



HAL
open science

SiC power devices operation from cryogenic to high temperature: investigation of various 1.2kV SiC power devices

T Chailloux, C Calvez, N Thierry-Jebaly, D. Tournier, Dominique Planson

► **To cite this version:**

T Chailloux, C Calvez, N Thierry-Jebaly, D. Tournier, Dominique Planson. SiC power devices operation from cryogenic to high temperature: investigation of various 1.2kV SiC power devices. International Conference on Silicon Carbide and Related Materials (ICSCRM) 2013, Sep 2013, Miyazaki, Japan. pp.1122-1125, 10.4028/www.scientific.net/MSF.778-780.1122 . hal-04169013

HAL Id: hal-04169013

<https://hal.science/hal-04169013>

Submitted on 23 Jul 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

SiC power devices operation from cryogenic to high temperature: investigation of various 1.2kV SiC power devices.

T. Chailloux¹⁾, C. Calvez¹⁾, N. Thierry-Jebaly¹⁾, D. Tournier¹⁾ D. Planson¹⁾,

¹⁾ First affiliation with address, Country

E-mail: dominique.tournier@insa-lyon.fr (corresponding author)

Silicon has long been the dominant semiconductor for high-voltage power applications. Thanks to the significant achievements in SiC technology, (bulk material growth and in SiC device processing), this semiconductor has reached a maturity level confirmed by recent reliability studies performed on both rectifiers [1] and switches (JFETs [2], MOSFETs [3] and BJTs [4]). In most cases, high voltage, high current and high temperature capabilities of SiC based devices has been proved [1,2], the maximum temperature limit being in the range of 175°C up to 250°C. *Previously, operation of 4H-SiC VJFETs has been demonstrated at junction temperatures over 300°C (1) and shown promise under high radiation (2). Performance of the 4H-SiC bipolar junction transistor at 100K has been also studied (3).* Among those studies, a very few are targeting temperature lower than 77°C (military specifications). For more critical ambient temperature (i.e. aerospace or cryogenic applications), [Cheng-2005, ISPSD] has reported the high temperature and cryogenic operation of VJFET.

In this work, we propose to investigate both high temperature and cryogenic operation of various SiC power devices commercially available with a maturity level better than devices used for previous investigations. Static and dynamic characterizations have been performed from 100K to 525K on a 20mOhm 1.2kV JFET, MOSFET, BJT. A cryogenic chamber has been used for low temperature range (100K-250K) characterization, and an air conditioner for the upper range (from 200K up to 525K), associated to an Agilent Curve tracer (B1505) to extract the power devices key parameters (R_{ON} , V_{TH} , I_{LEAK}). The specific on-resistance of a power switch is a key parameter to focus on in order to be able to calculate the power losses in an inverter leg for example. Its variation versus temperature is related to several physical phenomena, linked to the unipolar/bipolar operation mode of the analyzed devices.

For the unipolar devices, like normally-on JFETs, the ionization temperature of the free nitrogen donors must be considered [J. Pernot]. At temperature above xxx K, we could consider that the nitrogen donors ionization level is at its maximum. The specific on resistance being thus only dependent on the electron mobility [5] $\mu = \mu_0 (T/T_0)^{-2.1}$. Lowering the temperature below 300K, closed to the carrier freezeout one ($T < 100K$), imply a competition between acceptor and donor ionization rates, mobility dependence being then mostly alike $(T/T_0)^{-1.5}$. As a consequence, the JFET channel could then be fully depleted, i.e. the devices to switch from a normally-on behavior to a normally-off one. For the numerous measured JFETs (from Infineon and Semisouth), the on-resistance factor is about 2 (Fig. 1-left). Threshold voltage has also been extracted and the pinch-off is reduced from -3V at 300K to -1.5V at 80K (Fig. 1-right). Such quantifications are critical to define properly both a converter and driver topologies.

Concerning MOSFETs devices, the on-resistance is driven by both the epitaxial layer contribution and the inversion channel contribution. The channel mobility is strongly affected by the quality of the field-oxide/SiC interface state density. Two devices have been characterized: a CREE MOSFET and a SiC-Accumosfet. For gate bias $V_{GS} > 15V$, the On-resistance is almost stable as inferred on Fig.2-left.

Focusing on SiC BJTs, additional factors are impacting the on resistance: the carrier lifetime, the recombination rate and the traps defects activation. Both on-resistance 70mOhm@80K 50mOhm@300K, and current gain have been measured $\beta_{300k} = 80$ while $\beta_{80K} = 200$.

From table 1, we can conclude that all devices can operate over this temperature range without dramatic changes in their key parameters. Furthermore, we do not have observed any freezeout phenomena, as the temperature measurement has been experimentally limited to 100K. Apart packaging considerations and reliability issues, we can conclude that all SiC power devices are able to operate at low and high temperature.

The final paper will present additional electrical characterization results over the wide temperature range as well as time dependence evolutions in order to conclude on their best operability conditions over such a wide temperature range.

Table I. SiC power devices key parameters extracted at various temperatures.

Device	Ron@300K (mOhm)	Key parameters				
		Ron@100K (mOhm)	Ron@500K (mOhm)	I _{OFF} @100K (uA)	I _{OFF} @500K (uA)	Gain, V _{TH} (V) (100K/300K)
JFET-Non				2	-4 V / -3 V	4
JFET-Noff				6	+ 2.5 V	8
MOSFET					20 V	
BJT					170 / 80	
AccuMOSFET					-	

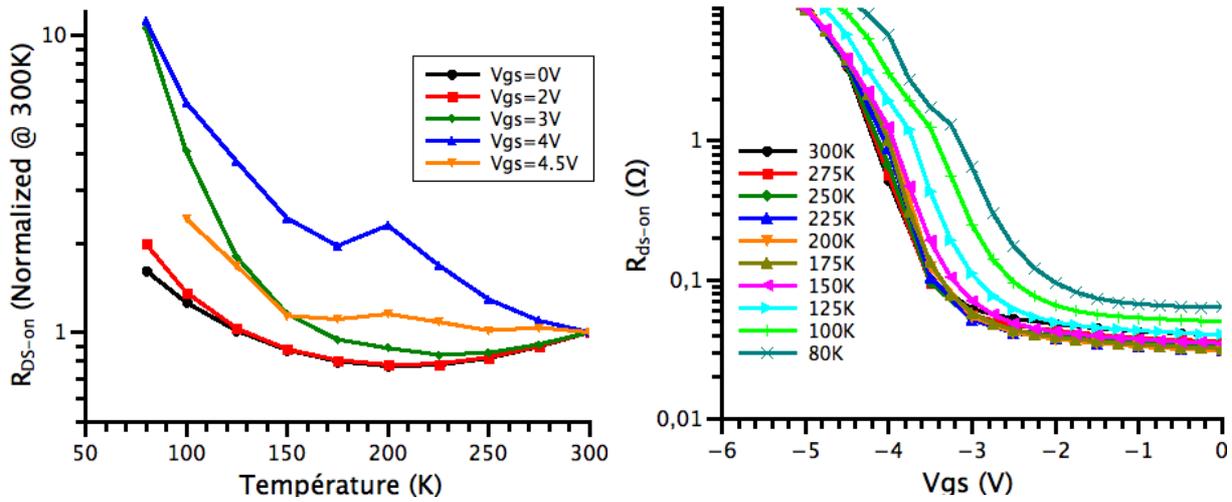


Fig. 1. Left : normally-on JFET on-resistance dependence on temperature (normalized to 300K); Right : on resistance variation versus gate reverse bias (illustrating pinch-off voltage reduction while lowering temperature).

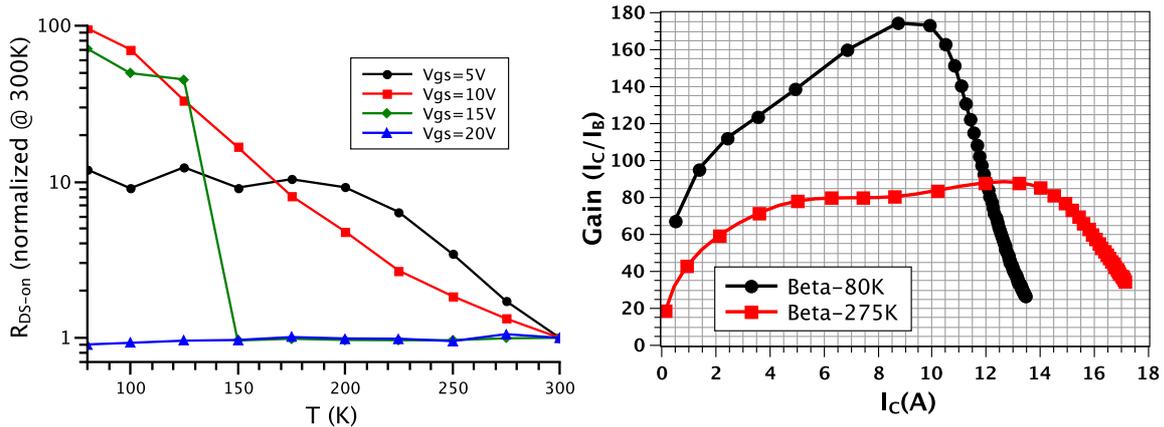


Fig. 2. Left : MOSFET on-resistance dependence on temperature (normalized to 300K) versus gate forward bias illustrating inversion channel impact on the threshold voltage while lowering temperature. Right : BJT gain dependence on collector current at low (80K) and room temperature.

(1) J. Merrett, W. Draper, J.R.B. Casady, J. B. Casady, I. Sankin, R. Kelley, V. Bondarenko, M. Mazzola, D. Seale, "SiC VJFETs Operated at Junction Temperatures Exceeding 300 °C," *Proceedings of IMAPS International Conference and Exhibition on High Temperature Electronics (HiTEC 2004)*, May 17-20, 2004, Santa Fe, NM, USA.

(2) J. N. Merrett, J.R. Williams, J.D. Cressler, A. Sutton, L. Cheng, V. Bondarenko, I. Sankin, D. Seale, M.S. Mazzola, B. Krishnan, Y.Koshka, and J.B. Casady, "Gamma and Proton Irradiation Effects on 4H-SiC Depletion-Mode Trench JFETs"

presented in 5th European Conference on Silicon Carbide and Related Materials (ECSCRM2004), Aug. 31-Sept. 4, 2004, Bologna, Italy.

(3) S. Balachandran, T. P. Chow, and A. Agarwal, "Low and High Temperature Performance of 600V 4H-SiC Epitaxial Emitter BJTs," presented in 5th European Conference on Silicon Carbide and Related Materials (ECSCRM2004), Aug. 31-Sept. 4, 2004, Bologna, Italy.

(4) J. Pernot, S. Contreras, J. Camassel, and J. L. Robert, W. Zawadzki, E. Neyret, L. Di Cioccio, "Free electron density and mobility in highquality 4H-SiC," *App. Phys. Let.*, v 77, No 26, Dec. 25, 2000.

- [1] R. Green, A. Lelis, and D. Habersat. Application of reliability test standards to SiC power MOSFETs. In Reliability Physics Symposium (IRPS), 2011 IEEE International, pages EX.2.1 – EX.2.9, april 2011.
- [2] Aivars J. Lelis, Daniel Habersat, Ronald Green, Aderinto Ogunniyi, Moshe Gurfinkel, John Suehle, and Neil Goldsman, Time Dependence of Bias-Stress-Induced SiC MOSFET Threshold-Voltage Instability Measurements, IEEE Transaction On Electron Devices, VOL. 55, NO. 8, AUGUST 2008
- [3] Martin Le-Huu, Holger Schmitt, Stefan Noll, Michael Grieb, Frederik F. Schrey, Anton J. Bauer, Lothar Frey, Heiner Ryssel, Investigation of the reliability of 4H-SiC MOS devices for high temperature applications, *Microelectronics Reliability* 51 (2011) 1346–1350
- [4] A Study on Pre-Oxidation Nitrogen Implantation for the Improvement of Channel Mobility in 4H-SiC MOSFETs, IEEE Transaction On Electron Devices, VOL. 57, NO. 6, JUNE 2010
- [5] Reza Ghandi. Fabrication Technology for Efficient High Power Silicon Carbide Bipolar Junction Transistors. PhD thesis, KTH, Integrated Devices and Circuits, 2011. QC 20110216.

From our characterization results analysis and TCAD simulations, a another point could also affect the ability of a power device to operate at high temperature: the elementary cell power density value. Indeed it seems, from our investigations, that the self-heating temperature increase induced closed to the channel could be enough to cause the device to operate at higher temperature that the cryogenic one in it's active area, while the elementary cell size is relatively low. This is inferred from comparison of Infineon and Semisouth normally-on devices.