SiC Hybrid Module Application Note
Chapter 1
- Concept and Features -

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Introduction

The improved characteristic of SiC devices relating to the high temperature operation and the high breakdown voltage capability compared to Si devices make them to a very effective technology to achieve a high efficiency and allow downsizing of equipment. Fuji Electric has commercialized SiC hybrid modules with breakdown voltages of 600 V ～ 3300 V as power devices for inverters that contributes to energy saving.

SiC hybrid modules combine Si-IGBT chips with SiC-SBD (Schottky Barrier Diode) chips. This allows further characteristic improvements compared to conventional Si modules.

This chapter explains the features and benefits of SiC hybrid modules in detail.

1 The basic concept of SiC hybrid modules

In order to prevent global warming, the reduction of greenhouse gases including CO_2 is more than ever necessary. One of the reduction possibilities is the energy conservation of power electronics equipment. Important items to achieve this are the increase of efficiency and the miniaturization of inverters. These is possible due to technological innovation like circuit control and power device optimization.

The strong demand for power devices with low losses was solved until now with the well-known IGBT (Insulated Gate Bipolar Transistor) module, using Si (silicon) IGBT chip and FWD (Free Wheeling Diode) chip. However, the performance of Si devices is reaching the theoretical limits because of the physical characteristics. Therefore, SiC (silicon carbide) power devices which can operate under higher temperature than Si devices and providing a high breakdown voltage are promising to achieve high efficiency operation and downsizing of equipment.

On this background, the SiC hybrid modules (Si-IGBT + SiC-SBD) were developed on this basic concept of "High efficiency and miniaturization of equipment".

The basic requirements for IGBT modules are the improvement of performance and reliability as well as the reduction of environmental stress. The parameters for performance, environmental stress and reliability are correlative and therefore it’s important to improve those characteristics in a good balance to achieve the defined target.

2 Features of SiC hybrid modules

2.1 Product composition

Table 1 shows an overview about the SiC hybrid module Series. Fuji commercialized 6in1/PIM using 600V class SiC-SBD for 200VAC systems, 2in1/6in1/PIM using 1200V class SiC-SBD for 400VAC systems, 2in1 using 1700V class SiC-SBD for 690VAC systems and 3300V class for traction applications.

In these SiC hybrid modules, the power dissipation can be reduced by about 25% compared to conventional Si - IGBT modules*. (* In case of 1700V/400A module、f_C=10kHz)

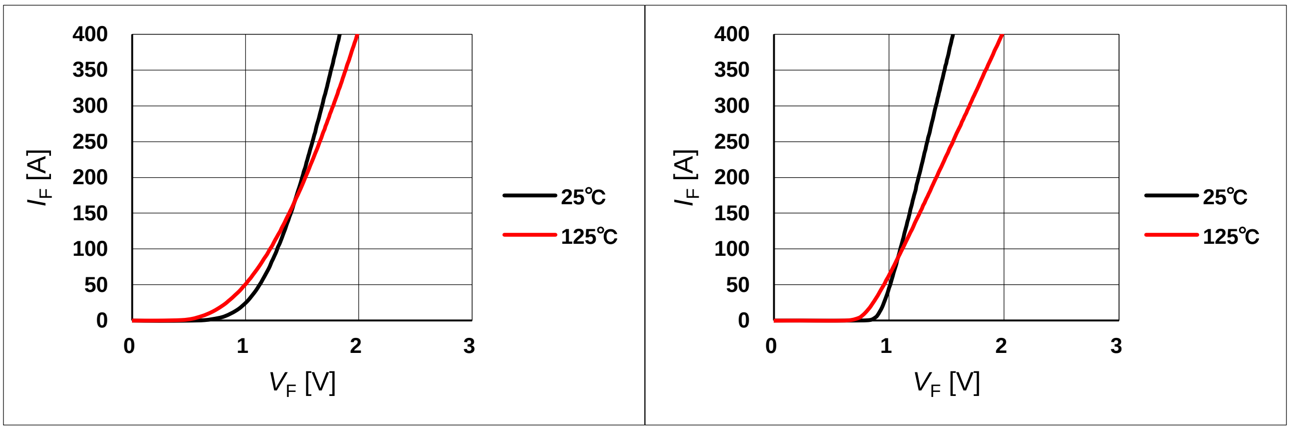
Table 1 Series of SiC hybrid modules

Application	Structure	Configuration
200VAC system	600V class SiC-SBD+ Si-IGBT	6in1/PIM
400VAC system	1200V class SiC-SBD+ Si-IGBT	2in1/6in1/PIM
690VAC system	1700V class SiC-SBD+ Si-IGBT	2in1
Traction	3300V class SiC-SBD+ Si-IGBT	1in1

2.2 Characteristic improvement

2.2.1 Forward characteristic of FWD

The forward voltage characteristics of FWD for a SiC hybrid module and a Si module are shown in Fig.2-1. Fig.2-2 shows an example of temperature dependency of these two types. When the junction temperature is 125°C and the rated current is 400 A, the forward voltage V_F of the SiC hybrid module is equal to the V_F of the Si module. The strong positive temperature coefficient of the SiC hybrid module makes it hard to get a current imbalance, even for multiple parallel connection.



(a) Si module (b) SiC Hybrid module

Fig.2-1 Forward characteristic of FWD（1700V/400A）

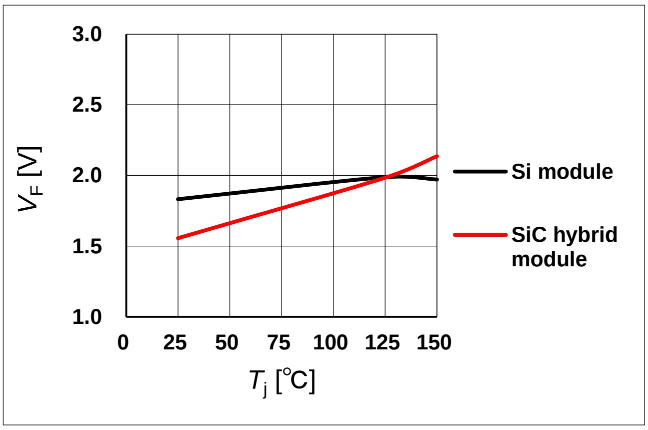
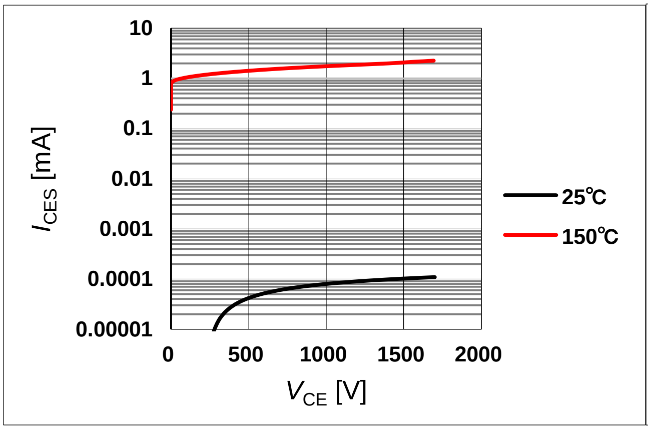


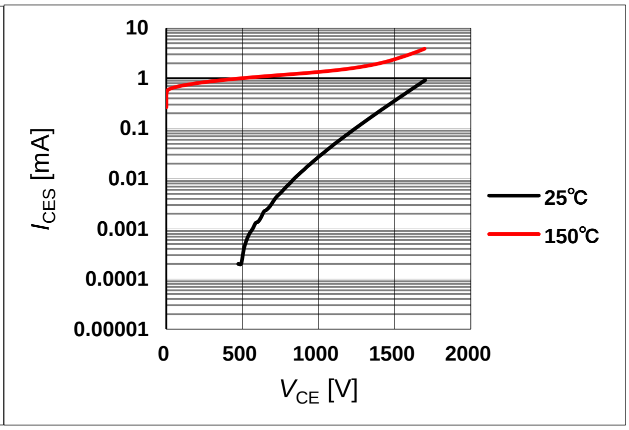
Fig.2-2 Temperature dependency of FWD（1700V/400A）

2.2.2 Leakage current characteristic

Leakage current characteristics for a SiC hybrid module and a Si module are shown in Fig.2-3. Leakage current I_{CES} of the SiC hybrid module at 25°C rated voltage is several thousand times larger than the Si module, but it drops to two times of the Si module at 150°C. The temperature dependence of leakage current of SiC-SBD is smaller compared to a Si-FWD. Therefore, SiC hybrid modules can operate at high temperatures similar to a Si module. One major reason for this behavior is the band gap of SiC which is about three times wider than the one of Si. SiC-SBD operates at high electric fields compared to Si-FWD. The leakage current is dominated by the tunnel current of the SiC-SBD. The SiC hybrid module is hard to be affected by temperature.



(a) Si module (V series)



(b) SiC Hybrid module（V series）

Fig.2-3 Temperature dependence of leakage current（1700V/400A）

2.2.3 Switching characteristic

(1) Reverse recovery characteristic

Because the SiC-SBD is a unipolar device there is no reverse recovery operation in SiC hybrid modules.

(Due to the influence of the junction capacitance, a small current will flow and create losses, but these are much smaller compared to the pin (positive, intrinsic, negative) diode.)

(2) Turn on characteristic

Turn on characteristic for SiC hybrid module and Si module are shown in Fig.2-4. The capacity charge current of the SiC-SBD affects the IGBT turn on current in the opposite arm side, which leads to a reduction of the turn on loss. The turn on loss of the 1700V/400A hybrid product is about 40% lower than the Si device.

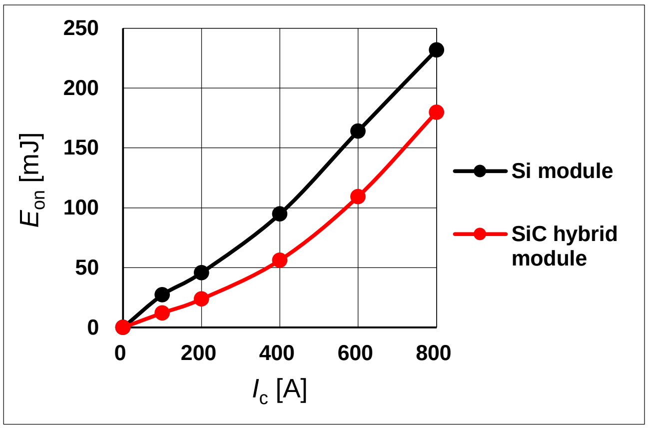


Fig.2-4 Turn on characteristic (1700V/400A)

(3) Turn off characteristic

Turn off characteristic for SiC hybrid module and Si module are shown in Fig.2-5. The peak value of surge voltage during turn off is expressed by equation (1). If the device characteristics of the IGBT and the inductance of the main circuit are equal, the only difference will be the transient on voltage V_{FR} of the Diode. This voltage is lower in comparison to SI-FWD because of the lower drift layer resistance. Therefore, the surge voltage at turn-off is suppressed, which leads to reduced turn-off losses.

$$V_{SP} = V_{CC} + L_S \frac{dI_C}{dt} + V_{FR} \quad \cdots\cdots (1)$$

V_{SP} : Surge peak voltage

V_{CC} : Applied voltage

L_S : Main circuit inductance

I_C : Collector current

V_{FR} : Transient on voltage

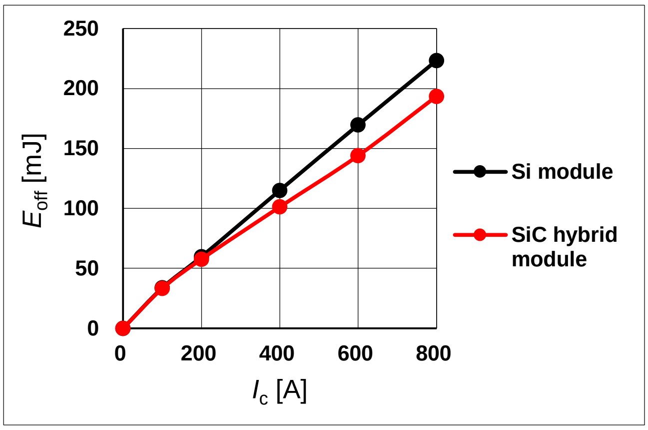


Fig.2-5 Turn off characteristic (1700V/400A)

3 Switching time definition of SiC hybrid module

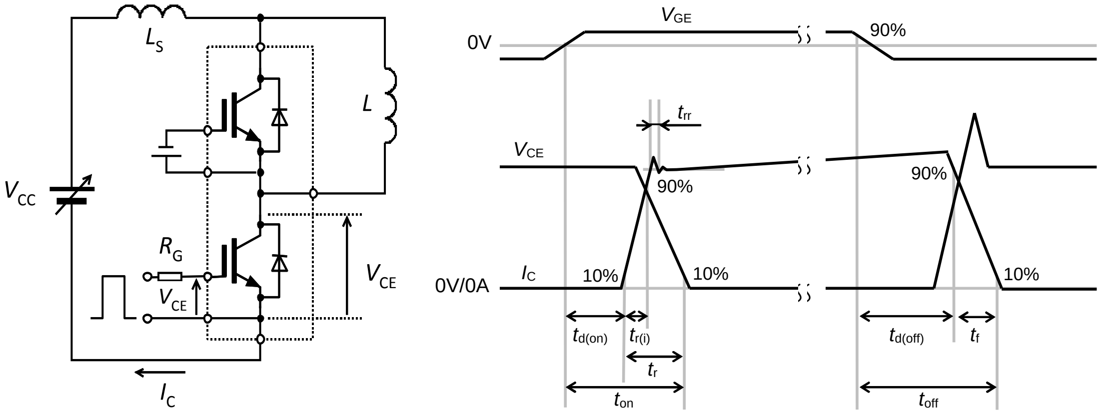


Fig.3-1 Switching definition of SiC hybrid module