With Sinter-Technology Forward to Higher Reliability of Power Modules for Automotive Applications

A new kind of applications, the whole automotive market describes more and more a “high end”-power module. The unprecedented combinations of thermal, electrical, and reliability performance with a very small volume and weight are the challenge today. A consistent further development of sinter technology for power modules comprises and answers to all these requirements. Sinter technology substitute all solder connections and also the aluminum bond wires. These are at present the weak points in a standard power module. The thermal and reliability results of a 400 A/600 V Dual IGBT power module will be shown in this article. **Jürgen Steger, Project-leader, SEMIKRON Elektronik, Nuremberg, Germany**

The motivation for a complete new development of a power electronic module is due two main reasons. First is the reliability for electric cars. Secondly, the latest generation of power semiconductor switching devices such as MOSFETs and IGBTs achieve very high power densities so that conventional thick aluminum wire bonding technology (Figure 1) represents a bottleneck for load current capability and reliability. The elimination of bond wires in power modules has been discussed for several years in industry and academia. Most of the new packaging approaches have been based on soldered or welded bumps.

Recently, attempts have been made to improve this technology [1]. However, these attempts lead to comparably large efforts in the power device metallization and processing. Environmental conditions such as humidity, temperature, industrial gas atmosphere, and mechanical shock and vibration play an increasingly important role for electric vehicles and other applications. However, not only these technical and environmental challenges have to be faced, but also power electronic modules need to be reduced in size and weight for use in vehicles and have to be interfaced in a simple and reliable manner, even at high load currents.

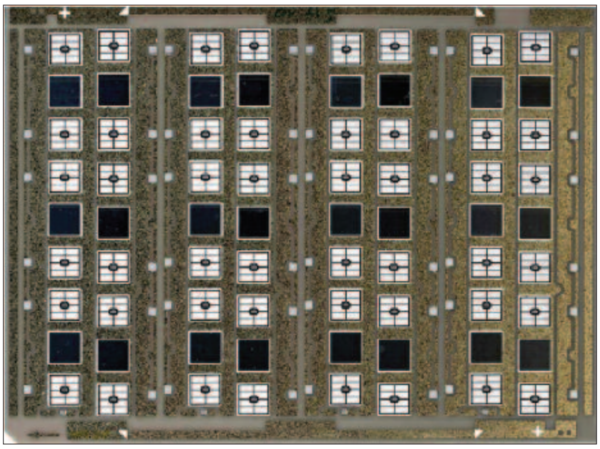

Figure 2: 5″x7″ DBC card with four substrates (before laser cutting) with sintered chips

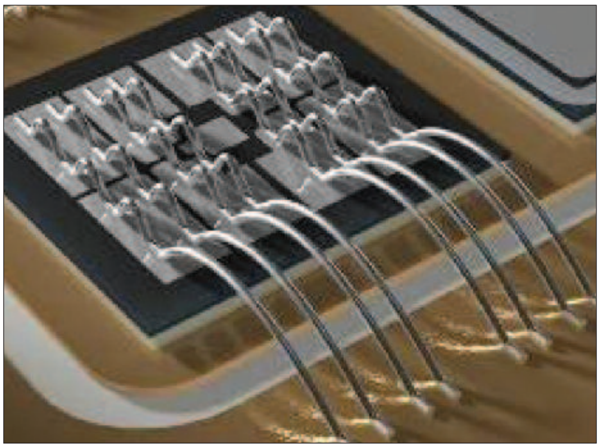

Figure 1: Conventional thick aluminium wire bonding technology

Chip-to-ceramic substrate sintering

Silver sintering is an established technology which has started to replace the soldering of chips to DBC substrates in mass production. Thanks to its unprecedented reliability and thermal behavior, this joining technology makes power modules better suited for higher temperatures and demanding applications, such as electric vehicles. However, two issues remain unaddressed: How to replace wire bonding on the chip front side, and how to interface the power module to the heat sink.

As examples, Figure 2 shows a 5″x7″ DBC card which contains four substrates

Figure 3: **DBC substrate after mechanical stress test**

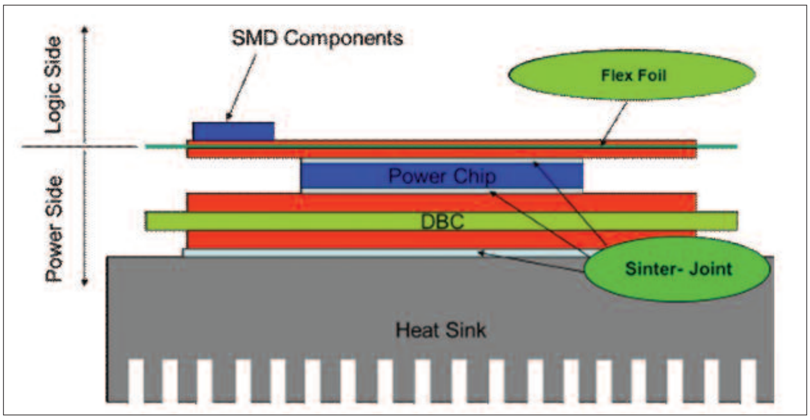

Figure 4: **Cross section of a newly designed power module integrated with a pin fin heat sink exhibiting no solder layers and wire bond interconnects**

(before separation by laser cutting) with sintered chips, as used today in series production for power modules in automotive applications. Figure 3 shows one substrate with sintered chips after an extreme mechanical stress test - the sinter joint are unbreakable.

Up to this point, the new technology follows this well established process. However, rather than continuing in the process sequence, which consists of Al-wire wedge bonding, electrical testing, laser cutting, and final automated optical inspection (AOI) as in conventional devices, sintering [3] proceeds differently.

New design possibilities

Figure 4 shows a schematic drawing of this packaging technology. The special flex foil with a metal layer on the bottom with a thickness comparable to bond wire diameters serves to connect the chip top side. A thin metal layer on the top represents the gate and sensor tracks which are connected to the power layer by vias. The two metal layers are insulated from each other by polyamide. Also, the top layer can be used for SMD components, such as temperature sensors and gate resistors. The second sinter joint connects the chip back side to a standard DBC substrate.

Figure 5 shows the flex board (top side), as it is prepared to be positioned and sintered within the next process step. In areas which are connected to the chips with the flex board, the power side of the board is screen or stencil printed with silver paste. In this particular design, the auxiliary contacts, such as gate and emitter, are carried out as tracks on the flex board, reaching out to the left and right to be folded-in later.

Interconnect and cooling

This new sinter technology proceeds in providing thermal and electrical interfaces by sintering the power terminals and the heat sink to the power device. Figure 6 shows the AC and DC power terminals, made from Ag-coated Al or Cu, as well as a pure Al pin-fin heat sink. On top of the heat sink, a defined area is stencil printed with silver paste where the power part will be attached.

Now the heat sink, the power terminals, and the power part are assembled into a sintering jig and put again into a conventional sinter press, this time forming the sinter connections from heat sink to substrate and substrate to power terminals. Afterwards a simple plastic frame is added to provide guidance for the auxiliary terminals and to provide alignment for the use of this device in the power electronic inverter system. Figure 7 shows how all parts are assembled together to form a 400 A, 600 V dual SKiN device. The device contains two 200 A IGBTs and one 400 A freewheeling (FWD) diode for the upper and the lower switch, as well as a temperature sensor chip.

Figure 8 shows the finished device as it is in production. In this specific layout, the auxiliary contacts are formed as flex layer tracks, folded in such way that they can be connected to a printed circuit board (not shown). The auxiliary contacts of the two switches come out to the left and the right of the long side of the heat sink, whereas the plus, minus and phase terminals come out on the short sides of the heat sink, opposing each other.

Test results

The electrical properties of the device demonstrate the superiority of a continuous metal layer on top of the chips, compared to discrete bond wires. A detailed comparison of electrical test results of the device with flex board, as shown here, versus a device with the very same design, but with bond wires instead of flex board has been published before [4]. The flex board leads to a significantly higher surge current capability of the free-

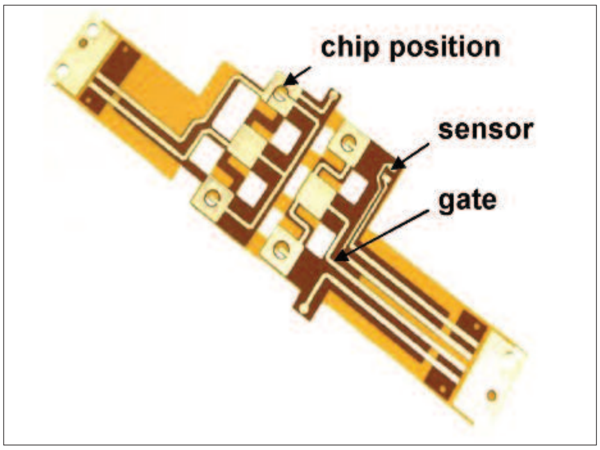

Figure 5: **Flex board (top side) prior to sintering to the substrate**

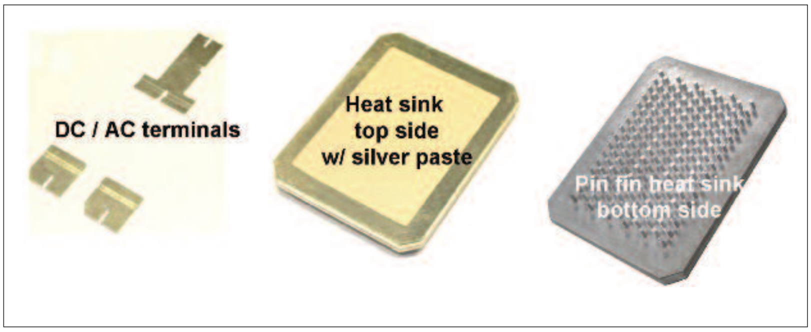

Figure 6: DC and AC power terminals as well as an Al pin-fin cooler with a silver paste area on the top side

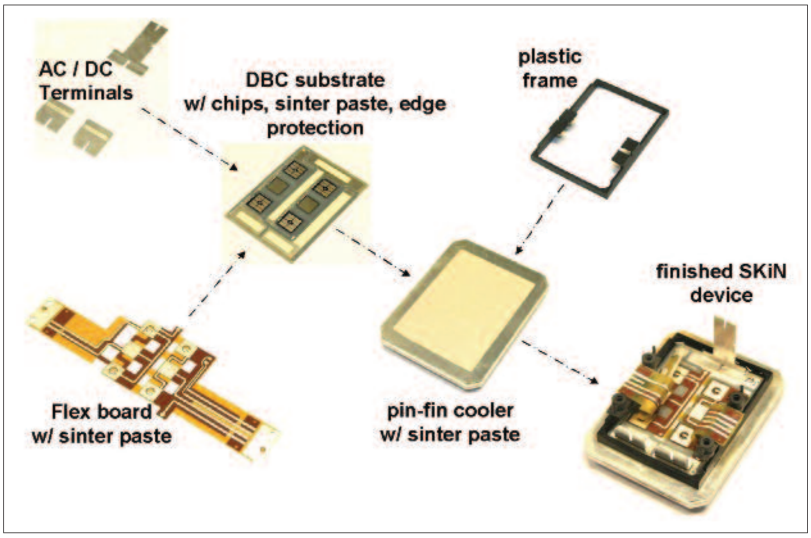

Figure 7: Exploded view of a 400 A, 600 V dual IGBT device comprising heat sink, DBC substrate with IGBT and FWD chips, flex board and power terminals - all being connected by silver sintering technology

wheeling diodes than for wire bonded diodes.

The device has a thermal resistance of junction to ambient of just 0.44 Kcm^2/W which is 35 % lower than that for conventional power modules. Therefore, the current rating can be increased accordingly. Figure 9 shows infrared images of the device under load current, for the IGBT and the FWD, respectively. As shown, the chip temperature is very uniform across the chip and from chip to chip. The spacing between the chips is designed such that there is almost no thermal overlap between the chips.

In power cycling, the device is heated by the power dissipation during the conduction period and then cooled down when the maximum test temperature is reached. The maximum number of cycles can vary orders of magnitude, depending on the temperature difference between the highest and lowest temperature and the medium temperature. The raise and fall times of the temperature, as well as the test being carried out under constant maximum power, constant maximum temperature, or constant maximum current [5]. Figure 10 shows power cycling results.

Passive temperature cycling is challenging for such an integrated device, as the thermal coefficients of heat sink, substrate, chips, and flex board are all different. Therefore, extensive temperature cycling tests were carried out, typically cycling the devices between -50°C and +150°C, with a temperature rise and fall time of 3 K/min. Several hundred cycles up to a thousand cycles were achieved, before the DBC substrate started to delaminate from the heat sink. In various experiments it could be shown that thickness and morphology of the sinter layer between substrate and heat sink are key parameters to achieve a good passive thermal cycling performance.

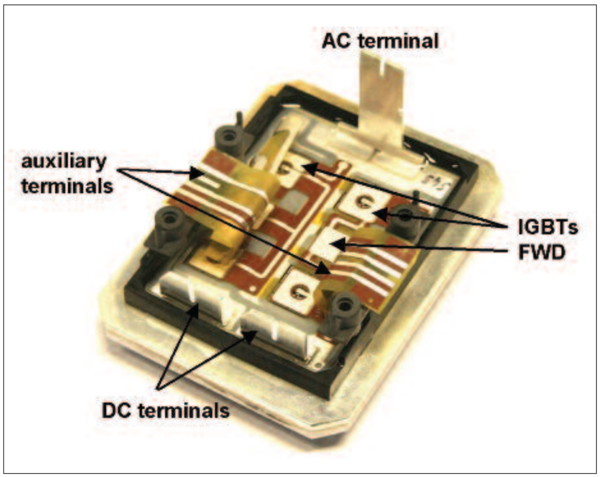

Figure 8: Series manufactured 400 A/600 V dual IGBT device in 74 mm x 56 mm x 11 mm dimension and 0,095 kg weight

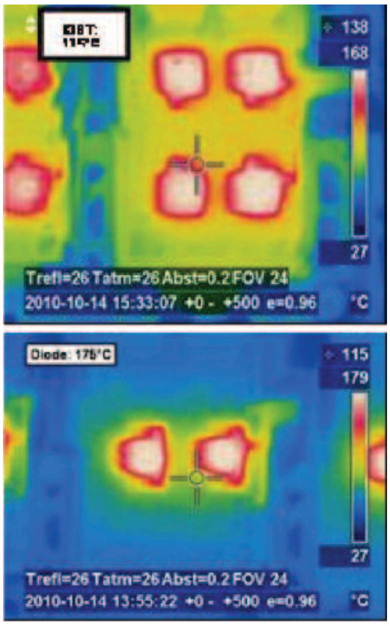

Figure 9: Infrared image of the device with DC IGBT load current of 400 A (upper image) and free-wheeling diodes heated by the same load current (lower image). The spacing between the chips is optimized to provide no thermal cross talk

Conclusions

SKiN, a new packaging technology without bond wires and solder layers has been introduced. All interconnections to chip top and bottom surface, DBC to heat sink and power terminals are made by an Ag sinter joint. The bond wires are replaced by a special flex foil which increases the chip top side attached contact area by a factor of 4.

In order to demonstrate the exceptional

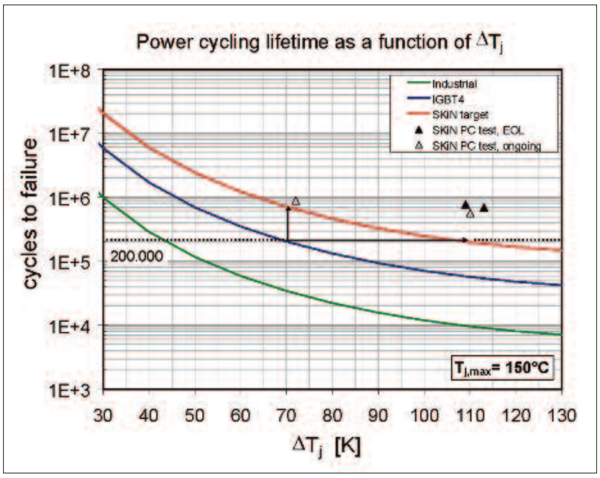

Figure 10: **Power cycling capability of SKiN as a function of ΔT_j, compared to standard and improved conventional devices. 500,000 cycles can be reached at ΔT_j =110K**

performance improvements of the overall construction and in particular the flex foil a comparison to a benchmark module with traditional Al bond wires has been made. Due to the elimination of thermal interface materials and the integration of a high performance pin fin heat sink it is possible to double the power dissipation in comparison to traditional designs. Just the elimination of the thermal grease layer exhibits an improvement of 25 % of the total thermal resistance junction to water. Due to the modified geometry and the increased chip contact area a 27 % increase of the diode surge forward current capability and a 2 nH reduction of the total commutation stray inductance has been achieved. The power cycling performance demonstrates an improvement of factor 70 over the industry standard and an improvement of 10 over the single sided sintered benchmark module.

Further activities are ongoing to exploit the new possibilities of the two layer flex foil. These are in particular a further improvement of the thermal resistance due to dual side cooling and the integration of passive and active components for gate drive, current and temperature sensing [6].

Literature

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