Expanded Lineup of High-Power 6th Generation IGBT Module Families

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ABSTRACT

To respond to growing demand in the renewable energy sector, including wind and solar power, Fuji Electric has expanded the lineup of modules in its high-power insulated gate bipolar transistor (IGBT) module families. These new high-power modules feature 6th-generation "V-Series" IGBTs. Operation is guaranteed at maximum junction temperatures up to 175 °C, and the modules deliver industry leading low on-voltage and low switching loss. Reliability is higher than conventional products due to the application of the latest packaging technology, including ultrasonic welded terminals and highly reliable lead-free solder.

1. Introduction

Insulated gate bipolar transistor (IGBT) modules are used widely due to their advantages of low loss, high breakdown resistance, ease of drive circuit design and so on. In the field of high-voltage and high-power device applications, the heretofore widely-used gate turn-off (GTO) thyristors are being replaced with IGBT modules, and IGBT modules are being applied widely to high-power inverters and high voltage inverter units.

In recent years, for the prevention of global warming, the market for renewable energy (wind power generation, solar power generation) has been growing rapidly. In this field, power conversion equipment has progressed to higher capacities, and in particular, the need for high-power IGBT modules has increased greatly. For applications in this field, Fuji Electric has previously developed the high power module (HPM) and PrimePACK™ *1 product series.[1][2]

Recently, in response to diverse customer needs, Fuji Electric has expanded the HPM and PrimePACK™ product series. Equipped with Fuji Electric's 6th generation "V-Series" IGBTs[3], these products achieve the industry's leading level of low on-voltage and, at the same time, low switching loss. Additionally, the latest package technology is applied to realize high power density and high reliability.

This paper presents an overview and describes the characteristics of Fuji Electric's "V-Series HPM Family" of high-power 6th generation IGBT modules.

*1: PrimePACK™ is a trademark or registered trademark of Infineon Technologies AG.

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2. Product Lineup

Figure 1 shows the appearance of the V-Series HPM Family packages. The PrimePACK™ product series consists of 2-in-1 and chopper module circuit

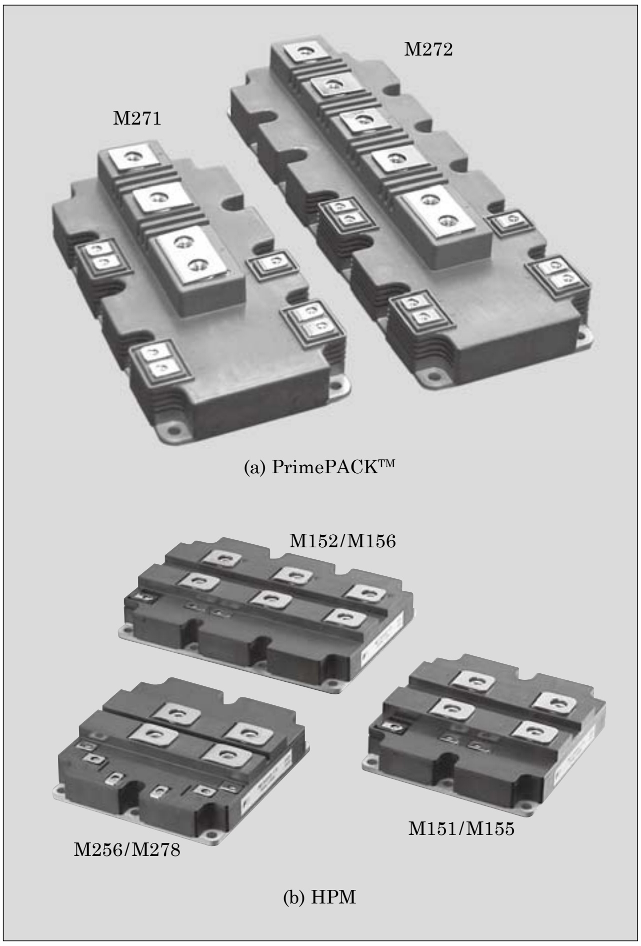

Fig.1 Appearance of V-Series HPM Family packages

Table 1 V-Series HPM Family product lineup

	Product lineup	Product type	Rated voltage (V)	Rated current (A)	Circuit configu-ration	Package type	Package size (mm)	Insulating substrate	Base material Base thickness
PrimePACK™	E-type	2MBI600VXA-120E-50	1,200	600	2-in-1	M271	172×89×38	Al_2O_3	Copper 3 mm
		2MBI900VXA-120E-50		900					
	P-type	2MBI900VXA-120P-50							
		2MBI1400VXB-120P-50		1,400		M272	250×89×38		
	E-type	2MBI650VXA-170E-50	1,700	650		M271	172×89×38		
		2MBI1000VXB-170E-50		1,000		M272	250×89×38		
		2MBI1000VXB-170EA-50							
		2MBI1400VXB-170E-50		1,400					
	P-type	2MBI1400 VXB-170P-50							
	E-type	1MBI650VXA-170EH-50		650	Chopper	M271	172×89×38		
		1MBI650VXA-170EL-50							
		1MBI1000VXB-170EH-50		1,000		M272	250×89×38		
		1MBI1000VXB-170EL-50							
Industrial-use HPM	TBD*1	1MBI1200VC-120*1	1,200	1,200	1-in-1	M151	130×140×38	Si_3N_4	Copper 5 mm
		1MBI1600VC-120*1		1,600					
		1MBI2400VC-120*1		2,400					
		1MBI2400VD-120*1		2,400		M152	190×140×38		
		1MBI3600VD-120*1		3,600					
		2MBI600VG-120*1		600	2-in-1	M256	130×140×38		
		2MBI800VG-120*1		800					
		2MBI1200VG-120*1		1,200					
	E-type	1MBI1200VC-170E	1,700	1,200	1-in-1	M151	130×140×38		
		1MBI1600VC-170E		1,600					
		1MBI2400VC-170E		2,400					
		1MBI2400VD-170E		2,400		M152	190×140×38		
		1MBI3600VD-170E		3,600					
		2MBI600VG-170E		600	2-in-1	M256	130×140×38		
		2MBI800VG-170E		800					
		2MBI1200VG-170E		1,200					
Traction-use HPE		1MBI1200VR-170E*2		1,200	1-in-1	M155	130×140×38	AlN	Al SiC
		1MBI1600VR-170E*2		1,600					
		1MBI2400VR-170E*2		2,400					
		1MBI2400VS-170E*2		2,400		M156	190×140×38		
		1MBI3600VS-170E*2		3,600					
		2MBI600VT-170E*2		600	2-in-1	M278	130×140×38		
		2MBI800VT-170E*2		800					
		2MBI1200VT-170E*2		1,200					

*1 : TBD：To Be Determined
*2 : underdevelopment

configurations, 1,200 V and 1,700 V class ratings, and current capacities of 600 to 1,400 A. The HPM product series consists of 1-in-1 and 2-in-1 module circuit configurations, 1,200 V and 1,700 V class ratings, and current capacities of 600 to 3,600 A. Table 1 lists the lineup of the V-Series HPM Family product series.

3. Electrical Characteristics

Incorporating a V-Series IGBT, the V-Series HPM Family of products guarantees non-continuous operation up to a maximum chip junction temperature of T_{jmax}=175 °C for momentary abnormal states, and guarantees normal operation at an operating temperature of T_{jop}=150 °C. By improving reliability and breakdown resistance during high-temperature operation, each of these temperatures was increased by 25 °C compared to those of the 5th generation “U-Series” IGBT modules.

3.1 IGBT chip characteristics

Because a high-power IGBT module will instantaneously cut off a large current, the surge voltage generated at turn-off is large. For the V-Series HPM

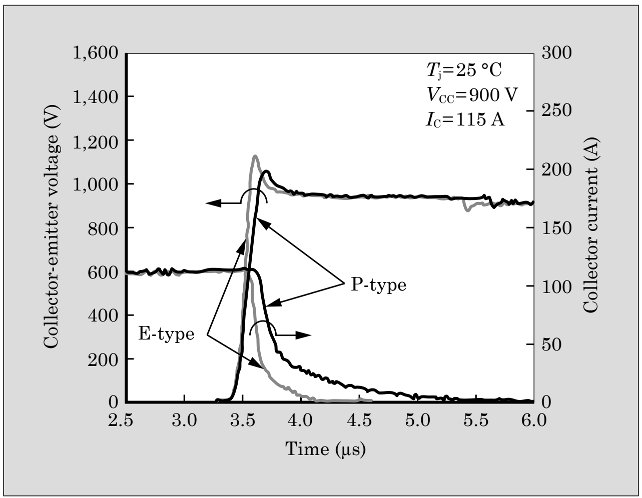

Fig.2 Comparison of IGBT turn-off switching waveforms

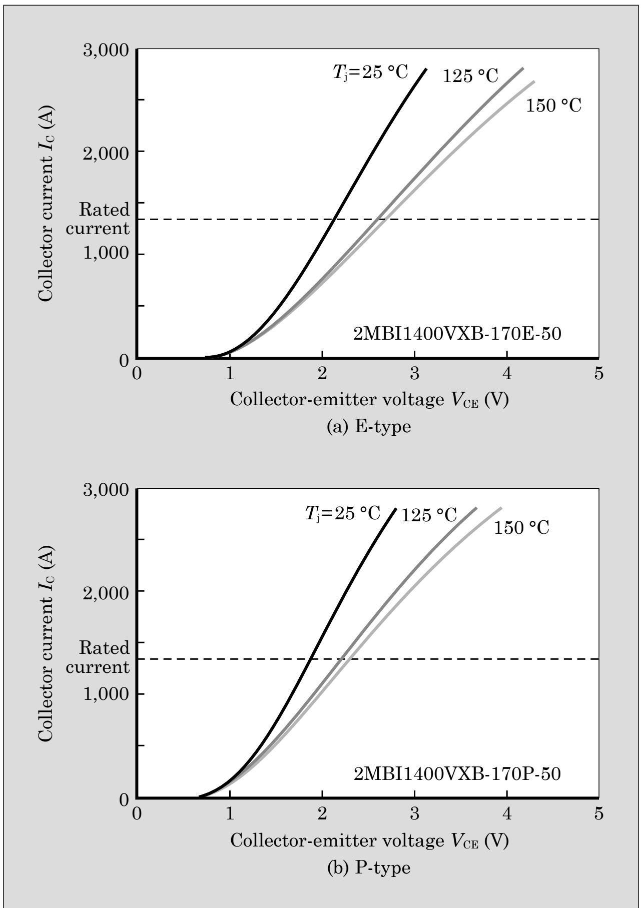

Fig.3 $V_{CE(sat)}$-I_c characteristics

Family, in addition to the previous (E-type) lineup of V-Series IGBT chips, an IGBT chip product lineup (P-type) having soft switching characteristics was newly developed by adjusting the IGBT chip characteristics for applications in the high-power device field. Figure 2 shows a comparison of the switching waveforms at turn-off for E-type and P-type 1,700 V-IGBT chips. Compared to the E-type, the P-type has a slower di/dt at turn-off, and achieves a lower turn-off surge voltage. Electrical characteristics are described below for the example of a 1,700 V/1,400 A module.

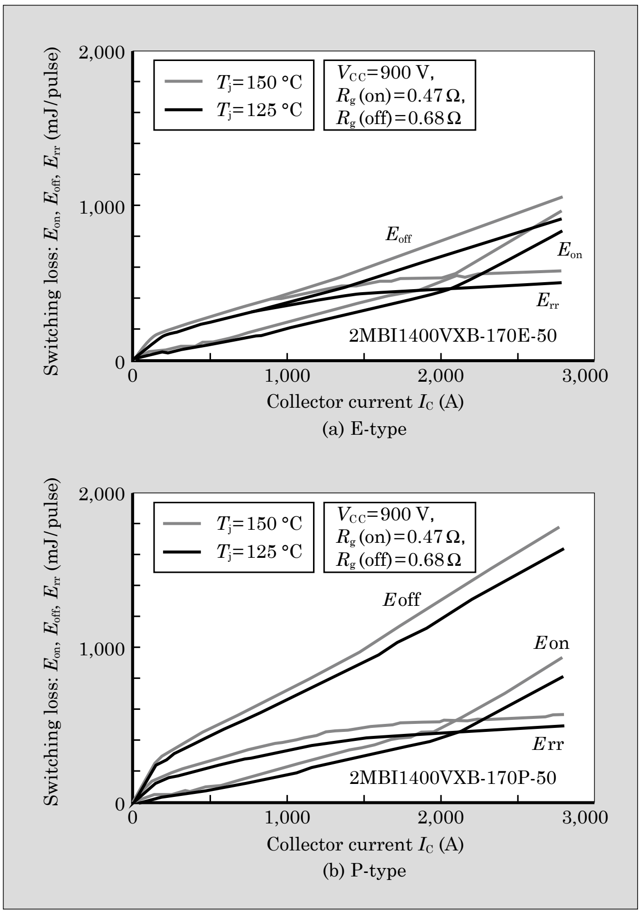

Fig.4 Switching loss vs. current characteristic

3.2 V-I characteristics

Figure 3 shows I_C vs. $V_{CE(sat)}$ characteristics of the module. Comparing the E-type and the P-type reveals that at the rated current of I_C=1,400 A and T_j=125 °C, the characteristic of the P-type is about 0.4 V lower.

3.3 Switching characteristics

Figure 4 shows the switching loss vs. current characteristic. In terms of turn-on loss and reverse recovery loss, the E-type and the P-type are the same, but the turn-off loss is about 1.8 times larger for the P-type.

As described above, the V-Series HPM Family contains two types of product lines with different IGBT chip characteristics so that suitable products can be provided for the drive conditions of our customers.

4. Package Structure

Power conversion equipment in the renewable energy field and elsewhere must have high reliability in order to provide a stable supply of electric power.[4] The V-Series HPM Family uses the latest package technology to ensure long-term reliability.

Figure 5 shows a cross-sectional schematic view of an IGBT module. Connecting a conducting/blocking electrical load to an IGBT module causes thermal stress is generated in the junction of the IGBT. The use of materials having a low coefficient difference of thermal expansion in the junction ensures high thermal cycling capability. Table 2 lists the technologies and materials applied to the V-Series HPM Family. The PrimePACK™ series uses ultrasonic welding technology and highly reliable lead-free solder material to achieve higher reliability than in previous products. The HPM product line uses a 5 mm-thick base, or an AlSiC base for traction applications, to achieve even longer term reliability.

4.1 Application of ultrasonic terminal welding technology

Figure 6 shows the external appearance and a cross-sectional view of an ultrasonically welded terminal. This product uses ultrasonic terminal welding to bond copper terminals directly to the copper circuit pattern. In a conventional solder joint structure, the greatest amount of stress is concentrated in the solder layer due to difference in the coefficients of thermal expansion of the solder material and the copper material. As a result, failure may result whereby cracks form in the solder layer and the copper terminal is pulled out. Figure 7 shows a comparison of the results of copper terminal tensile strength tests before and after a thermal cycle test (test conditions: −40 to+150 °C repeatedly). For the conventional solder joint, an approximate 50% decrease in tensile strength from the initial value was confirmed after 300 cycles. On the other hand, almost no decrease in tensile strength was observed in the case of ultrasonic welding. This is because the copper terminals and the copper circuit pattern are bonded together directly with ultrasonic terminal welding, and there is no difference in the coefficients of thermal expansion at the joint surface.

4.2 Improved power cycling capability

As shown in Fig. 5, thermal cycle stress occasionally causes cracks to form in the solder layer between the copper base and the copper pattern under the substrate. With the PrimePACK™ series, tolerance to high temperature cycling is achieved by using highly

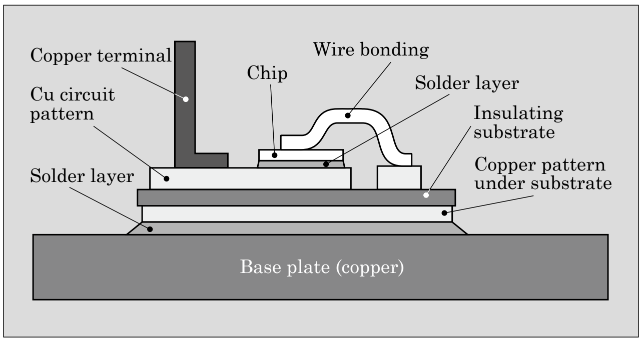

Fig.5 Cross-sectional schematic view of an IGBT module

Table 2 Technologies and materials applied to the V-Series HPM Family

	PrimePACK™	HPM	
		Industrial use	Traction use
Terminal welding method	Ultrasonic welding	Solder welding	Solder welding
Insulating substrate	Al_2O_3	Si_3N_4	AlN
Solder material under insulating substrate	Sn-Sb	Sn-Pb	Sn-Pb
Base material Base thickness	Copper 3 mm	Copper 5 mm	AlSiC 5 mm

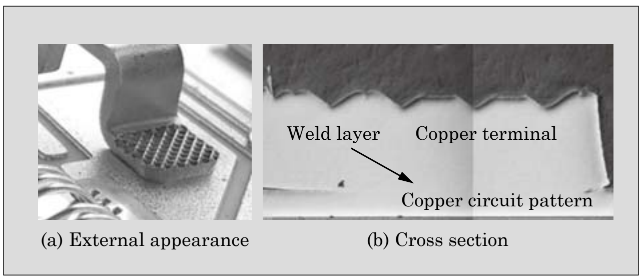

Fig.6 External appearance and cross-sectional view of ultrasonically welded terminal

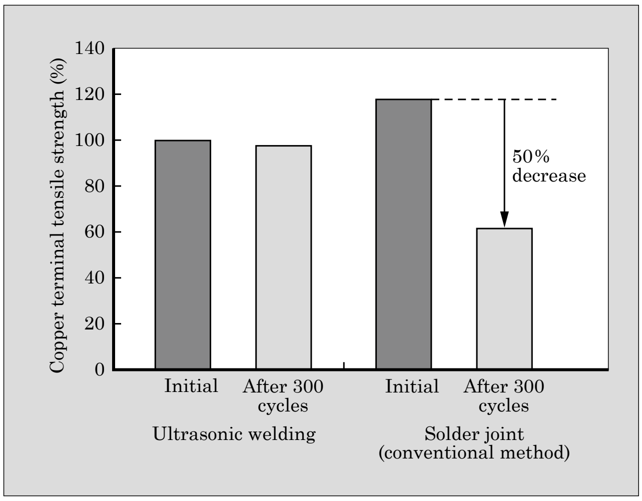

Fig.7 Copper terminal tensile strength test results

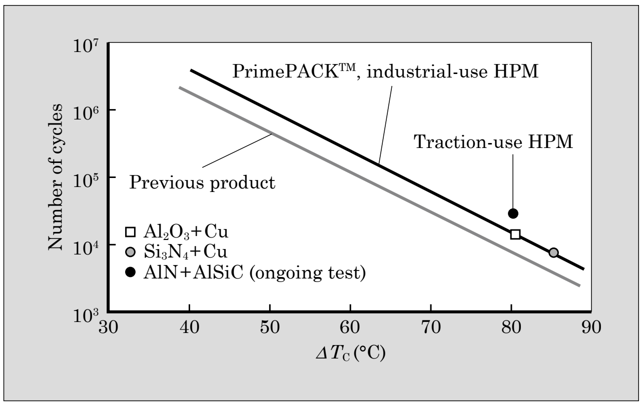

Fig.8 □T_C power cycling capability

crack-resistant Sn-Sb solder.

In traction-use HPMs, to ensure even higher reliability, an AlN substrate is used as the insulating substrate and an AlSiC base is used as the base material. AlSiC is a composite of Al and SiC, and having a coefficient of thermal expansion close to that of the AlN substrate, achieves higher thermal cycling capability and power cycling capability than in the case of a copper base. In the simulated tests of actual operation shown in Fig. 8, improved thermal cycling (ΔT_c power cycling) capability was realized. The V-Series HPM Family has a power cycle capability of greater than 10,000 cycles at ΔT_c=80 °C, and realizes more than twice the ΔT_c power cycling capability as the previous product.

4.3 Improved environmental durability of molded case

When the surface of a molded case is placed under a high electric field, dust and moisture adhering to the molded case surface cause the surface to become carbonized, and form a conductive path (track). This degrades the insulating performance and may lead to breakdown of the insulation. Wind and solar power generating equipment are often installed in high humidity environments containing large amounts of dust and salt. So that an IGBT module can be used in such an environment while maintaining high reliability, the development of a molded case on which a carbonized conductive path is not easily formed is needed. This product series uses a mold resin having a high comparative tracking index (CTI) of ≥ 600 to ensure high anti-tracking performance.

4.4 Reduction of internal inductance

The V-Series HPM Family introduced in Section 3 achieves electrical characteristics suitable for application in the high capacity field. Most power conversion equipment used in the high capacity field is required to be able to block large currents instantaneously. For this purpose, reducing the internal inductance L_m of the product to reduce the surge voltage is very important. In this product series, the collector and emitter terminals, which are main terminals, are located in close proximity to one another so as to actively utilize the mutual interactions of the magnetic field and reduce L_m.

5. Postscript

This paper has introduced the “V-Series HPM Family” which incorporates “V-Series” IGBTs and realizes significantly improved reliability. Fuji Electric is confident that these modules will be able to support the diverse needs of the high-power device field, as well as the needs of the renewable energy field for which a rapidly growing market is being formed.

Fuji Electric will continue to strive to advance the level of semiconductor technology and package technology so as to respond additional needs, and to develop new products that will contribute to the progress of power electronics.

References

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