Happenings

by J. Christopher Dries

SiC Research and Development at United Silicon Carbide Inc.—Looking Beyond 650–1,200-V Diodes and Transistors

For over a decade now, silicon carbide (SiC) Schottky diodes have been used in myriad high-performance power-conversion applications. Currently, the largest among these applications is power factor correction utilizing 650-V SiC Schottky diodes. The introduction of SiC transistor offerings at 1,200 V, beginning in 2010 with junction field-effect transistors (JFETs) and followed by SiC metal–oxide–semiconductor field-effect transistors (MOSFETs) and bipolar junction transistors in subsequent years, is simply the beginning of a wave of commercial devices of increasingly high voltage and current ratings. In this column, we describe the direction that United Silicon Carbide Inc. (USCi) is taking in advancing the state of the art of SiC devices following the introduction of our suite of 650- and 1,200-V diodes and JFETs to the marketplace in early 2014.

First and foremost is the development of normally OFF switch solutions utilizing a low-voltage MOSFET cascoded with 1,200-V normally ON JFETs, which are currently in production. The vertical-trench JFET technology presently provides the lowest drain source resistance-area product (Rds*A) in the world and results in an optimal cost solution switch for this voltage node. The specially designed low-voltage MOSFET eliminates the need for an additional SiC antiparallel diode. Customers are familiar with various cascode solutions, including Infineon's Cascode Light, which works equally well with USCi's JFETs as well as cascode solutions from a number of gallium nitride (GaN) companies. As voltage ratings go up, however, the channel contribution to the overall device resistance becomes negligible, so we have primarily implemented normally OFF designs at higher voltages, as discussed in the next section. The lone exception to this approach is the supercascode, which will be discussed in its own section.

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Higher Voltages

The 650-V node is often described by those in the wide-bandgap community as the battleground between GaN and SiC. Very few in this same community argue the advantages of SiC at voltages greater than 1,200 V. The performance most enjoyed by SiC, particularly against very high-voltage silicon insulated-gate bipolar transistors (IGBTs), such as those at 6.5 kV, is simply too great to ignore. To that end, USCi has spent the last several years extending our diode and JFET technologies up to 6.5 kV and beyond.

USCi recently developed enhancement-mode 6.5-kV JFETs rated for 15 A with matching Schottky diodes. The dies are 6 mm $\times$ 6 mm and packaged in a 60-A half-bridge module in collaboration with Powerex. Smaller, 15-A modules have been developed in collaboration with Arkansas Power Electronics International. Both solutions operate at temperatures up to 200 °C. The half-bridge is designed to work at 20 kHz, a switching frequency far beyond that at which silicon IGBTs could be expected to operate with reasonable switching losses. Applications for these devices range from traction drives to direct grid-tie inverter solutions. Figure 1 shows the 6.5-kV JFET alongside the 60-A half-bridge module.

USCi is currently in the process of expanding the voltage range of the Schottky diode and JFET product lines at the 1.7-, 3.3-, and 4.5-kV nodes, having successfully demonstrated these devices at 6.5 kV. Our current maximum die size is 8 mm $\times$ 8 mm, but as substrate and epitaxy improve over time, we expect reasonable process yields can be achieved on devices >1 cm^2 in the not too distant future.

Supercascode for High Voltages

As SiC devices push further up in voltage, particularly higher than 6.5 kV, epitaxy costs become a significant driver of the total costs (Figure 2). Several other groups [1] have explored solutions to this problem that stacks multiple 1,200-V normally ON JFETs in series with a low-voltage MOSFET to form the normally OFF supercascode. While care must be taken to ensure a proper voltage sharing among the JFETs in the stack, it is a resolved problem. We are currently exploring these devices as lower-cost alternatives to monolithic high-voltage chips. Figure 3 sheds some light on the performance of the supercascode alternative.

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FIG 1 The 6.5-kV enhancement-mode JFET and 60-A, 20-kHz half-bridge module with $T_{max} = 200$ °C. (Image used with permission from USCi.)

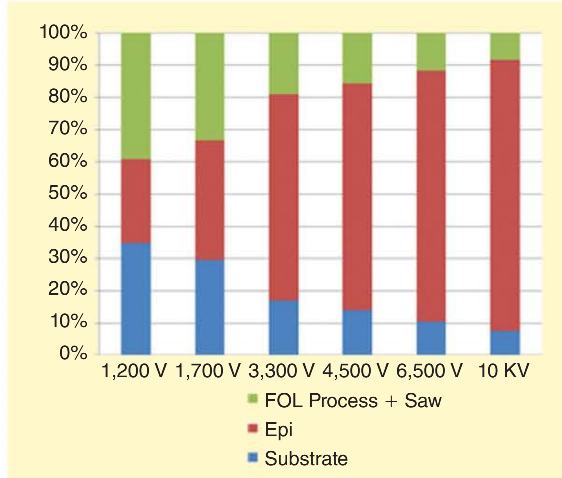
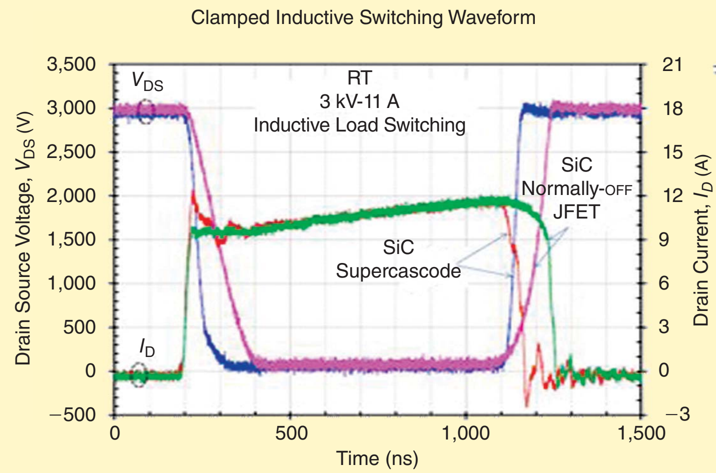
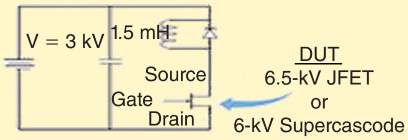


FIG 2 The cost breakdown of high-voltage SiC power devices. (Image used with permission from USCi.)

IGBTs at 10–20 kV

Bipolar devices have been an area of intense research and development within the SIC community for many years. However, concerns regarding device reliability and assuring that devices will not degrade due to basal plane defect propagation have limited their adoption. Nevertheless, it is clear that they will play an important role in delivering lower ON-resistance devices. This is particularly true in very high-voltage devices (>10 kV) as the drift layer resistance dominates the device ON-resistance. To reduce this resistance,





Parameter	6.5-kV JFET	Supercascode
Rise Time, t_r (ns)	149	67
Fall Time, t_f (ns)	99	35
E_{On} (mJ)	2.71	1.25
E_{Off} (mJ)	1.54	0.53

FIG 3 The switching performance of an SiC-based 6-kV supercascode transistor versus a 6.5-kV JFET.

conductivity modulation through bipolar injection becomes a necessity for devices of any reasonable die size and current rating. At USCi, we have focused on IGBTs for voltage ratings >10 kV. Techniques for improving the mobility and stability of the SiC–MOS interface, while not perfect, are suitable for high-voltage devices where channel resistance is not particularly important. At USCi, we are currently implementing split gate device structures in conjunction with unique field stop architectures to access the 10–20-kV voltage range.

Circuit Breakers

While power electronics engineers would generally prefer not to use normally-ON device architectures, a normally-ON device is an ideal solution for solid-state circuit breaker and disconnect applications. A number of groups have explored JFETs for use in the applications with excellent results, and, at USCi, we have developed significant competence in designing these devices for protection applications and surge waveform characteristics. Various topologies can be implemented that are both bidirectional and self-powered [2].

High-Temperature Integrated Circuits

Finally, while not necessarily geared for power applications, USCi has developed a number of unique high-temperature integrated circuit designs over the last several years using our SiC JFET processes. The devices we have developed include operational amplifiers, voltage references, temperature sensor circuits, and all SiC gate drivers. We are currently developing a process design kit that our customers may use to expand the use and ease the development of circuits in this process.

As demonstrations of the superior performance of SiC devices compared with IGBTs at high voltages continue to multiply, SiC devices are poised to address the applications that demand maximum efficiency, minimum size, and the highest performance.

About the Author

J. Christopher Dries is the president and chief executive officer of United Silicon Carbide, Inc. He received his M.A. and Ph.D. degrees in electrical engineering from Princeton University. From 2002 until 2007, he managed all research and new product development at Sensors Unlimited, where he developed a product line of avalanche photodiodes that are used in applications ranging from high data-rate telecommunications applications to focal plane arrays for three-dimensional imaging. After leaving Sensors Unlimited, he cofounded and served as the managing partner of DOLCE Technologies, which provides capital and advisory services to early stage technology businesses. The partners of DOLCE Technologies are the principal investors in United Silicon Carbide. In addition, he serves on the Princeton Graduate School Leadership Council, the Princeton Electrical Engineering Department Advisory Board, and the Duke University Engineering School Board of Visitors.

References

[1] J. Biela, D. Aggeler, D. Bortis, and J. W. Kolar, "Balancing circuit for a 5-kV/50-ns pulsed-power switch based on SiC-JFET super cascode," *IEEE Trans. Plasma Sci.*, vol. 40, no. 10, pp. 2554–2560, 2012.

[2] Z. Miao, G. Sabui, A. Chen, Y. Li, Z. J. Shen, J. Wang, Z. Shuai, A. Luo, X. Yin, and M. Jiang, "A self-powered ultra-fast DC solid state circuit breaker using a normally-on SiC JFET," in *Proc. IEEE Applied Power Electronics Conf. Expo.*, 2015.

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an investment in a hopeless application, it also allows the disclosure and claims to be prepared to maximize the chances of having the patent examiner rule that the invention is new and not obvious. In addition, prefiling searches sometimes locate active patents that must be considered when determining if a new product can be marketed without being accused of patent infringement.

About the Author

Art MacCord (amaccord@maccord-mason.com) has practiced patent, trademark, copyright, and trade-secret law for over 35 years and is a graduate of the University of Virginia and George Washington University Law School. He currently practices with MacCord Mason PLLC of Greensboro, North Carolina.

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