# Chapter 2 Terms and Characteristics

1. Explanation of Terms 2-2
2. Characteristics of IGBT and FWD 2-4

This chapter describes the terms and characteristics.

## 1. Explanation of Terms

This section describes the terms used in specifications.

Table.2-1 Absolute maximum rating

| Term | Symbol | Definition explanation (See specifications for test conditions) |
|---|---|---|
| Collector-Emitter Voltage | $V_{CES}$ | Max. Collector-Emitter (hereinafter referred to as C-E) voltage with Gate-Emitter (G-E) shorted |
| Gate-Emitter Voltage | $V_{GES}$ | Max. G-E voltage with C-E shorted (Normally ±20V max.) |
| Collector Current | $I_C$ | Max. DC collector current |
|  | $\mathrm{I}_{CP}$ | Max. pulse collector current |
| Diode Forward Current | $I_F$ | Max. DC FWD current |
|  | $I_{FP}$ | Max. pulse FWD current |
| Short Circuit Withstand Time | $t_{SC}$ | The time interval which the device can withstand in short circuit condition without failing |
| Collector Power Dissipation | $P_{D\_IGBT}$ | Max. power dissipation of IGBT |
| FWD Power Dissipation | $P_{D\_FWD}$ | Max. power dissipation of FWD |
| Operating Junction Temperature | $T_{vj}$ | Junction temperature range during continuous operation |
| Storage Temperature | $T_{stg}$ | Temperature range allowing storage or transportation without being subjected to electrical load |

Table.2-2 Electrical characteristics

| Term | Symbol | Definition explanation (See specifications for test conditions) |
|---|---|---|
| Zero Gate Voltage Collector Current | $I_{CES}$ | Leakage current when a specified voltage is applied to C-E with G-E shorted |
| Gate-Emitter Leakage Current | $I_{GES}$ | Leakage current when a specified voltage is applied to G-E with C-E shorted |
| Gate-Emitter Threshold Voltage | $V_{GE(th)}$ | G-E voltage (hereinafter, $V_{GE}$) at specified C-E (hereinafter, $I_C$) current and C-E voltage (hereinafter, $V_{CE}$). (It is used as a measure of $V_{GE}$ value at which $I_C$ begins to flow, and $V_{GE}$ at which the IGBT begins to turn-on.) |
| Collector-Emitter Saturation Voltage | $V_{CE(sat)}$ | $V_{CE}$ at a specified $I_C$ and $V_{GE}$ |
| Input Capacitance | $C_{ies}$ | G-E capacitance, when a specified $V_{GE}$ and $V_{CE}$ are applied with C-E shorted in AC |
| Output Capacitance | $C_{oes}$ | C-E capacitance, when a specified $V_{GE}$ and $V_{CE}$ are applied with G-E shorted in AC |
| Reverse Transfer Capacitance | $C_{res}$ | C-G capacitance, when a specified $V_{GE}$ and $V_{CE}$ are applied with G-E and C-E shorted in AC |
| Gate Charge | $Q_G$ | Amount of G-E charge to turn-on IGBT |
| Turn-On Delay Time | $t_{d(on)}$ | Time from when $V_{GE}$ reaches 10% of the max. value until $I_C$ reaches 10% of the max. value at IGBT turn-on (See Fig.2-4) |
| Rise Time | $t_r$ | Time from when $I_C$ rises to 10% of the max. value to 90% of the max. value at IGBT turn-on (See Fig.2-4) |
| Turn-Off Delay Time | $t_{d(off)}$ | Time from when $V_{GE}$ reaches 90% of its max. value until $I_C$ reaches 90% of the max. value at IGBT turn-off (See Fig.2-4) |
| Fall Time | $t_f$ | Time from when $I_C$ falls from 90% of its max. value to 10% of the max. value at IGBT turn-off (See Fig.2-4) |
| Turn-on Energy | $E_{on}$ | Loss that occurs during IGBT turn-on (See Fig.2-4) |
| Turn-off Energy | $E_{off}$ | Loss that occurs during IGBT turn-off (See Fig.2-4) |
| Reverse Recovery Energy | $E_{rr}$ | Loss that occurs during FWD reverse recovery (See Fig.2-4) |
| Forward Voltage Drop | $V_F$ | Forward voltage when a specified forward current is applied to FWD |
| Diode Reverse Recovery Time | $t_{rr}$ | Time from when the current crosses 0A to 10% of the reverse recovery peak current at FWD turn-off (See Fig.2-4) |
| Diode Reverse Recovery Charge | $Q_{rr}$ | Amount of charge required for reverse recovery current in FWD to disappear |
| Reverse Biased Safe Operating Area | RBSOA | Region of current and voltage where the IGBT can be safely turned-off under specified conditions |
| Thermal Resistance, Junction-Ambient | $R_{th(j-a)}$ | Thermal resistance between chip and surroundings without heat sink and without wind |
| Thermal Resistance, IGBT Junction to Case | $R_{th(j-c)\_IGBT}$ | Thermal resistance between the IGBT chip and case |
| Thermal Resistance, FWD Junction to Case | $R_{th(j-c)\_FWD}$ | Thermal resistance between the FWD chip and case |

## 2. Characteristics of IGBT and FWD

Discrete IGBT products include products in which a FWD is connected in anti-parallel to the IGBT, and products with only IGBT. Taking FGW40XS120C (1200V / 40A device) as an example, the explanation of various characteristics of IGBT and FWD described in the specifications etc. are shown below.

### ＜Output Characteristics＞

This characteristic shows the relationship between the drop voltage ($V_{CE}$) and the current ($I_C$) when the IGBT is in on-state, which is the loss that occurs in the IGBT. The lower the $V_{CE}$, the smaller the loss. Please note that these characteristics change depending on $T_{vj}$ and $V_{GE}$. Generally, the output characteristic of $V_{GE}$ = 15V is used.

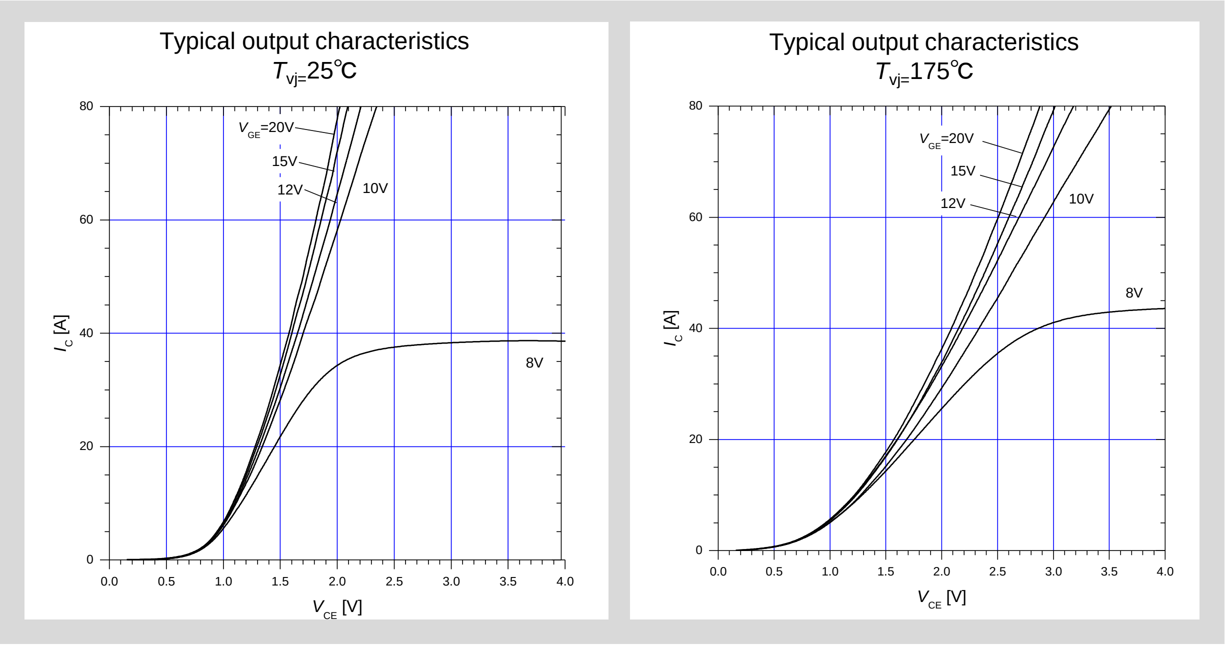


Fig.2-1 Characteristics of $V_{CE(sat)}$ - $I_C$

Fig.2-2 shows $V_F$-$I_F$ characteristics of FWD. This characteristic changes depending on $T_{vj}$.

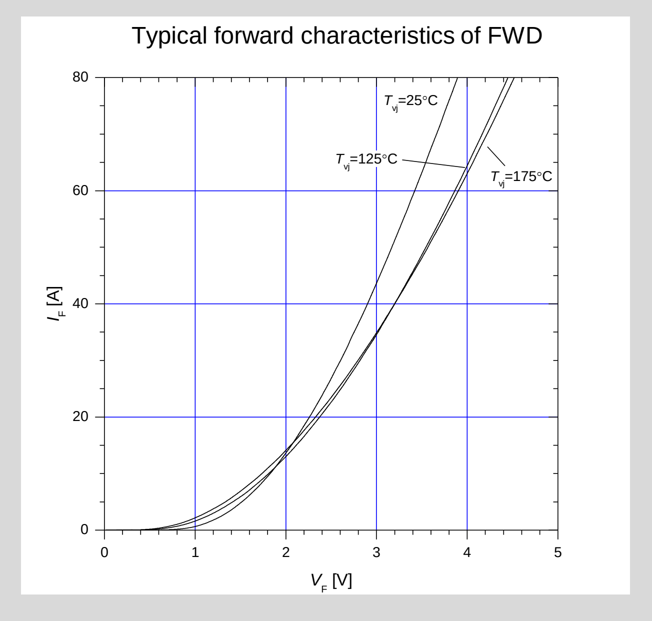


Fig.2-2 Characteristics of $V_F$-$I_F$

## ＜Switching Characteristics＞

Switching characteristics can be broadly divided into switching time and switching loss. The switching characteristics can be measured with the chopper circuit shown in Fig.2-3.

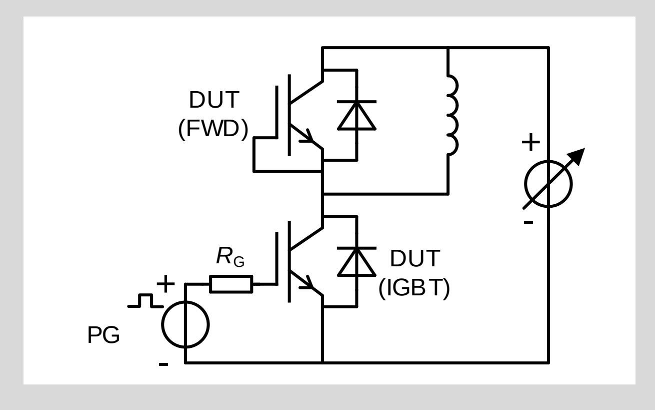
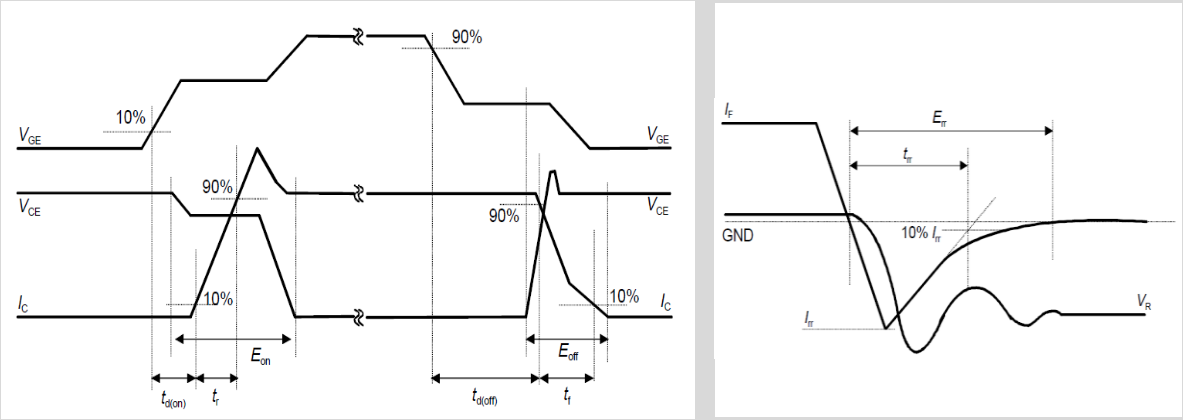


Fig.2-3 Switching characteristic measurement circuit

Fig.2-4 shows the definitions of switching time ($t_{d(on)}$, $t_r$, $t_{d(off)}$, $t_f$, $t_{rr}$) and switching loss ($E_{on}$, $E_{off}$, $E_{rr}$) shown in Table 2-2.



(a) Waveforms of turn-on and turn-off

(b) Reverse recovery waveforms

Fig.2-4 Definition of switching time

The relationship between switching time and $I_C$ is shown in Fig.2-5, and the relationship between switching time and $R_G$ is shown in Fig.2-6. Please note that the switching time varies depending on $I_C$, $T_{vj}$ and $R_G$.

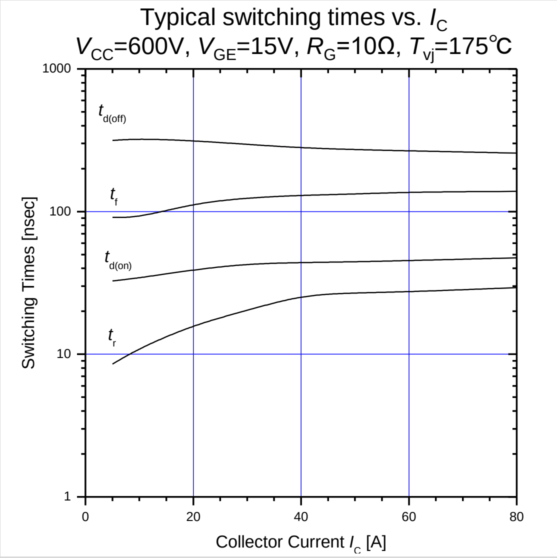


Fig.2-5 Characteristics of switching time-$I_C$

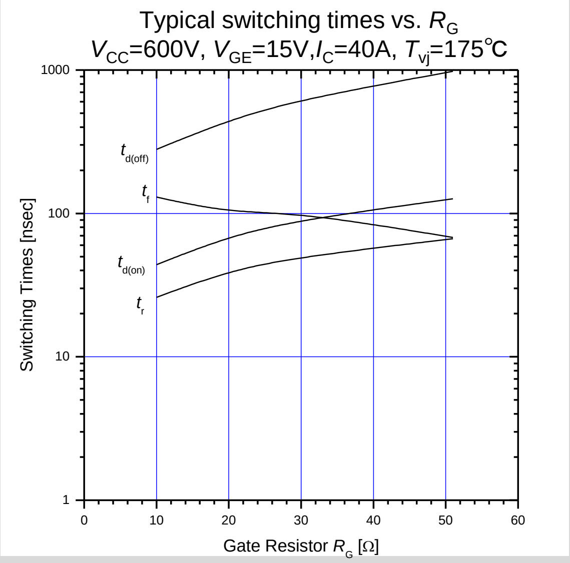


Fig.2-6 Characteristics of switching time-$R_G$

Fig.2-7 shows the relationship between the reverse recovery time of FWD and $I_F$. The reverse recovery time varies depending on $I_F$, $T_{vj}$, and $R_G$.

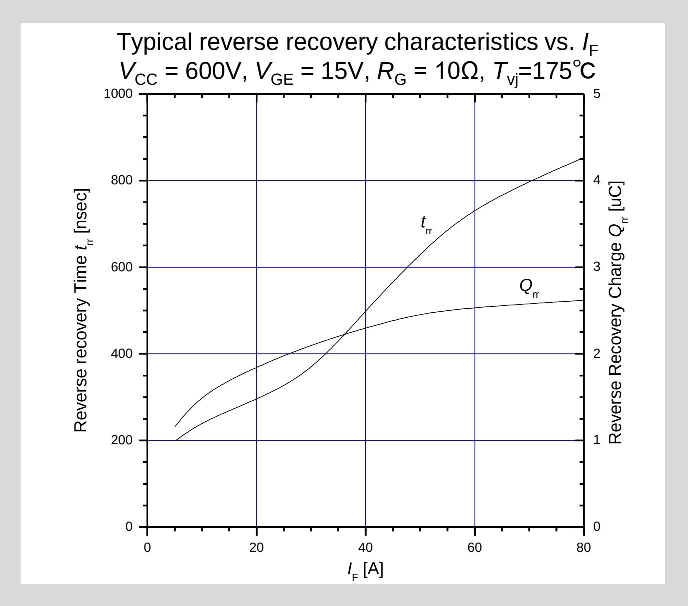


Fig.2-7 Characteristics of $t_{rr}$-$I_F$

Switching loss ($E_{on}$, $E_{off}$, $E_{rr}$) occurs when the IGBT switches (turn-on, turn-off). Fig.2-8 shows the relationship between $E_{on}$, $E_{off}$ and $I_C$, and Fig.2-9 shows the relationship between $E_{on}$, $E_{off}$ and $R_G$. The relationship between $E_{rr}$ and $I_F$ is shown in Fig.2-10. Please note that this characteristic varies depending on $T_{vj}$, $V_{GE}$, $I_C$, $I_F$, and $R_G$.

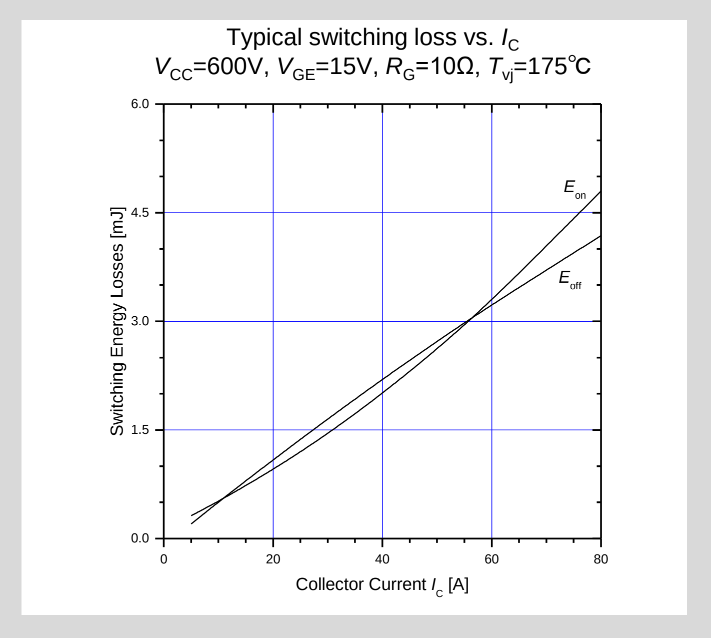


Fig.2-8 Characteristics of $E_{on}$, $E_{off}$-$I_C$

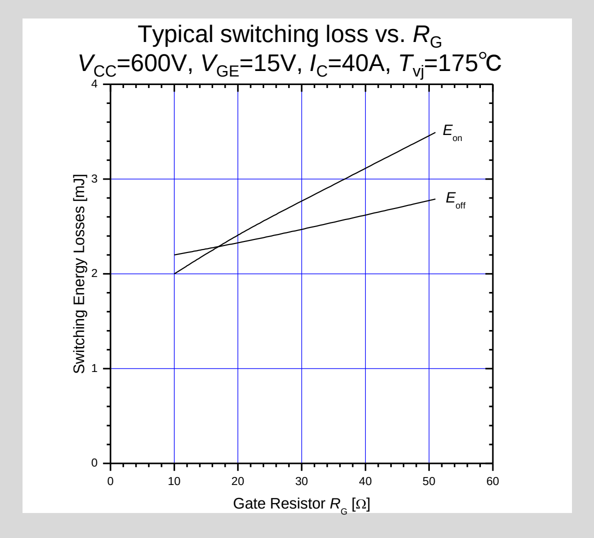


Fig.2-9 Characteristics of $E_{on}$, $E_{off}$-$R_G$

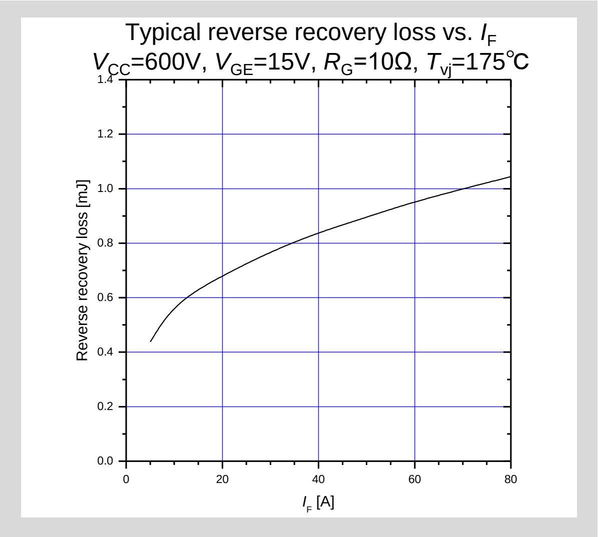


Fig.2-10 Characteristics of $E_{rr}$-$I_F$

## ＜Capacitance characteristics＞

The IGBT has parasitic capacitance due to its structure. The Parasitic capacitance includes $C_{ies}$, $C_{oes}$, and $C_{res}$. The relationship between $V_{GE}$ and $Q_G$ is shown in Fig.2-11, and the relationship between $C_{ies}$, $C_{oes}$, $C_{res}$ and $V_{CE}$ is shown in Fig.2-12.

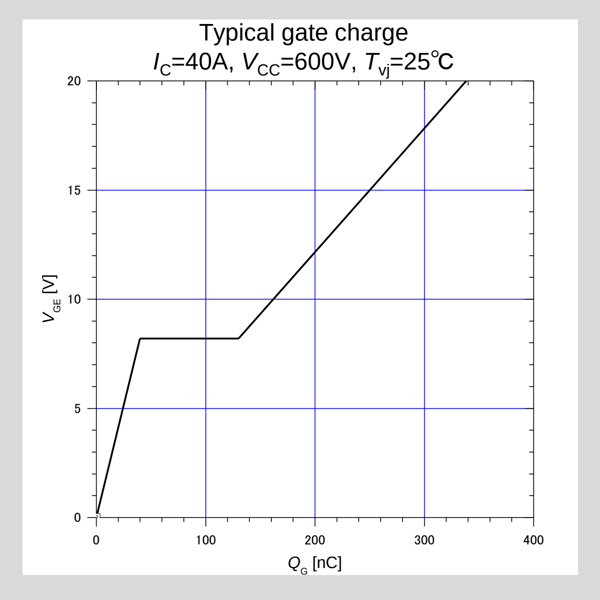


Fig.2-11 Characteristics of $V_{GE}$-$Q_G$

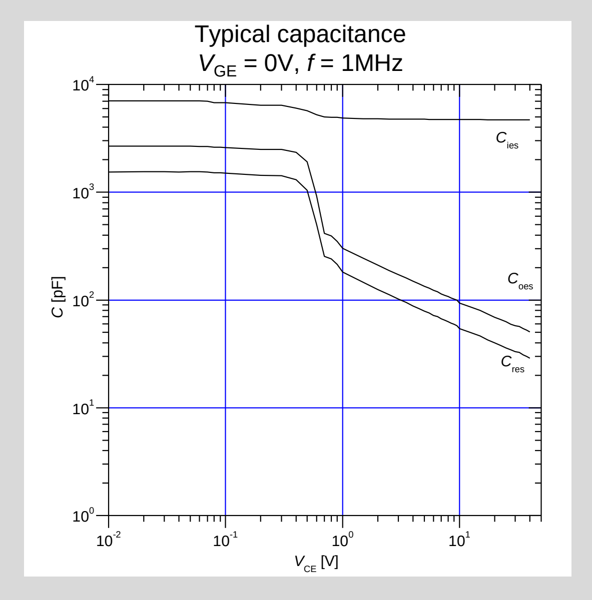


Fig.2-12 Characteristics of $C_{ies}$, $C_{oes}$, $C_{res}$-$V_{CE}$

## ＜Reverse Biased Safe Operating Area (RBSOA)＞

Fig.2-13 shows the region of $V_{CE}$-$I_C$ (RBSOA) where the IGBT can safely turn-off under specified conditions.

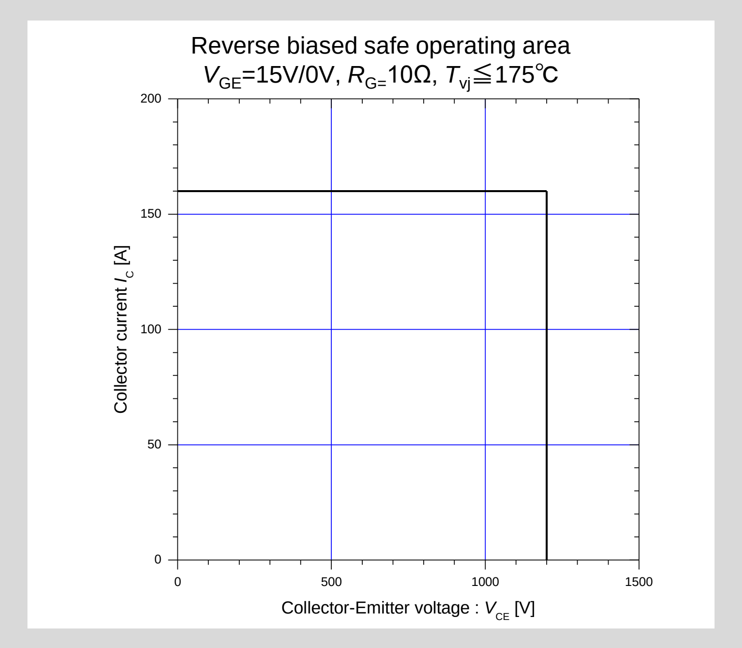
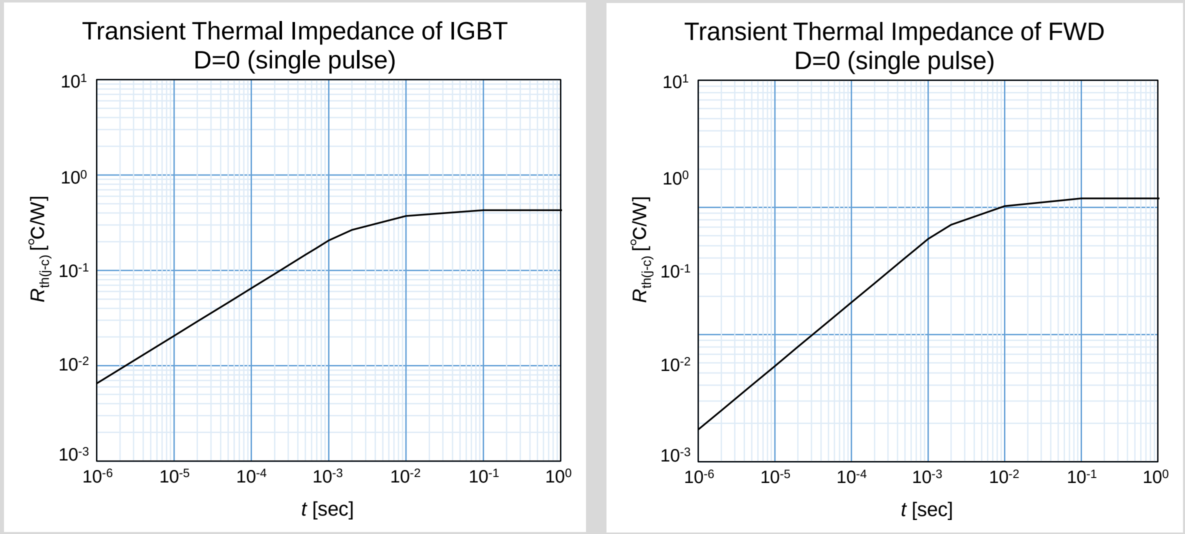


Fig.2-13 Reverse Biased Safe Operating Area (RBSOA)

## ＜Transient thermal resistance characteristics＞

Fig.2-14 show the transient thermal resistance characteristics. The thermal resistance value is the value obtained by dividing the temperature change that occurs by the applied power when a single constant power pulse is applied to the product. The value of thermal resistance expressed in pulse time is the transient thermal resistance characteristic.



(a) IGBT (b) FWD

Fig.2-14 Characteristics of transient thermal resistance characteristics