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Transient junction temperature measurement error of SiC MOSFETs in power cycling – Influence of cryogenic temperatures

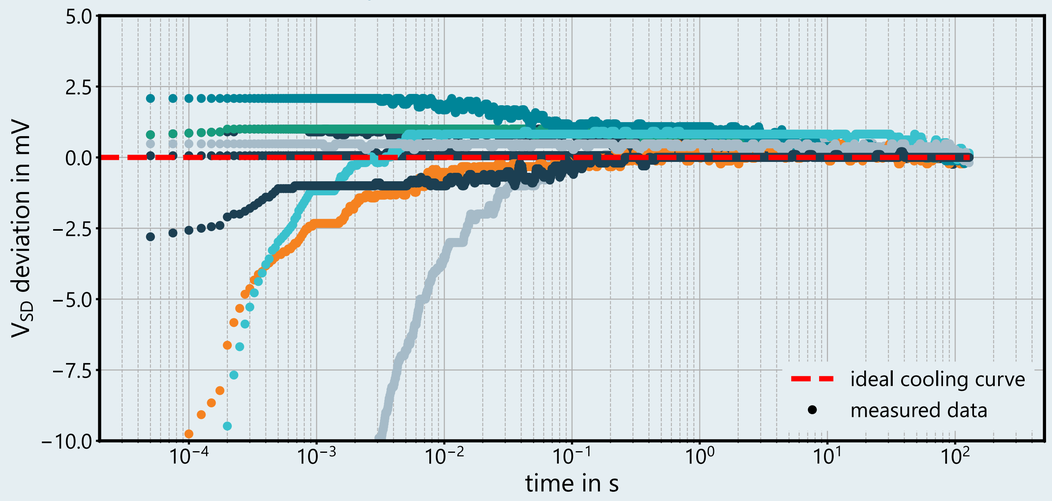
Lukas Farnbacher[1], Jakob Breuer[1], Fabian Dresel[1], Jürgen Leib[1], Bernd Eckardt[1]

lukas.farnbacher@iisb.fraunhofer.de

[1] Fraunhofer Institute for Integrated Systems and Device Technology IISB, Schottkystraße 10, Germany

Motivation

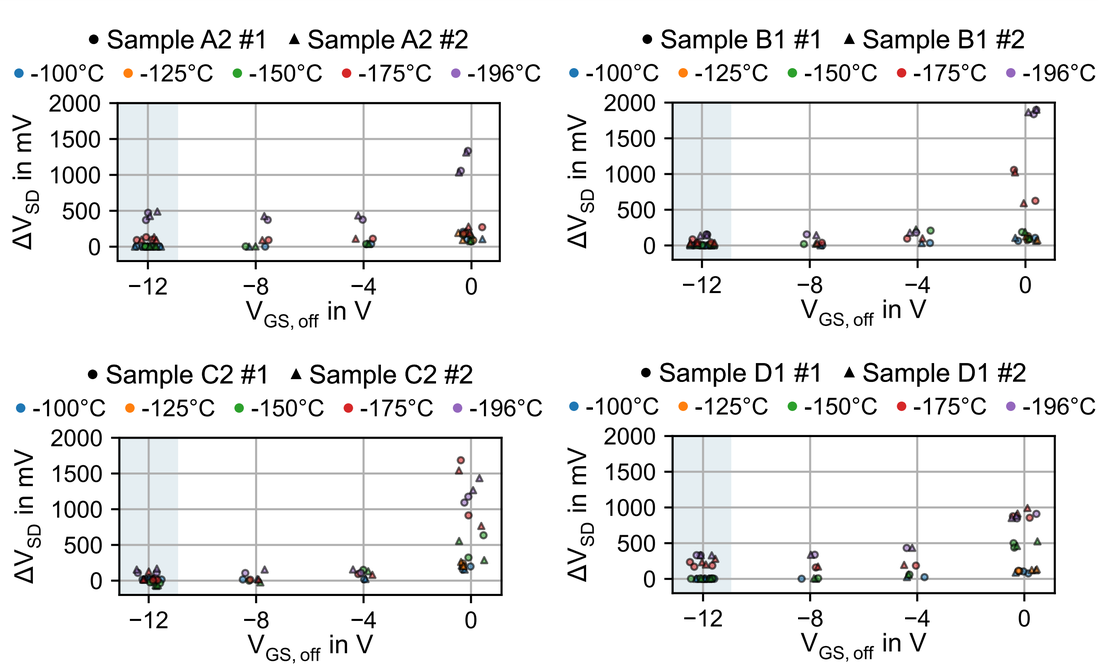
For active power cycling tests (PCT) of SiC MOSFETs, the body diodes forward voltage V_{SD} is used as a temperature sensitive electrical parameter (TSEP). Advanced SiC MOSFETs from several manufactures show a transient response of V_{SD} after a gate bias switch, although a constant temperature is present. Using conventional static temperature calibration, this effect leads to a calculation error of T_{vj} in the range of 10 K close to the beginning of the cooling phase. As a critical parameter in PCT, this value lies outside the *AQG 324* specification [1] and might lead to an overestimation in lifetime prediction.



V_{SD} vs. time after gate bias switch of recent SiC MOSFETs from ten different manufactures at constant temperature

Experiment

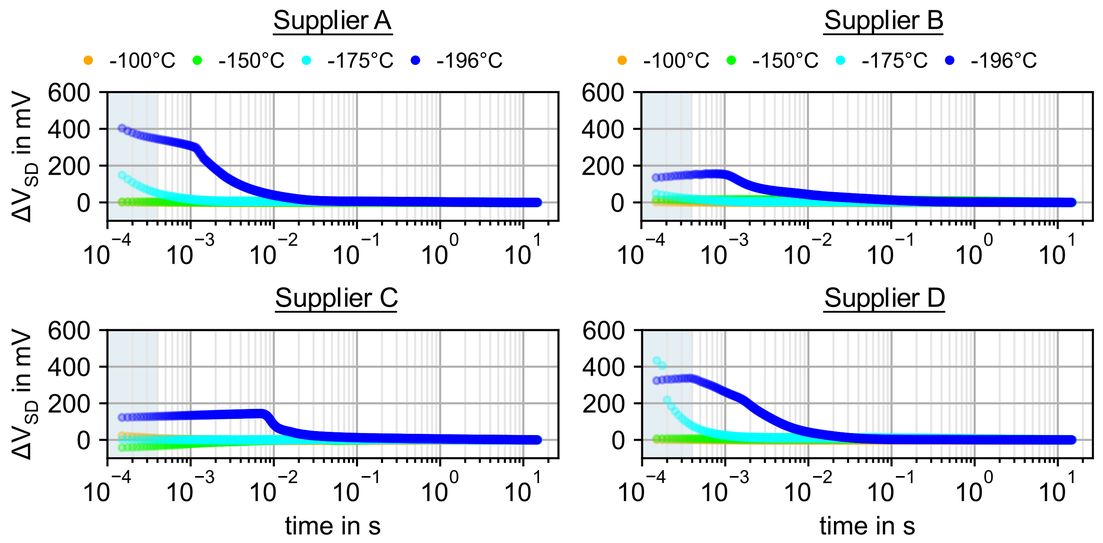
- Goal: Extend temperature range of previous studies [2-4] down to -196°C for four different manufacturers
- Measurement process:
  - Tempering DUTs at negative temperatures with specialized setup [5]
  - Constant measurement current through MOSFET in reverse
  - Gate switched from on-state to off-state with different $V_{GS,off}$
  - Monitoring of V_{SD} used for virtual temperature measurement at $V_{GS,off}$



Relative transient shift of V_{SD} (ΔV_{SD}) at different $V_{GS,off}$ and different temperatures for the examined suppliers; Measurement points are scattered around the $V_{GS,off}$ values for better visibility

Results

- Temperatures above -150°C: dynamic effect disappears with increasingly negative gate voltage for Suppliers A,B and D; for supplier C the dynamic effect gets reduced but does not disappear
- Temperatures below -175°C: all devices show a dynamic effect with different shapes per manufacturer – indicating a design dependent behavior

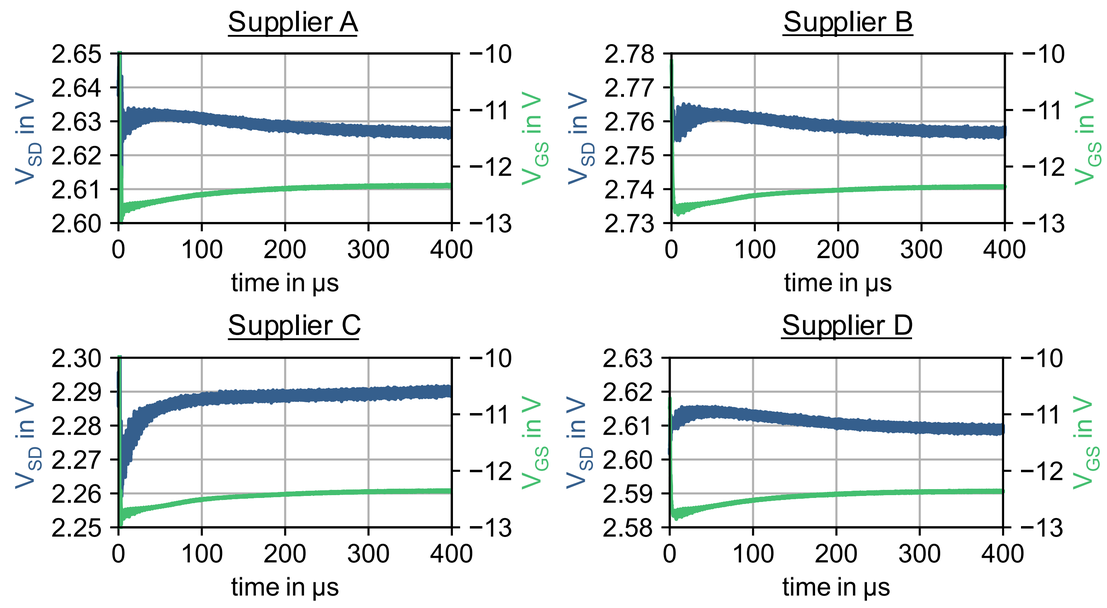


Transient shift of V_{SD} (ΔV_{SD}) after switching the gate to -12 V for 15 s from 16 V for 3 s with I_{meas} of 30 mA at different temperatures for the investigated suppliers; Exemplary curves of one device

- Measurement current gets reduced for supplier B from -175°C, for C and D at -196°C while supplier A shows no reduction in measurement current
- Reduction of measurement current indicating carrier freeze out in the body diode structure and voltage limitations of the test system [6]

Measurement close to gate switching at room temperature

Supplier C shows a dynamic effect different from the other suppliers.



Transient behavior of V_{SD} after switching the gate to -12 V for 15 s from 16 V for 3 s with I_{meas} of 30 mA in the first 400 µs

Conclusion

- Change in dynamic effect at cryogenic temperatures
- Carrier freeze out likely impacting dynamic behavior at temperatures below -150°C

[1] *ECPE Guideline AQG 324: Qualification of Power Modules for Use in Power Electronics Converter Units in Motor Vehicles*, 03.1/2021, ECPE European Center for Power Electronics e.V., May. 2021
[2] J. Breuer, F. Dresel, A. Schletz, J. Klier, J. Leib, and B. Eckardt, "Transient junction temperature measurement error of SiC MOSFETs in power cycling – Influence of gate voltage," in 35th European Symposium on Reliability of Electron Devices, Failure Physics and Analysis, Parma, 2024
[3] J. Breuer, F. Dresel, A. Schletz, J. Leib, B. Eckardt, and M. März, "Dynamic Calibration of Junction Temeperature of SiC MOSFETs for Power Cycling," in 2024 IEEE 10th Electronics System-Integration Technology Conference (ESTC), Berlin, Germany, 2024, pp. 1–6.
[4] J. Breuer et al., "Challenges of Junction Temperature Calibration of SiC MOSFETs for Power Cycling – a Dynamic Approach," in CIPS 2024 - 13th International Conference on Integrated Power Electronics Systems, Düsseldorf, 2024, pp. 239–245.
[5] S. Büttner, J. Windisch, and M. März, "Design and Operation of a Cost-Effective Cooling Chamber for Testing Power Electronics at Cryogenic Temperatures," IEEE Instrum. Meas. Mag., vol. 26, no. 3, pp. 46–51, 2023, doi: 10.1109/MIM.2023.10121411
[6] P. M. Gammon et al., "The Cryogenic Testing and Characterisation of SiC Diodes," MSF, 778-780, pp. 863–866, 2014, doi: 10.4028/www.scientific.net/MSF.778-780.863.

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