomerics is a major supplier in the EMI shielding and Thermal interface materials market
- Most of the products developed by the company have been designed for the power electronics, in the aerospace, military, telecoms, and automotive market places.


Chomerics original incorporation was 1961.

Brand names such as Cho-Therm, Thermattach, Therm-a-gap Therm-a-form are well established in the marketplace today.

We’ll cover some familiar topics along with some not so obvious subjects that come up when discussing thermal interface materials and problem with customers.

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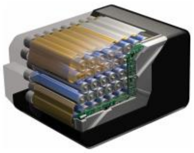
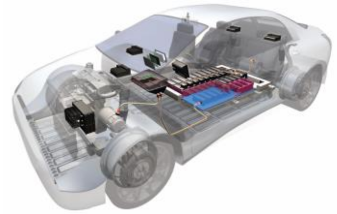
# Agenda

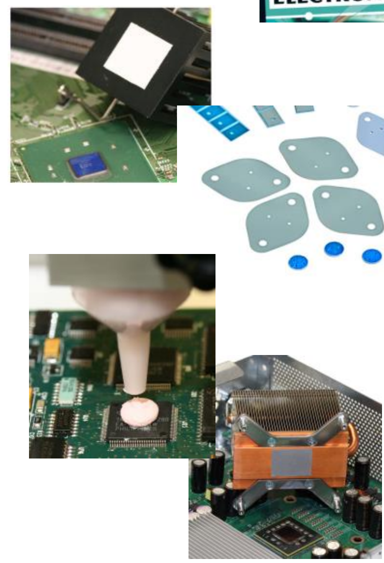
- Historical development of TIM Materials
- Challenges involved in developing TIM materials
- Thermal interface materials for use in Automotive applications
- Air as the Enemy
- Strategies for gap filling
- Closure forces generated during assembly
- How to read ( between the lines) a TIM data sheet
- When a 50w/mK TIM is not 50W/mK but is not a lie.





# Historical TIM development

- Pre Transistor – Little requirement as components were large and typically vacuum tube components failed frequently.
- Semiconductor devices
  - Mica washers
  - Thermal grease
    - typical conductivity ± 0.7w/mK .
- Substituted by
  - silicone pads
  - adhesive tapes
  - silicone gap fillers
- More recently: Phase change, Gel Materials and cure-in-place compounds.



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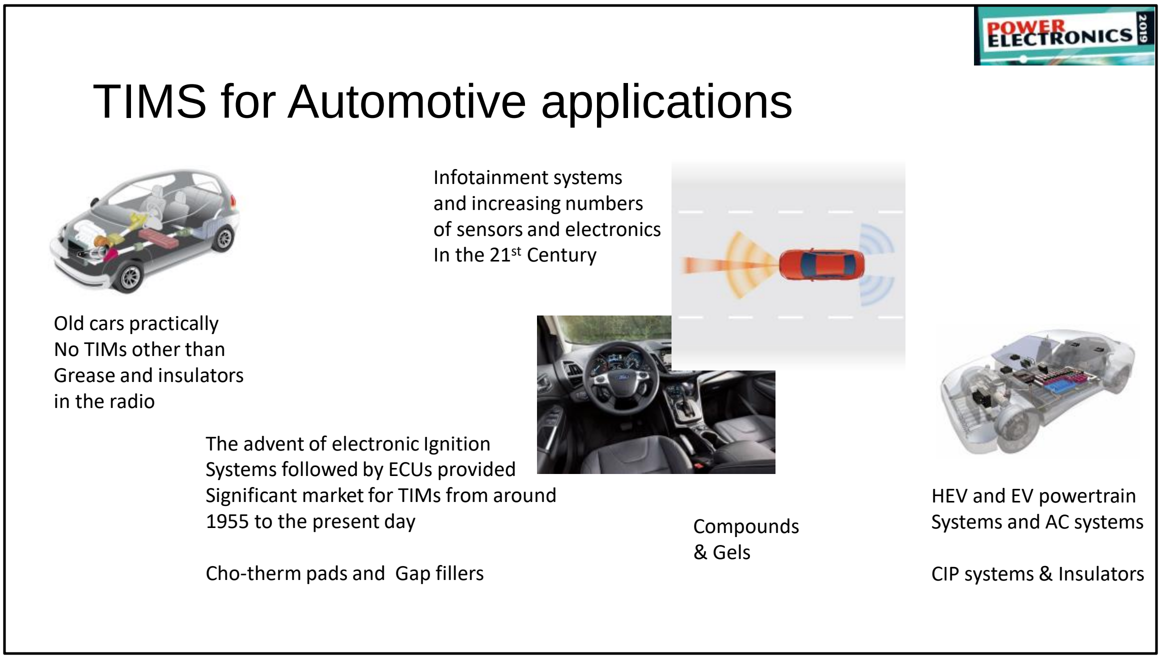


Now if you look at the figures above

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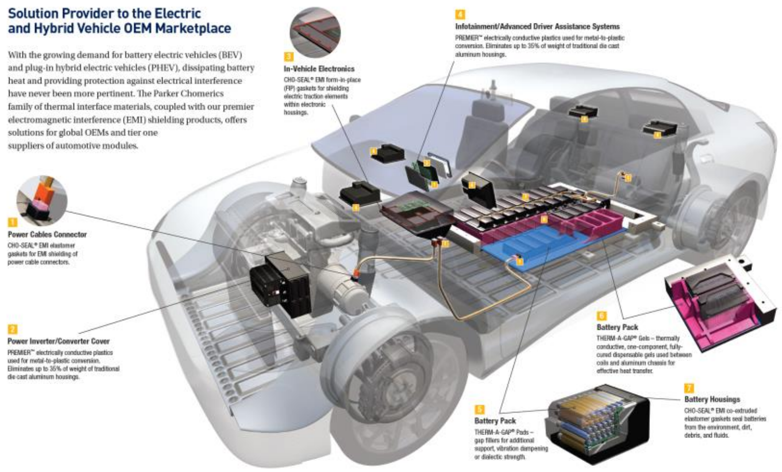
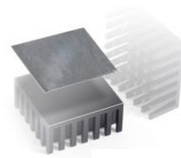
# TIMS for Automotive applications




Commentary for this slide

# Product ranges available today

- Grease & Mica
- Silicone thermal insulators
- Silicone thermal gap fillers
- Phase change materials
- Thermal adhesives- tapes and compounds
- Thermal Gels – 1 part and 2 part materials
- Thermal potting compounds



Grease & Mica –Still going strong
Silicone thermal insulators – just as popular
Silicone thermal gap fillers – now into their 3rd or 4th generation
Phase change materials- basically waxes with a variety of fillers
Thermal adhesives- tapes and compounds with a range of properties
Thermal Gels – 1 part and 2 part materials for high volume electronics
Thermal potting compounds – silicones, urethanes and epoxies mainly

They all do the same thing, eliminate the air from the gap and provide the excess heat with a path to the heatsink which is of lower thermal impedance. Which solution or solutions you finally decide on can depend on a number of parameters. These include:
the geometry,
the tolerance stack,
the method of assembly,
serviceability,
expected service conditions,
method of attachment,
to name but a few. The list is long and I am sure you can probably add many more

based on your industry sector.

The tendency however with modern electronics and high volume assembly methods has been towards the use of automated dispensing of adhesives, gels, and cure-in-place compounds that can accommodate a wide range of nominal gap sizes and at the same time be incorporated into flexible manufacturing systems simply be reprogramming the dispensing equipment for the product being manufactured. The electronic industry has been dispensing solder paste and adhesives for years so gap filling gels and cure-in place compounds are really just another addition to the solid/liquid material dispensing they already know and love/hate depending on the production staff you talk to.

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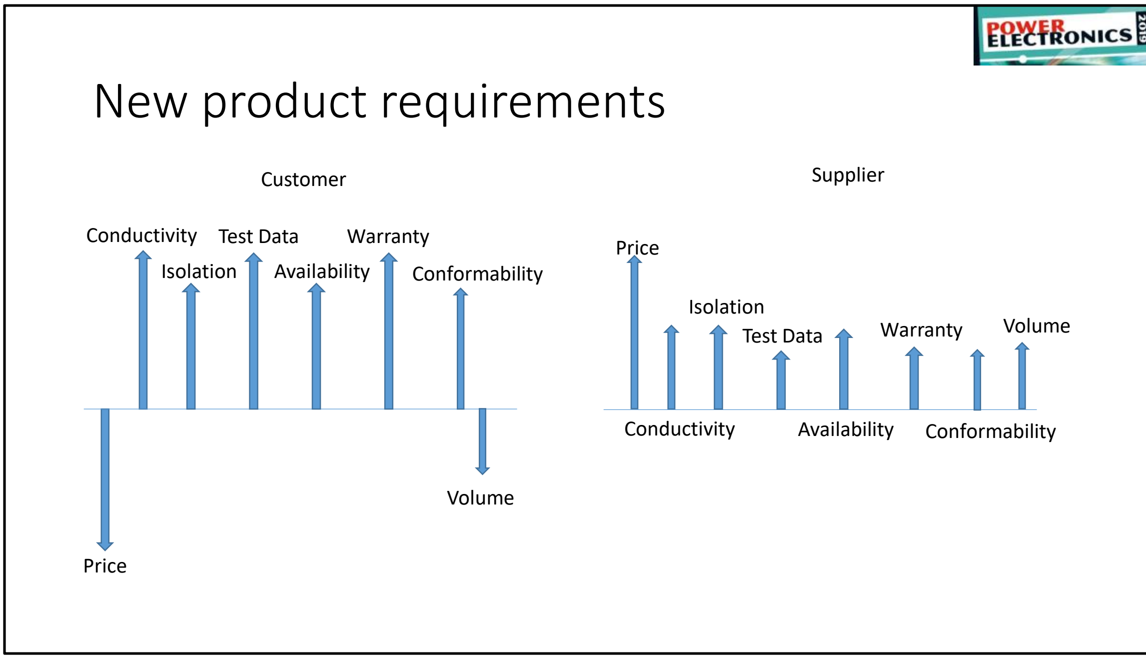



Parker Chomerics has been in the business of making Shielding materials since the 1960's and thermals materials as far as I can make out since the 1970's Not surprising really as you can fill silicone with Alumina really just as easily as filling it with metal particles.

Like our competitors in the Thermal interface market place we have to meet lots of customer requirements such as thermal conductivity whilst ensuring we meet the price targets and still make a profit. This is quite challenging as the raw materials which go into these products generally are produced primarily for other markets which have vastly bigger demands. This basically means that a customer in the TIM business requiring say a few hundred tonnes of alumina a year has very little influence on a business supplying industries which require tens of thousands of tonnes a year.

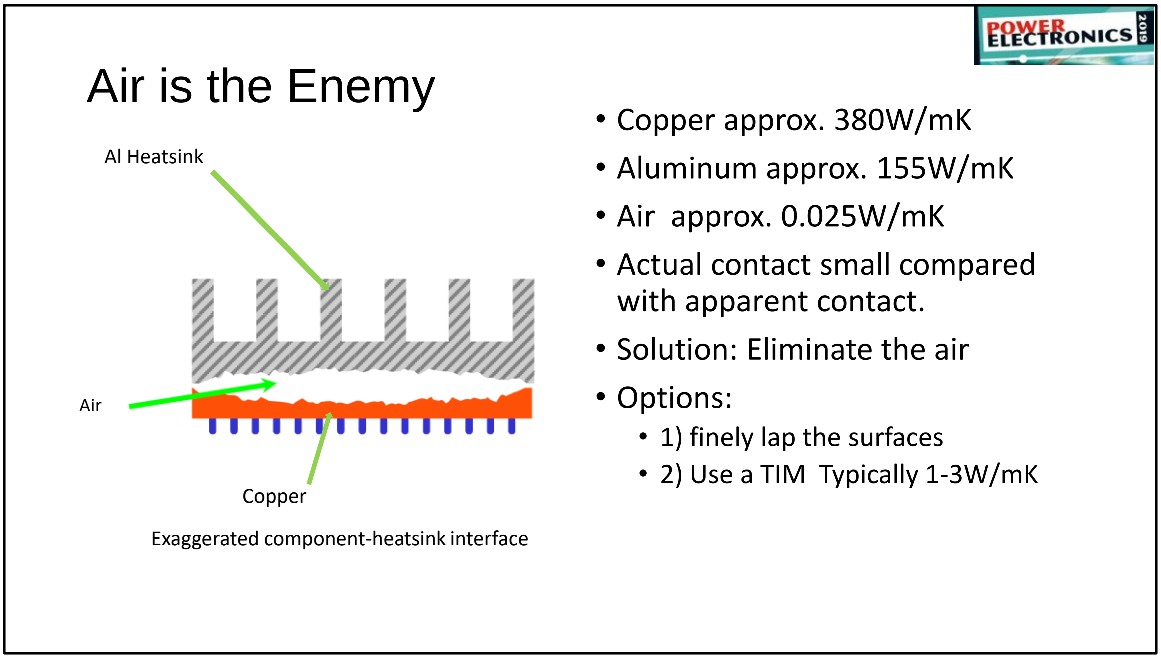
Customer considerations

- Conductivity
- Soft
- Conformable
- Low relative permittivity

High voltage breakdown
Robust
Highly reliable
Easy to use
Lots of test and reliability data
Shelf life
Life in application
Rework
Readily available
Low cost

Supplier considerations
Is the product safe ?
Is the product environmentally friendly?
Can we make it ?
Can we source the raw materials reliably?
Is the market big enough?
How long will the market exist ?
Can the technology be used for next gen products?
How much testing do we need to do?
How do we test it?
Is there any significant competition?
Can we make a profit?

Quite often the suppliers of the raw material have already branched out into making value added products themselves, quite often making the supplier also a competitor in one form or another. It also means that the security of the raw material supply can be a real issue if for example the product relies on a single source. Normal corporated product development rules, generally require the qualification of at least two suppliers of an item to allow the development product to pass on the road to product release.




In most thermal systems air is the final method which removes or dispersed heat from a system. The removal of the heat may initially be in the form of mass and heat transfer using say water cooling but eventually this arrives at a radiator over which air flows, either with natural or forced convection. Now we have plenty of surface area on the heat sink to allow the air to remove the heat with the air running across it. You can assume around a 10-20°C increase in air temp at around 1-2m/s so you can estimate the heat removal based on the mass and heat capacity of the air flowing across the heat sink per sec.

Now with no TIM in place the component will continue to increase in temperature until the system either reaches equilibrium or the component overheats and fails or if it is a bit more sophisticated shuts down to prevent damage

Air thermal conductivity approx. 0.025W/mK
Copper Thermal conductivity approx 380W/mK
Aluminium Alloys approx. 155W/mK

Solution 1) is the preferred solution of the vast majority of CPU overclockers in conjunction with high conductivity TIMs such as grease or PCM. However for most of us in the real world we do not have time or inclination to do such things so we just use a thicker TIM and accept that the interface will be less efficient. However even with a relatively  low 1W/mK material we will still be able to conduct  upto  40 times more heat  2W/mK  80 times more and 3W/mK  upto  120 times more.

The more conductive the material use as a TIM the more it will cost you,  Typically they are filled with Alumina or Boron Nitride, graphite metals, diamonds carbon nanotubes and can range from 1W/mK to 50W/mK  depending on  what you require. There are also foils made from indium which are also very conformable and used in cryogenic applications.

Note you can load the interface material with metals such as silver but there are many applications where an electrically conductive filler is not desirable or acceptable

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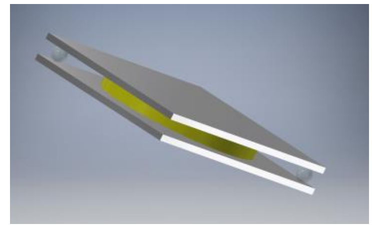
## Strategies for gap filling

- Force controlled
- Geometry controlled
- Permanent
- Reworkable



There are four basic issues that need to be addressed when it comes to filling any sort of gap be it for thermal or EMI purposes

Force controlled system are generally those which have no effective control other than the force deflecting the pad or the material either with, clips or springs.

Geometry controlled systems like mechanical screws, stand-offs, recession/groove, enclosure as heatsink.

The typical CPU heatsink  is generally held in place with spring loaded fixings while things like power IGBT modules  generally are screwed down with the tim already applied to a baseplate. In the case of the CPU heat sink what used to be grease has been replaced to a large extent by phase change material and this is true also of the IGBT power modules.  However in the case of the CPU the forces are relatively low whilst in the case of the IGBT they are relatively high.  The idea being in both cases that the operating temperature of the phase change material after the first cycle  is below the phase change temperature.  In both cases the material is reworkable.

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# Strategies for gap filling

- What is the area?
- How big is the gap?
- What is the tolerance stack on the gap?
- What sort of fixings have you?
- How much heat do you need to dissipate?
- What is the max allowable component temperature?
- What is the maximum ambient temperature likely to be?
- Volume?

When it comes to having a strategy for gap filling you have to ask a few fundamental questions most of which relate to the properties and customer requirements. Some however relate to the geometry and assembly requirements of the equipment.

Probably the first question to be answered is how big is the gap.?

(0 - 0.2mm) Small gaps are filled with solder, grease, phase change materials, adhesives or underfill compounds.
(0.2-0.5mm) Slightly larger gaps with gels, cure-in-place compounds, thin pads, and tapes.
(0.5 -10mm) form stable gap fillers, potting compounds, putty.
In all these cases there may be overlaps between the groups.

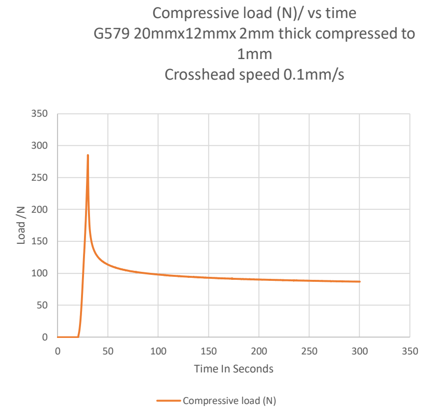
Control of the gap is also important for example if you have a zero-0.2mm gap you may need to be looking at a gel or phase change material especially if the allowable fixing forces are relatively low. On the other hand if you have sufficient screw fixings you may be able to use a form stable gap filler.

The next  question you probably should answer if not the first is how much heat do you need to dissipate and what is the max allowable component temperature and what is the maximum ambient temperature likely to be?

If you have components that are very efficient and can take high temperatures it may be possible to use lower performing TIM components. On the other hand if you want to have the heatsink as hot as possible in order to efficiently transfer heat from the component and into the air flow then a higher performing TIM is required.

# Closure forces generated during assembly

- Most stress strain data provided by TIM manufacturers is quasi static
- Assembly strain rate speeds result in forces considerably higher than the quasi static case.
- Real world assembly speeds between 5 and 10 [mm/sec]
- Note the graph for a small rectangular pad compressed to 50%



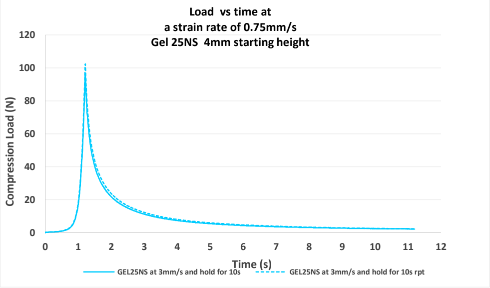

Peak loading at a mere 0.1 [mm/s] or 6 [mm] per minute reaches nearly 300N ( 30kg) between two stainless steel platens. However note how quickly the load drops once the crosshead stops moving and the final loading is about a third of the peak load.

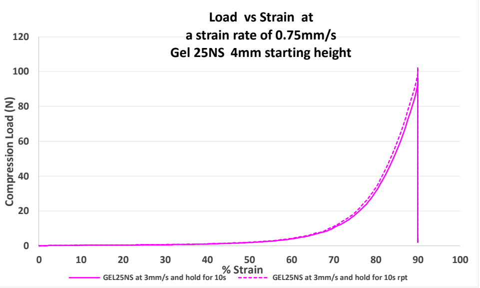
So even at a modest strain rate of 0.1 [mm/sec] we see quite significant loads that may damage the components. So what this means is either you have to be sure your components take very high loads on assembly or slow the whole process down considerably.

This and the residual high loading is one of the major reasons the Gel and CIP products were developed

# Closure forces generated during assembly

- 3 mm/s on starting cylinder height of 4mm.
- Note up to around 60% strain. Very low load
- 60-90% load rises rapidly upto about 100 N
- Rapid reduction in load once crosshead stops to around 2N
- Peak load approx. 50x more than final static loading for Gel



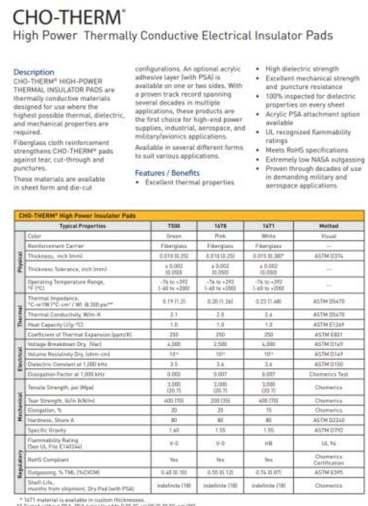

This compressive strain rate is 0.75mm/s and results in loads of upto 100N for a very brief amount of time. These Gels are designed to be dispensed and stay in position and are effectively non-Newtonian fluids. The viscosity and closure rate have significant influence on the forces experienced during assembly. So whilst the final loading is extremely low (around 2N) the transient values can be very high. This was the characteristic based on a 17x17mm square pedestal compressed by a 25mm crosshead.

So what is causing these high loads. If you note on the graph on the right the loads remain below around 10N up to 70% strain then they start to rise very rapidly.

# How to read between the lines

(TIM Data Sheets)

- So you want a high performing TIM?
- Do you choose high thermal conductivity?
- Do you choose low thermal impedance?
- Which test standard should you consider? (ASTM 5470? )

## CHO-THERM®

High Power Thermally Conductive Electrical Insulator Pads

**Description**

CHO-THERM® HIGH-POWER THERMAL INSULATOR PADS are thermally conductive materials designed for use where the highest possible thermal, dielectric, and mechanical properties are required.

Fiberglass cloth reinforcement strengthens CHO-THERM® pads against tear, cut-through and punctures.

These materials are available in sheet form and die-cut configurations. An optional acrylic adhesive layer (with PSA) is available on one or two sides. With a proven track record spanning several decades in multiple applications, these products are the first choice for high-end power supplies, industrial, aerospace, and military/avionics applications.

Available in several different forms to suit various applications.

**Features / Benefits**

- Excellent thermal properties
- High dielectric strength
- Excellent mechanical strength and puncture resistance
- 100% inspected for dielectric properties on every sheet
- Acrylic PSA attachment option available
- UL recognized flammability ratings
- Meets RoHS specifications
- Extremely low NASA outgassing
- Proven through decades of use in demanding military and aerospace applications

**CHO-THERM® High Power Insulator Pads**

| | Typical Properties | T500 | 1678 | 1671 | Method |
|---|---|---|---|---|---|
| Physical | Color | Green | Pink | White | Visual |
| | Reinforcement Carrier | Fiberglass | Fiberglass | Fiberglass | — |
| | Thickness, inch (mm) | 0.010 (0.25) | 0.010 (0.25) | 0.015 (0.38)* | ASTM D374 |
| | Thickness Tolerance, inch (mm) | ± 0.002 (0.050) | ± 0.002 (0.050) | ± 0.002 (0.050) | — |
| | Operating Temperature Range, °F (°C) | -76 to +392 (-60 to +200) | -76 to +392 (-60 to +200) | -76 to +392 (-60 to +200) | -- |
| Thermal | Thermal Impedance, °C-in²/W (°C-cm² / W) @ 300 psi** | 0.19 (1.2) | 0.20 (1.26) | 0.23 (1.48) | ASTM D5470 |
| | Thermal Conductivity, W/m-K | 2.1 | 2.0 | 2.6 | ASTM D5470 |
| | Heat Capacity (J/g-°C) | 1.0 | 1.0 | 1.0 | ASTM E1269 |
| | Coefficient of Thermal Expansion (ppm/K) | 250 | 250 | 250 | ASTM E831 |
| Electrical | Voltage Breakdown Dry, (Vac) | 6,000 | 2,500 | 6,000 | ASTM D149 |
| | Volume Resistivity Dry, (ohm-cm) | $10^{14}$ | $10^{14}$ | $10^{14}$ | ASTM D149 |
| | Dielectric Constant at 1,000 kHz | 3.5 | 3.6 | 3.6 | ASTM D150 |
| | Dissipation Factor at 1,000 kHz | 0.003 | 0.007 | 0.007 | Chomerics Test |
| Mechanical | Tensile Strength, psi (Mpa) | 3,000 (20.7) | 3,000 (20.7) | 3,000 (20.7) | Chomerics |
| | Tear Strength, lb/in (kN/m) | 400 (70) | 200 (35) | 400 (70) | Chomerics |
| | Elongation, % | 20 | 20 | 15 | Chomerics |
| | Hardness, Shore A | 80 | 80 | 80 | ASTM D2240 |
| | Specific Gravity | 1.60 | 1.55 | 1.55 | ASTM D792 |
| Regulatory | Flammability Rating (See UL File E140244) | V-0 | V-0 | HB | UL 94 |
| | RoHS Compliant | Yes | Yes | Yes | Chomerics Certification |
| | Outgassing, % TML (%CVCM) | 0.40 (0.10) | 0.55 (0.12) | 0.74 (0.07) | ASTM E595 |
| | Shelf-Life, months from shipment, Dry Pad (with PSA) | indefinite (18) | indefinite (18) | indefinite (18) | Chomerics |

* 1671 material is available in custom thicknesses.
** Tested without PSA. PSA typically adds 0.05 °C-in²/W (0.30 °C-cm²/W)

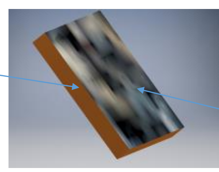
If you look at any regular TIM supplier data sheet you will generally see copious amounts of technical information.
Normally the first things people look for is the Thermal conductivity, which is reasonable enough. Since if you have done your calculations correctly you know you need a thermal material with a conductivity of say 2 W/mK. You choose your 2.1W/mK material and think: fine, take delivery of the sample, put it in the application and are surprised your device is running 50% hotter than your calculations were assuming.
Often the pressure of the test-data may be as high as 100psi or higher and your application may only be applying half that or less which in turn is resulting in higher contact seen in the test or, more likely, you ignored the presence of contact resistance by using the conductivity and not the thermal impedance.
The thermal impedance figure which comes from the same testing includes the resistance due to contact, as well as the resistance due to the material it's self. In fact in order to get a proper measurement for thermal conductivity, you need at least three measurements at three different thicknesses using the ASTM D5470 method.

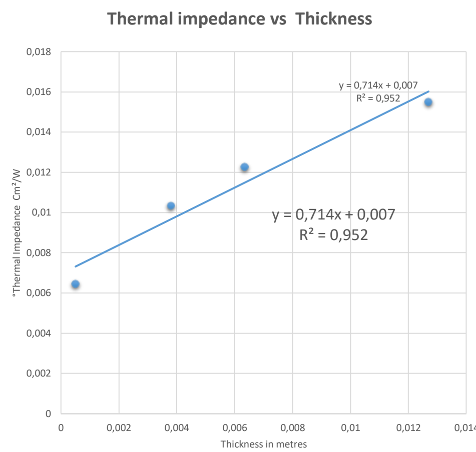
You'll note on all Parker Chomerics Data sheets we quote the test method we use and if it is Chomerics proprietary we will even send you a copy on request. Many suppliers do not even list the method they use and just give a value. Now you may think: there aren't that many methods for measuring thermal conductivity. There are plenty and some are not necessarily suitable for electronic TIMs even though they are used. Chomerics has always used ASTM D5470 which is a guarded heater parallel plate method.

# How to read between the lines

(TIM Data Sheets)

- Does the data sheet show a graph like the one on the right?
- Slope of the line is m=1/k
- Intercept on y axis is contact impedance
- Thermal impedance should include: contact impedance +impedance of pad
- Apparent thermal conductivity




So continuing from the previous slide, this slide shows a graph of thermal impedance in °Cm²/W and thickness in metres so the slope of the line which is the inverse of the conductivity is 0.714, which if we invert is give a thermal conductivity of 1.4W/mK. Now you can generate this line from a number of measurements as shown, and generally more is better. Note though that as the conductivity of the material increases the chances of making a bigger error in the conductivity increase.
For example the slope range between 2 and 0.5 covers conductivities between 0.5 to 2 W/mK
the slope range between 0.5 to 0.1 covers 2-10 W/mK
and the slope range between 0.1 and 0.01 covers conductivities between 10-100 W/mK.

If I am testing a 1 W/mK material and have a 0.05 error in the slope the measured conductivity is 0.95-1.05W/mK.
The same error on a 5W/mK material means: a range of 4-6.66W/mK
and for a 50W/mK material an error of 0.05 in the slope exceeds the value of the measurement. It basically indicates either you need lots of datapoints with $R^2$ very close to 1 to measure high conductivity materials, or you limit the use of the equipment to measuring lower conductivity materials.

What we have here is a graph with a slope of 1/k and an intercept which gives the contact impedance in SI units, or a classic y= mx+c line.  Where m =1/conductivity.

Now this graph makes a number of assumptions.

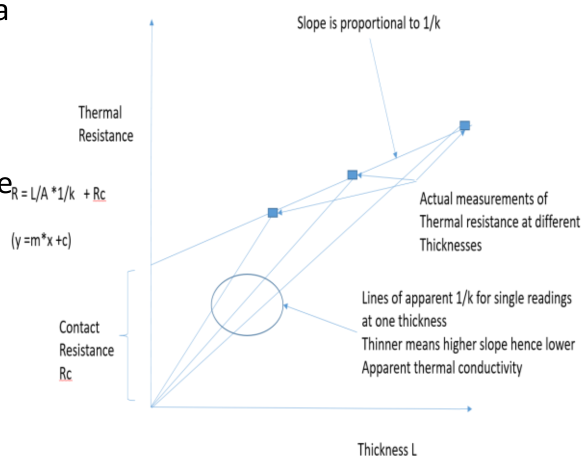
The first is that all measurements are at the same contact pressure, which generally they are.
It also assumes that the contact impedance remains constant with different thicknesses.
It also assumes the material is homogeneous and that heat is flowing through the material in a steady state uniform manner.

Most TIMS are not homogeneous, they are generally composites of a filler, binder and carrier.
So, the thinner the pad on the same carrier the bigger the effect the carrier has on the thermal overall thermal conductivity

# How to read between the lines

(TIM Data Sheets)

- Apparent thermal conductivity is a value represented from particular impedance reading at a particular pressure assuming zero contact resistance.
- This line is always steeper than the line with the intercept and effectively becomes worse the thinner the sample reading.
- This is often why the thermal impedance conversion to thermal conductivity does not always give the value on the data sheet.




So, the way your TIM performs may be very different from the data sheet because of a number of factors including:

Pressure or force on the pad. In theory this should just keep the pad slope of the line parallel and reduce the contact resistance.
What actually happens is: higher pressure on the thicker pads reduces the contact resistance slightly more proportionally than it does on the thinner pads.
So the shape factor is different, effectively moving the thicker readings lower while at the same time compressing the pad more moving them closer
to the lower points.

The apparent thermal conductivity is a value represented from particular impedance reading at a particular pressure assuming zero contact resistance.
This line is always steeper than the line with the intercept and effectively becomes worse the thinner the sample reading.

What it mean is that the material may be 3W/mK but what the user effectively sees is always less.

This is often why the thermal impedance conversion to thermal conductivity does not always give the value on the data sheet.

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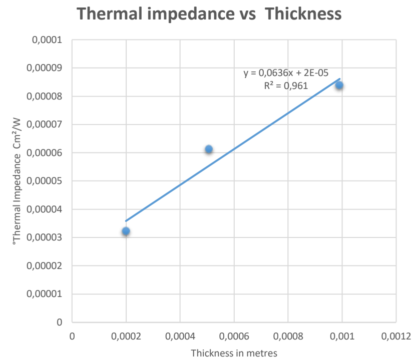
## When a 50 W/mK material is not 50 W/mK

But it is not untrue

- Graphite filled pads
- Tend to be non-isotropic
- XY conductivity tends to be much greater than Z axis conductivity




16W/mK not 50W/mK

- Always look for the thermal impedance values for the pad and be careful with some of the conversions.

This is the same plot as before from a graphite based material claiming to be 50W/mK

I did the same exercise on the thermal impedance data the supplier published for the 0.2mm, 0.5mm and 1mm thick material
Taking into account the deflection of the material at 90psi

It did not surprise me to discover that the published data gave me a value or nearer 16W/mK through the material rather than the 50W/mK

Is the 50W/mK claim wrong. No there was no method stated and Typically with graphite pads the xy conductivity tends to be considerably greater than
The through conductivity. This can normally be explained by the hexagonal layer like structure of graphite, indeed boron nitride is very similar and as
Mentioned before the carrier can sometime be a major contribution to the overall impedance of the pad.

So whilst not untrue the conductivity value does not really tell the whole story

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