

Power Modules

# Demands for Renewable Energy & Electric Vehicles

The wind power & electric vehicle markets today require power modules with high power density, high reliability, and mechanical, thermal and electrical ruggedness. How to meet these requirements? This article outlines demands and challenges.

*Thomas Stockmeier\**



Today's requirements for power components with high reliability are best met by solder-free pressure contact technology. In a next step, wire bonds will be replaced by a flex foil to overcome today's limitations on power cycling fatigue. Superior performance in power density could be achieved by deploying these technologies not only to power modules, but to un-package these modules and design embedded systems by mechanical integration.

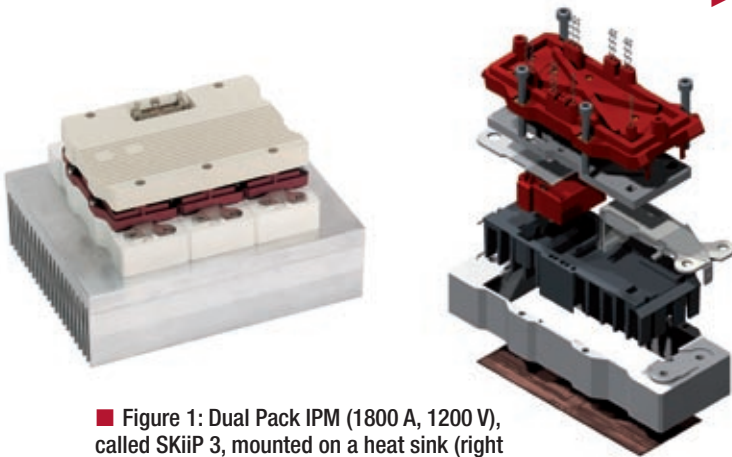
A power module can be defined as a device which contains more than one semiconductor chip and which provides a heat flux path separately from the electric path. These power modules, which entered the market in 1975, have been a success story. Power modules are one of the key building elements in almost all power electronic systems. Two of the fastest growing markets for power modules, renewable energies and electric driven vehicles shall be reviewed here in terms of enabling packaging technologies and their impact on these applications.

### The Wind Power Module Market is Estimated at 250 Million US-Dollar by the Year 2011

The power module market share for wind power is only 5%. However, with 25% annual growth, it has the strongest growth of all market segments. By 2011, this market is estimated at 250 Mio USD. Power modules for wind power require a very high intermittent operating lifetime, long term availability, very high reliability, and suitability for harsh environments. Figure 1 shows an Integrated Power Module (IPM) which is used widely in wind power applications. The power module is mounted on a customer specific heat sink (air or liquid cooled) and mechanically integrated with gate drive and protection, as well as current, temperature and voltage sensors.

The particular suitability of this power module for the wind power market lies in its unique pressure contact system which provides electrical power and auxiliary contacts, as well as thermal contact which are to a large extent free from fatigue induced by thermal and power cycling.

The automotive market share for power modules is only 4%, but is growing strongly with about 19% per year. High power automotive applications have a whole set of special requirements which drive the power module requirements. Technically most demanding are high ambient temperatures and a high number of thermal cycles. Figure 2 shows a representative power



■ Figure 1: Dual Pack IPM (1800 A, 1200 V), called SKiiP 3, mounted on a heat sink (left side: explosion drawing of one power module w/ integrated current sensor)

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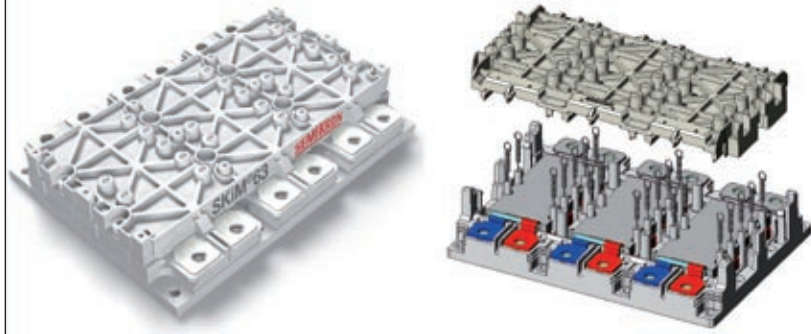
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## Power Electronics



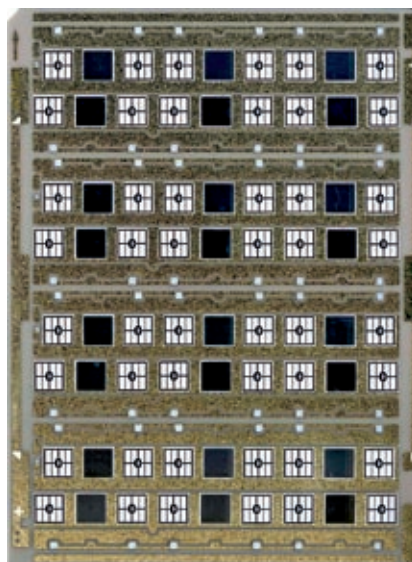
■ Figure 2: Six-pack IGBT (SKiM 63) for 300 A and 1200 V without any solder layers. On the right hand side, exploded views of the power module are shown.

er module, called SKiM. The SKiM power module also uses the pressure contact technology, as shown above. However, this module does not contain, for the first time, any solder materials and processes. Instead, IGBT and diode chips are sintered to the direct bonded copper (DBC) substrate.

### A Mismatch of Coefficient of Thermal Expansion Causes Lifetime Problems

In the sintering process, the chips are first placed into a silver paste layer which is pre-applied by stencil printing. Under very high pressure and moderate temperatures (250 °C), the silver paste transforms into a solid layer of silver.

Figure 3 shows a 5" x 7" DBC card where four substrates for the automotive power module, each containing 12 IGBTs and 6 diodes are sintered in one shot. After formation, the silver layer between chip and substrate would only melt at 961 °C, the melting point of silver. Therefore the operating temperature of 175 °C is only 18% of the disassembly temperature which means that the silver layer will not fatigue over time in the usual application. This is quite different in the classical chip solder process, where the operating temperature of the device is about 60% of the disassembly temperature, thus leading to the well-known solder fatigue mechanisms in power cycling and thermal cycling. All power modules shown above require thin aluminum wires to connect to the top side of the chips by ultrasonic bonding. The mismatch of coefficient of thermal expansion of the

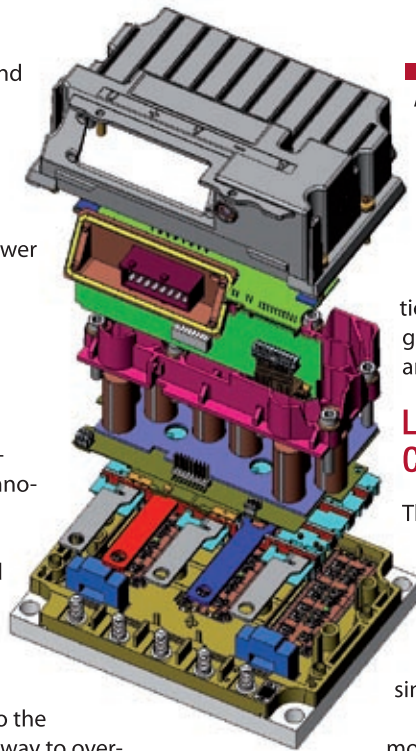


■ Figure 3: DCB card containing four substrates with sintered chips

aluminum wire and the chip causes these bond wires to lift off from the chip after a sufficient number of power cycles, limiting the lifetime of the power module. Although great progress has been made in materials, design and process, this fatigue is still a very limiting design factor, aiming at lower cost, higher power density and longer lifetime.

### The SKiN Technology Replaces Bond Wires by Flexible Foils

The solution may come in form of flex foils instead of wire bonds, which is called SKiN technology. Bond wires are replaced by welding the chips with a flip chip process to a sandwich layer composed of aluminium, polyimide and copper. The aluminum side provides the load and gate tracks, the copper side can be designed to carry the drive and sense electronics. Vias through the polyimide layer enable contacts from the upper metal layer to the gates and sensors by thin wire bonding. One way to overcome the limitations of package materials is to simply leave them out. Instead of producing power modules in the classical fashion, DBC substrates may be used to build an embedded power electronic systems „from scratch“ by mechanical integra-



■ Figure 4: The exploded view of a 360 Arms, 48 V, 3 phase motor drive which is build without using power modules. The total volume of the complete unit is only 2,3 litre which is important to fit this unit into various electric vehicles.

tion. This stripping of most of classical package components such as housings, terminals and base plates are called Un-Packaging.

### Less is More: Un-Packaging the Chip for Longer Lifetime

The entire assembly requires only a small number of steps: Substrates are fabricated which contain power MOSFETs (soldered or sintered) in a dual pack configuration, temperature sensors and filter capacitors. These substrates are mounted on a heat sink together with a frame (high temperature compatible plastic material) with already moulded-in screw type terminals. Next, a DC and AC bus bar system with integrated DC-link

capacitor is placed. A pressure part is mounted on top which contains pre-assembled springs for auxiliary contacts and presses the power terminals to the substrate, thus enabling thermal and electrical contact at the same time. Then a gate drive and sense electronic board and a controller board are mounted. Finally a metal or a plastic hood is placed over the assembly, providing environmental protection. The resulting motor drive inverter exhibits benchmark power density, withstands 20 g vibration and 100 g shock, and shows a very high thermal and power cycling capability and can therefore fully utilize the 200 °C junction temperature capability of advanced power MOSFETs. Due to its compact design and the integrated filter capacitors it exhibits very little conducted and radiated emissions. (ku) SEMIKRON Phone +49(0)911 65590

### Possibilities for the Future

Renewable energies and electric vehicles represent strongly growing markets for power semiconductor modules and systems. Besides the high market dynamics, both application areas have very high technical and economical expectations. Emerging technologies, such as IGBT pressure contact modules, flex foils and un-packaged, embedded system may provide the right answers. To be successful in the future, it will be important to serve the market perfectly by satisfying demands with existing products and at the same time to drive the innovation to inspire these new markets.

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