Technical Information

General Thermal Interface Problem:
The really important and basic stuff...

1) The goal of a thermal interface is to transfer heat efficiently
from a rigid, rough, uneven surface (typically an electronic component)
to another rigid, rough, uneven surface (typically a heat sink, heat pipe, chassis, circuit board, etc.)

2) Two rigid, rough, uneven surfaces may only touch over about 1/10,000 of their surface area. Theoretically they will touch at only three points.

3) The rest of the two surfaces is separated by AIR.

4) Air is a very poor thermal conductor (0.024 W/m.°K)
Aluminum = 200, Copper = 385 Silver = 419, Water = 0.59
Air is 8333 times less thermally conductive than Aluminum...
Air is a thermal barrier that prevents efficient transfer of heat from the electronic component to the heat sink.

5) To remove this thermal barrier you must replace the air with an EASILY deformable thermally conductive material that will contact all areas of both surfaces, even down in the little surface pores.

Ah, but not so easy as it sounds. Here are some of the problems:

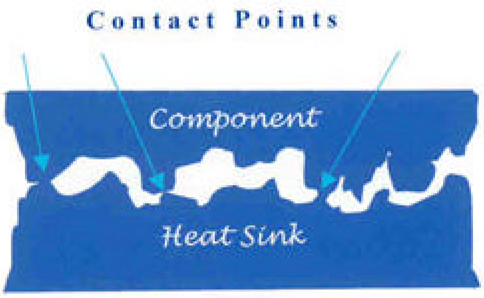
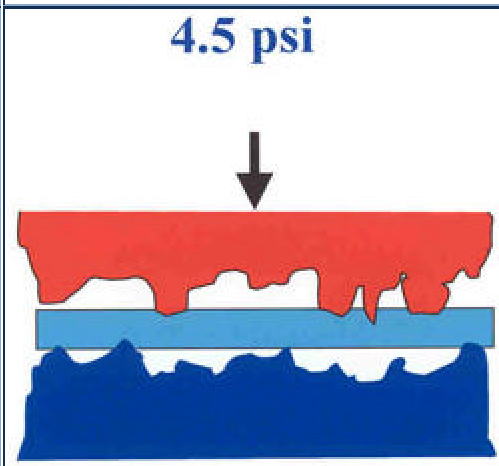
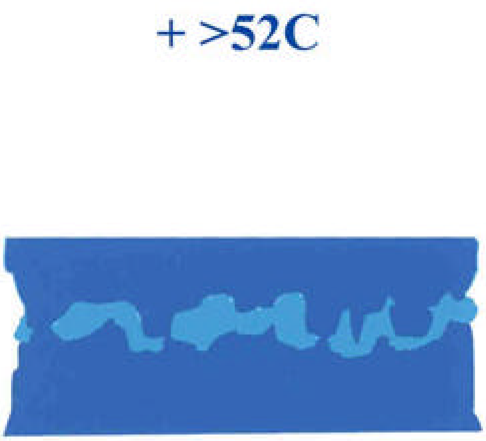
1) Thermal Grease materials will flow into the surface pores of component and heat sink, but then they start flowing out again. They flow away from the interface area. They are very messy to apply.
2) Elastomeric materials cannot get into all the small pores of component and heat sink even when very high closure forces are applied to them.
3) Interface Materials should be nontoxic
4) Interface Materials should be easy to handle, "manufacturing friendly"

Thermaphase solves these problems without introducing new ones...

By replacing the air with Thermaphase material, the efficiency of heat transfer is greatly enhanced.

It is tempting to think that the best way to choose an interface material would be to test its **Thermal Conductivity** then choose the material with the highest value, and "voila!". Unfortunately this will not guarantee efficient transfer of heat from your component to your heat sink as we will soon see in a dramatic example. Thermal Conductivity is a measure of a material's ability to conduct heat once you get heat into it. Another much more useful measurement is **Thermal Resistance.** This tells you how well a material conforms to the electronic component AND how much of the heat from the electronic component actually gets to the heat sink.

The illustrations and descriptions below show one specific example of how Thermaphase materials react to heat and applied closure force.

Two "mating surfaces may touch over only 1/10,000 of their surfaces. They may touch at only three points. Everywhere else there is air between them forming a thermal barrier		No power applied to component. No thermal Interface. Component and Heat Sink are separated by air.
Some thermal interface materials have high thermal conductivity but can't conform to the uneven surfaces and so they can't get beyond the picture to the right. Even Diamond which has a very high thermal conductivity is useless because it is rigid like the two rigid surfaces of component and heat sink.		Component under power heats up. The Phase Change Material doesn't flow and contact the uneven surfaces until the temperature reaches >52 °C under a closure force of >4.5psi. Then something **magic** happens ...
The thermal resistance between component and heat sink falls to a very low value, effectively transferring heat from component to heat sink. We make a wide range of materials having various reflow temperatures.		**Thermaphase** reflows wetting all of the surfaces. Any excess material that flows to the outside is thixotropic and does not migrate away from the interface area.

Thermal Conductivity

The rate of heat flow through any material depends is proportional to the cross sectional area through which the heat flows and to the temperature drop along heat path. In the case of steady state heat flow, the rate is given by Fourier's Law:

k = (q/A) (d/? ? ?

Thermal Conductivity "k" is measure of the ability of a material to conduct heat but it only describes its ability to conduct heat AFTER the heat gets into the material. It tells you nothing about how easy it is to get heat into and out of the material.

FORGET ABOUT THERMAL CONDUCTIVITY

There is another measurement that will tell you everything you need to know. It will tell you three things with one measurement:

1) How easily heat can get into the material
2) How well the material conducts heat
3) How easily heat can get out of the material

Thermal Resistance

Thermal Resistance (sometimes called Thermal Impedance) is an overall measure of how well a material is able to transmit heat from a heat source into the material and from the material to a heat sink. This measurement is much more useful than Thermal Conductivity because it tells you how well you are transferring heat away from the heat source (semiconductor, for example). Many materials used for thermal transfer have high thermal conductivity, but also have high thermal resistance. This means that after you get the heat into the material it will transmit it very effectively to the other side, but then the heat can't get from the material to the heat sink. Diamond, for example, has very high thermal conductivity but it is inflexible. It can't conform to the rough, uneven, inflexible surfaces of either semiconductor or heat sink. Therefore you have a thermal barrier on each side of the diamond interface material, so you have wasted your money on a material that has high thermal conductivity but you are unable to get heat into and out of it effectively.

Thermal resistance is given by the formula:

$$°C/W/in^2 = T_1 - T_2/Watts$$

Where:
° = Temperature in Centigrade Degrees
W = Watts
in² = square inch
T1 = Temperature in Centigrade Degrees of the Electronic Component
T2 = Temperature in Centigrade Degrees of the Heat Sink
Watts= Watts of applied power to Electronic Component

This tells you the one important thing you need to know. It tells you how well you are getting heat from the component to the heat sink. If your heat sink is as hot as your electronic component, you are transferring the maximum amount of heat from the component. In practice the heat sink will never be quite as hot as the component.

Conduction of heat in metals and non-metals

In metals the conduction of heat takes place mainly by movement of free electrons. When one end of a metal bar is heated, the atoms gain energy and vibrate. The energy is passed on to free electrons that then collide with each other and with other atoms. Some energy is also transferred by interatomic vibration. But most of the heat transfer is due to collision of electrons. In metals, the ratio of thermal conductivity to electrical conductivity is the same (Wiedmann and Franz).

In non-metals there aren't many free electrons. Heat is conducted by a different mechanism. When heat is applied to a non-metal the atoms vibrate and transfer energy from atom to atom. Energy is transferred by a sort of elastic wave. This is called a Debye wave.. These waves are also called "**phonons**". They travel at the speed of sound (not at the speed of light). We usually think of metals as better conductors of heat than non-metals. Generally this is true. Diamond, however has the highest thermal conductivity known. Natural diamond is monocrystalline and therefore the atoms tend to vibrate together when heat is applied, and therefore the Debye waves (phonons) transmit a lot of heat energy.

Thermal Conductivity is a material property that tells you about its intrinsic ability to conduct heat. Its value does not depend on the length of the heat path and it does not take into account the ability of an interface material to conform to rough, uneven surfaces. Thus, you can have a material with very high thermal conductivity which will not necessarily be effective in transferring heat from a rigid, rough, uneven electronic component to a rigid, rough, uneven heat sink.

So what is the thermal conductivity of various materials? The chart below shows the value of k (thermal conductivity) in Watts per m^2 per degree Kelvin (the most common way of expressing thermal conductivity).

Material	$Wm^2\ {}^{\circ}K$
Silver	419
Copper	385
Aluminum	200
Iron	80
Water	0.59
Air	0.024
Natural Diamond type IIa*	Up to 15000 at 80°K

* Note: The thermal conductivity of Natural Diamond varies. Type IIa can go up to 17500 $W/m^2/K$. Type Ia Natural Diamond is about 2000 to 4000 $W/m^2.K$. The highest ever measured thermal conductivity of type IIa natural diamond is 17500 W/m.°K at 65°K (Slack, 1973).
CVD (Chemical Vapor Deposition) diamond has considerably lower thermal conductivity because it is polycrystalline instead of monocrystalline like natural diamond. But enough of these pleasantries...

So you might say, "It's Diamond for me", because it has such high thermal conductivity. Even if diamonds were free, this would not be the best choice. The reason is that diamond is hard, inflexible. It is not going to flow into the millions of pores and surface irregularities. You are still going to have almost no contact between component, diamond, and heat sink. You will still have mainly air (at 0.024 $W/m^2.{}^{\circ}K$) instead of diamond (15 000 $W/m^2.{}^{\circ}K$)... Here is a website you might want to check out: http://epims.gsfc.nasa.gov/tva/diamond/

Now, you might say, the surface of electronic components we use and the heat sinks we use look pretty darn smooth to me. But these surfaces are rough on a microscopic scale. In the case of aluminum blocks, every place the blocks touch each other, the thermal conductivity (see above chart), the thermal conductivity is about 200 $W/m^2\ {}^{\circ}K$ but in those regions where aluminum does not touch aluminum, there is air and the thermal conductivity in these is that of air, 0.024 $Wm^2\ {}^{\circ}K$. The air is 8333 times less thermally conductive than the aluminum.

So, what is the typical range surface roughness of electronics components?

Metal tabs on plastic case transistors: 6 micro inches and up...
Extruded, Anodized Aluminum heat sinks: about 40 micro inches
Epoxy packages: about 40 micro inches
Sheet Metal straight from the factory: about 120 micro inches.

Do NOT take these figures as Gospel, because there is a quite a bit of variation. And there is also the problem of surface flatness. This also can be a "can of worms" ... Typical flatness of machined parts is about 0.001" per inch of surface. But some electronics packages warp when heated so this may be different when the component is hot than when it is cold. Some of these packages are "pre-warped" so that when they heat up, they have a more or less wavy surface.

What you need is a material that can make the temperature difference between your component and your heat sink as small as possible. To do this you need a material that will get into all of the surface imperfections of both component and heat sink. The closure force to get the material into the surface imperfections should be some reasonable value (from a few psi to a few dozen psi depending on the package), so you don't strips screws, break component packages, etc. You need a test to determine how well the material is doing this. Thermal Conductivity won't tell you that. We just saw that with the info about Diamond.

Thermal Resistance

Thermal Resistance is much more important than Thermal Conductivity in keeping electronics cool. The reason is that Thermal Resistance is simply the difference in temperature between the heat generating element and the heat radiating element (i.e. between electronic component and heat sink).

Your goal is simply to get as much heat away from the component as possible. A smaller temperature difference between component and heat sink means you are getting more heat away from the component and into the heat sink.

Thermal Resistance tells you not only how well the material conducts heat. It also tells you how well the material can conform to rigid, rough, uneven surfaces. It tells you how well the interface material is at keeping your components cool.

Thermal Resistance is usually expressed in °C/W/in^2.
In the above formula:

°C= Degrees Centigrade
W= Watts
in^2 = square inches

Thermal Resistance is the only test that will tell you about the temperature difference between the component and heat sink. The "Greatest Thing We Ever Learn" about thermal interface materials used for Electronics Cooling is that the only thing that counts is making the temperature difference between the component and heat sink as low as possible; ?T. Thermal Resistance measurements will give you this important information. Thermal Conductivity measurements will not tell you this.

The technology for making materials having low thermal resistance involves a number of disciplines in materials science. Since many materials presently on the market do not do this job well, manufacturers prefer test methods which obscure the real thermal resistance of their materials in real-life production applications. Many manufacturers use ASTM-5470-95 for measuring thermal resistance. They do this because they know most people are not going to carefully read this test procedure, therefore they won't realize that the test requires the use of polished copper blocks and that tests are to be done at 1,000,000 Pascal's. That is 438 psi! Try applying that closure force with the typical electronic component.