U-series IGBT Modules (1,200 V)

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1. Introduction

Power conversion equipment such as general-use inverters and uninterruptible power supplies (UPSs) is continuously challenged by demands for higher efficiency, smaller size, lower cost and lower noise. Accordingly, power-converting elements for inverter circuits are also required to have higher performance and lower cost. At present, IGBTs (insulated gate bipolar transistors) are the main power-converting elements used because of their low loss and easy drive circuit implementation. After commercializing the IGBT in 1988, Fuji Electric has made efforts to improve the IGBT in pursuit of lower loss and lower cost. This paper introduces fifth generation IGBT modules (U-series), and focuses on the 1,200 V series used mainly in 400 V AC power lines overseas. Adoption of a trench gate structure and a field stop (FS) structure has resulted in a large improvement in the trade-off characteristics of fifth generation IGBTs compared with those of the fourth generation IGBT (S-series).

2. Features of the New IGBTs

Figure 1 shows the trade-off relation of the saturation voltage between the collector and emitter ($V_{CE\ (sat)}$) and the turn-off loss of the newly developed IGBT (trench FS-IGBT). From this figure, it can be seen that the trade-off of the 1,200 V U-series IGBT is dramatically improved compared to that of the former generation S-series IGBT [planer NPT (non punch through) -IGBT]. This dramatic improvement in characteristics has been achieved through adopting a field stop structure, evolved from an advanced NPT configuration, and a trench gate structure, acquired during development of MOSFETs (metal oxide semiconductor field effect transistors). Each of these structures is described below.

2.1 Field stop structure

Figure 2 shows output characteristics and Fig. 3 shows comparison of cross section of unit cells of a planar NPT-IGBT and a planar FS-IGBT. An 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 such a thick drift layer as the NPT because a field stop layer to stop the depletion layer has been fabricated in the FS-IGBT and accordingly $V_{CE\ (sat)}$ can be lowered for the FS-IGBT. Furthermore, the FS-IGBT has fewer excess carriers because of its thinner drift layer. Moreover,

Fig.1 Trade-off between $V_{CE\ (sat)}$ and turn-off loss

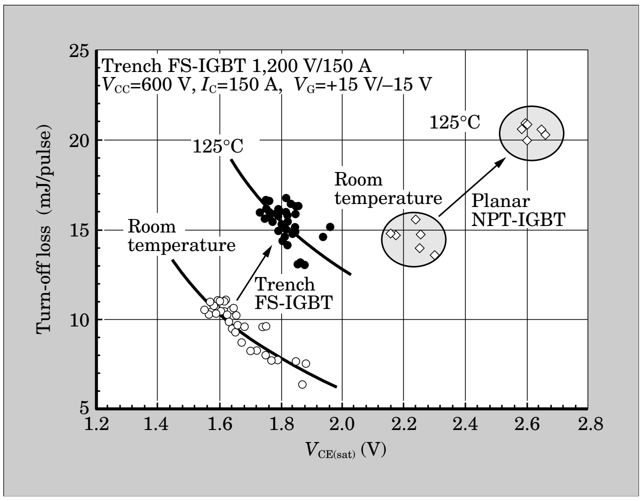


Fig.2 Output characteristics

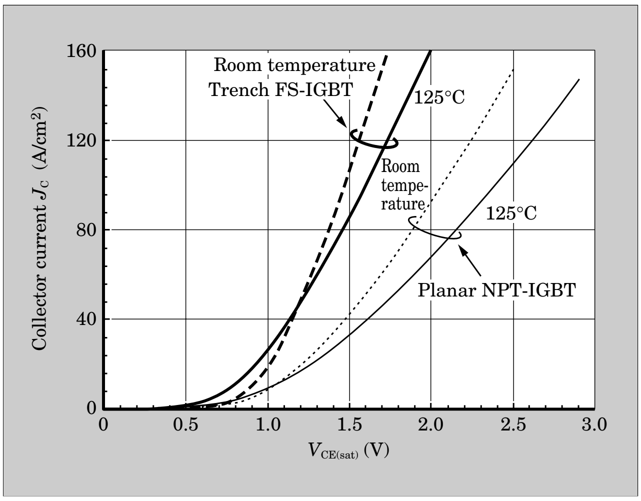


Fig.3 Comparison of cross sections of unit cells of a planar NPT-IGBT and a planar FS-IGBT

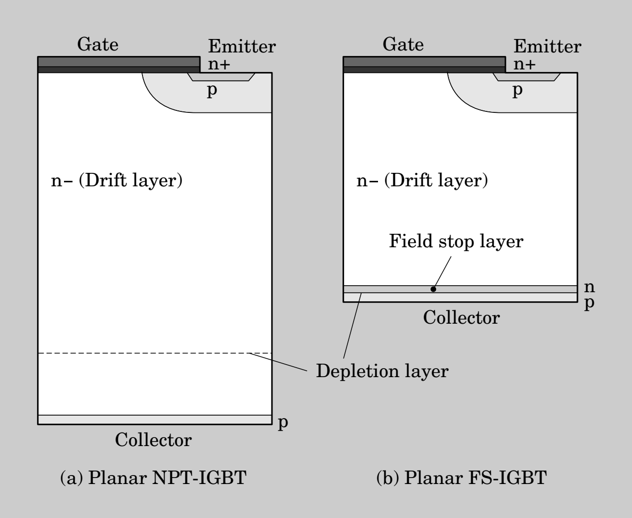


Fig.4 Comparison of cross sections of IGBT unit cells

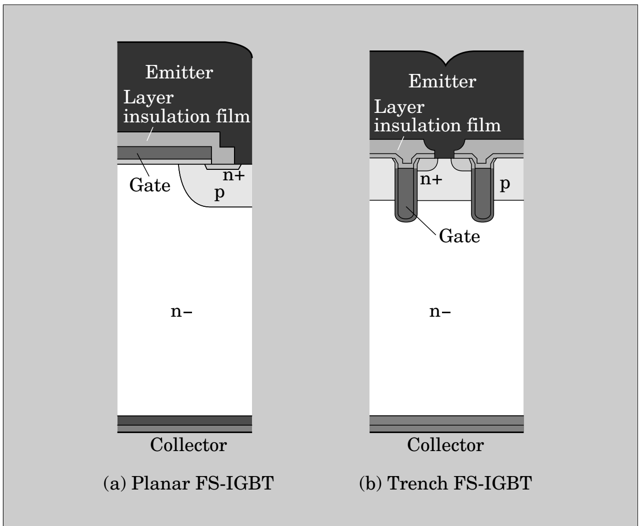


Fig.5 Short-circuit waveforms

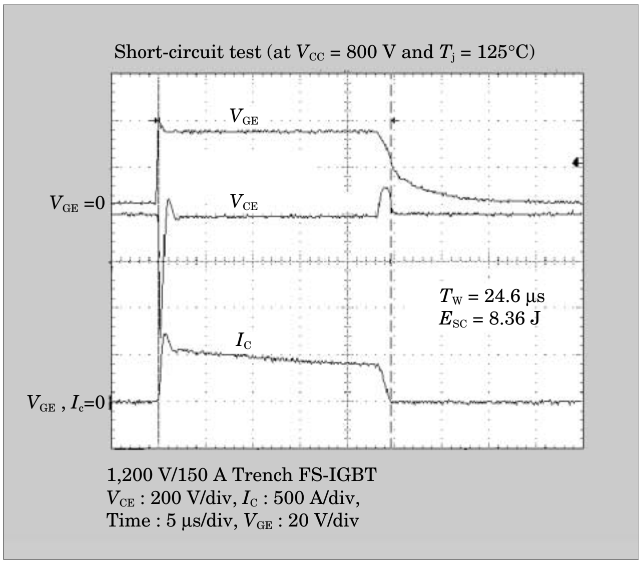


Fig.6 Comparison of turn-on waveforms

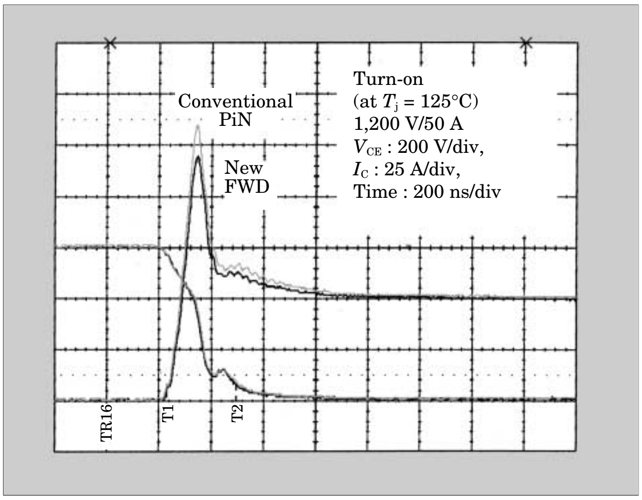
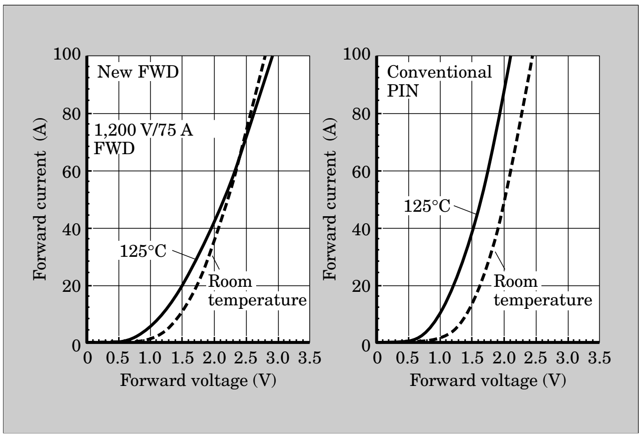


Fig.7 Comparison of FWD output characteristics



the FS-IGBT can achieve reduced turn-off loss because the remaining width of its neutral region is small when its depletion layer is completely extended.

2.2 Trench gate structure

Figure 4 shows a cross section of a trench FS-IGBT. By adopting a trench gate structure, channel density can be increased and $V_{CE\ (sat)}$ can be significantly lowered because resistance in the J_{FET} part, which was problematic for planar IGBTs when cell density increased, can be reduced to zero.

On the other hand, the high channel density of the trench IGBT causes a problem of low short-circuit capacity. However, the trench gate structure optimizes the total channel length to realize high short-circuit capacity without sacrificing $V_{CE\ (sat)}$ (Fig. 5).

Table 1 Characteristics of the 1,200 V U-series IGBT modules

(a) Absolute maximum ratings (at T_c = 25°C unless otherwise specified)

Item	Symbol	Condition		Max. rating	Unit
Collector-emitter voltage	V_{CES}			1,200	V
Gate-emitter voltage	V_{GES}			±20	V
Collector current	I_C	Continous	T_j =25°C	150	A
			T_j =80°C	100	
	$I_{C\ pulse}$	1 ms	T_j =25°C	300	
			T_j =80°C	200	
	$-I_C$			100	
	$-I_{C\ pulse}$	1 ms		200	
Maximum loss	P_C	1 device		600	W
Junction temperature	T_j			150	°C
Preserving temperature	T_{stg}			–40 to +125	°C
Isolation voltage (package)	V_{iso}	AC : 1 min		2,500	V
Screw fastening torque	Mounting			3.5	Nm
	Terminals			3.5	

(b) Electrical characteristics (at T_c = 25°C unless otherwise specified)

Item	Symbol	Condition		Characteristics min.	typ.	max.	Unit
Collector-emitter leakage current	I_{CES}	V_{GE} =0 V, V_{CE} =1,200 V		–	–	1.0	mA
Gate-emitter leakage current	I_{GES}	V_{CE} =0 V, V_{GE} =±20 V		–	–	0.2	μA
Gate-emitter threshold voltage	$V_{GE(th)}$	V_{CE} =20 V, I_C =100 mA		–	7.0	–	V
Collector-emitter saturation voltage	$V_{CE(sat)}$ (Terminal)	V_{GE} = 15 V, I_C = 100 A	T_j =25°C	–	1.95	–	V
			T_j =125°C	–	2.2	–	
	$V_{CE(sat)}$ (Chip)		T_j =25°C	–	1.75	–	
			T_j =125°C	–	2.0	–	
Input capacitance	C_{ies}	V_{GE} =0 V, V_{CE} =10 V f =1 MHz		–	13.3	–	nF
Output capacitance	C_{oes}			–	0.8	–	
Reverse transfer capacitance	C_{res}			–	1.2	–	
Turn-on time	t_{on}	V_{CC} =600 V I_C =100 A V_{GE} =±15 V R_g =4.7 Ω		–	–	1.2	μs
	t_r			–	–	0.6	
Turn-off time	t_{off}			–	–	1.0	
	t_f			–	–	0.3	
Diode forward voltage	V_F (Terminal)	I_F = 100 A	T_j =25°C	–	2.0	–	V
			T_j =125°C	–	2.0	–	
	V_F (Chip)		T_j =25°C	–	1.8	–	
			T_j =125°C	–	1.8	–	
Reverce recovery time	t_{rr}	I_F =100 A		–	–	0.35	μs

(c) Thermal resistance characteristics

Item	Symbol	Condition	Characteristics min.	typ.	max.	Unit
Thermal resistance (1 device)	$R_{th(j-c)}$	IGBT	–	–	0.21	°C/W
		FWD	–	–	0.33	
Thermal resistance between case and fins	$R_{th(c-f)}$		–	0.05	–	

Table 2 1,200 V U-series IGBT modules

Rated voltage (V)	Package	Rated current (A)	Types	Sale date
1,200	Small PIM	10	7MBR10UE120	April 2003
		15	7MBR15UE120	
	EP2	10	7MBR10UA120	
		15	7MBR15UA120	
		25	7MBR25UA120	
		35	7MBR35UA120	
	EP3	35	7MBR35UB120	
		50	7MBR50UB120	
		75	7MBR75UB120	
	HEP2	10	7MBR10UC120	
		15	7MBR15UC120	
		25	7MBR25UC120	
		35	7MBR35UC120	
	HEP3	35	7MBR35UD120	
		50	7MBR50UD120	
		75	7MBR75UD120	
	New PC2	75	6MBI75UA-120	
	New PC3	75	6MBI75UB-120	
		100	6MBI100UB-120	
		150	6MBI150UB-120	
		75	6MBI75UC-120	
		100	6MBI100UC-120	
		150	3MBI150UC-120	
	New PC2	150	3MBI150U-120	
	7in1 (M631 or P611)	75	7MBI75UD-120	
		100	7MBI100UD-120	
		150	7MBI150UD-120	
	M232	75	2MBI75UA-120	
		100	2MBI100UA-120	
		150	2MBI150UA-120	
	M233	150	2MBI150UB-120	
		200	2MBI200UB-120	
	M234	200	2MBI200UC-120	
		300	2MBI300UC-120	
	M235	300	2MBI300UD-120	
	M238	300	2MBI300UE-120	
		450	2MBI450UE-120	
	Large capacity module	225	6MBI225U-120	
		300	6MBI300U-120	
		450	6MBI450U-120	

Fig.8 Catalogue of packages of 1,200 V U-series

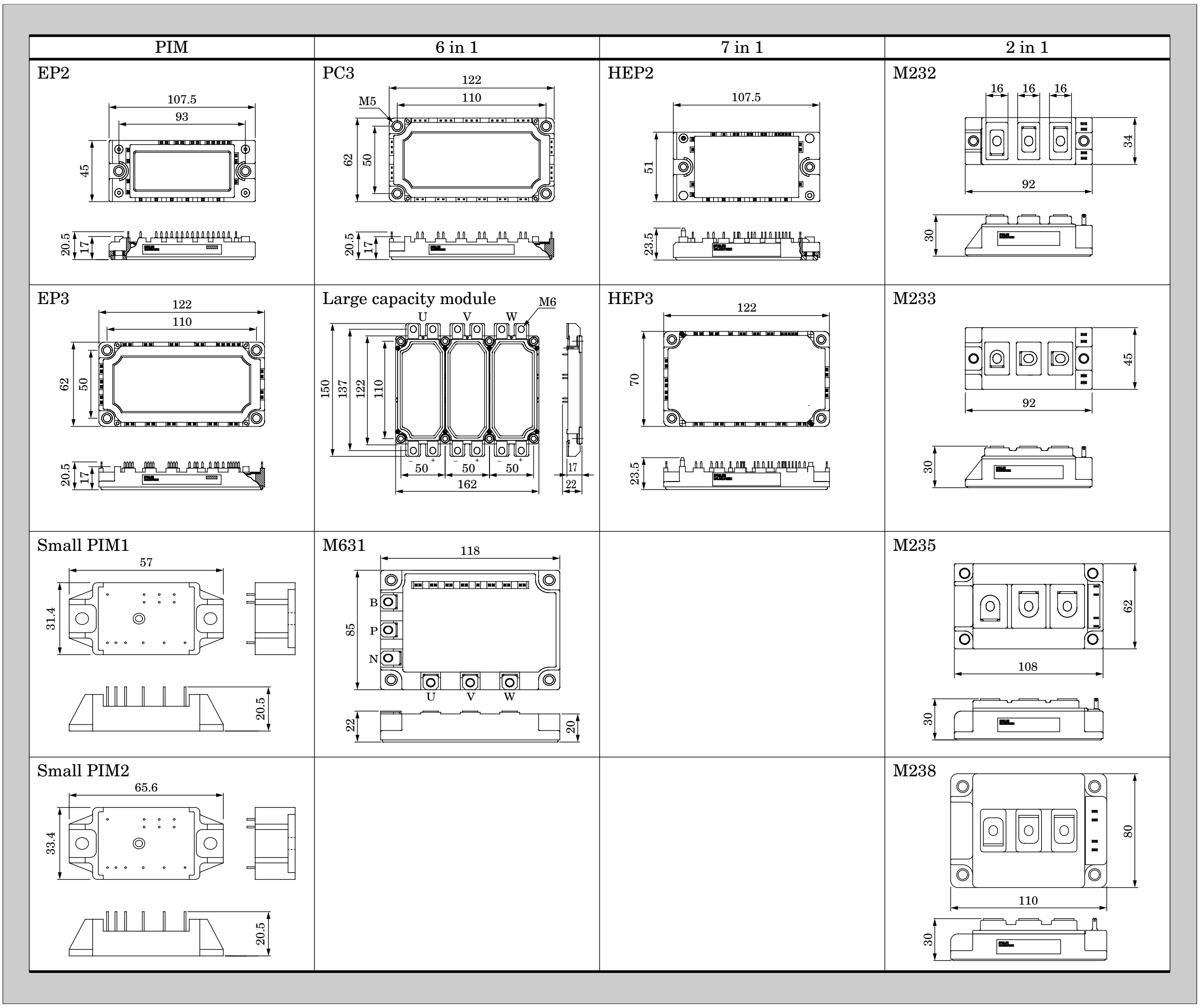
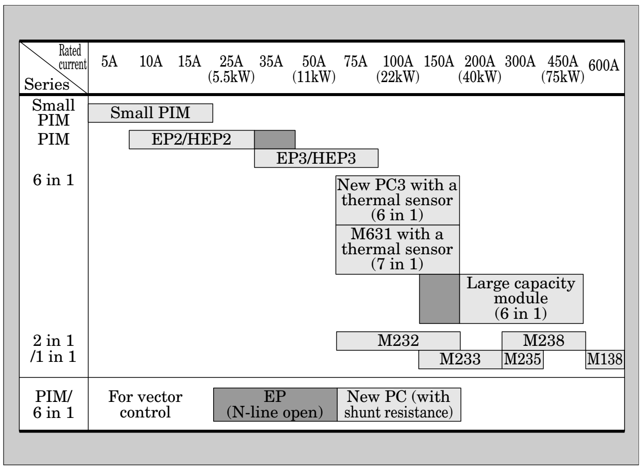


Fig.9 Correlation among 1,200 V U-series



3. Features of the New FWDs

As IGBT switching speeds have increased, the accompanying vibration at the time of switching has become a significant problem. Fuji Electric succeeded in realizing soft recovery to suppress the vibration even at a high di/dt by optimizing the surface structure and bulk impurities profile of the FWDs (free wheeling diodes) (Fig. 6).

Moreover, a newly developed FDW has been made suitable for parallel operation by optimizing a lifetime killer to achieve a positive temperature coefficient of the output characteristics (Fig. 7).

4. 1,200 V U-series IGBT Modules and Characteristics

Characteristics of 1,200 V U-series IGBT modules and an overview of U-series are presented in Tables 1 and 2, respectively. A catalog of packages available in this series is shown in Fig. 8 and the correlation among the 1,200 V U-series IGBT modules is shown in Fig. 9.

5. Conclusion

An overview of the 1,200 V U-series IGBT modules has been presented. The IGBTs of this series are extremely low loss devices and we believe they will make important contributions to the realization of smaller size and lower loss equipment.

Fuji Electric intends to continue to work toward realizing higher performance and higher reliability devices and to contribute to the development of power electronics.

Reference

(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.