PS-4-27 (Late News) Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp775-776

High current turn-off capability testing of a 3.3 kV SiC-MOSFET

Kazuto Takao, Tatsunori Sakano, Yusuke Hayashi and Su Hongliang

Toshiba Corporation, Corporate Research & Development Center
1, Komukai-Toshiba-cho, Saiwaiku,
Kawasaki 212-8582, Japan
Phone: +81-44-549-2064 E-mail: kazuto.takao@toshiba.co.jp

Abstract

Turn-off capability of a 3.3 kV SiC-MOSFET has been investigated by experiments and simulations. The maximum turn-off current of 95 A is confirmed for the SiC-MOSFET with the rated current of 5A. The rapid temperature rise starts when the turn-off current density is more than 1800 A/cm^2, and the temperature at the center of the SiC-MOSFET is reaches 2565 K. In this time, since bipolar region is formed inside the SiC-MOSFET, the thermal runaway is occurred.

1. Introduction

High-voltage power devices more than 3.3 kV are key components for high power converters such as electric power, industry and railway systems, and further performance improvement is required. High voltage Si-IGBTs have been widely employed in those application, while high voltage SiC -MOSFETs are expected for realizing low power loss, high speed switching, and high temperature operations.

Safe Operating Area (SOA) of high voltage devices is an important design parameter for high power converters to guarantee robust operations. It is essential to understand the physical phenomena related to the SOA for fully utilizing the potential of high-voltage SiC-MOSFETs [1]-[3].

In this study, the turn-off capability related to reverse blocking SOA (RBSOA) in a 3.3 kV SiC-MOSFET is evaluated experimentally. The maximum turn-off switching current density and device internal temperature distribution are characterized. The thermal instability and failure mechanism at turn-off of the SiC-MOSFET are analyzed using a TCAD simulation.

2. Measurement of turn-off capability of a 3.3 kV SiC-MOSFET

Turn-off capability of 3.3 kV SiC-MOSFETs produced by GeneSiC (3.3 kV, 5 A, GR350MOS33-263) are evaluated in an inductive load chopper circuit. Static I_D-V_{DS} characteristics of five SiC-MOSFET samples (A-E) are shown in Fig. 1. As shown in Fig. 1, although all SiC-MOSFETs show same on resistance R_{on} about 350 mΩ up to the rated current of 5 A. However, every R_{on} increases with increasing drain current I_d. The heat generation due to the R_{on} will have an influence to the turn-off capability.

Fig.2 shows measurement results of high current turn-off waveforms of the 3.3 kV SiC-MOSFET (sample A). In the measurements, the power supply voltage V_{cc} is 1.8 kV. The gate voltage V_g applied to the SiC-MOSFET is -5 V / + 20 V.

When the on-time T_p is in the range from 20 μs to 48 μs,

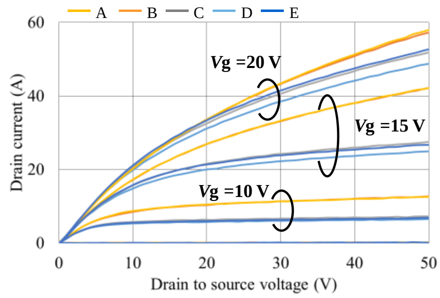

Fig. 1 I_D-V_{DS} characteristics of the 3.3 kV SiC-MOSFET (GR350MOS33-263)

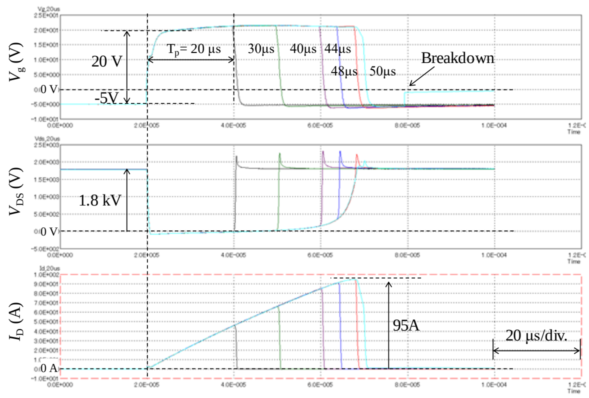

Fig. 2 Experimental results of high current turn-off waveforms of the 3.3 kV SiC-MOSFET (sample A)

the SiC-MOSFET has successfully completed the turn-off operation. According to Fig. 2, the maximum turn-off current is 95 A, and 19 times the turn-off capacity can be confirmed with respect to the rated current of 5 A.

As shown in Fig. 2, the breakdown of the SiC-MOSFET is confirmed when the on-time T_p is 50 μs. The breakdown occurs about 10 μs after the gate voltage V_g changes to -5 V. The gate voltage V_g is changed to 0 V about 10 μs after the gate voltage changes to – 5 V. It is expected that the gate-source is shorted due to the heat generation inside the device.

3. Analysis of the thermal instability of a 3.3kV SiC-MOSFET by TCAD simulations

The internal behavior of the 3.3 kV SiC-MOSFET at the high current turn-off conditions are analyzed using TCAD simulation. Fig. 3 shows the circuit model for analyzing the turn-off capability. A TCAD model of the 3.3 kV SiC-MOSFET is utilized in the simulation, while, an ideal SPICE model of a diode is utilized as a free while diode. The parasitic inductance of 200 nH is installed in the circuit.

Fig. 4 shows the drain voltage V_{DS}, the drain current I_D, and the maximum temperature in the SiC-MOSFET obtained with the TCAD simulation. Fig. 5 shows the time dependence of the temperature distribution in the SiC-MOSFET. It can be seen that the heat generation of the SiC-MOSFET is occurred by the conduction loss and turn-off loss. The rapid temperature rise starts when the turn-off current is around 1800 A/cm^2. In this time, the temperature of the entire device exceeds 2200 K.

In order to analyze the details of the thermal instability in the SiC-MOSFET, the analysis at the breakdown point shown in Fig. 4 is carried out by the TCAD simulation.

Fig. 6 (a) shows the temperature distribution in the SiC-MOSFET at the breakdown point. The temperature at the center of the device is the highest, and it reaches 2565 K. The electron and the hole densities at this time are also shown in Fig. 6 (a). It has been found that the conductivity modulation phenomenon, in which the electron density and the hole density coincide, is generated in the region from the maximum temperature point of the central portion of the device to the upper side of the device. As seen in the figure, the internal temperature of SiC greatly exceeded 1500 K, and the SiC turned into an intrinsic semiconductor. Hence, large amount of hole is generated, and bipolar region is formed. This phenomenon is considered to cause a thermal runaway of the device.

Fig. 6 (b) shows the relationship between drain voltage and drain current. A snapback phenomenon is observed in which the SiC-MOSFET operates in bipolar operation, which indicates that the operation has switched from unipolar operation to bipolar operation.

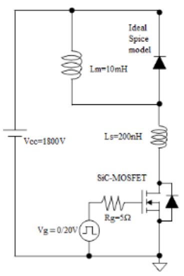

Fig. 3 Circuit model for analyzing the turn-off capability by TCAD simulation

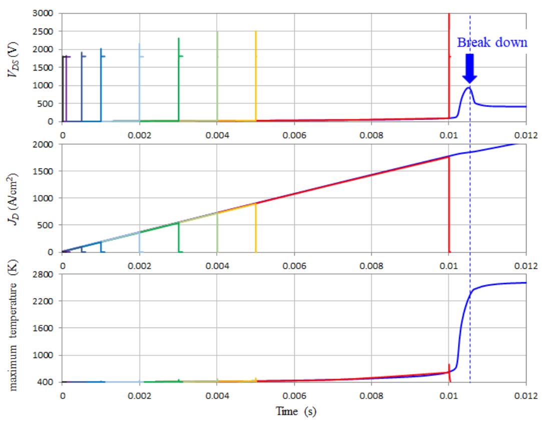

Fig. 4 Simulation results of high current turn-off waveforms of the 3.3 kV SiC-MOSFET

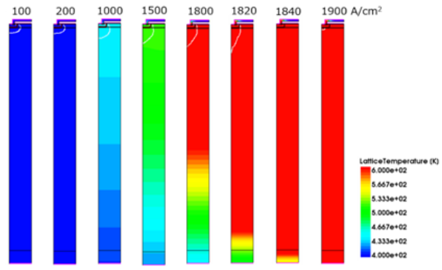

Fig. 5 Time dependence of the temperature distribution in the SiC-MOSFET obtained by the TCAD simulation

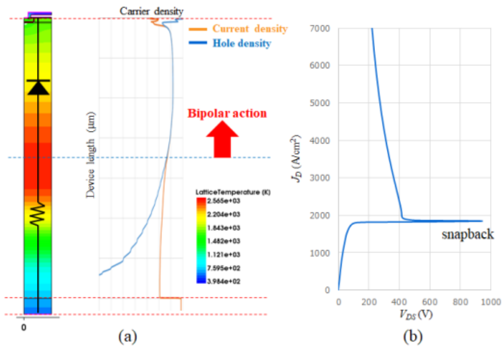

Fig. 6 (a) Temperature distribution in the SiC-MOSFET at the breakdown point, and (b) the relationship between drain voltage and drain current

4. Conclusions

Turn-off characteristics of a 3.3 kV SiC-MOSFET are evaluated. The maximum turn-off current of 95 A is confirmed in the experiment. The breakdown occurs due to the heat generation inside the SiC-MOSFET, and the gate-source is shorted. TCAD analysis shows that the rapid temperature rise starts when the turn-off current is around 1800 A/cm^2. At the breakdown, the temperature at the center of the device reaches 2565 K. Hence, bipolar region is formed inside the SiC-MOSFET, the thermal runaway is occurred.

References

[1] A Castellazzi *et al.*, Microelectronics Reliability **52** (2012) 2414.

[2] A. Fayyaz *et al.*, *European Conference on Power Electronics and Applications* (2013).

[3] M. Imaizumi and N. Miura, IEEE trans. on ED. **62** (2015) 390.