Silver sintering wire-bonding less power module for high temperature applications

F. Le Henaff[1], S. Azzopardi[1,2], L. Théolier[1], J.Y. Deletage[1], E. Woirgard[1], S. Bontemps[3], J. Joguet[4]

[1] University of Bordeaux, IMS Laboratory, UMR 5218, F-33400 Talence, France
Email: francois.lehenaff@ims-bordeaux.fr
[2] Bordeaux Institute of Technology, ENSEIRB-MATMECA , F-33400 Talence, France
[3] Microsemi Power Module Products, 33520 Bruges, France
[4] Alpha, South Plainfield New Jersey 07080, USA

Abstract - Integrity of the power module is mainly provided by interconnections between the different components. Due to RoHS restrictions, conventional lead-based solders cannot be used anymore. New solutions of die-attach have been investigated such as transient liquid phase bonding or silver sintering which is currently the most advanced alternative technology. Furthermore, the increase of electrification in transportation system requires a high thermal management because power electronics systems can be located in severe thermal environment and have to dissipate high self-heating. Double-side cooling power modules do not use wires bonding anymore, highly responsible for many failures. To match such requirements, a new structure combining silver sintering and double side cooling system has been developed and characterized. A prototype of a wireless single-phase bridge rectifier has been investigated.

Keywords: nano-scale silver sintering, 3D assembly, wireless power module, thermal and mechanical characterizations, high-temperature applications

1. INTRODUCTION

Severe environment and RoHS restrictions have increased the need for alternative and new die-attach technologies. Low Temperature Joining Techniques (such as silver sintering or Ni-Au Transient Liquid Phase Bonding) are particularly studied because they are processed below 300°C and stay reliable at high temperature. Over the past few years, silver sintering technology has been widely used and studied in academic and industrial research [1-5]. From an immature technology using a high pressure process in the early 2000's, industrial research such as Heraeus and Alent have developed fast and efficient industrial process. Low pressure (0 to 10 MPa) and low temperature (< 250ºC), using micro or nanoscale silver paste, have demonstrated high properties assembly and high reliability (more than 5 times higher than soldered assembly [2].

Additionally, severe environment regarding operating temperature is one of the major drawbacks for single side structure. Three-dimensional (3D) assemblies enable higher thermal performance by allowing cooling of components on both sides of the structure [6]. Therefore, the thermal resistance of a 3D assembly is theoretically 50% lower than for a conventional assembly. 3D structure using solder has been widely studied and published. In EPE2013, for the first time, we have proposed an experimental procedure to design silver sintering three-dimensional assembly [7]. An investigation of the thermal and electrical performances comparison between a soldered and the 100% silver sintered 3D assembly using a single die has been described in this former study in detail.

This new study focuses, for the first time, on the design of a 100 % silver-sintered 3D assembly using several dice processed all together to realize a single-phase bridge rectifier. Using Alpha® nanoscale silver paste (Argomax® 2020), processing and characterizations of this new structure have been developed. Such 3D structure is composed by silicon diodes and copper SMI substrates (and then extended to DBC substrate) which have been used due to their affinity with silver sintering technology. Experimental results (thermal resistance measurements and electrical tests) will be presented and compared to a single side diode bridge structure.

2. 3D ASSEMBLY PROCESS

The first part of our study was to process 2D and 3D assemblies using silver sintering technology. In ESREF 2012, we have presented a 2D assembly process using nano-scale silver pastes (from Alpha®: Argomax® 2020 and Argomax® 4020 [2]. The silver paste is deposited on the substrate by screen-printing (100µm). Then, the deposit is dried and finally sintered under low pressure using an Instron press equipped with two heating platens (250ºC, 10 MPa, 60s). A previous study has shown the high thermomechanical performance of such power modules for different types of substrate finish during passive thermal ageing [2]. Therefore, the 2D assemblies, for this study, were realized using the same silver sintering process.

Silver sintering process is done using uniaxial pressure applied on the power module. Therefore, the main difficulty for 3D assembly process is to apply the pressure only on the die in order to avoid breaking the 3D assembly during the sintering process. The alignment plan, seen below (fig. 1), describes the positioning of the different components during the sintering process. We used a rubber to insure that the pressure will be only applied on the die surface. Once this alignment plan was developed, we were able to process 3D assemblies using the same sintering parameters than for 2D assemblies.

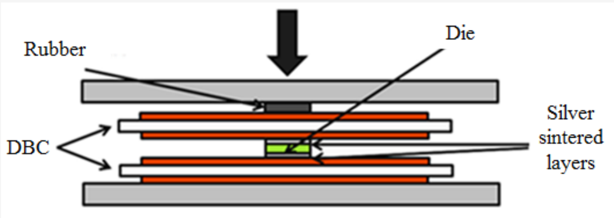

Figure 1: Fixture used for pressure-assisted sintering of 3D power module

Using the two previously detailed processes, 2D and 3D assemblies were processed with gold finish DBC alumina substrates and 3.5 x 3.5 mm^2 silicon bidirectional Tranzil (fig. 2). Both types of assembly will be compared to 2D soldered (PbSnAg) assemblies.

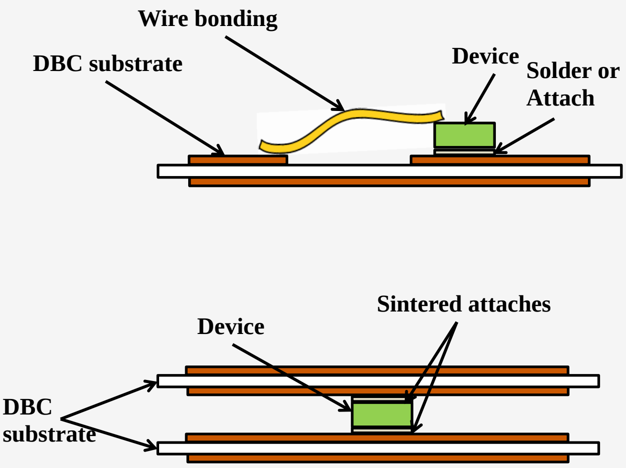

Figure 2: Structure of a 2D assembly (soldered or silver sintered) and a 3D silver sintered assembly

3. 3D ASSEMBLY CHARACTERIZATIONS

Different kinds of characterization were performed on the 3 types of test vehicles in order to demonstrate the feasibility of our 3D silver sintered process for producing 100% double-side cooling wire-less power module.

For the 3D structure, it was not possible to directly perform mechanical shear tests for the two joints. First, lower substrate was removed by manual leverage. It appears that the mechanical strength needed to remove the dice was quite high and initial damage occurred not at the joint level but at the DBC substrate metallization level. For the upper substrate, shear-measurement was done as for simple side test vehicles. Mechanical tests were also realized for the two other types of assembly: experimental results are given in table 1. It can be pointed out that mechanical strength is better for nano silver sintered joint than for conventional soldered assemblies.

Table 1: Mechanical strength of different die-attach assemblies for the 3 types of power module

Type	Minimum (MPa)	Maximum (MPa)	Average (MPa)
Soldered assemblies	17.8	21.7	19.6
Back-side sintered die-attach	26.7	44.8	36.5
Top attach of 3D structure	24.5	37.9	32.9

The output I-V electrical characteristics have been obtained for the three types of assembly (soldered, 2D sintered and 3D sintered). As it can be seen in figure 3, the I-V curves are the same whatever the die-attach process. This clearly shows that the experimental procedure developed for 3D silver sintered power module is reliable because electrical properties of the dices are not altered by the process.

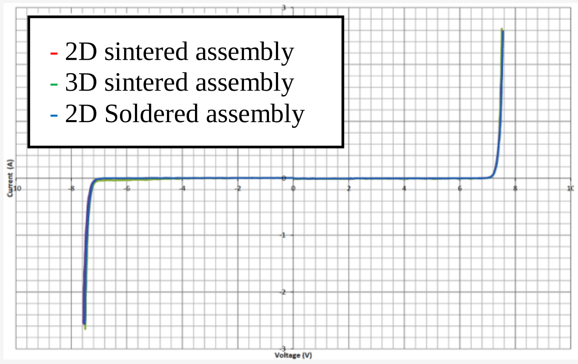

Figure 3: I-V curves for each kind of devices

Study of cross-sections shows that sintered attaches are homogeneous, with regular thickness all along the joint and no void can be detected. For 3D assemblies (figure 4), we can see that the two silver layers are identical. The thickness of the silver layer is about 26µm which is similar to 2D die-attach module realized previously with the same silver paste (Argomax® 4020) [2]. Therefore, the 3D silver sintered process developed is suited to produce 3D wire-bonding less power module with high mechanical and electrical performances.

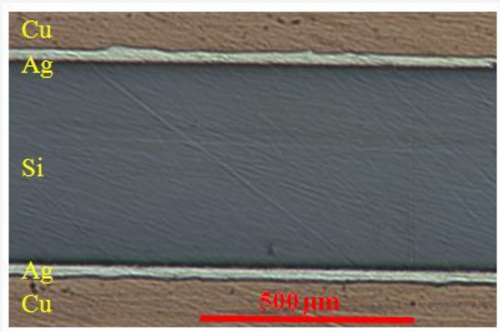

Figure 4: Cross-section of a 3D silver sintered assembly

4. SINGLE PHASE BRIDGE RECTIFIER PROTOTYPE

4.1. Test vehicles

The final part of this study was to realize a thermally optimized fully functional prototype power module with a 3D structure. Using the previous results for the 3D silver sintered assembly, we choose to realize a 3D bridge rectifier (fig. 5) assembly using the process described previously. Therefore, 2D and 3D assemblies were realized using the silver sintering processes. Due to the need to separate electrically the dice as shown in figure 6, SMI substrates were chosen as base for our assemblies. Indeed those substrates are easily sized. Therefore, we used 3mm thick SMI substrates for the final study.

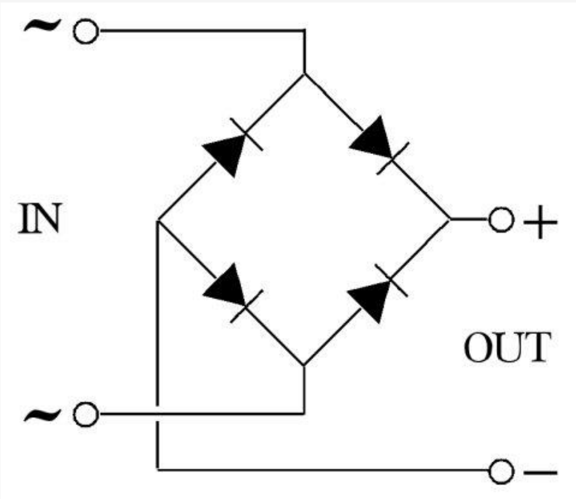

Figure 5: Bridge rectifier electric scheme

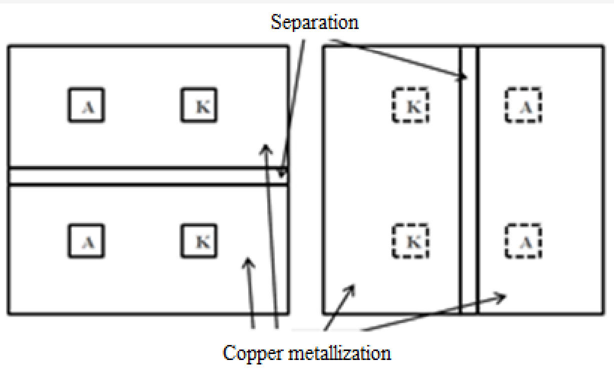

Figure 6: Scheme of the bridge rectifier - Top view of the lower substrate (left) and top substrate (right)

3mm thick SMI substrates were used with 6.35 x 6.35 x 0.120mm^3 silicon diodes (four for each test vehicles) to realize the 2D and 3D assemblies (fig. 7). Finally, both types of assemblies were electrically bonded in order to perform the thermal and electrical characterizations.

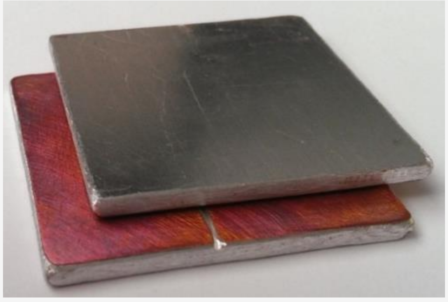

Figure 7: 3D silver sintered wireless bridge rectifier

4.2. Characterizations

Electrical and thermal characterizations were performed on the two kinds of device in order to compare both structures. A 5V sinusoidal signal was used to electrically characterize the device. As seen in figures 8 and 9, the resulting signals are the same for both devices as expected from the preliminary study.

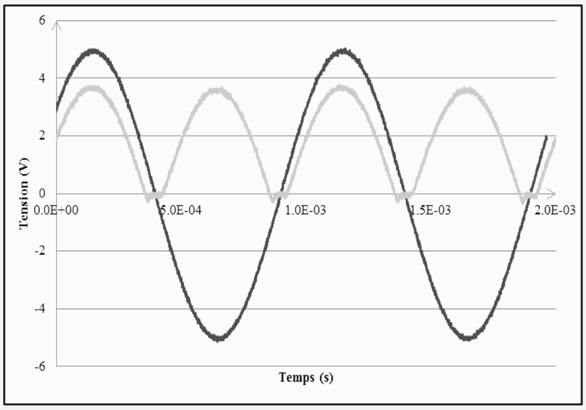

Figure 8: Electrical characterization of a 2D silver sintered bridge rectifier assembly

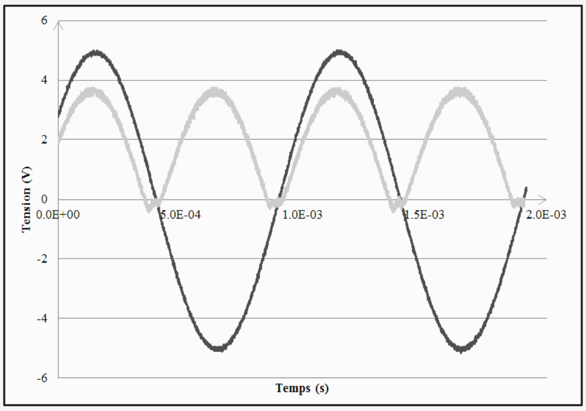

Figure 9: Electrical characterization of a 3D silver sintered wireless bridge rectifier assembly

Finally, the thermal resistance measurements of the devices were performed on an Analysis Tech Phase 10 thermal analyzer equipped with thermal sensors and a power generator. The thermal resistance is defined by the following equation including thermal and electrical power measurements (Eq. 1).

$$Rth = \frac{Tj - Ta}{P} \qquad \text{(Eq.1)}$$

Where P is the applied electrical power, T_a is the ambient temperature and T_j the junction temperature.

The thermal characterizations lead to obtain a thermal resistance of 6.5 ºC/W for the 2D assemblies and 3.8ºC/W for the 3D assemblies. Therefore, the measurements resulted in decrease of 42% of the thermal resistance for a 3D silver sintered assembly compared to a 2D assembly. The difference from the 50% decrease obtained theorically could come from the guard ring termination which decreases the thermal exchange surface on top of the dice.

5. CONCLUSIONS

This study demonstrates, for the first time, that a 3D power module can be realized using a 100% nano-scale silver paste sintered process under low pressure. Those 3D power modules have electrical, mechanical performance similar to 2D power modules. Finally, we have demonstrated the feasibility of a 3D bridge rectifier using a silver sintering process. 3D wireless power module provides an increasing thermal management capability as the thermal resistance of the 3D power module is almost 50% lower than 2D power module.

6. REFERENCES

[1] G. Bai, Low-temperature sintering of nanoscale silver paste for semiconductor device interconnection. Thèse de doctorat, Virginia Polytechnic Institute (USA), 2005.
[2] F. Le Henaff et al., A preliminary study on the thermal and mechanical performances of sintered nano-scale silver die-attach depending on the substrate metallization. Microelectronics reliability, 2012.
[3] A. Masson et al., High temperature die-attaches for SiC power devices. EPE 2011.
[4] U. Scheuermann, Power module design without solder interfaces - an ideal solution for hybrid vehicle traction application. 2009.
[5] W. Schmitt, Novel silver contact paste lead free solutions for die attach. PCIM, Nuremberg, 2010.
[6] C. Gillot, et al., Double-sided cooling for high power IGBT modules using flip chip technology. IEEE Transactions on components and packaging technologies, 2001.
[7] A. Masson et al., Processing and characterization of a 100% low-temperature Ag-sintered three-dimensional structure. 15th European Conference on Power Electronics and Applications (EPE), 2013.