

3.3 kV IGBT Modules

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ABSTRACT

Fuji Electric has developed a 3.3 kV-1.2 kA IGBT module in response to market needs for inverters suitable for industrial and vehicle applications. The package of the newly developed module incorporates IGBT high-power module technology. Compared to previous modules, internal inductance has been reduced by 33% and the current flow to chips on each insulating substrates shows good uniformity. Power cycle tests were implemented with this module, and sufficient durability was verified. 3.3 kV-0.8 kA IGBT modules has been developed. 3.3 kV-1.5 kA and 3.3 kV-0.8 kA IGBT modules are also being developed to expand the product lineup.

1. Introduction

IGBT (Insulated Gate Bipolar Transistor) modules have gained widespread popularity due to their low loss characteristics, suitability for configuring simple driving circuits, wide safety operation area and high reliability. The high-voltage high-power sector in which GTO (Gate Turn-OFF) thyristors have been used widely is also transitioning to the use of IGBT modules. IGBT modules are being applied widely in high power inverter and high voltage inverter systems and the like. Especially as a result of recent efforts to prevent global warming, the market for new energy (wind power generation, solar power generation) has grown rapidly. The inverter systems used in this sector have been advanced to achieve higher power capacities, and demand for IGBT modules is growing.

Fuji Electric has previously developed high-power IGBT modules for application to the high-power sector. In 2007, Fuji Electric enhanced the chip, package design and manufacturing technology of the previous high-power 1.2 kV and 1.7 kV IGBT modules to develop a 3.3 kV 1.2 A high-power IGBT module. In 2008, Fuji Electric improved the low-loss, thermal characteristics and environmental durability of the 1.2 kV and 1.7 kV modules to develop new high-power IGBT modules⁽¹⁾ and is expanding its product lineup. The package of these modules has low inductance and achieves excellent current balance.

This package technology is also applied to the newly developed 3.3 kV 1.2 kA IGBT module. The 3.3 kV IGBT modules are designed for use in vehicle applications as well as industrial applications. This paper presents an overview and describes the performance of the new 3.3 kV IGBT modules.

2. Specifications of 3.3 kV IGBT Module

Figure 1 shows an external view of 3.3 kV 12 kA IGBT module. With a package size of 190 mm × 140 mm, the module is compatible with modules made by other companies. Table 1 lists the target specifications of the 3.3 kV modules.

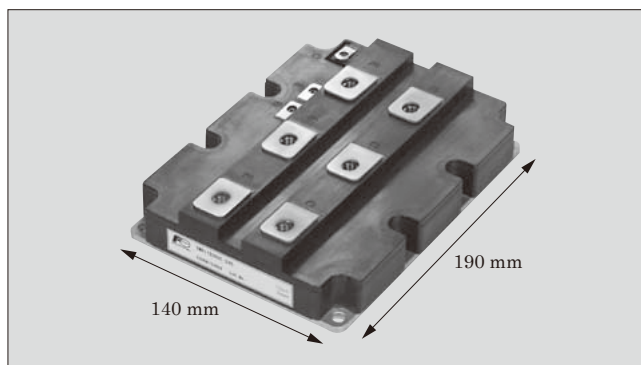
3. Electrical Characteristics

3.1 IGBT and FWD characteristics

(1) IGBT chip characteristics

IGBT chips incorporate a trench structure and a field stop (FS) structure (U-Series IGBT) that provide an excellent trade-off in the relation between the collector-emitter saturation voltage $V_{CE(sat)}$ and turn-off loss E_{off} , and utilize a cell-pitch optimized for 3.3 kV to achieve lower loss. Also, in the high-power sector, it is essential that an IGBT chip has high-power switching capability (wide reverse bias safety operation area (RBSOA) and short-circuit capability) in order to realize high reliability. To provide a wide RBSOA, the

Fig.1 External view of 3.3 kV 1.2 kA IGBT module



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Table 1 Target specifications of 3.3 kV IGBT module (1.5 kA modules are under development)

Item		Symbol	1MBI1200UE-330	1MBI1500UE-330	1MBI800UG-330	Units
Collector current		I_C	1,200	1,500	800	A
Package size		—	190×140	190×140	130×140	mm
Collector-Emitter saturation voltage (chip)		$V_{CE(sat)}$	3.15 V (typical value) (at 150°C and 1,200 A)	3.15 V (typical value) (at 150°C and 1,500A)	3.15 V (typical value) (at 150°C and 800 A)	V
Forward voltage (chip)		V_F	2.75 V (typical value) (at 150°C and 1,200 A)	2.75 V (typical value) (at 150°C and 1,500 A)	2.75 V (typical value) (at 150°C and 800 A)	V
Thermal resistance	IGBT	$R_{th(j-c)}$	8.5	8.0	13.0	K/kW
	FWD		17.0	15.0	25.0	K/kW
Isolation voltage		V_{iso}	6.0	6.0	6.0	kV

Fig.2 $V_{CE(sat)}$ - I_C characteristics

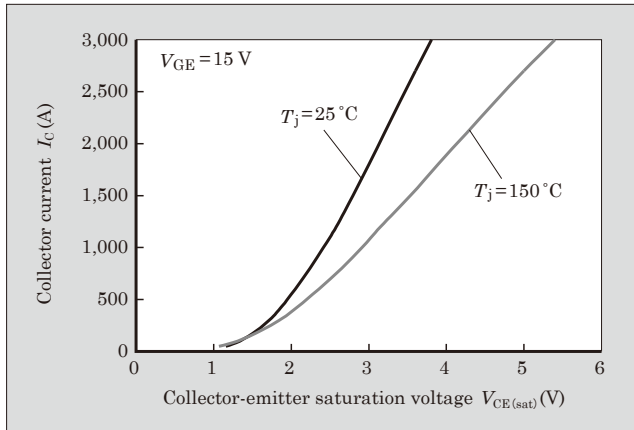
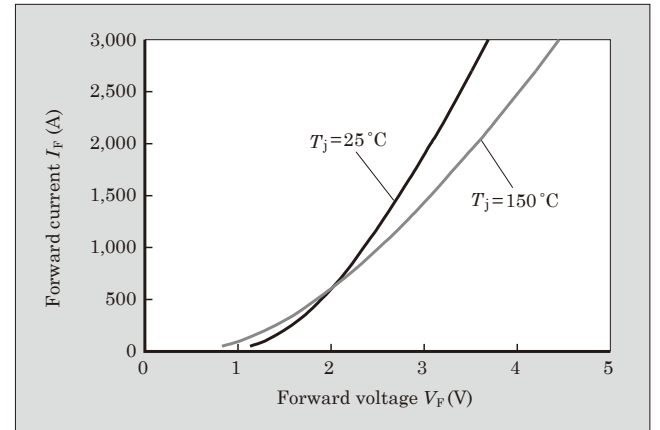


Fig.3 V_F - I_F characteristics



chip was designed with a structure that suppresses the concentration of current at the edge of the active area. In addition, carrier injection on the collector side is adjusted to ensure sufficient short-circuit capability.

(2) FWD (Free Wheeling Diode) chip characteristics

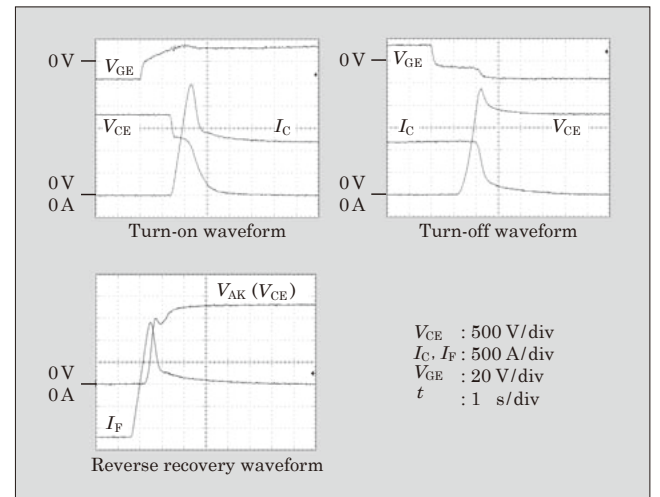
In order to achieve (1) lower loss and (2) suppression of oscillation and surge voltage during reverse recovery at low current levels, FWD chips are designed with an optimized crystalline wafer structure and a deep collector-side n^+ layer concentration profile. Also, to provide high reverse recovery capability (high di/dt capability) the cathode-side is designed with a structure that suppresses the concentration of current at the edge of the active area.

3.2 $V_{CE(sat)}$ - I_C characteristics and V_F - I_F characteristics

Figure 2 shows the $V_{CE(sat)}$ - I_C characteristics. Similar to Fuji Electric's low-voltage class of trench IGBTs, a positive temperature coefficient is exhibited. With a reduced current imbalance for parallel connections, these modules allows for easy parallel connections necessary for achieving larger currents.

Figure 3 shows the V_F - I_F characteristics. The FWD, at a forward voltage, also exhibits a positive temperature coefficient at currents of at least one-half of the rated value, and allows for easy parallel connections.

Fig.4 Switching waveforms (inductive load)
($V_{CC}=1,800$ V, $I_C=1,200$ A, $T_j=150$ °C)



3.3 Switching characteristics

Figure 4 shows the turn-on, turn-off and reverse recovery waveforms. These waveforms, exhibiting neither noise nor the generation of a large surge voltage, are free of problems.

4. Package Structure

High reliability and high thermal conductivity (low thermal resistance) are required for the high-power

modules used in high-power inverter system. The reduction of current imbalances among chips inside a module and the reduction of heat generation in a package are also important issues for achieving large currents.

4.1 General internal structure of package

Figure 5 shows the general internal structure of a 3.3 kV IGBT module.

To enhance the heat dissipation capability of the insulating substrate in a 3.3 kV module, instead of the alumina and silicon nitride substrates typically used with low-voltage modules, an AlN substrate having 2.5 to 8 times the thermal conductivity was used. The result realized the low thermal resistance shown in Table 1.

A copper (Cu) base is typically used as the base material in low-voltage modules. With the 3.3 kV IGBT modules, an AlSiC base is used to ensure high reliability. AlSiC is a composite of Al and SiC, and because its coefficient of thermal expansion is close to that of the AlN substrate, the heat cycle lifetime and power cycle lifetime are several times higher than in the case of a Cu base.

4.2 Improved structure of main terminal

In the design of the main terminal, the following three items are very important.

- Reduction of internal inductance
- Reduction of current imbalance of chips on each insulating substrates
- Reduction of stress at contact areas with insulating substrates (leading to higher heat cycle and power cycle lifetimes)

Fig.5 General internal structure of 3.3 kV IGBT module

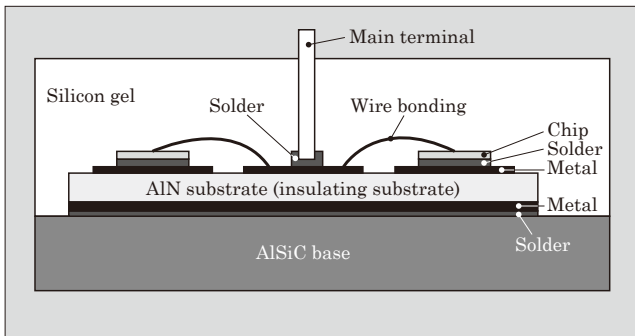
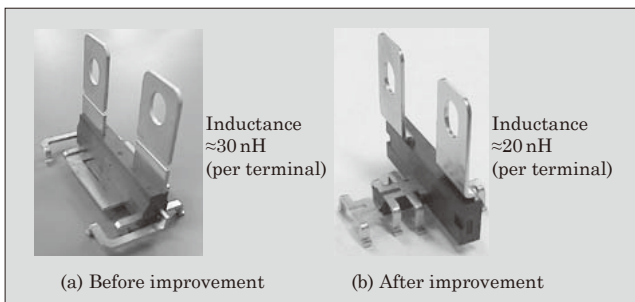


Fig.6 Main terminal before and after improvement



The main terminal was changed to the same new structure as used with high-power IGBT modules. Figure 6 shows the main terminal before and after the improvement.

(1) Reduction of internal inductance

The internal inductance was reduced by shortening the length of the main terminal lead as much as possible, arranging the conducting areas of the collector and the emitter leads vertically, and by actively using the mutual interaction of the magnetic field.

Measured results show that the internal inductance has been reduced from 30 nH for a conventional terminal to 20 nH. According to the value of the internal inductance L and the current turn di/dt during switching, a voltage $\Delta V = L \cdot (di/dt)$ is generated between the chip and the contact area of the terminal. Therefore a reduction in internal inductance reduces the overvoltage applied to the chip.

(2) Reduction of current imbalance between insulating substrates

Because of the main terminal arrangement of the module, the insulating substrate is separated into a substrate directly below the emitter terminal and a substrate directly below the collector terminal. These are connected in parallel with the shortest possible lead, thereby forming a structure in which a current imbalance between insulating substrates occurs easily.

Fig.7 Measured current distribution of chips on each insulating substrates

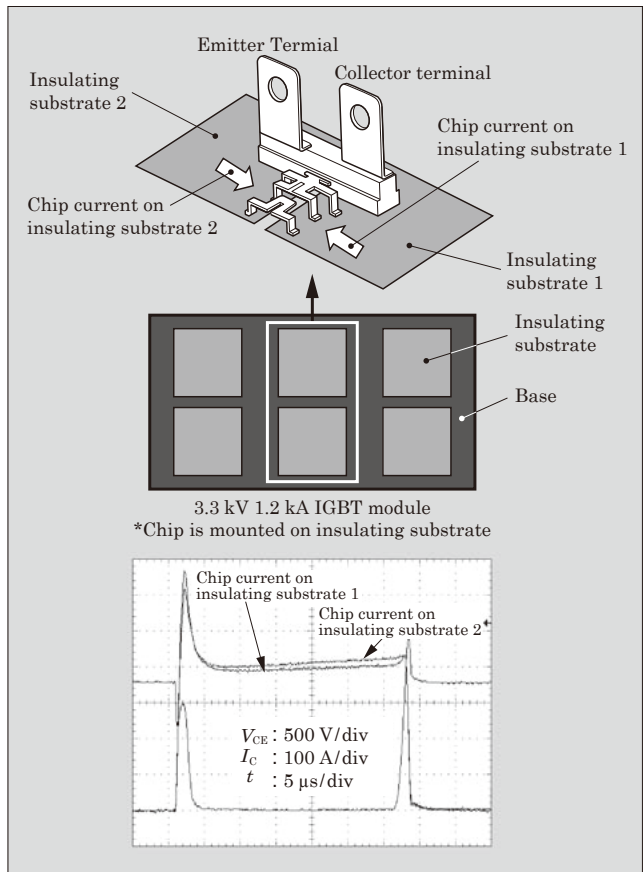
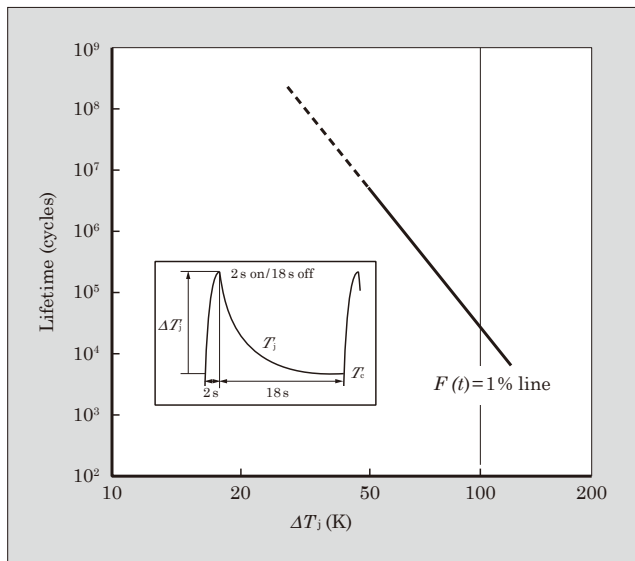


Fig.8 ΔT_j power cycle test results



The path of current flow in the emitter terminal and the collector terminal were analyzed. The structure was designed such that the currents would be equal.

Figure 7 shows waveforms of the current distribution measured of chips on each insulating substrates. The measured results and the distribution of current of chips on each insulating substrates were good.

(3) Reduction of stress at contact areas with insulating substrate

To reduce the stress at contact areas with the insulating substrate, an optimized heat treatment is applied to soften the material of the main terminal. Also, the main terminal is integrally formed with the terminal case so as to lessen the generation of stress on the main terminal.

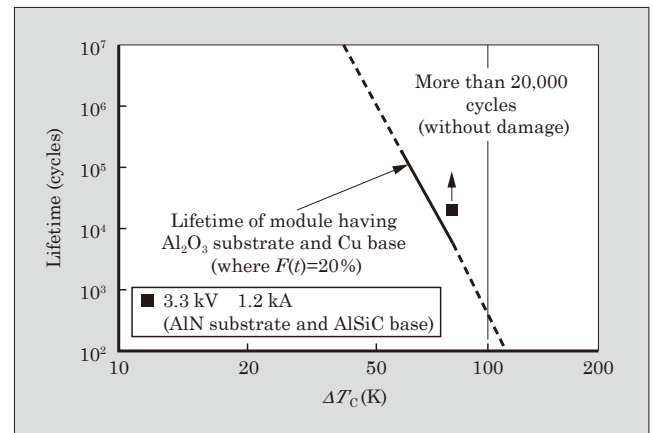
5. Ensuring Power Cycle Capability

High-voltage modules are required to provide high reliability for their intended applications. In the marketplace, the reliability considered to be important is the power cycle capability. A power cycle test (intermittent power-on test) is performed by applying energized and isolated electrical loads to an IGBT module with its heat dissipating fin temperature held constant, and causing the junction temperature T_j of the IGBT chip to rise and fall so as to generate thermal stress, and the test is carried out until the thermal stress damages the chip. Types of power cycle tests include the ΔT_j power cycle test that causes the junction temperature to rise and fall with a relatively short period and the ΔT_c power cycle test that causes the case temperature T_c to rise up and fall to a certain temperature with a long period.

5.1 ΔT_j power cycle evaluation results

From module analysis performed after a power

Fig.9 ΔT_c power cycle test results



cycle test of an IGBT module, Fuji Electric has verified that the ΔT_j power cycle capability is determined by the lifespan of the solder underneath the chip and aluminum wire junction of the chip.

Figure 8 shows the ΔT_j power cycle test results for 3.3 kV modules. The 3.3 kV modules, as in the case of the 1.2 kV and 1.7 kV high-power IGBT modules, use highly rigid Sn-Ag solder underneath the chip. By equalizing the current of chips on each the insulating substrates, ΔT_j power cycle test results that are equivalent to those of the 1.2 kV and 1.7 kV high-power IGBT modules could be verified.

5.2 ΔT_c power cycle test results

As shown in Fig. 9, a power cycle capability of more than 20,000 cycles was verified under the condition of $\Delta T_c = 80$ K. The 3.3 kV modules use an AlSiC base and thus have at least 3 times the ΔT_c power cycle capability as in the case of a copper base.

6. Product Lineup

At present, a 3.3 kV 1.5 kA IGBT module having the same package size as the 3.3 kV 1.2 kA IGBT (190 mm × 140 mm) but with larger IGBT and FWD chip sizes are being developed. A 3.3 kV 800 A IGBT module having a 130 mm × 140 mm package size has been developed. The target specifications for each 3.3 kV IGBT module are listed in Table 1.

7. Postscript

Fuji Electric has recently developed a 3.3 kV 1.2 kA IGBT module as a high-power IGBT module in a package. Compared to the module characteristics prior to improvement, internal inductance has been reduced by 33% and the current flow of chips on each insulating substrates showed good uniformity. Power cycle tests were carried out with this module and sufficient durability was verified. 3.3 kV 1.2 kA IGBT module is planned for commercial release in 2010.

References

- (1) Nishimura, T. et al. High-power IGBT Modules. Fuji Electric Review. 2008, vol.55, no.2, p.51-55.
- (2) Morozumi, A. et al. Reliability of Power Cycling for IGBT Power Semiconductor Module. Conf. Rec. IEEE Ind. Appl. Conf. 36th. 2001, p.1912-1918.





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