Thermal and electric design of power electronics MOSFET based on Silicon Carbide for electric vehicles inverters

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INTRODUCTION

The need of electrification arise from the fact that in Europe about one quarter of the total gas emission is coming from the transport sector, especially from road transport. Of these, 70% of the road transport emission is due to light-duty vehicles. To lower the emissions the focus is on new technologies, which include both efficiency improvements of existing technologies as well as new vehicle technologies and alternative drive engines. The extent to which the current automotive regime will be challenged depends on the extent to which new infrastructures technological developments and behavioral changes are shaped.

A possibility to improve conventional vehicles performances and to reduce emission is hybridization, this solution can reduce the use of gasoline but not avoid it. Vehicles 100% electric or based on hydrogen fuel cells are considered the best alternatives to fossil fuels, in particular because the amount of emissions depends on the sources of the primary energy used for electricity and hydrogen production and this can come from renewable energy sources.

The environmental impact of electric and fuel cells powered vehicles depends on which energy source is used for the production. In case electricity and hydrogen are produced from renewable energy sources a huge ecological advantage can be expected if they are used for transports. We will concentrate on an R&D project for electrification, which includes a battery simulator, a motor emulator and tests on the inverter.

OBJECTIVES

The objectives of the study is to evaluate thermal and electromagnetic properties of power MOSFETs based on silicon carbide (SiC) for applications in electric vehicles inverters.

Before the application, each component has to be tested in order to guarantee the best performances and avoid defects; in general, to run a test the complete setup of the engine is required, i.e. the battery, the inverter and the motor.

The solution offered by Loccioni is to use complex electronic machines in order to replace at least one of the components of the motor. This has two important results:

- more efficiency. A machine that can simulate several conditions allows to decrease the time needed to prepare the test. Different testing conditions can be obtained just changing few physical parameters instead of preparing a new setup;
- economic advantages. During a test some components could be defective, this means that the other parts could be damaged with a consequent loss of money. The use of such a simulating machine removes the economic loss due to broken parts, a defection in the test is reported by an error signal and the machine is not damaged.

This machines are the *Battery Simulator* and the *E-Motor Emulator*.

The Battery Simulator is used to simulate any battery and is essentially an AC-DC converter, the starting point is the AC input of the network, using a series of transformers and converters we obtain a DC output. The output values obtained are voltages in the range 36-1100V, output currents up to 800A and power of 350kW.

The technologies used in the Battery Simulator are SiC MOSFET and Si IGBT, these devices can handle currents greater than 400A and 600A respectively.

The Motor Emulator is a virtual and completely electronic motor used to test and validate the inverters for automotive applications. The advantage is that the test can be done without using the actual engine or the electric vehicle. There are not moving mechanical parts, everything is simulated by mathematical models with real time controls and the power electronic circuits are based on SiC technologies. All the parameters to simulate the motor, such as the physical inductance, the resistance and the rpm, can be set arbitrarily.

Using the complete setup of the Battery Simulator and the Motor Emulator, inverters are tested under different working conditions. The device under test (DUT) receive the power supply and input signals as if it is in a real electric vehicle, but actually it is simulated.

Before the test on the complete setup of the inverter, several tests, known as *static parametric tests*, can be performed in different working conditions to investigate the behavior of the internal components. Other types of tests can be run before the static parametric tests, the aim is to stress the major components and simulate critical conditions. I will take into account two different tests:

- Short circuit: is used to simulate the failure of the internal components, which leads to a short circuit condition. It is performed by applying 100A DC and the final temperature is measured;
- Multipulse: is the closest to the actual application, performed using 100A AC. The aim is to calculate the inductance of the components.

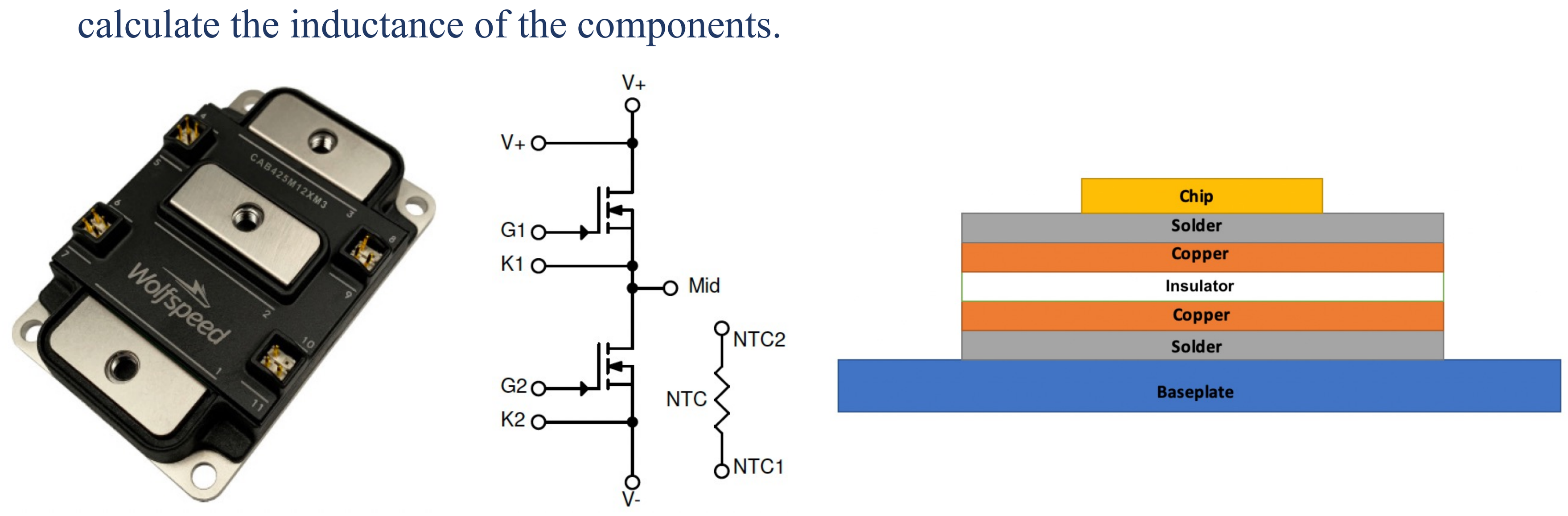


Fig. 1: power module CAB425M12XM3, electrical scheme and design of the die. The chip is made of SiC and the insulator used is SiN.

Is useful to simulate the test before running it, to set the best tools for the measure. The software used for the simulations is COMSOL Multiphysiscs® 5.4, a cross-platform for finite element analysis which allows to solve coupled systems of partial differential equations, several modules are available for COMSOL, categorized according to the applications areas of electrical, mechanical, fluid, acoustic, chemical, multiphysical and interfacing.

The sample used is a power MOSFET showed in Fig. 1 and manufactured by Wolfspeed that can handle voltages up to 1200V and a maximum current of 425A.

DISCUSSION

The short circuit test was made under test durations of 10µs, 50µs, 100µs and a validation test of 500ms. Starting from 20°C The temperature reached for each test is, respectively, 20.008°C, 20.033°C, 20.058°C and 23.998°C. The curves of the max temperature are shown in Fig. 2 for the longest time interval. In the inset the object that is monitored

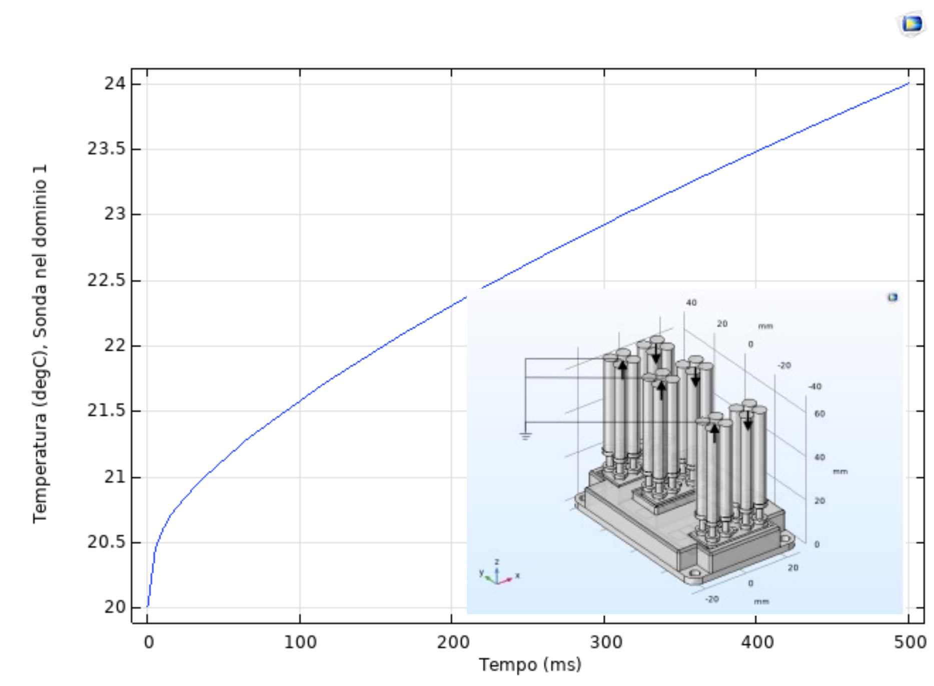


Fig. 2: plot of temperature against time. The curve for the test duration of 500ms is flattening due to the dissipation with the external environment. The other curve are quite linear.

The multipulse test is made for frequency values of 1MHz, 200kHz, 100kHz and 20kHz. From the impedance value obtained, the inductance is calculated as

$$L = \Re e\left(\frac{Z}{i\omega}\right)$$

and the values obtained are 0.120nH, 0.956nH, 1.695nH, 4.048nH respectively. Being preliminary tests, short circuit and multipulse do not directly give parameters of the actual working conditions, but they are useful to know the conditions of the module before running a parametric test.

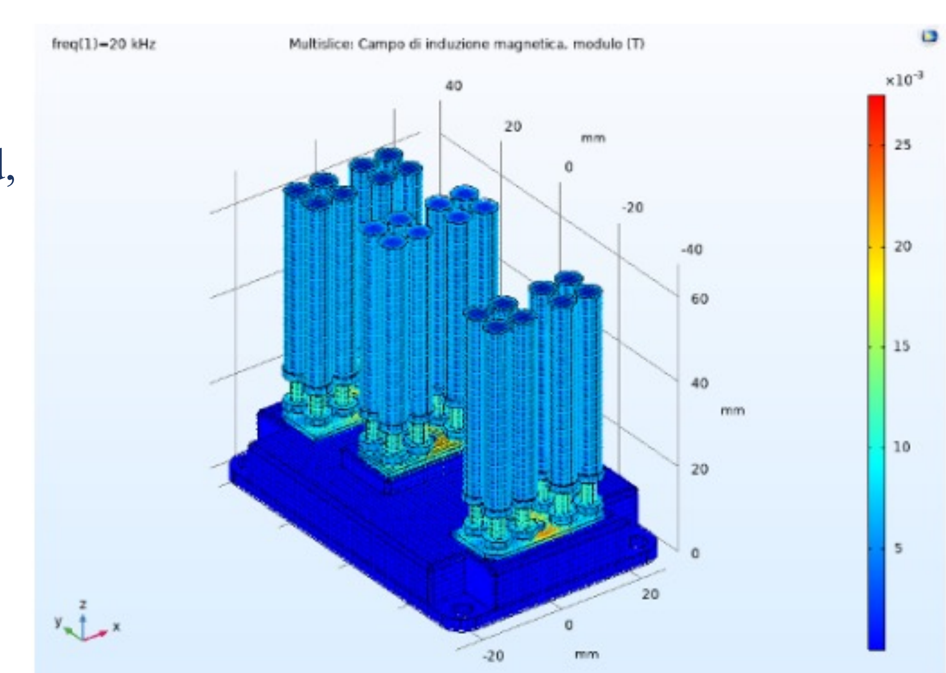
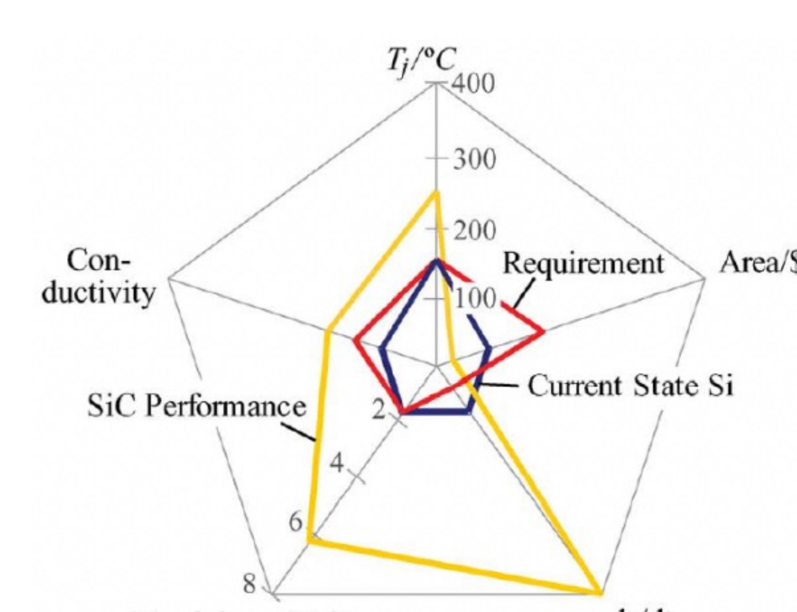


Fig. 3: Magnetic field plot depicted at 20KHz

CONCLUSIONS

A necessary condition for electric transition is the low cost of the energy and its availability in several situations, preferably from renewable sources.

The transport issue have pushed the researchers to build electric engines more and more powerful and efficient, but the development is also aimed to other parts of the engine, such as the battery and the inverter. We focused just on the inverter and its internal components, in particular on the material used in the power modules, the silicon carbide.



The advantages of SiC are several: the higher possible switching frequencies at low switching loss are advantageous for DC-DC converter systems since they allow reducing the size of the inductor and transformer. This is particularly true at medium voltage levels where fast switching devices based on silicon are missing and where new and ultraefficient converter systems are required for future energy distribution networks.

In the figure 4 above Radar chart for the switching devices. The current status with silicon devices is shown in blue and the offered performance of SiC devices is shown in yellow. The red curve shows the requirements on the switch level for low voltage industrial drive. It can be seen that the achievable switching speed of SiC and even of Si devices is exceeding requirements as the high breakdown voltages and the high possible junction temperature of SiC. Nevertheless the better conductivity of SiC, resulting in a smaller chip area, and the higher achievable efficiency could be beneficial for inverter systems, in case the costs do not increase. It is clear that at the moment the significant limit for SiC devices is the high cost.

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