“XS Series” Discrete IGBTs Line-Up Expansion

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ABSTRACT

To further improve the efficiency of electric systems, reducing power loss is pivotal to the semiconductor switching devices used in uninterruptible power systems (UPSs) and power conditioning systems (PCSs). Fuji Electric has thus been mass producing 650-V and 1,200-V “XS Series” discrete IGBTs, which improve conduction loss and switching loss trade-off characteristics to enhance the efficiency of UPSs and PCSs. We have developed and added a module to the product line-up that uses a TO-247-4 package, which has a sub-emitter terminal capable of further reducing switching loss. The new module has a rated capacity of 1,200 V/75 A and lower switching loss than the conventional TO-247 package products by 20% to 30%.

1. Introduction

In recent years, as the Internet of Things (IoT), big data, and artificial intelligence (AI) have been increasingly utilized, data usage has been increasing due to the sophistication of information and communication systems and the shift to cloud computing. There is a strong demand for power saving in servers and data centers that handle such data, and it is also essential to save power by improving the efficiency of uninterruptible power systems (UPS) that supply high-quality power to these devices.

In addition, renewable energy sources such as solar power and wind power are becoming increasingly widespread. For example, as for solar power generation, increasing the efficiency of power conversion equipment, such as power conditioners (PCSs), which converts DC power into AC power, has become a top priority.

Further reduction of power dissipation of semiconductor switching devices used in UPS and PCS is extremely important for increasing the efficiency of the devices.

Fuji Electric has mass-produced the XS Series discrete insulated gate bipolar transistors (IGBTs) with a blocking voltages of 650 V and 1,200 V that improves the trade-off characteristics between conduction loss and switching loss, making UPS and PCS more efficient[(1),(2)]. We have newly developed the 1,200-V/75-A TO-247-4 package product and added it to the XS Series. In this paper, we describe the characteristics of this product and its effects.

2. Overview of the “XS Series”

Figure 1 shows the main applications of discrete IGBTs. The XS Series targets UPSs and PCSs that are used at switching frequencies of around 20 kHz.

The newly developed 1,200-V XS Series TO-247-4 package product is equipped with IGBT and free wheeling diode (FWD) chips. Figure 2 shows the appearance of the package, and Table 1 shows the main maximum rating and electrical characteristics of the XS Series. For UPSs and PCSs of several kVA to several tens of kVA, we have a line-up of products with large current ratings of 40 A and 75 A.

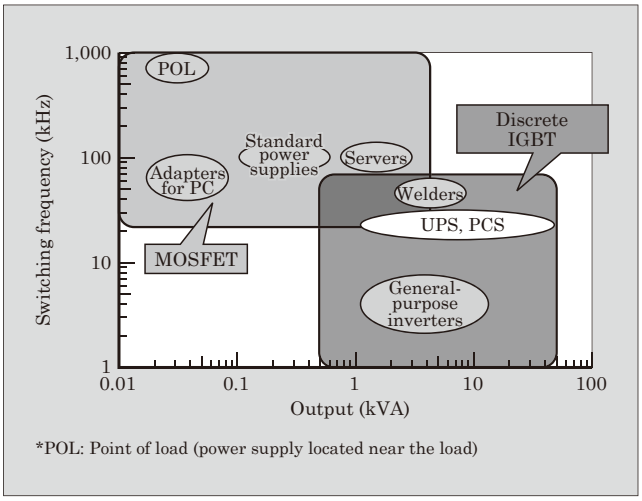

Fig.1 Main applications of discrete IGBTs

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Table 1 Main maximum rating and electrical characteristics of the XS Series

Model	Integrated FWD	Package	Maximum rating				Electrical property			
			IGBT			FWD	IGBT		FWD	
			V_{CES}	I_C T_{vj} = 100 °C	I_{CP}	I_F T_{vj} = 100 °C	$V_{CE(sat)}$ T_{vj} = 25 °C (typ.)	$V_{CE(sat)}$ T_{vj} = 125 °C (typ.)	V_F T_{vj} = 25 °C (typ.)	V_F T_{vj} = 125 °C (typ.)
			(V)	(A)	(A)	(A)	(V)	(V)	(V)	(V)
FGZ75XS120C*	Yes	TO-247-4	1,200	75	300	75	1.60	1.85	2.90	2.95
FGW75XS120C	Yes	TO-247	1,200	75	300	75	1.60	1.85	2.90	2.95
FGW75XS120	No		1,200	75	300	–	1.60	1.85	–	–
FGW40XS120C	Yes		1,200	40	160	40	1.60	1.85	2.90	2.95
FGW40XS120	No		1,200	40	160	–	1.60	1.85	–	–

* New series

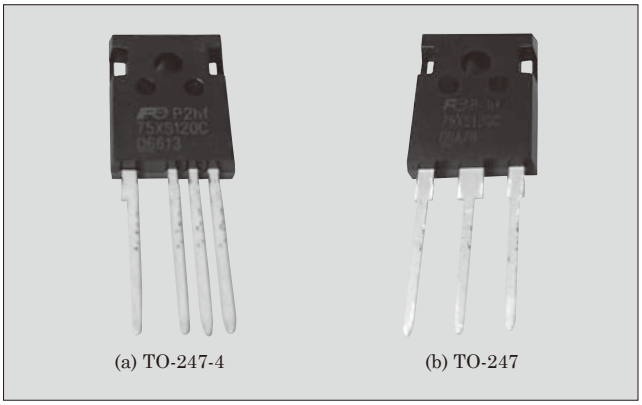

Fig.2 External appearance of the package

3. Challenges of Discrete IGBTs

For UPSs and PCSs of several kVA or more, the 3-level inverter is commonly used to improve power conversion efficiency.

Figure 3 shows the loss breakdown of IGBTs rated at 1,200 V in the main switch section (T1 and T2) of T-type 3-level inverters. It is important to reduce the conduction loss P_{sat}, which accounts for about 40% of the IGBT generation loss, and the switching loss (sum of P_{on} and P_{off}), which accounts for about 60%.

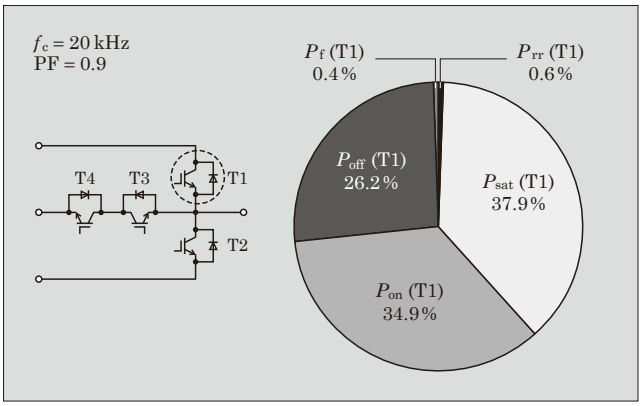

Fig.3 Results of analysis of device power losses (T-type)

4. Characteristics of 1,200-V "XS Series" and TO-247-4 Package

The 1,200-V XS Series is a discrete product based on the 7th-generation "X Series" IGBT and FWD chip technology, used at a drive frequency of approximately 20 to 40 kHz.

For products with large current ratings, such as 75-A rated products, the current flowing per element is large. Furthermore, for products with three terminals such as the conventional TO-247 package, the emitter common inductance and the wiring inductance of the gate-emitter loop affect the switching loss. Thus, as discussed in Section 4.3, TO-247-4 equipped with an additional sub-emitter terminal is adopted for the package so that the switching loss is improved compared with the TO-247 equipped with three terminals.

4.1 IGBT chip

Figure 4 shows the cross-sectional structure of the IGBT chip. Compared with the conventional "High-Speed W (HSW) Series[2]," which is based on the 6th-generation "V Series" IGBTs, the XS Series is based on the 7th-generation X Series IGBTs and features a surface structure that is optimized as a discrete IGBT for drive frequencies of 20 to 40 kHz, a field stop (FS) layer, an optimized collector layer that suppresses hole

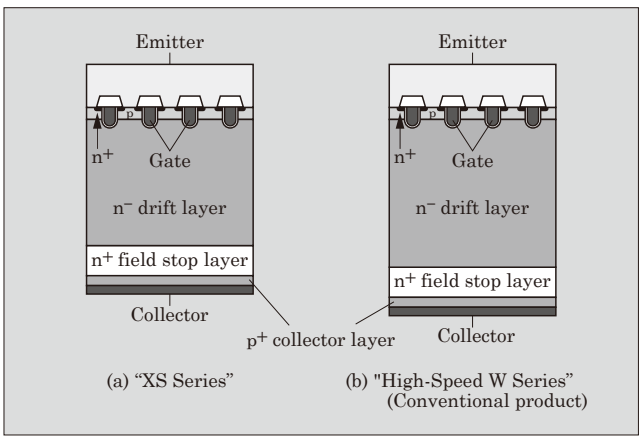

Fig.4 Figure of the cross-section structure of an IGBT chip

injection, and a thinner Si substrate. As shown in Fig. 5, the XS series thus reduces the turn-off loss E_{off} by approximately 6% compared with conventional products and at the same time reduces the collector-emitter saturation voltage $V_{CE(sat)}$ by 0.35 V, improving the trade-off characteristics.

4.2 FWD chip

Figure 6 shows the cross-sectional structures of a FWD chip. Based on the 7th-generation X series FWD with improved trade-off characteristics between forward voltage V_F and recovery loss E_{rr}, this FWD has optimized the thinning of Si substrate and the amount of lifetime killer[3),(4)]. The switching loss has been reduced by improving E_{rr} by approximately 60% compared to the conventional HSW Series.

4.3 Package

We use the new TO-247-4 package to add the sub-emitter terminal. As shown in Fig. 7, this package allows the gate current and collector current I_C to be separated to reduce the effect of the back electromotive force generated by the collector current and wiring inductance of the emitter on the gate voltage during turn-on and turn-off, reducing the switching loss.

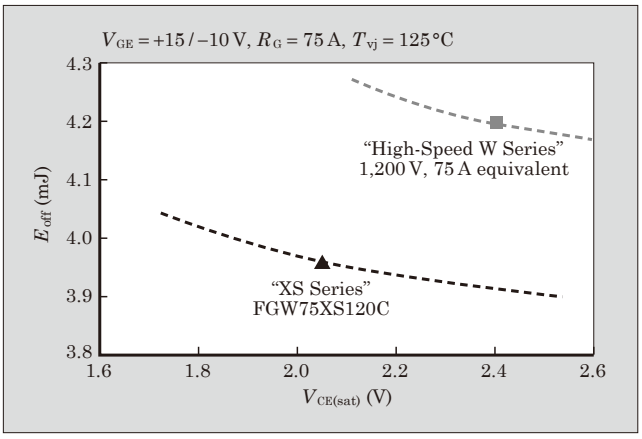

Fig.5 Trade-off characteristics (IGBT)

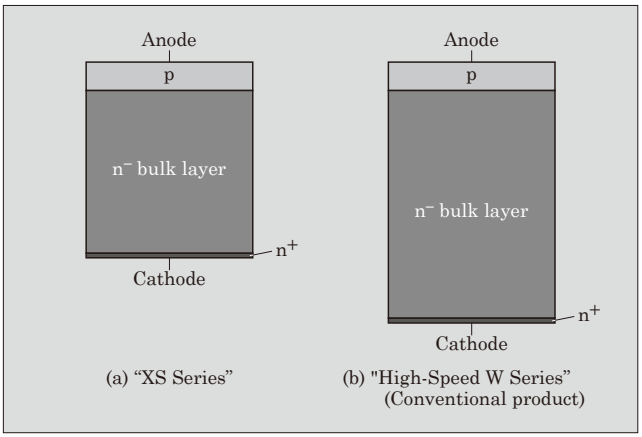

Fig.6 Figure of the cross-section structure of an FWD chip

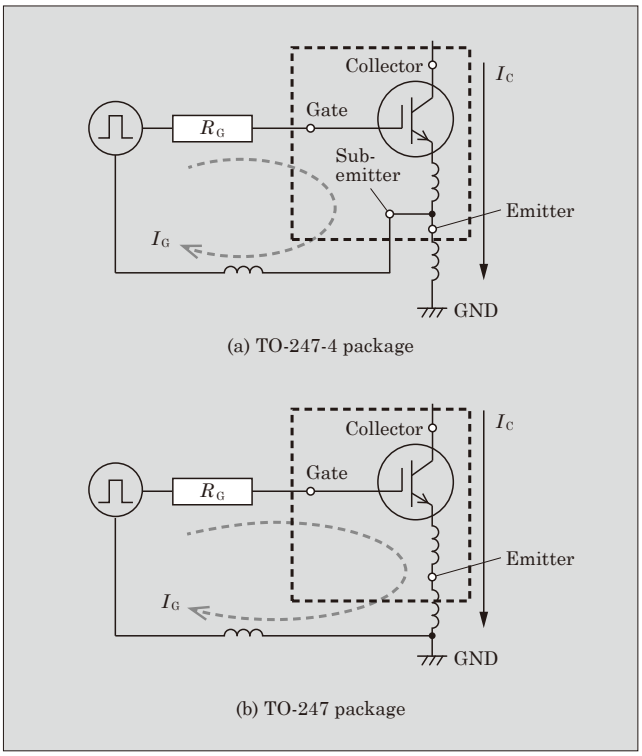

Fig.7 Gate current loop of the TO-247-4 and the TO-247 package products

5. Effect of the "XS Series" TO-247-4

5.1 Switching loss

Figure 8 shows the I_C dependence of the switching loss of the TO-247-4 package product and the TO-247 package product rated at 1,200 V / 75 A. The switching loss (turn-on loss E_{on} + turn-off loss E_{off}) of the TO-247-4 package product equipped with an additional sub-emitter is 30% lower than that of the TO-247 package product at a rated current of 75 A.

Figure 9 shows the gate resistance dependence of the switching loss. In the gate resistance range of 10 to 51 Ω, the switching loss of the TO-247-4 package

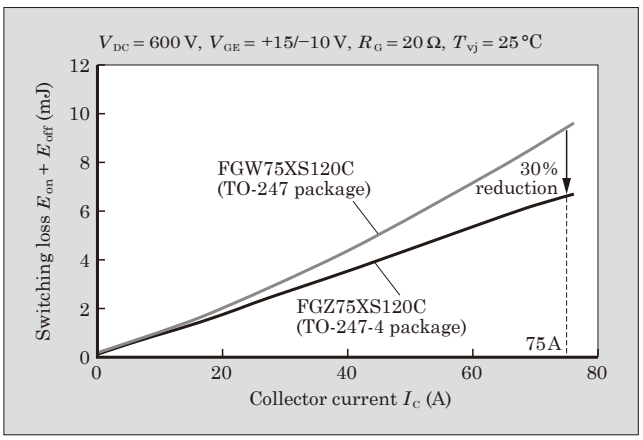

Fig.8 Comparison of switching loss between the TO-247-4 and the TO-247 package products (I_C dependence)

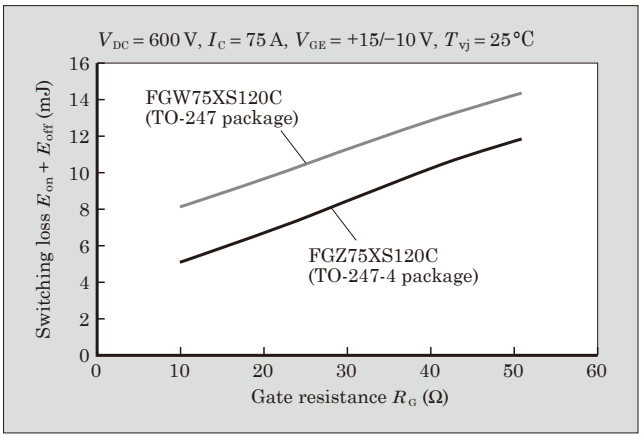

Fig.9 Comparison of switching loss between the TO-247-4 and the TO-247 package products (R_G dependence)

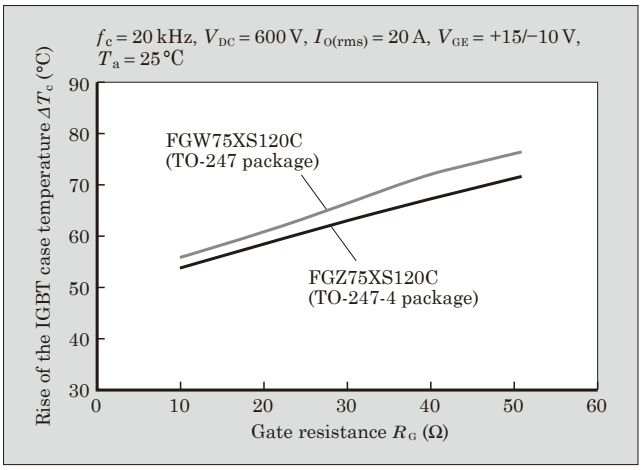

Fig.11 IGBT case temperature R_G dependence

product was reduced in the range of approximately 20% to 30% compared with the TO-247 package product.

5.2 Evaluation of actual operation

Figure 10 shows the package temperatures of the TO-247-4 and TO-247 package products, each rated at 1,200 V / 75 A, when operated using a simulated inverter circuit. Figure 11 shows the temperature R_G dependence of the IGBT case. The simulation confirmed that the case temperature of the TO-247-4 package product was up to 4.5 °C lower than that of the TO-247 package product. The lower case temperature is expected to allow for smaller heat dissipation fins for devices to be mounted and the handling of more power.

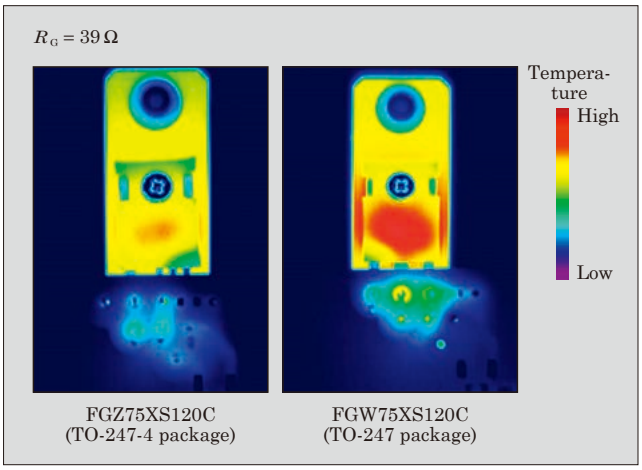

Fig.10 IGBT molded case temperature ($I_{O(rms)}$ = 20 A)

6. Postscript

We described the line-up expansion of the "XS Series" discrete IGBT. We confirmed that the TO-247-4 package product with an additional sub-emitter terminal is effective in reducing switching loss and package temperature rise.

This product was developed mainly for UPSs and PCSs, but it can also be used in PFC circuits of switching power supplies and industrial equipment.

We will continue to contribute to energy savings and high power conversion efficiency by further reducing the loss of devices and supplying products that meet the requirements of our customers.

References

(1) Hara, Y. et al. "XS Series" 1,200-V Discrete IGBTs. FUJI ELECTRIC REVIEW. 2019, vol.65, no.4, p.239-242.
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(3) Heinzel, T. et al. "The New High Power Density 7th Generation IGBT Module for Compact Power Conversion Systems". PCIM Europe 2015.
(4) Yoshida, K. et al, "Power Rating extension with 7th generation IGBT and thermal management by newly developed package technologies". PCIM Europe 2017.

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