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Performance Characteristics and Applications for Second Generation SiC Power MOSFETs

John W. Palmour, Brett Hull, Don Gajewski, Lin Cheng, Jimmy Liu, and Scott T Allen

Cree, Inc.
4600 Silicon Drive
Durham, NC 27703, USA
Phone: +1-919-407-5646 E-mail: john_palmour@cree.com

Abstract

Second Generation SiC MOSFETs have been released this year by Cree, Inc. which have improved switching characteristics and smaller die size than the first generation devices. These devices have a projected lifetime exceeding 1 million hours at a rated temperature of 150°C. Large chips capable of 50 Amps have also been released, rated at both 1200 V and 1700V, which are targeted for use in power modules.

1. Introduction

After many years of research, the first commercially viable SiC MOSFETs were broadly released in January of 2011 [1]. While these devices marked a significant milestone for SiC, there was still substantial performance improvements and cost reductions to be made. After two years of development, Cree's second generation SiC MOSFETs were released, which have both improved switching performance and reduced cost over the earlier generation. Through improvements in device design and layout, similar amperage could be derived from a chip that is 35% less in area. This resulted in lower parasitic capacitance and improved switching losses, as well as a substantial reduction in price. A similar design was adapted to a new line of 1700 V MOSFETs that were also introduced.

2. Generation 2 SiC MOSFET Characteristics

Cree, Inc.'s recently released 1200 V and 1700 V SiC MOSFETs were designed to enable the development of all-SiC power modules that could be used for a variety of applications. The design of these devices builds on the planar double implanted DMOS structure that was used in the Gen 1 devices, and is shown in Fig. 1. Fig. 2 shows the I-V characteristics of the 1200 V / 50 A MOSFET at 25°C with V_{GS} ranging from 10V to 20V. At 50 A, the V_{DS} is 1.4 V, resulting in an on-resistance ($R_{DS(on)}$) of 28 mΩ. The MOSFET active area is 0.179 cm^2, providing a specific on-resistance ($R_{on,sp}$) of 5 $m\Omega{\cdot}cm^2$. The $R_{DS(on)}$ increases to 40 mΩ with a temperature increase to 150°C. The leakage current is less than 1 μA at 1200 V at 25°C.

In the past, there was concern that oxides on SiC could not be made reliable. However, these problems have been overcome in recent years. There are two high field directions of concern. The first would be the high electric field that the oxide is exposed to in the blocking state. Accelerated lifetime testing was performed on the Gen 2 MOSFETs at electric fields far exceeding the ratings of these devices so that lifetime at lower biases could be extrapolated. Figure 3 shows the median lifetime at a variety of voltages very close to avalanche for the Gen 2 MOSFETs at a rated temperature of 150°C. One can see that under a nominal line voltage use of 960V, the devices would have a MTTF of $3x10^6$ hours. The other area of concern would be when the MOSFET is fully biased on with V_g=+20V. This was evaluated by performing time dependent dielectric breakdown (TDDB) testing on fully processed 80 mΩ Gen 2 1200 V MOSFETs. The results, shown in Fig. 4, show that the oxide MTTF in this bias direction is more than $8x10^6$ hours with V_g = +20V at a rated temperature of 150°C.

Switching tests performed on the 1200V, 50 A MOSFET in a clamped inductive load switching circuit, with V_{DD} = 800V, $V_{GS,on/off}$ = 20 V/-2 V, I_D = 50 A, $R_{G(ext)}$ = 3.8 Ω, and L = 856 mH, show the total switching energy is 2.23 mJ.

Similar I-V characteristics are observed for the 1700 V / 50 A SiC MOSFET. The $R_{DS(on)}$ is 40 mΩ at 25°C with V_{GS} at 20V, and increases to 80 mΩ at 150°C. The MOSFET active area is 0.211 cm^2, providing a $R_{on,sp}$ of 8.45 $m\Omega{\cdot}cm^2$ at 25°C. The total switching energy in a clamped inductive load switching circuit with V_{DD} = 1000V, $V_{GS,on/off}$ = 20 V/-2 V, I_D = 50 A is 3.1 mJ.

All-SiC power modules based on combining Gen 2 SiC MOSFETs and SiC Schottky diodes have also been released. In May of 2013, Cree introduced the first fully qualified All-SiC three-phase "six-pack" module, rated at 1200V and 50 A [3]. This module is targeted for use in next generation industrial motor drives and has an industry standard 45mm footprint.

3. Circuit Demonstration

A 100 kHz, 10kW interleaved Boost converter design was designed that clearly demonstrates the advantages of using full SiC devices (MOSFET+diode) in high power systems. Figure 5 shows the efficiency of the 10 kW boost inverter using a Gen 2 1200 V SiC MOSFET operating at 100 kHz, versus the same circuit operating at a much lower frequency of 20 kHz using a similarly rated Silicon IGBT.

This curve clearly shows that the SiC version is significantly more efficient throughout the entire power sweep for the SiC, despite the fact that it is operating at 5 times the frequency. This higher operating frequency will allow a large reduction in the size and cost of the magnetics and heat sink for such a boost converter over the silicon counterpart.

3. Conclusions

Second generation SiC MOSFETs rated for 50 A at both 1200V and 1700V have been introduced. This generation represents a 35% die shrink from the first generation and results in a 30% reduction in switching losses and a large reduction in cost. These devices also show excellent reliability characteristics, with a MTTF well above $1\text{x}10^6$ hours at 150°C. An all-SiC Three-Phase module has also been released based on this technology. These devices enable higher efficiency to be achieved even when operating at five times higher frequencies than what is feasible for Silicon IGBTs.

Acknowledgements

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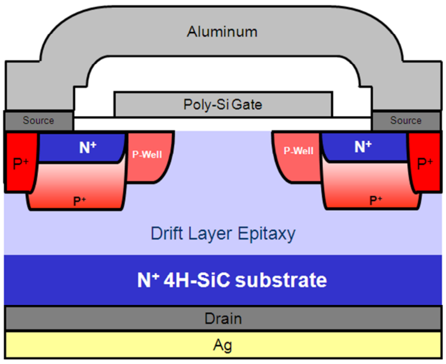

Fig. 1. Schematic cross section of Cree, Inc. vertical DMOSFET Generation 2 device.

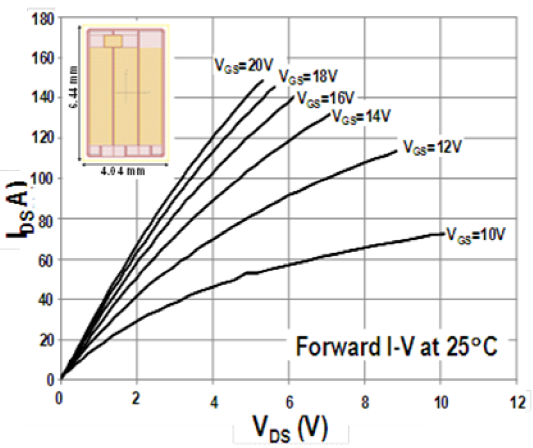

Fig 2. Forward I-V curves for commercial 2nd Generation 1200 V, 50 A SiC MOSFET

References

[1] www.cree.com/news-and-events/cree-news/press-releases/2011/january/110117-mosfet

[2] J. Liu, K.L. Wong, and P. Kierstead, *Proceedings of Power Control & Intelligent Motion (PCIM)* (2013).

[3] www.cree.com/news-and-events/cree-news/press-releases/2013/may/power-6pack-module

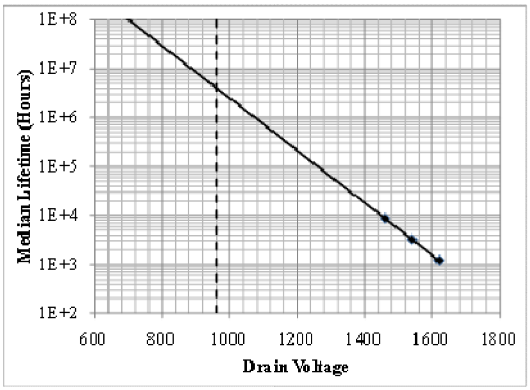

Fig. 3. ALT-HTRB results at 150°C on Generation 2, 1200 V devices. Data points obtained by fitting all lifetime data, including right-censored points. Dashed line: 960 V fiducial, for reference.

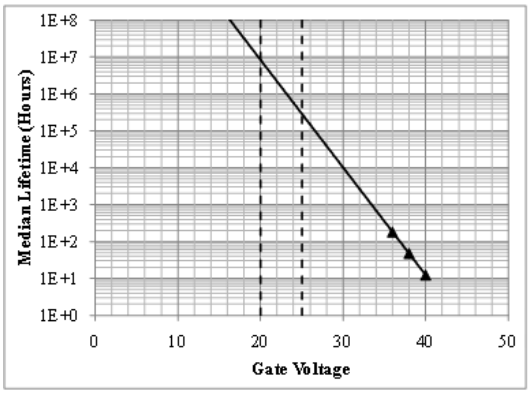

Fig. 4. TDDB results at 150°C on Generation 2, 1200 V devices. Data points obtained by fitting all lifetime data, including right-censored points. Dashed lines: 20 V and 25 V, for reference.

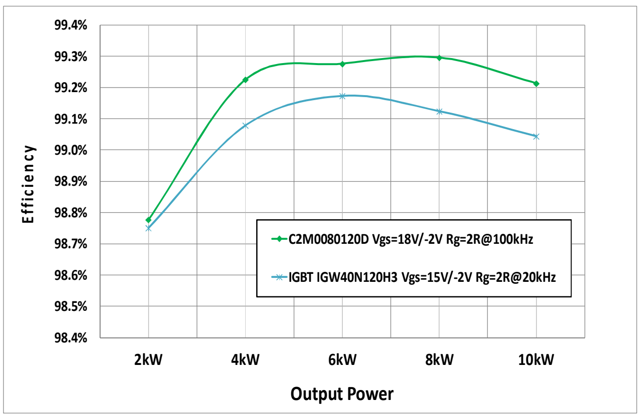

Fig. 5. Comparison of Gen 2 1200 V 80 mΩ SiC MOSFET operating at 100 kHz vs Si IGBT operating at 20 kHz in a 10 kW Boost Converter [2].