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Electrical and thermal modeling and aging study of a C2M0025120D silicon carbide-based power MOSFET transistor

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Abstract. In most papers studies about MOSFETs aging are treated from a materiel point of view, in this paper we consider the electrical aspects that contribute to such degradation. Two important degradation mechanisms are proposed related to the transistor bias and the increase of its temperature. This study consists to push the studied transistor to operate in an aging mode by imposing particular bias conditions and excessive junction temperature. Based on some electrical quantities, such as drain leakage current and on the junction temperature, the behavior of the transistor is deduced when operating in aging mode. The simulation results obtained show that during these particular operations, the junction temperature increases, which may destroy the transistor.

Keywords: Silicon Carbide, aging, power MOSFET, Boost converter, leakage currents.

1. Introduction

The field of power electronics has undergone considerable progress in recent years, allowing it to have a higher degree of industrialization. In addition, research in this area continues to progress to improve the performance of electronic components such as silicon carbide (sic) transistors. The latter represent high-performance technology [1-6]. They respond well to the problems of silicon-made transistors. Specifically, SIC transistors help to avoid certain problems encountered by those of SI (very high response time, a loss of power during switching, a significant $R_{ds(on)}$ resistance and a limited operating temperature). Despite this improvement, however, the application of SIC transistors in high power DC/DC converters suffers from several problems [7-10]. Among them, there is the problem of aging, caused by an overvoltage or current, high temperature, distortion or inadequacy of the amplitude of control PWM signal. Therefore, in order to solve this kind of issues the electro-thermal study is of a great help. In this context, we studied the problem of aging of the C2M0025120D transistor. To do this, we used this transistor in a medium power Boost DC/DC converter (3kW). This study was carried out, in the simulator (Pspice), by making the transistor operating in

particular conditions: high temperature, over-voltage or over-current. The objective of this study is to show the behavior of the studied transistor, during its operation in aging mode. The analysis of the electrical quantities (drain-source leakage current, gate leakage current, junction temperature and $R_{ds\ on}$ resistance) show that there is an abrupt variation, of these electrical quantities, during its operation in Aging Mode.

2 Aging study of the C2M0025120D MOSFET transistor

After studying the modeling of the transistor Sic C2M0025120D[1], we study in this paragraph the behavior of this transistor, during its exposure to the degradation conditions (aging), by using the transistor in a converter DC/DC (3kW) and 10 kHz switching frequency (Figure 1). Then, in order to create ageing conditions several techniques may be applied: exceeding the temperature supported by the transistor (in our case 150 °c), poorly controlled transistor.

In this study, the evolution of different electrical quantities representing the transistor studied are analyzed : the drain-source resistance, drain-source leakage current, the junction temperature.

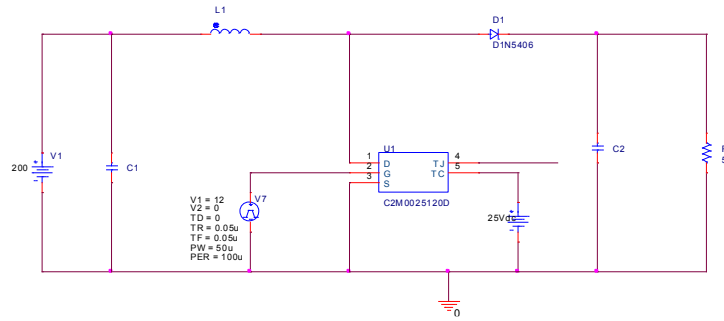


Fig.1. Application of the C2M0025120D transistor in a DC/DC Boost Converter

2.1 Influence of the change in grid-Source voltages V_{GS} on the Aging of the transistor

In order to validate the electro-thermal model of the transistor studied during this work. We used the transistor in a Power converter DC/DC Boost, which generates a power output of 3 KW. This study is based on the analysis of the behavior of the parameters of the transistor, In the Pspice simulator, by varying the Gate-Source voltage (V_{GS}) from the Transistor from 0 to 10v. In Figure 2, we represented the junction temperature of the transistor studied and the drain-Source leakage current. The results obtained show that :

- ✓ From 0v up to 3v: The transistor operates in a secure mode, the junction temperature of the transistor is in the range of 25 °c (Figure 2A). Then the drain-

Source leakage current (Figure 2B) remains constant at $4.4 \mu\text{A}$. As the transistor is OFF mode, the voltage Drain-Source V_{DS} is equal to that of the input generator (200V) (Figure 2C).

- ✓ From 3V to 6V: The transistor operates in degradation mode, during this period, it is noted that there is a peak of junction temperature (leakage current) with a maximum value of 50°C (Figure 2A and 2B). This abrupt variation of these two parameters clearly shows that the transistor studied works in aging mode. In addition, the V_{DS} voltage toggles from 200V to 87V, when the voltage varies from 5V to 6V (Figure 2C).
- ✓ From 6V to 12V : The transistor operates in ON mode, and the junction temperature returns to its initial value (25.6°C) (Figure 2A), the drain-source leakage current (I_{DS}) toggles from $4.4\mu\text{A}$ in OFF mode to $7.5 \mu\text{A}$ in ON mode (Figure 2C), then, the V_{DS} voltage becomes null from a 7V V_{GS} voltage, (it corresponds well to the voltage of the transistor threshold) (Figure 2B).

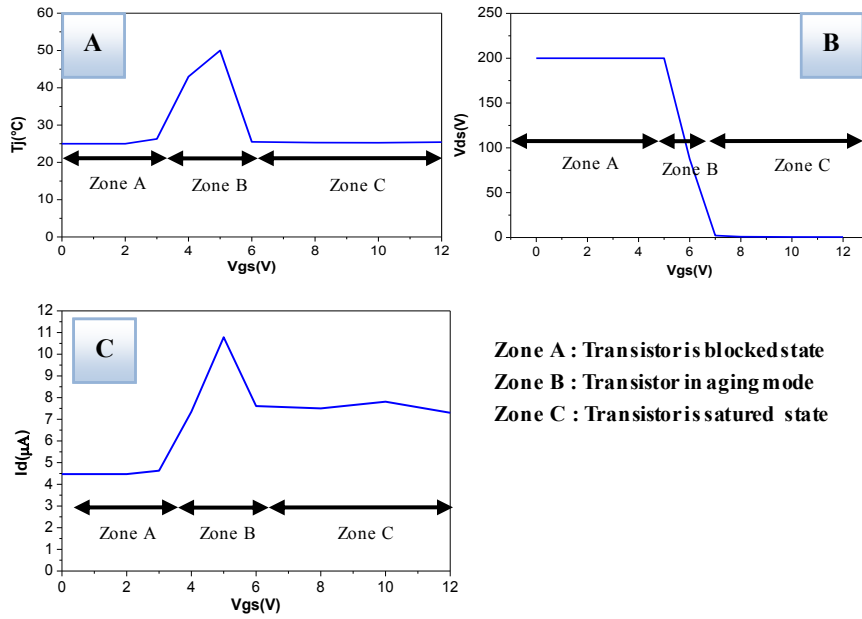


Fig. 2. Temperature junction (A) vs V_{GS} , Drain-source voltage V_{DS} vs V_{GS} (B) and $^\circ$ Drain-source leakage current vs V_{GS} vs V_{GS} (C)

2.2 Influence of the junction temperature variation on the transistor aging

In order to show the behavior of the transistor studied during this work, during its operation in aging mode, keeping the same application as that of the paragraph above. We have varied the junction temperature of the transistor from 0°C to 400°C , exceeding the maximum value of the temperature that can support the transistor, which is

of the order of 150 ° C. The different results obtained are shown in Figure 3. It appears that :

- ✓ The source drain leakage current I_{ds} of the transistor varies as a function of the junction temperature, the maximum value is obtained at 225 ° C, it is of the order of 70.3 μA . Beyond 225 ° C, by exceeding the maximum value of the junction temperature supported by the transistor, the leakage current I_{ds} decreases. (Figure 3A).
- ✓ The leakage current of the I_g gate remains almost constant from 25 ° C to 225 ° C, it varies around 70 μA . Beyond 225 ° C., the leakage current I_g decreases until it vanishes at 400 ° C, (FIG. 3B).
- ✓ The resistance R_{dson} is of no help for the transistor aging, even if one exceeds the supported temperature. It increases gradually as a function of the transistor junction temperature (FIG. 3C).

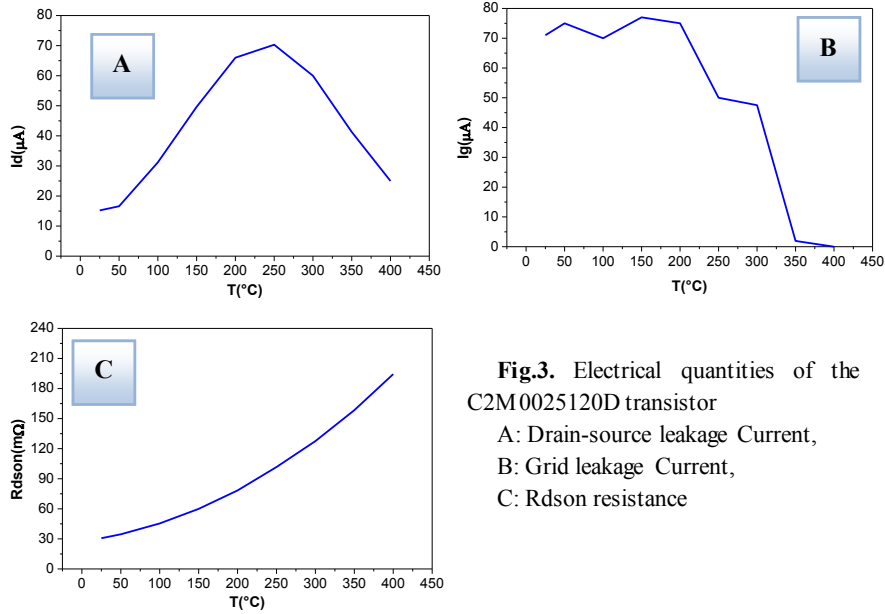


Fig.3. Electrical quantities of the C2M0025120D transistor
A: Drain-source leakage Current,
B: Grid leakage Current,
C: R_{dson} resistance

2.3 Influence of the change in grid-Source voltages V_{GS} on the Aging of the transistor

The functioning of the transistors also depends on the quality of the control PWM signal, this may result in a degraded operation of the transistor. In order to clarify this point, keeping the same application of Figure 1, we control the transistor by a PWM signal completely distorted, this distortion is due to the absence of the driver between the control part and the power one (Figure 4A), and another appropriate PWM signal using an 2111 driver (Figure 4B). Then, for each case, we plotted the resulting junction temperature (Figure 4C and D). All the results obtained show that:

- ✓ The junction temperature of the C2M0025120D transistor increases by 34 °C (figure 4D) in case of normal operation (appropriate PWM) at 115 °C when controlled by a distorted PWM signal (Figure 4C), i.e. an increase of 70.44%.
- ✓ The increase of the junction temperature results in the degradation of the performance of the transistor (aging) and consequently, its destruction

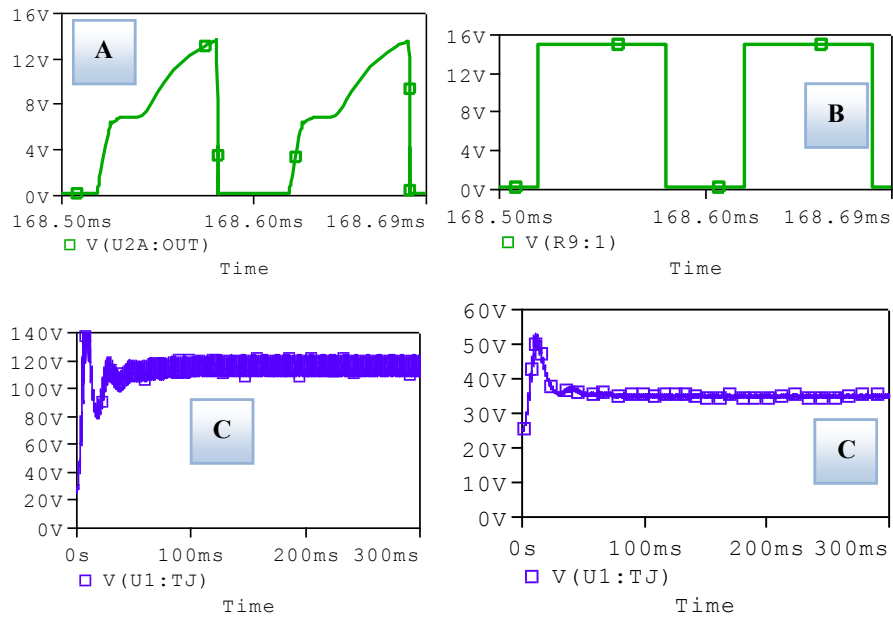


Figure 4: Influence of the PWM signal State on the aging of the C2M0025120D transistor

A and C: Distorted PWM Signal and the resulting junction temperature,
B and D: PWM Signal and the resulting junction temperature.

3 Conclusion

In this work, we studied an electro-thermal study of a power transistor based on silicon carbide C2M0025120D. This study consists of defining the different equations

linking the different parameters of the transistor (V_{DS} , I_{DS} , T_j ...), based on the electric and thermal model of the transistor developed during this work [1]. Then, we studied the aging of the transistor, by using the transistor in a DC/DC power converter, which generates a power output of 3 KW. The aging study is done by pushing the transistor to operate in particular conditions (temperature, drain current,...). From this study we deduced the behavior of the transistor by considering the electrical parameters (the drain-source leakage current, the junction temperature,...). The different results show that in aging mode, there are abrupt variations of some electrical parameters, which clearly shows that the electro-thermal model developed during this Work, for C2M0025120D transistor reflects well the reality.

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