1,200 V Withstand Voltage SiC Hybrid Module

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ABSTRACT

Fuji Electric is working on the development of a 1,200 V withstand voltage SiC hybrid module as a power device for inverters that contribute to energy conservation. This hybrid module uses a SiC-Schottky barrier diode (SiC-SBD) chip, which has been developed jointly with the National Institute of Advanced Industrial Science and Technology and has been mass-produced by Fuji Electric. As the insulated-gate bipolar transistor (IGBT), Fuji Electric's latest 6th-generation "V Series" IGBT chip was adopted. For its 300 A products, the generated loss has been reduced by approximately 25% compared with 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 achieve their reduction targets is to ensure energy saving in power electronics devices. An important aspect of this is to improve inverter efficiency by having technological innovation for components such as power devices, circuits and controls. An insulated gate bipolar transistor (IGBT), a major power device for which customers have a strong demand for low loss, 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 for silicon carbide (SiC) devices because of their heat resistance exceeding the limit of Si and high breakdown field tolerance, and it is hoped they will improve equipment efficiency and achieve miniaturization.

This paper describes a 1,200 V withstand voltage SiC hybrid module (2-in-1 package), of which a product line has recently been established.

2. Product Features

Table 1 shows the lineup of Fuji Electric's SiC hybrid modules. Hybrid modules that have been commercialized up to now include those in EP and PC packages that use 600 V withstand voltage SiC-Schottky barrier diode (SiC-SBD) for the 200 V series and 1,200 V withstand voltage SiC-SBD for the 400 V series[1], and those in 2-in-1 packages that use 1,700 V withstand voltage SiC-SBD for the 690 V series. Equipment that uses these hybrid modules can achieve a generated loss reduction of approximately 25% from that with the conventional Si-IGBT modules.

Table 1 SiC hybrid module lineup

Application	Composition	Package
200 V series	600 V withstand voltage SiC-SBD + V Series IGBT	EP package and PC package
400 V series	1,200 V withstand voltage SiC-SBD + V Series IGBT	
400 V series	1,200 V withstand voltage SiC-SBD + V Series IGBT	2-in-1 package
690 V series	1,700 V withstand voltage SiC-SBD + V Series IGBT	2-in-1 package

□ : Newly developed product

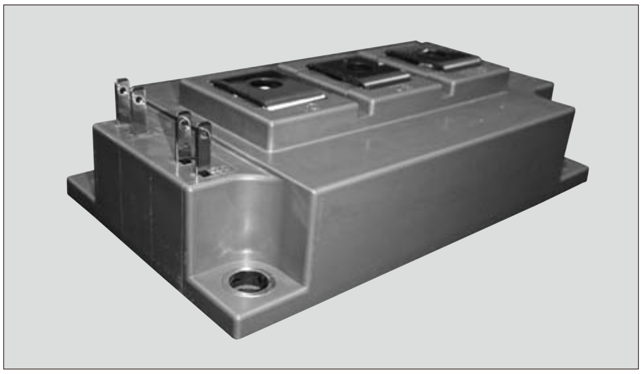

Fig.1 SiC hybrid module (2-in-1 package)

For the package of the 1,200 V withstand voltage SiC hybrid modules that have been built into a product line, a 2-in-1 package, as with Si modules, has been adopted (see Fig. 1). Adoption of 2-in-1 packages, which are widespread, in addition to the conventional EP and PC packages makes it possible to easily replace the conventional Si modules. Fuji Electric developed

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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. With 300 A products, the generated loss has been confirmed to be lower by approximately 25% from the conventional Si modules.

3. Features

3.1 Forward characteristics of FWDs

Figure 2 illustrates the forward characteristics of the FWDs of the SiC hybrid module and Si module. With a junction temperature T_j of 25 °C and rated current of 300 A, the forward voltage V_F is at the same level as the Si module V_F. While the V_F at 125 °C is higher for the SiC hybrid module than for the Si module, the total loss is smaller for the SiC hybrid module as indicated in Section 3.2.

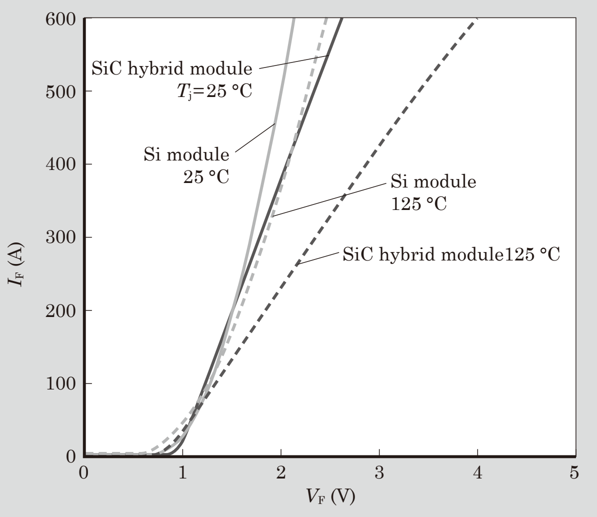

Fig.2 Forward characteristics of FWDs

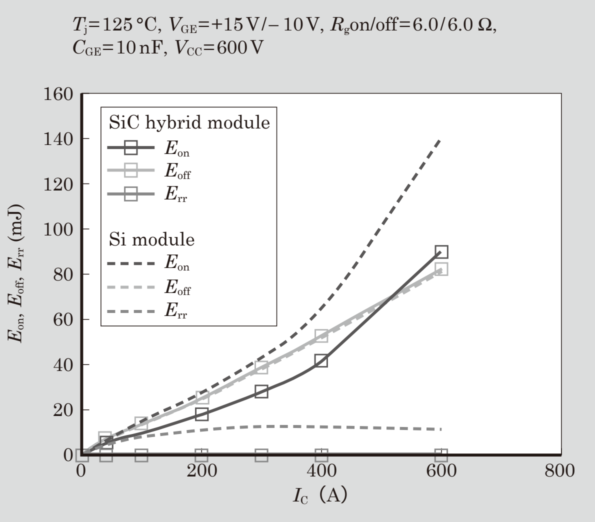

Fig.3 Switching loss

3.2 Switching loss

Figure 3 shows a comparison of the switching losses between the SiC hybrid module and Si module. Compared to the Si module, the turn-on loss E_{on} of the SiC hybrid module is smaller by approximately 35% and the reverse recovery loss E_{rr} is almost 0. Concerning the turn-off loss E_{off}, there is little difference between the SiC hybrid module and Si module.

(1) Turn-on waveforms

Figure 4 shows a comparison of turn-on waveforms. The peak reverse recovery current of the SiC-SBD has an effect on the IGBT turn-on current on the opposing arm side and the E_{on} of the SiC hybrid module is lower than that of the Si module by approximately 35%.

(2) Turn-off waveforms

Figure 5 shows a comparison of turn-off waveforms. The drift layer of SiC-SBD has an extremely low resistance compared to Si-FWD, and this lowers the transient on-voltage. Accordingly, the SiC hybrid module allows the surge voltage at turn-off to be held low.

(3) Reverse recovery waveforms

Figure 6 shows a comparison of reverse recovery waveforms. The SiC hybrid module scarcely has any peak reverse recovery current and the E_{rr} is almost 0. This is explained by the fact that SiC-SBD is a unipolar device, and so it causes no minority carrier injection.

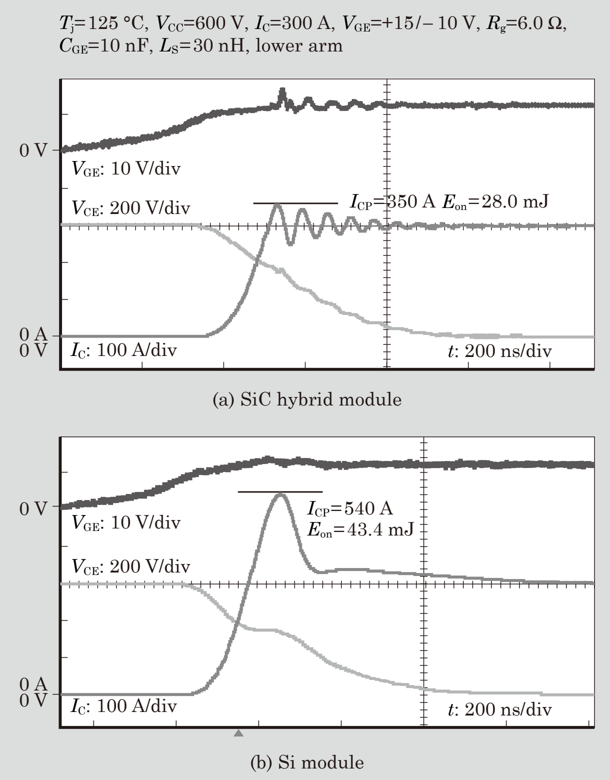

Fig.4 Turn-on waveforms

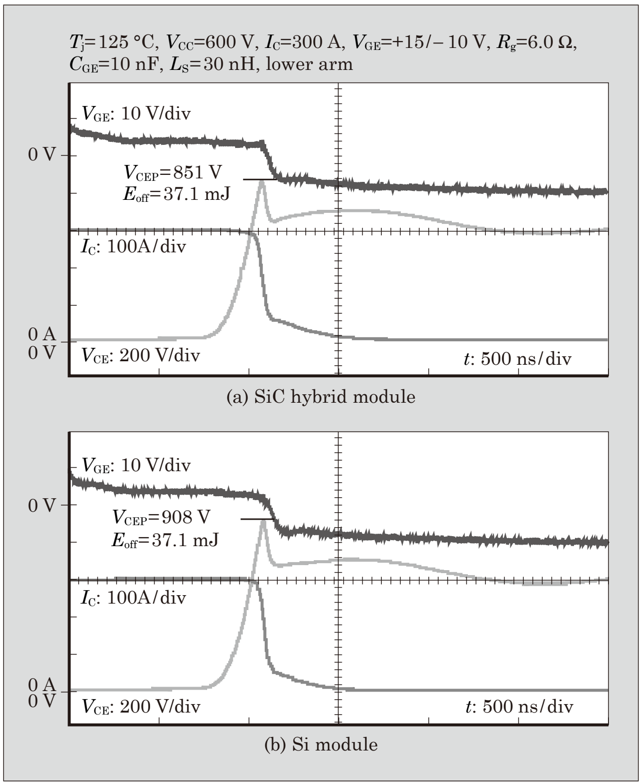

Fig.5 Turn-off waveforms

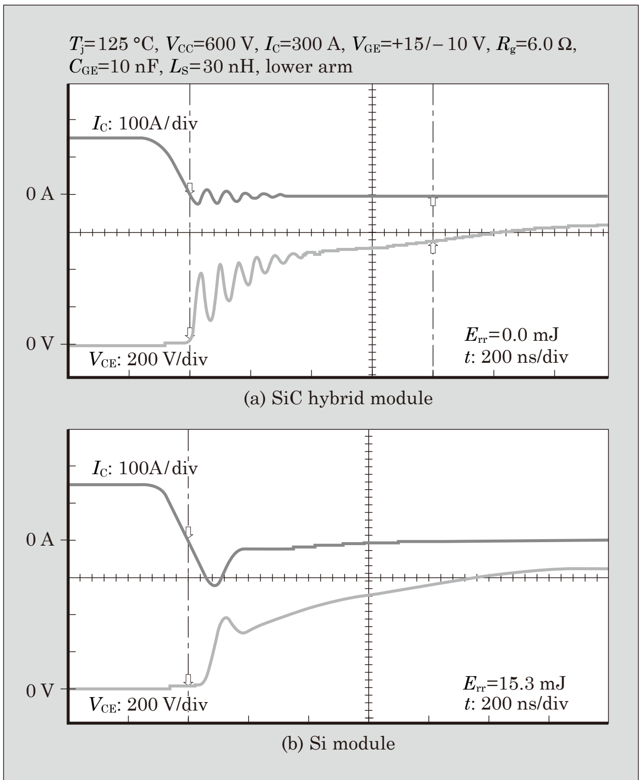

Fig.6 Reverse recovery waveforms

3.3 Load short circuit evaluation

Figure 7 shows load short circuit waveforms with the T_j of the SiC hybrid module varied from −40 to +125 °C. It has been confirmed that no problem occurs in the range from low to high temperatures.

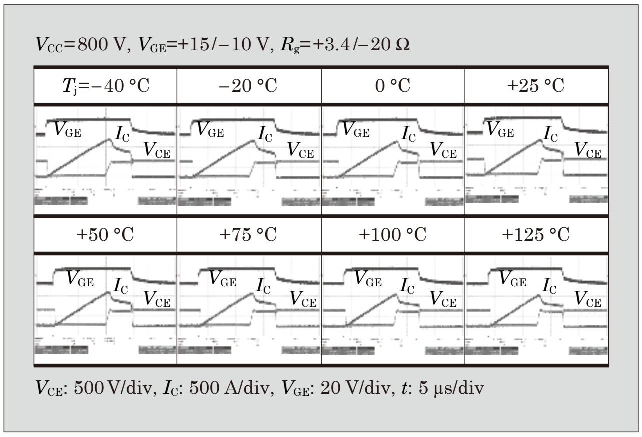

Fig.7 Load short circuit waveforms

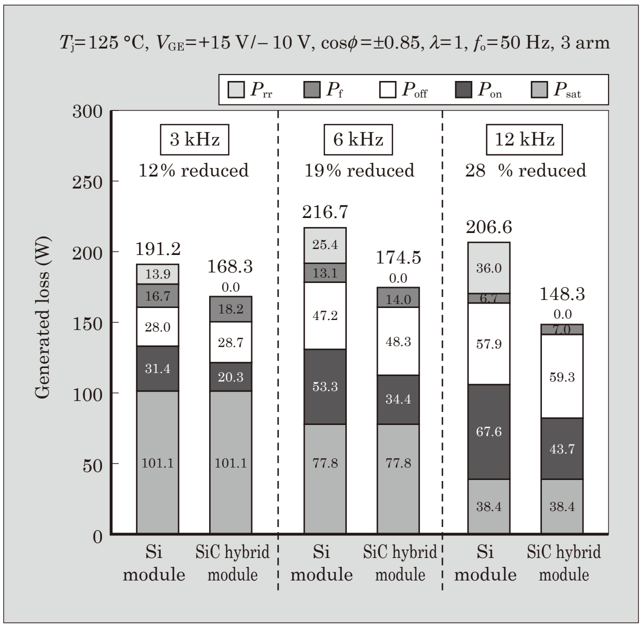

Fig.8 Inverter generated loss

3.4 Inverter generated loss

As shown in Fig. 8, the generated loss of an inverter with the SiC hybrid module is lower than that with the Si module by 12 to 28% and the reduction rate is higher with a higher carrier frequency. This means that the SiC hybrid module is more advantageous in high-frequency operation.

4. Postscript

This paper has described the SiC hybrid module that deploys 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. The SiC hybrid module has successfully attained a significant loss-reduction within the device, probably enabling an efficiency enhancement for inverters to a great extent. In the future, we intend to continue applying SiC chip products and establishing various product lines to meet the withstand voltage, current capacity and package type demanded in the market. In this way, we aim to help prevent global warming by saving on the energy consumed by power electronics devices.

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 the 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.

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