1,700 V Withstand Voltage SiC Hybrid Module

KOBAYASHI Kunio* KITAMURA Shoji* ADACHI Kazuya‡

ABSTRACT

In place of Si devices, silicon carbide devices (SiC devices) featuring heat resistance and high breakdown field tolerance are raising expectations for efficiency improvement and miniaturization of equipment. Fuji Electric is moving ahead with the development of a 1,700 V withstand voltage SiC hybrid module for high-efficiency inverters (690 V series). A SiC-SBD chip jointly developed with the National Institute of Advanced Industrial Science and Technology has been applied to a freewheeling diode (FWD), and a Fuji Electric's "V-Series" IGBT chip has been applied to an insulated gate bipolar transistor (IGBT). By improving leakage current and switching characteristics, the module has been verified to be capable of reducing generated loss by approximately 26% in a 300 A product compared to the conventional Si modules.

1. Introduction

Faced with the need to prevent global warming, the urgent task of reducing emissions of greenhouse gases such as CO_2 is greater than ever. One of the means to realize this is to ensure energy saving in power electronics devices. Highly efficient inverters are an important aspect of this, and they require technological innovation for components such as power devices, circuits and controls. In particular, there is a strong demand for lowering power dissipation in power devices that are the main elements of inverters. An insulated gate bipolar transistor (IGBT), a major power device, has used a silicon (Si) IGBT chip and free-wheeling diode (FWD) chip so far. However, Si devices are hitting the theoretical limit in terms of performance based on their physical characteristics. For this reason, there are high expectations now for silicon carbide (SiC) devices because of their properties of heat resistance and high breakdown field tolerance, and it is hoped they will improve equipment efficiency and achieve miniaturization.

This paper describes a 1,700 V withstand voltage SiC hybrid module that deploys SiC devices.

2. Product Features

Fuji Electric has so far completed the development of 600 V withstand voltage SiC- Schottky barrier diode (SBD) for 200 V systems and 1,200 V withstand voltage SiC-SBD for 440 V systems, followed by successful commercialization of an SiC hybrid module that combines these SiC-SBDs and Si-IGBT. SiC-SBD has low resistance and superior switching characteristics in comparison with an Si-PIN diode, a conventional high blocking voltage FWD. With these features, the SiC hybrid module has a capacity to reduce generated loss by approximately 26% compared with conventional Si-IGBT modules.

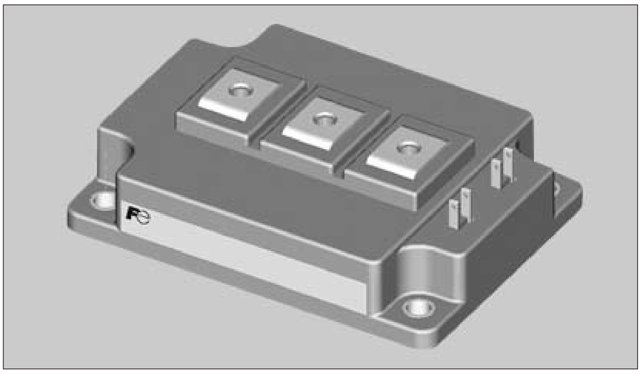

Fig.1 M277 package

The development of a 1,700 V withstand voltage SiC hybrid module is currently underway for 690 V input inverters. The M277 package (see Fig. 1) has been adopted for the SiC hybrid module to allow for easy changeover from conventional Si modules, which use the same package. Fuji Electric developed an SiC-SBD chip jointly with the National Institute of Advanced Industrial Science and Technology, followed by the Company's launch of a mass-production line. This chip has been applied to FWD, while IGBT has been equipped with Fuji Electric's latest product, the sixth-generation "V-Series" IGBT chip.

3. Features

3.1 Forward characteristic of FWDs

Figure 2 illustrates the FWD forward-direction

* Electronic Devices Business Group, Fuji Electric Co., Ltd.
‡ Corporate R&D Headquarters, Fuji Electric Co., Ltd.

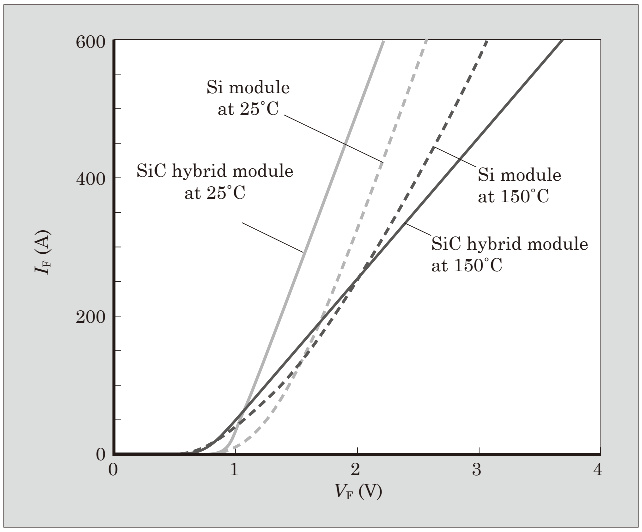

Fig.2 Forward characteristic of FWDs

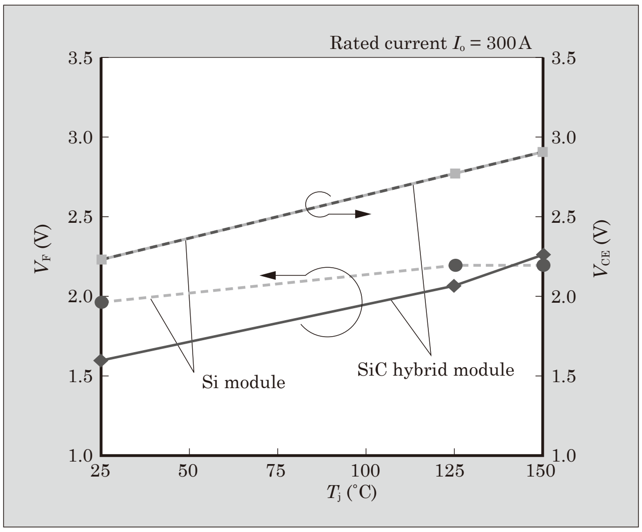

Fig.3 Temperature dependency of FWDs

characteristic of the SiC hybrid module and Si module, and Fig. 3 illustrates the temperature dependency. With a junction temperature at 150 °C and rated current of 300 A, the forward direction voltage V_F is on the same level as the Si module V_F. Owing to its strong positive temperature coefficient, the SiC hybrid module creates smaller current imbalance in multi-parallel connections.

3.2 Leakage current

Figure 4 depicts the leakage current temperature dependency of an SiC hybrid module and Si module. While the leakage current I_{CES} of the SiC hybrid module is nearly ten times greater than that of the Si module at the rated voltage at 125 °C (1,700 V), this difference shrinks to approximately twice at 150 °C. The difference in leakage current value between 125 °C and 150 °C under the rated voltage is smaller in the SiC hybrid module compared to that in the Si module. Therefore, SiC-SBD has a smaller leakage current temperature dependency compared with Si-FWD. This is because SiC's band gap is approximately three times that of Si, and as SiC-SBD operates at a higher electrical field than Si-FWD, thus the leaked current of SiC-SBD becoming predominantly tunneling current and making it less susceptible to temperature fluctuations. For these reasons, the SiC hybrid module can, like the V-Series, perform in a high temperature environment[(1)].

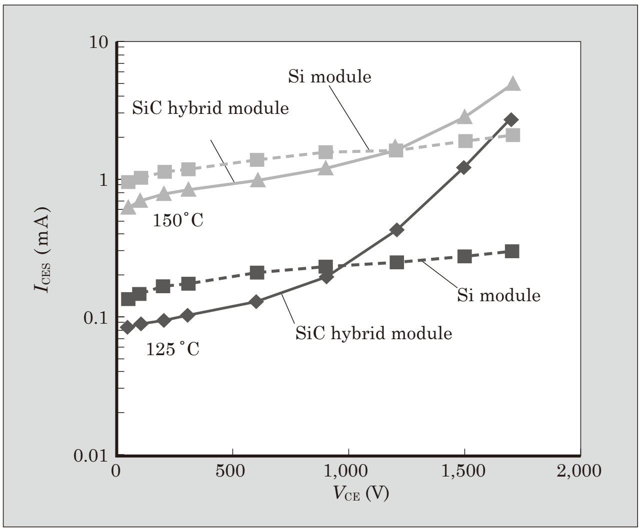

Fig.4 Leakage current temperature dependency

3.3 Switching

(1) Reverse recovery loss

Figure 5 illustrates the reverse recovery loss of the SiC hybrid module and Si modules. The SiC hybrid module scarcely has any peak reverse recovery current. This is explained by the fact that SiC-SBD is a unipolar device, and so it causes no minority carrier injection. The reverse recovery loss of 300 A products is lower than that of the Si module by approximately 83%.

(2) Turn-on loss

Figure 6 shows the turn-on losses of the SiC hybrid

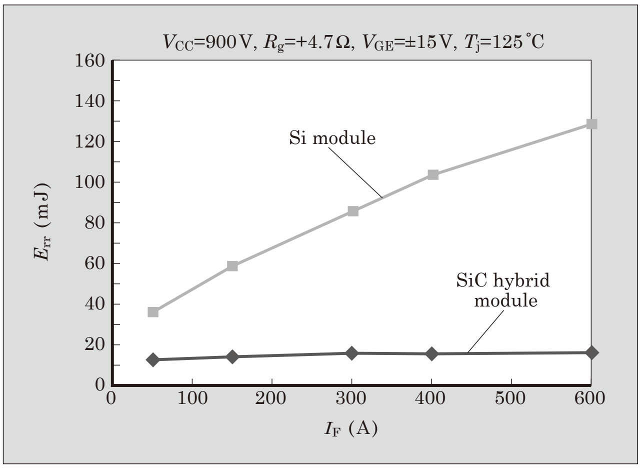

Fig.5 Reverse recovery loss

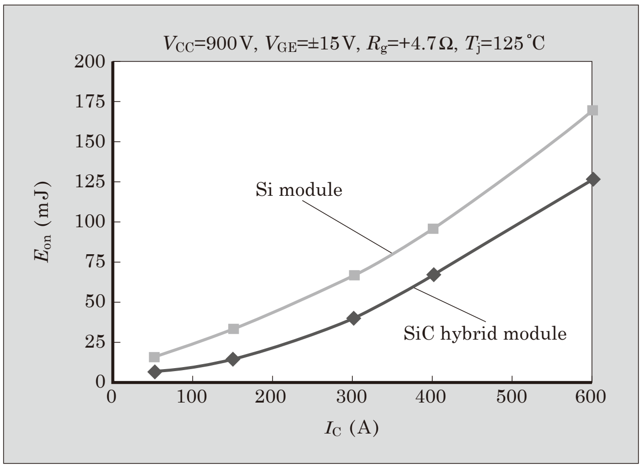

Fig.6 Turn-on loss

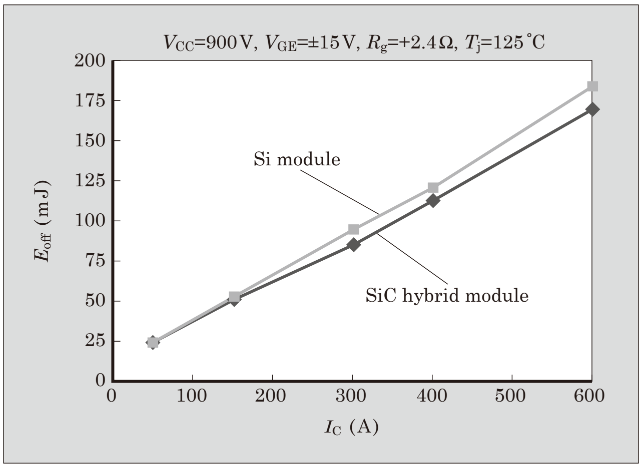

Fig.7 Turn-off loss

module and Si module. The peak reverse recovery current of SiC-SBD affects the IGBT turn-on current in the opposing arm, leading to a lower turn-on loss. The turn-on loss of a 300 A product is lower than that of the Si module by approximately 40%.

(3) Turn-off loss

Figure 7 depicts the turn-off losses of the SiC hybrid module and Si module. The surge peak voltage of the SiC hybrid module at a turn-off can be expressed as shown in Formula (1). Provided that the IGBT element characteristics and inductance of the main circuit are equal, the difference in the transient on-voltage becomes the difference in the surge voltage. The drift layer of SiC-SBD has extremely low resistance compared to Si-FWD, and this lowers the transient on-voltage. Therefore, the surge voltage at turn-off is kept low, and hence there is a low turn-off loss.

$$V_{sp} = V_{cc} + L_s \frac{dI_c}{d_t} + V_{fr} \cdots\cdots (1)$$

V_{sp} : surge peak voltage
V_{cc} : applied voltage
L_s : main circuit inductance
I_c : collector current
V_{fr} : transient on-voltage

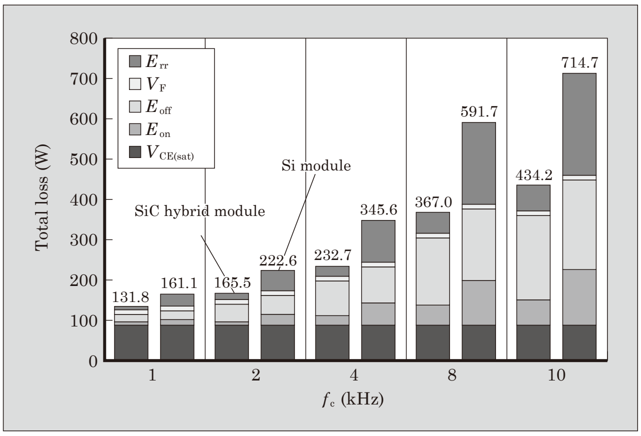

Fig.8 Inverter generated loss

3.4 Inverter generated loss

Figure 8 shows the inverter generated losses of the SiC hybrid module and Si module. The SiC hybrid module's total loss at the carrier frequency f_c of 2 kHz is lower than that of the Si module by approximately 26%. As the loss increase rate of the SiC hybrid module is more suppressed than the Si module at higher carrier frequencies, the SiC hybrid module has an advantage over the Si module in performing at high frequencies.

4. Postscript

The SiC hybrid module is a product deploying SiC-SBD, which was developed jointly with the National Institute of Advanced Industrial Science and Technology, and Fuji Electric's latest product, the sixth-generation "V-Series" Si-IGBT. SiC hybrid module has successfully attained a significant loss-reduction within the device, enabling an efficiency enhancement for inverters to a great extent. We will expand the range of SiC-chip-applied products and develop product families in the future to contribute to energy conservation.

We would like to thank everyone at the Advanced Power Electronics Research Center of the National Institute of Advanced Industrial Science and Technology who contributed to the development of SiC-SBD chip.

References

(1) Nakazawa, M. et al. Hybrid Si-IGBT and SiC-SBD Modules. FUJI ELECTRIC REVIEW. 2012, vol.58, no.2, p.70-74.

Fuji Electric

Innovating Energy Technology