Chapter 1
Structure and Features

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PREFACE

The insulated gate bipolar transistors (IGBTs), applied to devices such as variable-speed motor controls and uninterruptible power supplies (UPSs), widely used in response to the increasing demand for energy saving, weight saving, and downsizing of equipments in recent years. The IGBTs are switching devices 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 invention of IGBT was done with additional p+ layer formed on the drain side of power MOSFET to produce the (n-channel) IGBT, in which n-channel was formed when the positive voltage was applied to the gate. In this device, lower resistance can be obtained even at high current because of the 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 semiconductor surface. The other is the trench gate structure, in which the trenches are etched to form the vertical gates in the silicon surface. On the other hand, the bulk structure can be called as two different type the punch-through (PT) type, in which the depletion layer expands to the collector side at off-state, and the non-punch-through (NPT) type, in which it does not reach to the collector layer.

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

Fuji Electric has been providing 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 silicon wafer and the minority carriers were high-injected from the collector side to obtain strong conductivity to achieve the low on-state voltage drop. At the same time, the carrier lifetime control method was used because the carriers, which were high-injected into the n-base layer, had to be removed quickly for fast turn off. The low on-state voltage and the low turnoff switching loss (Eoff) were achieved in such way.

However, when the carrier lifetime control method was used, the improvement of characteristics was limited because it was hard to obtain ideal carrier profile with this method the high –injected carriers were suppressed by this technology. In addition, the disadvantages of relatively wider on-state voltage drope process variation had been an issue when IGBTs were connected in parallel especially for high power application.

The non-punch-through (NPT) IGBT was developed to solve these issues. In NPT IGBT, the minority carrier injection efficiency of carriers was suppressed by controlling the impurity concentration in the collector (p+ layer). The transport efficiency was increased by shortening the drift distance with thinner n-base layer The NPT IGBT were fabricated the float zone (FZ) wafer instead of the epitaxial wafer, which has advantages of less crystal defects. 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 thinner wafers production and contributed to keep improving the IGBT performance.

Thinner devices structures were necessary for additional improvement in IGBT characteristics because the thickness of the n-base layer was a major part of the chip thickness however the n-drift layer thickness is also important for the device blocking capability. It was hard to have simple thickness reduction in NPT IGBT structure while keep high performance as well as high breakdown voltage.

The field stop (FS) structure has solved this issue of improvement of the characteristics. In the FS structure, the high concentration FS layer is provided in the n-base layer, enabling additional improvement in IGBT performance.

Fuji Electric has also implemented fine patten silicon process in surface side structures to improve the characteristics of IGBT. The IGBT chip consists of many arranged structures called “unit cells”. In general 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 semiconductor surface, to the trench structure, in which the trenches are formed into the silicon to is form three-dimensionall gate structure.

As shown, Fuji Electric has improved the characteristics by applying various technologies to the bulk structure and the surface structure.
Fig. 1-1  Structure comparison of IGBTs
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 voltage isolation.

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

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

<table>
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<tr>
<th>Type</th>
<th>Example of IGBT module</th>
<th>Features</th>
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<tbody>
<tr>
<td>1 in 1</td>
<td><img src="image1.png" alt="Image" /></td>
<td>Each product contains one switch of IGBT chip and one FWD chipset. Products having a high current rating are often connected in parallel in large capacity applications.</td>
</tr>
<tr>
<td>2 in 1</td>
<td><img src="image2.png" alt="Image" /></td>
<td>Each product contains two switches of IGBT chips and two FWD chipset. Three units are generally used in a set to make up a 3-phase PWM inverter. Otherwise, products having a high current rating are often connected in parallel.</td>
</tr>
<tr>
<td>6 in 1</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Each product contains six switches of IGBT chips and six FWD chipset. Some modules have integrated NTC. Available to configure PWM inverter just with one module.</td>
</tr>
<tr>
<td>PIM (7 in 1)</td>
<td><img src="image4.png" alt="Image" /></td>
<td>7 in 1 contains seven switches of IGBT chips and seven FWD chipset in the inverter and brake section. PIM includes a converter section in addition to 7 in 1. Some types have integrated NTC.</td>
</tr>
</tbody>
</table>
4 Overcurrent limiting feature

During operation, a load short-circuit or similar insability may cause an overcurrent in the IGBT. If the overcurrent status keep continued, the device may quickly be overheated and results destruction. The time span from the beginning of an overcurrent to the destruction of the device, is generally called the “short-circuit withstand capability time”. The short-circuit withstand capability time depends on the conditions for example, it would be longer if lower short-circuit current and/or lower power supply voltage.

The IGBT module has feature of current saturation by itself to several times of the rated current. This feature makes it possible to have limited over current in the event of a short circuit, which results the device a relatively 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 parts is displayed.
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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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   - Submarine repeater equipment
   - Aeronautical equipment
   - Nuclear control equipment

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