ARTICLE IN PRESS
MR-12550; No of Pages 7
Microelectronics Reliability xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
Microelectronics Reliability
journal homepage: www.elsevier.com/locate/microrel

Innovative conception of SiC MOSFET-Schottky 3D power inverter module with double side cooling and stacking using silver sintering

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ARTICLE INFO

Article history:
Received 28 May 2017
Received in revised form 28 June 2017
Accepted 7 July 2017
Available online xxxx

Keywords:
Double side cooling
Topic:
Power inverter,
Power package
3D power
Module

ABSTRACT

In this paper, authors developed an innovative packaging for a power inverter SiC MOSFET-Schottky. The design, composed by 6 SiC-MOSFET and 6 SiC-Schottky diodes, places dice between 2 direct-bonding-copper substrates, it was optimized to equilibrate thermal repartition on the two DBC surfaces. We purpose to increase thermal dissipation of power modules by the use of two water-cooling blocks disposed on top and on the bottom of our power inverter; it permits to use both sides of power module to dissipate heat flux. According to Finite Element Method simulations performed with ANSYS®, double side cooling permits to enhance by up to two times thermal dissipation. Moreover solders are replaced by silver sintering and wire-bonds are suppressed by top substrate connections. We want to highlight that those improvements participates to increase reliability of power modules.

1. Introduction and context

Previous studies [1,2,3] and works performed in IMS laboratory on 3D power packages [4,5] as shown the feasibility of double-sided cooling packages without Pb-solder replaced by silver sintering. To ensure silver sintering on top of dice, it needs an added copper layer [5]. Top copper metallization is not present on ordinary dice.

Silver sintering process permits to reduce voids inside solder structure and to minimize the difference of Thermal Expansion Coefficients between die and solder.

A double sided cooling package allows removing wire-bonding, integrating a higher power density and reducing inductive and resistive losses [5].

During this work we would like to combine silver sintering and double sided cooling package to ensure better reliability of power packages.

The main objective of this paper is to validate the feasibility and the interest of 3D power modules. In the first place, power design methods will be presented by the use of electrical and thermal criteria. Secondly, our 3D power module realization will be presented. In the third place FEM simulations will be exposed in order to validate selected electrical and thermal criteria. In the next section, the setup of electrical and thermal experimentations will be described; a classic 2D power module will be used to compare our 3D power module.

2. 3D power inverter's design

2.1. Electrical connexions

Firstly to design our 3D power inverter module it is necessary to search electrical common connexions (Fig. 1). An inverter is composed by six commutation cells constituted of a MOSFET transistor in parallel of a Schottky diode. Common electrical connexions allow gathering dice surfaces.

2.2. Thermal distribution

A major parameter for 3D design is the thermal repartition [6,7]. Create a thermally equilibrated power module must be done by knowing conduction time of each component. We choose to place components of our 3D power inverter module artfully by using the table of conduction (Fig. 2).

In order to doing thermal equilibrated module, we used stacking of components. Stacking component is a design method currently used to maximize and to ensure top and bottom thermal convection. The electrical output connexions of the inverter are located between stacked

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http://dx.doi.org/10.1016/j.microrel.2017.07.037
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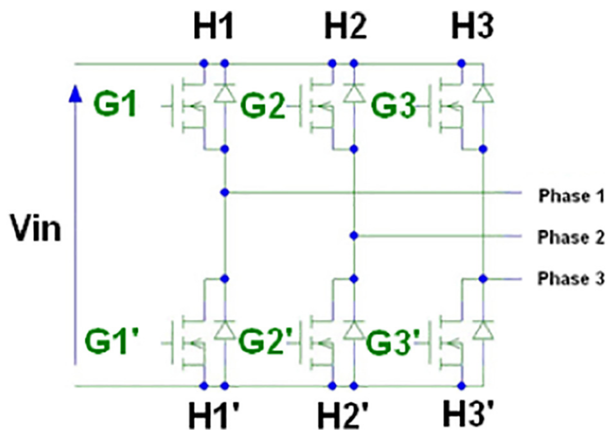

Fig. 1. Power inverter's electrical schematic.

components. Copper bars disposed between stacked dice permit to pull out electrical connexions of the inverter.

3. Realization of the 3D power inverter

In this section realization steps of our 3D power inverter are explained. Two major steps are necessary, first step is dice and substrates preparation and second step is the mechanical assembly.

3.1. Die and substrates preparation

In order to perform silver sintering, dice are previously chosen with 5 μm Cu metallization on top and bottom [3]. Our 3D power inverter is composed by MOSFETs and Schottky diodes (100 V @ 110 A).

To attached dice on DBC substrates ALPHA® Argomax® 8050 Film is used.

Silver film is transferred on the top and bottom of dice by applying low pressure and temperature [4,5], at 3 MPa and 150 °C.

Machining pattern on both substrates is created by mechanical then chemical etching process to protect alumina layer.

3.2. Mechanical assembly

After die and substrate preparation, the assembly process is done. This step corresponds to gather dice, copper bars and substrates together by silver sintering.

We used flip-chip machine to place dice on substrates [5], then a 10 MPa of pressure and 250 °C [4] (Fig. 3) are applied by our Instron® press equipped with heating plates (fig. 4).

Finally, the 3D power inverter module is shown Fig. 5. Die positions and electrical connections are described in Fig. 6a) and b).

4. FEM simulations

ANSYS® mechanical is used to do multi-physic analysis on the 3D power inverter. By exploiting symmetry conditions, only the middle half bridge is considered for simulations (Fig. 7). It permits to decrease the number of elements and reduces run time of simulations.

	0 to T/6	T/6 to T/3	T/3 to T/2	T/2 to 2T/3	2T/3 to 5T/6	5T/6 to T
Cells activated	H1			H1'		
	H2'		H2			H2'
	H3'	H3			H3'	

Fig. 2. Table of conduction of the power inverter.

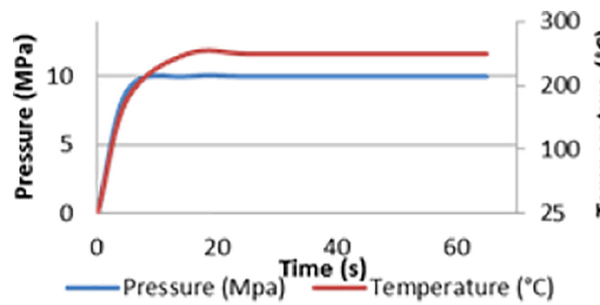

Fig. 3. Silver film Argomax® 8050 sintering profile [4].

The aim of electrostatic simulation is to determine requirement of an electrical insulation between the two substrates.

Also, thermal simulations were done to know thermal distribution in order to size the double sided heat sinks of the module.

4.1. Electrostatic simulations

An important issue of that 3D module could be the ionization of air between substrates.

The presented simulation is focused at the interface of top and bottom substrates near to the die; it is the thinnest space between substrates. Substrates are considered planar and perfectly parallel; if substrates are not parallel due to assembly process, the thinness space will be located on a side of the module.

Simulation conditions are the following:

- Top-substrate voltage is 100 V
- Bottom-substrate voltage is 0 V
- Boundary conditions are ambient air at 25 °C.

Fig. 8 shows repartition of electrical field between substrates. A high electrical field is located in the corner of the die. As 90° angles are subject to high boundary conditions, hot spots are due to the die shape.

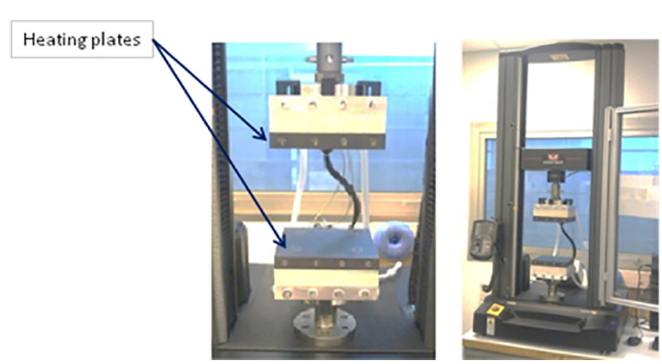

Fig. 4. Instron® press equipped with heating plates.

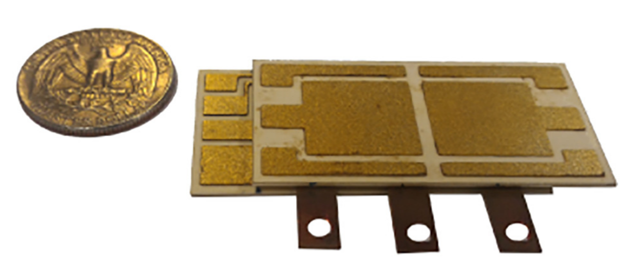

Fig. 5. View of our 3D power inverter module (in face of a quarter dollar).

Please cite this article as: M. Barrière, et al., Innovative conception of SiC MOSFET-Schottky 3D power inverter module with double side cooling and stacking using silver sintering, Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.07.037