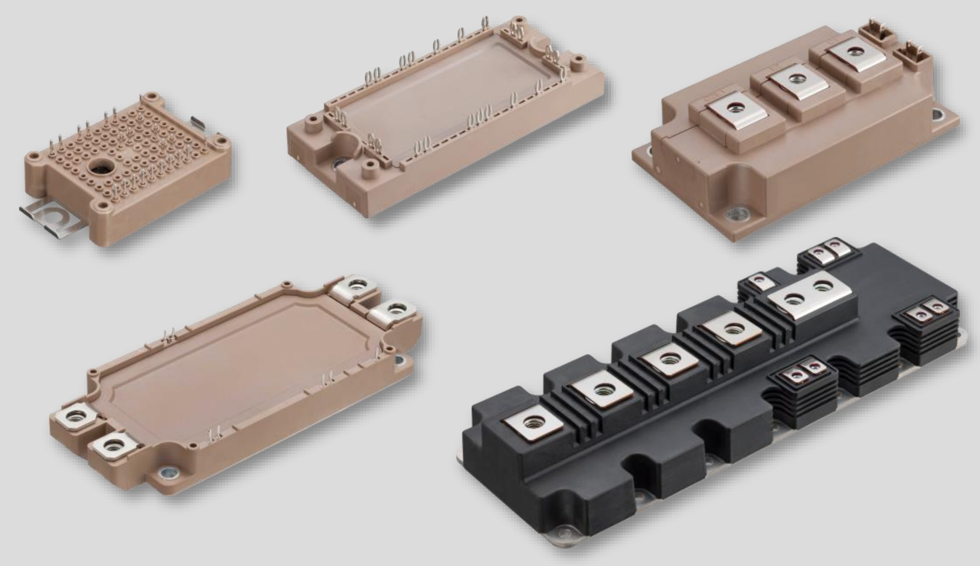

Fuji 7th Generation IGBT Module
X Series
Chapter 3
7th Generation X Series RC-IGBT Module

Application Manual

June 2021 Rev.2.0

Fuji Electric Co.,Ltd.

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Warning:

This manual contains the product specifications, characteristics, data, materials, and structures as of June 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.

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Chapter 3　7th Generation X Series RC-IGBT Module

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This chapter describes the 7th Generation X series RC-IGBT.

1. Basic Concepts and Features of 7th Generation X Series RC-IGBT Module

●Further miniaturization and higher power density (RC-IGBT technology)

The X-series RC-IGBT module uses our 7th generation X-series chip technology and packaging technology to achieve low power loss and 175 °C continuous operation guarantee. Furthermore, the chip area can be expanded compared with each of the IGBT or FWD, and the $R_{th(j-c)}$ has been reduced by integrating the functions of the IGBT and FWD into a single chip using RC-IGBT technology. In addition, the total number of chips and chip area have been reduced by applying RC-IGBT.

Through these technological innovations, the X-series RC-IGBT modules contribute to further miniaturization and total cost reduction of power conversion systems by achieving high power density with the same package size as before.

●Features of X series RC-IGBT chips

Fig.3-1 shows a schematic diagram and equivalent circuit of the X series RC-IGBT chip. The RC-IGBT integrates the IGBT and FWD into a single chip, so that during switching operation, the IGBT operation and FWD operation are repeated alternately on the same chip. Since the IGBT / FWD operations are continuous on the same chip, the junction temperature swing (ΔT_{vj}) is smaller than the case of the IGBT / FWD operating alternately on different chips. In addition, since the IGBT and FWD are integrated into a single chip, the thermal resistance has been reduced by increasing the chip area of each of the conventional IGBT and FWD.

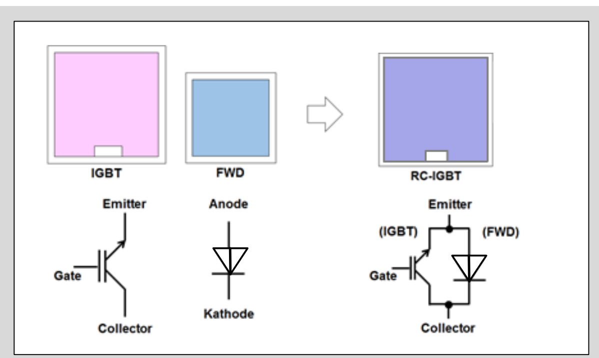

Fig.3-1 Schematic diagram and equivalent circuit of the X series RC-IGBT chip

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Fig.3-2 shows the output characteristics of the 1200V X-series RC-IGBT. The X-series RC-IGBT chip can output current in both the forward direction (IGBT) and the reverse direction (FWD) with one chip. In the forward direction, the application of X-series chip technology has achieved a lower saturation voltage than V-series IGBT chips. The characteristics of the X-series RC-IGBT chips have been improved by applying the thin wafer technology, which is the X-series chip technology. There is a concern of oscillation and lower breakdown voltage during turn-off due to the use of thin wafers, however, the X-series RC-IGBT chips suppress oscillation and breakdown voltage reduction by optimizing the wafer resistivity and each structure. As shown in Fig.3-3, the overvoltage of the X-series RC-IGBT is equivalent to that of the V-series IGBT, and the E_{off} is reduced by 23% by reducing the tail current compared to the V-series IGBT. The turn-on and reverse recovery operation are shown in Fig.3-4 and Fig.3-5 respectively. While the combination of V series IGBT and FWD has a steep current waveform, the X series RC-IGBT realizes a soft recovery current waveform by optimizing the structural parameters. In addition, the I_{frm} and the forward recovery charge have been reduced to reduce the forward recovery energy E_{fr} by 20%.

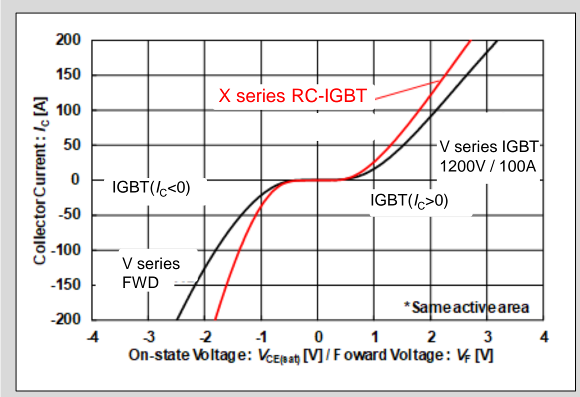

Fig.3-2 Output characteristics of X series RC-IGBT

Fig.3-3 Turn off waveform of X series RC-IGBT

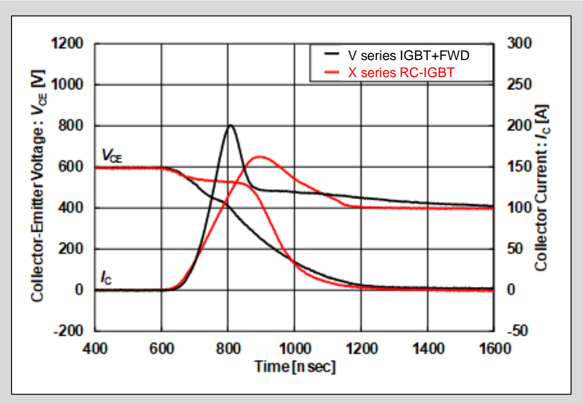

Fig.3-4 Turn on waveform of X series RC-IGBT

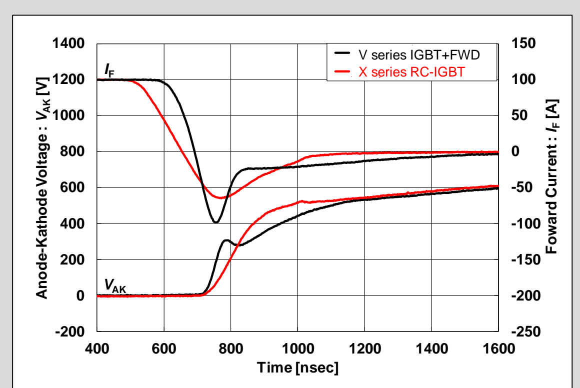

Fig.3-5 Reverse recovery waveform of X series RC-IGBT

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Fig.3-6 shows the trade-off relationship of IGBTs compared with the same active area. In case of the turn off energy is the same, the X-series RC-IGBT has an improved saturation voltage of 0.5V compared with the V-series IGBT. Fig.3-7 shows the trade-off relationship of FWD compared with the same active area. In case of the forward recovery (reverse recovery) energy is the same, the X-series RC-IGBT improves V_{RC} (V_F) by 0.3V compared with the V-series FWD.

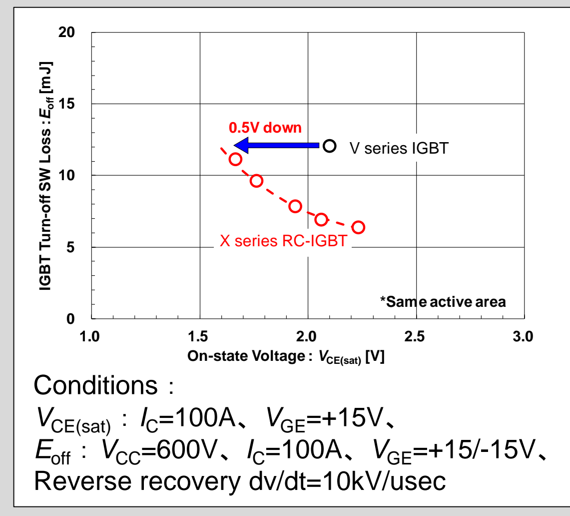

Fig.3-6 Trade-off relationship of X series RC-IGBT (IGBT)

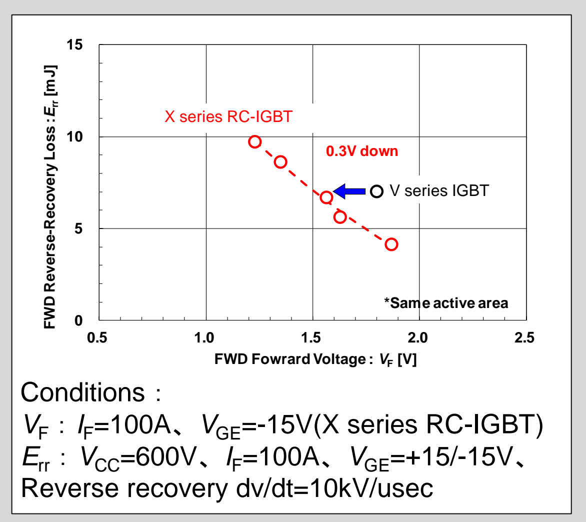

Fig.3-6 Trade-off relationship of X series RC-IGBT (FWD)

●Features of X series RC-IGBT package

The X-series RC-IGBT module uses an AlN (aluminum nitride) insulating substrate same as the X-series IGBT module in order to take advantage of features such as miniaturization and high power density by integrating the functions of the IGBT and FWD into a single chip. As a result, the thermal resistance has been further reduced. Fig.3-8 shows the junction-case thermal resistance. The AlN insulating substrate has lower thermal resistance than the Al_2O_3 (alumina) insulating substrate. It has been greatly improved to about 45% (same chip size ratio), and the issue of temperature rise due to the miniaturization of the IGBT module has been overcome. Furthermore, high reliability is ensured and continuous operation at 175 ℃ is guaranteed by optimizing wire bonding and adopting high-strength solder and high-heat-resistant silicone gel.

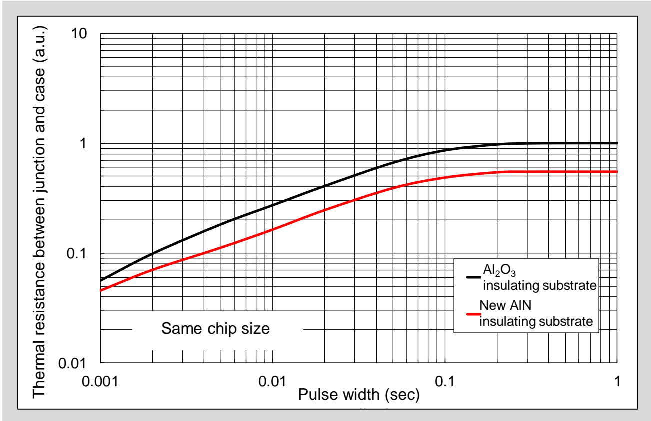

Fig.3-8 Thermal resistance between junction and case

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●Features of X series RC-IGBT modules

Fig.3-9 shows the inverter output current I_o and the maximum IGBT virtual junction temperature $T_{vj,max}$ assuming that the 1200V / 1000A X series RC-IGBT DualXT module in the same package as the 1200V / 600A V series DualXT module is mounted on the inverter drive equipment. The X-series RC-IGBT module have reduced power loss and junction-case thermal resistance compared with V-series IGBT module. Furthermore, by applying the 7th generation X series packaging technology, the guaranteed continuous operation temperature has been expanded from 150 ℃ to 175 ℃ for X series IGBT modules. As a result, a higher current density is possible in the same package compared with the V series IGBT module, and the IGBT module has achieved even higher power density and miniaturization.

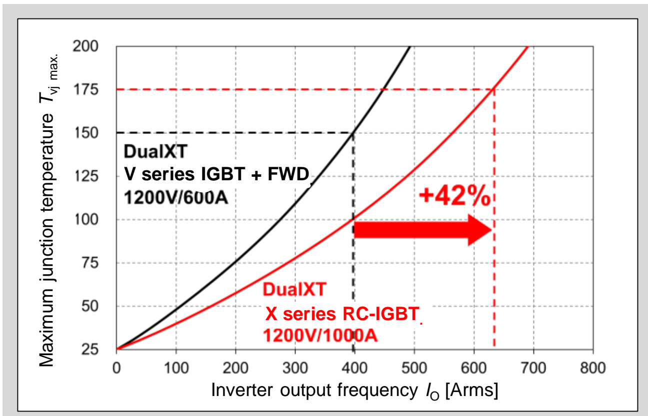

Fig.3-9 Maximum IGBT junction temperature and maximum inverter output current

Fig.3-10 shows the T_{vj} simulation results when the inverter operates at low frequencies, such as when accelerating or decelerating a motor. In the conventional IGBT + FWD structure, the IGBT and FWD repeatedly generate heat and dissipate heat, respectively. On the other hand, in RC-IGBT, the IGBT region and FWD region generate heat alternately. As a result, in RC-IGBT, the heat generated in the IGBT is also transferred to the FWD region, and the heat generated in the FWD is also transferred to the IGBT region, so the heat dissipation area is expanded compared to the IGBT + FWD structure. Therefore, the thermal resistance is reduced and the temperature swing ΔT_{vj} is significantly reduced. From the above, the thermal stress on the aluminum wire bonding and the solder under the silicon chip is relieved.

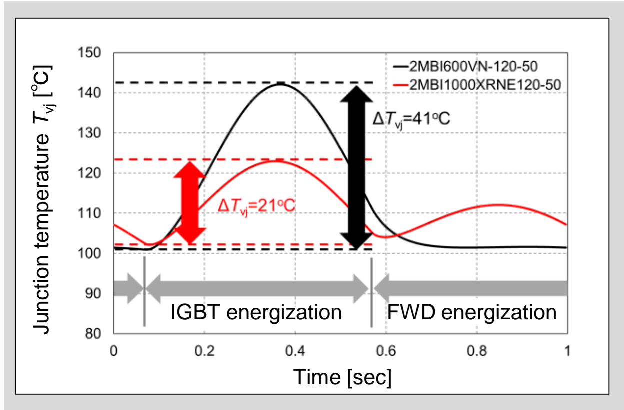

Fig.3-10 ΔT_{vj} simulation result

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The X-series RC-IGBT modules have significantly improved ΔT_{vj} power cycle by significantly reducing ΔT_{vj} during low-frequency operation. As a result, higher output can be expected for the same power cycle compared with the conventional IGBT + FWD structure. On the other hand, high reliability can be expected in the case of the same ΔT_{vj}. As a result, the X-series IGBT modules can meet the demands for miniaturization, low power loss, and high reliability required for IGBT modules.

2. 7th Generation X Series RC-IGBT Module Family

Increasing the rated current of the IGBT module can contribute to the increase in output power of power conversion systems. For example, as shown in Fig.3-11, in the 1200V series DualXT package, the maximum rated current of the V series was 600A. In the X series IGBT module, the maximum rated current has been expanded to 800A by applying the X series technology, and the maximum rated current of 1000A has been achieved by applying the RC-IGBT technology. By expanding the rated current in the same package, it is possible to increase the output power without changing the housing size of the power conversion systems. The expansion of the rated current of the IGBT module can also contribute to the miniaturization of the power conversion systems. For example, as shown in Fig.3-11, the 1200V / 900-1000A rated current module was realized in the PrimePACK™ 2 package (172mm x 89mm) in the V series, however, in the DualXT package (150mm x 62mm) in the X series RC-IGBT module. This has reduced the module installation area (footprint size) by 39%.

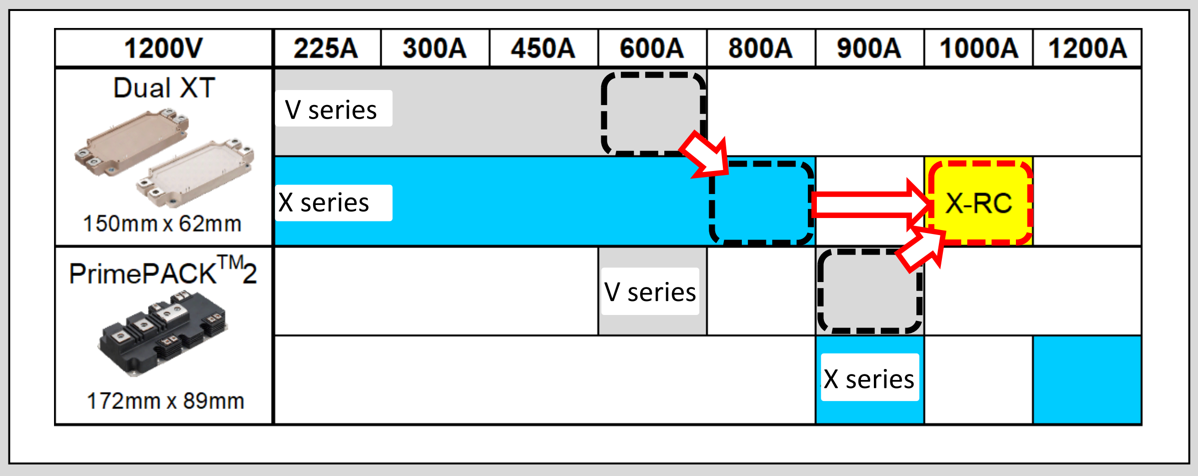

Fig.3-11 Fuji X series RC-IGBT module expansion

Note) PrimePACK™ is a registered trademark of Infineon Technologies.

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Fig.3-12 shows our X-series RC-IGBT module family. The expansion of the rated current, which was difficult with the conventional combination of IGBT and FWD, has been achieved by combining the X series technology and RC-IGBT technology.

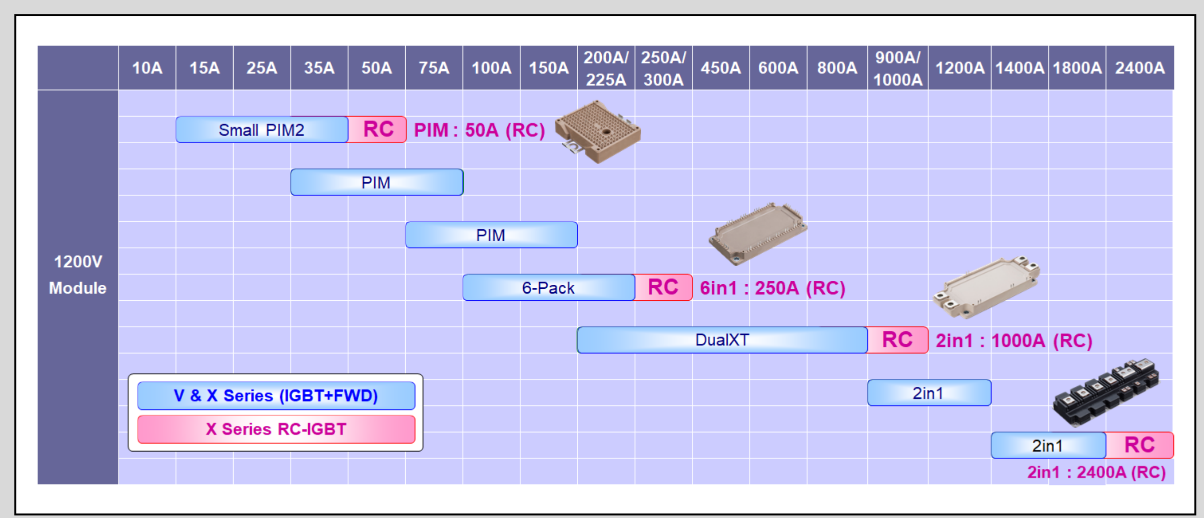

Fig.3-12 Fuji X series RC-IGBT module series

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