In Strong Contact

Highly thermally conductive interface materials can only work efficiently within the thermal path if the thermal contact resistance becomes almost zero. In order to minimise the contact resistance of influences caused by roughness and uneveness, pressure is exerted by spring-type fixing elements. The clamping force and the stress distribution of the clip can be optimised by finite element analysis, which leads to better cooling and improved performance and reliability of the whole application. **Wilhelm Pohl (HALA Contec), Jürgen Schmidt (ServiceforceCom), and Erwin Nagy (KBN Design Office), Germany**

When talking about cooling efficiency, the total thermal resistance R_{th} from the heat source to the heatsink is meant. Hereby, the thermal contact of the semiconductor to the heatsink, with the help of a thermal interface material (TIM), conducting the dissipative power is the crucial bottleneck.

Thermal resistance of power modules

The thermal resistance consists of two contact resistances and the material resistance caused by the material itself according to equation 1:

$$R_{th} = R_{th\ Contact\ 1} + R_{th\ Material} + R_{th\ Contact\ 2} \qquad (1)$$

The material resistance depends on the material thickness d and the thermal conductivity l of the interface material as well as on the contact area A according to equation 2:

$$R_{th\ Material} = d/(\lambda A) \qquad (2)$$

The contact resistances expressed by the thermal coefficient α mainly depend on the pressure p, as well as on evenesses and roughnesses being surface irregularities according to equation 3:

$$R_{th\ Contact} = 1/(\alpha A) \qquad (3)$$

Baseplates of semiconductors or power modules are typically far from plane and even. They show roughnesses of 0.5 to 5µm and evenesses W_t in a range of 10 to 50µm in transverse direction and alongside. The lower the thermal material resistance of a TIM, the more influential the thermal contact resistance, and it becomes the dominant factor. The impact of thermal contact resistances is, above all, influential for very thin and highly thermally conductive interface materials. Figure 1 shows the total resistance and the respective contact resistances of insulating films with phase change coating of different thicknesses, depending on the two exerted pressures shown. The contact resistances were graphically deduced from a theoretical thickness at zero PSI. The thermal conductivity λ and the thermal coefficient α can both be very accurately estimated by graphic extrapolation.

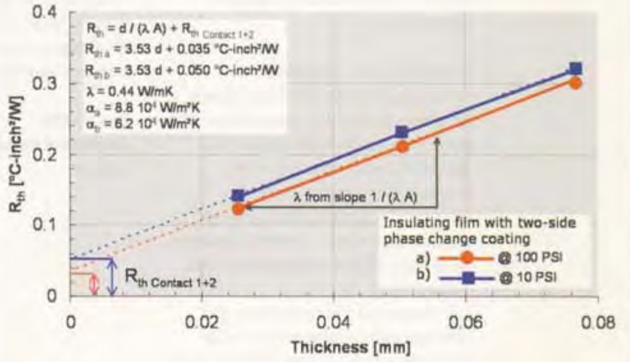


Figure 1: **Thermal contract resistance and thermal conductivity**

Electrically non-insulating interface materials with a metal basis, having an intrinsically high thermal conductivity (e.g. λ = 220W/mK for 99.5% aluminum), perform well only if the contact resistances making up most of the thermal resistance are minimised to almost 0K/W. When applying such materials, the thermal contact affected by surface roughnesses can be substantially improved by coating with phase changing materials or lamination of other contacting polymers. Trapped air (having a very poor conductivity of 0.025W/mK) can then be eliminated under pressure. Of course, the maximum achievable and tolerable pressures, as well as the costs for high surface finish, are limiting factors. Unevenesses are shape deviations of a lower rank and have a decisive impact on the thermal contact area, which can only be influenced by well-configurated fixing geometries.

In order to give base plates a pre-stress, their geometry is characterised by a certain convex shape, resulting in a correlation between the spot where the pressure is applied and the strength of the pressure itself. In order to generate both sufficient pressure and compensate all the unavoidable tolerances of the mechanical elements, spring clips are usually used as fixing devices. The clip has to be designed in a way that the operating points of a thermal interface material is applied on the robust asymptotic part of its characteristic pressure-sensitive R_{th} curve. This has to be guaranteed even in cases where the mechanical sum tolerances are at a minimum. On the other hand, the spring steel must not be overstressed in the case of maximum sum tolerances. The thermal contact is not entirely optimised by simply using high forces. Above all, the location where the force influx takes place is decisive, in order to reach an optimal compliance of the baseplate to the

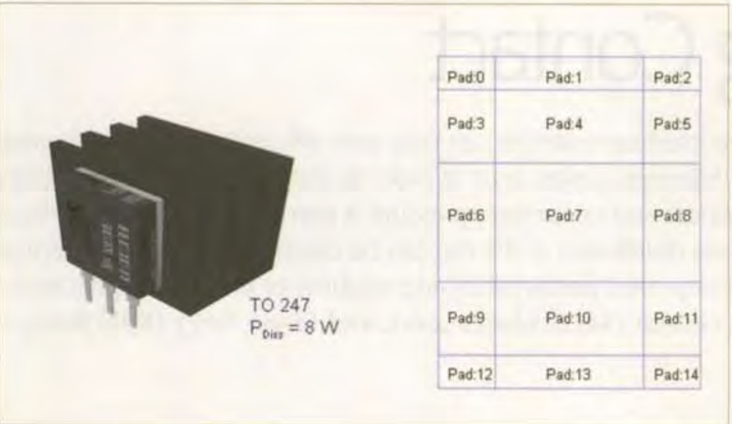


Figure 2: **Thermal analysis by base-plate segmentation of a TO 247 package plate**

heatsink. This leads to an improved contact area.

Simulation gives insights

The effects of different force influxes have been analysed by segmentation of a semiconductor baseplate before CFD analysis. For each segment of the convex shaped plate, a different working point appears, hence different pressure dependening thermal resistances ($R_{th} = f(p)$) are fed back to the thermal system (Figure 2).

It is assumed that contact over the complete plate is achieved and no air enclosures occur. Six scenarios have been examined by simulation, given a dissipative power of 8W generated by a MOSFET in a TO 247 package;

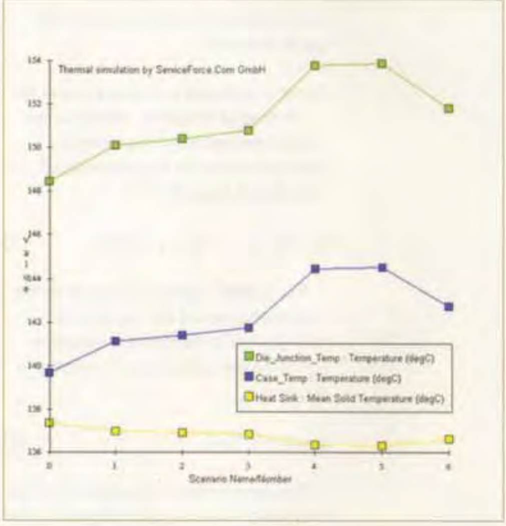
- scenario 0: ideal contact resistance of $R_{th\,Contact} = 0K/W$ - $R_{th} = R_{th\,Material} = d/(A\,\lambda)$,

- scenarios 1 to 4: ideally homogenuous pressure distributions for senario 1 (55 PSI), 2 (45 PSI), 3 (40 PSI), 4 (20 PSI),

- scenario 5: simulation of a one-side screwed fixture with tilting effect and inhomogenuous pressure distribution with pressures decreasing alongside the TO 247 package from 40 PSI to 7.5 PSI,

- scenario 6: central force influx with inhomogenuous pressure distribution

Figure 3: **CFD-simulation of thermal contacts**



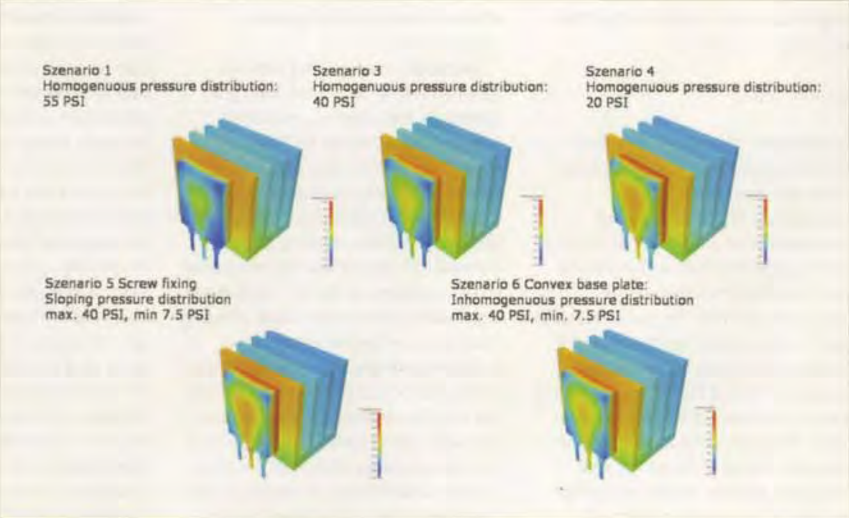


Figure 4: **CFD-simulated temperature distributions**

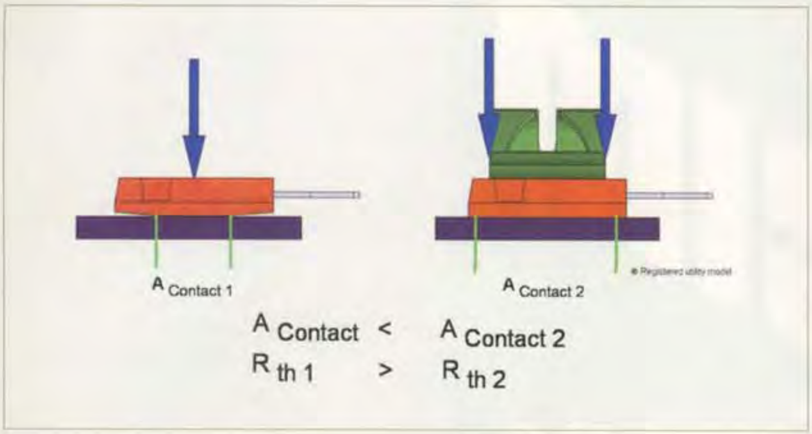


Figure 5: **Improved thermal contact by tailor-made clip geometry**

caused by remaining convexity of the baseplate (max. 40 PSI in the central area, min. 7.5 PSI at the outer plat segments).

Figure 3 shows the temperatures within the thermal path for each scenario.

Best results, however unrealistic, are reached in scenario 0. Scenario 1 leads to best thermal contacts given a homogenuous pressure distribution of 55 PSI. Impacts on the thermal path for scenarios 2, 3 and 4 depend on the respective pressures. Inhomogeneous pressure distributions through tilting effect caused by one-side screwing fixtures lead to worst results as shown in scenario 5. Scenario 6 proves that using only high forces centrally exerted on the semiconductor packages will not lead to improved thermal linkage, because the outer parts of the base plates remain badly connected due to a remaining convex shape. Figure 4 shows the temperature distributions of all scenarios 1 to 6.

Technically, a more or less homogeneous pressure distribution can only be realised by a tailor-made design of the fixing element and an individual geometry. The registered universal HALA clip shape shown in Figure 5 (right) is advantegous for force influx concentrated on the outer parts of semiconductor packages such as TO 247 and TO 220.

This leads to enlarging the contact area and thus, reducing the thermal resistance according to $R_{th} \sim 1/A$ independently, either on a transverse or alongside orientation of the clip and its force influx. At the same time, a more or less homogeneous stress distribution along the finger of the clip is realised by optimising its particular geometry by help of FE (finite element) analysis. Last, but not least, the characteristic spring curve and the force-sensitivity can be adjusted by tailoring the cut out, thus resulting in a better performance of the thermal system compared to massive semiconductor clips or clips with more dot-like application of force. Figure 6 shows the FE-optimised shape of HALA clips.

Conclusion

In order to achieve an optimum thermal contact, the interaction of thermal interface materials and the pressure exerted onto packages of semiconductors or power modules having convex baseplates is decisive. By help of a CFD-simulation, the effects of contacting the interfaces can be estimated. By use of a FE (finite element) analysis, the geometry of semiconductor clips is tailor-made and the characteristic spring curve of a clip can be individually adjusted to any mechanical needs. This results in effectively improving the thermal contact, while achieving a homogeneous pressure distribution on the semiconductor package. The sum of mechanical tolerances is compensated within the whole operating range, without exceeding the load limits of the steel.

Figure 6: **FE-analysis optimised HALA clip geometry**