# Investigation on the use of the MOSFET SiC body diode for junction temperature measurement

Quang Chuc Nguyen, Patrick Tounsi, Jean-Pierre Fradin, Jean-Michel Reynes

## To cite this version:

Quang Chuc Nguyen, Patrick Tounsi, Jean-Pierre Fradin, Jean-Michel Reynes. Investigation on the use of the MOSFET SiC body diode for junction temperature measurement. IEEE THERMINIC 2020, Fraunhofer Berlin, Sep 2020, Berlin, Germany. hal-03655865

**HAL Id: hal-03655865**

**https://hal.laas.fr/hal-03655865**

Submitted on 30 Apr 2022

# Investigation on the use of the MOSFET SiC body diode for junction temperature measurement

Quang Chuc NGUYEN*[1,2,3], Patrick TOUNSI[2], Jean-Pierre FRADIN[3], Jean-Michel REYNES[1,4]

[1] IRT Saint-Exupéry, Toulouse, France
[2] LAAS-CNRS, Toulouse, France
[3] ICAM, Toulouse, France
[4] aPSI$^{3D}$, Tarbes, France

* Corresponding Author: quang-chuc.nguyen@irt-saintexupery.com

## *Abstract*

*As Silicon-based semiconductors approach their limits in different areas, wide bandgap devices, such as Silicon Carbide components, offer an excellent alternative in many applications. Recently, SiC MOSFETs are replacing Si-based IGBT in various fields as automotive, solar energy… The junction temperature is important to evaluate the performance and the reliability of these components. For Silicon MOSFET, the body diode is usually used as a thermal sensitive electrical parameter (TSEP) for junction temperature measurement. For SiC MOSFET, however, in gate-source short configuration ($V_{GS}=0V$), some current still flows through the channel, which, with interface trapping, prevents from accurately estimating SiC MOSFET junction temperature. Practically, a sufficiently negative gate voltage $V_{GS}$ (-5V or below, depending on devices) must to applied to eliminate the current part through the MOS channel so that the body diode forward voltage is immune from interface trapping.*

## 1 Background

Silicon Carbide MOSFETs are becoming more frequently used in different power electronic applications such as solar inverters, power supply, railway traction inverter, electric vehicle and induction heating because of their numerous advantages: high blocking voltage, high working temperature and high switching speed [1]. Measuring the SiC MOSFET junction temperature is a mean to evaluate the performance and reliability of SiC-based power modules.

The power module package often prevents from directly measuring the junction temperature with optical or physical contact methods such as IR camera, thermocouple… Consequently, the junction temperature is usually indirectly measured by electrical methods via a thermal sensitive electrical parameter (TSEP): voltage under low current (diode, IGBT, MOSFET), threshold voltage, peak gate current… [2], [3]. The thermal sensitive electrical parameters are well understood for Silicon components but some phenomena related to TSEP are not yet clarified for SiC MOSFET.

In order to have a correct measurement, the change of the TSEP response before and after heating phase should only come from the change of the junction temperature. If any other electrical aspects can influence the TSEP response, then the measurement is not accurate [4], [5]. Therefore, the TSEP response compliance was first checked before being used for the junction temperature measureme.

## 2 Methodology and test bench

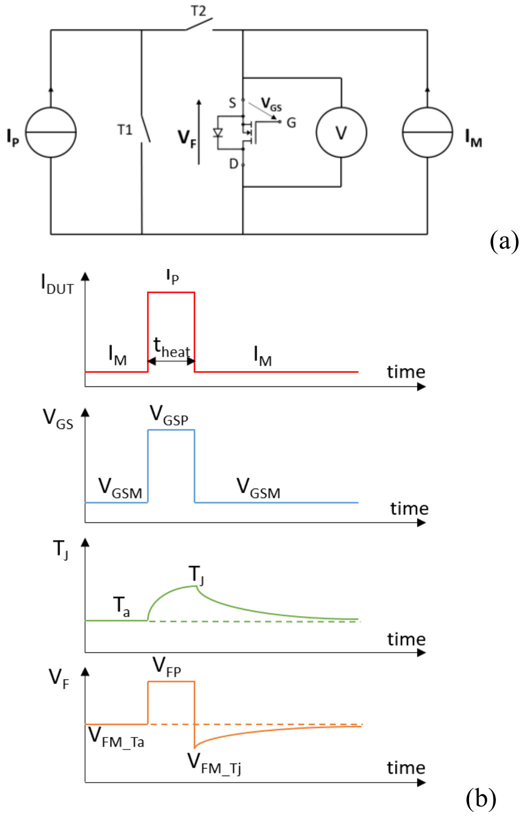


*Fig. 1. (a) Electrical circuit for junction temperature measurement (a), (b) diagram of different phases of the thermal characterization.*

Fig. 1 depicts the test bench electrical circuit dedicated to measuring the SiC MOSFET junction temperature using its body diode as a TSEP. The power source $I_P$ (high current of tens of amps to hundreds of amps) is used to heat the MOSFET. The measurement current $I_M$ (low current of 10mA) is applied to measure the forward voltage of the MOSFET body diode, which gives an estimation of the junction temperature.

The power module used in this study is designed and produced by Institute of Technology Saint-Exupery. It consists of 12 SiC MOSFETs, which are split in 6 switching cells (see fig.2a). In our tests, the module is mounted on a fan-cooled heat sink with a thermal paste within the contact. The control system contains a motherboard and 12 gate drivers, which are fixed on the upper side of the power module (see fig. 2b). The electrical system of the test bench consists of two power transistors (T1, T2) that drive the power current into the SiC MOSFET during the heating phase. A system of National Instruments chassis and control module allows us to send the control signal to the gate drivers. The forward voltage of SiC MOSFET body diode is measured by a voltage probe and a NI oscilloscope (see fig 2.c).

The measurement procedure consists of three phases:

**(i)** The switch T1 is turn-on, T2 is turn-off, the SiC MOSFET is controlled by a gate voltage $V_{GS} = V_{GSM}$ ($V_{GS}$ during measurement), only the current $I_M$ goes through the MOSFET, the junction temperature is also the ambient temperature $T_a$. The body diode forward voltage under low current is $V_F = V_{FM\_Ta}$;

**(ii)** The switch T1 is turn-off, T2 is turn-on, the gate voltage $V_{GS} = V_{GSP}$ ($V_{GS}$ during power phase), both currents $I_P$ and $I_M$ go through the MOSFET and heat it to a temperature $T_J$. The body diode forward voltage under high current is $V_F = V_{FP}$;

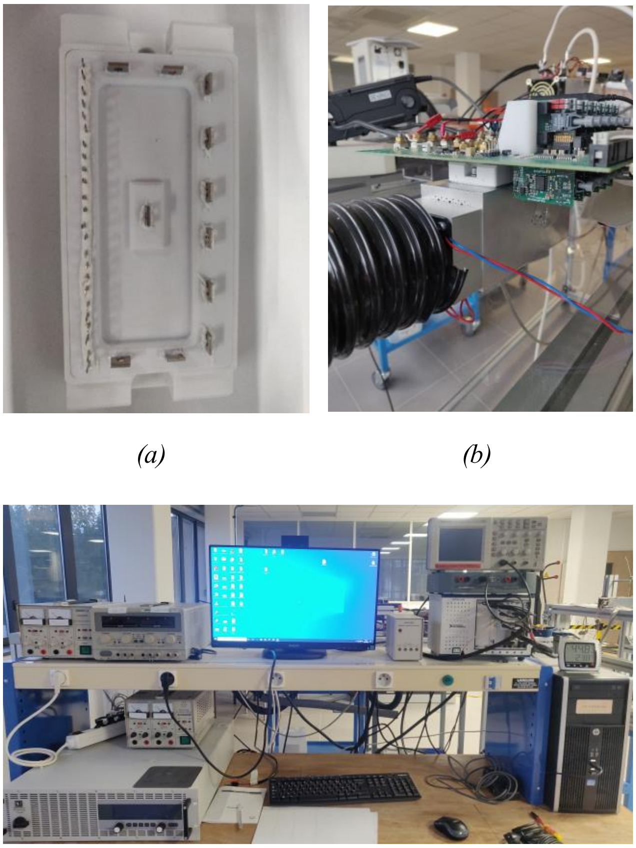
**(iii)** The switch T1 is turn-on, T2 is turn-off again, the gate voltage $V_{GS} = V_{GSM}$, only the current $I_M$ goes through the MOSFET. At the switching moment, the MOSFET is still at heating temperature $T_J$, the body diode forward voltage under low current: $V_F = V_{FM\_Tj}$.

The difference between $V_{FM\_TJ}$ and $V_{FM\_Ta}$ corresponds to the change of the junction temperature before and after heating phase:

$$V_{FM\_T_J} - V_{FM\_T_a} = k \times (T_J - T_a)$$

where $k$ is the temperature coefficient of the body diode forward voltage (usually between -2mV/°C and -3mV/°C). This coefficient is calibrated beforehand by using a curve tracer HP4142B and the thermostream Temptronic TP04200 (see fig. 3).

When power is dissipated in the SiC MOSFET ($I_P >> 0$), the junction temperature increases (from $T_a$ to $T_J$) so that the body diode forward voltage in phase (i) and phase (iii) ($V_{FM\_Ta}$ and $V_{FM\_Tj}$) are different Obviously, if there is no dissipated power in the SiC MOSFET ($I_P = 0$), the junction temperature is the same as the ambient temperature. Thus: $V_{FM\_Tj} = V_{FM\_Ta}$.



(a) (b)

(c)

*Fig. 2. Presentation of the test bench for thermal characterization: (a) SiC power module with control pins and power connections, (b) SiC power module with control system mounted on the heat sinks, (c) PC with Labview and NI components (chassis, control module, oscilloscope) for control and signal acquisisition.*

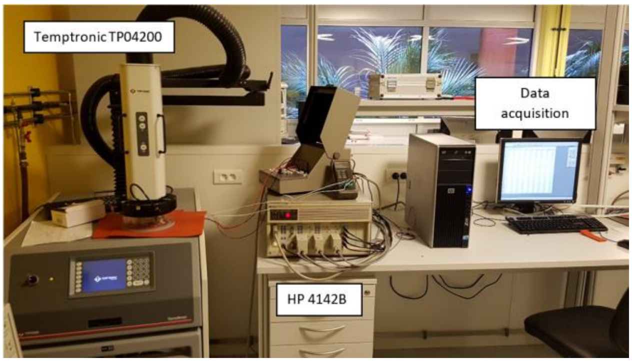


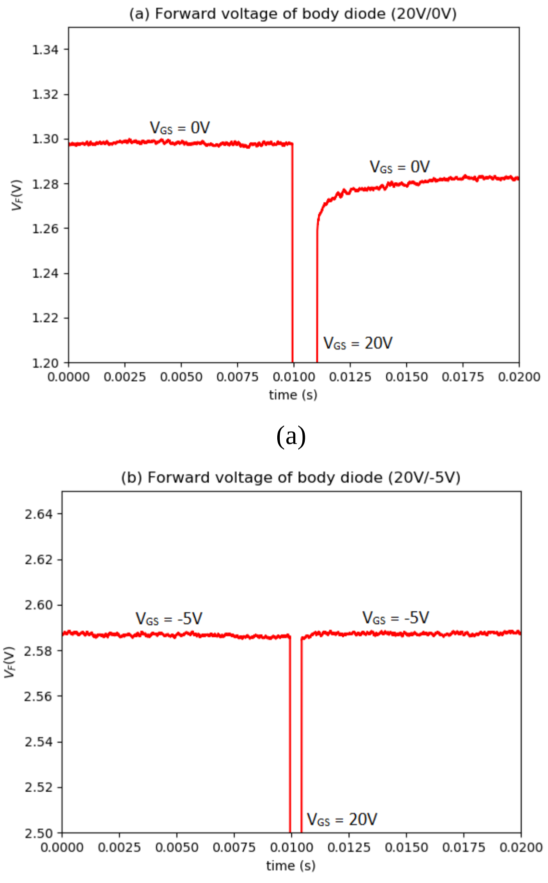
*Fig. 3. Electrical test bench for power module characterization.*

## 3 Results

Fig. 3 illustrates the body diode voltage $V_F$ under $V_{GSM}$ = 0V, $V_{GSP}$ = 20V (fig. 4a), $V_{GSM}$=-5V, $V_{GSP}$=20V (fig. 4b) and $I_P$=0A, $I_M$=10mA (no heating). Notice that under this condition, the MOSFET is not heated at all because of the absent of the heating power. As discussed above, in this case, we expected that under the same measurement current (10mA), the body diode forward voltage does not change between measurement phases (phase (i) and phase (iii)).

However, as was noticed in the first case, the body diode voltage $V_F$ changes when the controlled voltage $V_{GSM}$ = 0V (fig. 4a). It highlights the fact that the body diode voltage is influenced by a different cause other than the change of junction temperature.

On the other hand, the body diode voltage under $V_{GS}$ = -5V does not change at all after the pulse (fig 4.b).

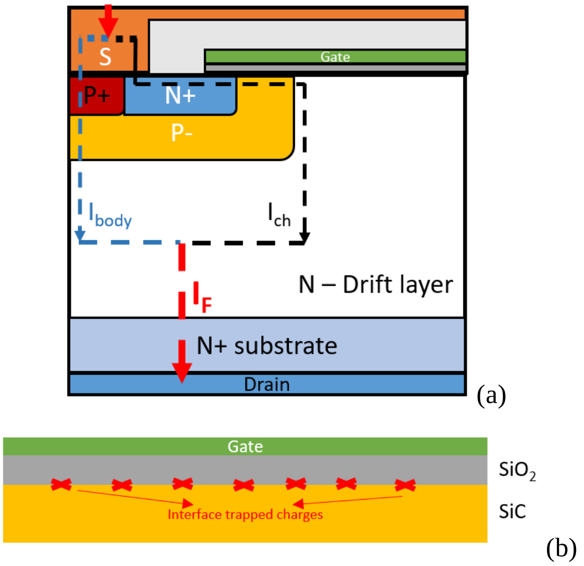


(a)

(b)

*Fig. 4. Forward voltage of the body diode under a current of 10mA and control voltages: $V_{GSP}$ = 20V, $V_{GSM}$ = 0V (a); $V_{GSP}$ = 20V, $V_{GSM}$ = -5V.*

In SiC MOSFET's reverse configuration, even when the gate voltage $V_{GS}$= 0V, because of the body effect [6], [7], the current is composed of two parts: $I_{body}$ (through the body diode) and $I_{ch}$ (through the channel) (see fig. 5a). When the gate voltage $V_{GS}$ changes value (from 0V to 20V then back to 0V), the charges are trapped in the interface between the SiC layer (p- region) and the gate oxide $SiO_2$ layer (see fig. 5b). This interface trapping changes the conductivity of the channel and so affects this channel current part $I_{ch}$ during temperature measurement procedure, which ultimately makes the body diode forward voltage $V_F$ unstable and distorts the measurement.



(a)

(b)

*Fig. 5. (a) Cross-section of current paths through the body diode and (b) a zoom of the interface between gate oxide ($SiO_2$) and p-region (SiC).*

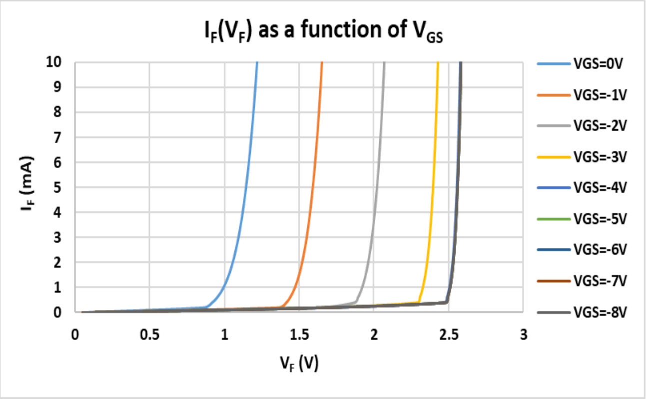


*Fig. 6. $I_F(V_F)$ as a function of the gate bias voltage $V_{GS}$*

As the gate voltage becomes progressively more negative (from 0V to -5V), the body diode voltage becomes higher until $V_{GS}$ = -5V (fig. 6), which means that the channel current part $I_{ch}$ is slowly eliminated. From then, $V_F$ remains constant, even if $V_{GS}$ becomes more negative (-5V to -8V), which means $I_{ch}$ has completely disappeared and only $I_{body}$ exists when $V_{GS}$=-5V or higher. In this case, when the gate is controlled at a sufficient negative level (-5V or more for this component), the body diode is fully turned on and can be used for junction temperature measurement.

## 4 Conclusion

The junction temperature of power devices is an important parameter to evaluate the performance and reliability of power systems. Because of the package, the junction temperature of power module is often measured indirectly via thermal sensitive electrical parameters. These parameters are well known and studied for Silicon-based devices. However, the mechanism of using TSEP for Silicon Carbide components such as SiC MOSFET still need to be studied. This work helps clarify the use of SiC MOSFET body diode as thermal sensitive electrical parameter. The current path in reverse configuration of SiC MOSFET includes two parts: a part through the body diode and a part through the channel. When the gate voltage changes, the charges are trapped in the interface between the gate oxide and the silicon. This phenomenon changes the conductivity of the channel and influences the current part through the channel. In order to address this issue, the gate voltage needs to be controlled at a sufficient negative level (-5V or more) to eliminate the current part through the channel. Only then, the body diode can be used as thermal sensitive parameter for SiC MOSFET junction temperature measurement.

## Acknowledgements

The authors would like to thank to the Institute of Technology Antoine de Saint-Exupéry for providing the SiC power module and their help in setting up the control system combined with the module.

## Literature

[1] She, X., Huang, A. Q., Lucía, Ó. & Ozpineci, B. (2017). Review of silicon carbide power devices and their applications. *IEEE Transactions on Industrial Electronics*, *64*(10), 8193-8205.

[2] Avenas, Y., Dupont, L., & Khatir, Z. (2011). Temperature measurement of power semiconductor devices by thermo-sensitive electrical parameters—A review. *IEEE transactions on power electronics*, *27*(6), 3081-3092.

[3] Brandelero, J., Ewanchuk, J., & Mollov, S. (2016, June). Online junction temperature measurements for power cycling power modules with high switching frequencies. In *2016 28th International Symposium on Power Semiconductor Devices and ICs (ISPSD)* (pp. 191-194). IEEE.

[4] Funaki, T., & Fukunaga, S. (2016, September). Difficulties in characterizing transient thermal resistance of SiC MOSFETs. In *2016 22nd International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)* (pp. 141-146). IEEE.

[5] Kato, F., Tanisawa, H., Koui, K., Sato, S., Aoki, T., Murakami, Y., ... & Sato, H. (2017, September). Effect of forward voltage change depending on gate voltage in body diode of SiC-MOSFET at thermal transient testing for analysing SiC power module package. In *2017 23rd International Workshop on Thermal Investigations of ICs and Systems (THERMINIC)* (pp. 1-4). IEEE.

[6] Pala, V., Van Brunt, E., Ryu, S. H., Hull, B., Allen, S., Palmour, J., & Hefner, A. (2016, June). Physics of bipolar, unipolar and intermediate conduction modes in Silicon Carbide MOSFET body diodes. In *2016 28th International Symposium on Power Semiconductor Devices and ICs (ISPSD)* (pp. 227-230). IEEE.

[7] Huerner, A., Heckel, T., Endruschat, A., Erlbacher, T., Bauer, A., & Frey, L. (2018). Analytical model for the influence of the gate-voltage on the forward conduction properties of the body-diode in SiC-MOSFETs. In *Materials Science Forum* (Vol. 924, pp. 901-904). Trans Tech Publications Ltd.