RC-IGBT Chip Technology for White Goods

Authors: *Tetsuo Takahashi** and *Takuya Yoshida***

1. Introduction

Today, power devices are used for various types of equipment such as industrial machinery, electric vehicles, and consumer appliances (e.g., air conditioners and refrigerators). Many of the main power devices currently used have IGBTs and FWDs, and their performance continues to be enhanced. The RC-IGBT, which combines an IGBT and FWD, is an example of development aiming at higher performance.

It is difficult to improve the performance of the RC-IGBT because the characteristics of both the IGBT and FWD must be taken into account simultaneously. However, the size of the chip can be reduced, so it is a key device for reducing the size and energy consumption of the latest power modules.

This paper introduces the second-generation RC-IGBT for consumer products and describes how its characteristics were significantly improved using Mitsubishi Electric Corporation's latest technologies.(1)

2. Structure of RC-IGBTs for Consumer Products and Applied Technologies

2.1 Basic structure of the RC-IGBT

The structure of the RC-IGBT consists of an IGBT and an FWD integrated into one chip. There is a trade-off relationship between the performance of the IGBT and FWD and fabrication cost.

The next section describes the technologies applied to the RC-IGBT for consumer products to improve its performance and suppress the cost at the same time.

2.2 Structure of the RC-IGBT and applied technologies

Table 1 lists the technologies of the latest second-generation RC-IGBT.

2.2.1 Optimization of the area ratio of the FWD region

The area ratio of the FWD region – the first item in the table above – is an important parameter that affects the power loss in the IGBT and FWD when each one is functioning. Figure 1 shows the dependency of the forward voltage drop (V_F) and the reverse recovery current (I_{rr}) on the FWD area ratio as an example.

As shown in Figure 1, V_F is in a trade-off relationship with I_{rr}, so the area ratio is optimized to minimize the total power loss depending on the application.

2.2.2 Review of the structure of the FWD

Generally, the FWD needs to be optimized in consideration of the forward voltage drop and reverse recovery characteristics as mentioned earlier.

To improve the characteristics of FWDs, the structure of the second-generation RC-IGBT is designed such that the current does not concentrate in a certain spot, which results in avoiding a rapid increase in the reverse recovery current and forward voltage drop.

2.2.3 Improvement of the layout of the IGBT and FWD

The layout of the second-generation RC-IGBT was designed such that heat is dispersed in the chip as much

Table 1 Design concept of the second-generation RC-IGBT

Item	Technology	Purpose
1	Optimization of the area ratio of the FWD region	Reduce the power loss.
2	Review of the structure of the FWD	Improve the trade-off between V_F and recovery.
3	Improvement of the layout of the IGBT and FWD	Optimize the heat radiation from FWDs.
4	Thinning of wafers	Reduce the power loss using the seventh-generation process.
5	Manufacturing method without lifetime control (Selectable depending on the application)	Reduce the variation in the characteristics and cost.

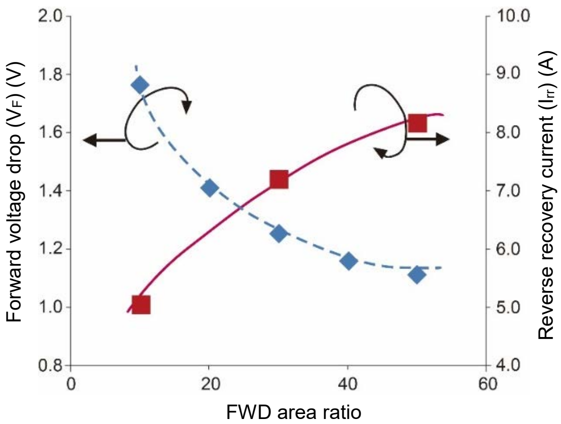

Fig. 1 FWD area ratio dependence of V_F and I_{rr}

*Power Device Works **Melco Semiconductor Engineering Corp.

as possible. Figure 2 illustrates the layout of the IGBT and FWD. By dividing the FWD region in which the current is concentrated into small sections in the design, the temperature rise at a certain spot in the FWD can be reduced. Figure 3 shows the dependency of the reverse recovery current (I_{rr}) and surge forward current (I_{FSM}) on the size of the FWD for the same FWD area ratio. The figure shows that optimizing the size can significantly improve the I_{FSM}, which is an index of the FWD's current-carrying capacity, without significantly increasing the I_{rr} that affects the power loss.

Optimally dividing the FWD region greatly improved the FWD's heat dissipation in the second-generation RC-IGBT.

2.2.4 Thinning of wafers

CSTBT[2] technology using the seventh-generation IGBT process in which wafers are made very thin was applied to the RC-IGBT for consumer products. This greatly improved its characteristics.

2.2.5 Manufacturing method without lifetime control

To reduce the cost and characteristic variation, a structure without lifetime control was applied to a wide carrier frequency range by comprehensively improving the characteristics. A structure with lifetime control was used for the section on the high-speed side to satisfy various applications of consumer products.

3. Characteristics of RC-IGBTs for Consumer Products

3.1 Characteristics of the chip

The characteristics of the second-generation RC-IGBT combined all technology mentioned before were greatly improved compared to those of previous-generation devices.

Figure 4 shows the trade-off characteristics between the collector-emitter saturation voltage (V_{CEsat}) and the turn-off loss (E_{off}) in IGBT mode. Figure 5 shows the trade-off relationship between the forward voltage drop (V_F) and the recovery loss (E_{rr}) in FWD mode. Both characteristics were greatly improved compared to the previous-generation RC-IGBTs.[3]

Figure 6 compares the loss in inverters for products, which was normalized by the effective area of the chip (Tj = 125°C, fc = 5 kHz). The loss in the new structure was reduced to approximately one-third that of the previous structure.

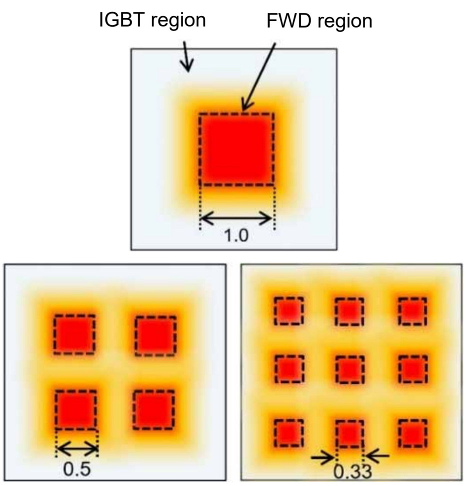

Fig. 2 Design concepts of FWD layout: optimizing the thermal distribution

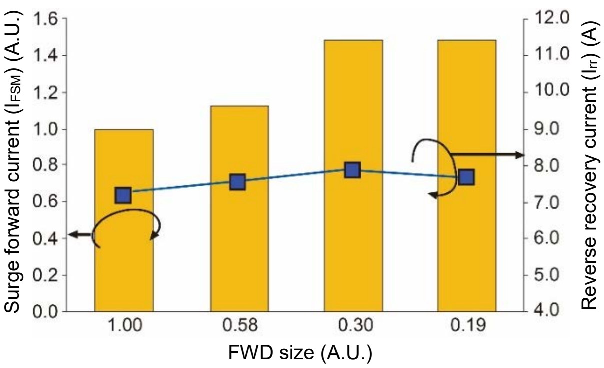

Fig. 3 FWD size dependence of I_{FSM} and I_{rr}

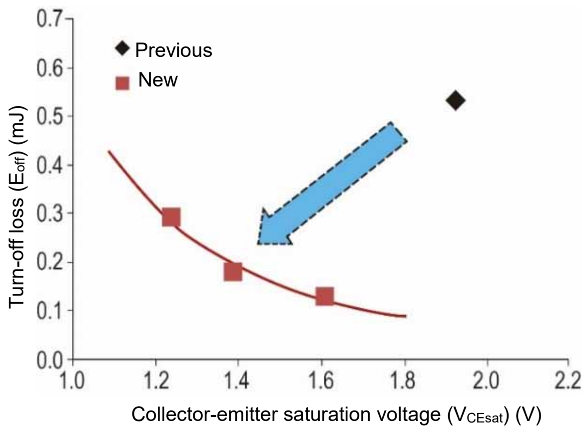

Fig. 4 Trade-off relationship between V_{CEsat} and E_{off}

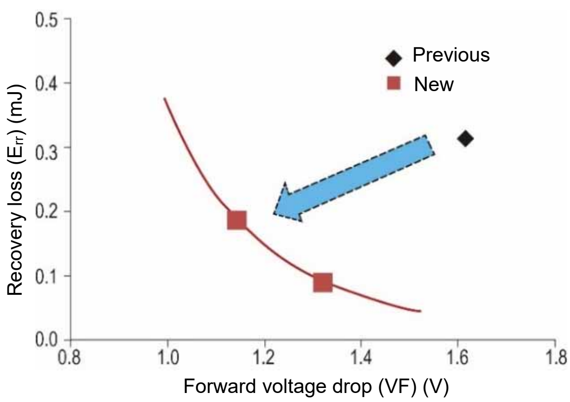

Fig. 5 Trade-off relationship between V_F and E_{rr}

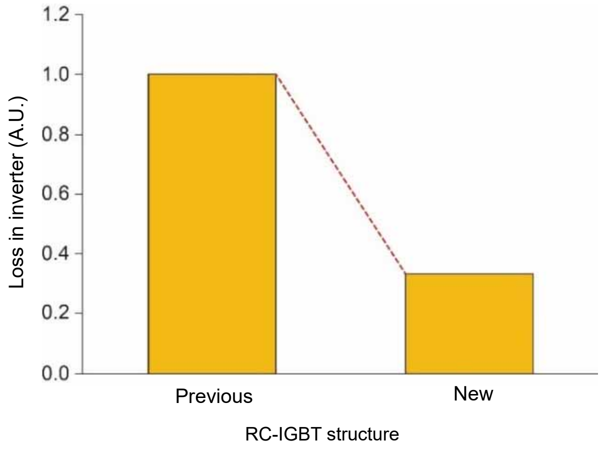

Fig. 6 Comparison of total inverter loss between previous RC-IGBT and second-generation RC-IGBT

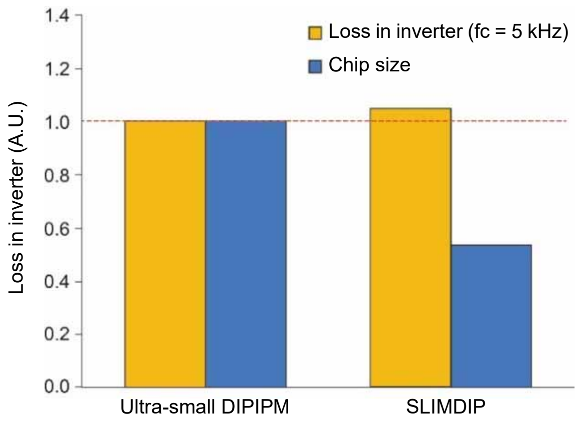

Fig. 7 Comparison of total inverter loss and chip size between the latest DIPIPM and SLIMDIP

3.2 Characteristics of products

The module size of the SLIMDIP series with the second-generation RC-IGBTs was greatly reduced.[4]

Figure 7 shows the ratio of the loss in the inverter between an ultra-small DIPIPM for which an IGBT and FWD are separately mounted and a SLIMDIP module of the same current rating along with the ratio of the area occupied by the mounted chips. The region occupied by the chip in the SLIMDIP module was reduced to approximately half compared to the ultra-small DIPIPM, thus allowing the power module to be approximately 30% smaller (Fig. 8).

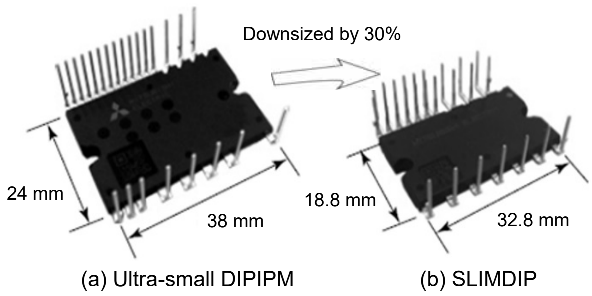

Fig. 8 Photograph of the latest DIPIPM and SLIMDIP

4. Conclusion

The power loss in 600V RC-IGBTs developed for consumer products was reduced to approximately one-third compared to the previous-generation devices and the size of the chip was reduced to approximately half. This reduction has led to commercialization of the SLIMDIP with a 30% smaller package.

We are presently developing the third-generation RC-IGBT with improved characteristics. We will continue contributing to the advancement of power electronics and the realization of an energy-saving society through the technical development and commercialization of devices.

5. References

(1) Suzuki K., et al.: 7th Generation Power Chip Technologies of High Performance with Wide Safe Operating Area, Mitsubishi Denki Giho, 88, No. 5, 281–284 (2014)

(2) Takahashi H., et al.: RC-IGBT for Motor Control, Mitsubishi Denki Giho, 81, No. 7, 313–316 (2007)

(3) Yoshida T., et al.: The second-generation 600V RC-IGBT with optimized FWD, IEEE, Proc. International Symposium on Power Semiconductor Devices, 159–162 (2016)

(4) Shibata S., et al.: “SLIMDIP Series” Power Module Using RC-IGBT, Mitsubishi Denki Giho, 90, No. 5, 307–310 (2016)