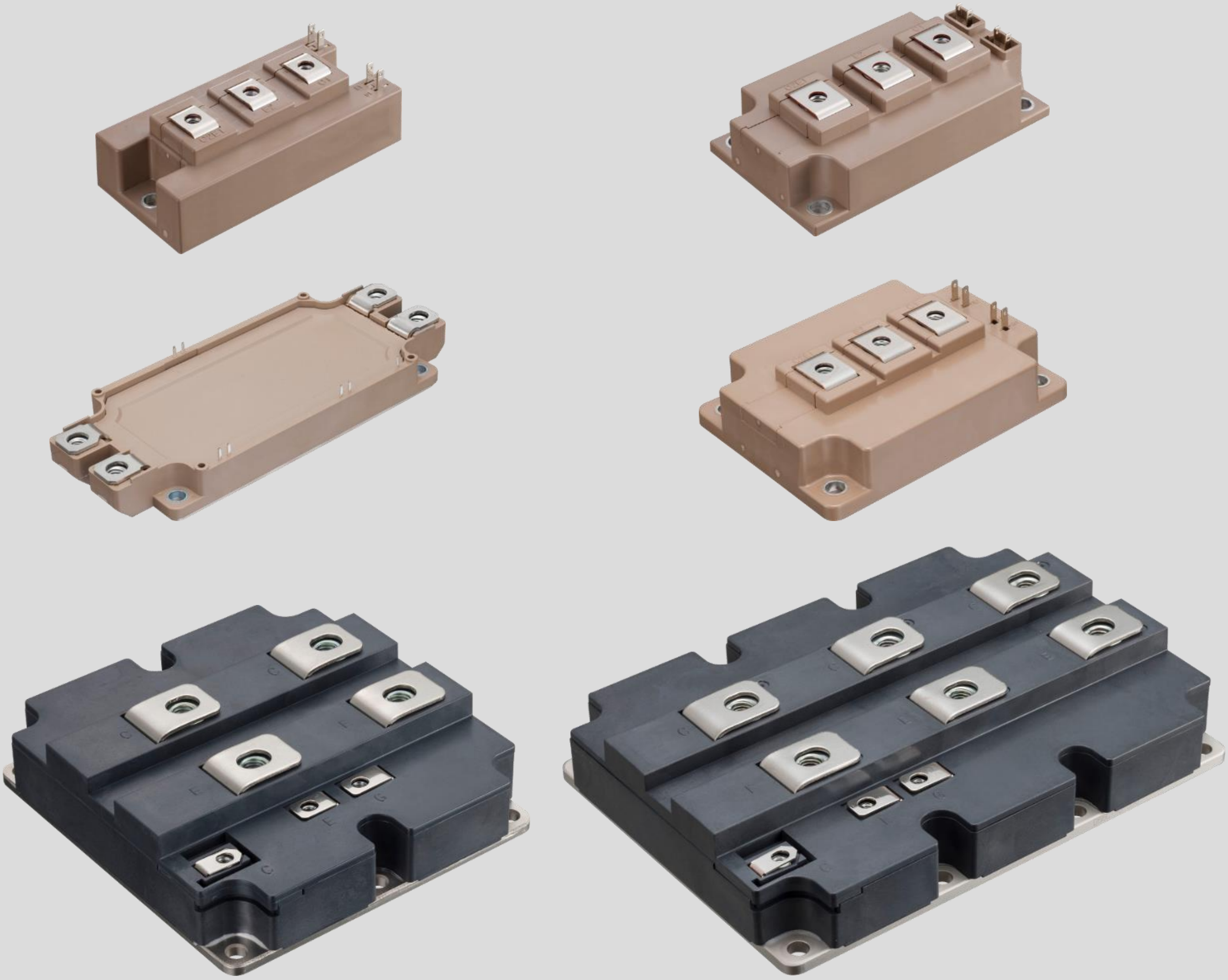
Innovating Energy Technology



Fuji SiC Hybrid Module
V series

Application Manual

Nov. 2021

Fuji Electric Co.,Ltd.

Warning:

This manual contains the product specifications, characteristics, data, materials, and structures as of Nov. 2021.
The contents are subject to change without notice for specification changes or other reasons. When using a product listed in this manual, be sure to obtain the latest specifications.

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⚠ Cautions

(1) During transportation and storage

Keep locating the shipping carton boxes to suitable side up. Otherwise, unexpected stress might affect to the boxes. For example, bend the terminal pins, deform the inner resin case, and so on.

When you throw or drop the product, it gives the product damage.

If the product is wet with water, that it may be broken or malfunctions, please subjected to sufficient measures to rain or condensation.

Temperature and humidity of an environment during transportation are described in the specification sheet. There conditions shall be kept under the specification.

(2)Assembly environment

Since this power module device is very weak against electro static discharge, the ESD countermeasure in the assembly environment shall be suitable within the specification described in specification sheet. Especially, when the conducting pad is removed from control pins, the product is most likely to get electrical damage.

(3)Operating environment

If the product had been used in the environment with acid, organic matter, and corrosive gas (hydrogen sulfide, sulfurous acid gas), the product's performance and appearance can not be ensured easily.

Chapter 1 Basic Concept and Features

The improved characteristic of SiC devices relating to high temperature operation and high breakdown voltage capability compared to Si devices make them a very promising technology for achieving high efficiency and downsizing of equipment. Fuji Electric has commercialized SiC hybrid modules with rated voltages of 1200V~3300V as power devices for inverters that contributes to energy saving.

The SiC hybrid module uses Si IGBT chip for the main switching device and SiC SBD (Schottky Barrier Diode) chip for the FWD. This allows further characteristic improvements compared to conventional Si modules. This chapter explains the features of SiC hybrid modules in detail.

1. Basic Concept of SiC Hybrid Module

In order to prevent global warming, the reduction of greenhouse gases including CO_2 is required more than ever. One of the means of reduction is the energy saving of power electronics equipment. Important items to achieve this are the improvement of efficiency and the miniaturization of inverters through technological innovations such as 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 based on 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 with the 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 impact. The characteristics for performance, environmental impact 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 Module

2.1 Product composition

Table 1 shows an overview of the SiC hybrid module series. 2in1 modules with 1200V SiC-SBD for 400VAC systems, 2in1 modules with 1700V SiC-SBD for 690VAC systems, and 1in1 modules with 3300V SiC-SBD for traction applications.

By using 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）

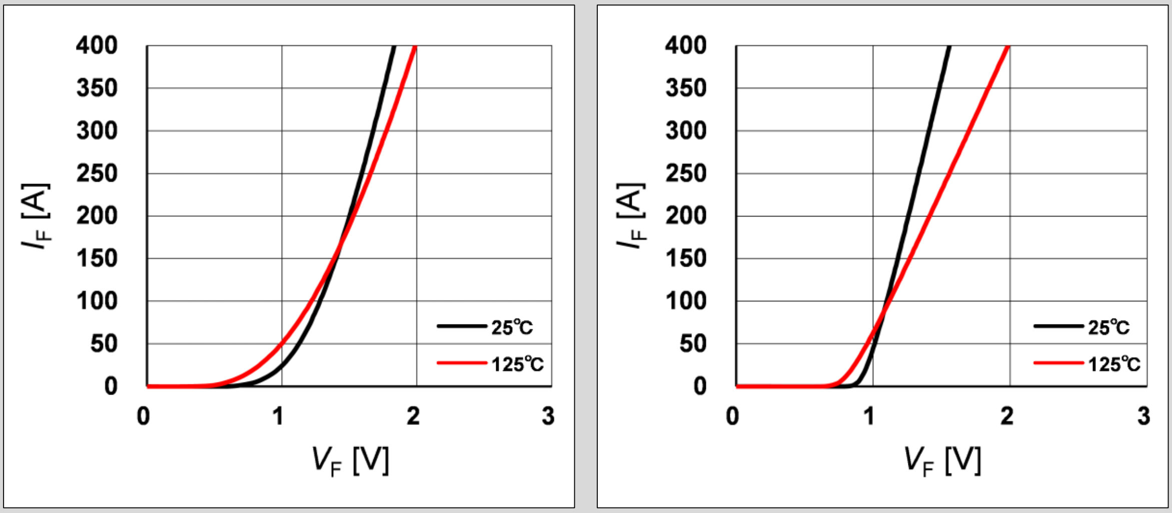
Table1 Series of SiC hybrid module

Application	Structure	Configuration
400VAC system	1200V SiC-SBD+ Si-IGBT	2in1
690VAC system	1700V SiC-SBD+ Si-IGBT	2in1
Traction	3300V 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.1-1. Fig.1-2 shows an example of temperature dependence. When the junction temperature is 125°C and the rated current is 400A, the forward voltage V_F of the SiC hybrid module is equivalent to the V_F of the Si module. The strong positive temperature coefficient of the SiC hybrid module makes current imbalance less likely to occur, even when using with multiple parallel connection.



(a) Si module (b) SiC Hybrid module

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

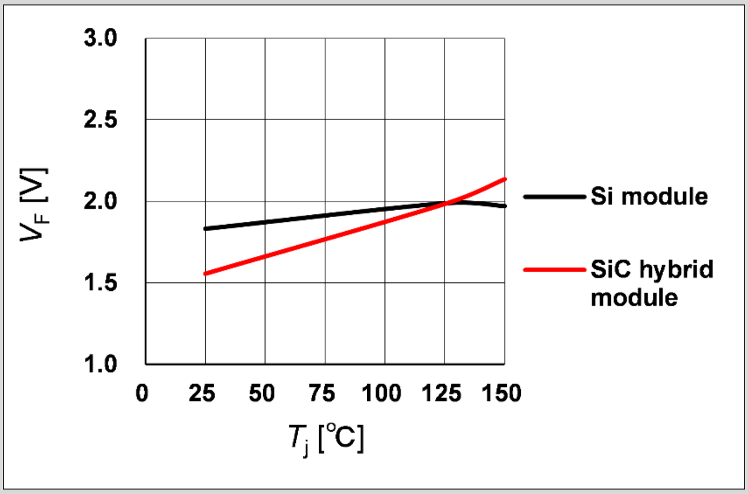


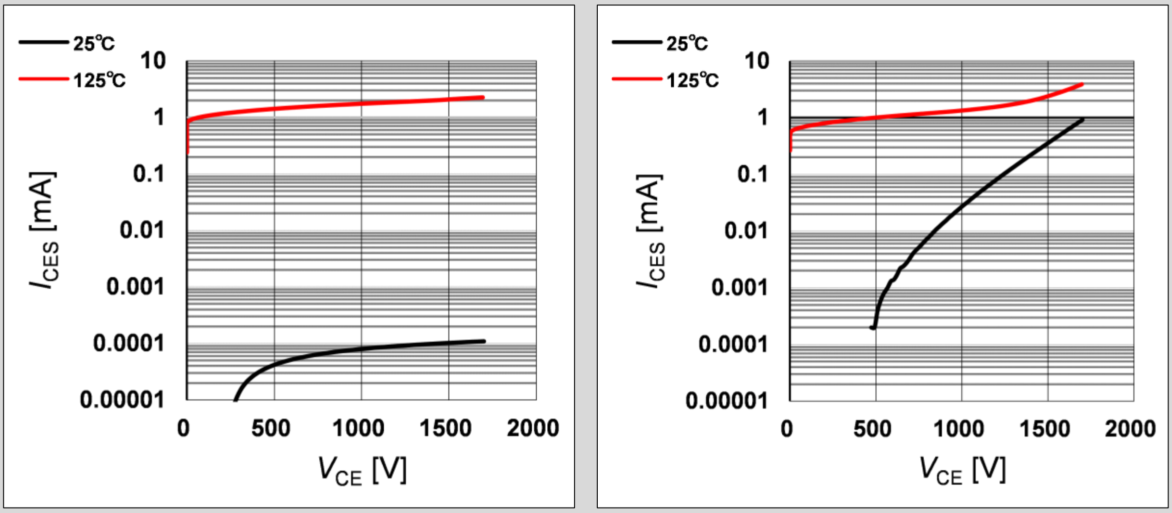
Fig.1-2 Temperature dependency of FWD (1700V/400A)

Note) SiC-SBD has a strong positive temperature characteristic in which V_F rises as the temperature rises, and is also characterized by high V_F at high currents. When applying to a circuit with an inrush current, carefully consider the generated loss and temperature rise.

2.2.2 Leakage current characteristic

Leakage current characteristics for a SiC hybrid module and a Si module are shown in Fig.1-3. Leakage current I_{CES} at rated voltage of SiC hybrid module at 25°C is several thousand times larger than the I_{CES} of Si module, but it drops to about two times the value of Si module at 125°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 Si modules. One major reason for this behavior is the band gap of SiC which is about three times wider than the one of Si. 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. This is because the band gap of SiC is about three times wider than that of Si, and SiC-SBD operates at a higher electric field than Si-FWD. Therefore, the leakage current of SiC-SBD is dominated by the tunnel current of the SiC-SBD and is less susceptible to temperature.

The Si-PN diodes used in Si modules and the SiC-SBDs used in SiC hybrid modules have different leakage current mechanisms, and therefore, there are significant differences in temperature and voltage dependence. It is recommended to fully consider the loss generated by the leakage current and the temperature rise, especially in the case of application where high temperature and high voltage are continuously applied.



(a) Si module (V series)

(b) SiC Hybrid module (V series)

Fig.1-3 Temperature dependence of leakage current (1700V/400A)

2.2.3 Switching characteristic

(1)Reverse recovery characteristic

There is no accumulated charge during the on period, and very fast reverse recovery operation can be expected.

(2)Turn-on loss characteristic

Turn-on loss characteristic of SiC hybrid module and Si module are shown in Fig.1-4. The capacitive charging current of the SiC-SBD affects the IGBT turn-on current in the opposite arm side, leading to a reduction in turn-on loss. The turn-on loss of the 1700V/400A hybrid module is about 40% lower than that of Si device.

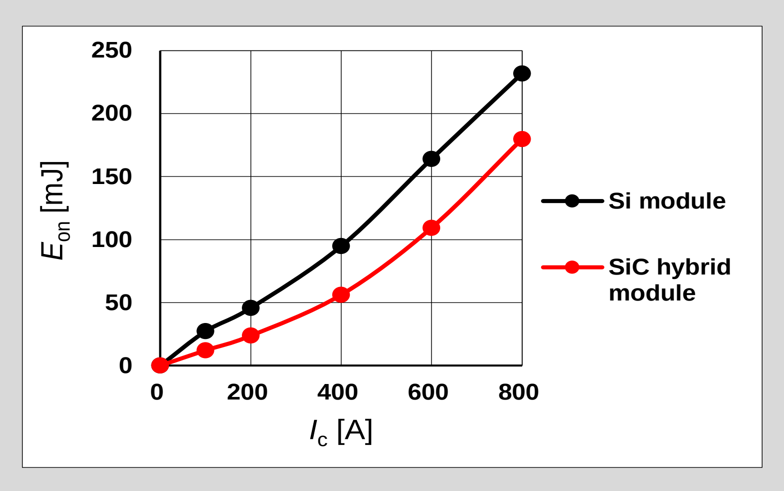


Fig.1-4 Turn-on loss characteristic (1700V/400A)

(3) Turn-off loss characteristic

Turn-off loss characteristic for SiC hybrid module and Si module are shown in Fig.1-5. The peak value of surge voltage during turn-off of SiC Hybrid module is expressed by equation (1). If the device characteristics of the IGBT and the inductance of the main circuit are equal, the difference of transient on voltage of the diode becomes the difference in surge voltage. SiC-SBD has a lower transient on voltage in comparison to Si-PN diode because of the lower drift layer resistance. Therefore, the surge voltage at turn-off is suppressed, leading to a reduction in turn-off loss.

$$V_{\mathrm{SP}} = V_{\mathrm{CC}} + L_{\mathrm{S}} \frac{dI_c}{dt} + V_{\mathrm{FR}} \quad \cdots\cdots (1)$$

V_{SP} : Surge peak voltage, V_{CC} : Applied voltage, L_S : Main circuit inductance
I_C : Collector current, V_{FR} : Transient on voltage

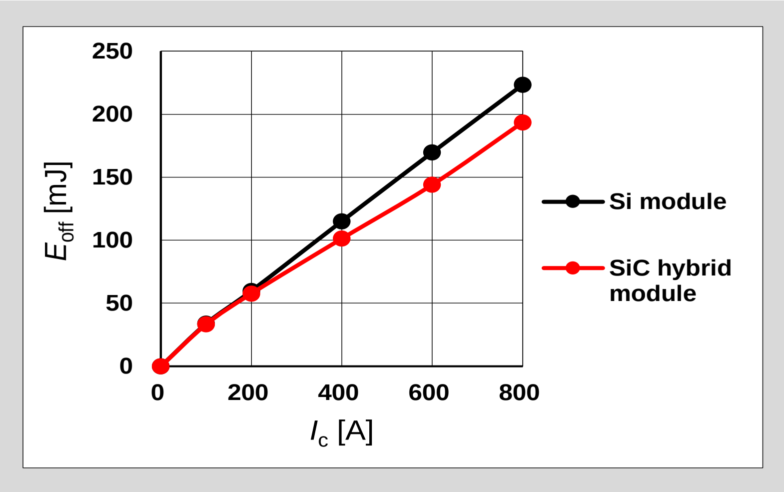


Fig.1-5 Turn-off loss characteristic (1700V/400A)

3. Switching Time Definition of SiC Hybrid Module

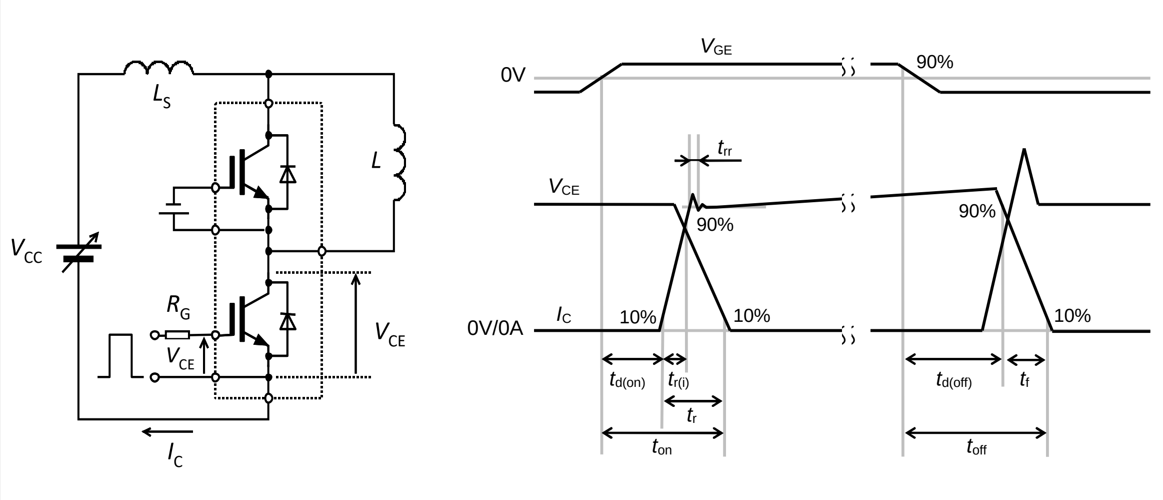


Fig.1-6 Switching definition of SiC hybrid module