Chapter 2

Technical Terms and Characteristics

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This section explains relevant technical terms and characteristics of IGBT modules.

1 IGBT terms

Table 2-1 Maximum ratings

Term	Symbol	Definition explanation (See specifications for test conditions)
Collector-emitter voltage	V_{CES}	Maximum collector-emitter voltage with gate-emitter shorted
Gate-emitter voltage	V_{GES}	Maximum gate-emitter voltage with collector-emitter shorted
Collector current	Ic	Maximum DC collector current
	Ic pulse	Maximum pulse collector current
	-Ic	Maximum forward DC current of internal diode
	-Ic pulse	Maximum forward pulse current of internal diode
Maximum power dissipation	Pc	Maximum power dissipation per element
Junction temperature	Tj	Maximum chip temperature, at which normal operation is possible. You must not exceed this temperature in the worst condition.
Operation junction temperature	$Tj_{(op)}$	Chip temperature during continuous operation
Case temperature	T_c	Case temperature during continuous operation. Especially base plate temperature is defined.
Storage temperature	T_{stg}	Temperature range for storage or transportation, when there is no electrical load on the terminals
FWD I^2t	I^2t	Value of joule energy (value of integration of overcurrent) that can be allowed within the range which device does not destroy. The overcurrent is defined by a line frequency sine half wave (50, 60Hz) and one cycle.
FWD surge current	I_{FSM}	The maximum value of overcurrent that can be allowed in which the device is not destroyed. The overcurrent is defined by a line frequency sine half wave (50, 60Hz).
Isolation voltage	V_{iso}	Maximum effective value of the sine-wave voltage between the terminals and the heat sink, when all terminals are shorted simultaneously
Screw torque	Mounting	Maximum and recommended torque when mounting an IGBT on a heat sink with the specified screws
	Terminal	Maximum and recommended torque when connecting externals wires to the terminals with the specified screws

Caution: The maximum ratings must not be exceeded under any circumstances.

Table 2-2 Electrical characteristics

Term		Symbol	Definition explanation (See specifications for test conditions)
Static characteristics	Zero gate voltage collector current	I_{CES}	Collector current when a specific voltage is applied between the collector and emitter with the gate and emitter shorted
	Gate-emitter leakage current	I_{GES}	Gate current when a specific voltage is applied between the gate and emitter with the collector and emitter shorted
	Gate-emitter threshold voltage	$V_{GE(th)}$	Gate-emitter voltage at a specified collector current and collector-emitter voltage
	Collector-emitter saturation voltage	$V_{CE(sat)}$	Collector-emitter voltage at a specified collector current and gate-emitter voltage
	Input capacitance	C_{ies}	Gate-emitter capacitance, when a specified voltage is applied between the gate and emitter as well as between the collector and emitter, with the collector and emitter shorted in AC
	Output capacitance	C_{oes}	Gate-emitter capacitance, when a specified voltage is applied between the gate and emitter as well as between the collector and emitter, with the gate and emitter shorted in AC
	Reverse transfer capacitance	C_{res}	Collector-gate capacitance, when a specified voltage is applied between the gate and emitter, while the emitter is grounded
	Diode forward on voltage	V_F	Forward voltage when the specified forward current is applied to the internal diode
Dynamic characteristics	Turn-on time	t_{on}	The time between when the gate-emitter voltage rises from 0V at IGBT turn-on and when the collector-emitter voltage drops to 10% of the maximum value
	Rise time	t_r	The time between when the collector current rises to 10% of the maximum value at IGBT turn-on and when collector-emitter voltage drops to 10% of the maximum value
		$t_{r(i)}$	The time between when the collector current rises to 10% and when the collector current rises to 90% of the maximum value at IGBT turn-on
	Turn-off time	t_{off}	The time between when the gate-emitter voltage drops to 90% of the maximum value at IGBT turn-off and when the collector current drops to 10% of the maximum value
	Fall time	t_f	Time required for collector current to drop from 90% to 10% maximum value
	Reverse recovery time	t_{rr}	Time required for reverse recovery current in the internal diode to decay
	Reverse recovery current	$I_{rr}(I_{rp})$	Peak reverse current during reverse recovery
Reverse bias safe operating area		RBSOA	Current and voltage area when IGBT can be turned off under specified conditions
Gate resistance		R_G	Gate series resistance (See switching time test conditions for standard values)
Gate charge capacity		Q_g	Gate charge to turn on IGBT

Table 2-3 Thermal resistance characteristics

Term	Symbol	Definition explanation (See specifications for test conditions)
Thermal resistance	$R_{th(j-c)}$	Thermal resistance between the IGBT case and the chip or internal diode
	$R_{th(c-f)}$	Thermal resistance between the case and the heat sink, when the IGBT is mounted on a heat sink using the specified torque and thermal compound
Case temperature	T_c	IGBT case temperature

Table 2-1 Thermistor characteristics

Term	Symbol	Definition explanation (See specifications for test conditions)
Thermistor resistance	Resistance	Thermistor resistance at the specified temperature
B value	B	Temperature coefficient of the resistance

2 IGBT characteristics

This section illustrates the characteristics of the new 6th- generation IGBT modules, using the V series 6MBI100VB-120-50 (1200V, 100A) as an example.

2.1 Static characteristics

While the IGBT is on, the collector-emitter voltage (V_{CE}) changes in accordance with the collector current (I_C), gate voltage (V_{GE}), and temperature (T_j). The V_{CE} represents a collector-emitter voltage drop in the ON state, and is used to calculate the power dissipation loss of the IGBT. The smaller the V_{CE} value, the lower the power dissipation loss. Therefore, it is necessary to design the IGBT to have the smallest V_{CE} value possible.

The dependence of V_{CE}-V_{GE} on I_C is shown on the graph in Fig. 2-1 (T_j=25°C), and Fig. 2-2 (T_j=150°C). V_{CE} increases in direct proportion to the collector current and inversely proportional to the V_{GE} value. Note that when the Ic value is small, as T_j increases V_{CE} decreases, and when the I_C value is large, as T_j increases V_{CE} increases. Keep this in mind when determining operating conditions.

It is generally recommended to keep V_{GE} at 15V, and the collector current at the rateed I_C current or lower.

Fig.2-3 shows the standard of V_{GE} in the limit that loss of V_{CE} increases rapidly in the graph where the data of Fig. 2-1 was replaced with the Ic dependency of the V_{CE} - V_{GE} characteristics.

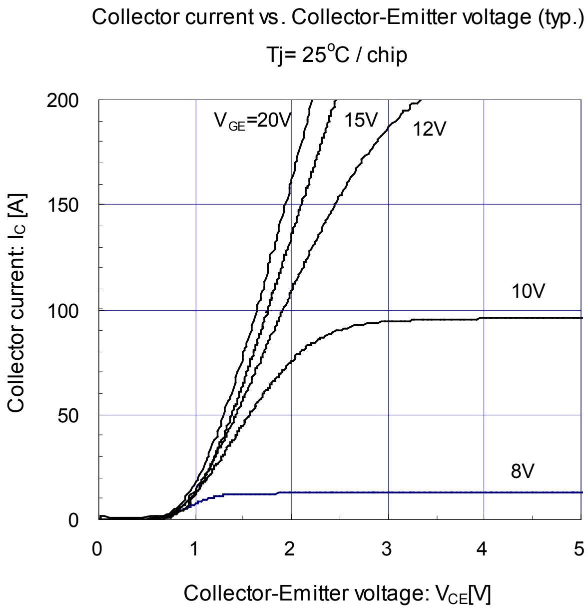

Fig. 2-1 $V_{CE(sat)}$ - I_C characteristics (Tj=25°C)

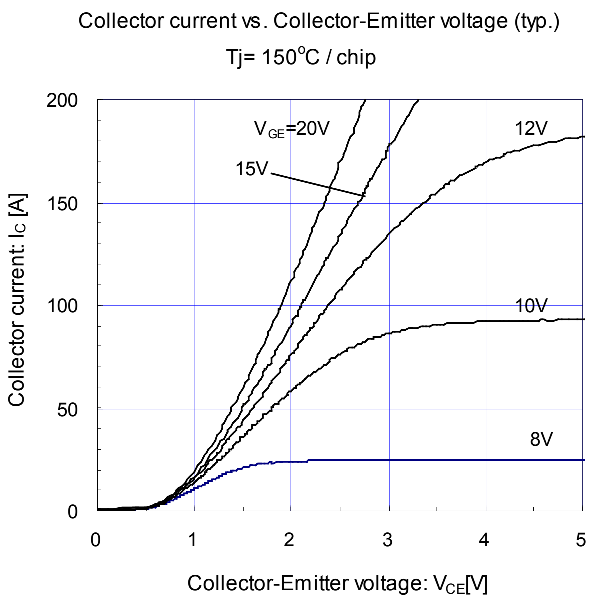

Fig. 2-2 $V_{CE(sat)}$ - I_C characteristics (Tj=150°C)

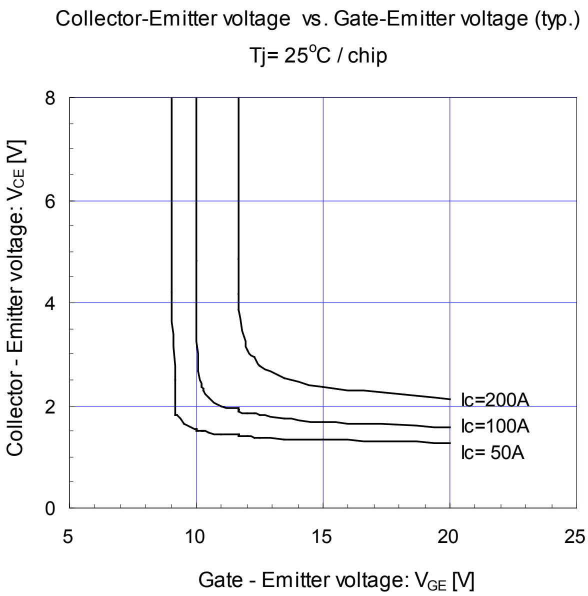

Fig. 2-3 VCE - VGE characteristics (Tj=25°C)

2.2 Switching characteristics

As the IGBT is generally used for switching, it is important to fully understand the turn-on and turn-off switching characteristics in order to determine "switching loss" (power dissipation loss at switching). It is also important to remember that these characteristics are affected by various parameters when determining operating conditions.

The circuit shown in Fig.2-4 is used to measure the four parameters of switching time, t_r, t_{on}, t_f and t_{off} as shown in Fig.2-5.

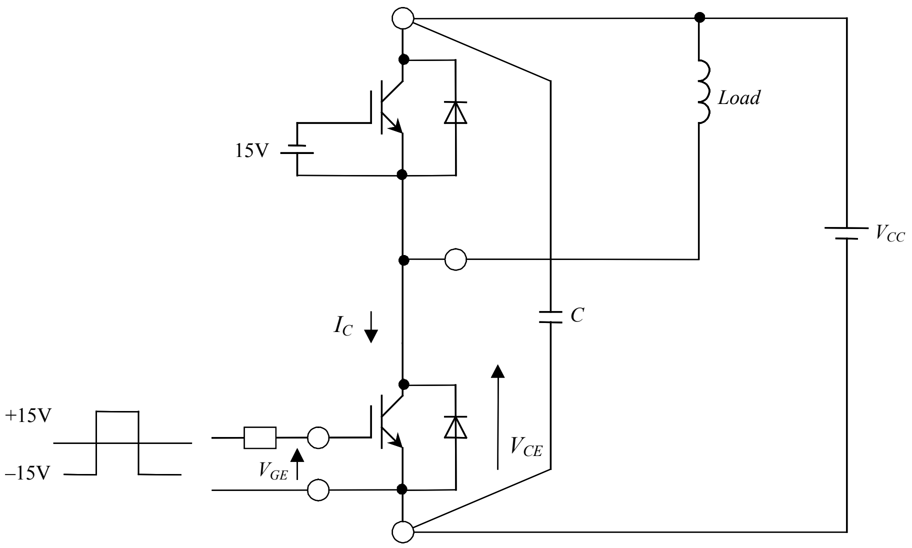

Fig. 2-4 Switching characteristics measuring circuit.

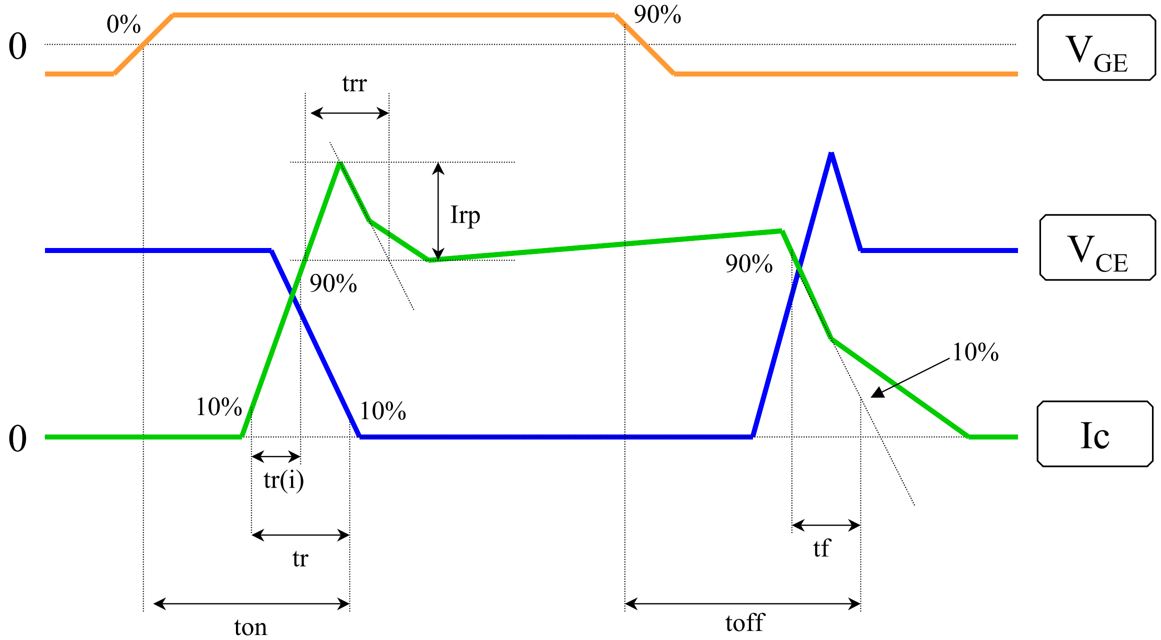

Fig. 2-5 Definition of switching time

The relationship between switching time and collector current is shown in Fig.2-6 (T_j = 125°C) and Fig. 2-7 (T_j =150°C). At greater collector currents or higher T_j, the switching time increases causing higher losses. The effect of gate resistance (R_g) vs. switching time can be seen in Fig.2-8. When the IGBT is installed in an inverter circuit or other equipment, should the switching time (especially t_{off}) become too long, it may exceed the dead time of the upper and lower transistors, thereby causing a short-circuit. It is also important to be aware that if the switching time (t_f) is too short, the transient current change rate (di/dt) will increase and then the circuit inductance may cause a high turn-off spike voltage (L di/dt). This spike voltage will be added to the applied voltage. In this case, destruction may be caused by overvoltage out of RBSOA.

Switching loss (Eon, Eoff, Err) occurs every time an IGBT is turned on or off, therefore it is important to minimize this loss as much as possible. As can be seen in Fig.2-9, the greater the collector current or the higher the T_j, the greater the switching loss will be. In the same way, switching losses depend on gate resistance R_G as shown in Fig.2-10.

Like these, IGBT characteristics are varied by collector current, T_j or R_g. Therefore, you should design your equipments in consideration with the above-mentioned characteristics.

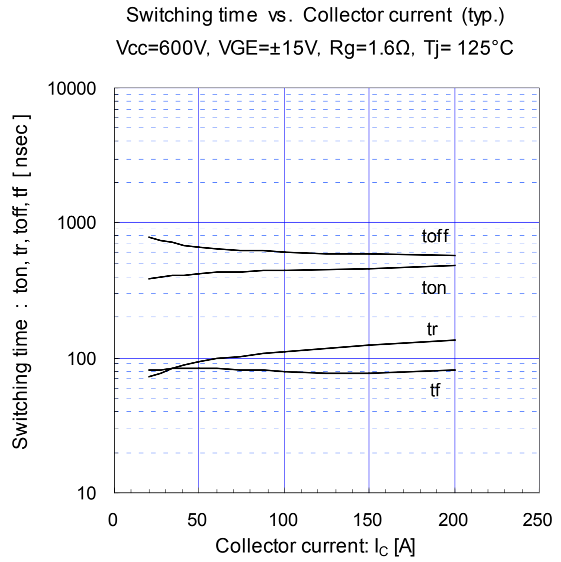

Fig. 2-6 Switching time - I_C characteristics (Tj=125°C).

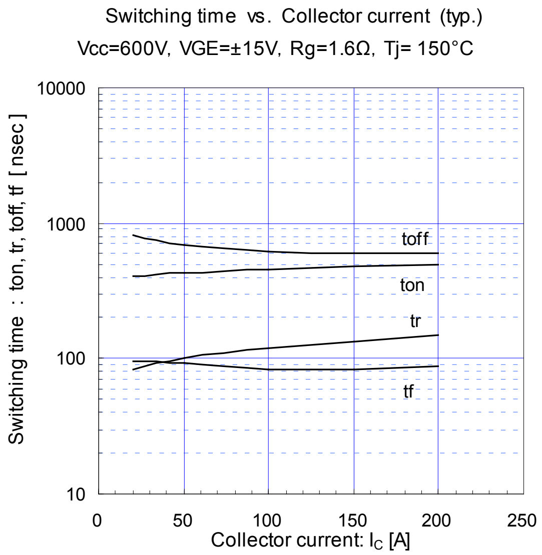

Fig. 2-7 Switching time - I_C characteristics (Tj=150°C).

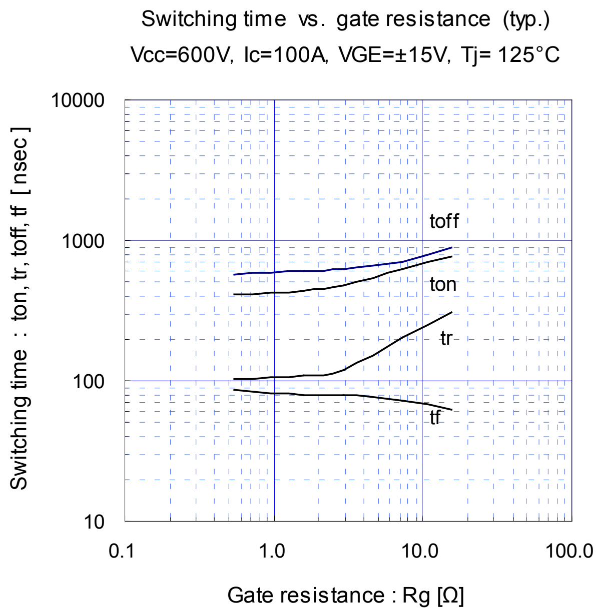

Fig. 2-8 Switching time - R_G characteristics (Tj=125°C).

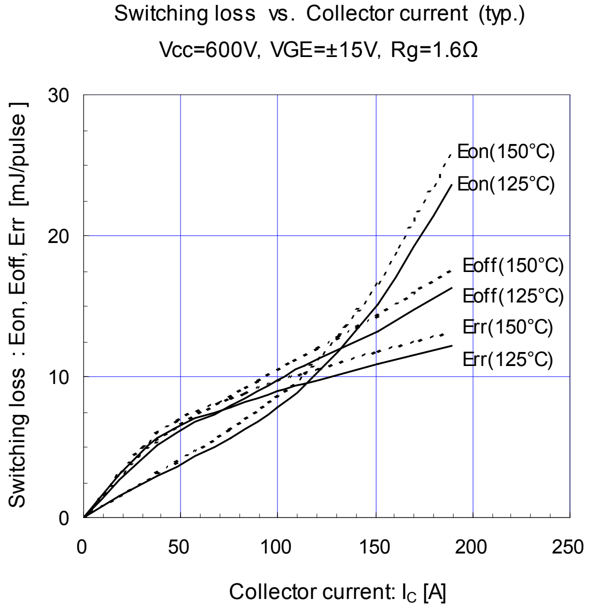

Fig. 2-9 Switching loss - I_C characteristics

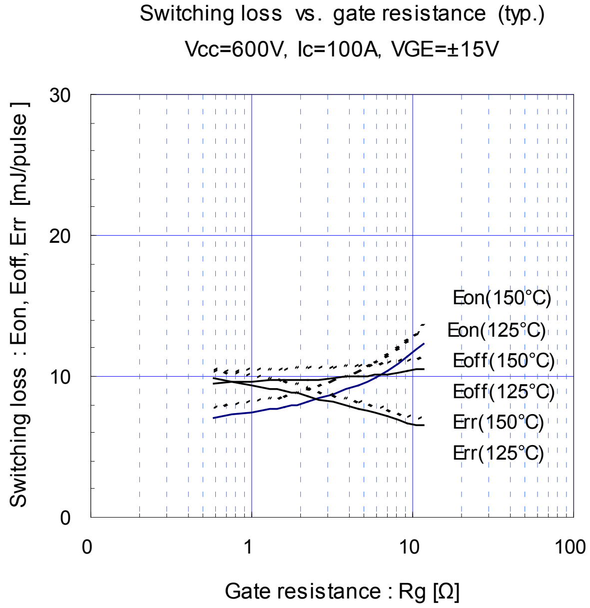

Fig. 2-10 Switching loss - R_G characteristics

2.3 Capacitance characteristics

The gate charge capacity (Q_g) characteristics, with the main circuit supply voltage (V_{CC}) as a parameter, are shown in Fig.2-11. Here can be seen how the collector-emitter voltage (V_{CE}) and gate-emitter voltage (V_{GE}) fluctuate when the gate charge charges. Since the gate charge capacity indicates the size of the charge required to drive an IGBT, it can be used to determine the power-supply capacity of the drive circuit.

Fig.2-12 shows the capacitance of each of the IGBT's junctions: gate-emitter input capacitance (C_{ies}), collector-emitter output capacitance (C_{oes}) and collector-gate reverse transfer capacitance (C_{res}).

Use these characteristics along with Q_g to design your drive circuits.

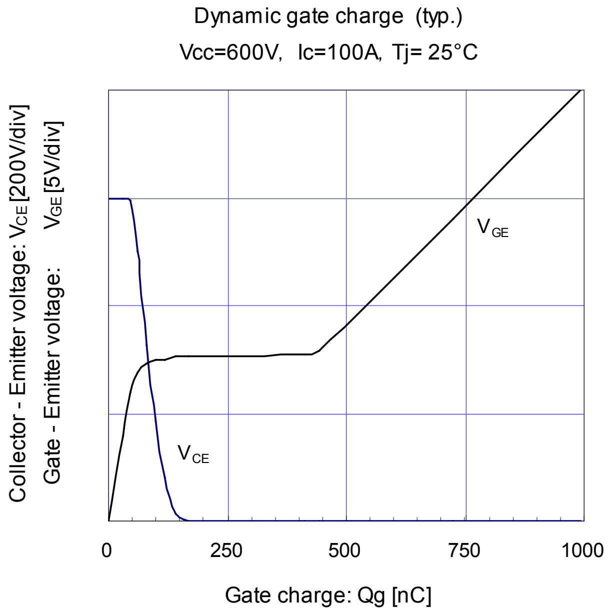

Fig.2-11 V_{CE}, V_{GE} - Q_g characteristics

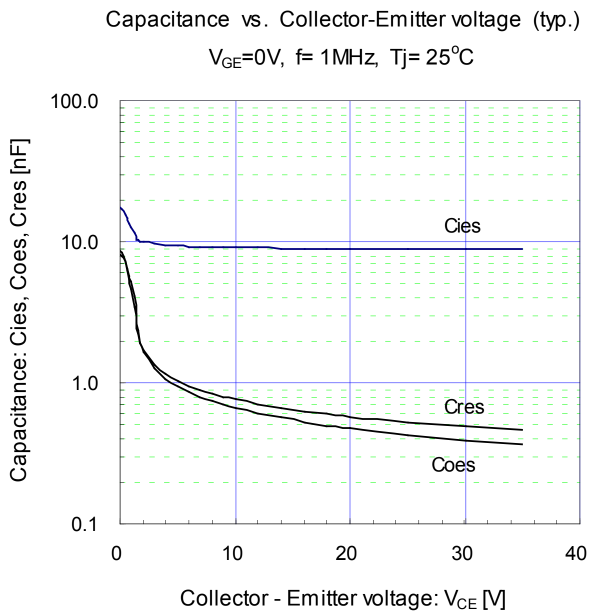

Fig.2-12 Cies, Coes, Cres - VCE characteristic

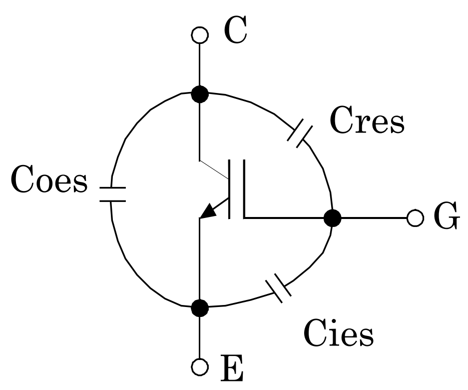

Fig.2-13 Junction capacitance.

2.4 Reverse biased safe operating areas

When turned off, the IGBT has a safe operating area defined by V_{CE} an I_c called the "reverse bias safe operating area" or RBSOA. This area is shown by the solid line in Fig.2-14.

It is important to design a snubber circuit that will keep V_{CC} and I_C within the limits of RBSOA when the IGBT is turned off.

Even in the case of a short-circuit (non-repetitive), an IGBT still has a safe operating area defined by V_{CE} an I_c called the "short circuit safe operating area" or SCSOA. SCSOA is various for each IGBT series. Refer to the technical data in details.

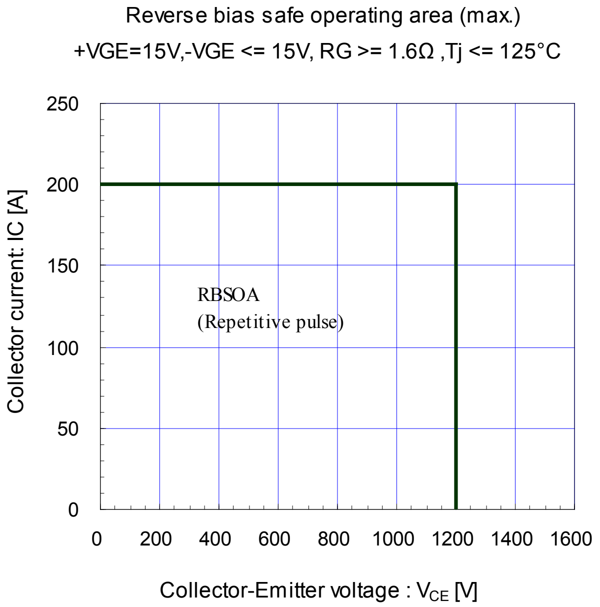

Fig. 2-14 Reverse bias safe operation area.

2.5 Internal diode (FWD) characteristics

The IGBT module has a high-speed diode (Free Wheel Diode / FWD) connected in anti-parallel with the IGBT for operating with reverse polarity. This FWD has the V_F-I_F characteristic shown in Fig.2-15, the reverse recovery characteristic (t_{rr}, I_{rr}) shown in Fig.2-16, and the switching power loss characteristic (E_{rr}) at reverse recovery shown in Fig.2-9 and Fig.2-10.

Use these characteristics to calculate the power loss in the FWD as well as the IGBT, but remember that the FWD characteristics vary in accordance with the collector current and temperature.

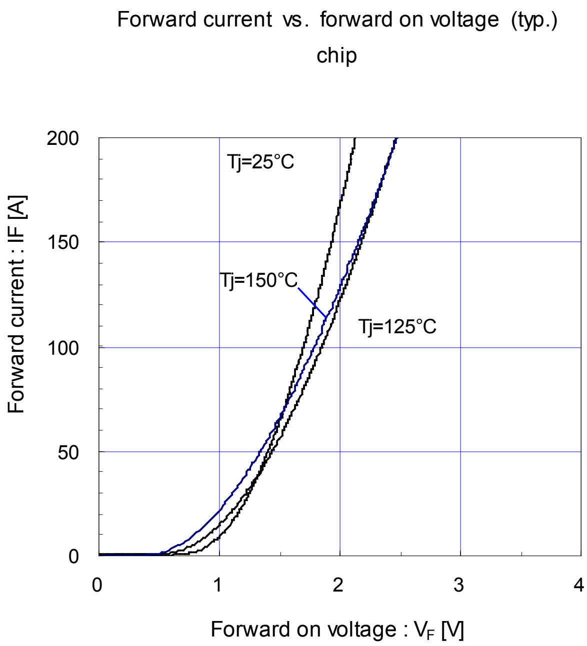

Fig. 2-15 V_F - I_F characteristics

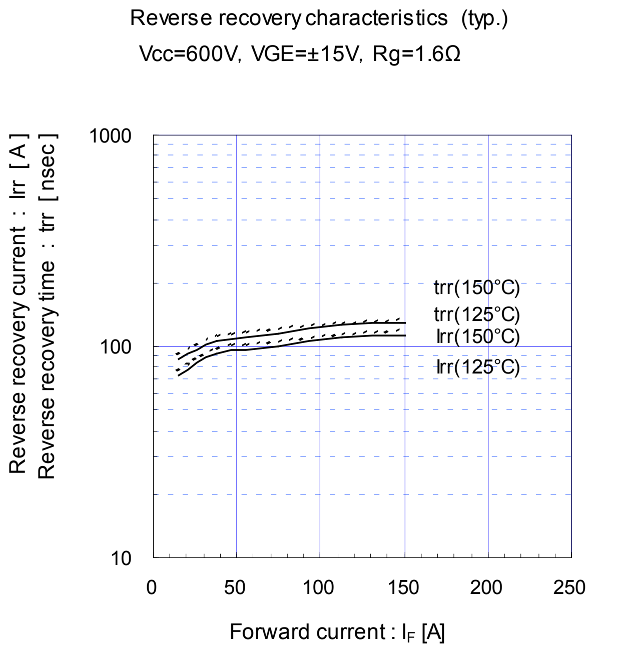

Fig. 2-16 t_{rr} , I_{rr} - I_F characteristics.

2.6 Transient thermal resistance characteristics

The transient thermal resistance characteristics, used to calculate the temperature rise of a module and to design a heat sink, are shown in Fig. 2-17.

The characteristics in the figure vary according to each individual IGBT and FWD.

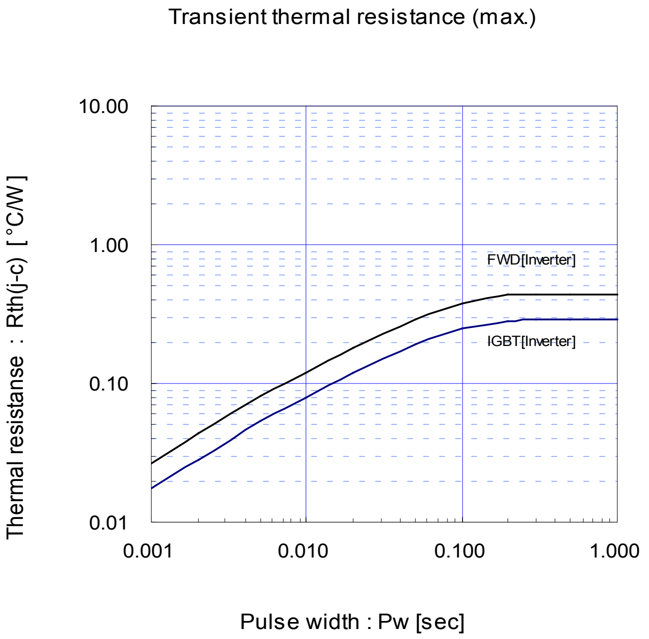

Fig. 2-17 Transient thermal resistance.

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