Chapter 1

Structure and Features

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PREFACE

The insulated gate bipolar transistors (IGBTs), applied to devices 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 saving, and downsizing of devices 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 capacity of a bipolar transistor.

1 History of IGBT structure

The p+layer is added to the drain side of power MOSFET to produce the (n-channel) IGBT, in which n-channel is formed when the positive voltage is applied to the gate. In this element, lower resistance can be obtained at high current by using conductivity modulation of the base layer.

The IGBT structure can be divided roughly into the surface gate structure and the bulk structure that constitutes the base layer. 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 the trenches are made to form the gates in the wafer. On the other hand, the bulk structure can be divided roughly into the punch-through type, in which the depletion layer contacts the collector side at turn-off, and the non-punch-through type, in which it does not contact the collector side.

The comparison of the n-channel IGBTs is shown in Fig. 1-1.

Fuji Electric has supplied 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 the carriers were high-injected from the collector side to obtain the low on-state voltage. At the same time, the lifetime control technology was used because the carriers, which were high-injected into the n-base layer, had to be removed quickly at turn off. The low on-state voltage and the low turnoff switching loss (Eoff) were materialized in this way.

However, when the lifetime control technology was used, the improvement of characteristics was limited because the high-injected carriers were suppressed by this technology. In addition, when the lifetime control technology was used, the on-state voltage characteristics varied and so the IGBTs at that time could not meet the increasing demand for large capacity by using them in parallel.

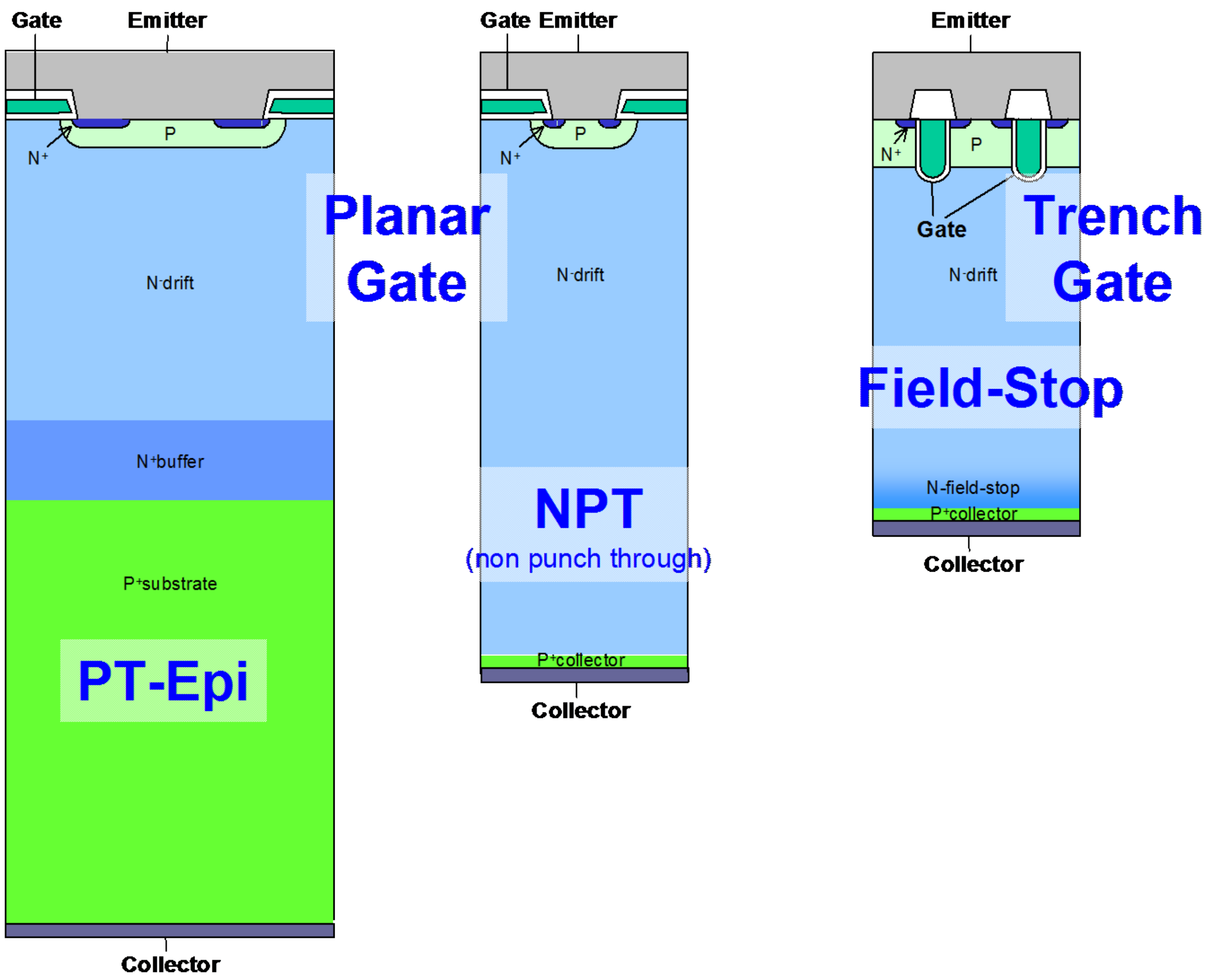
The non-punch-through IGBT was developed to solve these problems. In this IGBT, the injection efficiency of carriers was suppressed by controlling the impurity concentration in the collector (p+ layer) and the transport efficiency was increased by making the n-base layer thinner. The non-punch-through IGBT used the float zone (FZ) wafer instead of the epitaxial wafer and so had the advantage that it was less affected by crystal defect. On the other hand, it was necessary to have high transport efficiency and have the n-base layer thinner, namely make the chip thickness smaller, in order to have low on-stage voltage. Fuji Electric has developed new technologies for production of thinner wafers and improved the characteristics.

It is necessary to necessary to produce and IGBT, which has thinner chip, in order to further improve the characteristics. However, the thickness of the n-base layer constitutes most of the chip thickness, and if its thickness is made smaller, the specified voltage cannot be kept.

The field stop (FS) structure solved this problem for improvement of the characteristics. In the FS structure, the high concentration FS layer is provided in the n-base layer, enabling improvement of the characteristics.

Fuji Electric has also advanced the miniaturization of surface structure that is imperative to improve the characteristics of IGBT. The IGBT element consists of many arranged structures called cells. The more the IGBT cells are provided, the lower the on-state voltage will be. Therefore, the surface structure has changed from the planar structure, in which the IGBT cells are made planarly on the wafer surface, to the trench structure, in which the trenches are formed on the silicon surface and the gate structure is formed three-dimensionally.

As shown, Fuji Electric has improved the characteristics by applying various technologies to the bulk structure and the surface structure.



(a) Punch Through type (b) Non Punch Through type (c) Field Stop type

Fig. 1-1 Structure comparison of IGBTs

2 Module structures

Fig.1-2 and Fig.1-3 show typical IGBT module structures. The module integrated with a 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 cut the internal wiring inductance. In addition, the use of a direct copper bonding (DCB) substrate makes for a high-reliability product that combines low thermal resistance and high transverse breaking strength.

The wire terminal connection structure module shown in Fig.1-3 has main terminals bonded to the DCB substrate by wire, rather than by soldering, to simplify and downsize the package structure. This results in cuts in both thickness and weight, and fewer assembly person-hours.

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

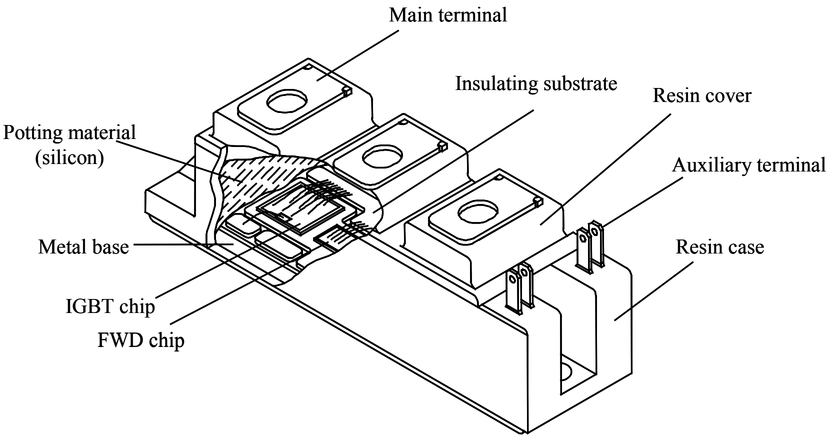


Fig. 1-2 Integrated with a terminal block type IGBT module

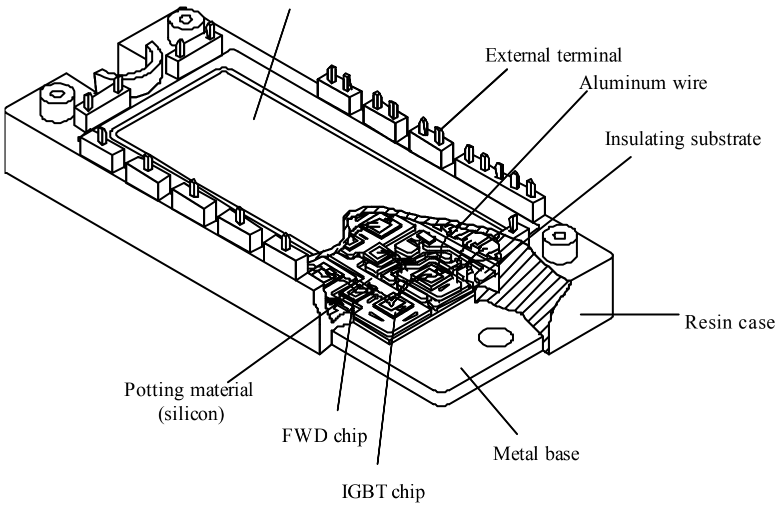


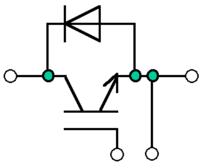
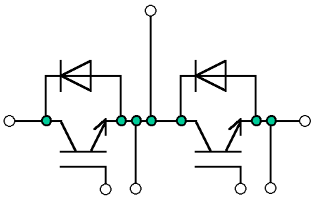
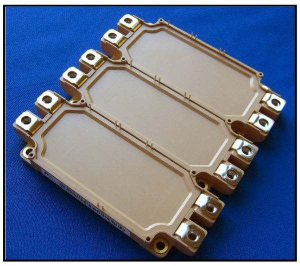
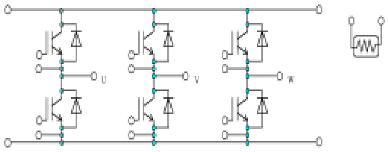
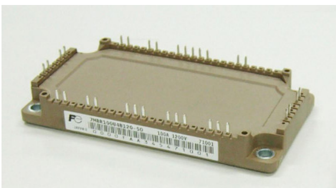
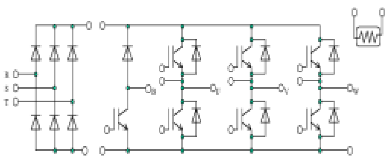
Fig. 1-3 Wire terminal connection structure type IGBT module

3 Circuit configuration of IGBT module

Table 1-1 shows typical circuit configuration of IGBT modules.

IGBT modules are configurationally grouped into four types: 1 in 1, 2 in 1, 6 in 1, and PIM (7 in 1). A circuit configuration is prescribed for each of these types. A summary description of the features of each type is also included in the figure to aid you in your device selection.

Table 1-1 Circuit configuration of IGBT modules

Type	Example of IGBT module		Features
	External view	Equivalent circuit	
1 in 1			Each product contains one IGBT chip and one FWD chip. Products having a high current rating are often connected in parallel in large capacity applications.
2 in 1			Each product contains two IGBT chips and two FWD chips. Three units are generally used in a set to make up a PWM inverter. Otherwise, products having a high current rating are often connected in parallel.
6 in 1			Each product contains six IGBT chips and six FWD chips. Some variations contain a NTC. One unit is generally used alone to make up a PWM inverter.
PIM (7 in 1)			7 in1 contains seven IGBT chips and seven FWD chips in the inverter and brake section. PIM includes a converter section in addition to 7 in1. Some variations contain a NTC or a thyristor used for an electrolytic capacitor charging circuit.

4 Overcurrent limiting feature

During operation, a load short-circuit or similar problem may cause an overcurrent in the IGBT. If the overcurrent is allowed to continue, the device may quickly overheat and be destroyed. The time span from the beginning of an overcurrent to the destruction of the device, is generally called the "short-circuit withstand capability time". In addition, short-circuit withstand capability time become longer in condition with lower short-circuit current and/or lower power supply voltage.

The IGBT module has the ability limited to several times the devices current rating. In the event of a short circuit, the overcurrent is limited, giving the device a high short-circuit withstand capability.

5 RoHS compliance

The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) was enacted by the EU on July 1, 2006 to restrict the use of certain hazardous substances in electrical and electronic equipment. The use of the following six substances are restricted: Pb (lead), Cd (cadmium), Cr6+ (hexavalent chrome), Hg (mercury), PBB (polybrominated biphenyl), and PBDE (polybrominated diphenyl ether). Products containing any of these hazardous substances cannot be sold in the EU.

In the IGBT module, lead (Pb) used to be contained in the solder used to connect between the respective chips and the DCB and between the base and the DCB. However, currently Fuji Electric uses the lead-free solder in compliance with RoHS.

6 Standards for Safety: UL Certification

In the areas such as North America where the UL standards are enacted, UL approval must be obtained for any part used for devices used in such areas.

In this connection, the UL approval (UL1557) is granted to the IGBT module of Fuji Electric. The approved models can be checked in following website:

http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/index.htm

When "e82988" is input into the UL file number on this website for search, a list of UL-approved is displayed.

WARNING

1. This Catalog contains the product specifications, characteristics, data, materials, and structures as of January 2017.
   The contents are subject to change without notice for specification changes or other reasons. When using a product listed in this Catalog, be sur to obtain the latest specifications.

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   - Communications equipment (terminal devices)
   - Measurement equipment
   - Machine tools
   - Audiovisual equipment
   - Electrical home appliances
   - Personal equipment
   - Industrial robots etc.

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   - Trunk communications equipment
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   - Gas leakage detectors with an auto-shut-off feature
   - Emergency equipment for responding to disasters and anti-burglary devices
   - Safety devices
   - Medical equipment

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