Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp809-810

PS-5-04

Analysis of Dynamic Characteristics of SiC SBD at High Switching Frequency Based on Junction Capacitance

Ryosuke Maeda[1], Takafumi Okuda and Takashi Hikihara

Graduate School of Engineering, Kyoto University
Katsura, Nishikyo, Kyoto 615-8510, Japan
[1]Phone: +81-75-383-2241   E-mail: r-maeda@dove.kuee.kyoto-u.ac.jp

Abstract

This paper focuses on relationships between dynamic characteristics and device structures of SiC SBD to investigate their switching capability. A device model is proposed based on junction capacitance and thermionic emission current. In order to measure the dynamic characteristics of SiC SBD, a high-frequency (10 MHz) and high-voltage (200 V_{pp}) wave generator is fabricated. Comparing simulated results with experimental results, it is found that the proposed model can represent dynamic characteristics at 10 MHz. The proposed device model is beneficial to design power converters in a wide-frequency range.

1. Introduction

Power semiconductor devices are key elements of power converters as switching devices. A wide-band-gap semiconductor such as silicon carbide (SiC) has superior material properties compared to silicon (Si) semiconductor [1–3]. Due to their superior material properties, SiC power devices have advantages such as low on-resistance, fast switching, and high breakdown voltage. SiC Schottky barrier diode (SBD) is one of the most promising power rectifiers, which take a place of conventional Si p-i-n diode [4,5]. 1-kV-class SiC SBD with low on-resistance is now viable for mass production and can significantly reduce switching losses in power converters.

A device model that is applicable to high switching frequency is important to design high-frequency power converters. SiC SBD can operate at a higher switching frequency, but the dynamic characteristics of SiC SBD have not been accurately verified in MHz-class switching. Thus, it is important to establish a device model of SiC SBD for high switching frequency.

Our group has proposed a device model based on junction capacitance [6]. The proposed model was verified at 10 MHz, but the measurement current range was limited below 0.5 A. In this study, we compare the simulated switching waveforms with the experimental switching waveforms to verify the proposed model at 10 MHz switching and 10 A current. As a result, it is found that our proposed model well represents the experimental switching waveforms of SiC SBD.

2. General Instructions

Modeling of SiC SBD

The device model to be used is based on the junction

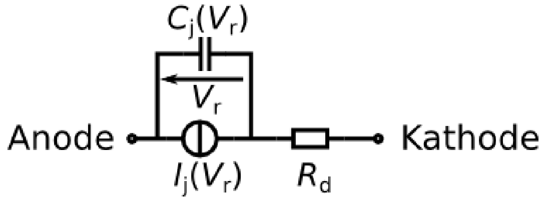


Fig. 1 Equivalent circuit of device modeling for SiC SBD.

capacitance and thermionic emission through the Schottky contact of SiC SBD. The equivalent circuit of the device model is shown in Fig. 1, which is composed of voltage controlled current source $I_j(V_r)$, junction capacitance $C_j(V_r)$, and internal series resistance Rd. Solving Poisson's equation at depletion region, $C_j(V_r)$ is given by eq.(1).

$$C_j(V_r) = S\sqrt{\frac{\varepsilon e N_d}{2(V_d + V_r)}} \quad (1)$$

$I_j(V_r)$, following Thermionic emission model, is given by eq.(2).

$$I_j(V_r) = I_s\left[\exp\left(-\frac{eV_r}{nK_BT}\right) - 1\right] \quad (2)$$

The Schottky diode used in this study is ROHM SCS220AE2 (650 V, 10 A). Device parameters of these equations are extracted by measuring *C-V, I-V* characteristics.

Measurement method

In order to evaluate the dynamic characteristics of SiC SBD, a high-frequency and high-voltage sinusoidal wave generator is fabricated. Figure 2 shows the proposed measurement circuit. This circuit consists of a square wave amplifier using SiC MOSFET (ROHM, SCT2450KE) and a band-pass filter using LC resonant. The proposed circuit can output a 10 MHz, 200 V_{pp} and 200 W sinusoidal wave for 10 μs.

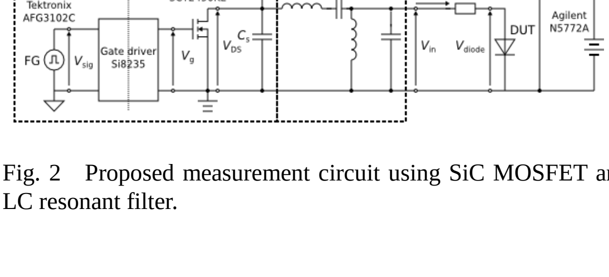


Fig. 2 Proposed measurement circuit using SiC MOSFET and LC resonant filter.

3. Results and Discussion

Comparing with experimental and simulated results

Figure 3 shows experimental waveforms about voltage (V_{diode}) and current (I_{diode}) of SiC SBD at 100 V_{pp} input and 500 mA current. The frequency of the sinusoidal input is set at (a) 1 MHz and (b) 10 MHz. The SiC SBD exhibits blocking characteristics at 1 MHz, whereas severe reverse recovery deteriorates rectifying characteristics at 10 MHz. This reverse recovery originates from carrier extraction of the junction capacitance. The influence of this recovery current becomes larger by increasing the input frequency, increasing the input voltage, and decreasing the diode current. Simulated waveforms using our proposed model are also shown in Fig. 3. It is found that the proposed model well reproduce the experimental switching waveforms of the SiC SBD.

At a high current range of over 1 A, however, simulated waveforms are not consistent with experimental waveforms. Figure 4 shows experimental and simulated waveforms of the SiC SBD at 10 MHz, 200 V_{pp} input, and 10 A current. In this case, the simulated waveforms have less oscillation components than the experimental results. Considering Lissajous plot of the experimental *I-V* switching characteristics, the switching trajectory rotate counterclockwise in forward condition, suggesting that parasitic inductances of the measurement circuit affects the experimental waveforms of the SiC SBD.

The parasitic inductance is estimated at 100 nH from the oscillation frequency, which is consistent with the total parasitic inductance of the circuit. Considering the parasitic inductance of 100 nH in the simulation, the dynamic characteristics are shown in Fig. 5. The numerical simulation well reproduce the experimental switching waveforms at 10 MHz and 10 A current. For verifying the model at high-frequency and high-power switching, the simulation taking parasitic elements into account is important.

4. Conclusions

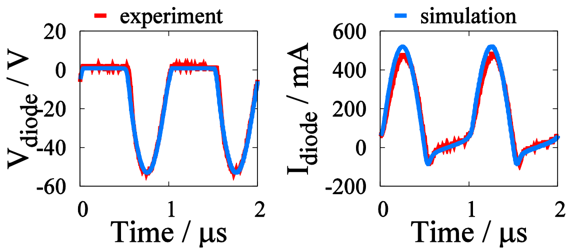
The device model of SiC SBD is investigated based on the junction capacitance. It is found that our proposed device model well reproduce the experimental switching waveforms at 10 MHz by considering the parasitic inductances. This model is applicable to design high-frequency power converter circuit. In the final paper, the temperature dependence of dynamic characteristics up to 200^{o}C is also discussed based on this proposed model.

Acknowledgements

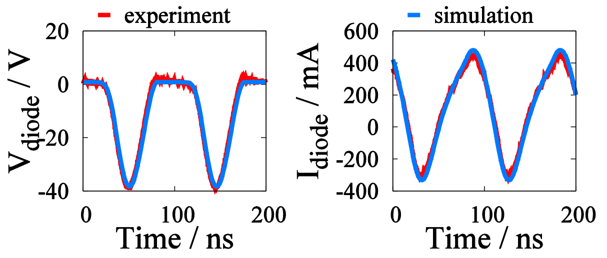
This research is partially supported by Kyoto Super Cluster Program (JST) and Cross-ministerial Strategic Innovation Promotion Program (SIP), "Next-generation power electronics" (NEDO).

References

[1] T. Kimoto, Jpn. J. Appl. Phys., **54** (4), 040103 (2015).
[2] H. Okumura, Jpn. J. Appl. Phys., **45** (10R), 7565 (2006).
[3] D. T. Morisette et al., IEEE Trans. Electron Devices, **48** (2), 349–352 (2001).
[4] J. L. Hudgins et al.,IEEE Trans. Power Electronics, **18** (3), 907–914 (2003).
[5] B. Ozpineci et al., IEEE Power Electronics Letters, **1** (2), 54–57 (2003).
[6] T. Funaki et al., IEEE Trans. Power Electronics, **23** (5), 2602–2611 (2008).



(a) Rectification waveforms at 1 MHz sinusoidal input.



(b) Rectification waveforms at 10 MHz sinusoidal wave input.

Fig. 3 Measurement and simulated waveforms about half-wave rectification at 100 V_{pp} input and 500 mA max current.

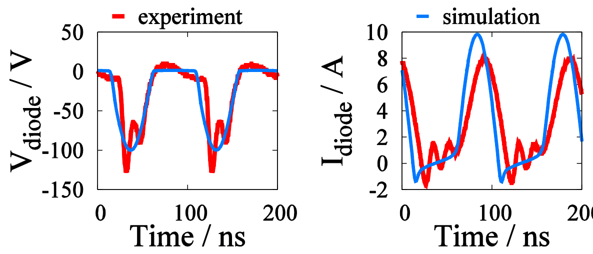


Fig. 4 Measurement and simulated waveforms about half-wave rectification at 10 MHz , 200 V_{pp} input and 10 A max current.

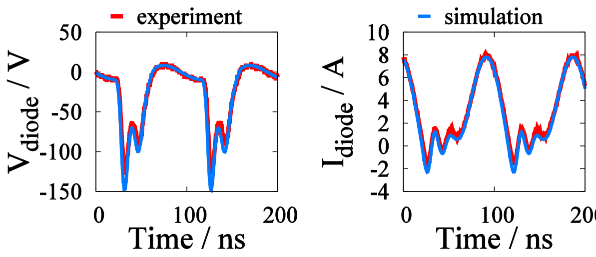


Fig. 5 Measurement and simulated waveforms about half-wave rectification at 10 MHz , 200 V_{pp} input and 10 A max current. Simulating with parasitic inductances.