

Hybrid half-bridge package for high voltage application

Bassem Mouawad, Jianfeng Li, Alberto Castellazzi, C. Mark Johnson
Power Electronics, Machines and Control Group (PEMC)
University of Nottingham, University Park Campus
NG7 2RD, Nottingham, United Kingdom
bassem.mouawad@nottingham.ac.uk

Abstract—3D power module structures allow for better cooling and lower parasitic inductances compared with the classical planar technology. In this paper, we present a hybrid half-bridge in a 3D packaging configuration, dedicated for high voltage application. A dynamic electrical test of the package is presented.

Keywords— *Half-Bridge, 3-D Packaging, Power Electronics, High Voltage, Si IGBT, SiC Diodes*

I. INTRODUCTION

The known requirements for insulated gate bipolar transistor (IGBT) modules in electricity network applications include high isolation voltage ($>10\text{kV}$), excellent cooling performance and high reliability. Present state-of-art manufacturing for plastic packaged IGBT modules involves the solder attachment of the dies to a substrate followed by ultrasonic bonding of IGBT emitter and diode anode connections, there being up to 600 individual bonds in a large module. Creation of such a large number of individual bonds is expensive, time consuming and a source of yield loss. Moreover, the thermal management arrangements in conventional modules remove heat from just one die surface, restricting the maximum heat flux that can be sustained for a given maximum junction temperature.

Over the past years, several replacements of wire-bonds, such as ribbon-bond, dimple array, embedded chip technology, silicon interposer, solder bump, metal bump and press-pack bus-bar-like interconnects have been proposed and investigated worldwide [1]. These replacements have been demonstrated to obtain dramatic improvement in the thermal and electromagnetic performance, and/or allow advanced integration schemes, e.g. stacked devices, for the optimization of basic power switch topologies, e.g. half bridge switch and bi-directional switch [2]. However, these interconnect techniques can be used to overcome only one or two aspects of the above problems for the IGBT modules. Also, there are concerns about the reliability and manufacturability for the implementation of these techniques. Other researchers have worked on so-called “sandwich structures” or “3-D structures”, which use two similar substrates with the dies in-between. These solutions are designed to offer double-side cooling of the devices [3]–[5].

In the present work, we describe an innovative packaging design that can simultaneously overcome the mechanical, electrical and thermal limitations of conventional modules.

II. CONCEPT OF THE STRUCTURE

A planar module for a half-bridge switch has been designed for demonstrating the present work to address the above-mentioned problems in the conventional IGBT modules. The designed module has a compact volume of $104\text{ mm} \times 103\text{ mm} \times 23\text{ mm}$, including an integrated turbulent cooler for double side cooling. It's been developed for fully Si power module. Knowing the benefit of the hybrid package on the reduction of the switching losses [6], the presented design in this work will be a hybrid package that accommodates 2 Si IGBTs and 4 SiC junction barrier Schottky (JBS) diodes which can be selected from devices with ability of blocking voltages up to 10 kV . Flexible printed circuit boards (PCBs) have been proposed as an alternative solution for Aluminum (Al) wirebonding technology, and been used on the “SKiN” power module for the internal connections that allows to have very low inductance comparing to that of Al wirebonds [7]. However, copper (Cu) bulk busbars were used for the power terminals.

In the presented design, a flexible PCB is employed not only as an intermediate interconnect of smaller features on power devices, but also as a replacement of conventional bus bars. This can makes use of the established PCB technology to achieve the spatial resolution to contact power device features, and at the same time reduce the lengths of conducting loops in the power modules for achieving extremely low parasitic inductance. Mechanical structures were introduced in order to achieve sufficient insulating distance. Moreover, sintering of silver (Ag) nanoparticles is used as joining technology for improving the reliability of the power module under high power density conditions.

III. MANUFACTURING PROCESS

A. Materials and preparation of the Dies

The materials used to build the half-bridge package are as follows:

- 2x Direct Bonded Copper (DBC) substrates
- 2x 3.3kV Si IGBT
- 4x 3.3kV SiC JBS diodes

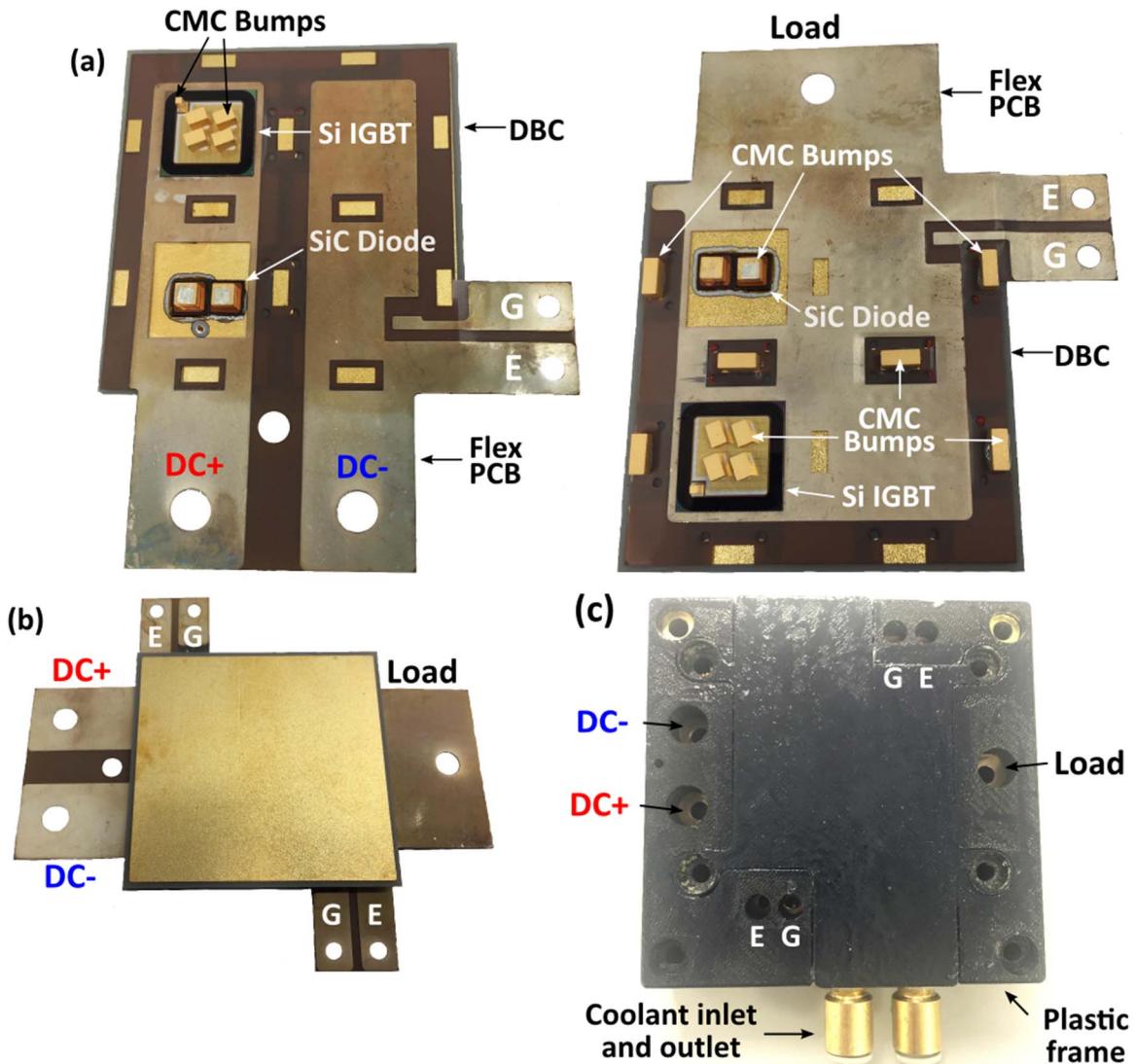


Fig. 1 (a) Photos showing the two parts with one Si IGBT, two SiC Diodes for each switch and CMC bumps for connection, (b) the assembled hybrid half bridge planar module and (c) mounted in its cooling system

- Flexible PCBs to replace Al wire bonds and Cu bus-bars in conventional power modules
- Copper/Molybdenum/Copper (CMC) composite brick bumps for achieving sufficient insulating distance and a better mechanical structure [1].
- Plastic frame integrated turbulent cooler that allows a double-side cooling.

From a device point of view, as these are commercially available with standard aluminum top terminology, a deposition of a new metal layer on the top of the existing Al is required to be suitable with the bonding technology. Therefore, thin titanium (Ti) and gold (Au) layers are then deposited on the Al pad of the dies to make it compatible with the Ag sintering technology.

For the DBC substrate, and for facilitating the Ag sintering technology, $\sim 5/0.1\mu\text{m}$ thick NiP/Au finish has been added on

all the Cu layers of the DBC substrates. For the flex PCB, the Cu layers were finished with Ag layer.

B. Assembly process

Fig. 1 shows all the parts and the assembling process of the presented hybrid half-bridge package. It should be noted that both the upper and lower switches are bonded separately on each DBC substrate. Each switch contains 1 Si IGBT and 2 SiC diodes and the flex PCB. Plasma etching was used to remove any residual organic contamination, prior to the assembly process. The latter was performed as follows:

- First, the two Si IGBTs and the corresponding flex PCBs are bonded on the DBCs using Ag sintering technology
- The SiC JBS Diodes are then soldered on the DBCs
- A die bonder is then employed for both accurate positioning of the CMC bumps on the top-side of each device and the sintering step (cf. Fig. 1 a)

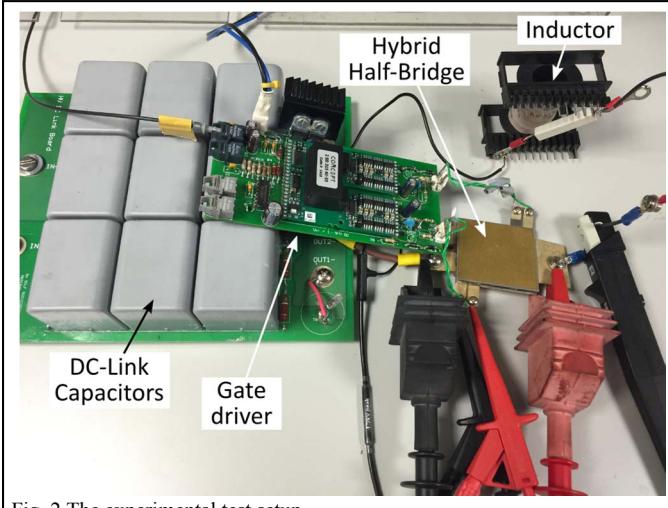


Fig. 2 The experimental test setup

- The two parts are then bonded together using solder technology; Fig. 1 b
- For insulation, the assembly is then filled with Silicone Gel under vacuum and cured at 125°C.

The assembled hybrid half-bridge planar module (shown in Fig. 1 b) is then mounted in its cooling system that allows a double-side direct cooling of the planar module (cf. Fig. 1 c).

IV. ELECTRICAL CHARACTERIZATION

Double-pulse test is a widely used approach to characterize the parasitic electric parameters of power module packaging and to test the switching performance of the latter. It is performed by operating the phase leg (or half bridge) module in a standard switching process including switch-on, conduction, switch-off and block with inductive load, which can control the current going through the switches and voltage applied. This test was carried out at room temperature on the designed hybrid half-bridge.

The experimental parameters are listed below in Table I. The lower side IGBT of the half bridge is the device under test

Table I Experimental parameters

Double Pulse test	
Part	Type
Collector current (I_c)	13A
Bus voltage (V_{bus})	2000V
Gate voltage (V_{gate})	15V
Gate resistance (R_g)	15Ω
Load inductance (L_{load})	420μH
Junction temperature (T_j)	22°C (Ambient temperature)
Oscilloscope	Tektronix DPO 7104 (BW=500MHz)
Voltage probe	Differential probe (BW=50MHz)
Current sensor	Rogowski coil PEM CWT1 (BW=20MHz)
Driver IC	Concept (2SD 315 AI-33)

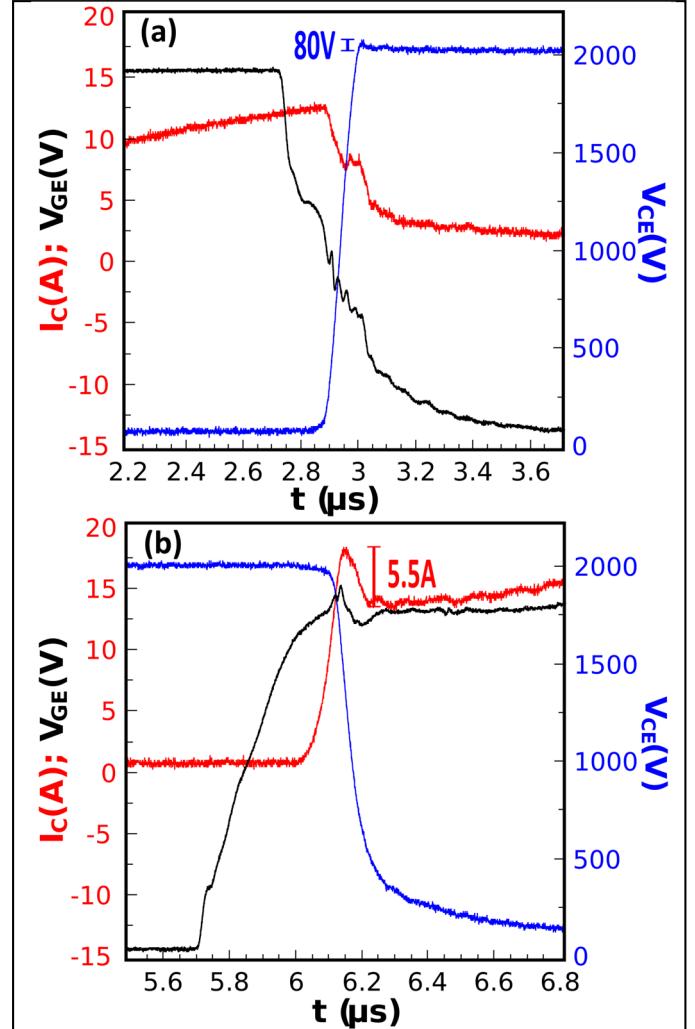


Fig. 3 Double-pulse test at room temperature showing the switching waveforms for the turn-off (a) and turn-on (b) state ($V_{gate}=15V$; $R_g=15\Omega$).

(DUT) and the inductor is connected in parallel with the higher side switch. Fig. 3 presents the voltage and current waveforms of the lower IGBT during the switching off and on transient in the designed package.

As seen in the switching waveforms, small voltage spike accompany the turn-off transient power switches. The overshoot voltage is equal to 80V over 2000V bus voltage, because of the smaller parasitic inductance of this planar package compared to the conventional module. The overshoot current of 5.5A over 13A is mainly due to the discharge of the output capacitance of the high side switch of the half-bridge package.

V. CONCLUSION

A planar module hybrid half-bridge based package has been presented in this paper. The complete assembly process of the hybrid package has been detailed showing the assembled planar module and its integrated turbulent cooler. A double-pulse test was carried out showing the switching waveforms with lower overshoot, comparing to that in a conventional power module.

A thermal characterization is under investigation in order to show the benefit of the double side integrated cooler for high power applications.

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