7th-Generation "X Series" RC-IGBT Module Line-Up for Industrial Applications

YAMANO, Akio*　TAKASAKI, Aiko*　ICHIKAWA, Hiroaki*

ABSTRACT

In order to meet the market demand of the smaller size, lower power dissipation and higher reliability for IGBT modules, Fuji Electric has developed a reverse conduction insulated gate bipolar transistor (RC-IGBT) that integrates an IGBT and a FWD on a single chip. We have also developed the "Dual XT" to expand the line-up of the 7th-generation "X Series" RC-IGBT module for industrial applications that has a rated voltage of 1,200 V. While the "Dual XT" 6th-generation "V Series" IGBT module for industrial applications had a maximum rated current of 600 A, the new module has an expanded rated current of 1,000 A. Compared with the conventional product, which uses the same package, the new product greatly improves the junction temperature and junction temperature rise of the chip during actual operation. This module will contribute to further increase of the output and extension of service life of the power converters.

1. Introduction

In recent years, there has been increasing expectations for power electronics technologies that can efficiently utilize energy and contribute to energy conservation in order to prevent global warming and realize a safe, secure and sustainable society. In particular, the demand for power semiconductors has been expanding as a key device of power conversion systems in various fields such as industry, consumer, automobile and renewable energy.

Since Fuji Electric commercialized an insulated gate bipolar transistor (IGBT) module in 1988, we have contributed to miniaturization, cost reduction and performance improvement of power conversion systems through many IGBT module technology innovations especially to miniaturize the size, reduce the loss and improve the reliability. However, further miniaturization of IGBT modules increases the power density, and it would lead to create the risk of lower reliability due to increasing the operating temperatures of IGBTs and free wheeling diodes (FWDs). For this reason, technological innovations for chips and packages are essentiality in order to maintain high reliability and increase the power density of the IGBT modules.

To achieve this, we have innovated chip and packaging technology and has developed 7th-generation "X Series" IGBT module, which has facilitated increased power density through its low loss and high reliability characteristics.[(1),(2)] In addition, we have also developed a reverse-conducting IGBT (RC-IGBT) that integrates an IGBT and FWD into a single chip.[(3),(4)] We have reduced the number of chips and total chip area while reducing generation loss. We have also achieved further increase in power density through our 1,200-V 7th-generation "X Series" RC-IGBT (X Series RC-IGBT) module for industrial applications by combining this chip and packaging technology. Currently, we are proceeding with the series of X Series RC-IGBT modules, and this time, we have developed the "Dual XT" with RC-IGBT.

* Electronic Devices Business Group, Fuji Electric Co., Ltd.

2. Characteristics of 7th-Generation "X Series" RC-IGBT Module for Industrial Applications

Figure 1 shows the schematic diagram and equivalent circuit of the X Series RC-IGBT. Inverters that are widely used as power conversion systems require antiparallel connection of an IGBT and a FWD chip. In contrast to this, the RC-IGBT integrates an IGBT and FWD into a single chip.

Compared with the 6th-generation "V Series" IGBT, the X Series RC-IGBTs have also applied finer pattern design rules of X Series chip technology and achieved significant reduction in collector-emitter saturation voltage $V_{CE(sat)}$. Moreover, the latest thin wafer

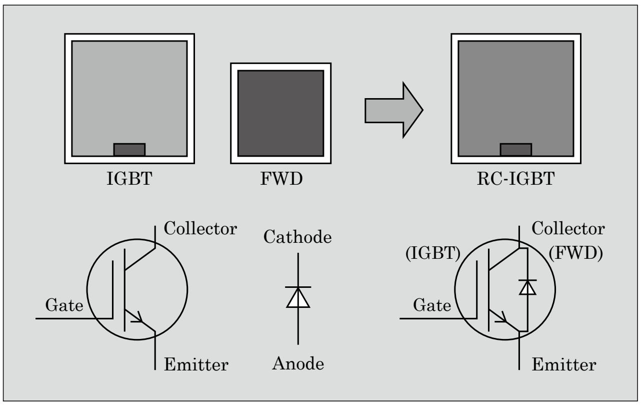

Fig.1 Schematic diagram and equivalent circuit for 7th-generation "X Series" RC-IGBT for industrial applications

processing technology has also been applied to improve the trade-off relationship between the saturation voltage and turn-off switching loss. In general, there is the risk of voltage oscillation and breakdown voltage reduction during turn off when utilizing thin wafers. However, the X Series RC-IGBT suppresses them through optimization of each structure for the chip.

Thermal resistance has also been greatly reduced through applying a heat high-dissipating insulating substrate, which is one of the packaging technologies of the X Series. In addition, the module guarantees operating virtual junction temperature under switching conditions T_{vjop} at 175 °C and secures high reliability through optimization of wire bonding, utilization of high-strength solder and highly heat-resistant silicone gel.

By employing these technologies, X Series RC-IGBT module achieves a higher rated current in the same package size as previous products that are composed of both conventional IGBT chip and FWD chip.[5]

3. Product Line-Up

Figure 2 shows the external appearance of the newly developed X Series RC-IGBT Dual XT module, Table 1 shows the line-up and Table 2 shows the characteristics. The 7th-generation X Series RC-IGBT Dual XT module has expanded maximum rated current to 1,000 A, whereas the 6th-generation "V Series" IGBT Dual XT module for industrial applications has a maximum rated current of 600 A.

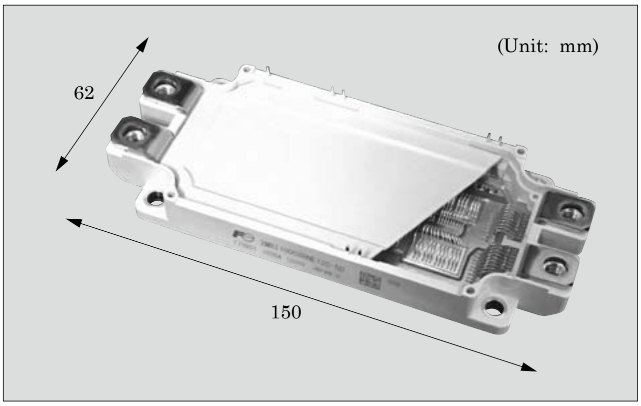

Fig.2 7th-generation "X Series" RC-IGBT "Dual XT" module for industrial applications

Table 1 "Dual XT" line-up

Rated voltage 1,200 V	Rated current (A)						
	225	300	450	600	800	900	1,000
Dual XT	V Series IGBT + V Series FWD						
	X Series IGBT + X Series FWD						X Series RC-IGBT

Table 2 "Dual XT" characteristics

Rated voltage	1,200 V		
Representative type	2MBI600 VN-120-50	2MBI800XNE120-50	2MBI1000XRNE120-50
Series name	6th-generation V Series IGBT module	7th-generation X Series IGBT module	7th-generation X Series RC-IGBT module
Chip	V Series IGBT + V Series FWD	X Series IGBT + X Series FWD	X Series RC-IGBT
Thermal resistance: $R_{th(j-c)}$ (a.u.)	1/1.5 (IGBT/FWD)	0.85/1.1 (IGBT/FWD)	0.55/0.55 (IGBT/FWD)

4. Characteristics of 7th-Generation "X Series" RC-IGBT "Dual XT" Module for Industrial Applications

Figure 3 shows the output characteristics of the X Series RC-IGBT Dual XT module with a rated current of 1,000 A compared with the V Series IGBT Dual XT module with a rated current of 600 A in the same package size. The X Series RC-IGBT allows an electric current to flow in both the forward (IGBT) and reverse (FWD) directions by a single chip. In the RC-IGBT, conductivity modulation of IGBT can become difficult to occur when a gate voltage is applied and the IGBT flows the current. In particular, the snapback phenomenon can occur in a low saturation voltage case.[6],[7] In contrast to this, the X Series RC-IGBT has solved the snapback phenomenon through optimization of each structure for the chip.

Figure 4 shows the turn off waveform of the X Series RC-IGBT Dual XT module. Compared with the V Series IGBT Dual XT module, surge voltage has been decreased by about 100 V during turn off under the same switching conditions. Furthermore, there was no observation of abnormal waveforms such as voltage oscillation or reach-through waveforms.

Figure 5 shows the IGBT trade-off relationship of

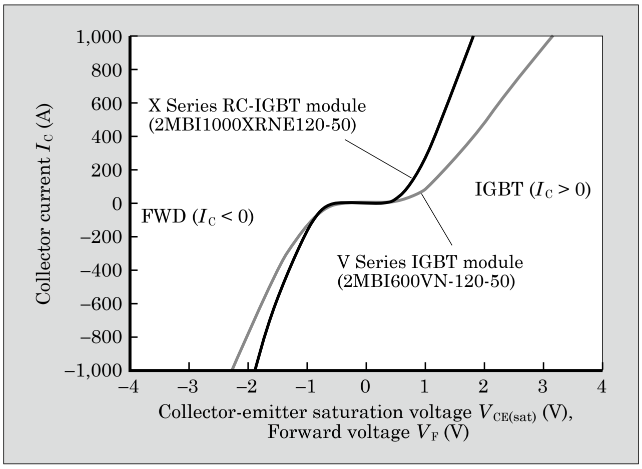

Fig.3 Output characteristics

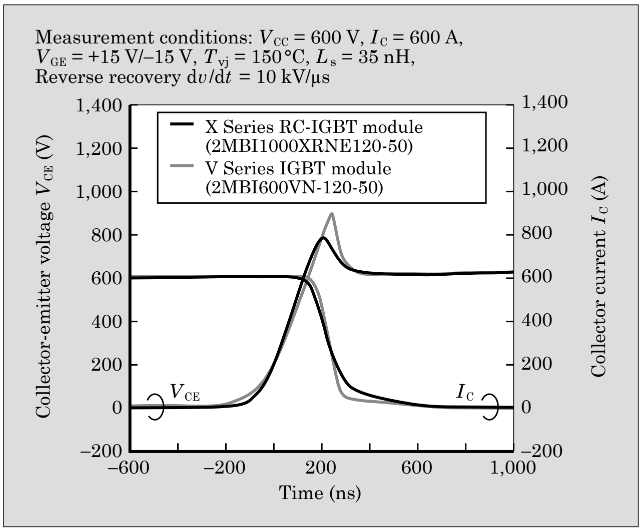

Fig.4 Turn-off waveforms

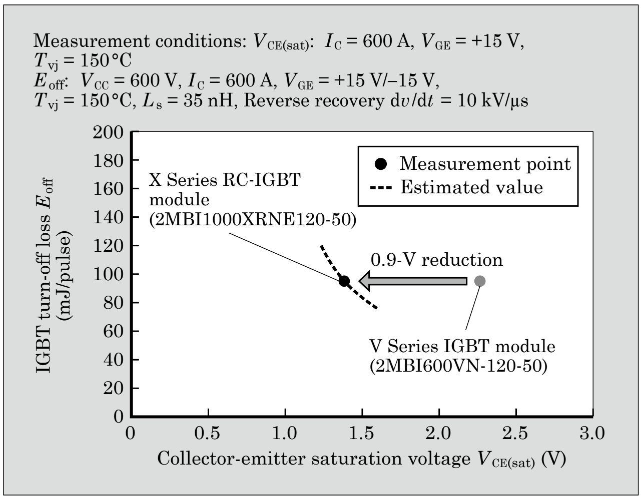

Fig.5 IGBT trade-off relationship

the X Series RC-IGBT Dual XT module. The dotted line in the figure represents the adjustment of trade-off through structural parameter control. In case of the same switching loss, the X Series RC-IGBT Dual XT module reduces saturation voltage by 0.9 V compared with the V Series IGBT Dual XT module.

Figure 6 shows the inverter power dissipation, virtual junction temperature T_{vj} and delta virtual junction-to-case temperature $\Delta T_{vj\text{-}c}$ of the X Series RC-IGBT Dual XT module. By combining X Series chip technology with RC-IGBT technology, the module has been able to expand maximum rated current and reduce power loss by 11% compared with the V Series IGBT Dual XT module under the same inverter power dissipation conditions. Furthermore, by combining X Series packaging technology with RC-IGBT technology, the module has been able to greatly reduce thermal resistance and also reduce virtual junction temperature T_{vj} by 34 °C and $\Delta T_{vj\text{-}c}$ by 41%.

Figure 7 shows the variation of T_{vj} during low-frequency operation. The X Series RC-IGBT Dual XT

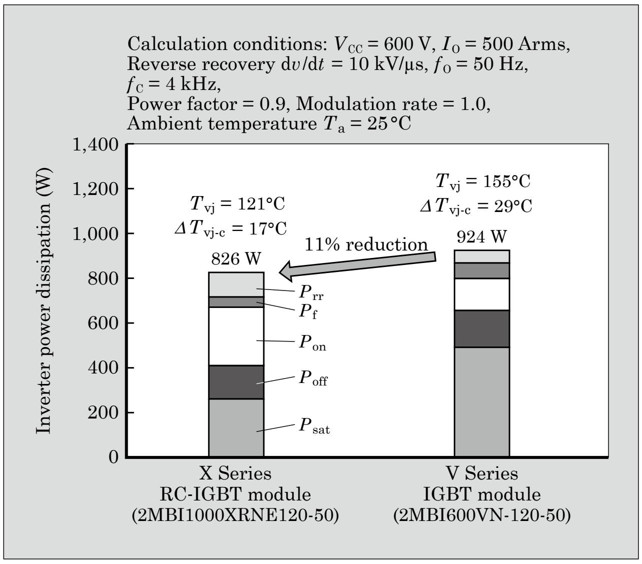

Fig.6 Inverter power dissipation and virtual junction temperature

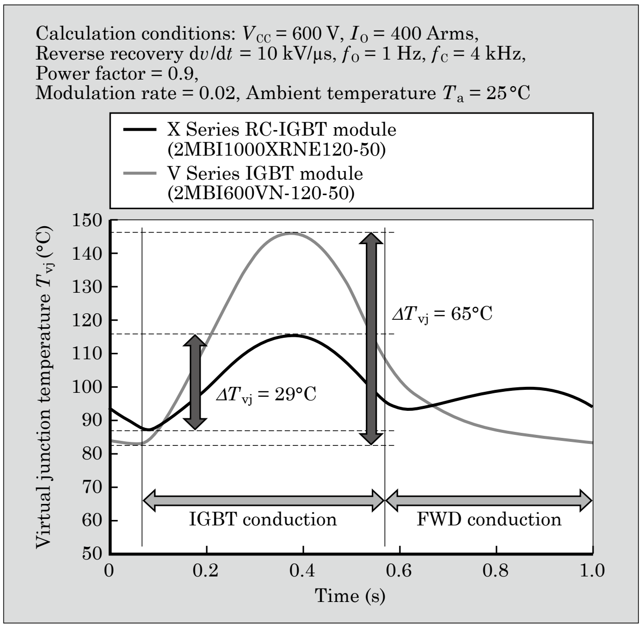

Fig.7 Time variation for virtual junction temperature T_{vj} during low-frequency operation

module significantly reduces T_{vjmax} through reduction in generated loss and thermal resistance. Furthermore, since the RC-IGBT can flow the current through both IGBT and FWD in the same chip, the thermal ripple is smaller than conventional chips.

Therefore, compared with the V Series IGBT Dual XT module, the X Series RC-IGBT Dual XT module greatly reduces the delta virtual junction temperature ΔT_{vj}. This makes it possible to relax the thermal stress at aluminum wire junctions and solder junctions under the silicon chip. Figure 8 shows the results of calculating ΔT_{vj} power cycle capability and temperature rise during low-frequency operation. The X Series RC-IGBT Dual XT module has dramatically improved

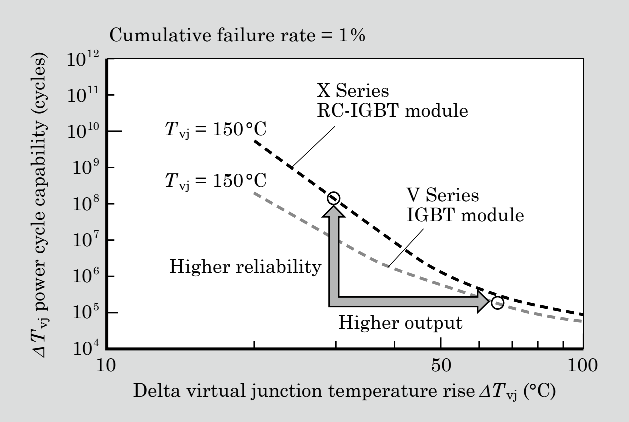

Fig.8 ΔT_{vj} power cycle capability

ΔT_{vj} power cycle capability during low-frequency operation by great reduction ΔT_{vj}. As a result, higher output power can be expected in the case of same power cycle capability, and higher reliability can be expected in the case of same ΔT_{vj}.

Figure 9 shows the inverter operation pattern during continuous operation and overload operation. Figure 10 shows the results of calculating output current I_o and T_{vj} when each I_o is 100% (rated current) under the continuous conditions. Figure 11 shows the results of calculating I_o and T_{vj} when each I_o is 200% in 3 seconds under the overload conditions. Figure 12 shows a contour figure created by finite element method (FEM) analysis at a T_{vj} of 150 °C during overloaded operation. As shown in Fig. 10, since reducing power dissipation and thermal resistance, moreover raising the T_{vjop} from 150 °C of the V Series IGBT module to 175 °C of the X Series IGBT module, the X Series RC-IGBT Dual

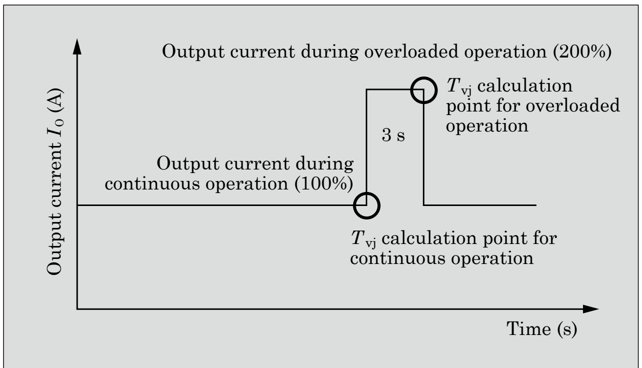

Fig.9 Operation pattern of inverter during continuous operation and overload

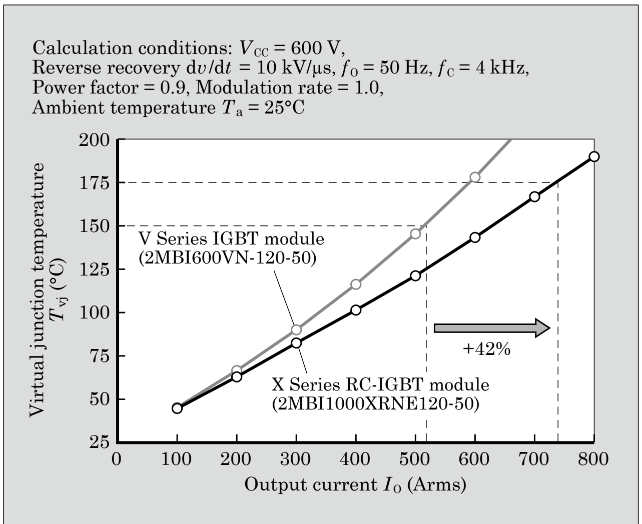

Fig.10 Virtual junction temperature during continuous operation

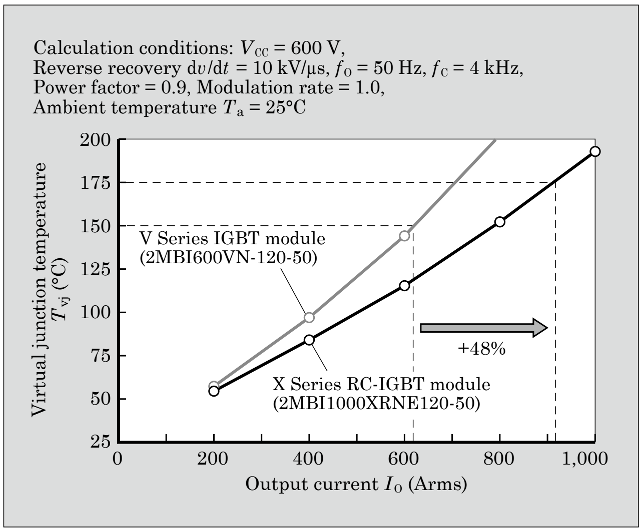

Fig.11 Virtual junction temperature during overloaded operation

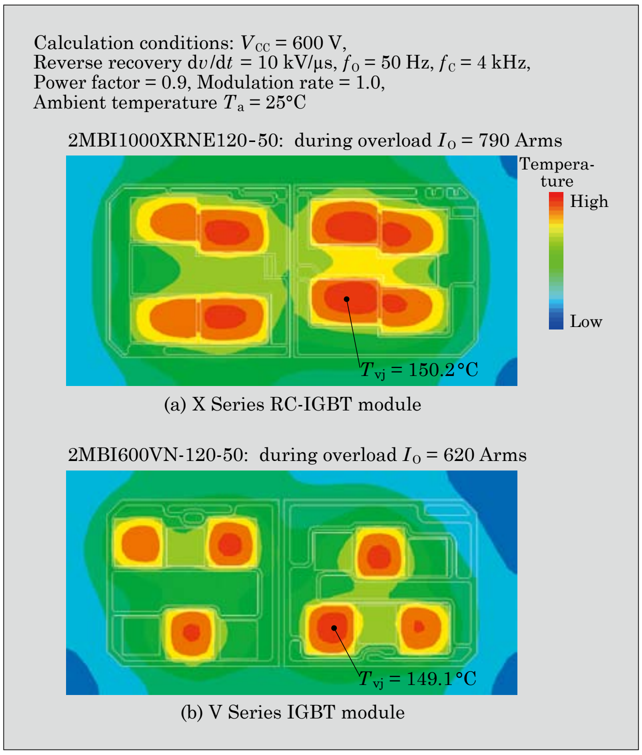

Fig.12 Contour figure created by FEM analysis during overloaded operation

XT module can expand the output current by 42% in the same package during continuous operation. As shown in Fig. 11, the X Series RC-IGBT Dual XT module can expand the output current by 48% even during overloaded operation. Furthermore, as shown in Fig. 12, the contour figure created by FEM analysis has confirmed that the X Series RC-IGBT Dual XT module is capable of achieving the same T_{vj} of 150 °C even when expanding output current by 27% compared with the V Series IGBT Dual XT module. Moreover, a more uniform temperature distribution was also observed as a result of optimizing the chip size and internal layout. Therefore, it can be expected that the module will achieve higher reliability through relaxing the thermal stress for all materials.

5. Postscript

In this paper, we introduced the 7th-generation "X Series" RC-IGBT module line-up for industrial applications. The module achieves a rated current expansion that is inconceivable through utilizing conventional IGBT and FWD. Thus we believe that the module will contribute further to the size and cost reduction of power conversion systems. In the future, we will continue to work for innovating IGBT module technologies so that we can realize a safe, secure and sustainable society.

References

(1) Kawabata, J. et al. "The New High Power Density 7th Generation IGBT Module for Compact Power Conversion Systems", Proceeding of PCIM Europe 2015.

(2) Kawabata, J. et al. 7th-Generation "X Series" IGBT Module. FUJI ELECTRIC REVIEW. 2015, vol.61, no.4, p.237-241.

(3) Takahashi, M. et al. "Extended Power Rating of 1200 V IGBT Module with 7 G RC-IGBT Chip Technologies, Proceeding of PCIM Europe 2016.

(4) Takahashi, K. et al. "1200 V Class Reverse Conducting IGBT Optimized for Hard Switching Inverter", Proceeding of PCIM Europe 2014.

(5) Yamano, A. et al. 7th-Generation "X Series" RC-IGBT Module for Industrial Applications. FUJI ELECTRIC REVIEW. 2016, vol.61, no.4, p.241-245.

(6) Takahashi, H. et al. "1200 V Reverse Conducting IGBT", Proceeding of ISPSD 2004. p.133-136.

(7) M, Rahimo. et al. "The Bi-mode Insulated Gate Transistor (BIGT) A Potential Technology for Higher power Applications", Proceeding of ISPSD 2009. p.283-286.

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