"PrimePACK™" of 7th-Generation "X Series" 1,700-V IGBT Modules

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ABSTRACT

The demand for large-capacity IGBT modules has been expanding for power conversion systems used in various sectors such as industrial, consumer, automotive and renewable energy. Fuji Electric has developed the "PrimePACK™" as the 7th-generation "X Series" IGBT modules. The module reduces power dissipation through characteristic enhancement of semiconductor chip and significantly reduces thermal resistance by using a newly developed high thermal conductive insulating substrate. Furthermore, by improving the capacity of ΔT_{vj} power cycle and the heat resistance of insulating silicone gel, the module has increased the guaranteed continuous operating temperature from 150 °C to 175 °C. With these technical development, Fuji Electric has achieved a product with a maximum rated current of 1,800 A using newly developed technologies.

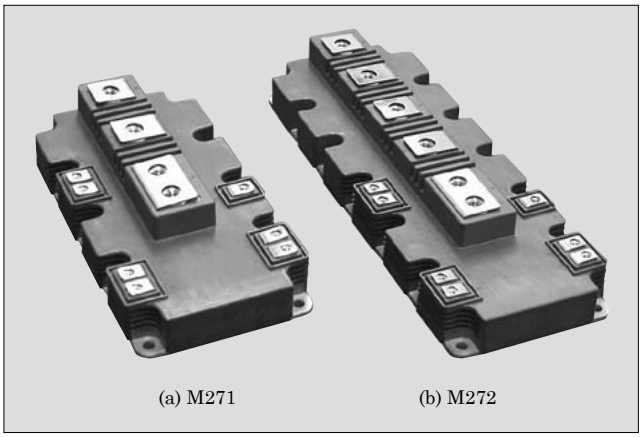
1. Introduction

These days, reduction of CO_2 emission is as worldwide trend to prevent global warming. Because of the background and expectation for power electronics technology, power conversion systems with power semiconductors are expanding in various application fields such as consumer and industrial, automotive applications. Especially, the demand for insulated gate bipolar transistors (IGBTs) has been expanding as a key device of power conversion systems for renewable energy, such as photovoltaic power generation or wind power generation, which have been introduced rapidly.

By many technological innovations, Fuji Electric has achieved downsizing, improvement of power dissipation and higher reliability of IGBT modules which contribute to higher efficiency or downsizing of power conversion systems in the past. In order to satisfy further market demands as more downsizing and higher efficiency, Fuji Electric has developed the 7th-generation "X series PrimePACK™*1".

2. Features of X Series PrimePACK™

Figure 1 shows the outline appearance of the X Series PrimePACK™. The X Series PrimePACK™ has 2 kind of packages named "M271" and "M272," as same shape as those of conventional "V Series" IGBT modules. Table 1 shows the X Series PrimePACK™ family. Maximum current rating of the X Series PrimePACK™ is 1,800 A for both 1,200 V and 1,700 V ratings. The maximum current rating is about 29% expansion compared with 1,400 A of conventional product. Furthermore, continuous operation junction temperature of T_{vjop} =175 °C has been achieved by advanced characteristics of semiconductor chips and package technologies with long-term reliability performance.



(a) M271 (b) M272

Fig.1 X Series PrimePACK™

3. Electrical Characteristics

In order to improve energy conversion efficiency, it is important to reduce power dissipation of IGBT module. The power dissipation is caused and affected by electrical characteristics of installed semiconductor chips, such as IGBT and free wheeling diode (FWD). The X Series PrimePACK™ enables significant reduction of power dissipation compared with conventional product by adopting the X series chips with latest fine cell technology and thin wafer technology.(1) Moreover, high temperature operating T_{vjop} =175 °C, 25 °C higher than conventional has been realized by improving reliability and withstand capability during higher tempera-

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

Table 1 X Series PrimePACK™ family

Package	Rating		Type	Insulating substrate	Insulation withstand voltage	CTI*	T_{vjop}
	Voltage	Current					
M271	1,200 V	900 A	2MBI900XXA120P-50	Al_2O_3	4.0 kV AC	>600	175 °C
		1,200 A	2MBI1200XXE120P-50	AlN			
	1,700 V	900 A	2MBI900XXA170-50	Al_2O_3			
		1,200 A	2MBI1200XXE170-50	AlN			
M272	1,200 V	1,400 A	2MBI1400XXB120P-50	Al_2O_3			
		1,800 A	2MBI1800XXF120P-50	AlN			
	1,700 V	1,000 A	2MBI1000XXB170-50	Al_2O_3			
		1,400 A	2MBI1400XXB170-50	Al_2O_3			
		1,800 A	2MBI1800XXF170-50	AlN			

* Comparative tracking index

ture operation.

3.1 IGBT characteristics

Trade-off relationship between saturation voltage and turn-off energy has been dramatically improved by the X series IGBT with newly developed fine cell technology and thinner wafer technologies. Figure 2 shows comparison of the trade-off characteristic for the X Series PrimePACK™ and a conventional product. The characteristics of the X Series are improved about 0.7 V of saturation voltage and about 11% of turn-off energy compared with conventional product. Moreover, optimized field stop layer has realized suppression of voltage oscillation during turn off and enough breakdown withstand voltage, even adapting thinner wafer.

3.2 FWD characteristics

Forward voltage of the X series FWD has been improved by thinner drift layer as well as X Series IGBT chip. Furthermore, both of soft recovery waveforms and improvement of reverse recovery energy have been realized by lifetime control optimization. Figure 3 shows trade-off relationship between forward voltage and reverse recovery energy. The characteristics of the X Series are improved about 0.15 V of forward voltage and about 16% of reverse recovery energy. In generally, thinner drift layer causes voltage oscillation and higher voltage spike during reverse recovery. However, the X Series has equal or better performances than the conventional product by optimization of back side voltage termination structure in FWD.

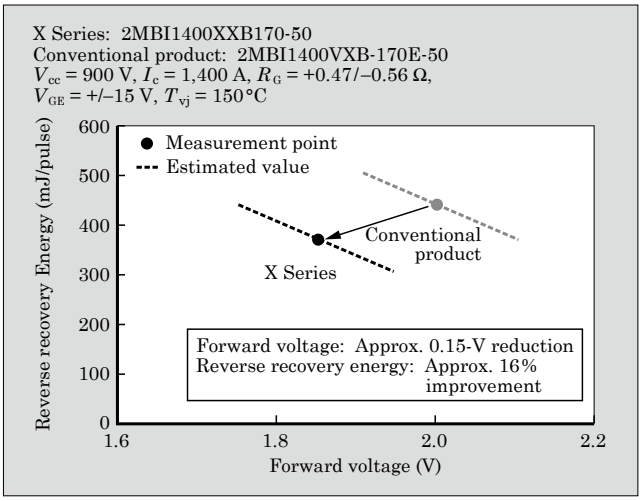

Fig.3 V_F – E_{rr} trade-off relationship (FWD)

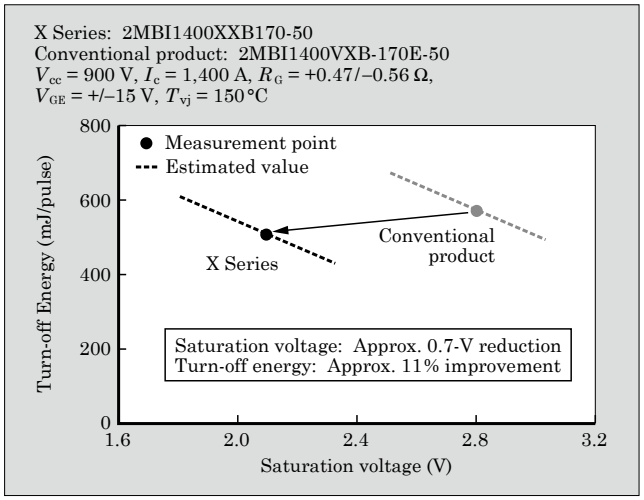

Fig.2 $V_{CE(sat)}$ – E_{off} trade-off relationship (IGBT)

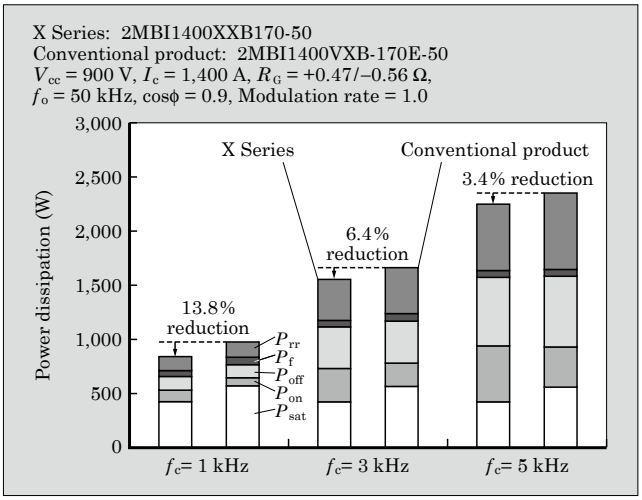

Fig.4 Power dissipation

3.3 Power dissipation

Figure 4 shows calculated results of power dissipation. According to the results, the X Series PrimePACK™ can reduce its power dissipation about 13.8% at a carrier frequency 1 kHz compared with conventional product, and enables to contribute higher efficiency of power conversion systems.

4. Packaging Technology

Table 2 shows a comparison of the X Series and conventional PrimePACK™. The X Series PrimePACK™ is designed to increase output current of power conversion systems with same package size as conventional product. In order to achieve the higher output current, it is necessary to consider countermeasures for higher temperature raising of semiconductor chips and degradation of long-term reliability performance. Reduction of semiconductor chips temperature rising is realized by newly developed packaging technologies. Additionally, continuous operation temperature upgrading also has been achieved from 150 °C to 175 °C as shown in Table 2. Long-term reliability has been also improved to realize high temperature operation in application field.[(2),(3)]

4.1 Newly developed high thermal conductive insulating substrate

Improvement of junction-to-case thermal resistance is important to realize effective cooling for heat from semiconductor chips and main terminals. Highest current rating of the X Series PrimePACK™ has newly developed high thermal conductive insulating aluminum nitride (AlN) substrate for higher cooling performance. As a results, thermal resistance of junction-to-case has been improved by about 45% compared with conventional alumina (Al_2O_3) substrate in case of same chip size. Figure 5 shows experimental results for temperature raise in package. The results show that about 11 °C temperature reduction of IGBT part has been achieved by the new AlN substrate compared with conventional. Main terminals temperature has also been improved by about 7 °C.

Table 2 Comparison of X Series and conventional PrimePACK™

	X Series PrimePACK™	Conventional product
Rated voltage	1,200 V, 1,700 V	1,200 V, 1,700 V
Max. rated current	1,800 A	1,400 A
Insulating substrate	AlN	Al_2O_3
Continuous operation junction temperature T_{vjop}	175 °C	150 °C
Silicone gel heat resistance	175 °C	150 °C

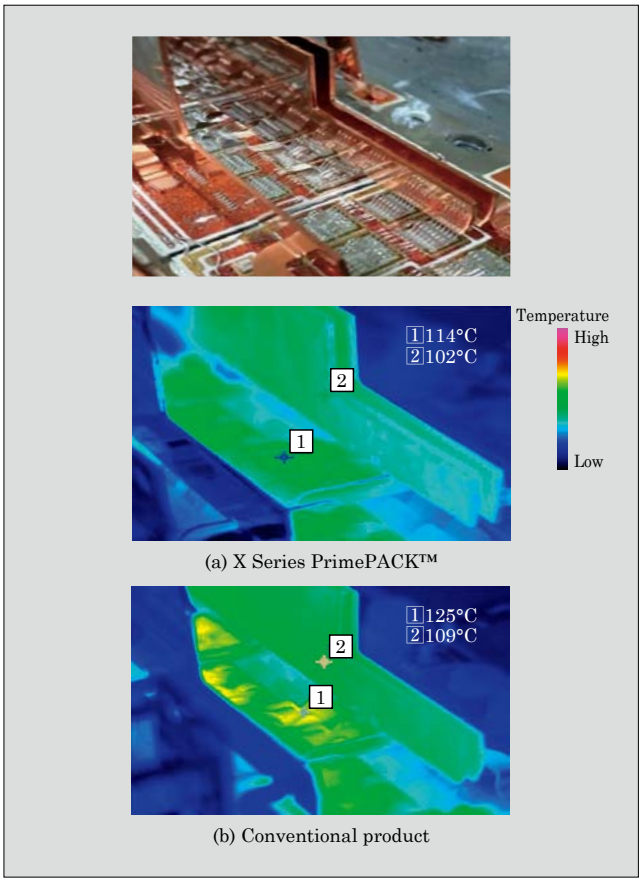

Fig.5 Experimental results of temperature rise

4.2 Expansion of continuous operation junction temperature T_{vjop}

In order to realize more higher output current, operation junction temperature T_{vjop} has been expended from 150 °C to 175 °C compared with conventional product. For the expansion, capability improvement against repetitive thermal stress (ΔT_{vj} power cycle capability) is necessary.

Figure 6 shows the ΔT_{vj} power cycle capability. The ΔT_{vj} power cycle capability is degraded by high

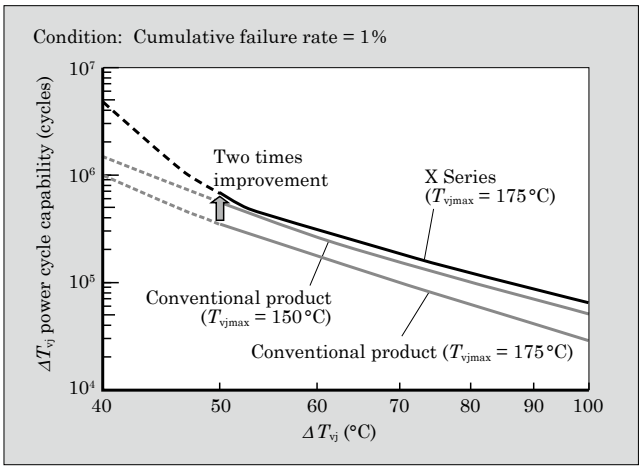

Fig.6 ΔT_{vj} power cycle capability

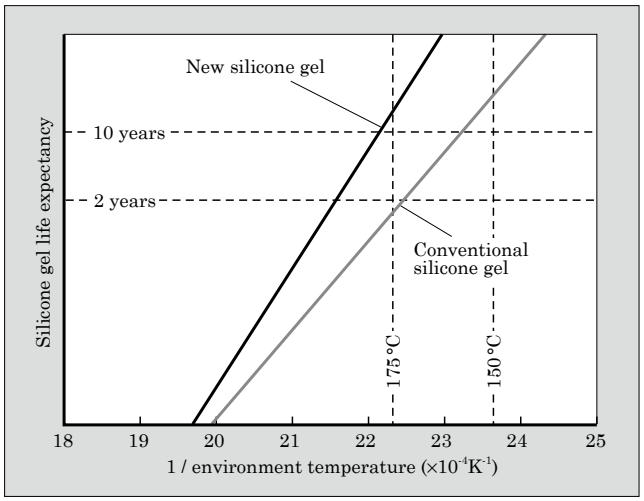

Fig.7 Relationship between temperature and estimated silicone gel life time

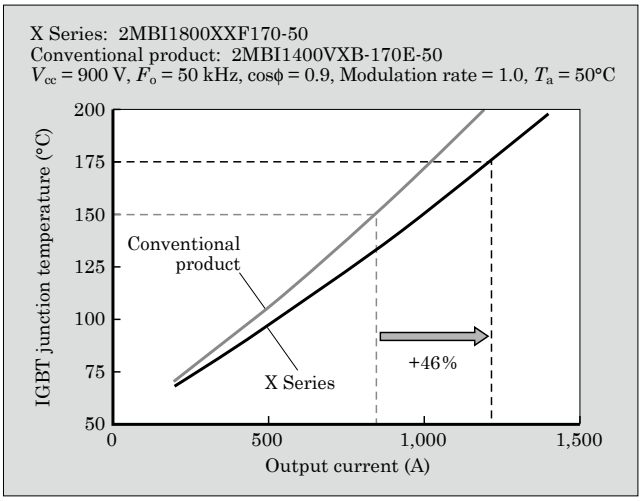

Fig.8 Output current and IGBT junction temperature

temperature operation. For example, the capability of conventional product at T_{vjmax} = 175 °C is lower than at 150 °C. However, the capability of the X Series PrimePACK™ has been improved about 2 times higher than conventional product under conditions of T_{vjmax} = 175 °C and ΔT_{vj} = 50 °C. The superior capability has been realized by newly developed solder material and new wire bonding technology for semiconductor chips.

According to the results, the X Series PrimePACK™ has realized higher ΔT_{vj} power cycle capability at T_{vjmax} = 175 °C than that of conventional product even at T_{vjmax} = 150 °C.

4.3 Newly developed silicone gel for high temperature operation

IGBT module has silicone gel in its inside to have enough insulation performance. However conventional silicone gel is degraded by high temperature operation such as 175°C.

Figure 7 shows the relationship between temperature and silicone gel life time. According to the data, conventional silicone gel has over 10 years life time at 150°C. However it's only about 2 years at 175°C. The X series products utilize newly developed silicone gel to have enough life time against high temperature operation such as 175°C. The new silicone gel has over 10 years life time at 175°C, it is almost same life time as convention one at 150°C.

5. Summary

Operation temperature upgrading to T_{vjop} = 175°C by the X Series PrimePACK™ family has been realized by serval advanced new technologies such as power dissipation reduction by semiconductor chips improvement, extra cooling by new AlN substrate, ΔT_{vj} power cycle capability reinforce and high temperature operating capability by new silicone gel. As a results of these Fuji Electric efforts, higher energy conversion efficiency and more output power of power conversion systems can be realized.

Figure 8 shows relationship between output current of the system and IGBT junction temperature as an example of improvements. As the result, 1.46 times output current can be achieved with the X Series PrimePACK™ compared with the conventional product.

6. Postscript

The 7th-generation "X Series" IGBT module "PrimePACK™" has achieved top class performance in the power semiconductor market by dramatic improvement of semiconductor chip characteristic and new packaging technology. Further downsizing and higher efficiency of power conversion systems will be achieved by the X series families. It will contribute to safe, secure and sustainable society. Fuji Electric will continuously offer superior products with advanced technologies and will contribute to achieving many benefits such as downsizing, higher efficiency and reliable performance of power conversion systems.

References

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(2) Momose, F. et al. "The New High Power Density Package Technology for the 7th Generation IGBT Module", PCIM Europe 2015.
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