Line-Up of 2nd-Generation Small IPM with 650 V / 50 A, 75 A

OKAYAMA, Kenichi* SIRAKAWA, Toru* TANAKA, Masanori*

ABSTRACT

In recent years, to deal with global environmental problems, there has been increasing demand for energy conservation to cope with greenhouse gas emission regulations and size reduction to save on resources. Fuji Electric developed a line-up of 2nd-generation Small-IPM with 650 V / 50 A and 75 A that integrate the power devices and control ICs to compose inverter circuits. The products adopting "X Series" IGBT chip technology reduce their power dissipation compared to conventional products and increase the maximum operating temperature from 125 °C to 150 °C by using a high heat-resistant packaging technology. These enhancements will contribute to saving energy, downsizing of power conversion systems and increasing their output current.

1. Introduction

In recent years, to deal with global environmental problems, there has been increasing demand for energy conservation to cope with greenhouse gas emission regulations and size reduction to save on resources. Inverter air conditioners, motor drives, and servos amp, which are the target of Small-IPM (intelligent power modules), also need to meet these requirements.

Especially, for the inverter air conditioners in principal countries, energy saving standard is established on the basis of the annual performance factor (APF), which represents the energy consumption efficiency estimated under actual usage.

In addition to an energy saving characteristic, equipment needs to have a low noise characteristic that conforms to standards related to electro magnetic compatibility (EMC) specified by the special committee of IEC, Comité international spécial des perturbations radioélectriques (CISPR).

In order to meet market demands, Fuji Electric has provided Small IPM integrated with power devices and control ICs to compose inverter circuits.[1]

The Small IPM includes a 3-phase inverter bridge circuit, a control circuit and a protection circuit on one package, contributing to a size reduction of inverter circuits. The 2nd-generation Small IPM (2G-IPM) with rated values 600 V/10 A to 30 A, which was released in 2015, applies the chip technology[2] of the "X-series" insulated gate bipolar transistor (IGBT). The product achieved lower power dissipation compared with the conventional types, further saving energy. Furthermore, this product realized increase of maximum operating temperature T_{vjop} from 125 °C to 150 °C based on the high heat-resistant package technology. In addition, thus, the easiness to design and the expansion of the application area of inverters are achieved by improving the accuracy of the over-current detection and the overheat protection function.

The product series of rated 650 V / 50 A, 75 A, which is developed on the basis of 2G-IPM technology, is added to the product line-up this time. In this paper, the features of 2G-IPM technology are described hereinafter.

2. Product Outline

Figure 1 and Table 1 show an external view of the product and its main characteristics respectively. The product has outer dimension of 79.0 × 31.0 × 7.8 (mm) and adopts a dual in-line structure. The safety standard of insulation conforms to the UL1557. The rated voltage is 650 V, and the rated currents is 50 A or 75 A. Each type has a line-up with or without the overheat protection function.

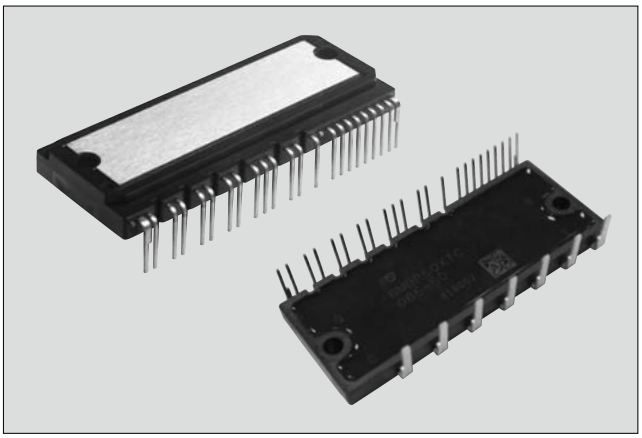

Fig.1 Product appearance

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

Table 1 Main characteristics of product

Voltage	Type name	I_C	I_{CP}	$V_{CE(sat)}$	V_F	Guaranteed operating temperature	Over-temperature protection function
650 V	6MBP50XTA065-50	50 A	100 A	1.30 V (typ.)	1.55 V (typ.)	$T_{vjop} \leq 150$ °C	None
	6MBP50XTC065-50						Yes
	6MBP75XTA065-50	75 A	150 A	1.30 V (typ.)	1.80 V (typ.)		None
	6MBP75XTC065-50						Yes

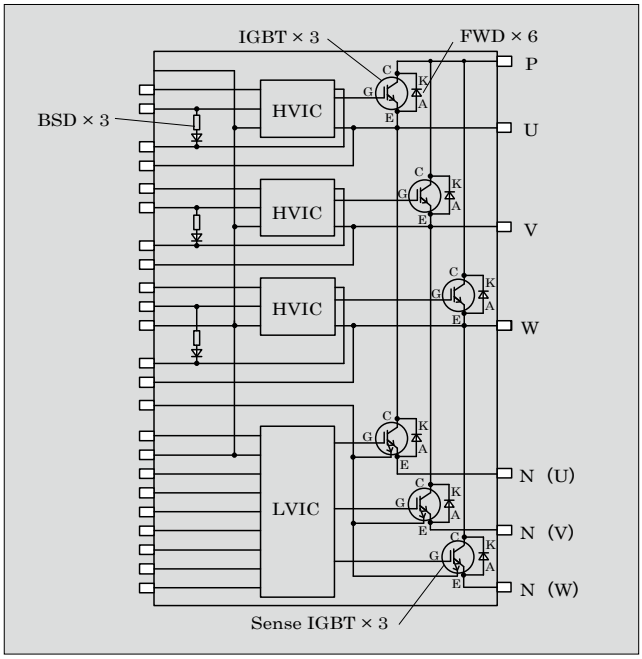

Fig.2 Internal equivalent circuit

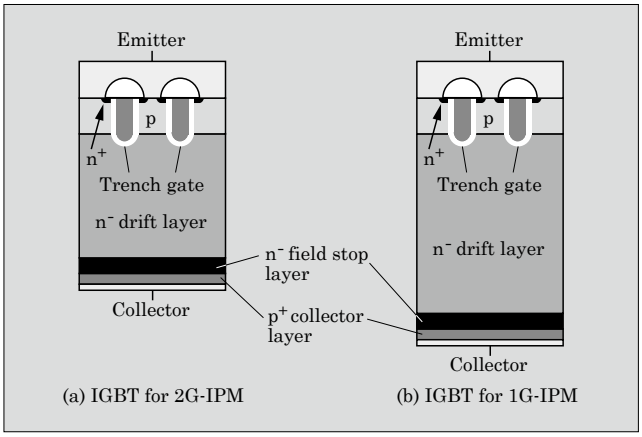

Fig.3 Comparison of cross section structures of IGBT chips

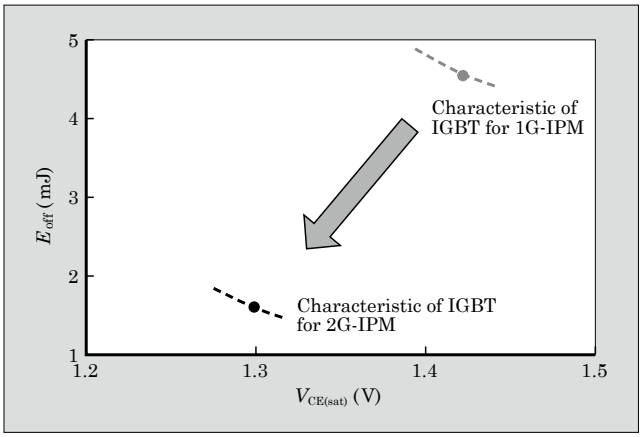

Fig.4 Trade-off relationship of $V_{CE(sat)}$-E_{off}

Figure 2 shows the circuit configuration of the 2G-IPM. The 2G-IPM includes a 3-phase inverter bridge circuit, which consists of 6 pairs of low-loss IGBTs and high-speed free wheeling diodes (FWD). Each low side IGBT has a shunt current sense IGBT*1. The 2G-IPM has a chip of low-voltage integrated circuit (LVIC) for driving the low-side IGBT and 3 chips high-voltage integrated circuits (HVIC) for driving high-side IGBTs. And this 2G-IPM has a 3 chips of the boot-strap diode (BSD) with current limitter resistors. These make it easy to compose high side power supply by only connecting the external capacitors. Therefore, an external insulating power supply is unnecessary, and the space of print circuit boards can be saved.

3. Product Design

3.1 Device design

(1) IGBT

Figure 3 shows the cross section structures of the IGBT chip for 1st-generation Small IPM (1G-IPM) and that for 2G-IPMs. The IGBT chip for 2G-IPMs is based on the X-Series IGBT technology, such as fine cell technology and thinner wafer technology. Those IGBT chips include a newly developed current sensing part, and the IGBT cells for sensing the current are shunted from those of the main current part. Figure 4 shows trade-off relationship between saturated voltage $V_{CE(sat)}$ and turn-off loss E_{off}. The $V_{CE(sat)}$ and turn-off loss of 2G-IPMs are improved by 0.5 V and about 56% respectively compared with 1G-IPMs by optimizing the resistivity and thickness of the drift layer, doping profile of the filed stop (FS) layer and channel density.

(2) FWD

For the improvement of FWD chip characteristics, it is necessary to suppress the dv_r/dt during the reverse recovery resulting in noise generation and to reduce the reverse recovery loss.

Figure 5 and Fig. 6 show trade-off relationship be-

*1: Sense IGBT: IGBT with a current sensing function for over-current protection

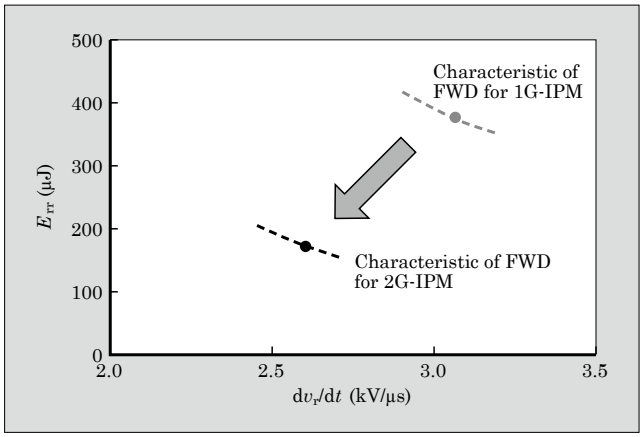

Fig.5 Trade-off relationship of dv_r/dt-E_{rr}

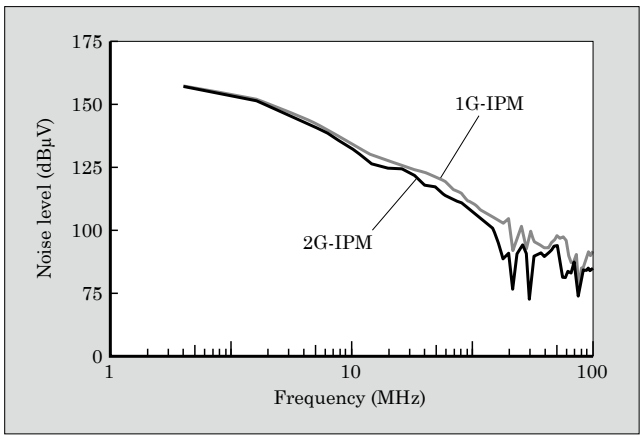

Fig.6 Result of FFT analysis of reverse recovery voltage waveform

tween dv_r/dt and E_{rr}, and the comparison of the FFT analysis of reverse recovery voltage waveforms between FWD chips for 1G-IPMs and those for 2G-IPMs respectively. The FWD for 2G-IPMs is based on the "X-Series FWD" technology. Furthermore, both of soft recovery waveforms and improvement of the trade-off characteristics have been realized by optimizing the anode diffusion profile and the lifetime control. Thus, 10-dB noise reduction by 15% decrease of the dv_r/dt and 55% reverse recovery loss reduction are expected compared with 1G-IPM.

3.2 Packaging

Figure 7 shows the cross section of the package structure. The package structure of newly developed 2G-IPMs is similar to that of 2G-IPMs in mass-production. This package structure has been realized by using the aluminum IMS (insulated metal substrate) and high adhesive strength with the molding resin. In the case of the 1G-IPMs in the actual operation, chip heat was transferred to the outer leads via wire, and there had been a problem that the outer leads reach high temperature. On the other hand, the temperature rise of the outer leads of 2G-IPMs is reduced with the structure in which the heat of the internal wire is dissipated to the aluminum IMS.

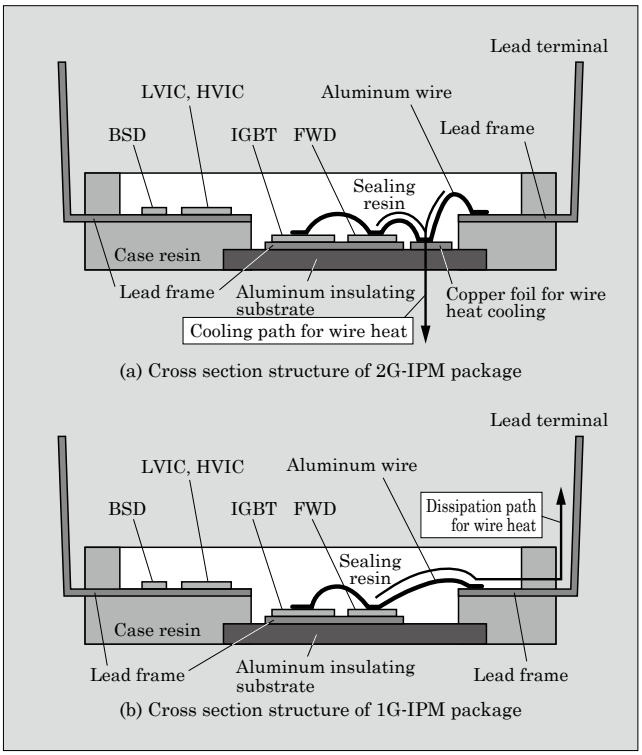

Fig.7 Cross section of package structure

Table 2 shows the results of reliability tests. To achieve the high reliability performance that is equivalent to that of the conventional types, the 2G-IPMs with rated values 650 V/50 A and 75 A are designed to suppress the heat generation due to the increase in the rated current and to reduce the internal stress of package caused by large package size.

(1) Suppression of heat generation due to increase in rated current

The rated current of 2G-IPM is enhanced to 75 A from the 30 A of the conventional products. Therefore, the heat generated from the IGBT, FWD chip, aluminum wire and copper foil of aluminum IMS increases. To suppress the temperature rise similarly as with that of conventional types, the aluminum wire diameter and the thickness of the copper foil are increased. Thus, the newly developed 2G-IPM achieves the ΔT_{vj} power cycle capability that is equivalent to that of 2G-

Table 2 Result of reliability test (main items)

Test items	Test condition	Guaranteed value	Judgment
Thermal cycle test	Low temp.: −40 °C High temp.: 125 °C	100 cycle	No characteristics variation
ΔT_{vj} power cycle test	ΔT_{vj} = 100±5 °C $T_{vj} \leq$ 150 °C $T_C \leq$ 125 °C $I_C \geq$ 50 A	15 kcycle	No characteristics variation
High temperature reverse bias test	T_{vj} = 150°C V_{CC} = 20 V V_{CE} = 510 V	1,000 h	No characteristics variation

IPM in mass production.

(2) Optimization of assembly process with rated current increase

The internal residual stress after resin molding increases with enlarging the package size. In this case, there is the concern that molding resin is delaminated from chip during the reliability test with heat stress, such as the temperature cycling test, and that leads to the electrical characteristics deteriorating. Thus, the assembly process is optimized to reduce the residual stress inside the package and the stress caused by temperature change, realizing the reliability of newly developed 2G-IPM equivalent to 1G-IPM in mass production.

3.3 Protection function

Figure 8 shows the over-current protection circuit. The newly developed 2G-IPM adopts a current detecting method using a sens-IGBT and shunt resistor R_s. In addition, the overcurrent protection and short-circuit protection availability of 2G-IPM is same as 1G-IPM with external shunt resistor method shown in Fig. 8(b). The method of detecting current with the sense

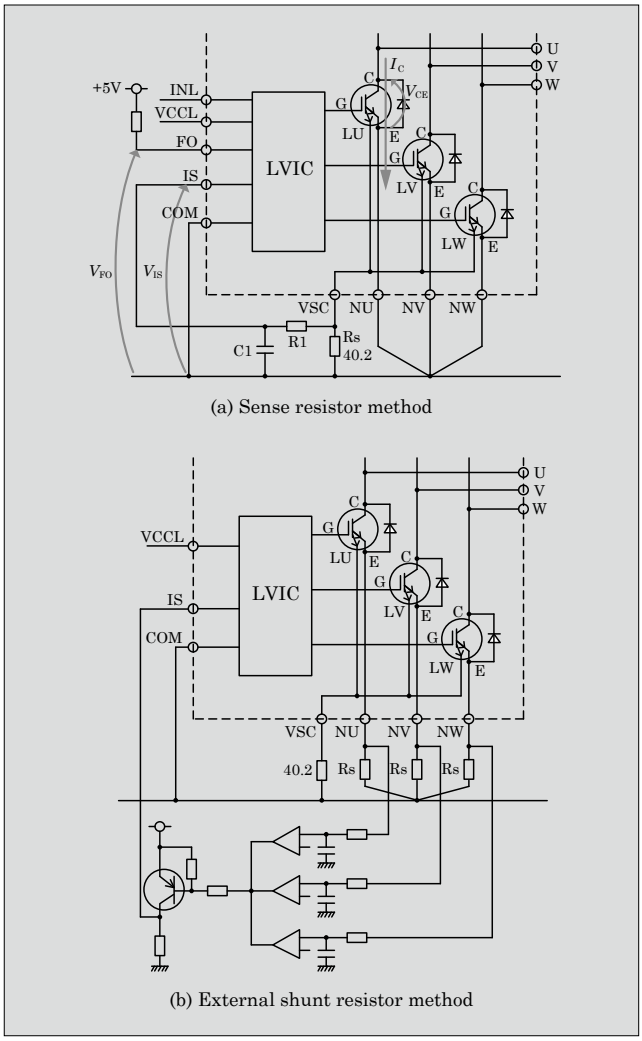

Fig.8 Over-current protection circuit

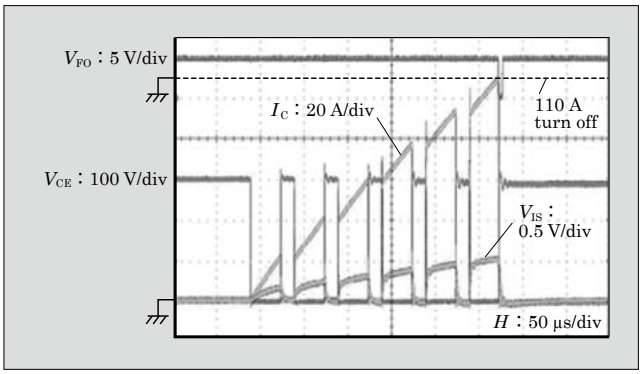

Fig.9 Waveform at over-current protection

IGBT and R_s can reduce the number of components of a filter circuit for current detecting, reducing costs of the total system and saving space of the print circuit board. Figure 9 shows the waveform at the time of over-current protection. As shown in Fig. 9, the alarm output signal V_{FO} is output at the threshold level of the current detection, and the low side IGBT cuts off.

4. Advantage for the Power Conversion System

Figure 10 shows the simulation result of the inverter loss assuming an minimum load of a package air conditioner (PAC) as 10 horsepower unit. The 2G-IPM is expected to exhibit loss of approximately 32% that of 1G-IPM with the same rated current as 75 A of 2G-IPM, improving the APF performance.

Figure 11 shows the simulation result of the inverter loss assuming the maximum load of the same model, and Fig. 12 shows the result of the temperature rise at this time. The 2G-IPM showed low power loss of about 27% that of 1G-IPM with same rated current. The loss reduction of 2G-IPM results in decreasing 20 °C of temperature rise compared with 1G-IPM with same rated current. Further more, the rated maximum operating temperature range was increased by 25 °C,

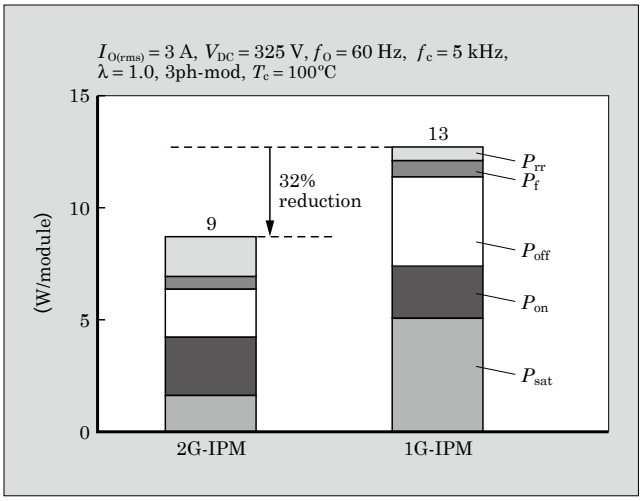

Fig.10 Calculation result of power dissipation [2G-IPM 650 V/50 A, PAC (10HP) medium load condition]

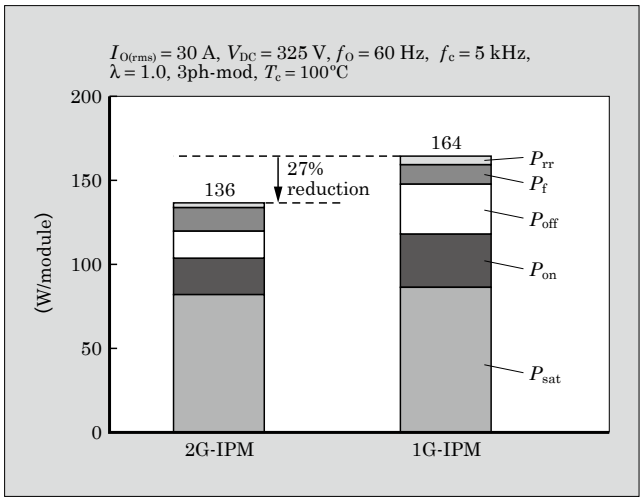

Fig.11 Calculation result of power dissipation [2G-IPM 650 V/50 A, PAC (10HP) maximum load condition]

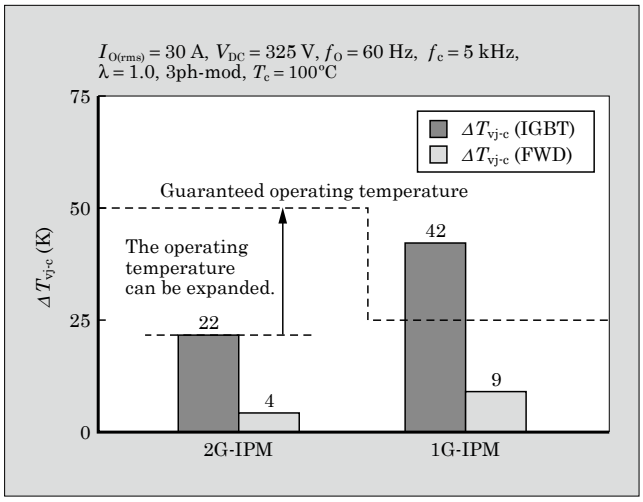

Fig.12 Calculation result of temperature rise [2G-IPM 650 V/50 A, PAC (10HP) maximum load condition]

and the output current can be expanded and equipment can be downsized.

5. Postscript

The series of the 2nd-generation IPM 650 V/50 A and 75 A has been described. This series is a part of the products that meet the requirements of motor drive inverter, servo amp and package air conditioner (PAC), which are expected to increase in demand of world wide. In addition, we are considering of expanding the line-up of 1,200-V series.

Fuji Electric will continuously offer superior products with advanced technologies and will realize many benefits such as downsizing, higher efficacy and reliable performance of power conversion systems.

References

(1) Yamada, T. et al. "Novel Small Intelligent Power Module For RAC". proc. 2012 PCIM Asia.
(2) Kawabata, J. et al. 7th-Generation "X Series" IGBT Module. FUJI ELECTRIC REVIEW. 2015, vol.61, no.4, p.237-241.
(3) Araki, R. et al. 2nd-Generation Small IPM. FUJI ELECTRIC REVIEW. 2015, vol.61, no.4, p.242-246.
(4) Ohashi, H. et al. "The 2nd Generation Small Intelligent Power Module for General-purpose Inverter". proc. 2016 PCIM Asia.

Fuji Electric

Innovating Energy Technology