New superior assembly technologies for modules with highest power densities

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Abstract

Power module development is striving for higher power densities, not only in new but also in already established packages. Two main challenges for such kinds of upgrades are to meet the increased requirements towards ampacity and heat dissipation. These new requirements may enforce adjustments in the utilized packaging technologies to overcome the given package limitations. The current article investigates the challenges of increased power densities in existing module packages and how they can be mastered.

1. Introduction

The continuous trend of IGBT chip optimization [1], [2] enables IGBT power module development to increase the power density in their packages from IGBT generation to IGBT generation.

For example, the nominal current rating of Infineon 62mm half-bridge modules was increased continuously over the different IGBT generations from IGBT 1st generation (I_{nom} = 150A) to IGBT 4th generation (I_{nom} = 450A) by a factor of three (see Fig. 1).

This increased power density is doubtlessly beneficial especially for the design of more and more compact inverters and therefore more than welcomed by the IGBT power module market.

In particular, there is a strong demand for increased power densities in already well established IGBT power module packages, as it offers the inverter designers the opportunity not only to integrate such packages into newly developed inverters, but also to upgrade existing inverter designs to higher output powers without changing the mechanical set-up. Especially this fact makes it a very fast, cheap and therefore extremely attractive opportunity.

However, handling of the increased power densities in a given module package might be limited by several boundary conditions, as inverter cooling conditions and maximum system temperatures. But also from the IGBT module's point of view, measures might have to be taken to assure that the current rating offered by the implemented silicon dies can be fully utilized in the real application.

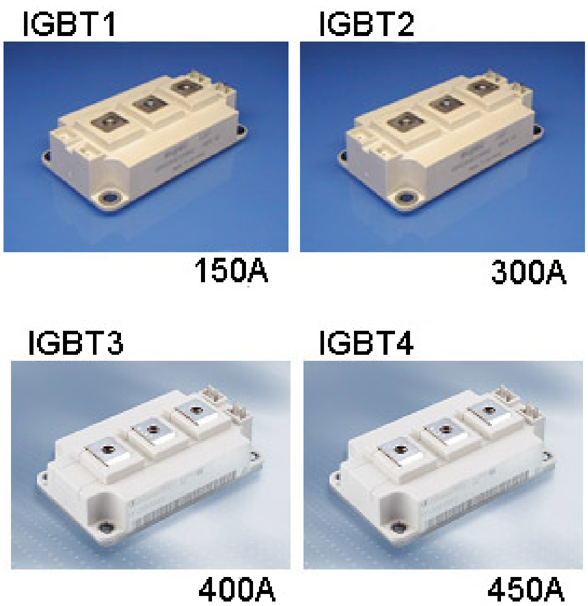

Fig. 1. Steadily increasing power density at the example of Infineon's 62mm half-bridge IGBT module: For each IGBT generation, the maximum realized current rating is given.

Most probably, the two most relevant parameters of a given IGBT power module package will be

- the ampacity / conductivity and
- the thermal resistivity.

A detailed analysis of the influence of ampacity and thermal resistivity of IGBT module packages on the utilization of increased power densities will be carried out in the next chapter.

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2. Enabling higher power densities

2.1. Ampacity / Conductivity

Currently established modules like the Econo-PACK™ + or the EconoDUAL™ use Aluminium bond wires for contacting the power connections, the conductor pathes and the silicon dies. Fig. 2 shows the Al bond wire connections of the EconoDUAL™ 3 package as an example.

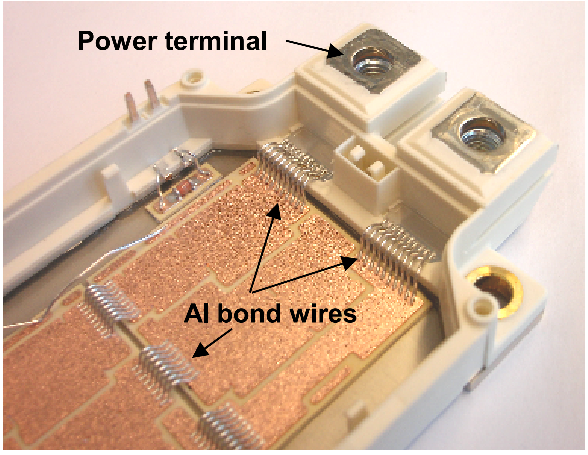

Fig. 2. Wire bonding connections from DBC to DBC and from DBC substrate to power terminal of the EconoDUAL™ 3.

However, with future increased current ratings, this well established interconnection technology may come, in certain cases, to its limits. For newly developed power module packages, the implementation of ultrasonic welding connections proofs to be a smart and reliable solution to overcome possible ampacity limits [3], but staying with existing module package lay-outs may require other adaptable solutions.

	Copper	Aluminium
Electrical resistivity	1.7µOhm*cm	2.7µOhm*cm
thermal conductivity	400 W/m*K	220 W/m*K
CTE	16.5 ppm	25 ppm
yield strength	≈140MPa	≈29MPa
Elastic modulus	110-140GPa	~50GPa
Melting temperature	~1083°C	~660°C

Tab. 1. Selection of relevant material properties of Copper and Aluminium.

As copper wire bonding was recently introduced as a new alternative contact technology [4] and reveals several significant advantages over Aluminium bond wires, the idea suggests itself to investigate this technology as a possible solution for the interconnections from DBC to DBC and from DBC to the power terminals as well.

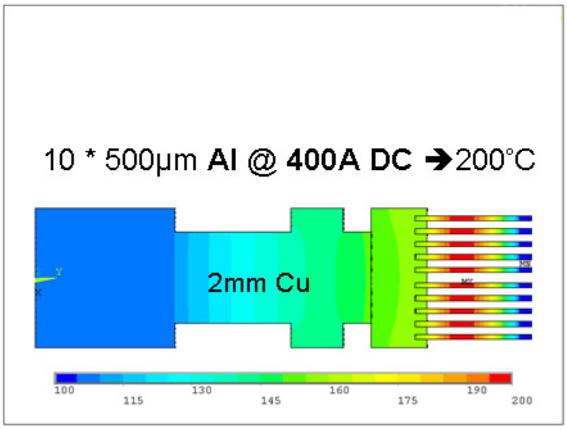

Fig. 3. Simulated ampacity of a power terminal connected with 10 *Aluminium* bond wires of 500µm thickness (assumed temperature limit: T = 200°C).

A general comparison of the relevant material properties of both Copper and Aluminium (as shown in Tab. 1) reveals a decreased thermal resistivity, an increased thermal conductivity and a higher melting temperature of the Copper bonds, promising higher ampacities at similar boundary conditions.

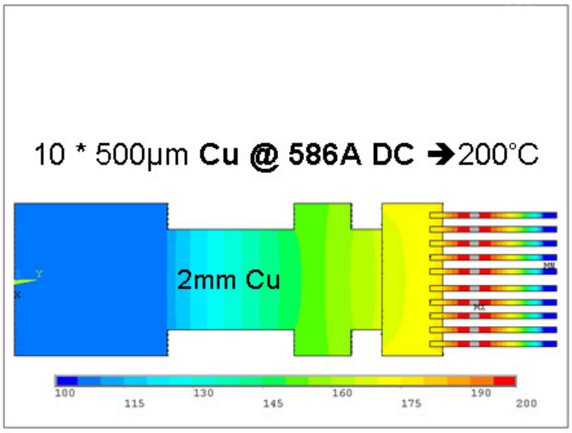

Fig. 4. Simulated ampacity of a power terminal connected with 10 *Copper* bond wires of 500µm thickness (assumed temperature limit: T = 200°C).

Numerical simulations (Fig. 3 and Fig. 4) illustrate the electro-thermal advantages of the Copper bond wires over the Aluminium bonds in more detail:

At similar boundary conditions, the ampacity of a chosen standard set-up with 10 bond wires of each 500µm thickness was increased by a factor of ~1.5 from 400A to almost 600A dc collector current. This result makes copper bond wires an ideal candidate for the substitution of Aluminium bond wires in existing IGBT module packages, whenever an increased ampacity is required.

2.2. Thermal resistivity

Increasing the power density in a given package might lead to a higher power dissipation density, being not only a challenge for the cooling system of the inverter, but also for all thermal interfaces inside the module.

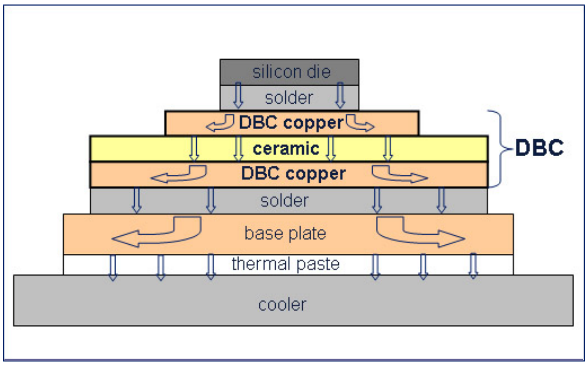

Fig. 5. Heat flow and spreading in a state-of-the-art IGBT power module with base plate. The DBC parts are highlighted.

In general, the thermal resistivity R_{th} of a specific material is determined by the thickness (s), the thermally active area (A) and the thermal conductivity λ:

$$R_{th} = \frac{s}{A \cdot \lambda} .$$

Following this equation, it can be concluded that a reduction of the thermal resistance of a layer inside a power module system can be achieved by

- reducing its thickness s,
- increasing its thermal conductivity λ or
- increasing its thermally active area A by improved heat spreading in previous layers.

Fig. 5 shows the schematic of heat flow and spreading in a state-of-the-art IGBT power module with base plate. At a given set-up (module with or without base plate, thermal interface material, cooler), the layers to be particularly optimized are the DBC copper and DBC ceramic layers, e.g. by

- increasing the DBC conducting layer thickness for improved conductivity and heat spreading,
- increasing the thermal conductivity λ of the DBC ceramic layer or
- reducing the DBC ceramic layer thickness.

The decisions of the specifically appropriate measures have to be drawn case by case. Furthermore, the technical feasibility as well as the cost of all possible solutions has to be taken into account.

3. Transfer to a real product: EconoDUAL™ 3

Based on the previous considerations, the development of a new EconoDUAL™ 3 module has been started. The development target was not only to achieve a nominal current rating of 600A in the 1200V blocking voltage class by the implementation of the latest IGBT 4^{th} generation dies, but also to provide a real increase of the achievable RMS output current of the inverter, compared to the already existing 450A EconoDUAL™ 3.

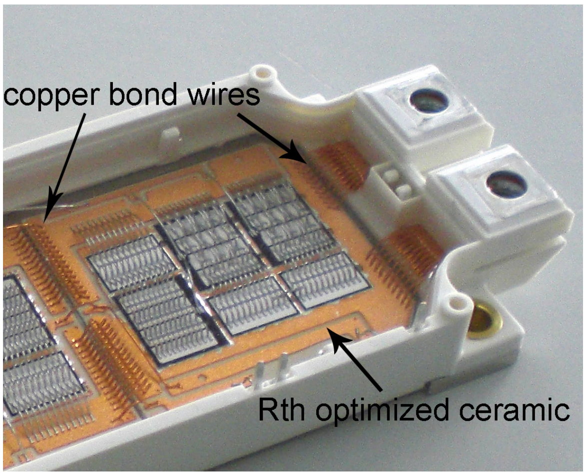

Fig. 6. Newly developed 1200V EconoDUAL™ 3 with 600A nominal current, utilizing copper bond wires and optimized DBC.

For the realization of this target, copper bond wires were implemented for the interconnections of the copper conductor paths on the DBCs as

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well as for the connections to the power terminals (see Fig. 6).

Additionally, the DBC was thermally optimized by a combination of several appropriate measures as described in chapter 2.2, significantly improving heat spreading and thermal resistance of the package.

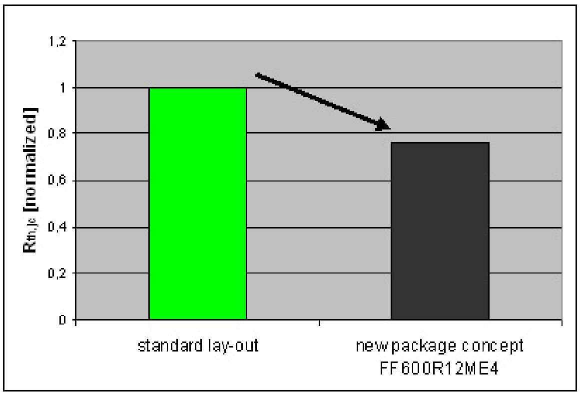

Fig. 7. Comparison of the normalized thermal resistance (R_{th}) of a standard EconoDUAL™ 3 module package (green) and the optimized lay-out of the newly developed 600A 1200V EconoDUAL™ 3.

Fig. 7 shows the effect of these measures on the thermal resistance of the package (at similar die sizes): compared to a standard EconoDUAL™ 3 module lay-out, the R_{th} of the new package concept was reduced by more than 20%.

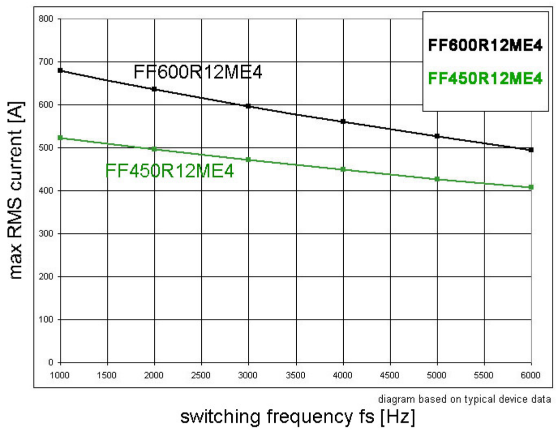

Fig. 8. Exemplary IPOSIM [5] calculation of the achievable RMS current of a module build by standard assembly technologies (FF450R12ME4, green) in comparison to a module utilizing all presented new technologies (FF600R12ME4, black). In both cases, the application conditions are similar.

To evaluate the adequateness of the implemented new technologies, an exemplary calculation of the achievable output current of a

- state-of-the-art EconoDUAL™ 3 with standard assembly (FF450R12ME4) and
- the new FF600R12ME4 utilizing all presented new assembly technologies

was performed at similar application conditions (DC link voltage 600V, cos φ = 1, max. ambient temperature 40°C, heat sink air cooled). The calculation (Fig. 8) proofs that the proposed measures are effective: The achievable RMS output current is increased by up to 30%, fully utilizing the implemented new IGBT 4th generation dies with increased current rating.

4. Summary

In this article, it is proven that established IGBT power module packages can be toughened up for significantly higher power densities by consequent implementation of new, beneficial assembly technologies. This is also demonstrated by means of a newly developed half-bridge module in the well established EconoDUAL™ 3 housing that provides, in combination with Infineon's latest 4th generation IGBTs, up to 30% more output power.

Offering higher power densities in established module packages includes the advantage to upgrade existing inverter designs to higher output powers without changing the mechanical set-up, making this approach a fast, cheap and therefore very attractive opportunity.

5. Literature

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