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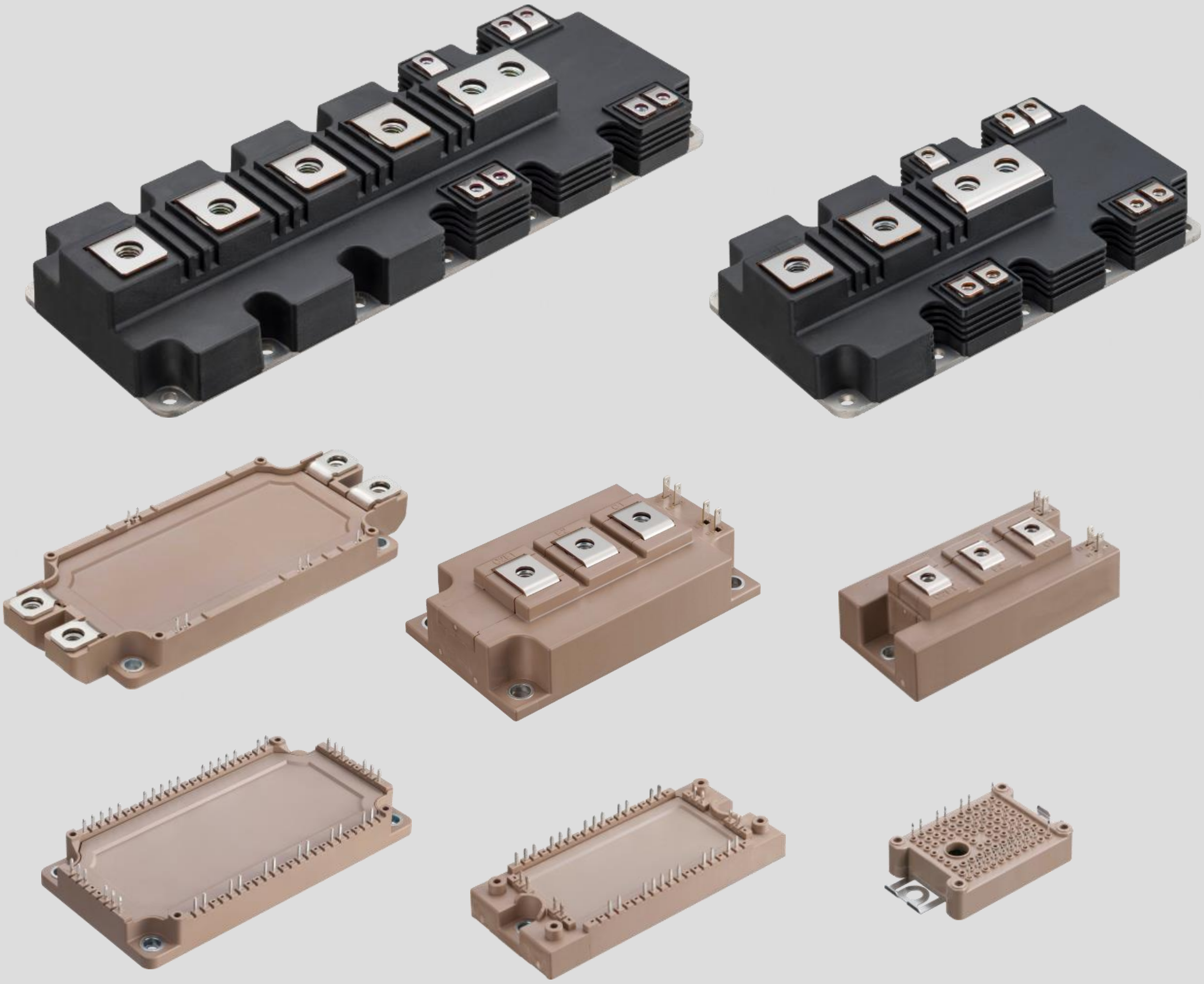

Fuji IGBT Module

Application Manual

March, 2023

Fuji Electric Co.,Ltd.

⚠Cautions

This manual contains the product specifications, characteristics, data, materials, and structures as of March 2023.
The contents are subject to change without notice for specification changes or other reasons. When using a product listed in this manual, be sure to obtain the latest specifications.

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Chapter 1 Structure and Features

The insulated gate bipolar transistors (IGBTs), applied to equipment such as variable-speed motor drives and uninterruptible power supplies for computers, are developing rapidly in response to the increasing demand for energy saving, weight reduction, and downsizing of equipment in recent years. The IGBT is a switching device designed to have the high-speed switching performance and gate voltage control of a power MOSFET as well as the high-voltage / large-current handling capability of bipolar transistor.

1. History of IGBT Structure

The n-channel IGBT, which forms a n-type inversion layer when positive voltage is applied to the gate, has a structure in which the n+ layer on the drain side of the power MOSFET is replaced with a p+ layer. It is a bipolar device that can reduce on-resistance at large current with conductivity modulation.

The IGBT structure can be roughly divided into the surface gate structure, the bulk structure that forms the n-drift layer, and the backside structure. There are two types of surface gate structures. One is the planar gate structure, in which the gates are formed on the wafer surface, namely the chip surface. The other is the trench gate structure, in which trenches are made to form the gates in the wafer. On the other hand, the bulk structure can be roughly divided into the punch-through type, in which the depletion layer reaches the collector side at turn-off, and the non-punch-through type, in which it does not reach the collector side. The comparison of the n-channel IGBTs is shown in Fig. 1-1.

Fuji Electric has been supplying IGBTs to the market since it commercialized them in 1988. The planar-gate punch-through IGBT was the mainstream IGBT at that time. The punch-through IGBT used the epitaxial wafer and low on-state voltage was achieved by injecting a large amount of minority carriers from the collector layer to obtain conductivity modulation effect. At the same time, the lifetime control technology was used because the excess carriers, which were high-injected into the n-base layer, has to be removed quickly at turn-off. As a result, both low on-state voltage and low turn-off switching loss (E_{off}) were achieved. The lifetime control technology was widely used because it was relatively easy to apply into the IGBT manufacturing process. However, there were problems such as large variations in on-state voltage and the output characteristics showing negative temperature characteristics. Therefore, with the increasing capacity of IGBT modules and the power converters using them, the demand for IGBT characteristics that facilitate parallel connection has increased.

The non-punch-through IGBT was developed to overcome these issues. The non-punch-through IGBT controls the minority carrier injection efficiency by controlling the concentration of impurities in the collector (p-collector layer), and controls the internal electric field and transport efficiency by controlling the thickness and resistivity of the n-drift layer. The non-punch-through IGBTs use the FZ (Floating Zone) wafer instead of the epitaxial wafer. Therefore, the superiority of the FZ wafer compared to the epitaxial wafer can be reflected in the IGBT chip. For example, FZ wafers have less crystal defects and low internal stress, making it easy to manufacture high voltage chips of 1700V and above. In addition, the carrier lifetime of FZ wafers is very long, and the excess carrier distribution control of the IGBT chip only needs to consider minority carrier injection from the p-collector layer. Furthermore, variations in characteristics such as on-state voltage are greatly reduced.

On the other hand, in order to achieve a low on-state voltage, it was necessary to improve the transport efficiency. In particular, IGBT wafers with a withstand voltage of 1200V or less required a special manufacturing technology to thin the n-drift layer. Therefore, Fuji Electric has developed new technologies for production of thinner wafers and improved the characteristics.

To further improve the characteristics, IGBTs with thinner chip thickness are required. However, the thickness of the n-drift layer constitutes most of the chip thickness, and if the thickness is too thin, the specified voltage cannot be maintained. The FS (Field Stop) structure solved this problem that hinder the improvement of the characteristics. In the FS structure, a high concentration FS layer is provided in the n-drift layer. This structure makes it possible to further reduce the thickness of the chip and improve its characteristics.

Fuji Electric has also advanced the miniaturization of the surface structure that is imperative to improve the characteristics of IGBT. The IGBT is formed by arranging many basic structures called cells. The higher the number of IGBT cells, the lower the on-state voltage will be. In order to increase cell density, the surface structure has changed from the planar structure, in which the IGBT cells are formed on the wafer surface two-dimensionally, to the trench structure, in which the trenches are formed on the wafer surface and the gates structure are formed three-dimensionally. In this way, Fuji Electric has improved the characteristics by applying various technologies to the bulk structure and the surface structure.

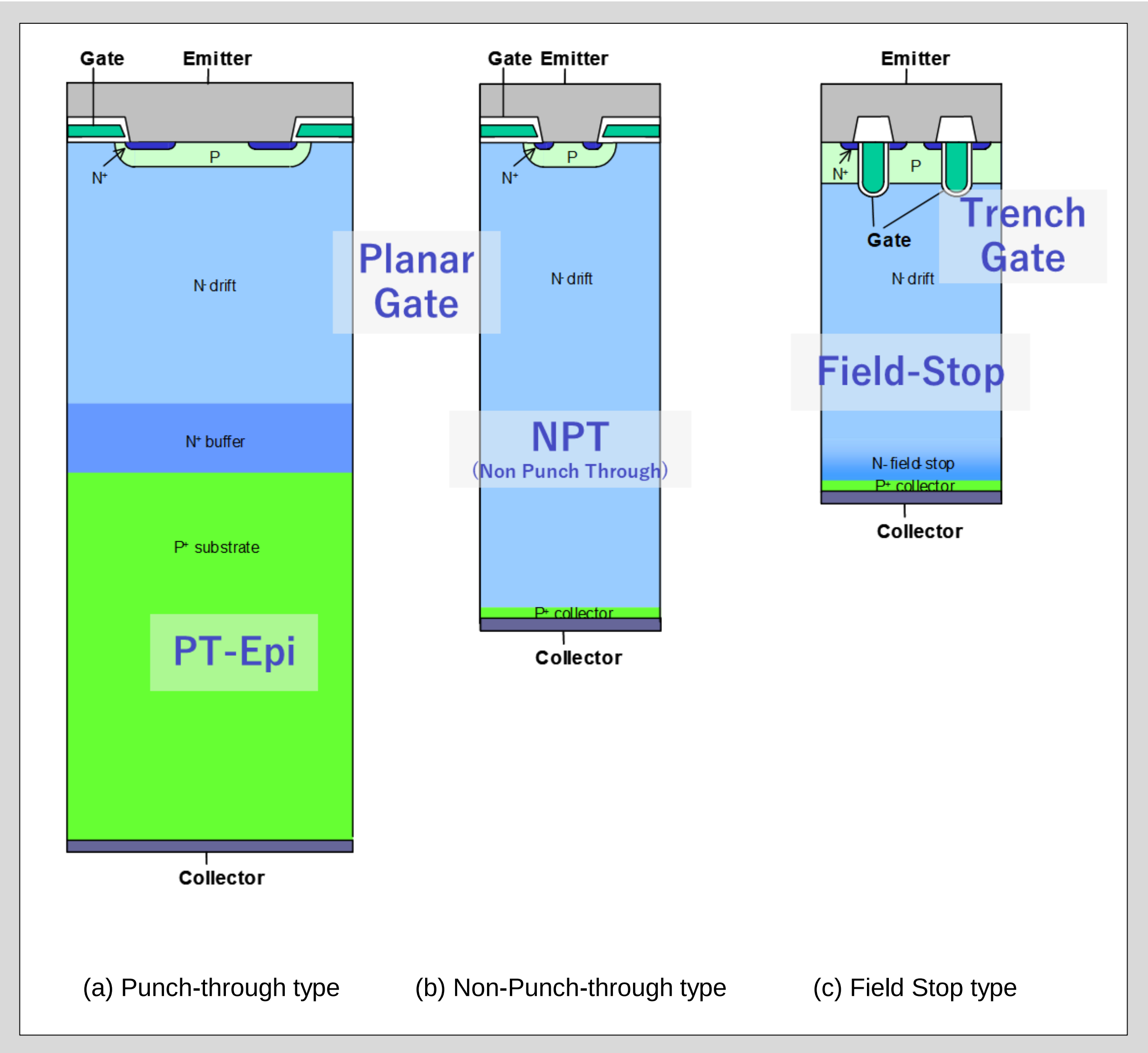


Fig. 1-1 Structure comparison of IGBT

2. Module Structure

Fig. 1-2 and Fig. 1-3 show typical IGBT module structures. The module integrated with terminal block shown in Fig. 1-2 has a case and external electrode terminals molded into a single unit to reduce the number of parts required and the internal wiring inductance. In addition, the use of DCB (direct copper bonding) substrate realizes a high-reliability product that combines low thermal resistance and high bending strength.

The wire terminal connection structure module shown in Fig. 1-3 has main terminals bonded to the DCB substrate by wire. As a result, the package structure has been simplified, made smaller, thinner, lighter, and reduced in assembly time.

Other design considerations implemented include optimal IGBT and FWD chips layout to assure efficient heat distribution, and the equal arrangement of IGBT chips in the upper and lower arms to balance the turn-on transient current and thus prevent the increases in turn-on loss.

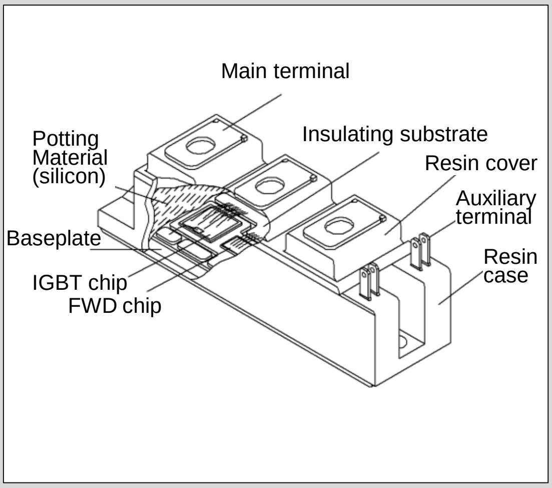


Fig. 1-2 Integrated with terminal block type

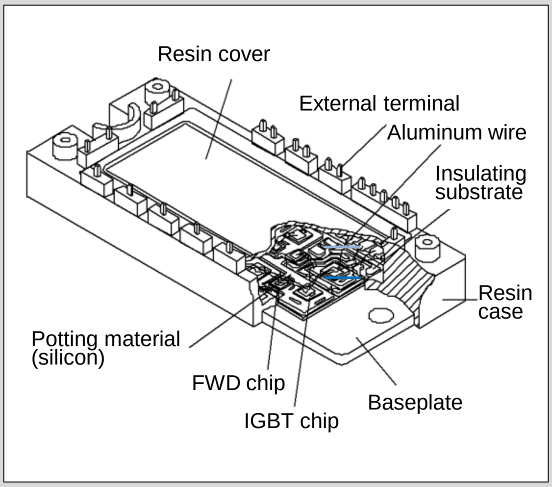
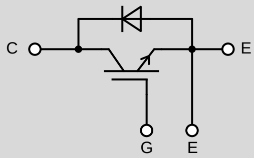
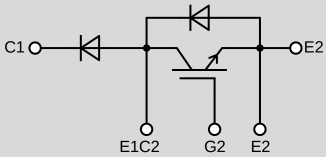
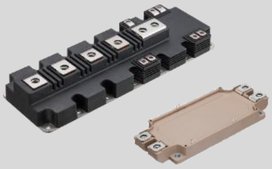
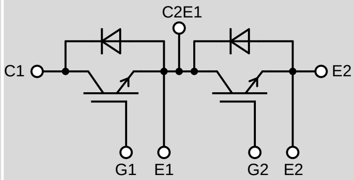
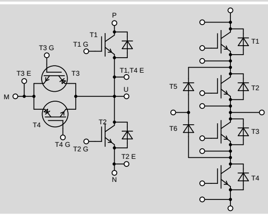
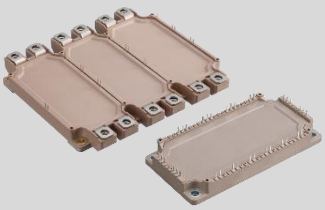
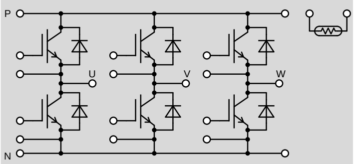
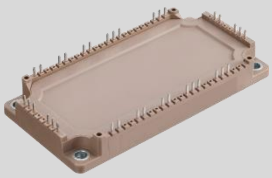
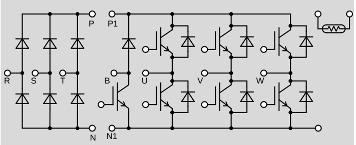


Fig. 1-3 Wire terminal connection structure type

3. Circuit Configuration of IGBT Module

Table 1-1 shows typical circuit configuration of IGBT modules. As shown in Table 1-1, there are basically four types of IGBT modules: 1-Pack, 2-Pack, 6-Pack, and PIM. Each type has its own features. The circuit configuration is also shown. Use them as reference when selecting a module.

Table 1-1 Circuit configuration of IGBT modules

Type	Example of IGBT module		Feature
	External view	Equivalent circuit	
1-Pack			Module which contains one IGBT and one anti-parallel FWD. Modules with high current rating are often connected in parallel in large capacity applications.
Chopper			Module which a FWD is connected in series to an IGBT and its anti-parallel FWD. For application in brake for PWM inverter. I-type 3-level circuit can be configured by combining with 2-Pack.
2-Pack			Module which contains two sets of IGBT and its anti-parallel FWD. Generally 3 modules are used to configure a PWM inverter. Products with high current rating are often connected in parallel in large capacity applications.
3 Level			Module consisting of IGBTs and FWDs arranged in T-type or I-type. It is generally used for solar inverters. Also, modules are often connected in parallel in large capacity applications.
6-Pack			Each module contains six sets of IGBT and its anti-parallel FWD. Module with built-in NTC thermistor for temperature detection is also available. It is common to configure a PWM inverter with a single module.
PIM			A module with built-in converter, inverter, and brake. Module with built-in NTC thermistor for temperature detection is also available.

4. Overcurrent Limiting Feature

During operation, a load short circuit or similar problem may cause overcurrent in the IGBT. If the overcurrent is allowed to continue, the device may quickly overheat and be destroyed. Generally, the time span from the beginning of the overcurrent to the destruction of the device is called the “short circuit withstand capability”. In addition, short circuit withstand capability becomes higher (longer) in condition with lower short circuit current and/or lower power supply voltage. In other words, the smaller the short circuit energy, the higher the short circuit withstand capability.

The short circuit current is dependent on the gate voltage. The IGBT is designed to limit the short circuit current to several times of the device current rating. Thus, in the event of a short circuit, the overcurrent is limited, allowing protection to be applied with a margin after overcurrent is detected.

5. RoHS Compliance

The RoHS (Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment) was enacted by the EU (European Union) on July 1, 2006 to restrict the use of certain hazardous substances in electrical and electronic equipment.

The use of the following ten substances are restricted: Pb (lead), Cd (cadmium), Cr6+ (hexavalent chromium), Hg (mercury), PBB (polybrominated biphenyl), PBDE (polybrominated diphenyl ether), DEHP (bis (2-ethylhexyl) phthalate), BBP (butyl benzyl phthalate), DBP (dibutyl phthalate) and DIBP (diisobutyl phthalate).

Products containing these 10 substances above the threshold (0.01% for Cd, 0.1% for others) cannot be sold in the EU.Exemptions are allowed for uses that are technically difficult to replace.

Lead (Pb) contained in the solder used to connect each chip and DCB is particularly relevant to the RoHS compliance of IGBT modules. Fuji Electric uses Pb-free solder to commercialize products that comply with RoHS regulations.

6. Standards for Safety: UL Certification

When using various devices in the market in regions that require compliance with UL safety regulations such as North America, UL certification is required for the parts used in those devices.

Fuji Electric IGBT modules comply with UL1557 and are certified. The approved models can be checked in the following website.

https://productiq.ulprospector.com/en/profile/1972723/qqqx2.e82988?term=E82988&page=1

A list of Fuji Electric products which is currently UL certified is displayed.