Sinter Technology for Power Modules

High-power applications such as automotive, wind, solar and standard industrial drives require power modules which fulfil the demand for high reliability, thermal and electrical ruggedness. These demands are met by deploying state-of-the-art packaging technologies such as solder-free pressure and spring contacts, but also sinter technology. The engineers in the New Technologies Department were challenged to develop, optimise and employ this new packaging technology. **Christian Göbl, Head of New Technologies, SEMIKRON, Nuremberg, Germany**

Silver sinter technology has been used to connect chips to substrates since 1994. Even back then, the properties of sintered silver bonding layers and the benefits they boast in terms of reliability were analysed and reported on within the contexts of numerous international congresses. At that time, however, it turned out that this type of bonding technology was not quite ready for use in large-scale industrial electronics.

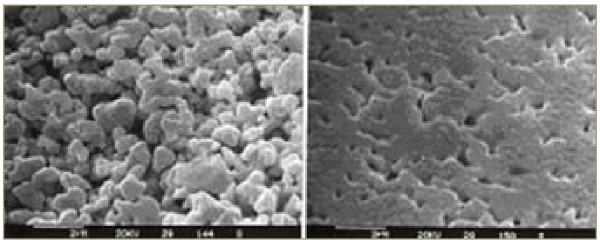

Figure 1: The silver diffusion layer before (left) and after (right) the sinter process

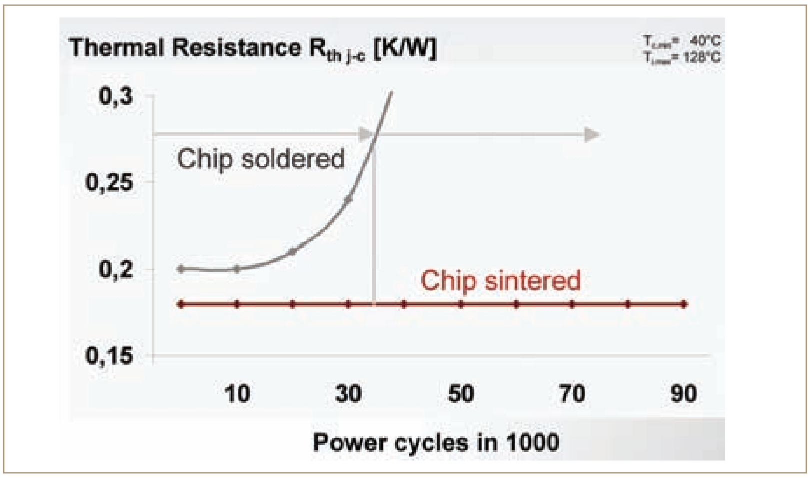

Figure 2: Power cycling capability of sintered versus soldered chips

Sinter technology basics

These sinter chip/substrate connections are made solely out of special silver particles which, in certain circumstances, produce sinter bridge formations that create a reliable connection between the two bond parts. Figure 1 shows the silver particles before and after sintering. In relation to this, it is important to know that each and every one of these particles is surrounded by a special coating material. Producing a bond is simple: just place the amount of particles needed for the desired layer thickness between the two bond parts and apply a given temperature and pressure to the bond for a given time. The result is a stable sinter connection. This basic process is, however, only sufficient for the first technology evaluations.

The past years have been devoted to the industrialisation of sinter technology. An independent sinter paste has been developed, which today is the basis of the sinter paste approved and implemented by Semikron. Additionally, sinter engineering tools have been developed to manufacture multi-chip DCBs in formats of 5 x 7in. The sinter press was designed to handle pressure loads depending on the process action. The production staff that are responsible for the assembly are well-trained and the process in place continuously improved.

The contact strength achieved by the sinter layer between chips and substrates is extraordinarily high. The sintered layers display high load cycling capability in the reliability tests. A further advantage of sinter technology is that no solder stop layers have to be washed out. The achieved accuracy of chip position relative to the substrates is as much as 50µm. In solder technology, in contrast, a positional accuracy of just 400µm is achieved, a fact

Table 1: Material parameters for the silver diffusion sinter layer in comparison to a standard solder layer (the high temperature stability of sinter technology indicates that the connecting layers do not age)

		Ag pure silver	Ag sinter layer	SnAg solder layer	Factor
Liquidus	°C	961	961	221	4
Electric conductivity	MS/m	68	41	7,8	5
Thermal conductivity	W/mK	429	250	70	4
Density	gr / cm³	10,5	8,5	8,4	1
CTE	µm / mK	19,3	19	28	1
Tensile strength	Mpa	139	55	30	2

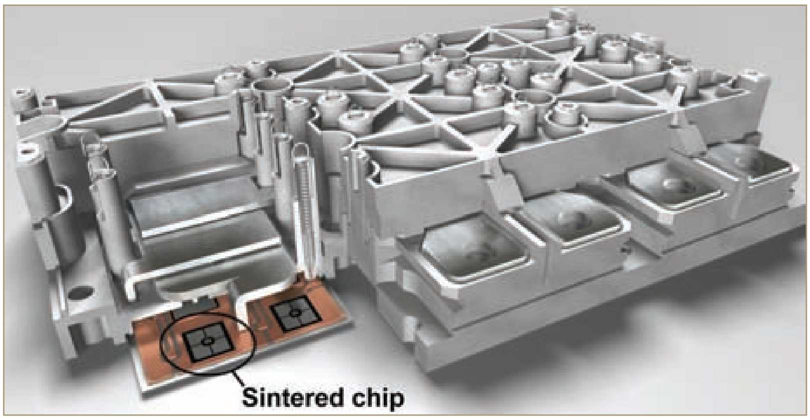

Figure 3: **Cross-section of the SKiM 63 module case, the pressure contact system and the spring contacts for the gate connections**

that can be considerably encumbering in the subsequent image processing procedures.

Considering the thickness of the sintered layers, the sintered layer is 4.5 times thinner than a standard soldered layer and has 4 times the thermal conductivity. This results in excellent thermal properties in the sintered connection. The layers also demonstrate far higher cycling capability than soldered layers (see Figure 2). This is due to the fact that the melting point of the silver used in the sintered connection is also four times higher than that of the lead-free solders commonly used today (see Table 1). The long-term experience has paid off - an alternative packaging technology, completely solder-free, has been established.

Sinter technology in application

Sinter technology was employed in the SKiM IGBT module family for 22 to 150kW train drive converters in electric and hybrid vehicles. SKiM has five times the thermal cycling capability compared to modules with base plate and soldered terminals. Instead of soldering the DCB, the ceramic substrate required for isolation, to the copper base plate, the connection to the heat sink is assured by way of pressure contact technology for all thermal and electrical contacts (see Figure 3). Pressure points positioned directly beside each chip guarantee that the DCB is connected evenly. The fact that no base plate is used ensures superior thermal cycling capability and low thermal resistance.

Solder connections are omitted entirely. This makes the SKiM family the first ever 100% solder-free module series on the market. The combination of sinter technology, pressure contact technology and base plate-less design ensures five times the thermal cycling capability of a soldered module with base plate.

In the past 15 years, the maximum permissible chip temperatures have risen steadily. Today, state-of-the-art silicon components, for instance IGBT 4/CAL 4 diodes, can be operated at a maximum chip temperature of 175°C. In the future, the use of silicon carbide will create even greater challenges in terms of sufficient thermal cycling ability in the connecting layers. Silicon carbide components can be operated at temperatures as high as 300°C. The sinter technology however, is ideally suited for such high temperature ranges. This is due to the fact that the melting point of these connecting layers is 961°C, around 740°C higher than for the solder connections commonly used today. This high temperature stability that this sinter technology boasts means that the connecting layers do not age, as verified in reliability tests performed today.

Over the years, the areas of application for power semiconductor modules have changed dramatically. In the past, semiconductor modules were used in easily accessible and stationary control cabinets with defined cooling technology/ systems. Today, in contrast, power modules are to be used in mobile applications, i.e. vehicles with cooling conditions of up to 110°C. The challenge faced today is how to ensure that the power semiconductor component can generate its maximum permissible current I_{Cmax}. under the cooling conditions. Figure 4 illustrates the relation between these two parameters, as well as the current that can be controlled at increased chip temperatures with no compromise to reliability.

The future of sintering

Sinter technology is a key technology that allows for the production of components that are more powerful and reliable with a longer life-time. The same principles applicable to the SKiM module family for electric and hybrid vehicles – base plate-less module, pressure contact system and sinter technology – were applied in the development of the 4th generation of the intelligent power module SKiiP for applications, for example, in the fields of wind and solar power, elevator systems, trolley buses, metro and underground vehicles.

The benefits of sinter technology continue in the 4th generation of SkiiP power modules such as five times the thermal cycling capability thanks to the silver layer, unbreakable joint between the die and DBC, and twice the power cycling capability.

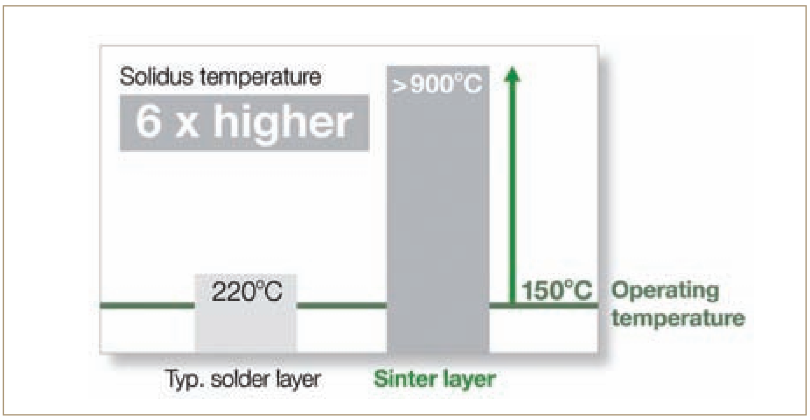

Figure 4: **The melting temperature in modules with sintered chips is six times higher than the operating temperature**