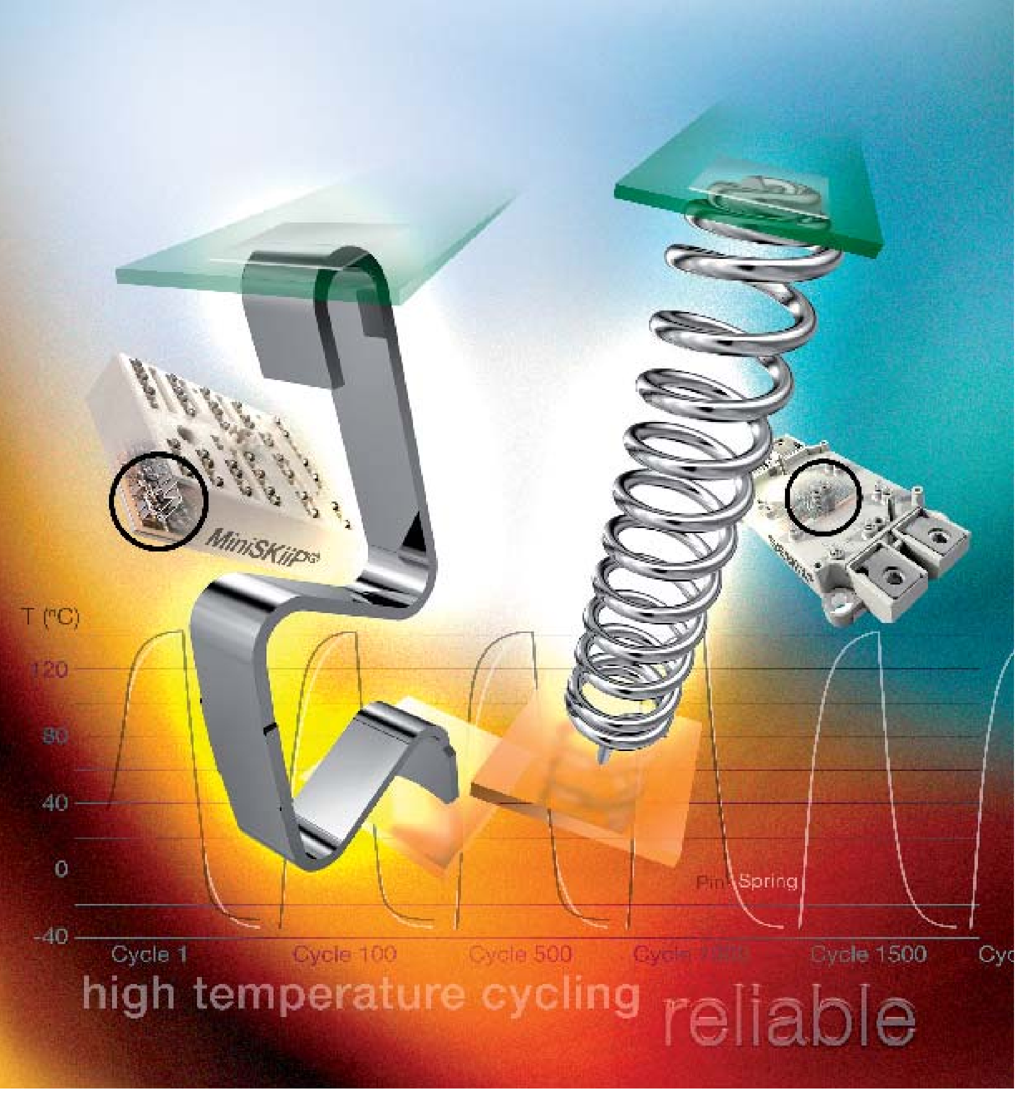

Control the Future

New alternative materials and concepts for Power Electronics

Besides replacing mechanical gears, variable speed drives have been particularly successful due to the energy saving potential when using power electronics. According to the 2004 IMS study, the power semiconductor market boasts a volume of US$12.5 billion in 2006, around 15% of which is covered by IGBT, MOSFET and diode/thyristor modules. The main markets are electrical drives and power supplies/UPS. Other markets with above-average growth rates are the automotive sector and regenerative energies; at present, these markets account for as little as 2-3% of the overall market.

*Peter Beckedahl, Thomas Graßhoff**

Power semiconductors are used in applications across a wide power range from just a few watts right into the megawatt range. Due to the vast range of applications for power semiconductors, various mounting and assembly technologies have established themselves on the market over the past decades. Figure 1 shows the different mounting and assembly technologies for semiconductor chips.

Nowadays, primarily soldered and bonded connections are used for integrated power semiconductor modules, as these connections meet the high reliability demands and also offer a high degree of flexibility with regard to configuration and circuit topology. In virtually every type of module, the insulating layer between the power semiconductors and the heat sink is a direct bonded copper (DBC) or active metal brazed (AMB) ceramic substrate. The most widespread substrate is Al_2O_3 ceramic. Over the past few years the thickness of this substrate was reduced from 0.63 to 0.38 mm for a number of applications to reduce the thermal resistance (R_{th}) of the chip to the heat sink. Module manufacturers were able to compensate for any increase in thermal resistance caused by the smaller chip area in new chip generations. Figure 2 shows a graph of thermal resistance plotted over chip area and ceramic substrate thickness for an Al_2O_3 substrate. An AlN ceramic substrate allows for a further reduction in R_{th} of around 25%.

The newest alternative materials are zircon doped Al_2O_3 as well as Si_3N_4 ceramics. These new materials are only 0.32 mm thick, have thicker copper layers of up to 0.6 mm and demonstrate even lower thermal resistance and better thermal spreading properties.

One fundamental difference between power modules is that they are designed either with or without a base plate. In modules with no base plate the DBC substrate is mounted directly onto the heat sink (Fig. 3).

The base plate, which is made, for instance, of 3-mm-thick copper, increases the thermal capacitance and the thermal spreading beneath the chips, thus reducing the transient thermal resistance in the time range of around 0.1 to 1 s by some percent compared with modules in which the insulating ceramic substrate is an outer layer. What must be noted is that the large soldered area between the ►

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insulating ceramic substrate and the base plate clearly reduces the load cycle capability of the components. The reason for this is that the ceramic substrate and the base plate have significantly different thermal expansion coefficients. This difference leads to tension and ultimately solder fatigue. An alternative to copper base plates are base plates made from composite materials such as AlSiC or CuMo, which are used solely in traction applications due to their low thermal conductivity and high costs. Composite materials based on graphite may gain importance as base plate materials in the future due to their low cost.
In real applications the lower thermal spreading capability in modules with no base plate can be compensated by applying a thinner layer of thermal paste. This is possible since the air gap to the heat sink is smaller in modules with no base plate.

Latest trends in mounting technology

The power electronics market is marked by growing demands for compact systems at affordable prices. This means that an increase in current density is needed, since power electronic modules are becoming increasingly smaller without compromising performance. A number of steps were taken to increase current density: heat dissipation was improved; semiconductors with less losses and new materials were used.
Another important trend is the use of spring contacts for auxiliary and load terminals. Spring contact technology allows for the simple and secure connection of power electronic components to modules. The forerunner in this field is MiniSKiiP from Semikron, a technology based on spring contacts that was used to connect auxiliary and load terminals to converter PCB's as early as 1996. Over the past few years this development has also been used to connect auxiliary contacts from other manufacturers even in the case of high-power modules.
Besides the different mounting technologies, power semiconductors now also offer a higher degree of integration. Intelligent power modules are modules in which the driver electronics, sensor technology or parts thereof are integrated into the power module itself. For low power requirements, the mounting technology used is based on copper frames to which the chips and driver electronics are soldered. These are then mechanically protected by epoxy. Heat is dissipated via special insulating layers, epoxy materials or using a ceramic substrate. Low and medium-power IPM´s (up to 300 A) are used predominantly in Asia, but are expected to become more widespread in Europe and the USA over the next few years. For higher power applications, power modules are based on the use of a conventional DBC substrate and solder technology. The forerunner in the field of IPM´s is SKiiP from SEMIKRON, which has been on the market for 15 years.

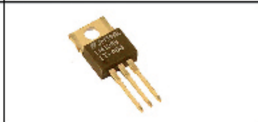
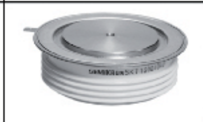
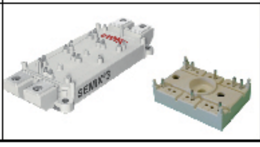
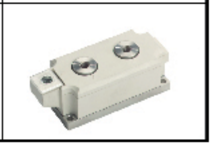
	Soldered on two sides	Soldered / bonded	Pressure contacts
discrete components			
Isolated modules with and without base plate			

Figure 1: Mounting technologies for power semiconductors

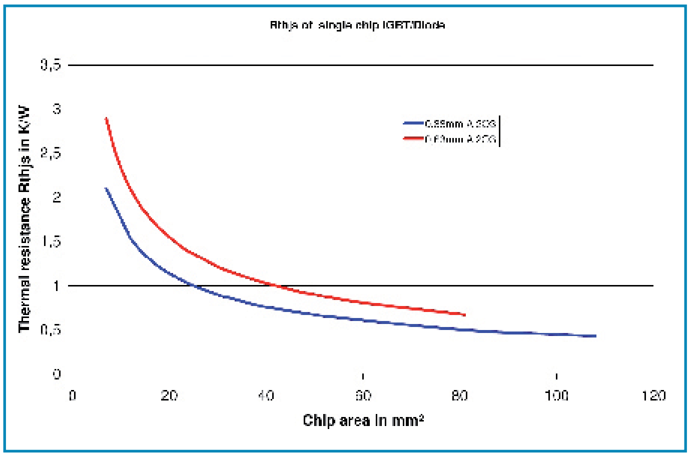


Figure 2: Correlation between thermal resistance and chip area

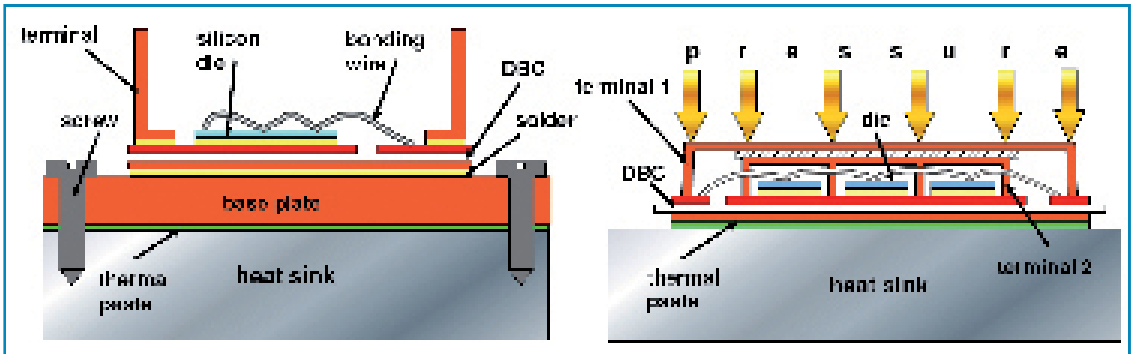


Figure 3: Power modules with and without base plate

The latest developments in the field of semiconductor chips

Improved semiconductor technology has brought about components with finer structures and faster switching speeds. With the introduction of the third IGBT chip generation, current density could be

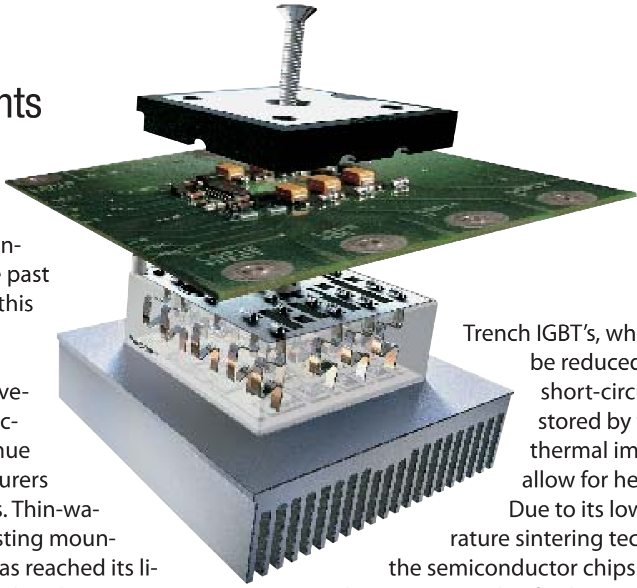


Figure 4: MiniSKiiP with spring contact technology

increased by 50%. Figure 5 shows the increase in current density of 1200 V IGBT chips over the past decades. One of the reasons for this improvement in current density was the substantial decrease in chip thickness. This course of development, i.e. the consistent reduction of chip thickness, will continue to be pursued by chip manufacturers for subsequent chip generations. Thin-wafer technology based on the existing mounting and assembly technology has reached its limits. This can be seen in the fact that the maximum permissible short-circuit duration for the latest 600 V Trench IGBT's, which have 70 µm thick chips, had to be reduced from 10µs to 6 µs. The immense short-circuit power surges can no longer be stored by the thin silicon wafers and the thermal impedance of the design does not allow for heat to be dissipated quickly.
Due to its low thermal impedance, low-temperature sintering technology, which is used to connect the semiconductor chips to the DBC substrate, could also be instrumental in further increasing current density.
Higher current densities and more compact components ultimately lead to higher heat sink and chip temperatures. Moreover, higher operating temperatures are also essential for new applications in the automotive sector. What is needed here is the possibility of cooling the semiconductor modules with the same liquid cycle as for the engine. This means "coolant" temperatures of 105 °C and above.
The need for higher heat sink temperatures, however, is not consistent with the ongoing reduction in size. Figure 6 shows how the maximum permissible collector current values fall as the heat sink temperature rises.
Improvements and developments in semiconductor technology made this possible. In 2005 the maximum permissible chip temperature of 600 V IGBT's and free-wheeling diodes was increased by 25 to 175 °C and is already heading towards the 200 °C mark.
Higher operating temperatures and current densities have an adverse affect on reliability, in particular load cycle capability. To combat this, improved mounting technology is vital.
It can therefore be said that power semiconductors are very important in the electronics industry for the transfer and conversion of electrical energy. New emerging markets for power semiconductors are the field of alternative energies and the automotive industry. The most important trends marking the development of power semiconductors are improved cooling yet higher current densities and integrated driver electronics. Higher operating temperatures and better cooling are only feasible at the cost of reliability. The only way to combat this problem is to develop new mounting and assembly concepts. *(ku)*

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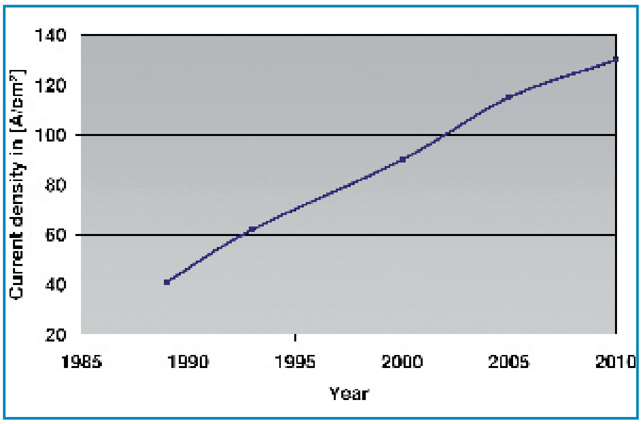

Figure 5:
Current density of 1200 V base plate modules for nominal current ($T_j = T_{j\,max}$, T_c = 80 °C)

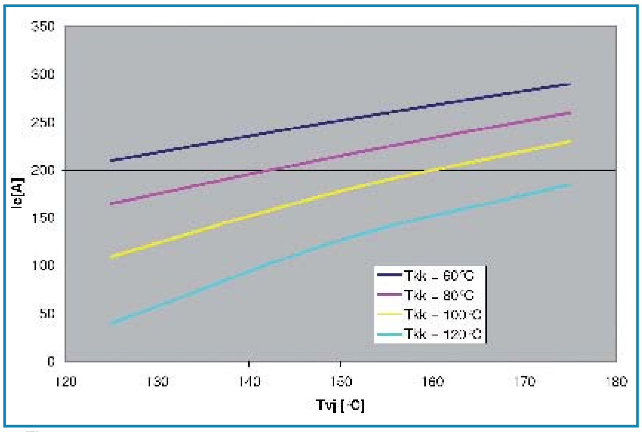

Figure 6:
Permissible current I_C of an IGBT for various maximum chip temperatures T_{vj} plotted over heat sink temperature T_{kk}

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