About Thermal Interface Materials

Thermal management is to ensure a long-term lifetime and functioning of electronic components such as power semiconductors in electronic circuits. All starts with a profound knowledge of the occurring power dissipation and of the whole thermal path.

To do so the thermal path should be optimized from the scratch when defining the electronic components, taking into consideration their behavior under load, by selecting the best fitting thermal interface material (TIM). At the same time the periphery including heat sinks, housings, as well as the fixing of electronic parts to the heat sink has to be considered.

Thermal resistance

TIMs minimise the thermal gradient ΔT, thus reducing the thermal resistance between two contact surfaces.

The thermal conductivity k [W/mK] is the intrinsic property of materials to conduct heat. Normally one-dimensionality, steady state operation, homogeneity of the material are given as simplifying premises. The thermal conductivity of any homogeneous material is independent from its thickness. This is not the case with non-homogeneous materials such as elastomers or composites being reinforced by engineering plastics or glass fibers. The thermal conductivity is defined by the induced heat dissipative power Q [W] through the contact surface A [m²] along the length of the thermal path - corresponding to the material thickness [d] - and the temperature gradient ΔT:

$k = Q\, d / (A\, \Delta T)$; with $d / \Delta T = \text{const.}$ for homogeneous materials

All materials which are not based on electrically conductive materials and therefore serve as electrically insulators need to be compounded with thermally conductive ceramics e.g. aluminum oxides or boron nitride in order to increase their specific thermal conductivity. The conductivity depends on the filling degree as much as the thermal conductivity of the particles and their microstructure. As a rule, the thermal conductivity decreases with increasing operating temperatures due to positive expansion factors.

The thermal resistance through the material itself $R_{th\ Material}$ is an internal resistance and is defined after Fourier series development:

$R_{th\ Material} = \Delta T / Q$ or $d / (k\, A)$

It depends on the following factors:

- material thickness
- the thermal conductivity
- surface area

The thermal resistance of soft materials such as compliable elastomers and gap fillers are subjected to pressure.

In addition to the internal material resistance, the temperature gradients on both contact surfaces are decisive. They effect two contact resistances $R_{th\ Contact\ 1}$ and $R_{th\ Contact\ 2}$. Thermal contact resistances are mainly caused by incomplete fitting and air interstitials affecting the border areas with $k_{Air} = 0{,}027$ W/mK at the acting as thermal insulators.

Thermal contact resistances depend on:

- Surface structures, surface roughness and surface unevenness
- Pressure
- Time
- Volumetric expansion

Depending on the material, contact resistances decrease with time due to better compliance in the first operating hours. The higher the mounting pressure from the electronic package against the thermal interface, the lower the contact resistances.

The overall thermal resistance is defined as:

$R_{\text{th Total}} = R_{\text{th Material}} + R_{\text{th Contact 1}} + R_{\text{th Contact 2}}$

By use of thermally conductive interface materials, both the contact resistance and the overall resistance are lowered. The better the material complies with both surfaces, the less air interstitials there are , thus minimizing the contact resistance under pressure. The thicker the thermal interface material is the higher is the material resistance against the contact resistance. This applies to thick gap fillers having low thermal conductivities in particular. Figure 1 shows the principle of linear temperature drops.

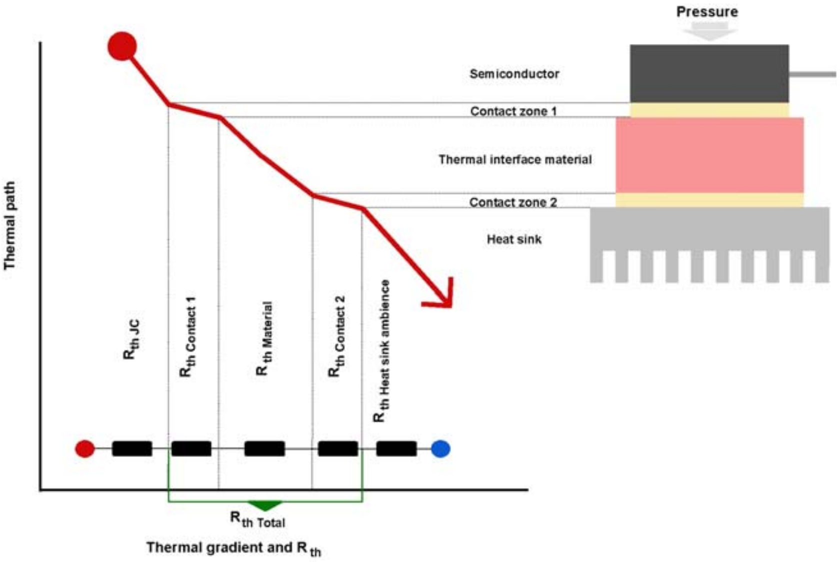

Figure 1:Thermal gradients along the thermal path

Design-in criteria

Apart from thermal requirements, the specific needs for the electrical insulation of electronic parts and other parameters, e.g. minimum distances and CTI have considerable impacts on the product design-in of thermal interface materials.

TIMs therefore can be classified into

- electrically insulating or
- electrically non-insulating materials

Further on, parameters such as chemical consistence, proper surface properties for compensating surface deviations or mechanical tolerances, softness and flexibility, tensile strength, processability, easy handling and delivery shapes and last but not least the economic efficiency among others have to be considered when doing the product design-in.

Environmental compatability, reworkability, suitability to adhesive coating, chemical, temperature and ageing resistance, as well as life time and low out-gasing of silicone are other important influences.

Classifications

a) Electrically insulating

Electrically insulating TIMs can be grouped as:

- Silicone foils with or without mechanical reinforcement e.g. glass fiber mesh
- Engineering plastics with increased thermal conductivity e.g. Kapton® MT coated with
  - phase change films or
  - compliable contact coatings e.g. made of polymers
- Gap fillers based on flexible elastomers with or without mechanical reinforcement e.g. by glass fiber
- Thermally conductive adhesive films with electrically insulating carriers
- Engineering plastics with improved thermal conductivity and contact properties

Very thin thermally conductive foils and films are bound to contact electronics to heat sinks or housings along very short distances of only very few tenth of millimeters

Thermally conductive foils and gap fillers are mostly elastomers e.g. silicones enriched and filled by thermally conductive ceramics such as boron nitride, aluminum oxide or composites. Boron nitride is very often used and expensive. It is characterized by its high thermal conductivity and its softness compared with a suitable microstructure realizing very good thermal contacts.

Gap fillers are installed for thermal links over big air gaps of mostly more than 0.5 mm and for compensating big tolerances of packages and stacking ups in the range of millimeters. Through their flexibility they themselves function as springs, generating sufficient contact pressure. The types and properties e.g. thickness must be selected carefully. Accrued tolerances have to be considered thoroughly as well as their compressibility. It´s indispensable that their resilient forces act over the whole operating range. When entering plastic deformation the forces decrease through creeping and relaxation. Plastic deformable gap fillers serve to fill any gaps with almost zero pressure. Their adherence leads to a stable contacting.

Advanced electrically insulating plastics e.g. based on polyimide with Kapton® ,among others, have proved to be ideal for the use in thermal management. Their intrinsic thermally conductivity could be enhanced notably by ceramic fillers and their contact resistance was dramatically reduced by thermally conductive phase change or contact coatings e.g. made of adjusted polymers. At the same time, engineering plastics e.g. Kapton®coated with PSA have been developed as adhesive films, realizing good compliance and thermal contact to the surfaces in touch.

b) Electrically non-insulating

Electrically non-insulating thermal interface materials can be categorized into

- Carriers e.g.made of aluminum with

  - phase change coating or
  - coatings for improved contact e.g. based on polymers
- Pure phase change films without carrier
- Graphite foils for effective heat spreading from hot spots
- Thermally conductive adhesive films as
  - tapes made of electrically conductive carriers e.g. of aluminum with PSA coating
  - pure PSA transfer tapes
- Thermal grease

Coatings as well as carriers of these composites are not electrically insulating and therefore have a very high natural thermal conductivity. Aluminum, Graphite and copper are mostly used as carriers. Analog to electrical insulators, additional phase change coatings or contact polymers or thermally conductive adhesive coatings effect to improve the thermal contact. Phase change materials and transfer tapes can also be made as pure films without stabilizing reinforcement. Adhesive tapes combine fulfilling the needs of thermal management together with requirements to the fixing techniques at the same time.

Graphite foils consist of more than 98% pure Graphite. Made of particles having a flake-like structure, the heat conduction is anisotropic in-plane (x-y plane) and vertical (z-direction). By this, heat can be spread from hot spots and be conducted in a well directed way. Their relative softness makes them pliable to rough or uneven surfaces, thus maximizing the thermal contact. Their electrical conductivity contributes improving EMI.

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Typical pressure dependencies

All TIMs have specific pressure dependencies of the thermal resistance.

Figure 2 compares typical dependencies taken from TIMs with small thicknesses.

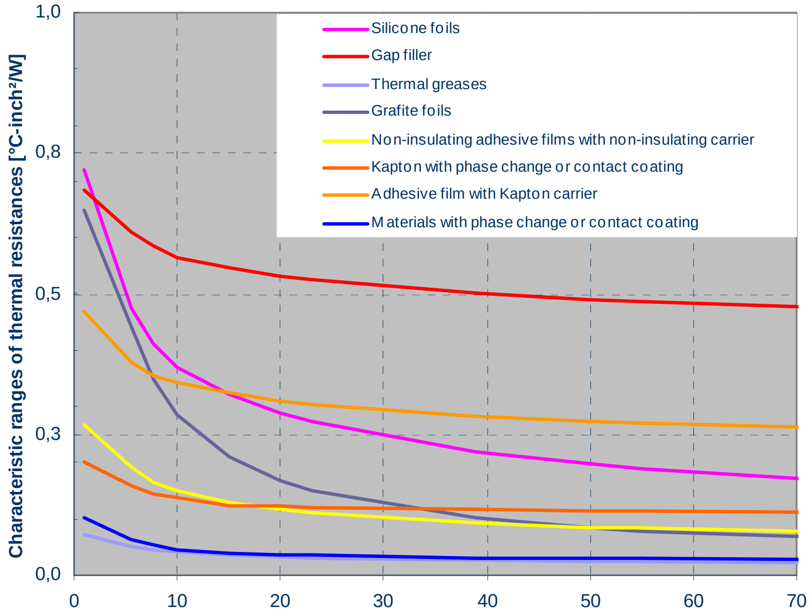

Figure 2: Typical pressure dependencies of the thermal resistance for representative TIMs

Mounting pressures must be lower than the maximum load put on the electronic packages, the PCB, the soldering points, lead frames and the system itself at any rate. Very often pressures are tolerated between 5 - 10 N/cm² only or must be even less. Only gap fillers made of very soft and flexible elastomers may be applied.

Systems, however, using semiconductor clips for fastening electronic packages to heat sinks with TIMs acting in the interface require sufficient clip forces. The optimum thermal link is realized taking into account both the specific dependencies of TIM on pressure and the mechanic limitations. Figure 3 shows the interaction of TIMs and semiconductor clips in principle. The operating range is defined as overlap of optimum TIM operation and the mechanical limitations.

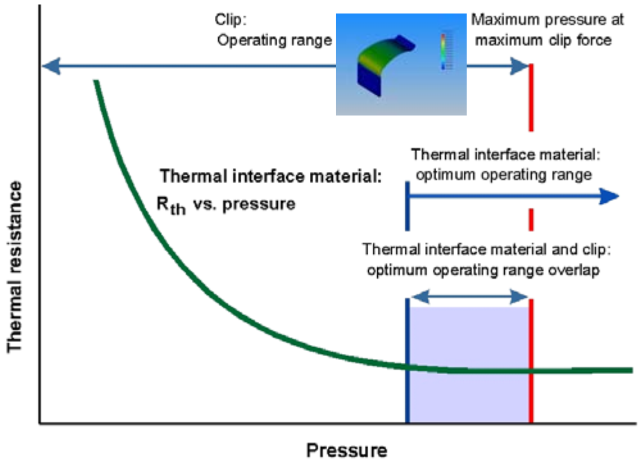

Figure 3: Optimum operating range of TIMs and clip type fastening in principle

Phase change materials

Phase change substances help maximizing the thermal contact, thus reducing the total thermal resistance to a minimum. They are applied by coating very thin foils and films in particular where diminishing the temperature drop at the contact zone is more important compared to the thermal gradient of the carrier material itself. They ideally replace thermal greases due to their easy handling and process reliability of coating thicknesses – the two striking disadvantages of using grease. They are mostly based on polymers or monomers which get wet when the aggregate state changes from solid to soft. This happens when the phase change temperature is reached for the first time during warm up. With complete filling up and a positive volumetric expansion of 10 to 15%, air interstitials are expelled out of the microstructure of the surfaces, unevennesses get filled and contact zones get covered. When cooling, the opposite phase change take place and the materials return to solid. With every single new cycle, phase change materials run through the same phases. However the thermal contact remains permanently low after the first warm up. Through their thixotropic properties, run out is widely avoided. From figure 4 the principal of operation with the situation before and after the first warm up leading to improved thermal contacts can be gathered. It is obvious that air voids are eliminated during the initial warm up. Figure 5 shows how thermal resistances develop in principle during first warm up and after.

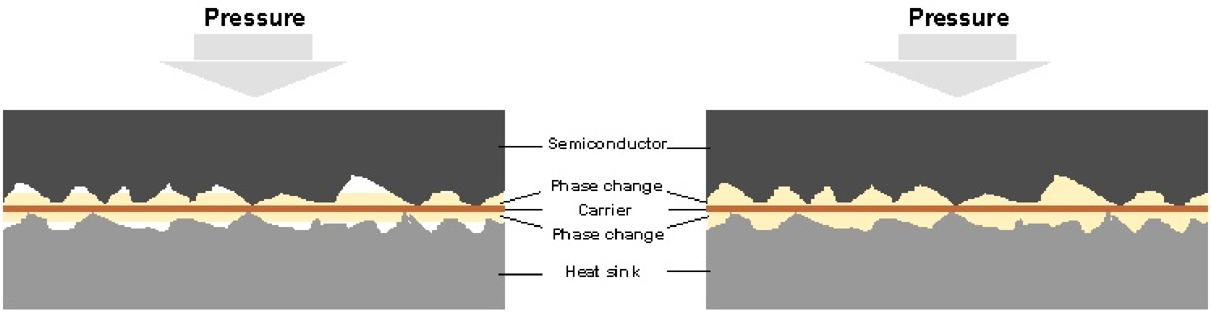

Figure 4: Principle of operation for phase change materials and coatings

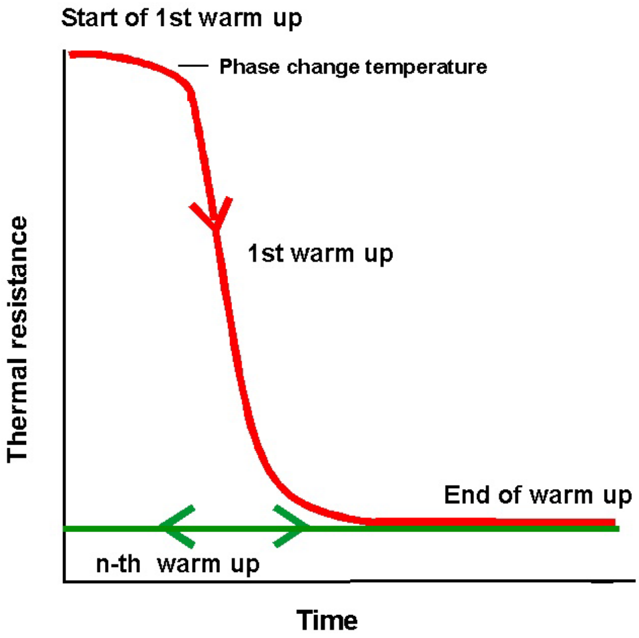

Figure 5: Development of thermal resistances during warm up cycles