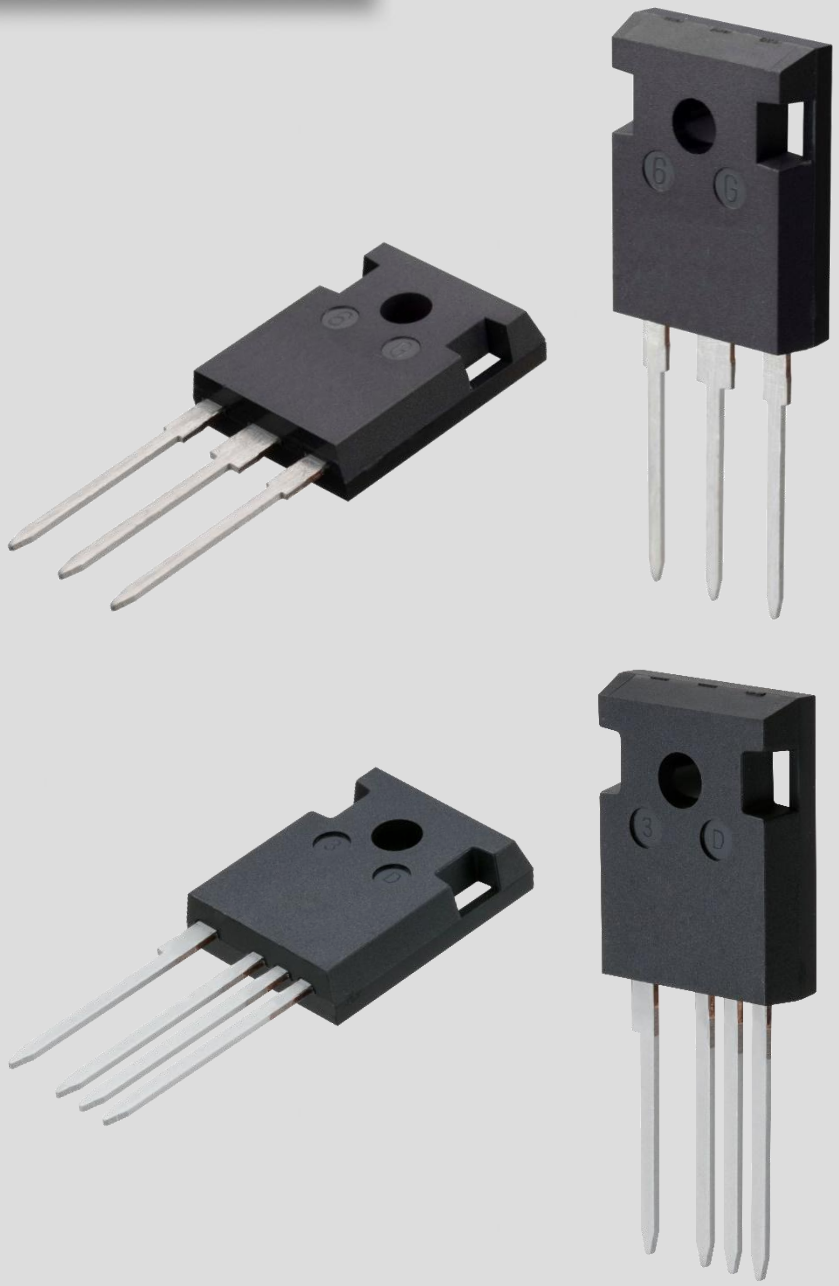

Discrete IGBT

Application Manual

Dec. 2025

Fuji Electric Co.,Ltd.

⚠ Cautions

This manual contains the product specifications, characteristics, data, materials, and structures as of December 2025.
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.

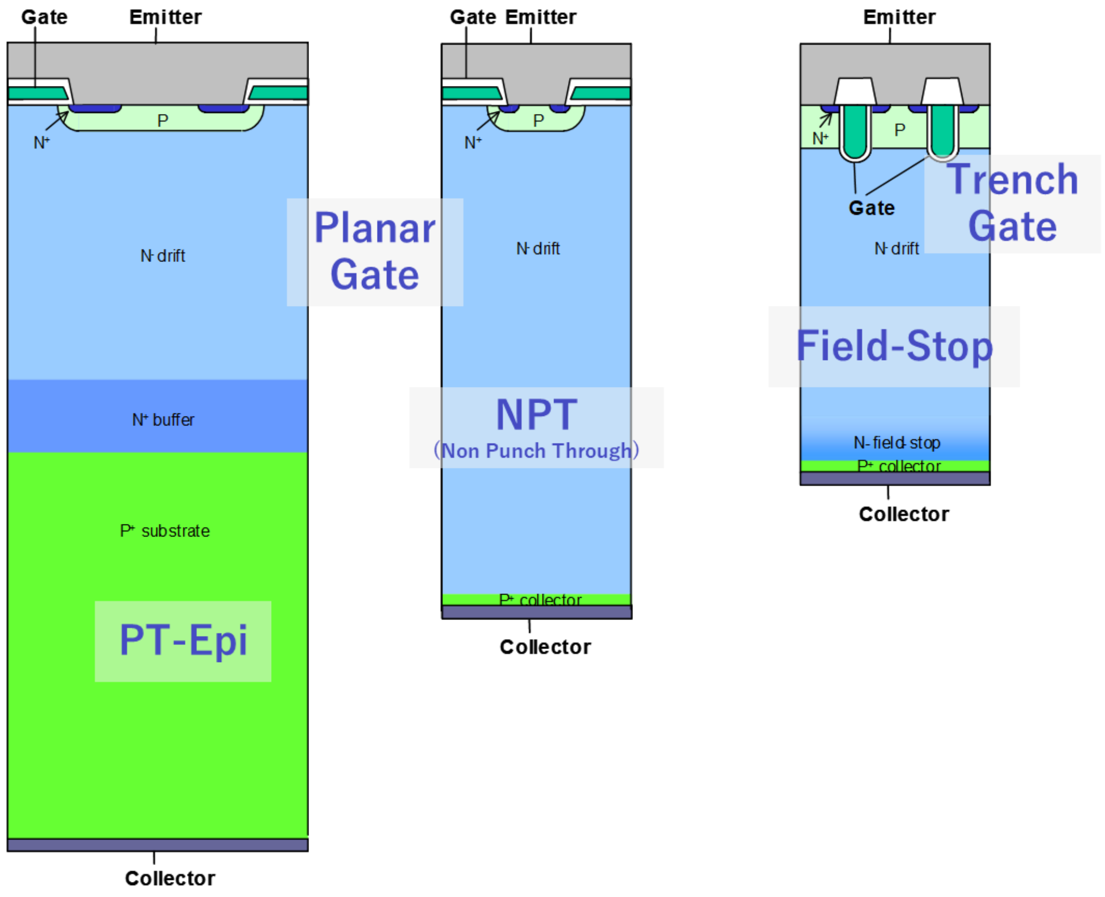
Fuji Electric has been supplying IGBTs to the market since it commercialized them in 1988. The planar-gate punch-through IGBT was the mainstream IGBT at that time. The punch-through IGBT used the epitaxial wafer and low on-state voltage was achieved by injecting a large amount of minority carriers from 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-drift 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.

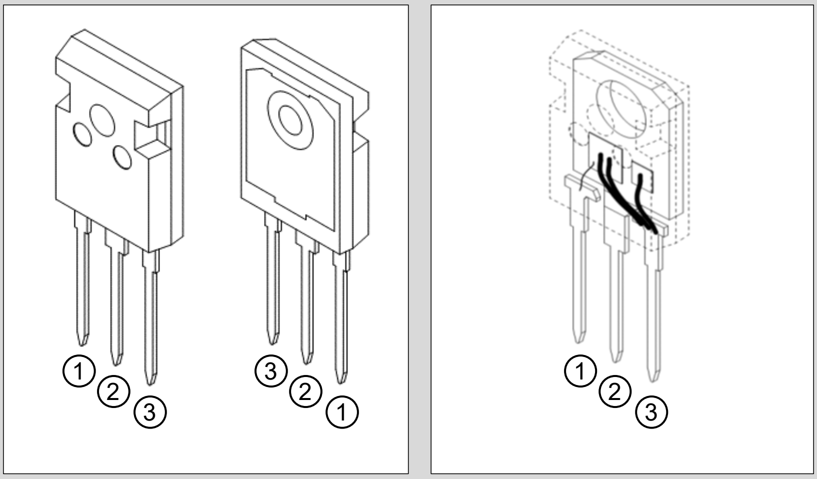


(a) Punch-through type (b) Non-Punch-through type (c) Field Stop type

Fig. 1-1 Structure comparison of IGBT

2. Structure of Discrete IGBT

Fig. 1-2 shows the structure of a TO-247 device that incorporates an IGBT and a FWD. Fig. 1-2(a) shows the external appearance, while Fig. 1-2(b) shows the internal structure. ①, ② and ③ correspond to the Gate, Collector, and Emitter terminals, respectively. Unlike typical IGBT modules, discrete IGBT does not have an insulating substrate.



(a) External appearance

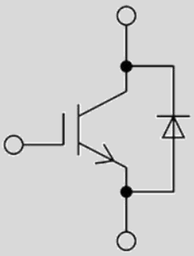
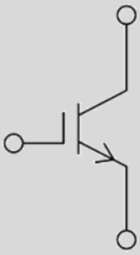
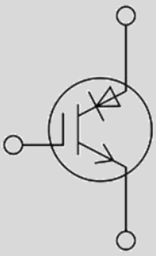
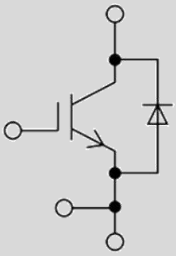
(b) Internal structure

Fig. 1-2 Structure of a discrete IGBT

3. Circuit Configuration of Discrete IGBT

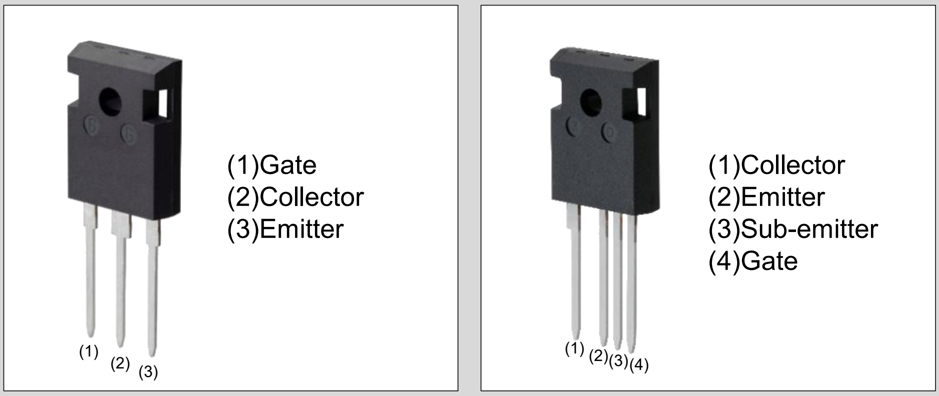
Table1-1 shows the circuit configuration of the Discrete IGBT.

Table1-1 Circuit configuration of discrete IGBT

Package name	Appearance	Equivalent circuit	Features
TO-247			This product contains an IGBT and a FWD connected in anti-parallel. It is widely used in applications such as 2-level and 3-level PWM inverter circuits and chopper circuits.
			This product contains only IGBT. It is typically used in application where FWD is not required, such as in chopper circuit.
			This product contains an IGBT with reverse blocking voltage (RB-IGBT). It is used as a bidirectional switch such as the midpoint device in T-type NPC 3-level PWM inverter circuits.
TO-247-4			This product is a TO-247 package with an additional sub-Emitter terminal. Compared with the standard TO-247 package, it offers lower switching loss and reduced ringing of the gate-voltage. (refer to Section 4. “Features of TO-247-4” and Chapter 3 for details)

4. Features of TO-247-4

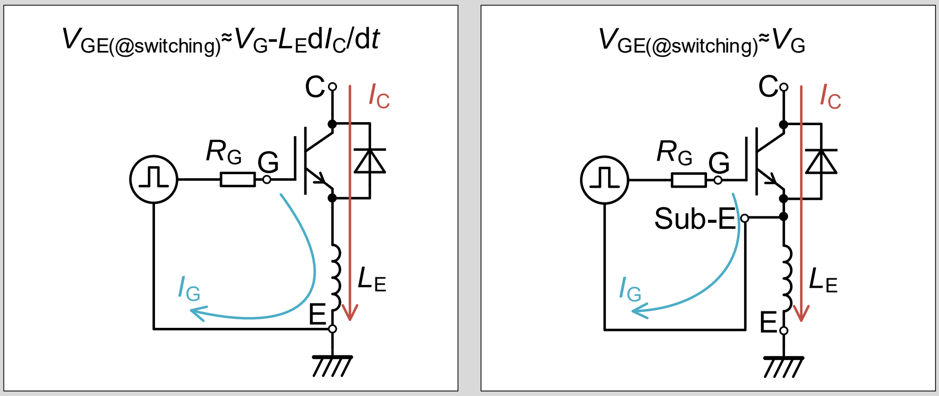
In addition to the 3-terminal type TO-247 package shown in Fig. 1-3 (a), Fuji Electric also offers the 4-terminal type TO-247-4 package shown in Fig. 1-3 (b).



(a) TO-247 (b) TO-247-4

Fig. 1-3 Package appearance and terminal arrangement

In the 4-terminal TO-247-4 package, which adds an additional sub-emitter terminal, the common-emitter inductance LE can be separated from the gate drive circuit as shown in Fig. 1-4 (Kelvin connection). This configuration mitigates the induced voltage $-L_E \cdot dI_C/dt$ generated by the current loop in the gate drive path. As a result, compared with the conventional 3-terminal TO-247, the gate responds more quickly, switching loss are reduced (refer to Chapter 2 for details), and gate-voltage ringing is suppressed.



(a) TO-247 (b) TO-247-4

Fig. 1-4 Schematic diagram of internal circuit

Fig. 1-5 and Fig. 1-6 compare the I_C dependence of the switching loss for the TO-247 device (FGW75XS120C) and TO-247-4 device (FGZ75XS120C). These figures show that the impact of the induced voltage $-L_E \cdot dI_C/dt$ is mitigated, resulting in lower switching loss.

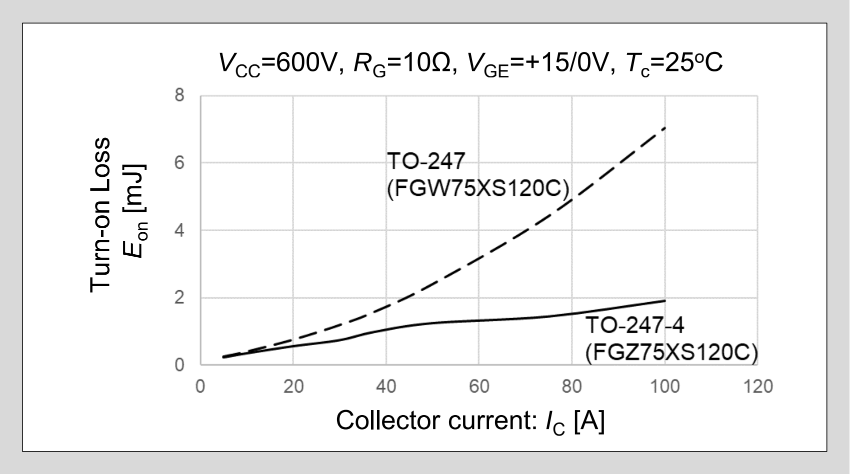


Fig. 1-5 TO-247 versus TO-247-4 turn-on loss

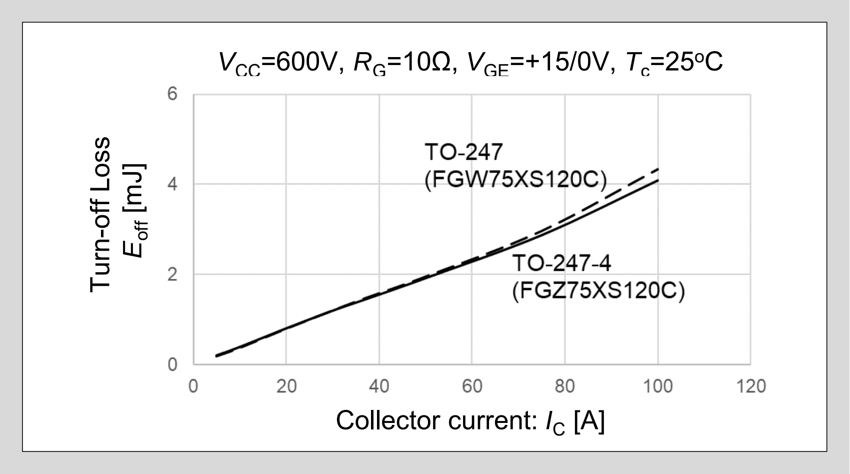
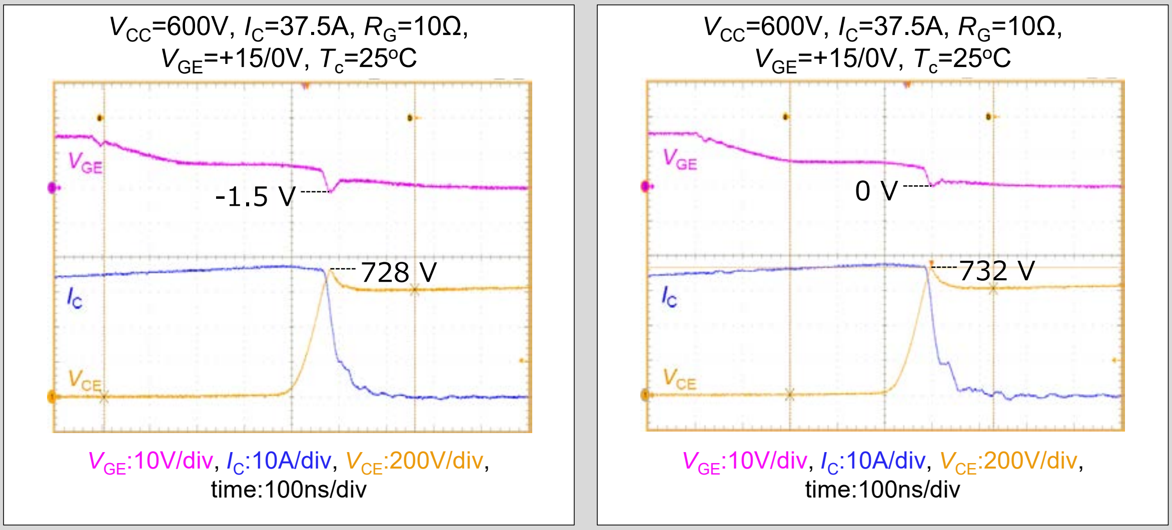


Fig. 1-6 TO-247 versus TO-247-4 turn-off loss

The turn-off waveforms for TO-247(FGW75XS120C) and TO-247-4(FGZ75XS120C) are shown in Fig. 1-7. It can be seen that when the current is interrupted, the TO-247-4 package suppresses the V_{GE} ringing that is present with the conventional package. Keep in mind, however, that although the TO-247-4 package reduces the $-L_E \cdot dI_C/dt$ induced voltage, thereby lowering switching loss and mitigating ringing, it also makes the device switch faster. Consequently, the rate of change of collector current (dI_C/dt) becomes higher, and the turn-off surge voltage increases. For details, refer to Chapter 3.

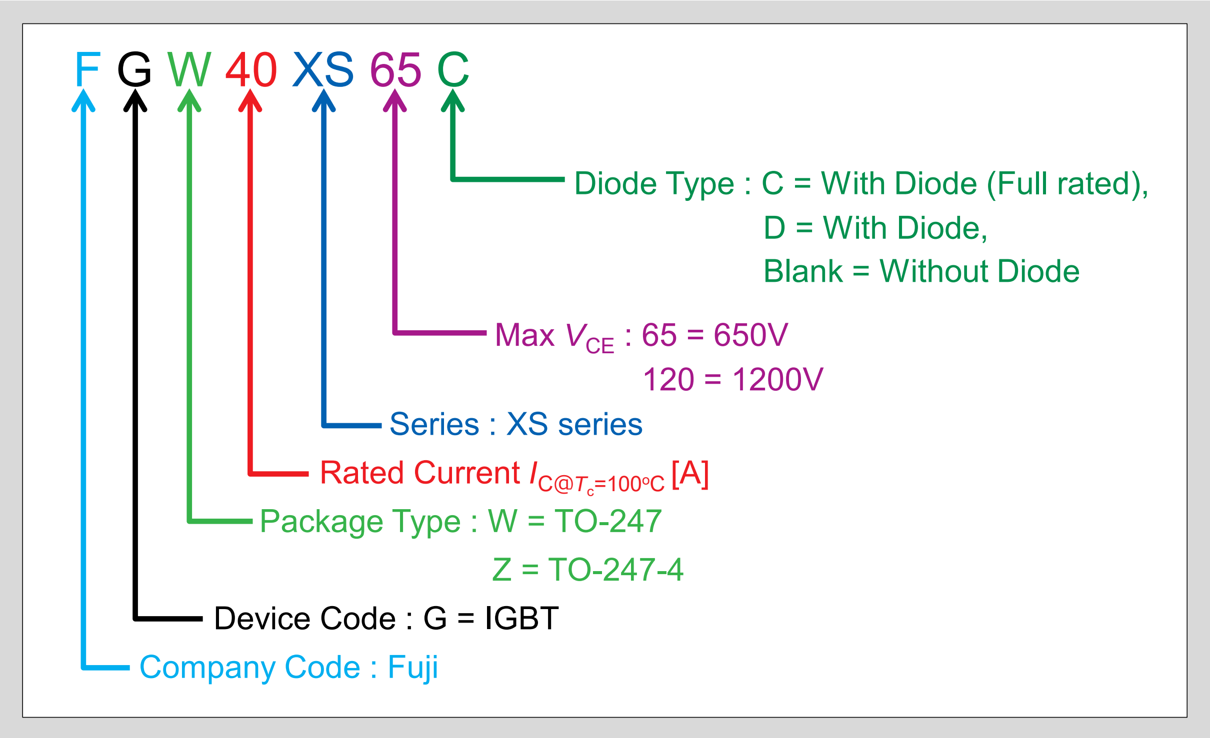


(a) TO-247(FGW75XS120C)

(b) TO-247-4(FGZ75XS120C)

Fig. 1-7 Turn-off waveform comparison

5. How to Read Discrete IGBT Product Part Number



F G W 40 XS 65 C

Diode Type : C = With Diode (Full rated),
D = With Diode,
Blank = Without Diode

Max V_{CE} : 65 = 650V
120 = 1200V

Series : XS series

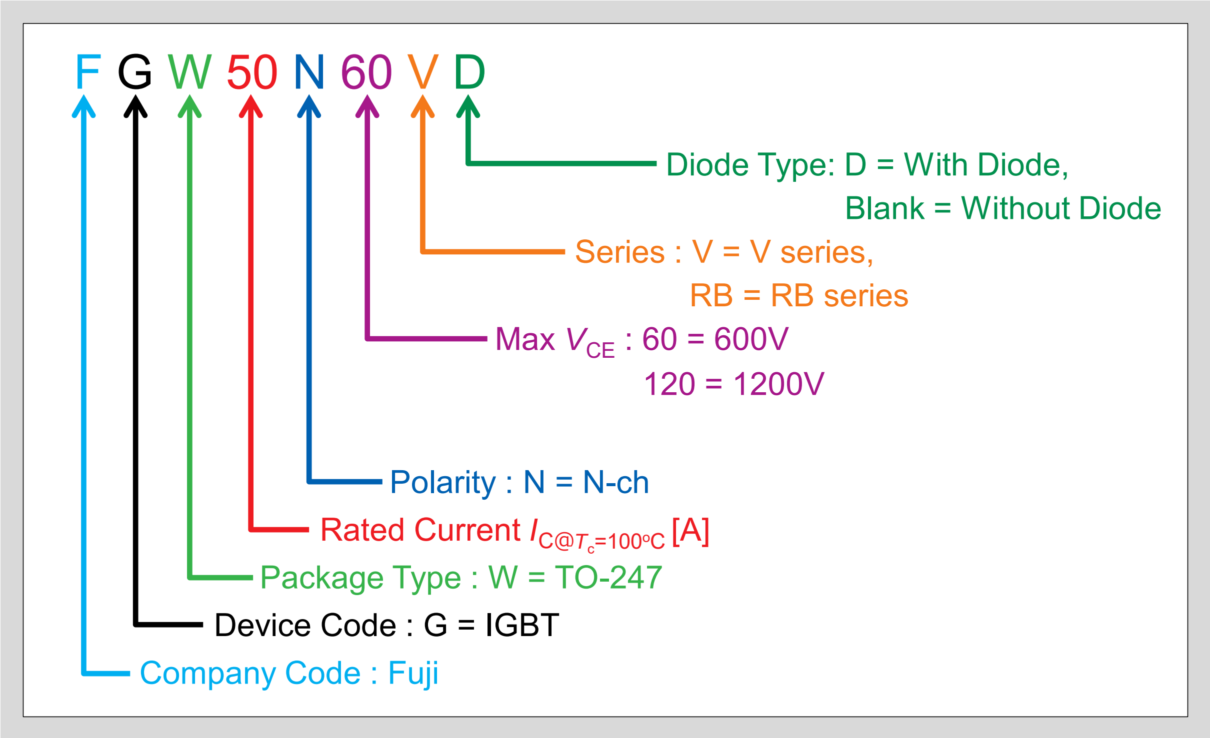
Rated Current $I_{C@T_c=100^{\circ}C}$ [A]

Package Type : W = TO-247
Z = TO-247-4

Device Code : G = IGBT

Company Code : Fuji

Fig. 1-8 XS series product part number



F G W 50 N 60 V D

Diode Type: D = With Diode,
Blank = Without Diode

Series : V = V series,
RB = RB series

Max V_{CE} : 60 = 600V
120 = 1200V

Polarity : N = N-ch

Rated Current $I_{C@T_c=100^{\circ}C}$ [A]

Package Type : W = TO-247

Device Code : G = IGBT

Company Code : Fuji

Fig. 1-9 V series product part number

6. Product Marking

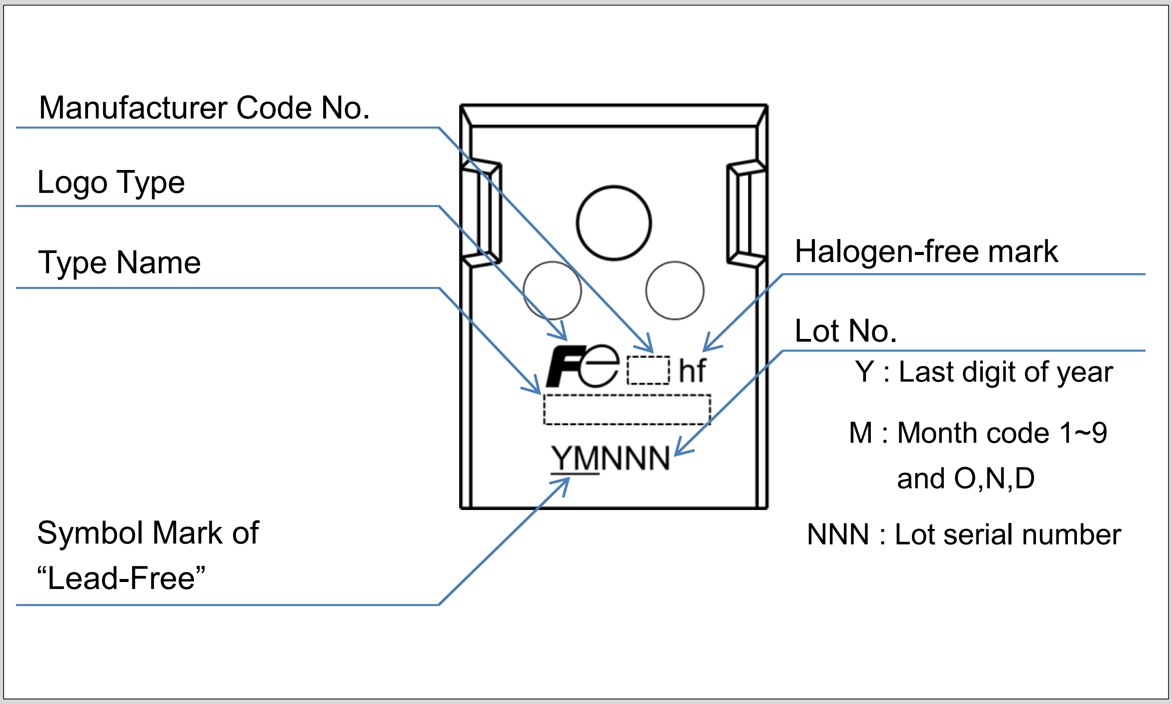


Fig. 1-10 Contents of the marking

Table 1-2 Example of marking

Series	Product part number	Type name
XS	FGW75XS120C	75XS120C
V	FGW40N120VD	40N120VD

7. RoHS Compliance

The RoHS Directive (Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment) is a regulation enacted by the European Union (EU) on July 1st, 2006, that restricts the use of specific hazardous substances in electrical and electronic equipment.

Under (EU) 2015/863, the ten restricted substances are:

- Pb (lead)
- Cd (cadmium)
- Cr^{6+} (hexavalent chromium)
- Hg (mercury)
- PBB (polybrominated biphenyls)
- PBDE (polybrominated diphenyl ethers)
- DEHP (bis(2-ethylhexyl) phthalate)
- BBP (benzyl butyl phthalate)
- DBP (dibutyl phthalate)
- DIBP (di-isobutyl phthalate)

Products containing any of these substances above the threshold levels (0.01 % for Cd; 0.1 % for all others) may not be sold within the EU, except for applications where substitution is technically impracticable and an exemption is granted.

Our discrete IGBT products are RoHS-compliant. The terminal solder plating uses lead-free solder (Pb < 0.1 %).