U4-series IGBT Modules

Kouichi Haraguchi
Shuji Miyashita
Yuichi Onozawa

1. Introduction

General-purpose inverters, uninterruptible power supplies (UPSs) and other types of power conversion equipment are subject to never-ending demands for higher efficiency, smaller size, lower cost and lower noise. Moreover, higher performance, lower cost and higher reliability are also required of the power semiconductor devices used in the inverter circuits of such equipment. In recent years, the IGBT (insulated gate bipolar transistor) have become the most prevalent power semiconductor element due to its low loss, easy drive circuit implementation and high ruggedness.

Fuji Electric first developed commercial IGBTs in 1988, and since then has accelerated efforts to improve the characteristics and reliability of those devices. Fuji Electric has also developed a new 5th generation of IGBT modules (U-series)[1] that use IGBTs having trench and field-stop (FS) structures[2].

This paper introduces Fuji Electric's latest device technology and product series, using the example of the U4-series EconoPACK-plus*1 1,200 V breakdown voltage IGBT module developed for the purpose of improving noise suppression and higher performance.

2. Characteristics of the U4-series IGBT Module

2.1 Concept

Fuji Electric has previously developed a trench gate IGBT based on trench-type power MOSFET (metal oxide semiconductor field-effect transistor) technology.

The U4-series realizes further improvements in the performance characteristics based on this technology, and was developed to achieve the following objectives.

(1) Lower loss generated by the device itself

By using a configuration in which the p-layer and emitter of a conventional trench-type IGBT chip are shorted via a high resistance R_s, the newly developed U4-series IGBT module (hereafter referred to as U4-IGBT) aims to improve controllability of the turn-on speed and to realize 30 % lower turn-on loss compared to the conventional trench-type IGBT. U4-IGBT aims almost the similar level of turn-off loss and reverse recovery loss as the conventional type.

(2) Narrow distribution of device characteristics in order to facilitate implementation of parallel connections

By using U4-series FWD (free wheeling diode) (hereafter referred to as the U4-FWD), the U4-series aims to reduce the distribution in forward voltage (V_F) to 0.3 V or less in order to facilitate the implementation of parallel connections, and to realize a high-speed soft recovery characteristic.

(3) Low EMI noise when installed in actual equipment

Although the FWD reverse recovery characteristic is considered to be the main factor that determines the EMI noise during switching, the FWD characteristic is not the only factor. In fact, the characteristics of the IGBT chip determine the reverse recovery characteristic of the FWD chip. The noise level changes according to the matching between the IGBT chip and the FWD chip, and therefore, it was planned to reduce the level of noise by optimizing the characteristics of both the IGBT and FWD chips.

(4) Reuse of conventional technology

The U4-series package is intended to be used in the same manner as a conventional IGBT module, and therefore, redesign of the main circuit, cooling fins and the like was unnecessary.

2.2 U4-IGBT chip features

Figure 1 compares the structures of the U4-IGBT chip and a conventional trench IGBT chip, and Fig. 2 shows the relationship between IGBT capacitance and the turn-on characteristic. By shorting the p-layer and emitter with the high-resistance R_s, a Miller capacitance (C_{res}) actually smaller than that of a conventional IGBT can be realized.

In a conventional trench IGBT, the gate is fabricated in a trench configuration, and since there is no JFET (junction field effect transistor) component corresponding to a planar IGBT, the collector-emitter

*1: EconoPACK-plus is a trade mark of Eupec GmbH. Warstein.

saturation voltage ($V_{CE(sat)}$) decreases but capacitance increases due to the trench configuration. In particular, if C_{res} is large, the turn-on switching-speed becomes slower and switching loss increases. Therefore, in order to reduce the switching loss at turn-on, it is effective to make C_{res} smaller and to optimize the ratio between input capacitance (C_{ies}) and C_{res}. In the development of the U4-IGBT, simulations and verification testing were performed to optimize these issues.

Figure 3 compares the turn-on switching waveforms of the conventional trench IGBT and the U4-IGBT. Since the effective C_{res} has been reduced due to the R_s shown in Fig. 1, the collector-emitter voltage (V_{CE}) tail is short, and as a result, the turn-on loss is less than that of a conventional trench IGBT. Moreover, even if the gate resistance (R_G) is increased, since the tail voltage is small, the turn-on loss will be relatively low, thereby expanding the range over which the turn-on speed can be controlled by R_G.

Figure 4 shows the I_C–V_{CE} characteristic of the U4-IGBT.

Since a positive temperature coefficient can be obtained as in a conventional trench IGBT, the current unbalance during a parallel connection is mitigated, and parallel connections to a large capacity inverter circuit or the like are easy to implement.

Fig.1 Comparison of conventional trench IGBT and U4-IGBT chip structures

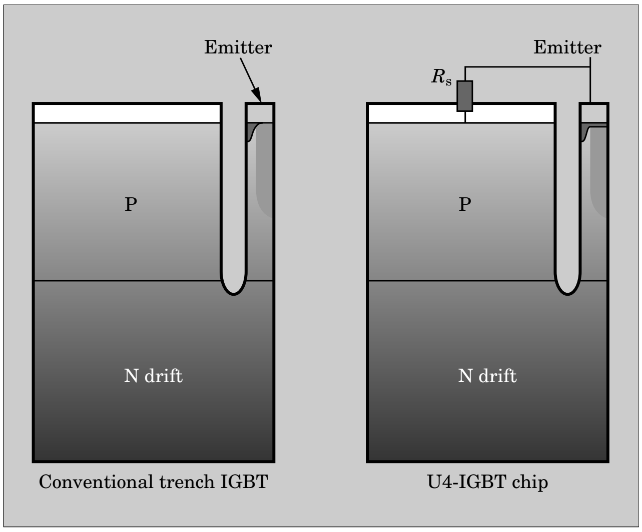
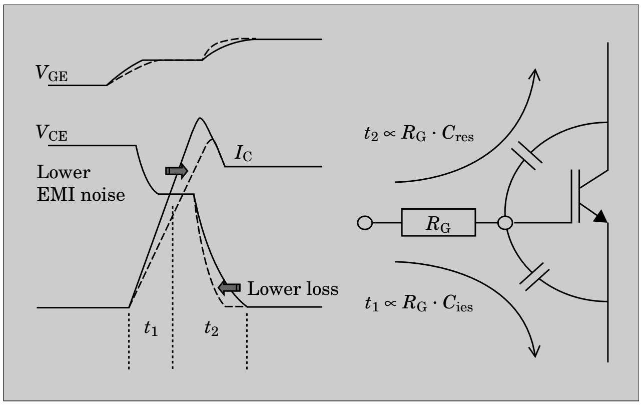


Fig.2 Relation between IGBT capacitance and turn-on characteristic



2.3 U4-FWD features

Recent general-purpose inverters tend to increase torque during low-frequency output, and the thermal duty of the FWD is large. Moreover, as with the IGBT, it is important to equalize the current balance when the FWD is in a parallel connection. For this purpose, a new diode having less distribution in its V_F characteristic is needed. Since the newly developed U4-FWD aims for higher reliability, it uses an FZ (floating zone) wafer that is not a significant cause of such distribution. The result is V_F variation of 0.3 V or less, which is comparable to that of the IGBT, thereby eliminating

Fig.3 Comparison of conventional trench IGBT and U4-IGBT turn-on waveforms

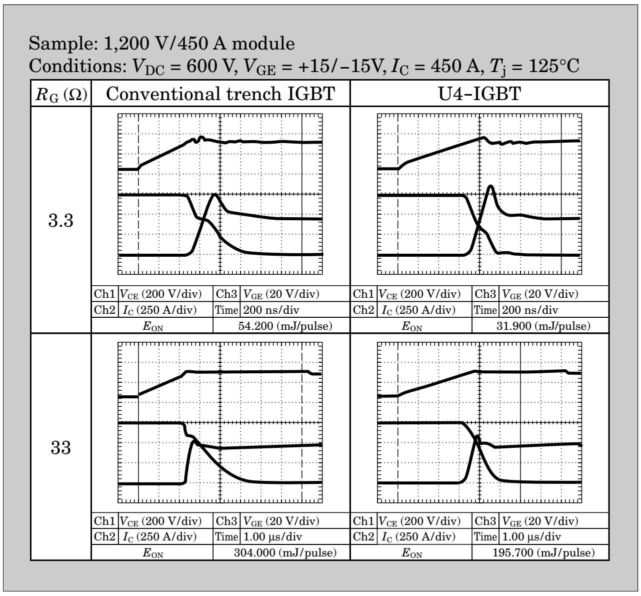
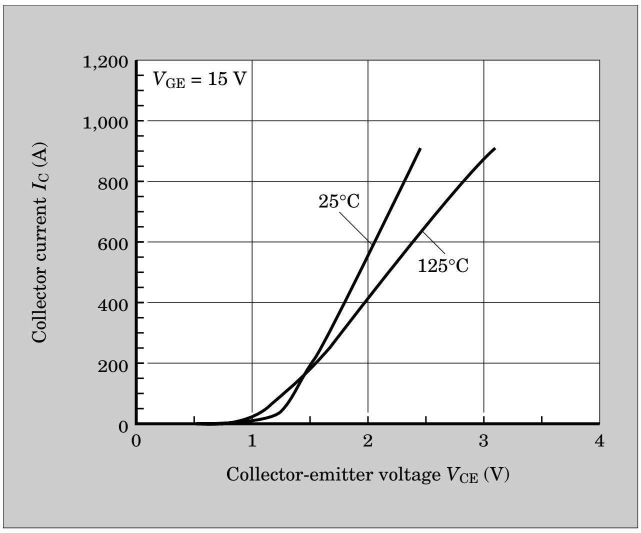


Fig.4 I_C–V_{CE} characteristic of U4-IGBT



the need for V_F classification for parallel connection module implementations, and facilitating the implementation of parallel connections of modules for large-capacity inverters.

Figure 5 compares the structures of the conventional FWD and the U4-FWD. For the use of an FZ wafer, it is necessary to optimize the crystal profile of the FZ wafer in order to reduce surge voltage during reverse recovery and to achieve a low V_F. We simulated the carrier profile and reverse recovery characteristic to derive the optimal values.

Fig.5 Comparison of conventional FWD and U4-FWD structures

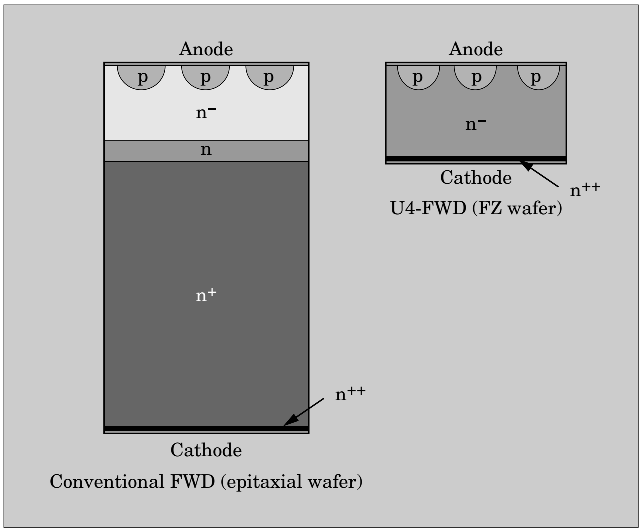


Fig.6 Simulated and measured waveforms of low-current reverse recovery characteristic

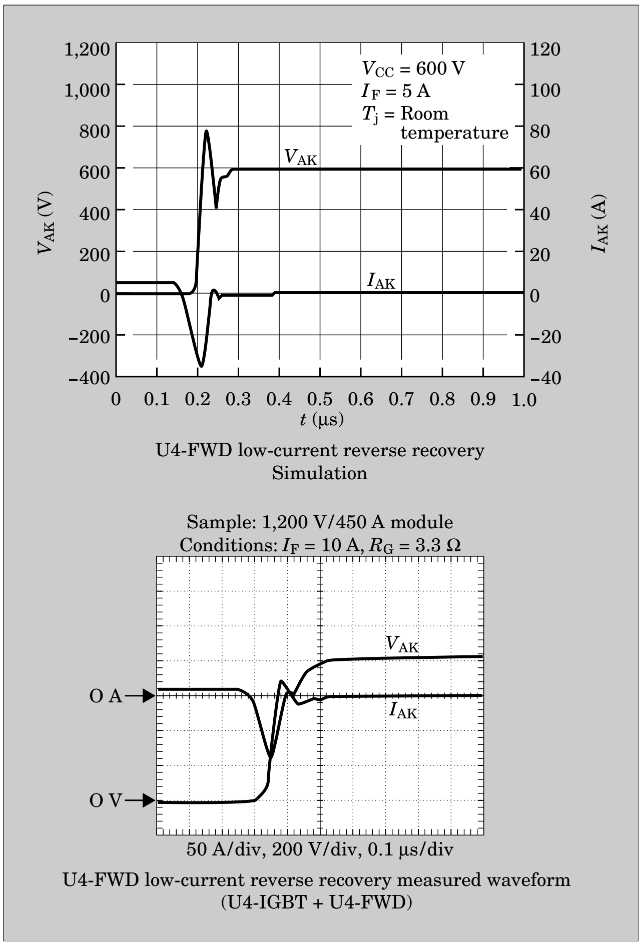


Figure 6 shows the simulated results and actual measured waveforms of the low-current reverse recovery characteristic. As a result, the combination of the U4-IGBT and U4-FWD inhibits the generation of oscillation and surge voltage due to low-current reverse recovery, and contributes to the streamlining of the snubber circuit and reduction of EMI noise.

Figure 7 shows the I_F–V_F characteristic of the U4-FWD. Since a positive temperature coefficient can be obtained as with the U4-IGBT, the U4-FWD is effective in balancing the current during a parallel implementation.

2.4 Comparison of EMI noise

When an IGBT module is installed in actual equipment, EMI noise is generated and radiates out to the exterior, and the level of that noise is regulated by

Fig.7 I_F–V_F characteristic of U4-FWD

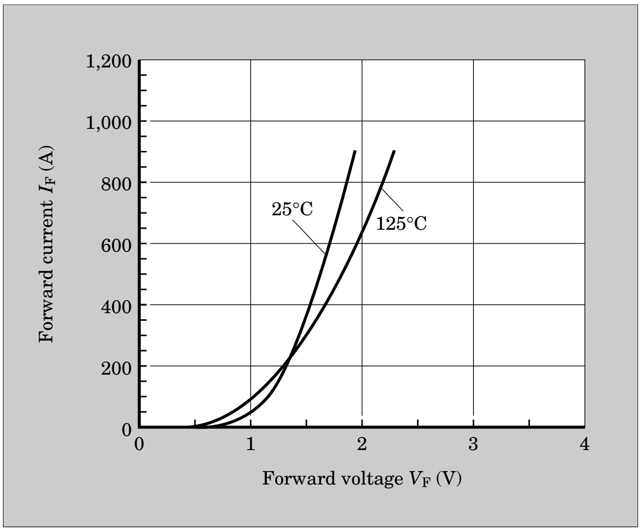
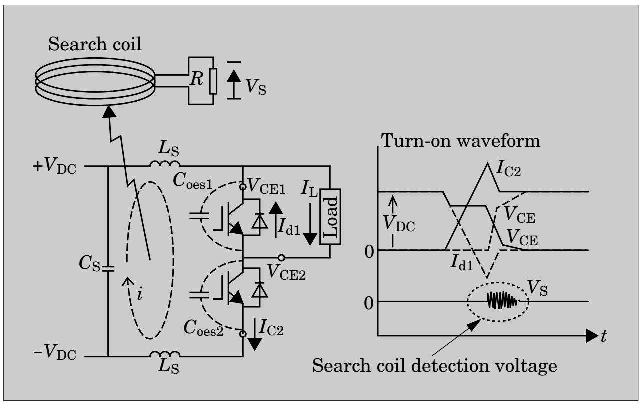


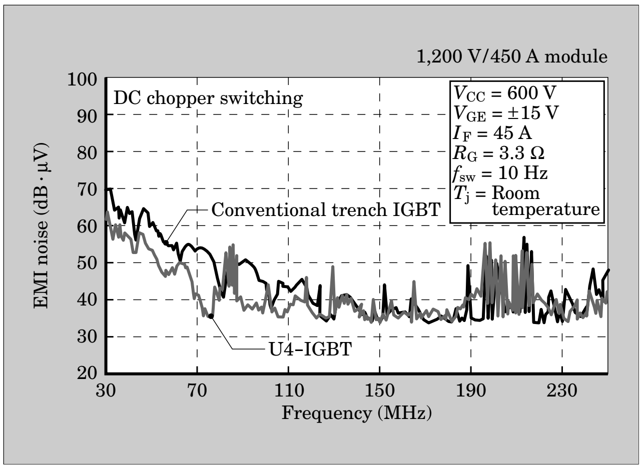
Fig.8 EMI noise-generating mechanism and simplified measurement method



the European standard EN61800-3 and the like. Figure 8 shows the EMI noise-generating mechanism and a method for measuring that noise. With this method, noise measurement is easy to implement. It has been reported that oscillation due to the resonance circuit between the IGBT module and snubber circuit is the source of the EMI noise. That oscillation is triggered by the values of di/dt and dv/dt during switching. The di/dt and dv/dt are determined by the IGBT turn-on characteristic, and the FWD reverse recovery characteristic is similarly determined by the turn-on characteristic. Thus, to reduce EMI noise, it is necessary to optimize both the FWD and IGBT characteristics.

Figure 9 compares the EMI noise (3 m method) during a DC chopper test. The U4-IGBT achieved improved R_G controllability of the turn-on speed and less turn-on switching loss, the U4-IGBT generates less EMI noise than a conventional trench IGBT and also dissipates less device power loss under the same gate drive conditions.

Fig.9 Comparison of EMI noise during DC chopper test



3. U4-IGBT Product Lineup

Fuji Electric has combined the abovementioned U4-IGBT technology and U4-FWD technology, while continuing to utilize the package technology of high-power cycling capable U-IGBT modules, to complete the development and establish a product line of U4-IGBT EconoPACK-plus modules, which provide improved performance compared to the conventional trench IGBT modules.

Figure 10 shows examples of U4-IGBT packages

Fig.10 Examples of U4-IGBT packages

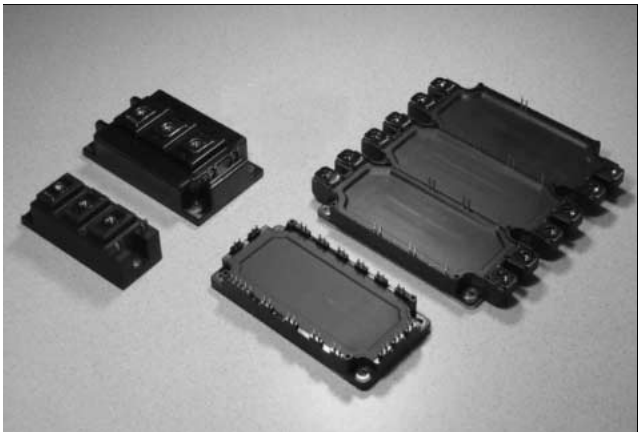


Table 1 U4-IGBT product lineup

Voltage rating	Package	I_C rating 50 A (11 kW)	75 A	100 A (22 kW)	150 A	225 A 200 A (40 kW)	300 A	450 A 400 A (75 kW)	600 A	800 A	1,200 A	1,600 A	2,400 A	3,600 A
1,200 V	PIM		EP3	EP3										
	6 in 1	New PC2 with NTC	New PC2 with NTC											
			New PC3 with NTC	New PC3 with NTC	New PC3 with NTC									
						EconoPACK-plus (6 in 1)	EconoPACK-plus (6 in 1)	EconoPACK-plus (6 in 1)						
	2 in 1				M232	M233								
						M235	M235							
						M249	M249	M249	M248	M248	M248			
	1 in 1							M127	M127	M138	M142	M142	M143	M143
1,700 V	6 in 1			New PC3 with NTC	New PC3 with NTC	EconoPACK-plus (6 in 1)	EconoPACK-plus (6 in 1)	EconoPACK-plus (6 in 1)						
	2 in 1					M249	M249	M249	M248	M248	M248			
	1 in 1										M142	M142	M143	M143

and Table 1 lists details of the IGBT module package product lineup.

The new U4-IGBT modules are available in a variety of packages in two product lines having breakdown voltages of 1,200 V and 1,700 V, respectively, and having current ratings ranging from 50 to 3,600 A. This wide range of products can be applied to various types of power conversion equipment.

4. Conclusion

The U4-IGBT and U4-FWD technologies, characteristics, and product lineup of IGBT modules has been presented above. These products make full use of the latest semiconductor technology and package technology to realize lower loss devices, and we are confident that these products will make significant contributions toward achieving smaller size and lower loss in equipment having inverter circuits.

Fuji Electric is committed to the future development of devices having even higher performance and reliability, and intends to enhance its own technology while contributing to the development of power electronics.

References

(1) Laska, T. et al. The Field Stop IGBT (FS IGBT) A New Power Device Concept with a Great Improvement Potential. Proc. 12th ISPSD. 2000, p.355-358.

(2) Otsuki, M. et al. 1200 V FS-IGBT module with enhanced dynamic clamping capability. Proc. ISPSD'04. 2004, p.339-342.