Newly Developed High Power 2-in-1 IGBT Module

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ABSTRACT

Aiming for applications to new energy sectors, such as wind power and solar power generation, which are continuing to exhibit growth, Fuji Electric has developed the new High Power 2-in-1 IGBT (insulate gate bipolar transistor) module suitable for parallel connections. This product is equipped with a new 6th generation "V Series" IGBT. Operation is guaranteed for semiconductor chip junction temperatures of up to 175 °C, and the industry's leading level of low on-voltage and low switching energy are achieved. Package technology such as ultrasonic weld-ing and high reliability lead-free solder are utilized to ensure higher reliability than ever before.

1. Introduction

IGBT (insulated gate bipolar transistor) modules are widely used because of their benefits of low power loss, high voltage tolerance, and ease with which drive circuits can be designed. In high-voltage high-power applications as well, IGBT modules are replacing GTO (gate turn-off) thyristors, which had been widely applied until now, and are being used extensively in high power inverters and high voltage inverters.

In recent years, markets for new energy (solar and wind power) have grown rapidly as part of the efforts to prevent global warming. For these applications, there is an ongoing trend of higher power capability in power conversion equipment, and there is a greatly expanded need for high power IGBT modules. Fuji Electric has a history of developing high power IGBT module products that target applications in this field.

For this new energy field, Fuji Electric has developed a new high power 2-in-1 IGBT module having an elongated structure suited for parallel connections. This product is equipped with a "V Series" IGBT, and simultaneously achieves industry-leading levels of low on-state voltage and low switching energy. Furthermore, the latest package technology is used to realize also high power density and high reliability.

This paper presents an overview and describes the performance of Fuji Electric's new high power 2-in-1 IGBT modules.

2. Product Lineup

The package appearance and product lineup of Fuji

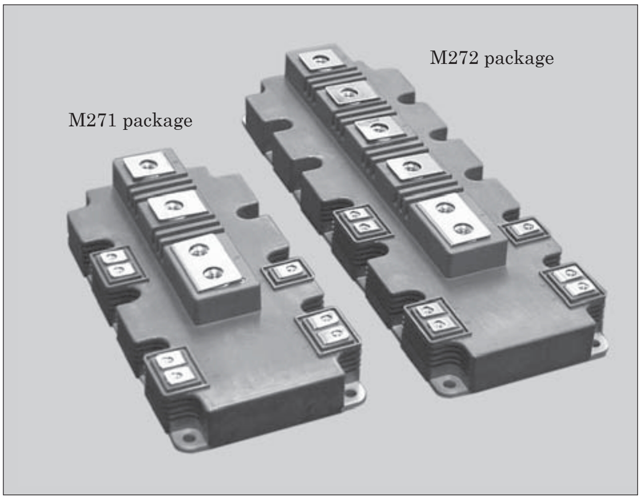

Fig.1 Appearance of new high power 2-in-1 IGBT module packages

Table 1 New high power 2-in-1 IGBT module product lineup

Product type	Package type	Package size (mm)	Rated voltage (V)	Rated current (A)
2MBI600VXA-120E-50	M271	172×89×38	1,200	600
2MBI900VXA-120P-50				900
2MBI1400VXB-120P-50	M272	250×89×38		1,400
2MBI650VXA-170E-50	M271	172×89×38	1,700	650
2MBI1000VXB-170E-50	M272	250×89×38		1,000

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Electric's new high power 2-in-1 modules are shown in Fig. 1 and Table 1, respectively. The product lineup consists of two packages for the voltages classes of 1,200 V and 1,700 V, and the modules have rated currents ranging from 600 to 1,400 A.

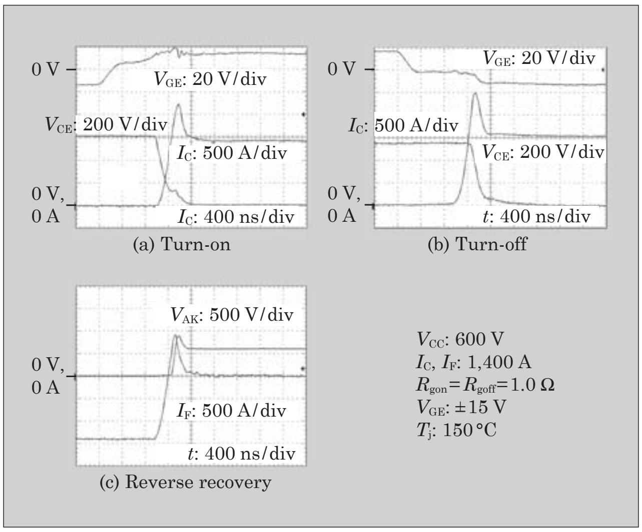

Fig.2 Switching waveform

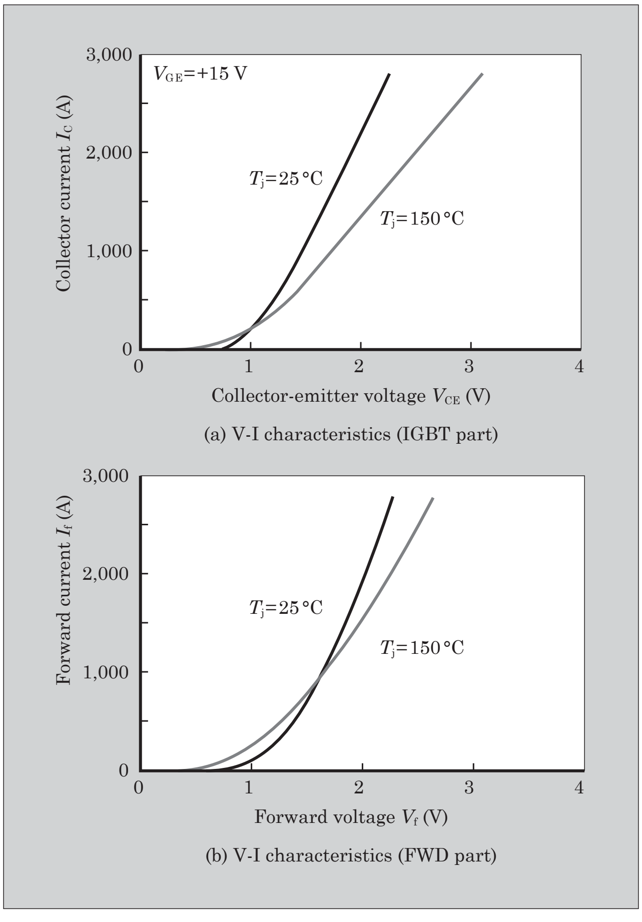

Fig.3 V-I characteristics

3. Electrical Characteristics

This product line is equipped with a V Series IGBT, and ensures a chip maximum junction temperature of T_j = 175 °C, and an operating temperature $T_{j(op)}$ = 150 °C. The electrical characteristics are introduced below using the example of the 2MBI1400 VXB-120P-50 (2-in-1 1,200 V/1,400 A) module.

3.1 IGBT chip characteristics

High power IGBT modules are used to block large currents instantaneously, and their surge voltage generated during switching is also large.

With the new high power 2-in-1 IGBT module of the 1,200 V series, IGBT chip characteristics have been adjusted for high-power applications, and as shown in Fig. 2, compared to devices for low and medium power applications, softer switching characteristics have been realized. Specifically, the silicon thickness, rate of hole injection from the back of the chip, and the chip area have been optimized to realize low saturation voltage and low off-state surge voltage, which are essential performance characteristics for a high power IGBT module.

3.2 V-I characteristics

Fig. 3 shows the V-I characteristics of the module. Both the IGBT and FWD (free wheeling diode) have positive temperature coefficients and their on-state voltage increases as their junction temperatures rise.

A positive temperature coefficient has characteristics well suited for parallel connections, and indicates that the module operates to self-regulate current imbalances that occur among modules.

3.3 Switching characteristics

Fig. 2 shows turn-on, turn-off and reverse recovery waveforms of a module at the rated current of 1,400 A and under the conditions of V_{cc}=600 V, R_{gon}=R_{goff}=1.0 Ω and T_j=150 °C. These waveforms are favorable, without the occurrence of a large generated surge voltage that exceeds the rated voltage. In addition, Fig. 4

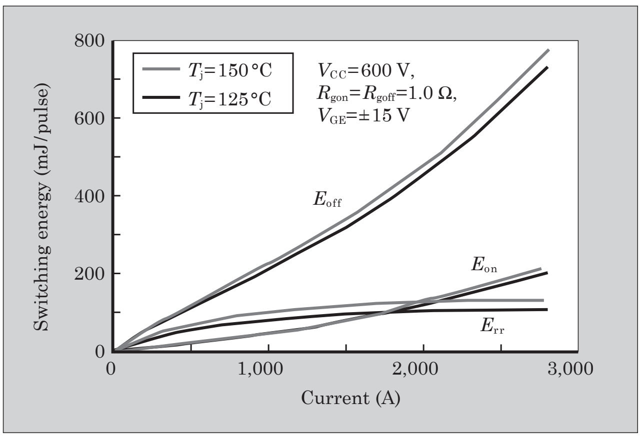

Fig.4 Current dependence of switching energy

shows the current dependence of switching energy under the same operating conditions.

4. Package Structure

Most power conversion systems used in the new energy field and elsewhere achieve high power through parallel connects of multiple modules. Moreover, in this field, a high level of reliability is required in order to supply power stably[1]. For the new high power 2-in-1 IGBT modules, an elongated package structure, as shown in Fig. 1, is selected so as to facilitate parallel connections with a bus bar. As will be described later, various improvements have been made to achieve high reliability. Additionally, in response to environmental concerns, the package has also been made with lead-free materials. Fig. 5 shows a schematic cross-sectional view of the new high power 2-in-1 IGBT module.

4.1 Application of ultrasonic terminal bonding technology

Fig. 6 shows the external appearance and a cross-sectional view of a terminal that has been attached by ultrasonic bonding. This product uses an ultrasonic terminal bonding method to bond a copper terminal directly to a copper circuit pattern. In a soldered bond structure, formed with the conventional method for bonding copper terminals, due to different coefficients of thermal expansion for the solder material and the copper material, the concentrations of stress was greatest in the solder layer. As a result, defects would occur whereby cracks would form in the solder layer and the copper terminal could be pulled off. Fig. 7 compares the results of tensile strength tests for copper terminals before and after thermal cycle tests (repeated test conditions of −40 to +150 °C). For a conventional solder bond, after 300 cycles, an approximate 50% reduction in tensile strength compared to the initial state was verified. With ultrasonic bonding, however, absolutely no decrease in tensile strength compared to the initial state was observed after 300 cycles. With the ultrasonic terminal bonding technology used in this product, copper terminals are bonded directly onto a copper circuit pattern and therefore there is no difference in the coefficient of thermal expansion at the adjoining surfaces. As a result, a significant improvement in the above-mentioned thermal cycle tolerance was achieved.

4.2 Application of highly reliable lead-free solder

In the solder layer existing between the copper base and the copper pattern under the substrate, as shown in Fig. 5, cracks form due to stress generated by

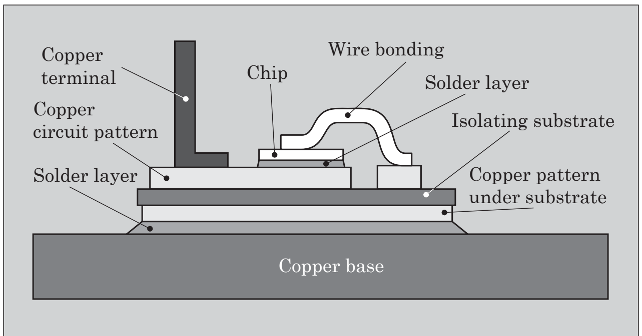

Fig.5 Schematic cross-section of new high power 2-in-1 IGBT module

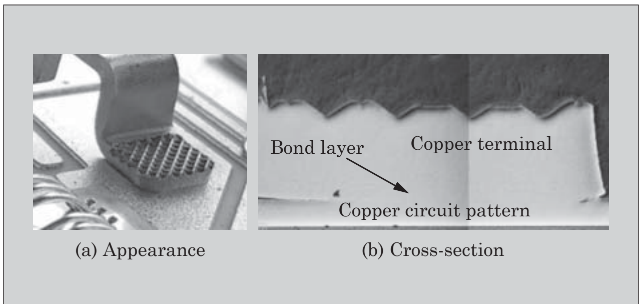

Fig.6 Appearance and cross-section of ultrasonic terminal bond

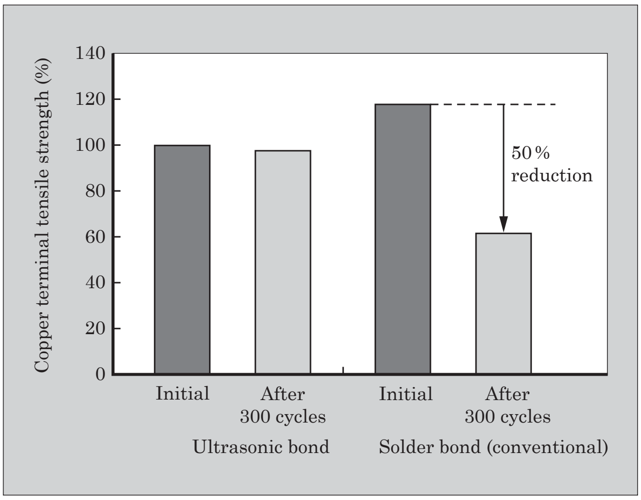

Fig.7 Copper terminal tensile strength test results

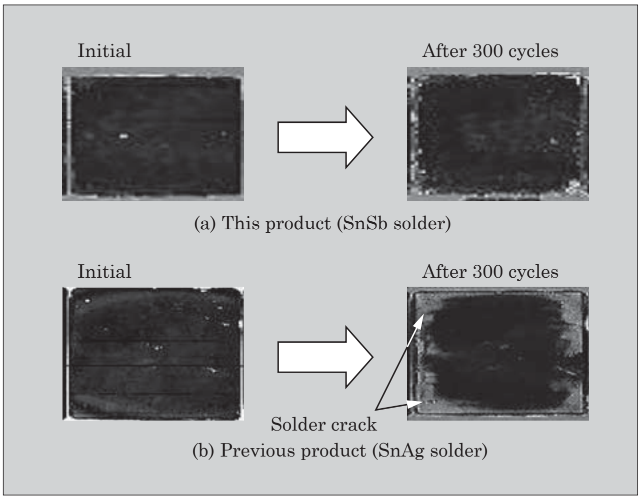

Fig.8 Results of ultrasonic crack inspection underneath isolating substrate

thermal cycling, as has been described in section 4.1. This product uses SnSb solder which is highly resistant to cracking to realize high thermal cycle tolerance. Fig. 8 shows the results of an ultrasonic crack inspection underneath the isolating substrate before and after 300 cycles of a thermal cycle test.

Compared to the conventional SnAg solder that cracked after 300 cycles, the SnSb solder used in this product exhibited almost no signs of cracking after 300 cycles. As a result of the improved solder material, greater tolerance to repeated thermal cycles (ΔT_c power cycles) that simulate actual operation was achieved as shown in Fig. 9. This new product is capable of withstanding 10,000 cycles or more at ΔT_c=80 °C, which is more than two times the ΔT_c power cycle tolerance of the prior product.

4.3 Improved environmental durability of molded case

In the state where the surface of the molded case is placed in a high electric field, particles and moisture adhering to the surface of the molded case carbonize and form conducting carbonized paths (tracks) that decrease the isolation and possibly lead to dielectric breakdown. Wind and solar power generators are sometimes installed in regions that lack a complete power infrastructure, and are often installed in high-humidity environments that contain large amounts of dust and salt. So that IGBT modules can be used with high reliability in such an environment, molded case technology that inhibits the formation of conducting carbonized paths must be developed. This product uses molding resin having a high comparative tracking index (CTI) of at least 600, thereby ensuring high tracking performance.

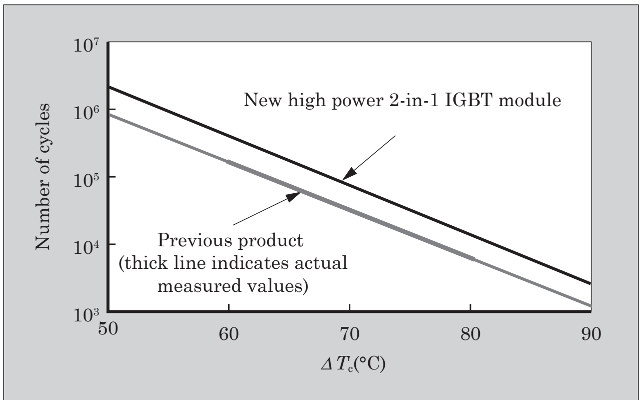

Fig.9 Tolerance to ΔT_c power cycles that simulate actual operation

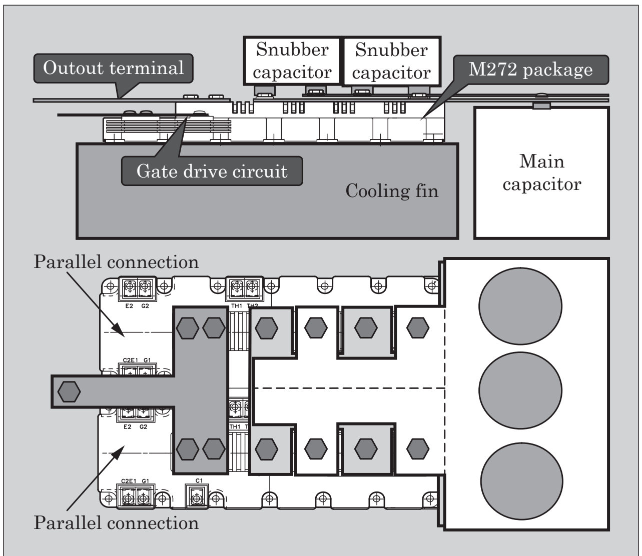

Fig.10 Schematic of layout when connected in parallel

4.4 Reduced stray capacitance

As described in Chapter 3, the new high power 2-in-1 IGBT module realizes electrical characteristics that are suited for high power applications. Most power conversion systems used in high power applications are required to have the capability to block large currents instantaneously. For this purpose, it is important to reduce the stray inductance within the product and to lower the surge voltage. With this product, the conducting portions of the main collector and emitter terminals are formed as flat parallel plates, and magnetic field interactions are actively utilized to reduce the internal stray capacitance from the previous value of 21 nH to 10 nH, thus achieving an approximate 50% decrease.

5. Operation With Parallel Connections

In the case where modules are connected in parallel, a reduction in reliability may result unless there is uniform current flow among the modules connected in parallel. Accordingly, it is important that current be shared evenly among modules. As mentioned above, in order to facilitate the trend toward higher power in power conversion systems, this product has electrical characteristics and a package structure suited for parallel connections. Fig. 10 shows a schematic layout

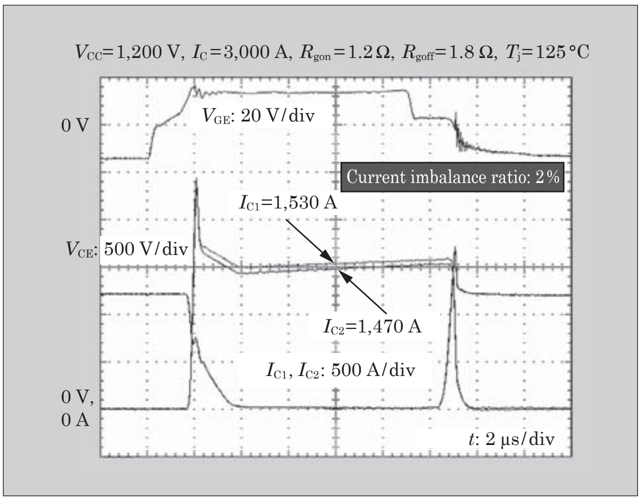

Fig.11 Measured results of current sharing among modules

of the M272 package when two modules are connected in parallel. Fig. 11 shows examples of actual measurements when two modules are connected in parallel. These measurements show favorable parallel connection characteristics with a current imbalance among modules of less than 2%.

6. Postscript

This paper has described Fuji Electric's new high power 2-in-1 IGBT module equipped with a "V Series" IGBT and featuring significantly improved reliability. These modules will certainly represent a product group capable of supporting a wide range of applications in the new energy field for which a market has been growing rapidly, as well as applications in the high power field in which needs are diversified.

In order to meet further needs in the future, Fuji Electric intends to continue to improve its semiconductor technology and package technology and to develop new products that contribute to the advancement of power electronics.

References

(1) Morozumi, A. et al. Reliability of Power Cycling for IGBT Power Semiconductor Module. Conf. Rec. IEEE Ind. Appl. Cof. 36th. 2001. p.1912-1918. [in Japanese]