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Characterization and aging test methodology for power electronic devices at high temperature

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Introduction

Power electronic modules are key elements in the chain of power conversion. The application areas include aerospace, aviation, railway, electrical distribution, automotive, home automation, oil industry ... But the use of power electronics in high temperature environments is a major strategic issue in the coming years especially in transport. However, the active components based on silicon are limited in their applications and not suitable for those require both high voltages and high ambient temperatures. The materials with wide energy gap like SiC, GaN and diamond, have the advantage of being able to exceed these limits [1,2]. These materials seem adequate to extremely harsh temperature environments and allow the reduction of cooling systems, but also the increasing of switching frequency.

However, the use of wide band gap components is not a simple substitution of silicon component by these components and a new technology of converters using wide band gap components is needed. Researches should be undertaken concerning materials and assembly technologies and interconnections which are still non-existent today for temperatures between 200°C and 300°C, which is not however yet satisfactory on the temperature range of 150-200°C. The modes and mechanisms of failures on these levels of temperatures must also be highlighted, including those concerning the SiC dies themselves, in order to improve technologies. We thus envisage extending work on the physics of the failures towards the components containing SiC.

Framework of the study

The proposed work is a contribution to the study of modes and mechanisms of failures of power electronics components at high levels of temperatures, including the silicon carbide (SiC) dies, to improve packaging technologies. It deals the characterization and aging tests of power components based on SiC in high temperature environments (200°C) by comparing two kind of :

- Metallization : Al & Au
- Bonding : Al & Au
- Substrate : AlN & Si_3N_4
- Solder : SnPb & AuGe

We present different techniques to characterize the assembly technologies (bonding, metallization, solders, substrates ...), the preliminary characterization to determine the thermo-electrical parameters, and the dependence of voltage forward drop with junction temperature; we present also a methodology to conduct aging tests and characterization during the active cycling at 200°C.

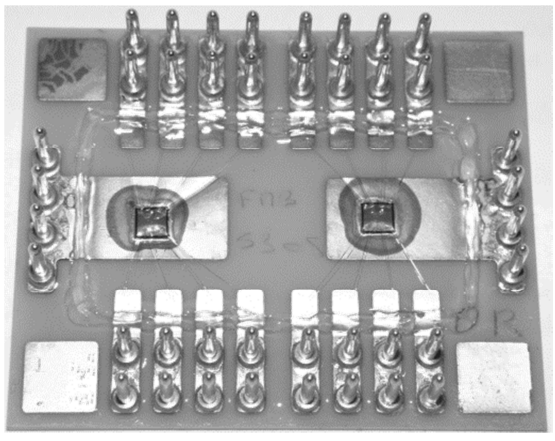


Fig. 1 : Prototype of test

To reply to our test needs, we conceived the test vehicle with a maximum of bonding as shown on Fig. 1. In fact there are two diodes soldered on AlN or Si_3N_4 substrate and there are 8 or 16 wire bonding. We go back over this subject to the paragraph 4.

Power cycling: Test bench and methodology

The active power cycling test bench is presented in Fig. 2. The principle is to age six samples in the same series of test. Thermal simulations have shown the need to use three identical hot-plates sized to accommodate two modules of test because it was almost impossible to have a uniform temperature in case we use a single large plate. The three hot-plates are connected simultaneously to a system control temperature (Presto JULABO) which allows a large working temperature range (-40°C to 250°C) it maintains the 200°C in our case. Six test vehicles, 2 vehicles per plate, will be aged at the same time.

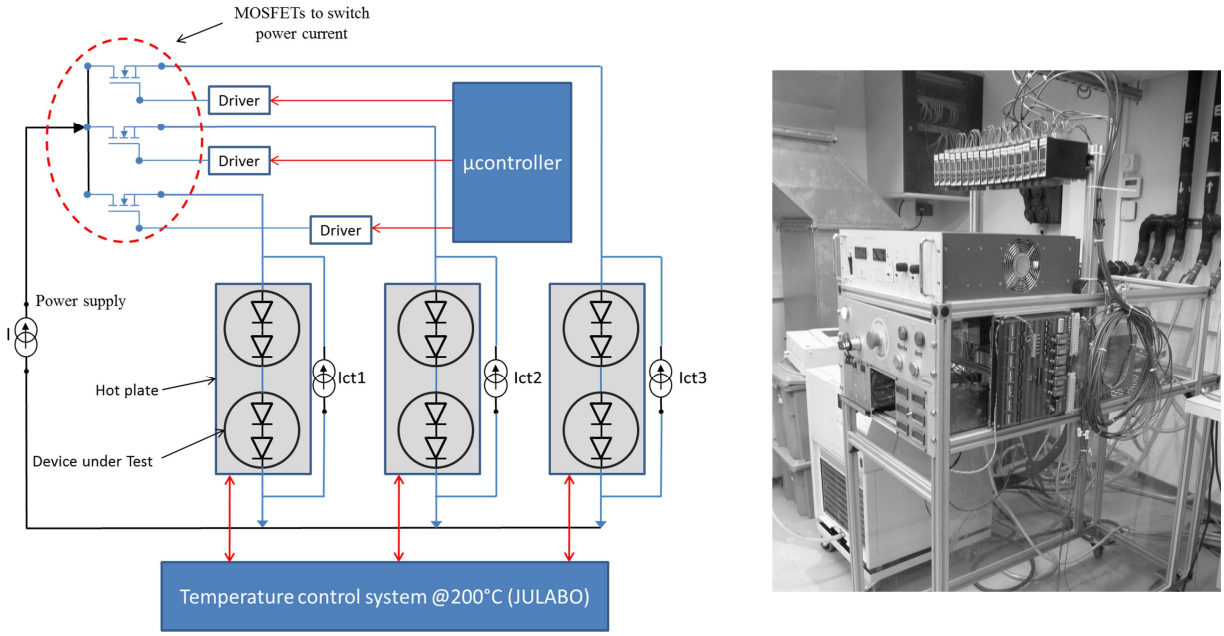


Fig. 2 : Aging test bench (schematic left, picture right)

The switch of power is provided by three MOSFET driven by a microcontroller (16F876A). Knowing that the injection time may differs from sequence to other and it depends on the injected current and the maximum junction temperature. The power injection time for each sequence is managed by the microcontroller with a base time of 200ms and can be adjust up to 50s.

Three current sources (Ict1,2.3) deliver a small currents needed for measurement of indirect temperature of junctions. Indeed preliminary characterization determines the dependence of voltage forward drop with junction temperature at different current level. So throughout the aging test, a small current is injected in the diode permanently and the voltage junction is measured just after power injection end to deduce junction temperature (we do same for all components under test).

Electrical and thermal parameters, which are used for the ageing evaluation, are periodically recorded during the test. After a calibration step and an initial characterization, active power cycling starts for N cycles (N is relatively short in our study particularly as the manufacturing process and assembly technology is not mastered). Some parameters will be measured during cycling: Vds, Ids, Rth, Ict, temperature of input and output cooling fluid. We carry on a series of characterization and cycling to aging all of device under test. This process will end with a final characterization and damage analysis by acoustic microscopy, µsections, and SEM (Scanning Electron Microscopy)

The following parameters will be taken at each characterization:

- Temperatures: Thermocouples under dies, Temperatures of cooling circuit (in, out)
- Electrical measurement in static : Von, Ron, Vgs, Vge, Vbe, Vgth, Vp, leakage
- Measure of contact resistance (wire/metallization)

Some thermal and electrical parameters are controlled continuously during the test for safety reasons for long time using.

Characterization results

The reliability of power electronic modules is of utmost importance all the more so since they would be exposed to high ambient temperatures and frequent power cycling. Ageing tests must be performed in order to assess the devices lifetime. These tests need to estimate power dies temperatures (junction temperatures Tj). This is necessary both for controlling the thermal constraints during ageing and performing thermal characterizations (Rth, Zth) [3].

We present here the thermo-sensitive characterization and a medium to characterize the ageing of dice metallization.

Four SiC-Schottky diodes (1200V-30A, 0.5x0.5 mm) are characterized using the four-wire method for drop voltage measurements. Two diodes are metalized gold and two others are metalized aluminum. The devices were mounted on two hot-plates of ageing test bench. The diode voltage measurements have been performed at several temperatures (from 40°C to 220°C) and for several current injection levels (Ict from 0.5mA to 100mA).

To perform the metallization resistance [4,5], a current is injected into the end points of the diagonal (Fig. 3) and we measure the potential difference at the center. Two combinations are done: set the current between 1 and 3 and measure the voltage between 6 and 8, or pass current between 2 and 4 and measure the voltage between 7 and 9. These measurements were repeated at different temperature levels (from 40°C to 220°C) and for some current levels (50mA, 100mA, 120mA). The voltage were evaluated with a nanovoltmeter (KEITLEY 2182A).

The electrical test bench is developed and controlled with a LabView application to perform semi-automatic characterization of the diode under test. A source meter unit (SMU KEITHLEY 2635) is used to control the current injection (Ict). The diodes reference temperatures are measured with highly accurate thermocouples located under the diodes chip. The measurement uncertainty has been estimated at ±0.5°C for the range between 0°C and 250°C.

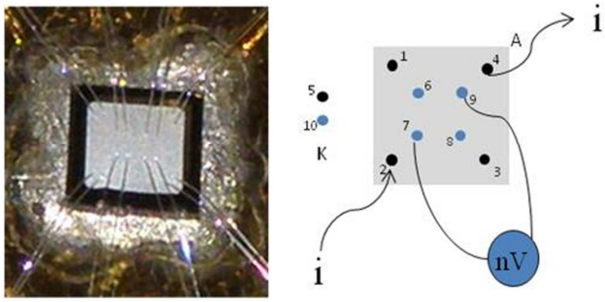


Fig. 3 : Bond wires location on anode pad

As a result, Fig. 4 shows linear variations of both aluminum and gold resistance metallization. This parameter will be monitored during cycling to reveal the damage related to the metallization and to compare the life time of each technology.

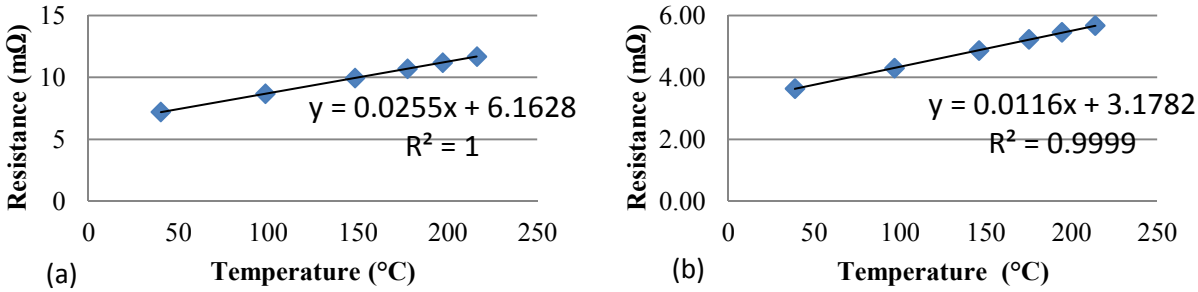
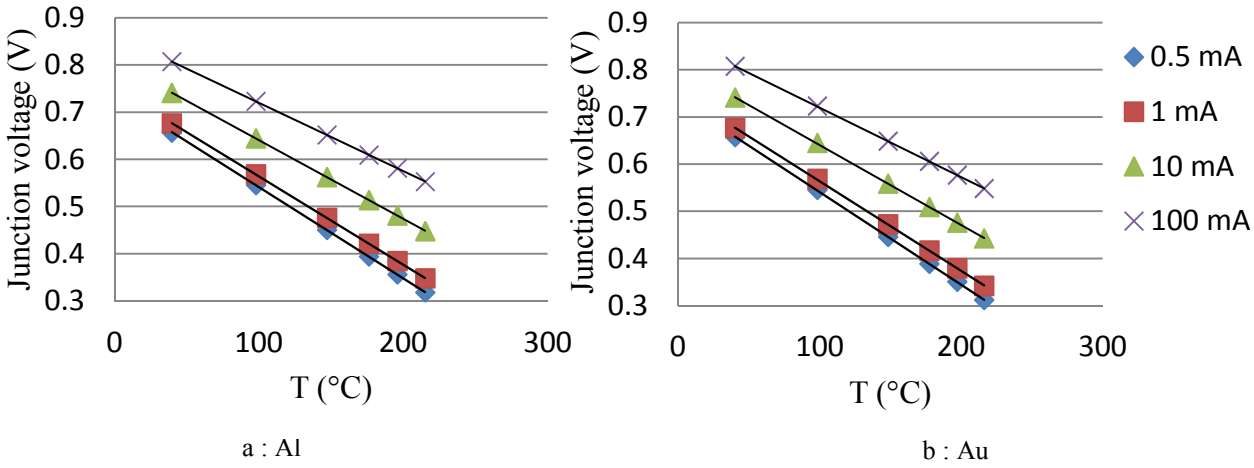


Fig. 4 : Resistance versus temperature: (a) Al, (b) Au



a : Al b : Au

Fig. 5 : Thermo-sensitive characterizations

Fig. 5 gives the experimental thermo-sensitive characterization (graph points) for four current levels (0.5mA, 1mA, 10mA and 100mA) and for the temperature range 40°C-220°C. The result is redundant for similar diode (Au or Al). It is clear that there are linear variations of voltage versus temperature for all current levels and it is important to note that this linearity is maintained even at low current injection. This is an advantage of SiC and it shows that there is not a self-heating effect and will gain precision on the estimation of temperature based on the low injection current.

Conclusion

This paper is an experimental contribution to characterize the assembly technologies. First, the test bench for active power cycling and a methodology to conduct the tests were presented. Then we present the thermo-sensitive characterization to highlight the dependence of voltage forward drop with junction temperature at several current levels. In this way the characterization of metallization is performed to compare between two technologies (Aluminum and gold). Aging tests will start soon in order to compare the lifetime of metallization and bonding and other test campaigns will be undertaken to study the whole assembly technologies.

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