Enhanced Over-Current Capability of IGBT Modules for xEVs

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ABSTRACT

In recent years, measures to achieve energy savings and reduce CO_2 emissions have accelerated the switchover to xEVs, such as hybrid vehicles and electric vehicles, throughout the world. The IGBTs used in the inverters of xEVs are being required to enhance their capability to withstand over current (I^2t capability) at the time of accident. Fuji Electric has developed IGBT modules for xEVs that use RC-IGBTs and a lead frame to connect to the circuit of RC-IGBT surface electrodes, improving I^2t capability. The I^2t capability is 2.6 times higher for the new structure combining RC-IGBTs with a lead frame than for the conventional method using discrete FWDs and wire bonding.

1. Introduction

Recently, due to energy saving initiatives and CO_2 emissions regulations, the switch to electrified vehicles (xEVs) such as hybrid electric vehicles (HEVs) and electric vehicles (EVs) has been accelerating around the world. For HEVs and EVs, demand is increasing not only for inverters mounted to drive electric motors but also for xEV insulated gate bipolar transistor (IGBT) modules, which are a component of these inverters. This xEV IGBT module is a key device for achieving more compact vehicles, improved efficiency, and higher reliability.

Fuji Electric has developed an IGBT module for xEVs (see Fig. 1) with improved overcurrent capability (I^2t capability), which is equipped with a reverse-conducting IGBT (RC-IGBT) that combines an IGBT and a free wheeling diode (FWD) in a single chip, and used the lead frame (LF) method to connect the surface electrode of the RC-IGBT to the circuit instead of the conventional wire bonding method.

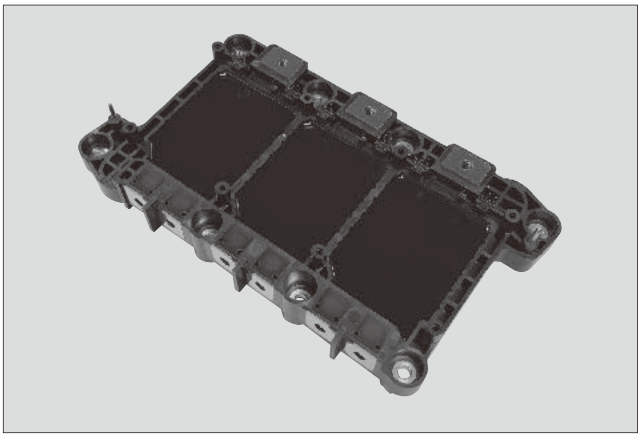

Fig.1 1 xEV module (newly developed product)

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2. I^2t Capability

2.1 Need for improving I^2t capability

In the inverter equipment mounted on a vehicle, a process of decelerating to stop is executed when abnormality occurs due to overcurrent or overvoltage. To prevent the breakdown of smoothing capacitors resulting from counter electromotive force of the motor at that time, active short circuit (ASC) control may function to activate the IGBT of either the upper or the lower arm (see Fig. 2). There is a trend of increasing the voltage of batteries to improve the efficiency of HEVs and EVs. Because of this increase, the drive voltage of the motor increases, which in turn causes more overcurrent to instantaneously flow into semiconductor chips in the power module when the ASC control is activated. The challenge is how to improve the I^2t capability of FWD chips in the IGBT module to withstand the heat generated by this overcurrent(1).

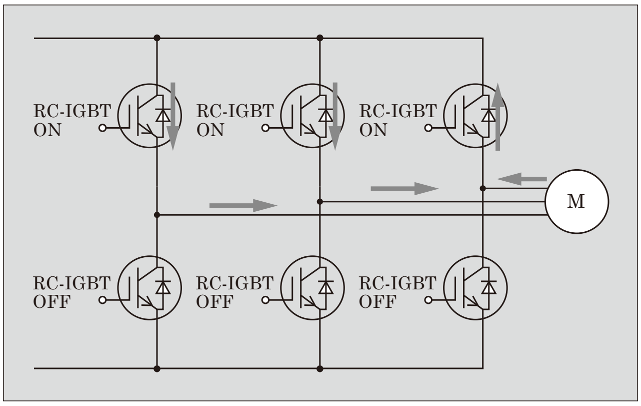

Fig.2 Example of current route in active short circuit (ASC)

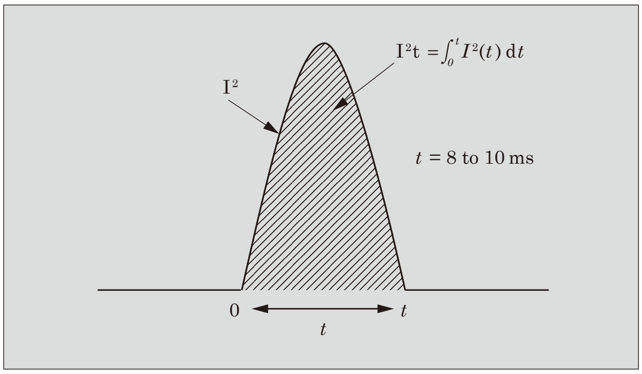

Fig.3 Current waveform to define I²t

2.2 Definition of I²t capability and factors to determine capability

As indicated by formula (1), I²t capability, which is defined as the capability at which the element breaks down in one cycle of a semisinusoidal wave with a duration of 8 to 10 ms related to Joule heat generated by current and voltage while power is supplied, is a value obtained by integrating the square of the current with respect to time, as shown in Fig. 3.

$$E = \int_0^t IV\mathrm{d}t = \int_0^t I \cdot IR\mathrm{d}t \propto \int_0^t I^2\mathrm{d}t \quad \cdots\cdots (1)$$

The I²t capability depends not only on the heat generated by the chip itself, but also on the heat generated by the surface electrodes and connections to the circuit, as well as on the heat dissipation characteristics. Therefore, it is necessary to improve the heat dissipation to improve the I²t capability.

3. Exothermicity Improvement with the Use of RC-IGBTs

Figure 4 shows schematic cross-sectional views of the conventional combination of discrete IGBT and FWD chips (IGBT and FWD chip structure) and an RC-IGBT. With the conventional module, IGBT and FWD chips were arranged separately. An RC-IGBT has a structure with IGBT regions and FWD regions arranged in stripes in one chip, which reduces the footprint. Another characteristic is that since IGBTs and FWDs are never energized at the same time, heat can be dissipated from the entire chip surface when either is activated, resulting in low thermal resistance[(2)].

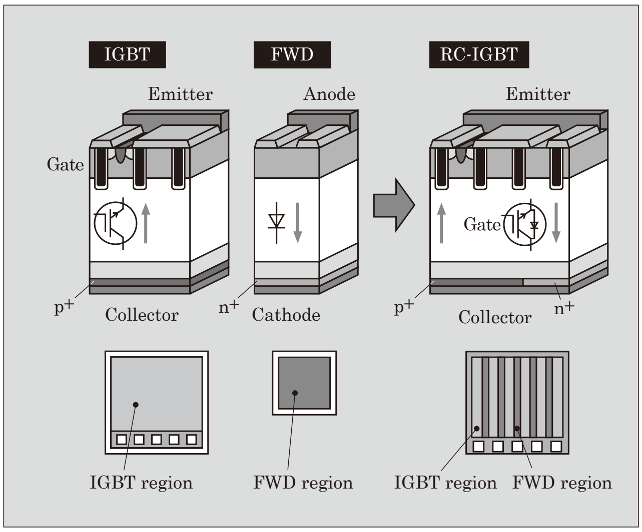

Fig.4 Comparison between separate chips and RC-IGBT

With the conventional IGBT + FWD combination, the FWD chip area is smaller than that of the IGBT. Accordingly, thermal resistance of the FWD chip tends to be high and I²t capability low.

Figure 5 shows the result of actual measurement of I²t capability of FWD and RC-IGBT chips. As the FWD chip area (active area) becomes larger, both thermal resistance and current density are reduced, which improves I²t capability. Comparison under the condition of the same active area of the FWD regions has shown that I²t capability of RC-IGBT is approximately twice as much as that of FWD. This capability improvement is due to the effect of improved heat dissipation resulting from a 20% larger number of wires of an RC-IGBT than that of a FWD, in addition to the reduction in thermal resistance of the chip as described above.

Figure 6 shows the result of a simulation conducted while power is supplied to a FWD to verify the validity

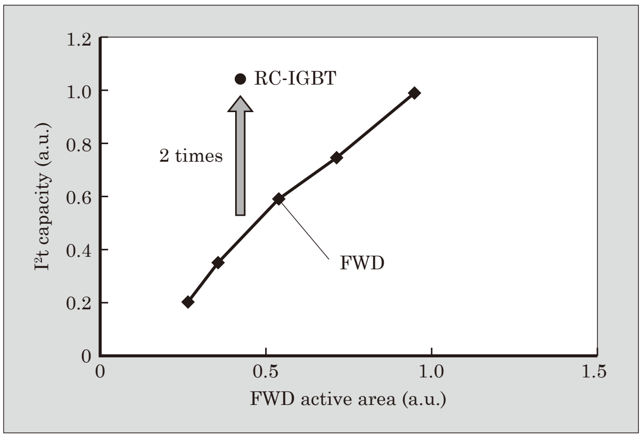

Fig.5 I²t capability comparison

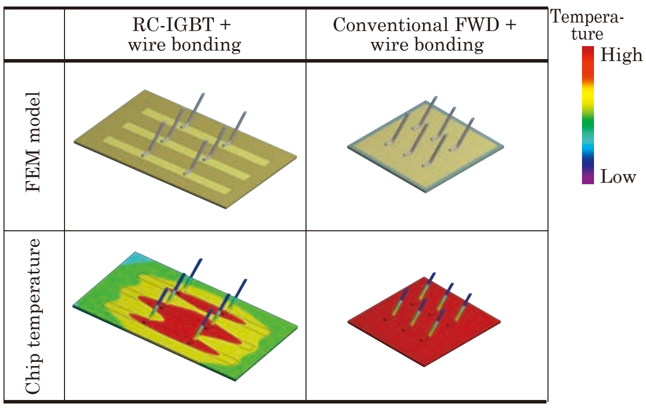

Fig.6 Thermal simulation of wire bonding structure

of the experiment result. This simulation is based on the same chip thickness, number of wires, and FWD active area. With the RC-IGBT chip, heat generated in the FWD regions is diffused to IGBT regions and the simulation shows that the high temperature area at 160 °C or higher is smaller than that of the FWD chip. As a result, the RC-IGBT has achieved lower thermal resistance than that of the conventional FWD, which is thought to have improved the I^2t capability.

4. Exothermicity Improvement with the Use of Lead Frames

The heat dissipation condition, which has an influence on I^2t capability, is also improved by increasing the area of bonding between the chip and wiring. With the conventional wire bonding method [Fig. 7(b)], wires are ultrasonic-bonded to chip surface electrodes. Unlike this, the LF method [Fig. 7(a)] uses a LF solder-bonded to the chip surface electrodes to increase the bonding area, thereby improving the heat dissipation(3). This has been confirmed by the thermal simulation shown in Fig. 8.

Table 1 shows the result of actual measurement of I^2t capability of the LF and the wire bonding methods. Comparison based on the same active area indicates that adopting the LF method improves I^2t capability from 0.3 to 0.4, or by approximately 30%.

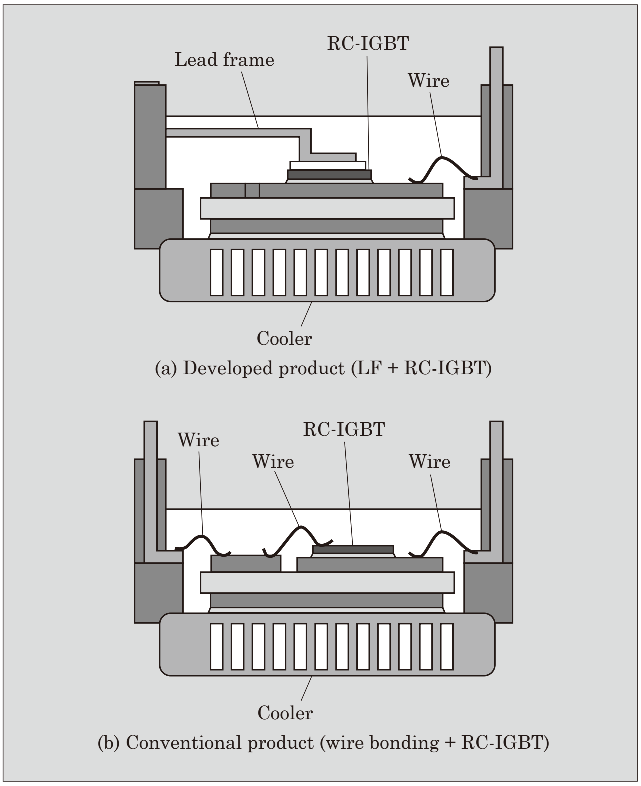

Fig.7 Structure comparison between developed and conventional products

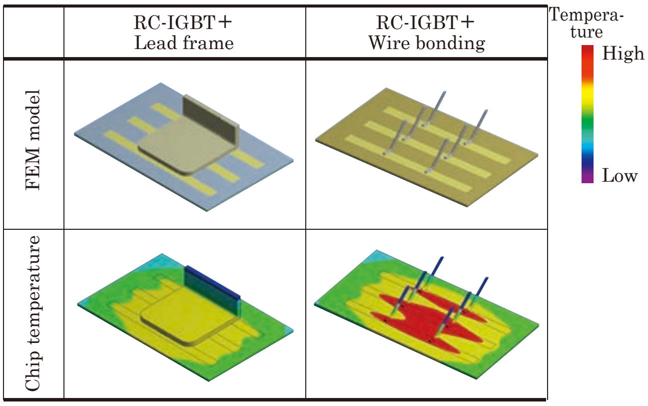

Fig.8 Thermal simulation of LF and wire bonding structures

Table 1 I^2t capability comparison (between LF and wire bonding)

Connection method	I^2t capability (a.u.)
LF	0.4
Wire bonding	0.3

5. I^2t Capability Comparison Between Developed and Conventional Products

As compared with the conventional IGBT module consisting of separate FWDs and IGBTs that employs the wire bonding method, the I^2t capability of the RC-IGBT module (developed product) that employs the LF method has been improved by 2.6 times. This is the effect of improved dissipation achieved by combining RC-IGBT and the LF method.

6. Postscript

This paper has described the improvement of withstand capability of a xEV IGBT module. We have achieved improved I^2t capability by adopting RC-IGBT and the LF method for a xEV IGBT module. In this way, we have successfully provided a xEV IGBT module that is useful to deal with overcurrent in ASC control of inverter equipment and offers high reliability.

In the future, we intend to work on further loss reduction, size reduction and reliability improvement as a xEV IGBT module and contribute to improved performance of inverter equipment.

References

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