Chapter 1 Basic Concept and Features

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This chapter describes the basic concept and features of the automotive IGBT module.

1. Basic Concept of the Automotive IGBT Module

From the viewpoint of protecting the global environment, the reduction of Carbon dioxide (CO_2) emissions has recently been required in the world. In the automotive field, use of hybrid electric vehicles (HEV) and electric vehicles (HV) has been increasing to reduce CO_2 emissions. HEV and EV drive a running motor. A driving motor in HEV and EV is driven by converting DC power stored in a high-voltage battery into AC power using a power conversion system. IGBT modules are mainly used for such power conversion system. The IGBT module used for the power conversion system is required to be compact since a high-voltage battery, power conversion system, motor, etc. must be installed within a limited space.

In view of such circumstances, Fuji's automotive IGBT module has been developed based on the concept of "downsizing."

Fig. 1-1 shows the basic needs in the market for IGBT modules, which include the improvement in performance and reliability and reduction in environmental impact. Since characteristics determining performance, reliability, and environmental load are related to one another, it is essential to improve them in good balance to downsize the IGBT module.

The newly developed automotive IGBT module achieves the basic concept "downsizing" by adopting (i) 3rd-generation direct liquid-cooling structure with water jacket, (ii) 7th-generation X-series RC-IGBT[*1)] chip, and (iii) high-strength soldering material, thus optimizing the performance, reliability and environmental impact. And two on-chip sensors, which are current sensor and temperature sensor, can support high reliability. Additionally, the P-voltage monitor terminal can assist the fine control of the power control system according to the battery voltage.

*1) RC-IGBT: Reverse Conducting Insulated Gate Bipolar Transistor

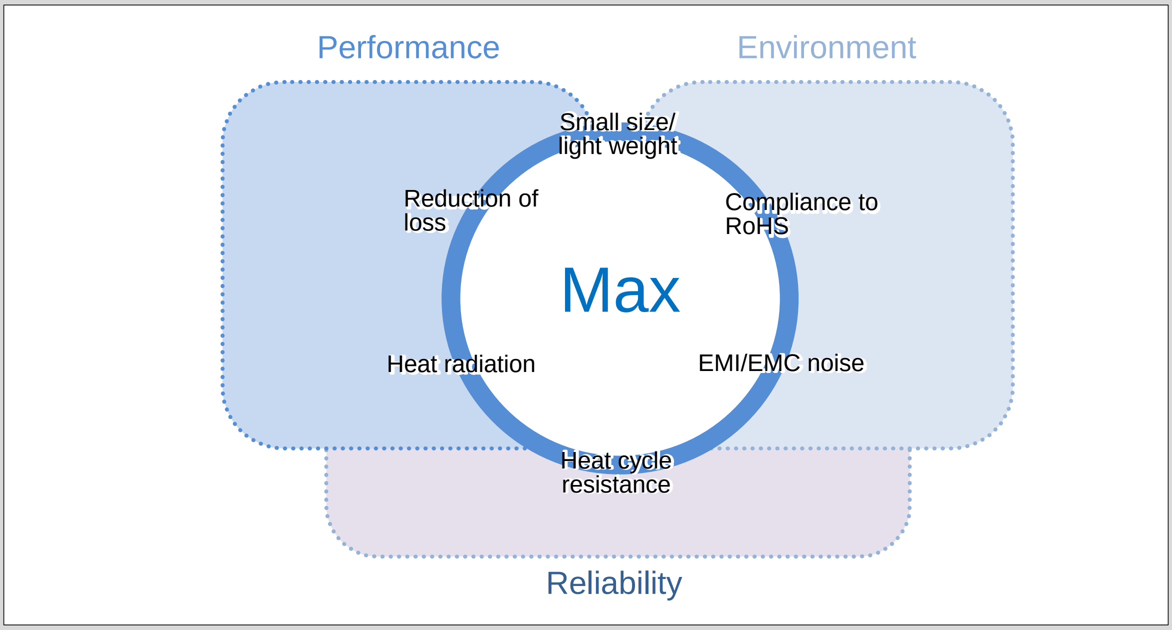


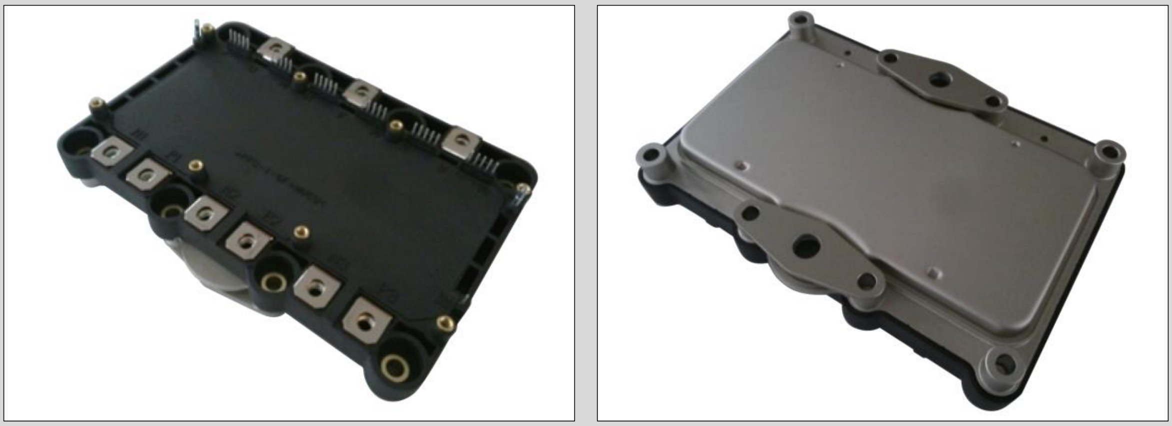
Fig. 1-1 IGBT module development concept targeted by Fuji Electric

2. Direct Liquid-cooling Structure

The newly developed automotive IGBT module has achieved the decreasing of thermal resistance significantly by adopting 3rd. generation direct water-cooling structure. Although 1st. generation direct cooling system could be achieved 33% of thermal resistance improvement comparing to indirect cooling system, 3rd. generation system can be improved more 30% gain in thermal resistance by integrated base fins and water jacket. This concept can present not only better thermal resistance performance but also water flow design free. And applying flange type water flow connection, it is able to easily design to integrate motor and control module.

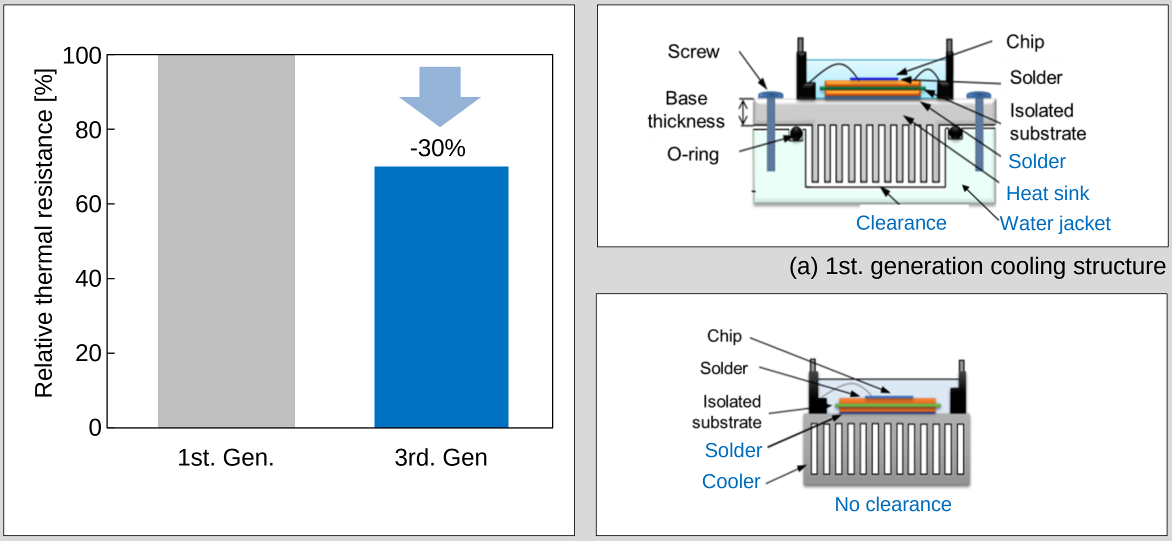
Fig. 1-2 shows the appearance of the newly developed automotive IGBT module developed this time.

Fig. 1-3 is a comparison of steady-state thermal resistance between the 1st. generation and the 3rd. generation. On 3rd. generation cooling system, a cooling design without clearance increases coolant flow speed between fins, as a result 30% of the thermal resistance is improved.



(a)Top face (b)Bottom face

Fig. 1-2 Appearance of 6MBI800XV-075V-01



(a) 1st. generation cooling structure

(b) 3rd. generation cooling structure

Fig. 1-3 Thermal resistance comparison

3. Feature of X-series RC-IGBT Chips

The newly developed model of automotive IGBT module (6MBI800XV-075V) is using 750 V "X-series" RC-IGBTs . The X-series RC-IGBT has decreased on-state voltage and switching loss by optimizing field-stop (FS) structure. Furthermore, switching-speed controllability has also been improved by optimizing trench gate structure.

As shown in below schematic, RC-IGBT has IGBT part and FWD part in the same die like stripe shape.

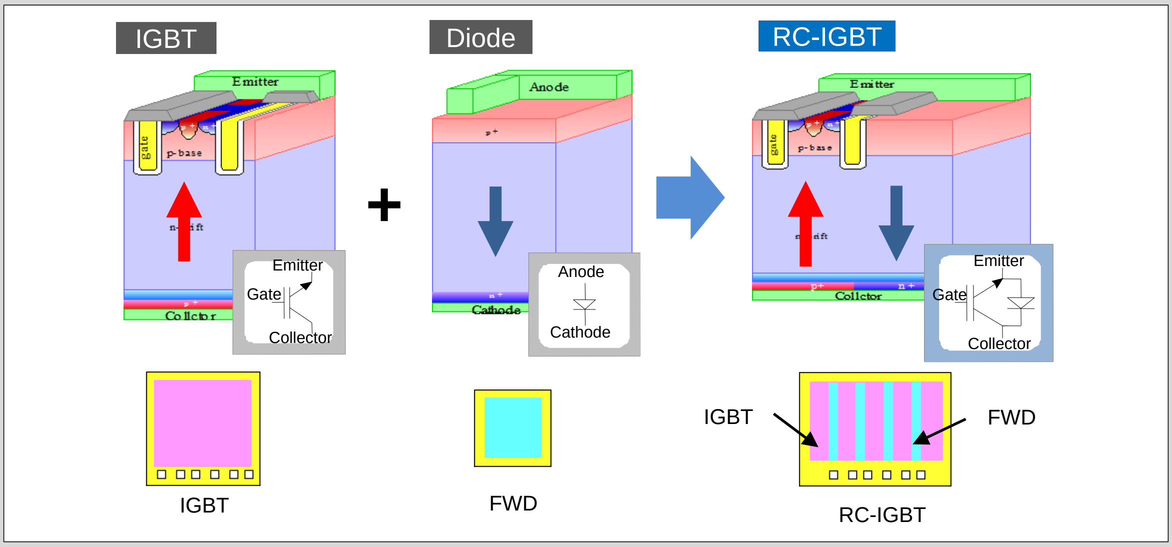


Fig. 1-4 Basic concept of the RC-IGBT

Advantage of the RC-IGBT is better $V_{CE(sat)}$-E_{off} performance than conventional IGBT.

As shown in below image, during the turn-off operation, the electron is easily swept because of corrector-shorted structure on the bottom side.

That is why turn-off loss is improved compare with conventional one.

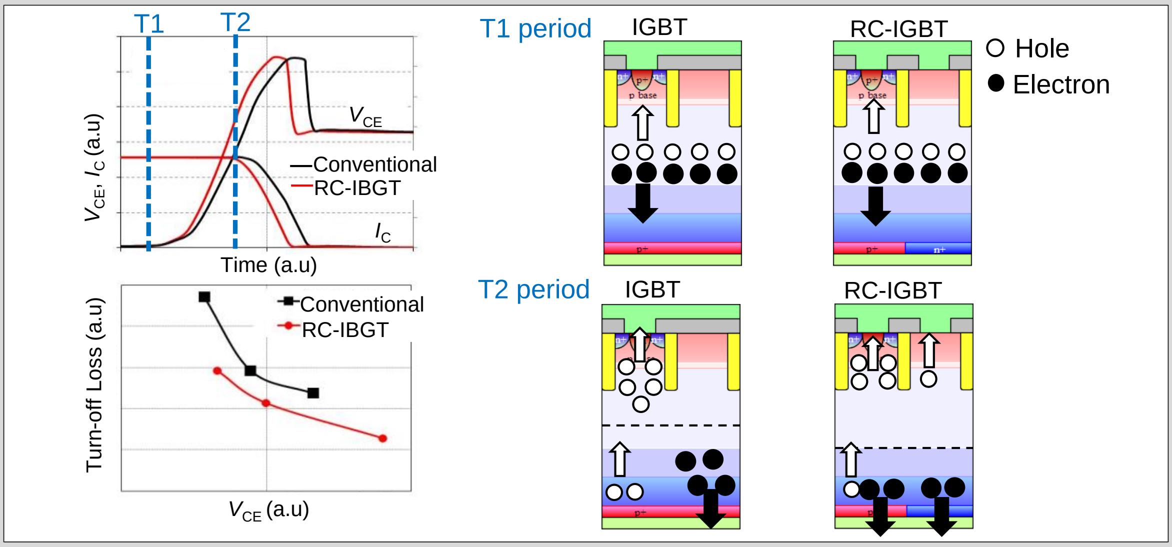


Fig. 1-5 Advantage of the RC-IGBT in loss

As shown in below schematic, IGBT and FWD part are alternately located on the die. Therefore thermal resistance is better than conventional one because the loss from each part are radiated from whole die surface.

Especially, the effect is big on rotor-lock mode, step-up converter and active short circuit operation.

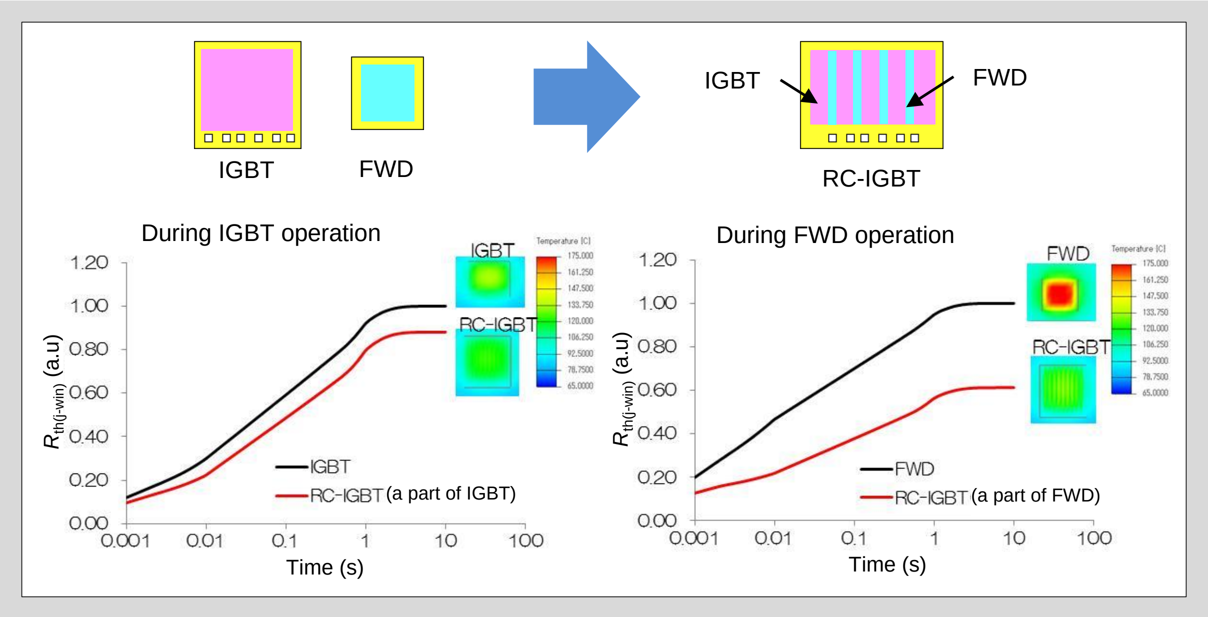


Fig. 1-6 Advantage of the RC-IGBT in thermal resistance

In the case of rotor-lock mode, RC-IGBT can dramatically suppress heating up because of large radiation area.

On the other hand, RC-IGBT has a little bit demerit on 3 phase operation since there is thermal interference between IGBT part and FWD part.

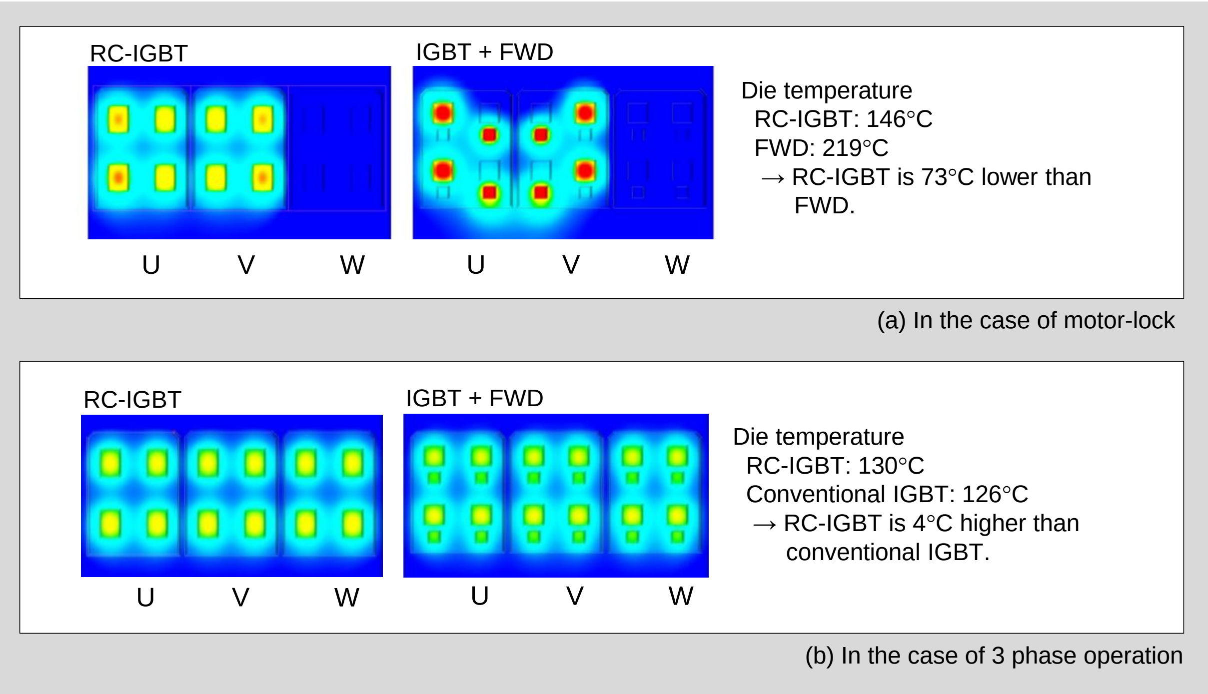


Fig. 1-7 Advantage of the RC-IGBT in rotor lock mode

4. On-chip Sensors

As shown in Fig. 1-8, a temperature sensor and a current sensor are integrated on a same IGBT chip. By current source and a shunt resistor, a T_{vj} and a current can be monitored, respectively.

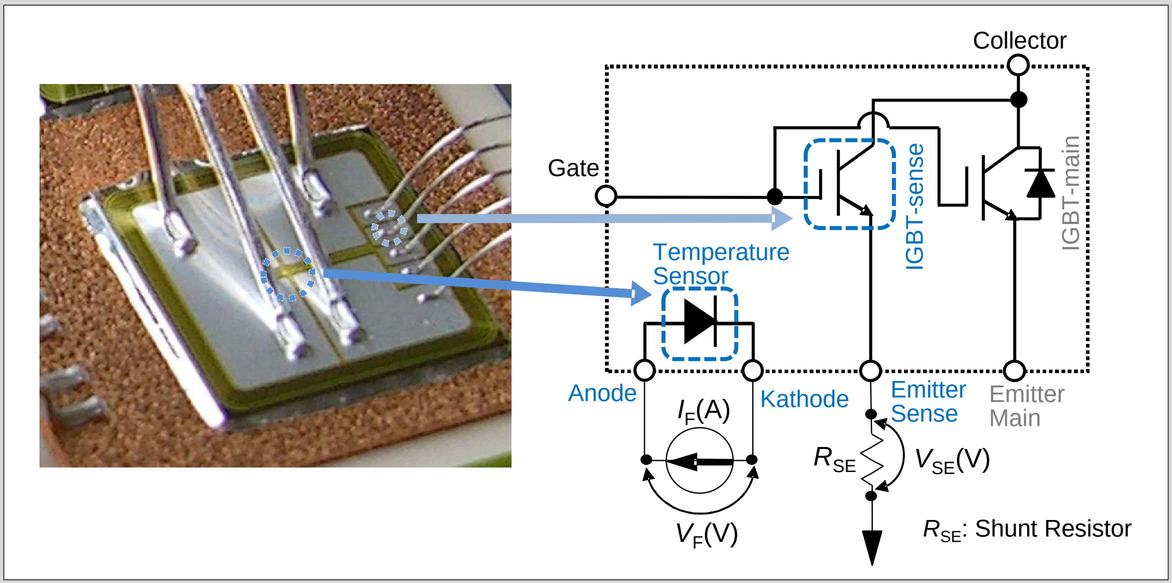
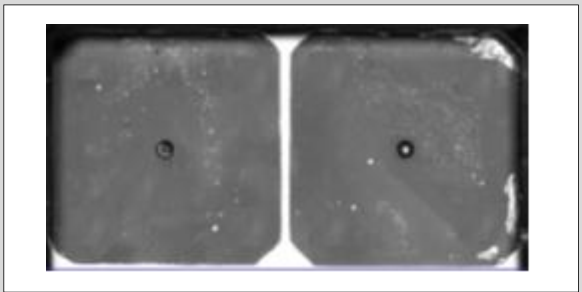


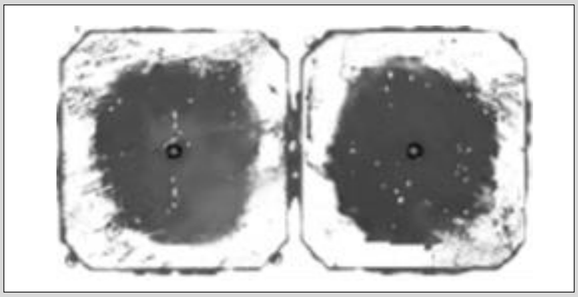
Fig. 1-8 On-chip sensors

5. Application of High-Strength Soldering Material

Since automotive semiconductors are often used in a severe condition compared to industrial or consumer use, higher reliability is required. In particular, if a crack is generated in a solder layer between the insulated substrate and the baseplate due to mechanical stress by temperature cycles, the thermal resistance is increased then abnormal chip heating might be occurred, and it cause a failure of the IGBT module. Fuji's automotive IGBT module suppresses generation of cracks significantly by changing solder material to newly developed SnSb series solder from conventional SnAg-series solder (Fig. 1-9).



(a) SnSb-series solder



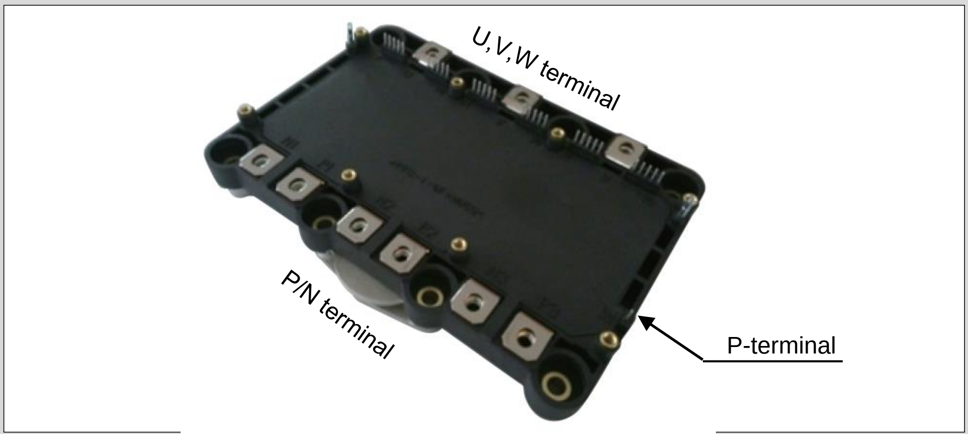
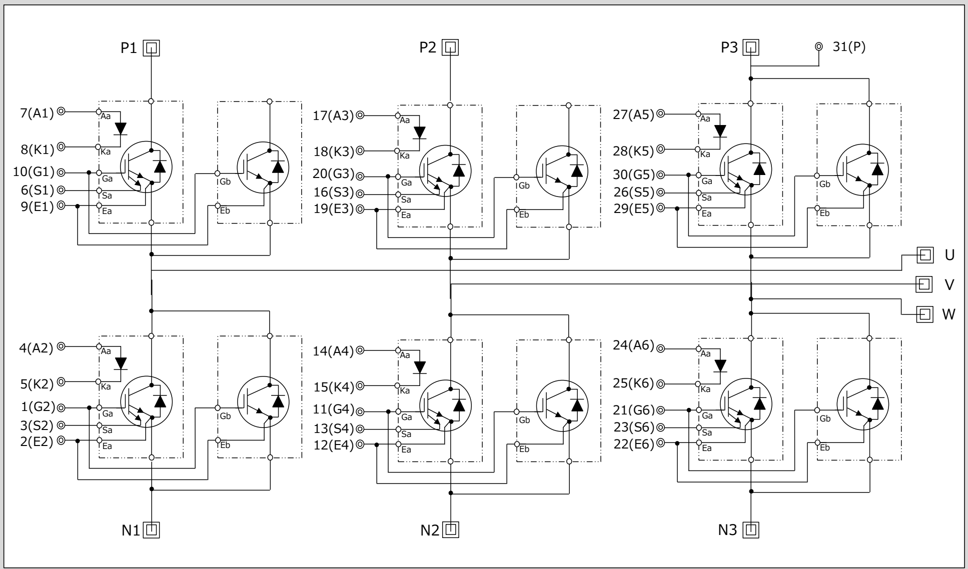
(b) SnAg-series solder

Fig. 1-9 Comparison in progress of cracks after temperature cycle test between SnSb-series solder and SnAg-series solder (Ultrasonic flow detection image after 2,000 temperature cycles)

6. Circuit Configuration

Table 1-1 shows the circuit configuration of the automotive IGBT modules.

Table 1-1 Circuit configuration

Name		6 in 1
Model name		6MBI800XV-075V
Appearance		
Equivalent circuit		
Features		One is constituted by one pair of RC-IGBT. Each arm at the outlet side of the cooling water has two on chip sensor. One is temperature sensing diode, and the other is current sensing IGBT.
Function	Temp. sensor	Temperature diode specification is shown in the specification sheet. Typical performance between V_F and T_{vj} is shown in Fig. 7-3(a) of chapter 7.
	Sense IGBT	Sense IGBT specification is described in the specification sheet. And its typical characteristics and the usage examples are explained in the chapter 8.
	P-terminal	P-terminal can monitor the positive voltage of V_{dc} value. Negative voltage shall be taken from the terminal number 22, which is the emitter terminal of the lower arm of the phase W. This terminal voltage is same as voltage of P terminal so please take care of electric shock. An example of the P terminal voltage monitoring is shown in Fig. 7-5 of chapter 7.

7. Numbering System

The numbering system of the automotive IGBT module for 6MBI800XV-075V-01 is shown in Fig. 1-10 below as an example.

6	MB	I	800	X	V	-	075	V	-	01
(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)		(9)

	Symbol	Description
(1) Number of switch elements	6	6 arms
(2) Model group	MB	IGBT model
(3) Insulation type	I	Insulated type
(4) Maximum current	800	800 A
(5) Chip generation	X	X series
(6) In-house identification No.	V	Identification No.
(7) Element rating	075	Withstand voltage: 750 V
(8) Automotive product	V	Automotive product
(9) In-house identification No.	01	Identification No.

Fig. 1-10 Numbering system