U-series of IGBT-IPMs (600 V)

Kiyoshi Sekigawa
Hiroshi Endo
Hiroki Wakimoto

1. Introduction

Intelligent power modules (IPMs) are intelligent power devices that incorporate drive circuits, protection circuits or other functionality into a modular configuration. IPMs are widely used in motor driving (general purpose inverter, servo, air conditioning, elevator, etc.) and power supply (UPS, PV, etc.) applications.

The equipment that uses these IPMs are required to have small size, high efficiency, low noise, long service life and high reliability.

In response to these requirements, in 1997, Fuji Electric developed the industry's first internal overheat protection function for insulated gate bipolar transistors (IGBTs) and developed an R-IPM series that achieved high reliability by employing an all-silicon construction that enabled a reduction in the number of components used.

Then in 2002, Fuji Electric changed the structure of its IGBT chips from the punch through (PT) structure, which had been in use previously, to a non-punch through (NPT) structure, for which lifetime control is unnecessary, in order to realize lower turn-off loss at high temperature, and also established finer planar gate and thin wafer processing technology to develop an R-IPM3 series that realizes low conduction loss.

With the goal of reducing loss even further, Fuji Electric has developed an IGBT device that employs a trench NPT structure to realize lower conduction loss and has developed a new free wheeling diode (FWD) structure to improve the tradeoff between switching noise and loss. Both of these technologies are incorporated into Fuji Electric's newly developed U-series IGBT-IPM (U-IPM) which is introduced below.

2. U-IPM Development Concepts and Product Line-up

The concepts behind the development of the U-IPM are listed below.

(1) Realization of lower loss

Lower loss can be realized by developing new power elements and optimizing the drive performance. Increasing the carrier frequency of the equipment contributes to improved control performance. Also, larger output can be obtained from the equipment during the operation at the same carrier frequency.

(2) Continued use of the same package as prior products

Table 1 Product line-up, characteristics and internal functions of the U-IPM series

No. of elements	Model	V_{DC} (V)	V_{CES} (V)	Inverter part		Brake part		Internal function								Package type
				I_C (A)	P_C (W)	I_C (A)	P_C (W)	Both upper and lower arms			Upper arm		Lower arm			
								Dr	UV	TjOH	OC	ALM	OC	ALM	TcOH	
6 in 1	6MBP 20RUA060	450	600	20	84	–	–	Yes	Yes	Yes	None	None	Yes	Yes	None	P619
	6MBP 50RUA060			50	176	–	–	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P610
	6MBP 80RUA060			80	283	–	–	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P610
	6MBP100RUA060			100	360	–	–	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P611
	6MBP160RUA060			160	431	–	–	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P611
7 in 1	7MBP 50RUA060	450	600	50	176	30	120	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P610
	7MBP 80RUA060			80	283	50	176	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P610
	7MBP100RUA060			100	360	50	176	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P611
	7MBP160RUA060			160	431	50	176	Yes	Yes	Yes	Yes	None	Yes	Yes	Yes	P611

Dr: IGBT driving circuit, UV : Under voltage lockout for control circuit, TjOH: Device overheat protection, OC: Over-current protection, ALM: Alarm output, TcOH: Case temperature over-heat protection
*6MBP20RUA060 uses a shunt resistance-based over-current detection method at the N line.

Fig.1 External view of U-IPM packages

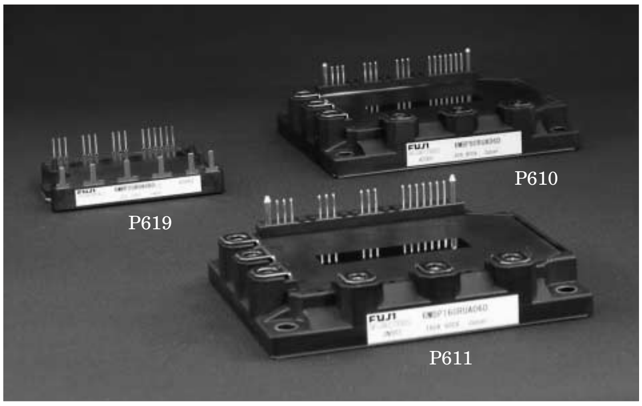
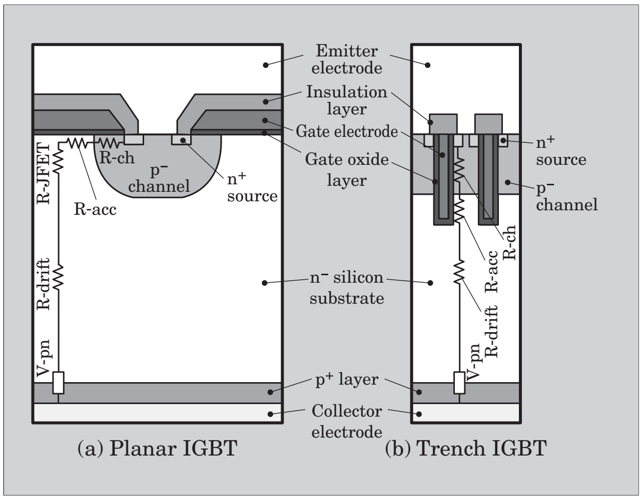


Fig.2 Comparison of planar IGBT and trench IGBT chip cross sections



The continued use of the same package as with prior products makes it possible to improve equipment performance by replacing the IPM without having to modify the design of the equipment.

Table 1 lists the product line-up, characteristics and internal functions of Fuji Electric's 600 V U-IPM series. The U-IPM series maintains internal functions and a package size that are interchangeable with the R-IPM series; its rated current is 20 to 160 A for the "6 in 1" pack and 50 to 160 A for the "7 in 1" pack (containing an internal IGBT for braking use). Figure 1 shows an external view of the packages.

3. Characteristics of the Power Devices

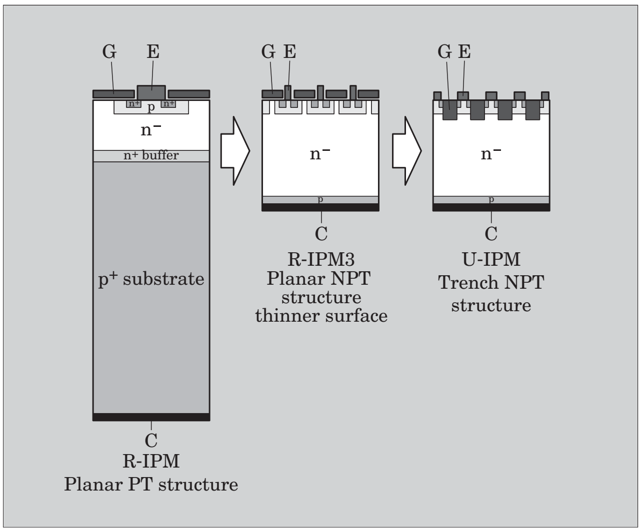
A fifth-generation U-series IGBT (U-IGBT) is used as the power device. This U-IGBT combines trench gate technology with a basic design comprising Fuji Electric's floating zone (FZ) wafer technology, thin wafer processing technology, carrier injection control technology, and transportation factor improving technology.

Figure 2 compares the structures of the conventional planar IGBT and the trench IGBT. The adoption of a trench gate structure results in a smaller voltage drop at the channel (R-ch) due to increased surface cell density and results in a lower saturation voltage due to the smaller voltage drop resulting from the elimination of the planar device's characteristic J_{FET} region (R-JFET). Moreover, short circuit immunity capability is realized through optimization of the design of the surface structure. Figure 3 illustrates the changes that have occurred in the cross-sectional IGBT structure in the transition from the conventional IGBT to the U-IGBT, and Table 2 compares their applied technologies.

Table 2 Changes in IGBT technology

IGBT technology	R-IPM	R-IPM3	U-IPM
	N-IGBT	T-IGBT	U-IGBT
Wafer	Epitaxial	FZ	
Wafer thickness	350 μm	100 μm	
Structure	PT	NPT	
Gate structure	Planar		Trench
Lifetime control	Yes	None	
Carrier injection	High	Low	
Transportation factor	Low	High	

Fig.3 Change in cross-sectional structure of 600 V IGBT chip



The FWD, in accordance with the U-IGBT, incorporates a new design featuring optimized wafer specification, control of anode-side injection and optimal lifetime control technology to realize the characteristics of low peak current during reverse recovery operation, low generated loss, and soft recovery.

4. U-IPM Loss

4.1 Comparison of total loss

The marketplace requires that new IPM products achieve lower levels of loss. (1) Increased carrier frequency to enhance controllability and (2) larger output current at the same carrier frequency are necessary for the achievement of the goal. The loss

Fig.4 Comparison of total loss (at same current) for the U-IPM, R-IPM3 and R-IPM series

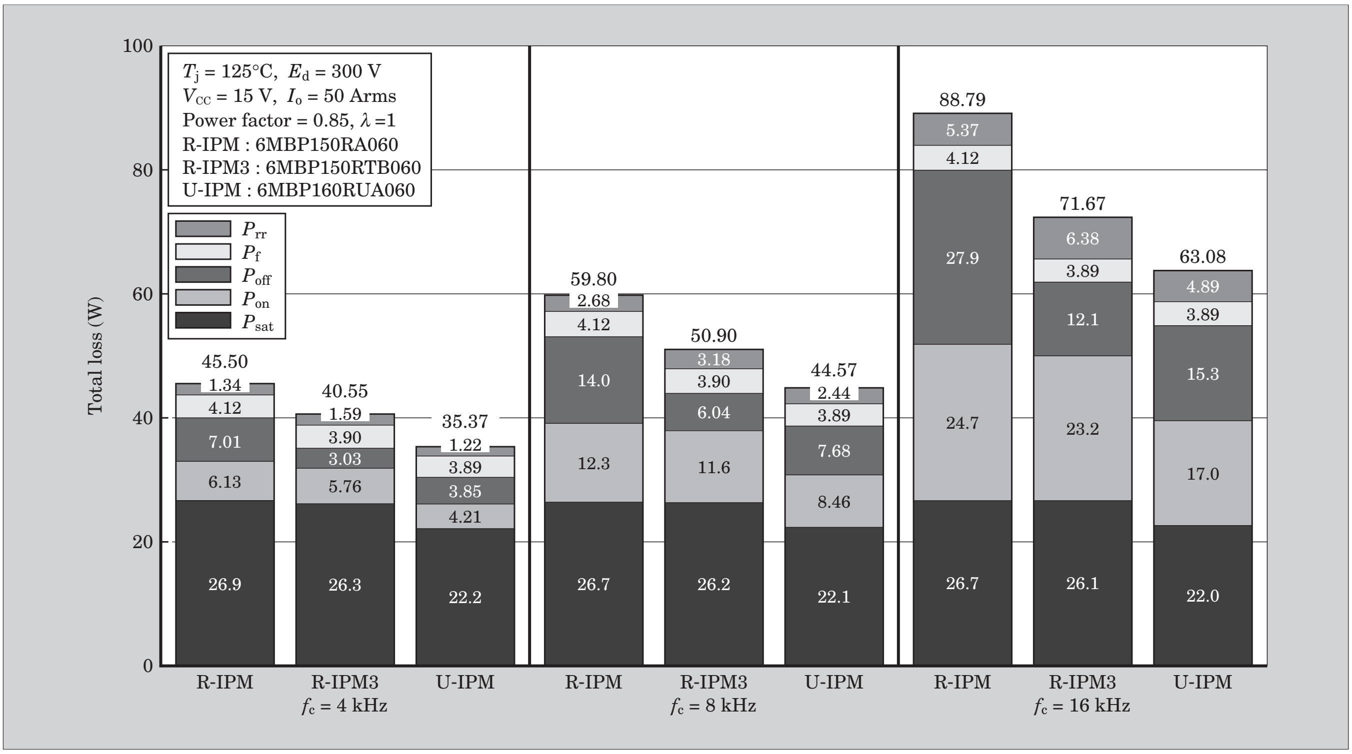


Fig.5 Current vs. total loss (at same frequency) for U-IPM, R-IPM3 and R-IPM

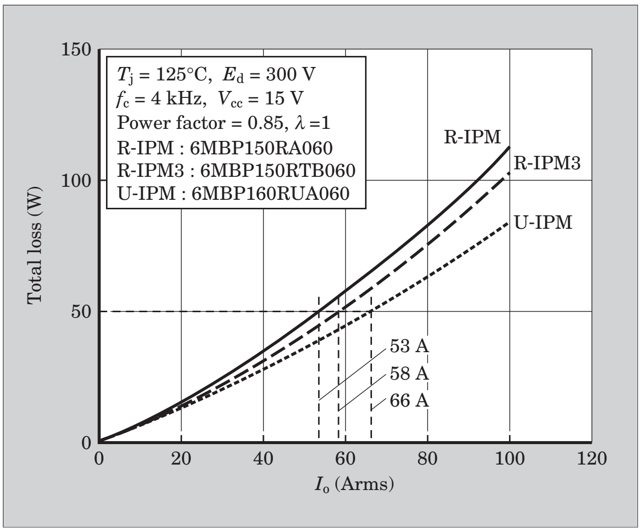
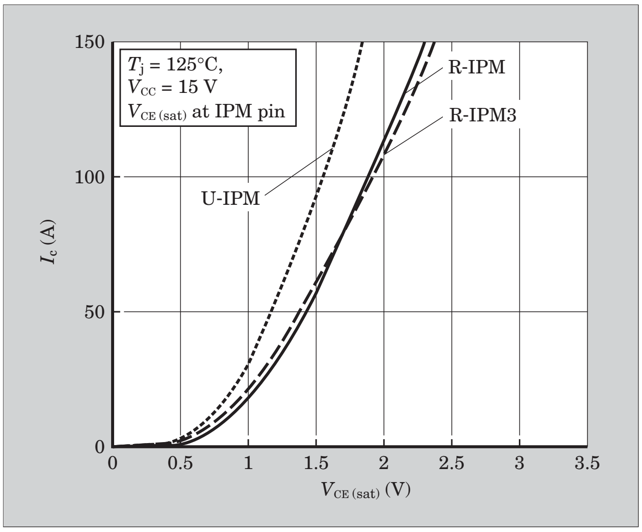


Fig.6 I_C-V_{CE} characteristics for U-IPM, R-IPM3 and R-IPM



generated by existing models and by the U-IPM is described below.

Figure 4 compares the loss of the U-IPM and the existing R-IPM and R-IPM3 devices in the case of operation at carrier frequencies of 4, 8 and 16 kHz, and a current of 50 Arms (1/3 of the rated current). As can be seen in the figure, the newly developed U-IPM realizes a total loss that is approximately 22 to 28 % lower than that of the R-IPM and approximately 11 to 12 % lower than that of the R-IPM3. In particular, it can be seen that the loss generated when using the U-IPM at a carrier frequency of 8 kHz is less than the loss generated by a R-IPM operating at a carrier frequency of 4 kHz, and therefore, the carrier frequency can be increased from 4 kHz to 8 kHz by replacing a R-IPM with a U-IPM of the same size package. Moreover, according to Fig. 5 which shows the relationship between current and total loss at f_c = 4 kHz, to generate the same amount of loss (50 W) as the R-IPM, the output current of the U-IPM can be increased by 24.5 % compared to that of the R-IPM, or increased by 13.7 % compared to that of the R-IPM3.

These techniques for reducing loss were focused on reducing the conduction loss, which accounts for more than 50 % of the total loss, and on reducing the turn-on

Fig.7 Characteristics of turn-on waveform and emission noise

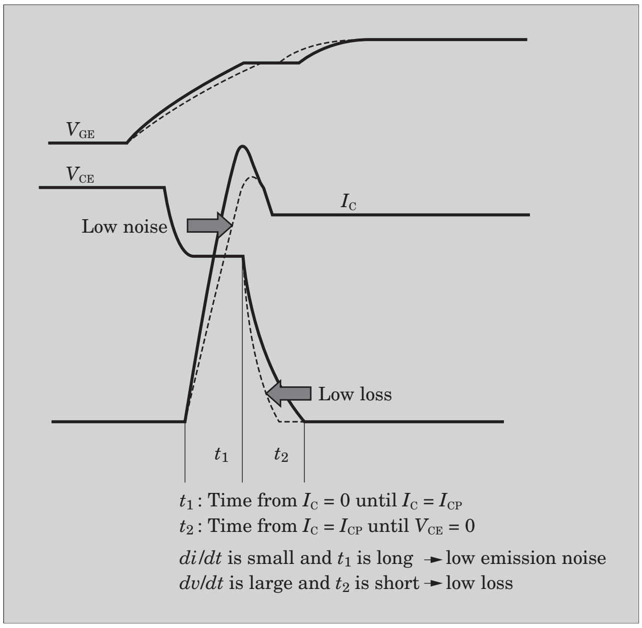


Table 3 Characteristics of gate resistance and turn-on waveform

		Turn-on di/dt	Turn-on dv/dt	Loss	Emission noise
Gate resistance R_G	High	Low	Low	Increases	Decreases
	Low	High	High	Decreases	Increases

loss, which accounts for a large percentage of the switching loss of the R-IPM3. Each type of loss reduction is described below.

4.2 Reduction of conduction loss

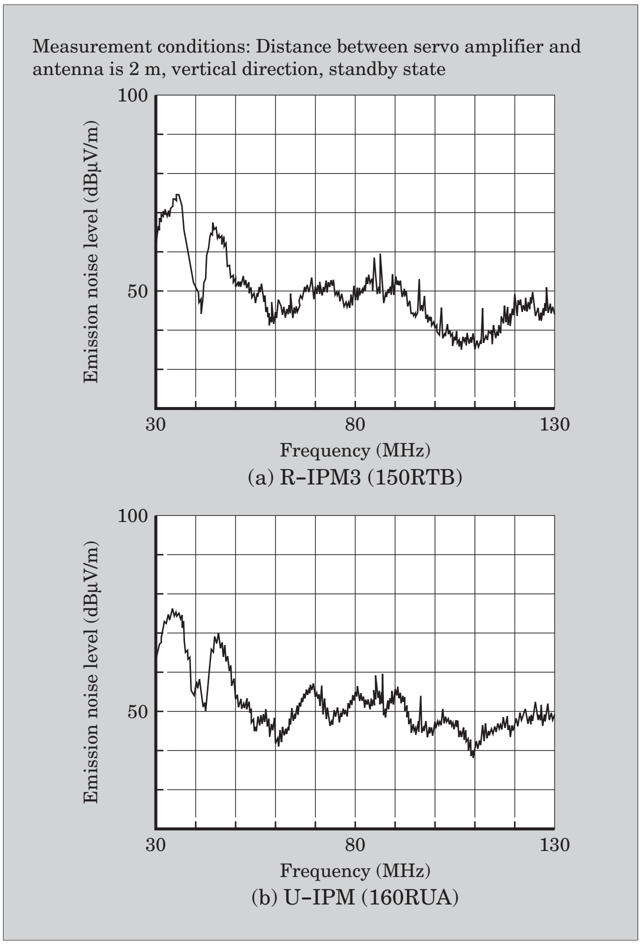
Figure 6 shows I_C-$V_{CE(sat)}$ characteristics for U-IPM, R-IPM3 and R-IPM devices. It can be seen that when $I_C = 150$ A, the $V_{CE(sat)}$ of the U-IPM is 0.45 V less than that of the R-IPM and 0.55 V less than that of the I-RPM3. This is the $V_{CE(sat)}$ reduction effect due to the trench IGBT described in chapter 3.

4.3 Turn-on loss and emission noise

Figure 7 shows a schematic drawing of the current (I_C) and voltage (V_{CE}) at the time when the device is turned on. As can be seen in the figure, typically, loss can be reduced by making dv/dt larger and emission noise can be reduced by making di/dt smaller. However, in the case where turn-on operation is controlled by the typical method of gate resistance only, there is a tradeoff relation as shown in Table 3, and it is difficult to establish both high dv/dt and low di/dt simultaneously.

In the newly developed U-IPM, the following two techniques suppress the emission noise that usually increases when gate resistance is decreased and di/dt is increased, thereby enabling di/dt to be increased and turn-on loss to be decreased without any increase in

Fig.8 Emission noise



the emission noise.

(1) Application of the new soft recovery FWD suppresses dv/dt.
(2) The capacitance between the gate and emitter is optimized in order to reduce di/dt, which increased as a result of the lower gate resistance, without reducing dv/dt

Through application of the above techniques, even if currents of all sizes are controlled with the same gate resistance, emission noise will be maintained at the same level as that of the R-IPM3 as shown in Fig. 8, and lower loss can be realized. Accordingly, the total loss generated in all these products is linearly proportional to the current, and the total loss and temperature rise that occur during actual use can easily be estimated.

5. Conclusion

Fuji Electric's 600 V U-IPM that uses a U-series IGBT chip having a trench NPT structure has been described above. This U-IPM provides suitable performance to satisfy the marketplace in which lower loss is required. In the future, Fuji Electric intends to continue to develop new IPMs that will satisfy market requirements.