U-series IGBT Modules

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1. Introduction

Power conversion equipment such as general-purpose inverters and uninterruptible power supplies (UPSs) is continuously challenged by demands for higher efficiency, smaller size, lower cost and lower noise. Accordingly, the power-converting elements used in inverter circuits are also required to have high performance, low cost and high reliability. At present, insulated gate bipolar transistors (IGBTs) are widely used as the main type of power converting elements because they exhibit low loss and enable the easy implementation of drive circuitry. After commercializing the IGBT in 1988, Fuji Electric has made efforts to improve the IGBT further in pursuit of lower loss and higher reliability.

This paper introduces the technology and product line-up of Fuji Electric's fifth generation IGBT modules (U-series), which feature a large improvement in electrical characteristics compared to the fourth generation IGBTs (S-series).

2. Features of the New IGBTs

2.1 Trench gate IGBT

Fuji Electric is producing trench-gate type power metal oxide semiconductor field effect transistors (MOSFETs), to which design and process technologies have been applied in order to ensure sufficient reliability. The trench IGBT is the result of applying these technologies to IGBTs.

Figure 1 shows a comparison of the planer and trench IGBT cell structures. The trench IGBT achieves a drastic increase in cell density, enabling the voltage drop at the channel part to be suppressed to a minimum. Since the distinctive JFET region, sandwiched between channels of the planer type device, does not exist in the trench IGBT, the voltage drop across this region can be completely eliminated. On the other hand, the high channel density of the trench IGBT causes the problem of low capability to withstand a short-circuit condition. However, the trench gate structure developed by Fuji Electric optimizes the total channel length of the MOS device to realize high short-circuit withstand capability without sacrificing the saturation voltage.

2.2 NPT-IGBT

The unit cell structures of a non-punch through (NPT) IGBT and a punch through (PT) IGBT are

Fig.1 Comparison of planer and trench IGBT cell structures

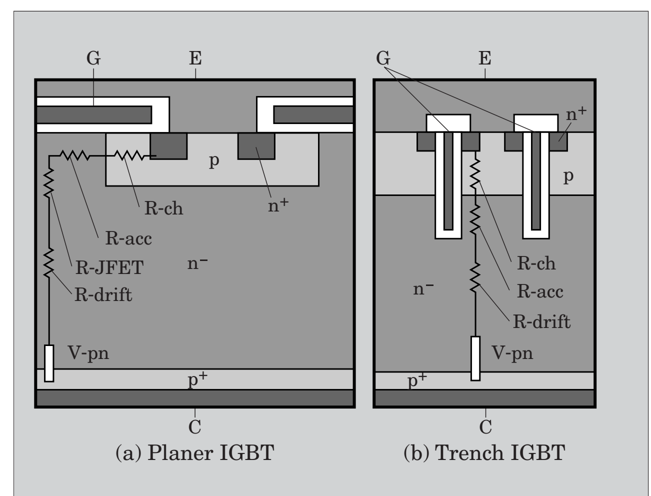
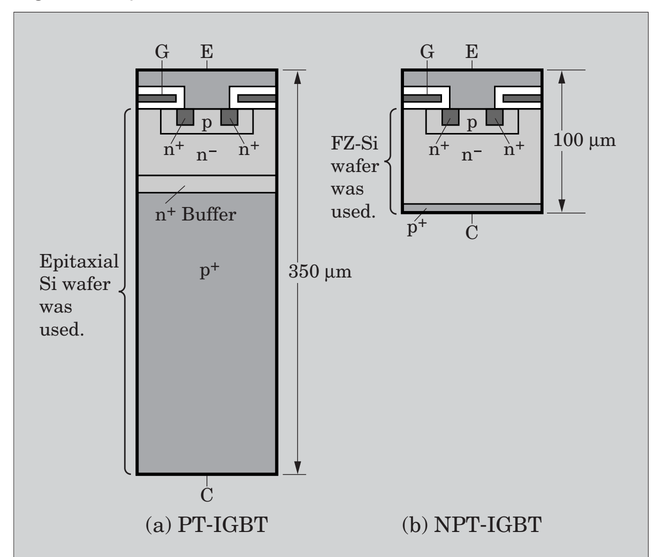


Fig.2 Comparison of PT and NPT-IGBT cell structures



shown in Fig. 2. Features of the NPT-IGBT are as follows.

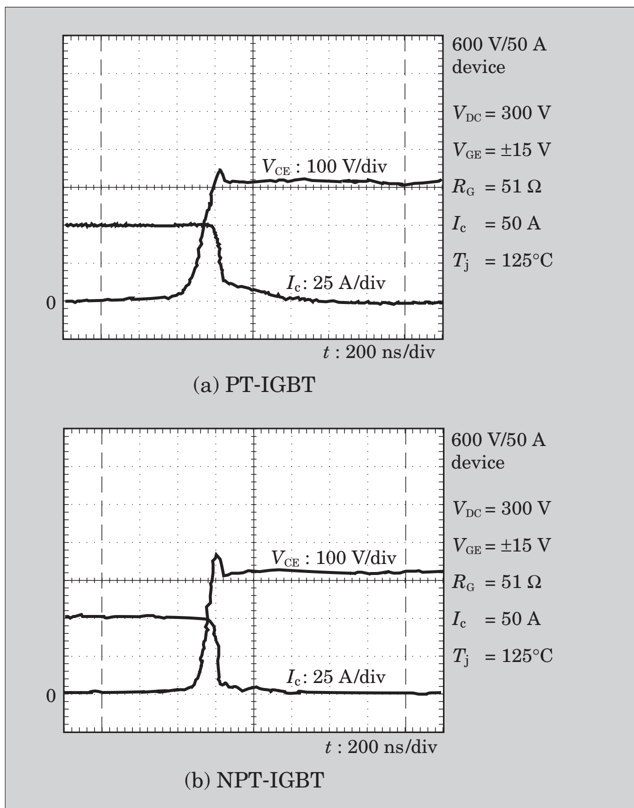
(1) Since injection from the collector-side can be suppressed, lifetime control is unnecessary and the switching loss does not increase even at high temperatures.
(2) Because the temperature dependence of output characteristics is positive (the saturation voltage increases at higher temperature), these devices are well suited for parallel applications.
(3) Withstand capability, including the load short-circuit withstand capacity, is higher than that of a PT-IGBT.
(4) Use of a floating zone (FZ) wafer achieves better cost performance and higher reliability owing to its low rate of crystal defects.

Also, it is important for NPT-IGBTs to suppress saturation voltage while maintaining the collector-emitter (C-E) blocking voltage. The saturation voltage will be lower when thinner wafers are used, however, the thickness of the depletion layer end must be maintained sufficiently thick so there will be no punch through even when the maximum rated C-E blocking voltage is applied, and this sufficient thickness is the minimum value. Therefore, the optimal thickness is thinner for devices having lower C-E blocking voltage, making their manufacture even more difficult. For 600 V NPT-IGBTs, Fuji Electric has established mass production technology to handle the optimal wafer thickness by carefully choosing the optimal wafer specification and improving the precision of back-grinding process technology so that the reduction of saturation voltage could be achieved.

Thinner wafers also feature a reduction in turn-off switching loss. Figure 3 shows a comparison of turn-off waveforms. In the PT-IGBT, which has more carriers injected from the collector side, lifetime control is implemented to promote the recombination of carriers at the time of turn-off. However, this effect decreases as the temperature increases, and therefore the turn-off switching loss tends to increase due to an increase in fall time. For the NPT-IGBT, on the other hand, lifetime control is not implemented and therefore this temperature dependence does not exist and there is no change in the turn-off waveform and no increase in turn-off switching loss. Accordingly, the trade-off relationship between saturation voltage and turn-off switching loss has been improved, and both can be reduced simultaneously with the use of an NPT-IGBT.

When the load is short-circuited, the NPT-IGBT, having a thick n^- drift layer, can support the voltage with its wide n^- drift layer, thereby suppressing the temperature rise which causes breakdown and achieving high short-circuit withstand capability. Even a thin-wafer 600 V NPT-IGBT can achieve a short-circuit withstand capability of 22 µs.

Fig.3 Comparison of turn-off waveforms



2.3 Field stop (FS) structure

Figure 4 compares the cross sections of NPT-IGBT and FS-IGBT unit cells. The NPT-IGBT requires a thick drift layer so that the depletion layer does not contact the collector side during turn-off. The FS-IGBT does not, however, require as thick a drift layer as the NPT type because it is provided with a field stop layer to block the depletion layer, and accordingly, saturation voltage can be lowered for the FS-IGBT. Furthermore, the FS-IGBT has fewer excess carriers because of its thinner drift layer. Moreover, the FS-IGBT can achieve reduced turn-off switching loss because the remaining width of its neutral region is

Fig.4 Comparison of NPT and FS-IGBT cell structures

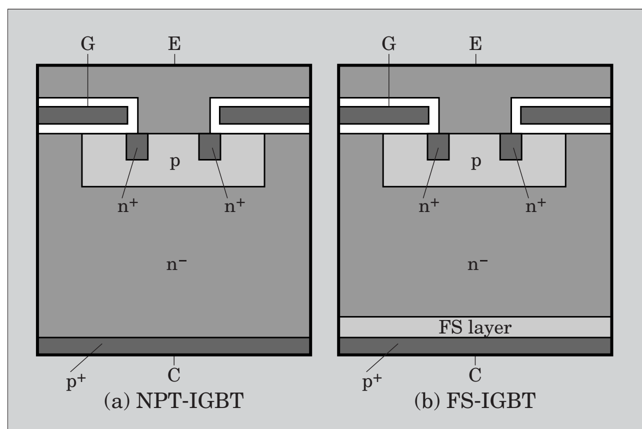


Fig.5 Comparison of conventional and new FWD cell structures

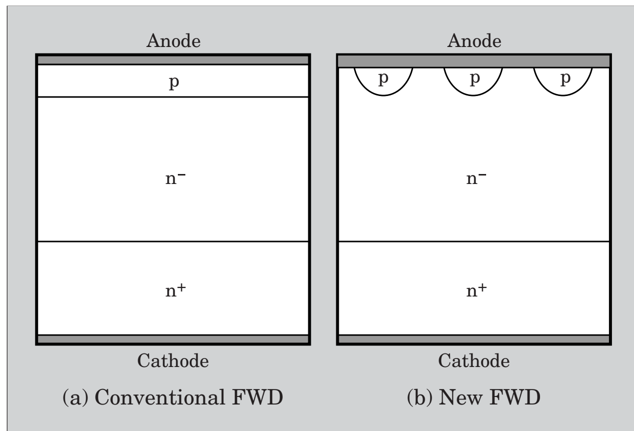
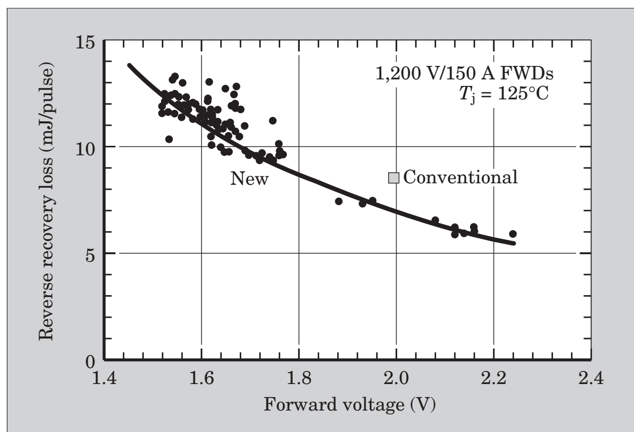


Fig.6 Trade-off between forward voltage and reverse recovery loss



small when its depletion layer is completely extended. Thus, by applying the FS structure to 1,200 V and 1,700 V devices, their trade-off relationship between saturation voltage and turn-off switching loss has been improved, and both can be reduced simultaneously.

3. Features of Fuji's New FWD

As IGBTs are improved, free wheeling diodes (FWDs), which are packaged together with IGBTs into IGBT modules are then installed in inverter circuits, are also subject to improvement. The FWDs are required to have lower conduction loss, which is caused by forward voltage, and lower reverse recovery loss. Also, soft reverse recovery of FWDs, which correlates to the faster turn-on switching of IGBTs, is an especially important characteristic in order to suppress a rise in surge voltage, protect the IGBT from damage, and to suppress malfunction of peripheral circuitry. By optimizing the wafer specifications, applying injection control from the anode at the chip's front structure and implementing optimal lifetime control, Fuji Electric has developed a new FWD having superior soft reverse recovery characteristics.

Fig.7 Trade-off relationship for 1,200 V devices

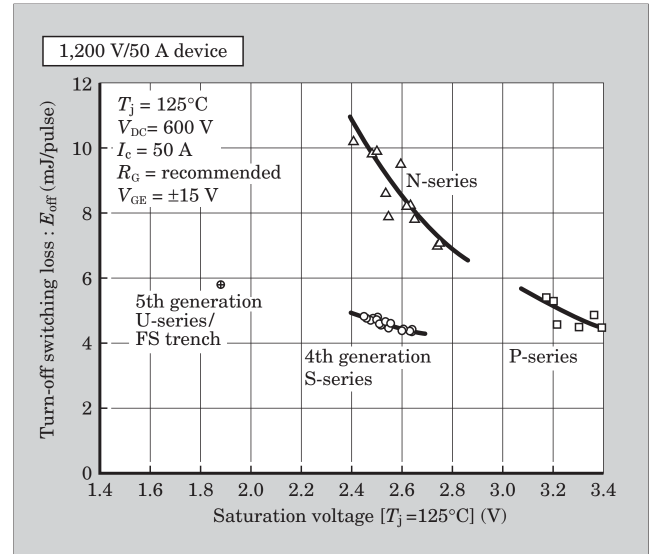


Fig.8 Examples of packages for U-series IGBT modules

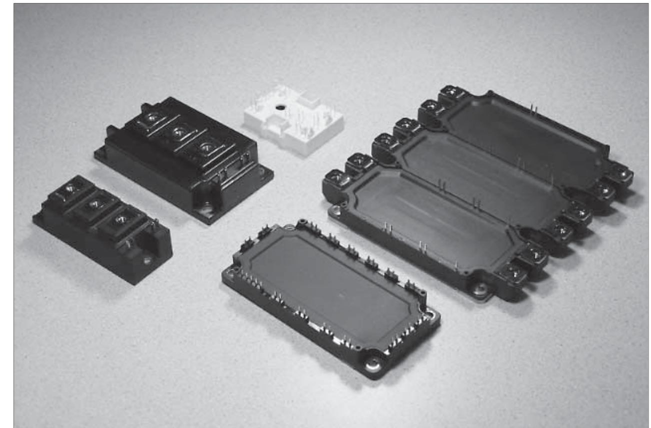


Figure 5 compares the cross sectional structures of a conventional and a new FWD. The new FWD has a structure that is able to suppress carrier injection. Peak current during reverse recovery is reduced, and the new FWD achieves not only a softer reverse recovery characteristic but also less reverse recovery loss. Figure 6 shows an example of the trade-off relationship between forward voltage and reverse recovery loss. The new FWD shows the better result of improved reverse recovery loss compared to that of the conventional FWD. On the other hand, the forward voltage was designed to be approximately 1.6 V at a higher temperature (T_j = 125°C). Therefore, the conduction loss in an inverter circuit application would be lower due to the lower forward voltage of the new FWD. Furthermore, since the output characteristic of the new FWD has a positive temperature coefficient, similar to the U-series IGBT, the current imbalance among parallel-connected devices will be smaller. Therefore, in a parallel connection application, for

Table 1 U-series IGBT modules line-up

I_C rating (Inverter rating), 600 V: 10 A, 15 A, 20 A, 30 A, 50 A (5.5 kW), 75 A, 100 A (11 kW), 150 A, 200 A (22 kW), 300 A, 400 A (40 kW), 600 A, 800 A, 1,200 A, 1,600 A, 2,400 A, 3,600 A

I_C rating (Inverter rating), 1,200 V / 1,700 V: 10 A, 15 A, 25 A (5.5 kW), 35 A, 50 A (11 kW), 75 A, 100 A (22 kW), 150 A, 200 A (40 kW), 300 A, 400 A / 450 A (75 kW), 600 A, 800 A, 1,200 A, 1,600 A, 2,400 A, 3,600 A

V_{CES} rating	Package	Module	I_C rating range
600 V	Small	PIM	10 A – 30 A
		6 in 1	50 A
	PIM	EP2	30 A – 50 A
		EP3	75 A – 100 A
	6 in 1	NewPC2	75 A
		NewPC3	100 A – 150 A
	2 in 1	M232	150 A – 200 A
		M233	300 A – 400 A
		M247	600 A
1,200 V	Small	PIM	10 A – 15 A
		6 in 1	25 A – 35 A
	PIM	EP2	25 A – 50 A
		EP3	35 A – 100 A
	6 in 1	NewPC2	50 A – 75 A
		NewPC3	75 A – 150 A
		EconoPack-Plus* (6 in 1)	150 A – 450 A
	2 in 1/ 1in1	M232	75 A – 150 A
		M233	150 A – 200 A
		M247	300 A – 450 A
		M138	600 A – 800 A
		M234	200 A – 300 A
		M249	450 A
		M142	1,200 A – 1,600 A
		M143	2,400 A – 3,600 A
		M235	200 A – 300 A
		M127	450 A – 600 A
	PIM/ 6 in 1	For vector control: NewPC3 (with Shunt R)	75 A – 150 A
1,700 V	6 in 1	EconoPack-Plus (6 in 1)	150 A – 450 A
	2 in 1	M248	600 A – 1,200 A
	1 in 1	M142	1,200 A – 1,600 A
		M143	2,400 A – 3,600 A

(Shaded) General purpose Inverter (Unshaded) High performance Inverter

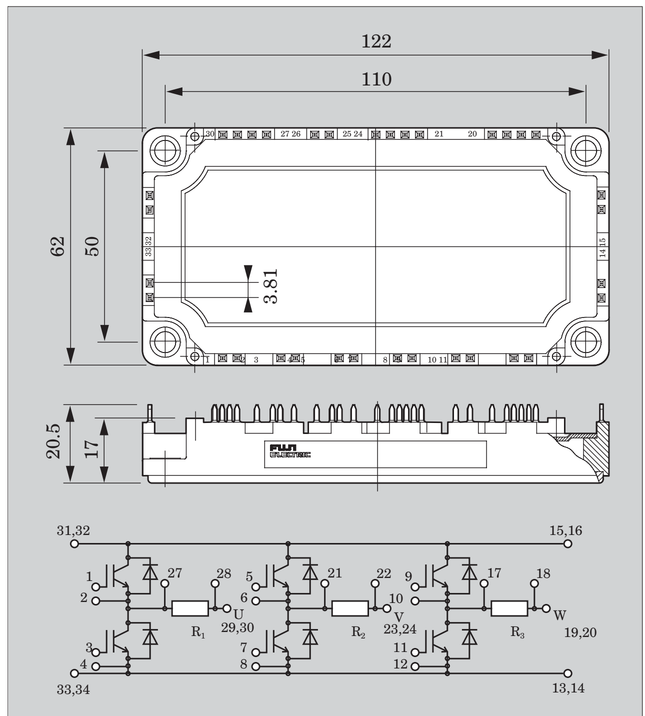
*EconoPack-Plus : A registered trademark of Eupec GmbH, Warstein

example, high power inverter circuits will be easier to use.

4. Introduction of Fuji Electric's Product Line-up

Fuji Electric has combined the above IGBT and FWD technology while continuously employing the same packaging technology as used in fourth generation IGBT modules which have higher power cycling capability, and has finally completed the development and product line-up of U-series IGBT modules that exhibit much improved characteristics in comparison to fourth generation S-series IGBT modules. Figure 7 shows an example of the trade-off relationship for a 1,200 V device. Both the saturation voltage and the turn-off switching loss are simultaneously reduced. It can be seen that the trade-off relationship is dramatically improved in comparison to that of fourth generation IGBT modules, and that almost 20 % less power dissipation loss can be expected in the case of an inverter circuit application. Figure 8 shows examples of packages for these U-series IGBT modules, Table 1 lists Fuji Electric's line-up of U-series IGBT modules. Three blocking voltage ratings of 600 V, 1,200 V and 1,700 V, a wide current range from 10 A up to 3,600 A, and many package variations have been prepared to enable application to various types of power conversion equipment. Also, new module packages with shunt-resisters have been developed as an addition to the U-series product line-up. A schematic drawing of the package and its equivalent circuit are shown in Fig. 9. The modules are designed for vector control inverters,

Fig.9 Module package (6 in 1) with shunt-resisters



and the shunt resisters and their voltage drop detection terminals are installed at the AC output terminals of a three-phase inverter bridge. In contrast to the conventional current detection method that uses an external current detector, a voltage detection method that uses these modules will be able to control the motor output current, thereby enabling inverter equipment to be made simpler and smaller.

5. Conclusion

IGBT and FWD technology of Fuji Electric's U-series IGBT modules, its features and product line-up have been presented. Through using the latest semiconductor technology and packaging technology, these products achieve superior low loss characteristics, and we believe they will make important contributions to the realization of smaller size and lower loss inverter circuit equipment.

Fuji Electric intends to continue working to improve this technology further, with the goals of realizing higher performance and higher reliability devices, and to contribute 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.