Educational Whitepaper

Thermal Management of RF and Digital Electronic Assemblies using Optimized Materials and PCB Designs

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1. Introduction

As far as the cooling of electronic devices is concerned, the first question one would ask is "Why are cooling and thermal management of these devices required, with so much hype associated with it?" The simple answer to it is that in any electronic device, its performance, reliability, efficiency and life expectancy are related inversely and *exponentially* to the magnitude of increased temperature above its optimum operating range. As the semiconductor transistor junction temperature rises, its life cuts down exponentially. For example, reducing the junction temperature by only 5°C above its optimum operating temperature range will result in approximately doubling the expected life of the component. Thus, considerable increase in performance, efficiency and life expectancy can be achieved by a relatively small reduction in operating temperature. These observations are well documented by Edwards Wyrwas et al [(1)] and also in an excellent free online tutorial on component reliability [(2)]. On the other hand, for extremely low environmental temperatures, such as in deep outer space, operation of semiconductor-based devices and circuits has often been reported down to temperatures as low as a few degrees above absolute zero (about −270 °C, the absolute zero, of course, being -273.15 °C). This includes devices based on Si, Ge, GaAs and other semiconductor materials. There seems no reason to believe that the active device should not operate satisfactorily all the way down to absolute zero. The problems at lower temperatures are thus not primarily due to the electronic device itself, but rather on the properties of materials surrounding it, like those of bonding interface, passive circuitry materials and other protective coatings surrounding the device. However, these indirect lower temperature problems are not the topics of the current paper, as they have no significance with the issues posed by the elevated operating temperatures.

To begin with, there are three main components in the discussion of thermal management of electronics devices. These are:

(1) Thermal interface material (TIM): TIM is used to fill the gaps between the adjoining surfaces, such as between the ground plane of the PCB and the heat sink, in order to increase the efficiency of thermal transfer. An efficient thermal transfer from the active electronic device region to the heat sink will obviously help in preventing excessive heat build-up of electronic components. The space between the semiconductor device and heat sink is normally filled with air, which, of course, is a very poor thermal conductor (4). The heat generated by electronic devices must be dissipated to improve reliability and prevent premature failure. This efficient heat dissipation is also required from the PCB as the semiconductor devices are in direct thermal contact with them and PCB can get heated easily due to due to the resistance in pathways of electrical and electronic signals. Techniques for heat dissipation usually include heat sinks and fans for air-cooling as well as liquid cooling. In each of these cases, an efficient heat transfer interface is required That would quickly and completely transfer the heat from the circuitry to the heat sink body.

In this paper, we will be talking about the thermal interface materials (TIM) which are designed to transfer rapidly the heat generated from the semiconductor device to a properly designed and sized heat sink. The TIM can be either both electrically and thermally conducting or can be only thermally conducting but electrically insulating, and the choice, of course, depends upon the application.

All electronic switches or devices are unfortunately imperfect in the sense that a considerable amount of the energy used during signal transmission is wasted as heat. The amount of heat generated depends on the device functionality, whether the signal transmission is for RF communication, power amplifiers, power devices or LEDs, etc. The semiconductor transistors and other electronic components used for various signal transmission dissipate power internally during both the “on-state” and the “switching between the on and off states.” Generally, the more the power is involved in any electronic process, the more will be the dissipation and thus more will be the rise in temperature. The maximum amount of power that is permissible to be allowed for dissipation is dictated by the safe maximum operating temperature of the device, which depends on the application of the device.

(2) Thermal time constants: The thermal mass of a heat sink can be considered as a capacitor (storing heat instead of electrical charge) and the thermal resistance as an electrical resistance (giving a measure of how fast stored heat can be dissipated). Together, these two components form a thermal circuit (resistance capacitance, RC circuit) with an associated time constant given by the product of R and C. This quantity can be used to calculate the dynamic heat dissipation capability of a device, in a way analogous to the electrical case. A specific type of TIM can be inserted between the heat sink and the heat source (PCB, microprocessor chip, power source, etc.) to increase thermal throughput and to stabilize its temperature via increased thermal mass and heat dissipation by conduction, convection and radiation routes.

(3) Thermal resistance of devices: This is usually expressed as the thermal resistance from a semiconductor junction to case of the semiconductor device. The unit of thermal resistance is °C/W. For example, a heat sink rated at 10°C/W will get 10°C hotter than the surrounding air when it dissipates 1 Watt of heat. Thus, a heat sink with a low °C/W value is more efficient than a heat sink with a high °C/W value.

Depending on the type of electronic device, the allowable maximum junction temperature values, in general, range (4) from:

- 115°C in microelectronics applications
- 180°C for some electronic control devices
- 65°C to 80°C for military and other special applications.

In the printed circuit board (PCB) fabrication process, if the materials' selection and circuit designing are done properly, it is possible to manage effectively the heat dissipation of the electronics assembly without causing any harm to the system or degradation of its performance. In this review, we will discuss various topics related to the thermal management of electronic devices and the types of products offered by American Standard Circuits to address successfully those issues.

The main objective of this paper is to provide a greater understanding and appreciation of challenges posed in efficient thermal management of electronic assemblies and how to figure out an optimized solution in terms of cost, volume production, product performance and reliability.

2. Some basics on thermal management of electronic devices

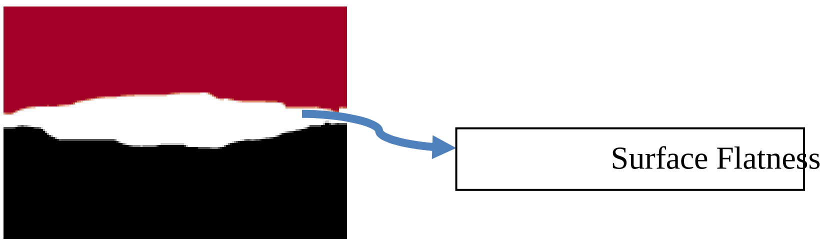
2.1 Generation of Heat:

Power dissipation results in a rise in junction temperature and the more the temperature rises, the more severe are the physical and chemical damages around the junction area. This would proportionately shorten its life, increase erratic behavior and reduce the efficiency of the device.

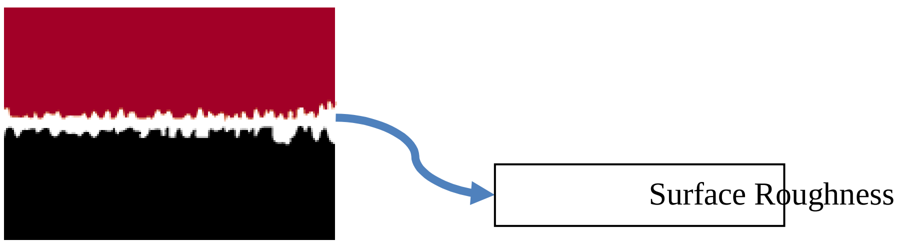
It is therefore of utmost importance that any electronic device runs below the maximum permissible temperature limit dictated for that particular device application. It is also necessary that the device temperature be maintained at less than its power dissipation rating, including various thermal resistances associated with the device.

As an example, in the case of power semiconductors like rectifiers, the power dissipation limitation rating can be easily translated in terms of current ratings for products such as, diodes and thyristors, since in the on-state, the voltage drop is well defined. However, for transistors, it is more complicated, since in its on-state it can operate at any voltage up to its maximum rating depending on the circuit conditions. Thus, for transistors it is necessary to specify a safe operating area that specifies the power dissipation limit for current and voltage values. Usually the mounting base temperature is kept around 25 C. At higher temperatures, it will be necessary to ensure that junction temperature does not exceed the allowed operating limit.

Let us now look into the factors that cause the major thermal transfer problems. It is well known that the solid-air interface represents perhaps the greatest barrier in thermal management. Solid surfaces are never really completely flat on an atomic scale to permit intimate contact between the heated electronic device and the heat sink surfaces. These surfaces can have surface roughness either due poor surface flatness between two typical electronic components (Fig. 1(a)) or due to microscopic hills and valleys (Fig 1(b)). For example, Miksa de Sorgo reports[4] that as much as 99% of the surfaces are separated by a layer of interstitial air! Unfortunately, for such electronic packaging since air is a very poor conductor of heat, this would result in very large thermal resistance. Two typical scenarios of air separation between the active component and heat sink surfaces are shown in Figure 1 below. On an average, between 95 and 99 % of thermal air resistance (and therefore heat build-up) is due to poor surface flatness and surface roughness.



(a) Poor Surface Flatness



(b) Poor Surface Roughness

Figure 1: Thermal air resistance due to (a) poor surface flatness and (b) surface roughness (courtesy: Dr. Miksa de Sorgo[4], Electronics Cooling, 2000)

2.2 Heat Flow:

Heat always flows from a higher temperature to a lower temperature area. We can imagine this to be similar to the flow of electric current from a higher potential to a lower potential. In electric circuits, heat is generated due to the electrical resistance, wherein a portion of the electrical power is not participating in the charge movement but is wasted due to the poor electrical conductivity (or drag on the movement of electrons) of the medium.

Q = Time rate of heat generated in Watts

R = ΔT/Q, where ΔT is the temperature difference between the two locations (This is similar to Ohm's law: $R_e = \Delta V/I$).

For example,

$R_{sa} = (T_{sa})/Q = (T_s - T_a)/Q$, where R_{sa} is the resistance between heat sink and air interface.

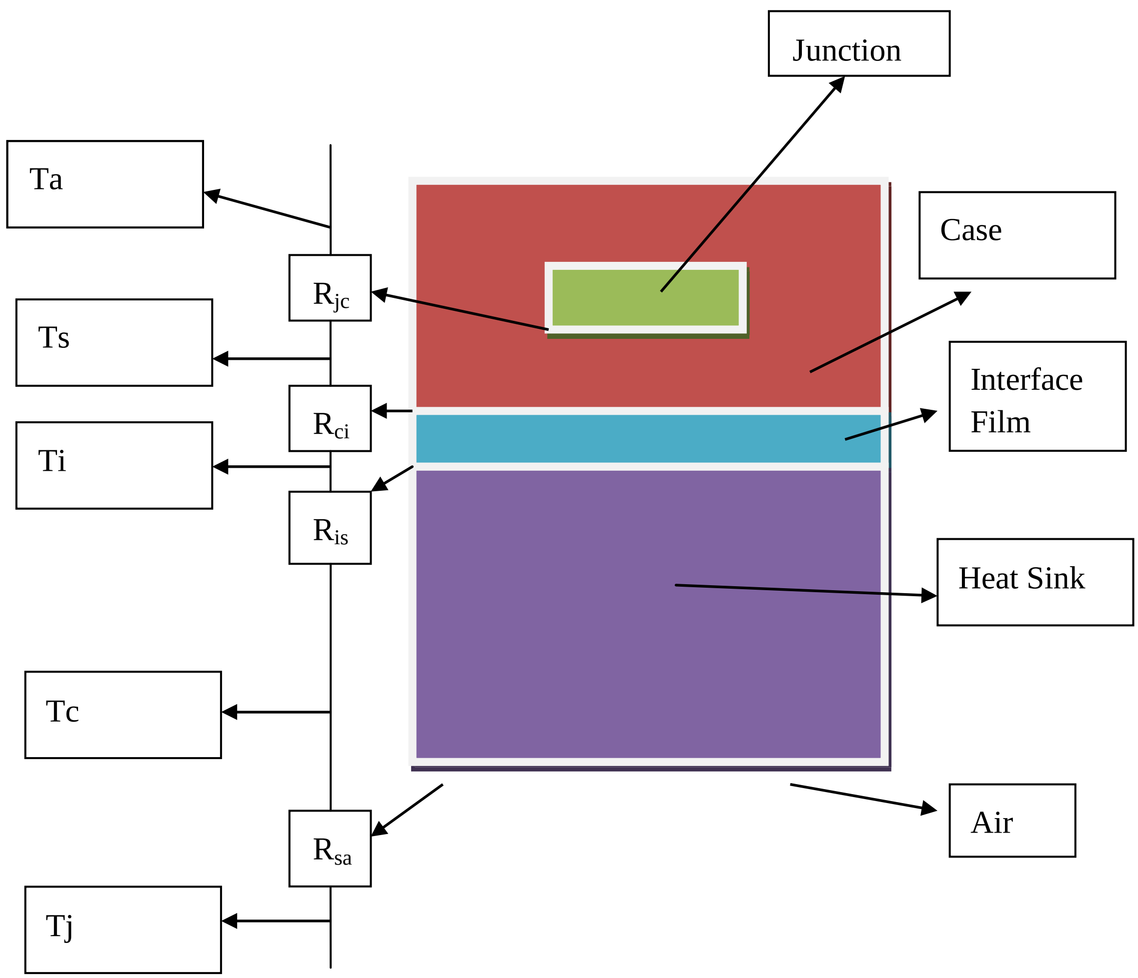


Figure 2: Thermal resistance diagram of the PCB assembly

Thus, the total thermal resistance of a PCB assembly is given by,

$$R_{ja} = R_{jc} + R_{ci} + R_{is} + R_{sa} = (T_j - T_a)/Q \qquad \text{-----------------------------} \quad (1)$$

Where Q is the heat generated in Watts/time.

The thermal resistance diagram of a PCB assembly is depicted in Figure 2 above. It is interesting to note that the values of R_{ci} and R_{is} can be decreased significantly (and the thermal transfer efficiency can therefore be increased significantly) by surface finish of the heat sink and ground plane PCB and the type of interface material. Similarly, the amount of heat radiated out by the heat sink S to the surrounding outside air can be managed by its thermal radiative behavior:

A key question that arises for the PCB design engineer and the circuit board manufacturer is how much cooling is required to keep the device operating under safe conditions and how to fabricate such an assembly. To answer this question, let us consider the thermal resistance of the heat sink. The heat sink resistance between the solid block of heat sink and the surrounding air is given by

$$R_{sa} = [(T_s - T_a)/Q] - R_{jc} - R_{ci} - R_{is} \qquad \text{-----------------------------} \quad (2)$$

Therefore, the thermal resistance value of the chosen heat sink and interface material for the application has to be equal to or less than the R_{sa} value so that the junction temperature is maintained at or below a specified T_j value:

$$(Rjc + Rci + Ris) < Rsa \qquad \text{-----------------------------} \quad (3)$$

Once we have ensured that we are able to efficiently transfer the heat from the semiconductor junction to the ultimate heat sink through a proper strategy of PCB layout, thermal interface material selection to transfer the heat from the casing to the heat sink and a proper selection of heat sink, it remains to be seen how to dissipate away the heat from the heat sink quickly and efficiently to the outside environment.

Electronic components with exposed pads can be efficiently cooled by appropriate design and material selection of the PCB. Temperature rise for electronic components depends strongly on the material composition and thickness of the thermal interface, PCB construction, spreader plane area and its thickness, and the thermal characteristics of various components in the assembly.

Cooling can be accomplished by increasing the surface area of the heat sink by methods such as introducing fins, corrugation of the outer surface, etc. It is equally important to increase the thermal emissivity of the surface (which is an intrinsic property of the sink's surface) so that most of the thermal radiation is emitted out quickly to avoid buildup of temperature. How do we maximize the thermal emittance? Thermal emittance is a function of the surface temperature as well as the intrinsic thermal property of the surface. A "perfect" black body is one whose surface will absorb all the incident energy of the electromagnetic radiation. In addition to being a perfect absorber, this body is also a very good emitter. A perfect black body has equal thermal absorbance and emittance, i.e., $\alpha = \varepsilon$ (T). As shown in the diagram below (Figure 3), the peak of the black body spectrum as per Wein's displacement law depends on the body temperature. Thus, in the case of a heat sink thermally coupled with the electronic device mounted PCB, the wavelength at which $\alpha = \varepsilon$ (T) occurs depends upon the sink temperature. If the heat sink's outer surface in contact with ambient air is (a) textured in such a way that the textured groove dimensions are close to the λ_{max} value corresponding to the maximum sink's temperature (that it will go up to under practical operating conditions), and (b) coated with a high emissivity coating (which is easily available for a variety of colors), then the sink's radiation would likely resonate out most effectively into the ambient air, thereby resulting in an efficient cooling of the overall device.

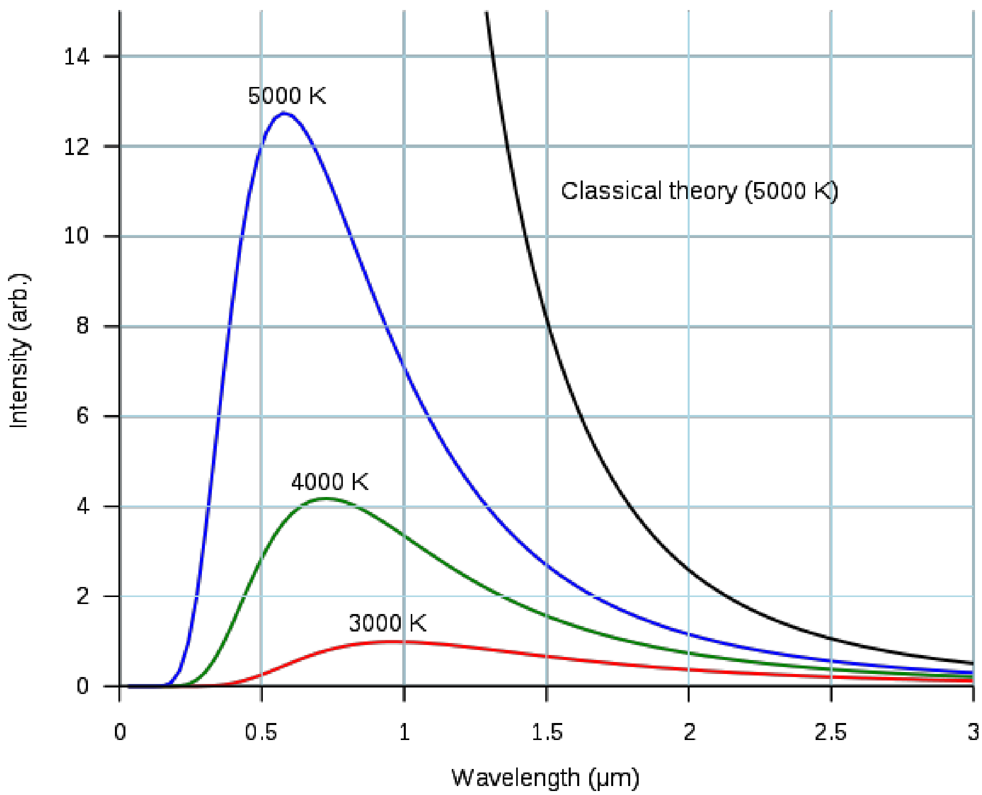


Figure 3: Blackbody Spectrum for various blackbody temperatures

2.3 Thermal Modeling:

Thermal modeling of a PCB can give the circuit designer a good understanding of various thermal issues that would affect the overall performance of the device. Using appropriate modeling software the designer can figure out the optimum design and placement of various components in the layout. At the most basic level, thermal modeling can map several things: heat flow, heat sink design, and a method for cooling effectively various active devices. Effective cooling will hold the electronic device below the upper critical operating temperature limit. Using computer aided design (CAD) the designer can design a prototype and evaluate its performance before going for full volume production.

Equally important is that the thermal modeling gives the PCB designer a critical tool for conducting the thermal fatigue failure analysis. In turn, these analyses can be modeled to provide failure prediction models. While board failures may not occur in near term future, the model can tell when various components of the device will start failing in actual performance and thus help in deciding the selection of materials and over design of the device.

2.4 Heat Sinks

Heat sinks are the most important component in managing the heat of a PCB. They ensure that the devices are held at temperatures below their specified maximum operating temperature. There are many versions, different designs and various ways of optimizing heat sinks. Over time, the technology has progressed with the use of new materials. For example, carbon fiber and boron nitride are recent materials applied to heat sinks.

Unidirectional heat spread: High thermal conductivity carbon fiber spreads heat well at 800 watt per meter Kelvin (W/m-K) in the direction of the fiber. However, along the other two directions, the thermal conductivity is only about 0.5 W/m-K; therefore, it does not spread heat in directions perpendicular to its lay out direction. The heat is thus anisotropically spread only in one direction. Obviously, there would be situations where this type of spread is required. If the fiber is crisscrossed along the XY plane, one can achieve high directional thermal transfer on XY plane. Another highly anisotropic thermal conducting material is graphite, since the heat transfer phonons propagate very quickly along the tightly linked planes, but are slower to hop from one plane to another.

Graphite is another promising candidate for directional heat transfer due to its lamellar structure. Graphite obtained from various geographical locations is known to have widely different thermal conductivities. A list of ultra-high thermal conductivity materials that can be used to make thermally and electrically conducting bonding interfaces is given below.

Materials with Ultrahigh Thermal Conductivities

Material	Sp Gr	CTC	ITC	TTTC	SITC (ITC/SG)
CVD-Diamond	3.52	1-2	1100-1800	1100-1800	310-510
HOPG	2.3	-1.0	1300-1700	10-25	565-740
Diamond-SiC	3.3	1.8	600	600	182

ITC: In-plane thermal conductivity, W/mK. TTTC: Through thickness thermal conductivity, W/mK. SITC: Specific in-plane thermal conductivity, W/mK. HOPG: Highly oriented pyrolytic graphite.

Boron nitride crystals are an excellent source of heat transfer agent and are a good electrical insulator. By separating each carbon fiber layer with sufficient thickness of alternate layers of boron nitride stacks, it is possible to obtain a high degree of heat transfer along XY plane by carbon fibers, allow heat to be transmitted along the Z direction by boron nitride layers (by up to 4 W/mK) and keep the complete thermal transfer layer to act as a good dielectric. Developers have applied boron nitride crystals as a way to move efficiently heat from one fiber ply to the next. These crystals are used to “salt” carbon fiber sheets or prepregs. Two or more sheets are then laminated together to form the heat sink material and heat throughput for up-down directions has been improved from 0.5 to about 4 W/m-K.

Due to their high cost, however, boron nitride will likely find limited use in future PCB fabrication and may not replace aluminum heat sinks in many applications. Still, carbon fiber heat sinks may best be used in systems that don’t use air-cooling. . These may include aircraft, missile and spacecraft components, automobiles, high-end computers and medical equipment.

On the other hand, fin-based aluminum or copper heat sinks find greater acceptance in many applications due to their low cost and ideal thermal dissipation characteristics. Aluminum has a highly acceptable 205 W/m-K thermal conductivity, while copper is about twice as high at about 400 W/m-K. Aluminum heat sinks are less expensive; copper heat sinks cost more and they also weigh more. Consequently, aluminum, with an appropriate final protective finish, is a preferred heat sink material for most cost-effective applications, and copper is used in selected ones where and weight are not any issues.

3 Thermal Interface Material Selection

To understand clearly which thermal interface bonding material is the most suitable for a particular PCB assembly for its desired application, it is necessary to know the requirements of the bonding material. The bonding interface should be able to handle the signal transfer task with minimum overall cost. In digital applications, with increasing clock frequencies of computers, the thermal load also increases thereby demanding a more efficient thermal interface. In high frequency telecommunication applications, the complexity of circuits and challenges posed by the environment in which they have to perform makes the bonding material selection process quite challenging.

3.1 Bonding material considerations:

Several properties of the thermal interface bonding layer play crucial role in optimizing the performance of the final device. Most materials have been developed to optimize one or more of the following properties:

3.1.1. Relative Dielectric Constant, e_r: This property is a measure of the effect an insulating material has on the capacitance of a conductor imbedded in or surrounded by it. It is also a measure of the degree to which an electromagnetic wave is slowed down as it travels through the insulating material. The higher the relative dielectric constant, the slower a signal travels on a wire, the lower the impedance of a given trace geometry and the larger the stray capacitance along a transmission line. Given a choice, lower dielectric constant is nearly always better.
The dielectric constant of nearly all PCB dielectrics changes with frequency and usually goes down as frequency goes up. This manifests itself in two ways in transmission lines. The velocity of signals increases as the frequency goes up, resulting in phase distortion in broadband amplifiers. Broadband RF and microwave amplifiers usually need to be made from laminates with relative dielectric constants as flat with frequency as possible to minimize this problem.

3.1.2. Loss tangent: Loss tangent is a measure of how much of the electromagnetic field travelling through a dielectric is absorbed or lost in the dielectric. This property is one of the least well understood of all those that characterize laminates. As a result, ultra-low loss materials are often used in digital applications when they are not needed. This results in increased PCB cost without a corresponding benefit.

4 Applications and Thermal Management Materials

Some key electronic devices where thermal management is critical are given below. This list is by no means an exhaustive list, but it just exemplifies certain key electronic products where thermal management plays a very crucial role.

1. Microprocessors used in various computers
2. Power semiconductor modules used in various industries such as, automotive, aerospace, navy and space explorations.
3. High power laser diodes
4. High power RF modules
5. High brightness LEDs and LEDs with uniform color scale
6. High power laser and RF weapons with extreme temperature build ups.

For example, the recent technological advancements in the LED design and processes can greatly increase the brightness of the LED assembly and the LED industry is now rapidly emerging to capture the markets of CFL and incandescent lamps, Not only for indoor usage that require much lower wattage but also exterior lighting such as highway street lighting and which normally use typically 250 High Pressure sodium Lamp. The new LEDs would have enough power to light up the entire streets and these LEDs are capable of continually boosting light output to rival incandescent, fluorescent and halogen light sources. In developing these high intensity LED modules, the need to protect the LEDs against heat build-up is greater than ever before. Power LEDs of greater than one-watt are usually surface mounted devices. This is because the axial leads to the die in a leaded package do not conduct enough heat away from the LED. Chip-on-board (COB), ceramic submounts and other thermally efficient packages are emerging as the standard thermal management packaging solution for Power LEDs.

New thermal management materials and techniques are continuously being added in the PCB designs to meet heat dissipation demands introduced by new generations of mostly analog and some digital ICs that dissipate high current and high power. Thermal management focuses on effectively dissipating heat generated by those high-power designs, on high thermal conductivity, and on maintaining low coefficients of thermal expansion (CTE), while managing CTE mismatches between components, their interconnects and the PCB.

Chipmakers use a variety of packaging such as plastic, ceramic, flip chip, leadless chip carrier (LCC) and wafer-level packages (WLP). Each has a lower CTE than a standard PCB. Consequently, a CTE mismatch occurs between device packaging and the PCB. Depending on the application and associated cost budgets, PCB designers, hardware engineers and PCB fabricators implement a variety of different materials and techniques to deal with those CTE mismatches and manage thermal issues.

While chipmakers are doing their part to improve thermal management for their devices, EMS providers are placing special attention on thermal management issues at the PCB design level. In these instances, remedies range from using applicable board materials to paying special attention to mounting holes. In between, there are several new as well as tried-and-proven materials and methods to improve thermal conductivity and heat dissipation.

The industry continues to patent new inventions and offers a variety of new thermal management materials and techniques. Those discussed here are prominent ones in the tool kit of seasoned PCB designers and engineers. They include advanced thermal modeling software, new heat sink material, new in-plane high conductivity carbon composite material, special casing material and edge plating. Proven techniques include copper thieving, increasing trace thickness, and ultimately and even exploiting the mounting holes to dissipate heat.

Types of Thermal Interface Materials: There are basically four types of thermally conducting interfaces. Further, in addition to being thermally conducting, these interfaces can be either electrically conducting or electrically insulating. Accordingly, these four types are:

1. Greases
2. Reactive compounds to give a hard bonding interface
3. Elastomeric compounds that give soft bonding interface
4. Pressure sensitive adhesives.

All are designed to conform to surface irregularities, thereby eliminating air voids and improving heat flow.

1. **Greases:** Thermally conducting greases are filler compounds that replace the air with the greasy compound. The surfaces to be joined are cleaned well with suitable solvents and dried. A thin layer of grease is then applied and the two mating surfaces are kept together. Most of the time, the two surfaces are held together by screws or spring clips. The grease thus acts as a thermal transfer medium. Greases are used when high thermal conductivity is required and thin bond lines that require intimate contact between the substrates. These greases are formed by mixing thermally conducting ceramic fillers (boron nitride, aluminum oxide, aluminum nitride, silicon nitride, graphite, etc.) in silicone or hydrocarbon oil to form a paste of right consistency that can properly fill the air gap between the mating surfaces. Most of the time these greases do not provide electrical insulation, although it is possible to select grease that can act only as a thermal transfer compound and remain electrically insulating[6]. After the two surfaces are held in close proximity, the excess grease is carefully wiped off from the sides. The thermal conductivity can be varied over a wide range, typically from 0.6 W/mK to 220 W/mK depending upon the composition (the thermally high conductive compounds, $\geq$ 10 W/mK, are typically electrically conducting also). The important considerations that need to be kept in mind while selecting particular grease are (a) its ability to fills the gaps and conforming to both the component's and the heat sink's uneven surfaces. (b) good adherence to the surfaces being joined, (c) to maintain the consistency over the device operating temperature range, (d) ability to resist drying out or flaking over time, and (e) it must not degrade due to oxidation or break down during the life time of the device.
2. **Reactive hard compounds:** These are generally thermosetting epoxy compounds, also known as polyepoxides. The adhesives join by chemical reaction between an epoxide resin and a polyamine hardening compound. The NH group of the amine reacts with three ring atom ether epoxide, $C_1(R_1R_2)$:$C_2(R_3R_4)$:O to form a heavily cross linked hardened polymer. The extent of polymerization (curing) is controlled by temperature, curing time, resin type and hardening agent. The epoxy is dispersed with suitable thermally conducting compounds to get the desired thermal conductivity and made in a sheet form. The sheet is hot pressed using an appropriate press cycle to bond the heat sink with the ground plane of the circuit board. Another advantage is that there is no migration or bleeding issues like in greases. Before curing takes place,

the material flows freely as grease to eliminate the air voids and thus reduce any thermal resistance caused by air voids. This type of thermal interface is ideal if the two sides have comparable CTE values. If there is a CTE mismatch between the two mating surfaces, then the shear forces will break the rigid thermoset bond and lead to device failure; in such cases, one needs to use elastomeric (thermoplastic) bonding compounds (see item 3 below) that can well accommodate the CTE mismatch and allow lateral movement. We offer thermally conducting ThermEx bonding films.

3. **Elastomeric compounds:** Printed circuit boards used in aerospace and automotive electronic assemblies operate in demanding environments with exposure to low and high temperatures, and vibrational shocks. Our silicone based products described in the following sections are a unique class of elastomeric thermal interface materials that provide thermo-mechanical stress decoupling and a reliable heat transfer path. Thermasil* is electrically insulating and thermally conducting film and thus can provide very good electrical insulation between surfaces that are different electrical potential. As an example, it can be used for discrete power devices where electrical isolation is required. On the other hand, Electrasil 1, 2 and 3 are thermally and electrically conducting films. Both the thermally and electrically conducting and thermally conducting – electrically insulating compounds are available over a wide range of conductivities as shown in later sections. The bonding interface of this composite will experience a high degree of shear force due to the relative movement of the planar surfaces and the natural elastomeric properties of silicones will allow independent planar movement, so that the shear forces are decoupled and thus prevent bonding failure. Our silicone based Thermasil and Electrasil family of adhesives are softer with more elongation than other class of organic adhesives like epoxies. The soft character provides a cushion for the adjoining components that many customers value because of increased device reliability. Further, the thermal cycling range of silicone based bonding materials is over a much wider temperature range (-140 F to +550 F) than epoxies (-76 F to +356 F). The higher temperature stability of silicones arises from the fact that a stable Si-O bond results owing to the higher bond energy of 88-117 kcal/mol of the Si-O bond as compared to the 83-85 kcal/mol bond energy of

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* *All Thermasil and Electrasil materials are protected by the following ASC patents:*

Thermally and Electrically Conductive Interface *(United States Patent 7,527,873; Issued May 5, 2009)*

Thermally and Electrically Conductive Interface *(United States Patent 7,867,353B2: Issued June 18, 2008)*

Thermally conductive interface *(United States Patent US 7540081 B2; Issued November 7, 2006).*

the C-C bond. Also any oxidative attack is less for the primary H of CH_3 in silicone than the secondary or tertiary carbon atoms found in the epoxy polymers.

4. **Silicone elastomer pads filled with ceramic or metal particles.** These are available in thickness from about 3 MIL upward and if required, elastomers pads can provide electrical insulation and be used between surfaces that are at different electrical potential. Elastomers combine the advantages of not exhibiting melt or flow during solder flow, and remain flexible after curing to accommodate stress due to CTE differences. The thermal conductivity can be tailored from about 0.5 –5.0 W/mK. Since the binder cures to a rubber, these compounds do not have the migration or the dry joint problems associated with thermal greases. Bonding compounds developed by American Standard Circuits (ASC) uses a unique proprietary silicone. Our silicone does not have any low molecular weight silicone (oil) that is normally present in routinely used silicones to incorporate various additives, pigments, fillers etc. These low molecular weight silicones are the prime cause for outgassing which is a serious issue for normal silicones. We also do not introduce any reinforcing fillers or carriers that are otherwise responsible for outgassing. More important is, we do a vacuum post curing during our bonding process to eliminate completely any possibility of outgassing. These silicones can also be used to fill large gaps where greases would otherwise bleed from the joint on account of their migratory nature. Clean-up is also simple as excess material is easily removed by simple trimming after it curing and post curing steps have been completed.
5. **Pressure sensitive adhesives:** Pressure sensitive adhesives (PSAs) are used in situations where any heating of the components to be joined may cause thermal decomposition or degradation in the device performance. In such situations, the parts are cleaned and conditioned, and the pressure sensitive adhesive is then applied by simply applying the desired pressure over a certain period of time, without heating the device. We provide double sided PSA films of thickness ranging from 5 mil upwards, both for Electrasil* and Thermasil type of films (i.e., whether the film should be both electrically and thermally conducting or whether it should be only thermally conducting and electrically insulating). No mechanical support to maintain the mechanical or thermal integrity is required. The thermal and electrical conductivities can be varied over a wide range by appropriate selection of the dispersing media.

Proper selection of thermal interface materials is decided by many factors such as, power density to be transmitted, how much heat is going to be dissipated, final thickness of the bonding adhesive, process requirements, whether it needs attach-detach of the assembled parts in which case the bonding should be only semi-permanent. In general pads and gels are used in applications where there is large separation between the mating surfaces or there are sensitive components that need cushioning. The following are the main considerations to decide the selection of the adhesive: (a) Thermal conductivity or thermal resistance, (b) Thickness of the adhesive, (c) Mechanical properties such as elongation and flexural strength, (d) Adhesion strength (e) Modulus of elasticity and Hardness and (f) Curing or bonding conditions allowed by the device without suffering any damage, such as, temperature, time and pressure during bonding stages.

High thermal conductivity of Electrasil type of materials can be obtained, for example, by adding calcium carbide, calcium oxide, yttrium oxide and carbon. Thermal conductivity of 180 W/mK has been reported to have been obtained in AlN by adding these materials and hot pressing it (Y Kurokawa et al, J Am Cer Soc 71,
588 (1988)). Similarly, thermal conductivity of as high as 107 W/mK has been obtained by using diamond particle reinforced silicon carbide heat spreader technology.

5 ASC Thermal Management Products

Regarding the selection of thermal interface materials for electronic packaging, we can broadly divide the device applications into the following two areas. Each one of this has its unique requirements.

(a) RF/Analog circuits
(b) Digital circuits

RF/Analog and Digital have somewhat different materials requirements.

RF/Analog applications invariably require lowest possible dielectric losses, a very low leakage current, need to maintain a low and uniform dielectric constant under the operating frequencies and other conditions, and should be accompanied by a low
layer count. The PCBs used in such applications are usually much smaller than in digital PCBs. Since the cost of the bonding material depends on the size of the PCB
to be bonded and therefore would turn out to be low, its cost has much less bearing on the overall cost of the complete assembly. As a result, using more expensive materials to meet performance goals is acceptable. For this class of PCB, choosing a material based on its dielectric constant characteristics and losses usually dominates over other considerations.

Digital applications are characterized by high layer counts and large numbers of drilled and plated holes. The processing costs associated with registering and laminating many layers, coupled with drilling and plating ease usually dominate the choice of bonding materials. Absolute dielectric constant value of the insulating material is important, but less important than processing costs and dimensional stability. Digital applications are nearly always subjected to pricing pressures, so bonding materials choices must be made that just achieve performance requirements without adding extra cost. The PCB design engineer should calculate the thermal load for the design, which in turn decides which type and thickness of ceramic filling will serve the purpose. This would result in considerable saving on the overall cost. *Please consult ASC for guidance in deciding which ASC bonding material would meet your requirements without sacrificing the performance.*

Obviously, the requirements in each of these two classes are quite different:

1. **Digital Applications:** For digital applications, epoxy based multilayer bonding materials are most suitable since epoxies are well suited for multilayer bonding. Because of their high hardness, they are well suited for multilayer stackup symmetry and allowing good registration during drilling operations. They are usually cheaper than other class of bonding materials, so for high layer count the cost of using epoxy based materials is not an issue. However, for flexible digital circuits, epoxies are obviously not good candidates and silicone based pliable bonding films are recommended. For digital applications, all our epoxy based bonding materials are thermally conducting dielectrics. Since these PCBs have high layer count, they tend to become thick and soldering and reworking these thick PCBs puts significant thermal stress on the vias and other plated through holes on a PCB. The thermal conductivity can be varied over a wide range from 1.0 to 4.8 W/mK. The higher thermal conductive films are more expensive than the lower thermal conductivity films. Based on the customers' thermal load, we will offer them the right type of bonding material and its thickness to come with the most cost effective solution. For flexible digital applications, we offer pliable silicones with a range of thermal conductivity dielectrics with thermal conductivity ranging from 1.5 to 4.8 W/mK. Here again, price is decided by the thermal conductivity. For complex shape (non-planar) circuits, we offer thermally conducting dielectric putty whose conductivity can be tailored as per customers' requirements anywhere from 1.5 to 4.8 W/mK. In all these three cases, depending upon the customers' requirements, the curing time, temperature and pressure can be varied over a wide range: from 40 minutes to several hours; 100 to 300 C, a pressure from 100 to several hundred pounds per square inch. The following is a list of thermally conducting dielectric bonding films we offer:

a. Thermally conducting and electrically insulating silicone based flexible bonding films for flexible PCBs (Thermasil).
b. Thermally conducting and electrically insulating epoxy based rigid bonding films for rigid PCBs (ThermEx)
c. Highly thermally conducting and electrically insulating silicone in putty form for complex surface contours (Thermasil-BNp).

The following table summarizes the physical properties of Thermasil and Thermasil-BNp type materials.

Physical Properties:

Property	***Value***	***Method of Test***
Thickness, mils	*3 to 30*	
Specific Gravity	*1.55 to 1.75*	
Durometer, Shore A	*90 ± 5*	*ASTM D2240*
Tensile (PSI)	*1020 to 1030*	*ASTM D412*
Elongation (%)	*50 ± 5*	*ASTM D412*
Tear, Die B (PPI)	*50*	*ASTM D624*
Bond Strength, PPI	*17 Minimum*	*ASTM D429*
Continuous Operating Temp	*260 Deg C (500 Deg F)*	
Thermal Conductivity, W/m-K	*1.5 to 4.5*	*ASTM C 408-82*
Flame Retardance	*Pass UL94VO*	
Dielectric Constant	*3.5 ± 0.2*	*INSTEK LCR Meter 817*
Breakdown Voltage	*50 kV*	*ASTM D-149-97*

2. **RF/Analog Applications:** For RF and analog applications, the circuits usually process signals that are precise and small. Obviously, it is necessary that the signal losses are kept at a minimum if these circuits need to process small signals reliably. It becomes important to avoid any signal losses due to reflections in situations where impedances change. Impedance changes can occur due to variation in the dielectric layer thickness. The bonding material must be able to a have a stable dielectric constant over wide frequency range. The signal is also lost due to absorption by the dielectric material and from reflections, which are traceable to variations in impedance. These losses are due to variations in bonding dielectric thickness, variations of its dielectric constant and variations in final etched trace width. The first two of these are traceable to characteristics of the bonding layer itself. Epoxies are not good candidates for this application and we offer silicones with matched dielectric constants as per the customers' requirement. Again the thermal conductivity can be varied as per the thermal load as mentioned section 1 above. For RF applications, there is also a great need for thermally and electrically conducting bonding films, particularly to bond the ground layer of a PCB with the heat sink layer, which is usually an aluminum based alloy with appropriate final finish. We offer a range of thermally and electrically conducting bonding materials that would suit to various requirements in telecommunication and defense sectors. The circuit complexity of RF/analog circuits is low enough and usually PCBs of two or up to three layers are used to house the entire assembly. Therefore, in this case, the ability of a material to laminate into high count layers does not arise and the main constraints are signal-losses, dielectric constant and dielectric constant uniformity. The following is a list of various thermally and electrically conducting ASC materials:

1. Electrically and thermally conductive silver plated copper silicones for flexible PCBs

(ELECTRASIL-1)

2. Electrically and thermally conductive silver plated copper epoxies for rigid PCBs (ELECTRASIL-1A)
3. Highly electrically and thermally conductive pure silver silicones for flexible PCBs (ELECTRASIL-2)
4. Highly electrically and thermally conductive pure silver epoxies for rigid PCBs (ELECTRASIL-2A)
5. Electrically and thermally conductive graphite/nickel silicones for EMI Shielding (ELECTRASIL-3)
6. Electrically and thermally conductive graphite/nickel epoxies for rigid PCBs (ELECTRASIL-3A)

For all silicone based adhesives in the above list, by a proper selection of the curing agents, it is possible to bond the heat sink permanently or temporarily, that is, attach and detach the assembly whenever required. The bonding in the latter case will, of course, be not permanent, but it would be strong enough to hold well the adjoining surfaces together. Please contact us at technology@asc-i.com or sandy@asc-i.com (phone: 1-630-639-5444 / 1-949-929-5119) for more details and type of applications of any of the above products.

Electrasil 1 and 1-A

Electrasil 1:

Electrasil 1 is a silicone based bonding sheet that contains silver plated copper particles to give the desired thermal and electrical conductivity. The silver plated copper particles uniformly dispersed in the cured silicone matrix give the desired thermally and electrically conductivity as well as a strong bond between the PCB and metal carriers or heat sinks. Although the formulation of this material was specifically targeted toward meeting the critical requirements and performance goals for RF power amplifier applications, it also lends itself extremely well to other high or low frequency applications where specialized flexible PCBs need to be mounted to a metal surface or housing. As a 0.005” thick sheet of a thermoplastic elastomer material, it provides a uniformly thick and strong bonding between the adjacent surfaces. Being an elastomer, it accommodates any TCE mismatch of the bonded layers, so there is no residual stress left in the bonded assembly. It can withstand a continuous operating temperature of 260°C (500°F) as well as multiple excursions up to 288 °C (550 °F) for subsequent operations, such as solder reflow for component installation. The ability to retain its bond strength and thermal and electrical performance after multiple high temperature excursions at these higher temperatures also lends itself very well to the use of higher temperature lead-free solders. As a silicone elastomer, its flexible nature makes it ideally suited for improved life cycle performance, without any delamination problems, when used with thermoplastic circuit materials such as PTFE where large X and Y dimensional changes may occur during the bonding process. This product is well suited for RF applications ranging from 15 GHz to 45 GHz. For Applications greater than 45 GHz please contact ASC sales for a custom solution.

Physical Description: This adhesive is a silicone based thermoplastic elastomer that utilizes both mechanical and chemical bonding mechanisms to insure reliable adhesion at the bond-line interface. The high thermal and electrical conductivity is due to heavily loaded silver plated copper that ensures very low electrical and thermal resistivity. With the proven stability under adverse environmental conditions of the silicone adhesive (in space, land or water), combined with excellent physical and electrical properties of the silver plated copper, ElectrasilTM-1 bonded PCBs would consistently deliver high performance over an extended life cycle.

Typical Applications of Electrasil 1:
Electrasil-1 is used to bond PCBs to metal carriers (heat sink) prior to the assembly of components. If the customer prefers, American Standard Circuits offers the bonding service to bond the PCB layer to the metal carrier. The bonding process requires a minimum pressure of 50 PSI to be applied to the bonding surface and a heat source capable of maintaining a bond line temperature of 150 °C (330 °F) for 15 minutes. Pressure is applied through use of a Fixture Clamping Device, Heated Press or an Autoclave. Heat sources include hot plate, I/R Oven, Convection Oven or an Autoclave. American Standard Circuits has application engineers on staff to help design a compatible bonding process for our customers. Once cured, ElectrasilTM-1 compresses about 20% of its initial thickness.

Property	Value	Method of Test
Shelf Life	6 months (40-70 F storage)	
Thickness, mil	4 mil and above (tailored as per customer's requirements)	
Specific Gravity	3.0 to 3.5 ± 0.1	ASTM D297
Durometer (Hardness)	Shore A 70 to 90	ASTM D2240
Tensile Strength, PSI	200 minimum	ASTM D412
Elongation, %	100 minimum	ATM D412
Tear Strength, PPI	35 to 40	ASTM D624
Bond Strength, PPI*	20	ASTM D429
Continuous Operating Temperature	-60 C to 260 C (-76 F to 500 F)	
Thermal Conductivity, W/mK	>10.00	ASTM F 443
Flame Retardance	Pass UL94V0 Test	
Volume Resistivity, Ohm-cm at 77 F**	<0.001	ASTM D991 (modified) or Mil-G-83528

*All Electrasil -1 samples maintained a cohesive bond after a convection reflow process (at 230 °C) and accelerated life testing (85 °C / 85 % RH for 1000 hours) as demonstrated by destructive peel tests. ** Resistivity value is also dependent on the type of metal carrier finish used.

Electrasil 1-A:

In Electrasil 1-A, the bonding medium is an epoxy layer, instead of the silicone film. Inasmuch as silicones are pliable and soft materials, epoxies on curing become hard and rigid. Thus, whereas the silicones are ideal for flexible and soft circuit layers, epoxies are most suited for rigid and flat PCBs. Epoxies are somewhat brittle also; therefore, it gets cracked even under moderate mechanical shocks. Further, epoxies are not suitable for high frequency PCB application due to high tangent losses. They are most suited for digital PCBs. The epoxy layer is a thermoset layer that results in a highly rigid interface between the bonded layers. Therefore epoxy bonding is not suitable for flexible circuits. On the other hand, due to its high rigidity, the advantage is that any pressure applied on the PCB surface during the assembly operations will not give any dents on the top copper layer without showing any deformation on the top finished copper layer.

The epoxy bonds strongly the PCB layer and the heat sink. The bonded epoxy layer containing silver plated copper particles provides a cost effective technique to create a thermally and electrically conducting interface between the PCB and metal carrier or heat sink. It can withstand a continuous operating temperature of 200°C as well as multiple excursions up to 220 °C for subsequent operations, such as solder reflow for component installation.

Physical Description:
The adhesive is an epoxy based compound that utilizes both mechanical and chemical bonding mechanisms to insure reliable adhesion at the bond-line interface. The high thermal and electrical conductivity is due to heavily loaded silver plated copper that ensures very low electrical and thermal resistivity.

Typical Applications of Electrasil 1-A:

Electrasil-1A is used to bond PCBs to metal carriers (heat sink) prior to the assembly of components when the electrical resistivity should be less than 0.001 but can be greater than 0.0004. ASC can perform the bonding of the ground plane of the PCB with properly finished heat sink. The bonding process requires a minimum pressure of 50 PSI to be applied to the bonding surface and a heat source capable of maintaining a bond line temperature of 150 °C (330 °F) for 15 minutes. Pressure is applied through use of a fixture clamping device, heated press or an autoclave. Heat sources include hot plate, I/R oven, convection oven or an autoclave. ASC staff can help design a compatible bonding process for our customers. Once cured, the final thickness of Electrasil 1-A reduces to about 80% of its initial thickness. The following table summarizes the physical parameters of Electrasil 1-A

Property	Value	Method of Test
Shelf Life	6 months (50-70 F storage)	
Thickness, mil	3 and above (tailored as per customer’s requirements)	
Specific Gravity	3.0 to 3.5 ± 0.1	ASTM D297
Durometer (Hardness)	Shore A 70 to 90	ASTM D2240
Tensile Strength, PSI	200 minimum	ASTM D412
Elongation, %	100 minimum	ATM D412
Tear Strength, PPI	35 - 40	ASTM D624
Bond Strength, PPI	20	ASTM D429
Continuous Operating Temperature	-60 C to 260 C (-76 F to 500 F)	
Thermal Conductivity, W/mK	>20	ASTM C408
Flame Retardance	Pass UL94V0 Test	
Volume Resistivity, Ohm-cm at 77 F	<0.0004	ASTM D991 (modified) or Mil-G-83528

Electrasil 2 and Electrasil 2-A

Electrasil 2 is a silicone based pure silver filled conductive adhesive that provides a cost effective technique to create a thermally and electrically conductive bond between flexible PCBs and metal carriers or heat sinks. On the other hand, Electrasil 2-A uses epoxy instead of silicone for the bonding process. Although the formulation of Electrasil 2 was specifically targeted toward meeting the critical requirements and performance goals for RF power amplifier applications, it also lends itself extremely well to other high or low frequency applications where specialized PCBs need to be mounted to a metal surface or housing. As a 0.005" thick sheet of a thermoplastic elastomer material, it provides a uniformly thick and strong bonding between the adjacent surfaces. Being an elastomer, it accommodates any coefficient of thermal expansion (TCE) mismatch of the bonded layers, so there is no residual stress left in the bonded assembly. It can withstand a continuous operating temperature of 260°C (500°F), multiple excursions up to 288 °C (550 °F), and multiple thermal cycling between -60 C to 250 C. It will not degrade during solder reflow for component installation. The ability to retain its bond strength and thermal and electrical performance after multiple high temperature excursions at these higher temperatures also lends itself very well to the use of higher temperature lead-free solders. As a silicone elastomer, its flexible nature makes it ideally suited for improved life cycle performance, without any delamination problems, when used with thermoplastic circuit materials such as PTFE where large X and Y dimensional changes may occur during the bonding process. This product is well suited for RF applications ranging from 15 GHz to 45 GHz. For Applications greater than 45 GHz please contact ASC sales for a custom solution.

Physical Properties:

The adhesive is a silicone based thermoplastic elastomer that utilizes both mechanical and chemical bonding mechanisms to insure reliable adhesion at the bond-line interface. The high thermal and electrical conductivity is due to heavily loaded silver that ensures very low electrical and thermal resistivity. With the proven stability under adverse environmental conditions of the silicone adhesive (in space, land or water), combined with excellent physical and electrical properties of the silver fillers, Electrasil bonded PCBs would consistently deliver high performance over an extended life cycle.

Applications:

Electrasil 2 is used to bond PCBs to metal carriers (heat sink) prior to the assembly of components. If the customer prefers, American Standard Circuits offers the bonding service to adhere the PCB to the metal carrier. The bonding process requires a minimum pressure of 50 PSI to be applied to the bonding surface and a heat source capable of maintaining a bond line temperature of 150 °C (330 °F) for 15 minutes. Pressure is applied through use of a Fixture Clamping Device, Heated Press or an Autoclave. Heat sources include hot plate, I/R Oven, Convection Oven or an Autoclave. American Standard Circuits has application engineers on staff to help design a compatible bonding process for our customers. Once cured, Electrasil-2 compresses about 20% of its initial thickness.

Electrasil 3 and Electrasil 3-A

Recently, American Standard Circuits has developed a new type of thermally and electrically conducting bonding material to bond the PCB ground plane with the heat sink for RF circuits and electromagnetic shielding applications. In this newly developed class of materials, there are two types of such bonding materials: Electrasil 3, released in December 2011 and available to the customers; Electrasil 3-A which is in the final testing stages is planned to be released around September 2012.

ASCI was an early participant in the thermal management of more demanding PCBs used in telecommunication RF circuits, under-the-hood high end automobile customers, high density LEDs and under water navigation, to name a few. ASC has much expertise and has done considerable investment in this area, owning several material and process patents in this area. Electrasil 3 is a silicone based elastomeric interface that is suitable for bonding surfaces that have widely dissimilar values of coefficient of thermal expansion (CTE). Being elastomeric in nature, Electrasil 3 can easily absorb mechanical shock or dimensional changes due to changes in temperature, or other sudden movements. Thus, it is ideally suited for components used under severe shocks, temperature extremes and harsh atmospheric conditions. Some examples are military fighter planes, aerial spy sensors or missiles. Such elastomeric bonding agents are also very pliable and are therefore ideal for flexible circuitries, as silicones can be bent around without cracks or disjoints.

Electrasil 3 can be supplied as bonding sheets of any thickness starting from 3 mils and higher, or as a putty material that can easily fill circuitry involving complex shapes that are not necessarily planar. Thus, the putty form is ideal to replace air in complex shaped cavities between the heat sink body and the PCB ground layer. By changing the catalyst of the curing process, the bonding characteristics of these interface materials can be customized to suit the need for both permanent bonding and temporary bonding when the components have to be assembled and disassembled multiple times, such as in rework applications.

The thermal and electrical conductivities can be varied over a wide range. The properties of Electrasil-3A are summarized in the tables below.

Table: Electrasil 3 (Silicone based elastomeric (flexible) thermally and electrically conducting bonding film)

Property	Value	Method of Test
Shelf Life	6 months (50-70 F storage)	
Thickness, mil	3 and above (tailored as per customer's requirements)	
Specific Gravity	2.0 to 3.5 ± 0.1	ASTM D297
Durometer (Hardness)	Shore A 68 to 77	ASTM D2240
Tensile Strength, PSI	180 minimum	ASTM D412
Elongation, %	100 minimum	ATM D412
Tear Strength, PPI	40	ASTM D624
Bond Strength, PPI	20	ASTM D429
Continuous Operating Temperature	-60 C to 260 C (-76 F to 500 F)	
Thermal Conductivity, W/mK	5 to 8.5	ASTM C408
Flame Retardance	Pass UL94V0 Test	
Volume Resistivity, Ohm-cm at 77 F	0.05 Max	ASTM D991 (modified) or Mil-G-83528

Thermasil-1 and ThermEx

Both Thermasil and ThermEx class of materials are dielectrics in nature. In this class of compounds, there are two important characteristics that play an important role in the device performance: the dielectric breakdown voltage (DBV) and the moisture absorption. DBV is a measure of an insulator's ability to withstand the stress of high voltages placed across it. Usually all of the commonly available laminates have DBV values of at least 1000 volts per mil of thickness. This means that a 2 mil thick laminate can withstand a voltage stress as high as 2000 volts, more than adequate to meet the Telco specifications applied to many networking products.

Unlike silicone based systems, ThermEx is epoxy based. All epoxy systems absorb some moisture or water when exposed to high humidity environments. This absorption affects the PCB in two ways. Water has a relative dielectric constant of approximately 73. If a laminate absorbs a significant amount of water the resulting relative dielectric constant of the combination will be higher than normally used to calculate impedance and can cause impedance mismatches.

A more important effect of moisture absorption is the increased leakage current. Materials with high moisture absorption may exhibit leakages in excess of what the circuits housed on them can withstand. In order to use high absorption materials in such applications, it is often necessary to seal these ThermEx based PCBs with a protective coating after first taking them dry. Of course, this represents an additional cost as well as dealing with the problem of reworking, since the coating must be removed to do the rework and then reapplied.

Thermasil-1

Thermasil 1 is a patented elastomeric dielectric adhesive that has the requisite thermal interface properties that are particularly useful for making PCBs for (a) cooling of power supplies, (b) aerospace components, (c) under-the-hood, (d) other automotive PCBs and (e) various motor controls. The Thermasil type of bonding film is silicone based which is very flexible and is therefore ideally suited for flexible PCBs. The processing conditions and material properties of Thermasil are summarized below. This material is especially suitable for devices that should properly function over wide temperature ranges (from -100 F to +500 F). It also has high shear strength due to its elastomeric nature, and thus would not crack or rupture between dissimilar CTE bonded surfaces. The shelf life of uncured Thermasil-1 is 6 months, when stored between 32 F and 42 F. The bonding is done by applying a pressure of 100 to 120 PSI at 330 F for 20 to 30 minutes. Depending on the filler used, the thermal conductivity can be tailored from 0.6 to 4.8 W/mK. The other main characteristics of Thermasil-1 are given below:

1. Long Term Temperature Stability: -100 F to 500 F

2. Specific gravity of final product: 1.4 to 1.8

3. Durometer, Shore A: 60 to 90

4. Tensile Strength: 1200 to 1250 PSI

5. Tear Strength: 180 to 200 PPI

6. Elongation: 350 to 430 %

7. Flame Test: Pass UL 480 V0 Test

ThermEx

ThermEx is an epoxy based bonding dielectric material thermal interface. It is a rigid bonding film and is therefore suitable for rigid PCBs. The bonding film thickness can be varied over a wide range starting from 2.5 mil to any desired higher thickness. Being epoxy based, its thermal stability is limited from -60 F to 350 F. It is particularly useful for cooling of power supplies, under-the-hood and other automotive PCBs and various motor controls that operate within the temperature range of -60 to 350 F. The processing conditions and material properties of ThermEx are summarized below.

Shelf Life of uncured material: 6 months (stored at 32 F to 42 F)

Curing process: hold at 280 F at 100 PSI for 20 to 40 minutes

Thermal Conductivity: 0.6 to 4.8 W/mK

Long Term Temperature Stability: -60 F to 350 F

Specific gravity of final product: 1.3 to 1.9

Durometer, Rockwell R: 140 to150

Tensile Strength: 40-45 PSI

Tear Strength: 180 to 200 PPI

Flame Test: Pass UL 480 V0 Test

Power components have a maximum junction temperature, which must not be exceeded to prevent damage to the device. Devices are encapsulated in packages, which have different levels of thermal resistance. When designing power electronics, the heat dissipation of the device, coupled with any heat sinks, as well as the maximum power dissipated by the device, must be analyzed to insure that the device operates within allowable specified limits.

6. Conclusions:

In this White Paper we have summarized the origin of heat in electronic devices, some basic concepts of thermal phenomenon, various parameters or properties that govern the thermal management of the electronics assembly, selection and application of thermal interface materials for various electronics components, criteria governing the selection of thermal interface materials for RF and digital applications and a broad range of thermal interface materials made and supplied by ASC for various applications in the RF and digital industries including the emerging high intensity LEDs.

7. Acknowledgements:

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8. References:

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