What is an IGBT?

General description of IGBTs and our IGBT products

Contents

1. Description

This document provides a general description of IGBTs. For more information on our IGBT products, please refer to the links below.

- **IGBT**
  https://www.semicon.sanken-ele.co.jp/ctrl/en/product/category/IGBT/

- **Selection Guide**
  https://www.semicon.sanken-ele.co.jp/common/pdf/selectionguide/sge0007.pdf

2. IGBTs

2.1. What is an IGBT?

An IGBT (Insulated Gate Bipolar Transistor) is a transistor whose input section has a MOS structure and its output section has a bipolar structure (see Figure 2-1). This transistor has the characteristics of a MOSFET with high input impedance and high switching speed, and the characteristics of a bipolar transistor with low saturation voltage.

See Section 2.3 for the structure of the IGBT.

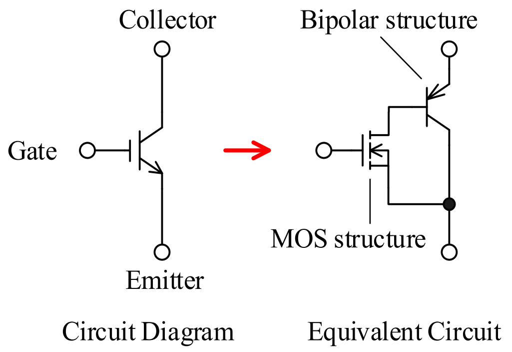
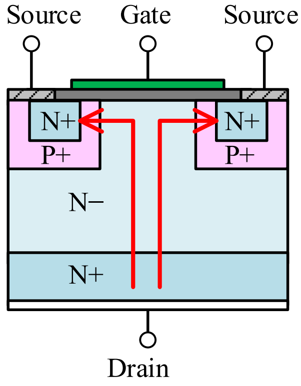
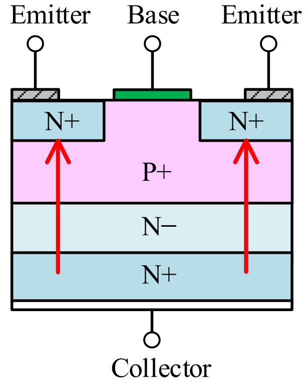
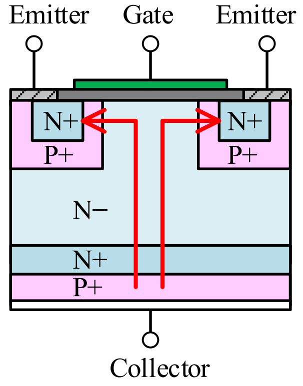
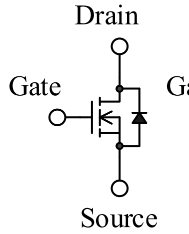
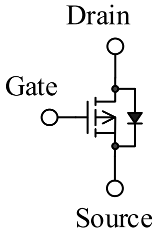
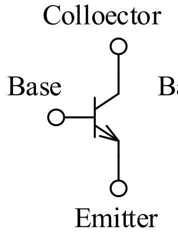
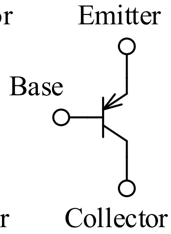
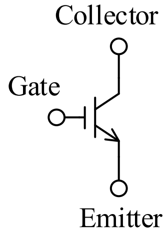


Figure 2-1. Equivalent Circuit of an IGBT

2.2. Features of IGBTs

The features of IGBTs when compared with power MOSFETs and bipolar transistors are shown below.

Item	Power MOSFET	Bipolar Transistor	IGBT
Structure (arrows indicate the direction of the drain current / collector current)	 N-channel	 NPN	
Circuit Diagram	 N-channel  P-channel	 NPN  PNP	
Control Systems	Voltage control	Current control	Voltage control
Driving Power	Small	Large	Small
Switching Speed	Fast	Slow	Medium
Breakdown Voltage	About 30 V to 800 V	About 50 V to 800 V	About 400 V to 1200 V
Increasing the Current	Easy (about 1 A to 100 A)	Difficult (about 2 A to 25 A)	Easy (about 15 A to 40 A)
Applications	● Low Stepping Motor ● Low-voltage/high-voltage brushless DC motor ● Switching power suply	● Audio ● Low-voltage/high-voltage brushless DC motor ● Solenoid	● High-voltage brushless DC motor ● Inverter

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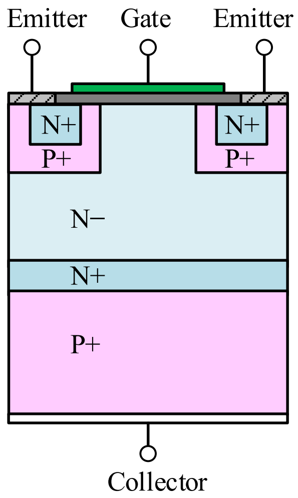
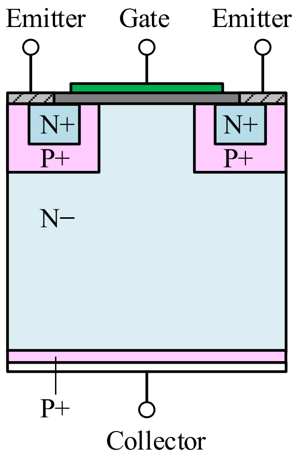
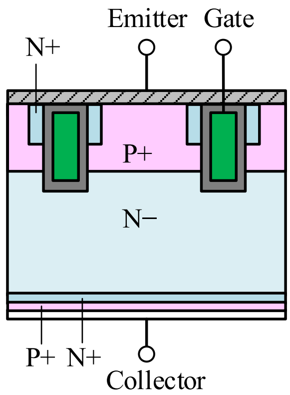
2.3. IGBT Structure

This section describes the structure and features of IGBTs. Compared to the punch-through type, the non-punch-through type and field-stop type have faster switching speed, lower loss, and thinner / smaller size.

Structure	Punch-through (PT) Type	Non-punch-through (NPT) Type	Field-stop (FS) Type
Section View			
Switching Speed	Slow	Fast	Fast
Short Circuit Withstand Time	Short	Long	Medium
Manufacturing Difficulty	Easy	Difficult	Difficult

2.4. Absolute Maximum Ratings

The absolute maximum ratings are defined as the allowable limits that should not be exceeded, even instantaneously. If one or more of these values are exceeded, the semiconductor device will break. Therefore, it is required to design electronic devices that use semiconductors so that the stress exceeding the values is not applied to semiconductors even instantaneously.

Absolute maximum ratings do not guarantee reliability. Even within the absolute maximum ratings, if the recommended conditions are exceeded, their durability decreases and as a result, semiconductors may not withstand long-term use.

Typical characteristics of the absolute maximum ratings listed in the IGBT data sheet are shown below. The parameters of absolute maximum ratings listed depend on the type of IGBTs.

Parameter	Symbol	Description
Collector-to-Emitter Voltage	V_{CE}	Maximum voltage that can be applied between collector and emitter
Gate-to-Emitter Voltage	V_{GE}	Maximum voltage that can be applied between gate and emitter
Collector Current (DC)	I_C	Maximum current that can flow continuously in the collector pin
Collector Current (pulse)	$I_{C(PULSE)}$	Maximum current that can flow in the collector pin for a short time
Diode Forward Current (DC) *	I_F	Maximum current that can flow continuously in the fast recovery diode
Diode Forward Current (pulse) *	$I_{F(PULSE)}$	Maximum current that can flow through the fast recover diode for a short time
Short Circuit Withstand Time	t_{SC}	Maximum time the IGBT can withstand a short circuit
Power Dissipation	P_D	Allowable maximum power dissipation
Operating Junction Temperature	T_J	Allowable maximum temperature in the semiconductor junction in the product
Storage Temperature	T_{STG}	Temperature range at which the product can be stored when the device is not operating

* Only for products with a built-in fast recovery diode (FRD)

2.5. Electrical Characteristics

Electrical characteristics show the performance of a product by specifying conditions such as temperature, voltage, and current.

The following are typical parameters of electrical characteristics described in the data sheet. The parameters of electrical characteristics to be listed depend on the type of IGBTs.

Parameter	Symbol	Description	Remarks
Collector-to-Emitter Breakdown Voltage	$V_{(BR)CES}$	Breakdown voltage between collector and emitter	
Collector-to-Emitter Leakage Current	I_{CES}	Collector leakage current when the gate voltage is 0 V	
Gate-to-Emitter Leakage Current	I_{GES}	Gate leakage current when the gate voltage is under the specified conditions	
Gate Threshold Voltage	$V_{GE(TH)}$	The gate voltage when the IGBT turns on and the collector current starts to flow	
Collector-to-Emitter Saturation Voltage	$V_{CE(SAT)}$	Collector-emitter voltage when the collector current reaches the specified value with the gate voltage set under the specified conditions.	
Input Capacitance	C_{ies}	Sum of gate-to-collector capacitance and gate-to-emitter capacitance	Section 2.8
Output Capacitance	C_{oes}	Sum of gate-to-collector capacitance and collector-to-emitter capacitance	
Reverse Transfer Capacitance	C_{res}	Capacitance between gate and collector	
Total Gate Charge	Q_G	Total charge that the gate voltage increases to the specified voltage from 0 V	Section 2.9
Turn-on Delay Time	$t_{d(ON)}$	Delay time until the IGBT turns on	Section 2.10
Turn-on Rise Time	t_r	Rise time until the IGBT turns on	
Turn-off Delay Time	$t_{d(OFF)}$	Delay time until the IGBT turns off	
Turn-off Fall Time	t_f	Fall time until the IGBT turns off	
Turn-on Energy	E_{ON}	Switching loss at the IGBT turns on	
Turn-off Energy	E_{OFF}	Switching loss at the IGBT turns off	
Emitter-to-Collector Diode Forward Voltage	V_F	Voltage drop when forward current flows through the diode	
Emitter-to-Collector Diode Reverse Recovery Time	t_{rr}	Time from when the recovery current flows through the diode to when the recovery current recovers to 90% of the peak value	

* Only for products with a built-in fast recovery diode (FRD)

2.6. Thermal Characteristics

The following are typical parameters of thermal characteristics described in the data sheet. The parameters of thermal characteristics to be listed depend on the type of IGBTs.

Parameter	Symbol	Description
IGBT Thermal Resistance	$R_{\theta JC(IGBT)}$	Thermal resistance between semiconductor junction and case
Diode Thermal Resistance *	$R_{\theta JC(Di)}$	Thermal resistance between semiconductor junction and case

* Only for products with a built-in fast recovery diode (FRD)

2.7. Static Characteristics

This section describes the typical static characteristics of IGBTs.

2.7.1. I_C－V_{CE} Characteristics

Figure 2-2 shows an example of characteristics of the collector current, I_C, and the collector-emitter voltage, V_{CE}, at each gate voltage, V_{GE}. I_C－V_{CE} characteristics are also called the output characteristics. Due to the structure of IGBTs, a PN junction is generated between the collector and emitter. When the junction potential of the PN junction (V_{CE} = 1.5 V in this characteristic example) is exceeded, the I_C starts to flow. The higher the V_{GE}, the lower the V_{CE} when the specified I_C is flowing. To reduce conduction loss ($I_C \times V_{CE}$), set the IGBT in a region where $V_{CE(SAT)}$ changes are small (generally gate voltage is about 15 V).

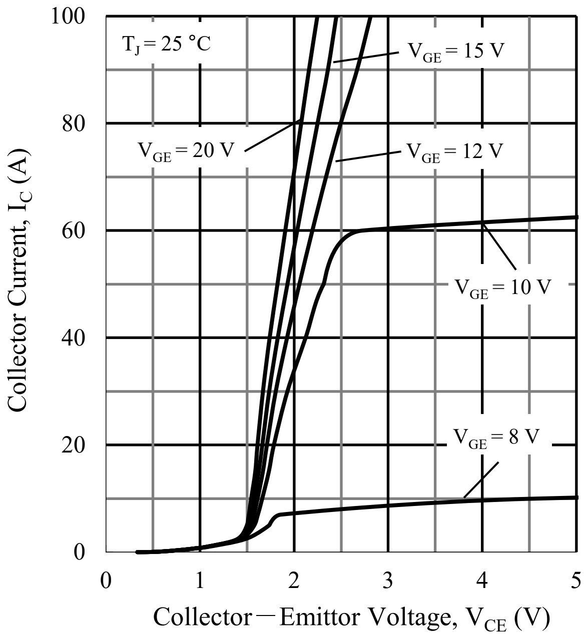


Figure 2-2. I_C－V_{CE} Typical Characteristics

2.7.2. I_C－V_{GE} Characteristics

Figure 2-3 shows an example of characteristics of the collector current, I_C, and the gate-to-emitter voltage, V_{GE}.

In this characteristic example, in the region of $V_{GE} < 10$ V, the higher the junction temperature, T_J, the lower the V_{GE} when the specified I_C is flowing (negative temperature coefficient). Conversely, in the region of $V_{GE} \geq 10$ V, the higher the junction temperature, T_J, the higher the V_{GE} when the specified I_C is flowing (positive temperature coefficient). To prevent the permanent damage due to heat generation, it is recommended to use the IGBT in the region of positive temperature coefficient.

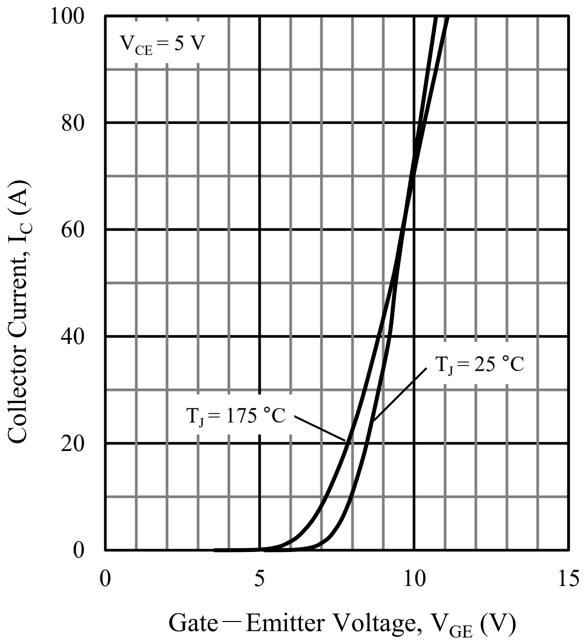


Figure 2-3. I_C－V_{GE} Typical Characteristics

2.7.3. $V_{GE(TH)}$ — T_J Characteristics

Figure 2-4 shows an example of characteristics of the gate threshold voltage, $V_{GE(TH)}$, and the junction temperature, T_J.

The higher the T_J, the lower the $V_{GE(TH)}$ (negative temperature coefficient). When the circuit operates and the IGBT temperature becomes high, the IGBT turns on at a low gate voltage. Therefore, changes in $V_{GE(TH)}$ due to temperature characteristics must be taken into account in designing the circuit in order to avoid malfunction due to noise.

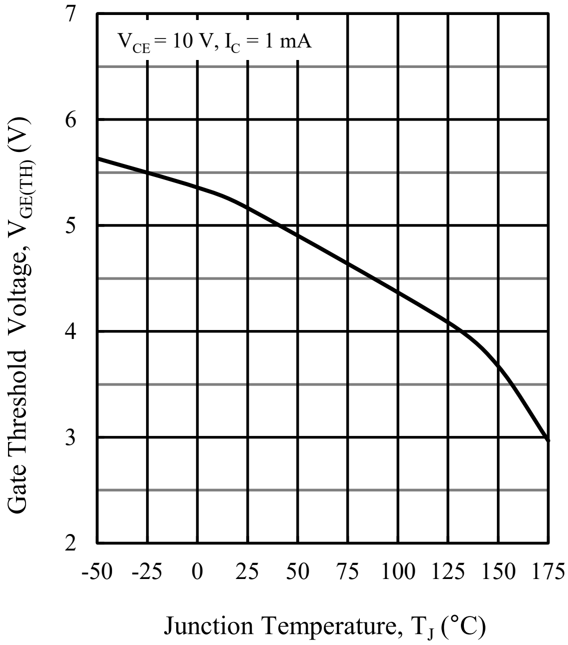


Figure 2-4. $V_{GE(TH)}$ — T_J Typical Characteristics

2.8. Capacitance Characteristics (C_{ies}, C_{oes}, C_{res})

As shown in Figure 2-5, due to the structure of IGBTs, parasitic capacitances (C_{GC}, C_{GE}, C_{CE}) are generated. These parasitic capacitances affect the switching characteristics.

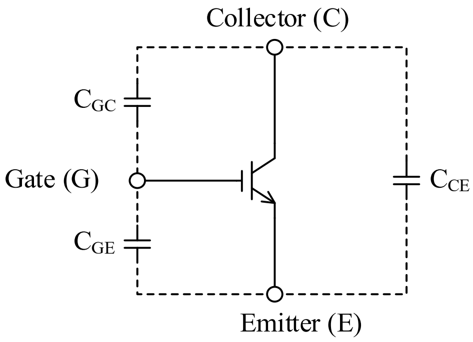


Figure 2-5. Parasitic Capacitances of IGBT

- **Input Capacitance, C_{ies}**

Input capacitance, C_{ies}, affects the delay time. The larger the C_{ies}, the longer the turn-on delay time, $t_{d(ON)}$, and the turn-off delay time, $t_{d(OFF)}$, because a large amount of charge must be charged/discharged at the IGBT turning on/off. In addition, the larger the C_{ies}, the larger the power loss. Therefore, the IGBT with small C_{ies} is ideal.

C_{ies} is calculated by the following equation.

$$C_{ies} = C_{GE} + C_{GC}$$

- **Output Capacitance, C_{oes}**

The output capacitance, C_{oes}, affects the turn-off characteristics. When the C_{oes} is large, the voltage change rate, dv/dt, of the collector-to-emitter voltage, V_{CE}, is reduced at the IGBT turn-off, resulting in reducing the influence of noise but increasing the turn-off fall time, t_f.

C_{oes} is calculated by the following equation.

$$C_{oes} = C_{CE} + C_{GC}$$

- **Reverse Transfer Capacitance, C_{res}**

Reverse transfer capacitance, C_{res}, is also called mirror capacitance.
C_{res} affects the high frequency characteristics. The larger the C_{res}, the more the following characteristics appear.

- The fall time of collector-to-emitter voltage, V_{CE}, at turn-on is long
  (The turn-on rise time, t_r is long)
- The rise time of collector-to-emitter voltage, V_{CE}, at turn-off is long
  (The turn-off fall time, t_f, is long)
- Power loss is large

Reverse transfer capacitance, C_{res}, is calculated by the following equation.

$$C_{res} = C_{GC}$$

2.9. Charge Characteristics (Q_G, Q_{GE}, Q_{GC})

Total gate charge, Q_G, gate-to-emitter charge, Q_{GE}, and gate-to-collector charge, Q_{GC}, are the charges required to drive the IGBT (see Figure 2-6). These affect the switching characteristics. The smaller the value, the smaller the power loss, and the fast switching is achieved.

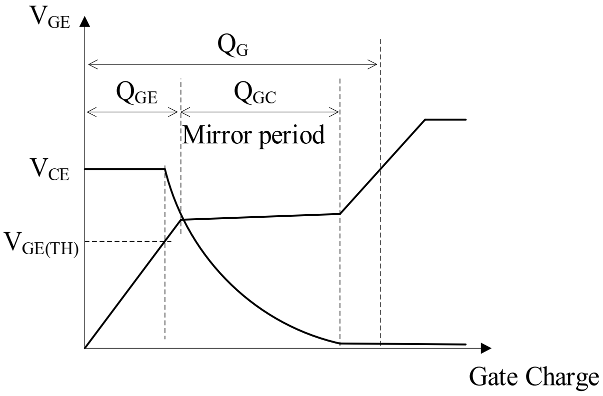


Figure 2-6. Relationship between V_{GE} and Gate Charge

2.10. Switching Characteristics ($t_{d(ON)}$, t_r, $t_{d(OFF)}$, t_f)

Figure 2-7 and Figure 2-8 show the measurement circuit of switching time and switching waveforms, respectively.

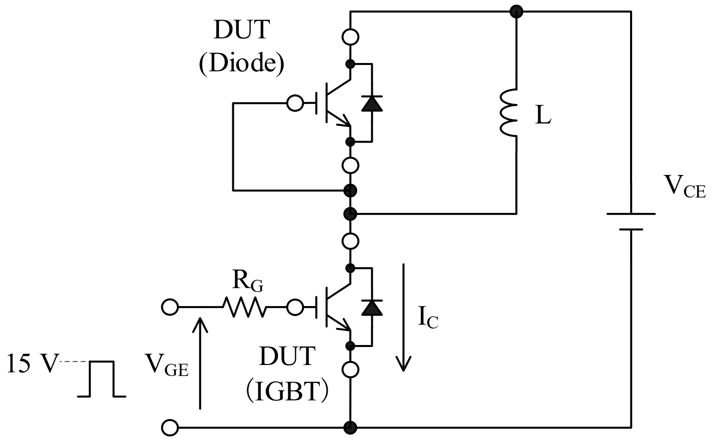


Figure 2-7. Switching Time Measurement Circuit

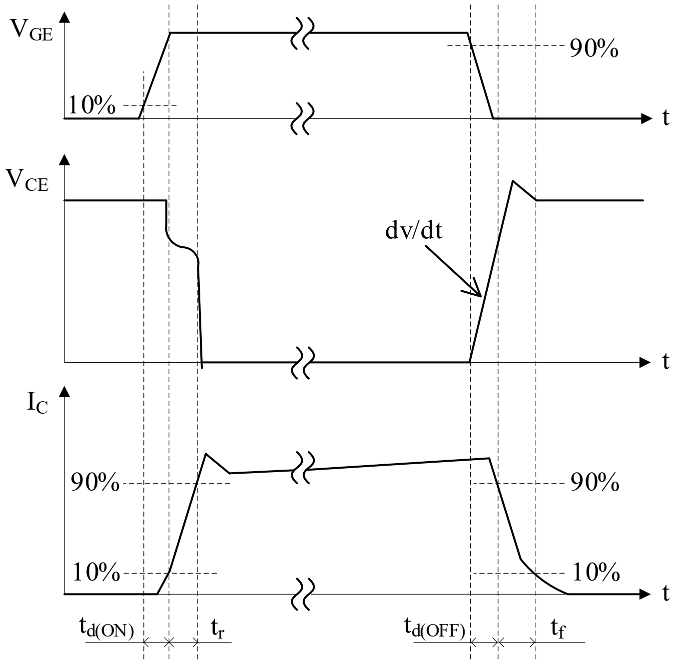


Figure 2-8. Switchig Waveforms

- **Turn-on Delay Time, $t_{d(ON)}$**
  Time from 10% of the V_{GE} setting value to 10% of the I_C setting value

- **Turn-on Rise Time, t_r**
  Time from 10% to 90% of the I_C setting value

- **Turn-on Time, t_{ON}**
  The total time of $t_{d(ON)}$ and t_r.

- **Turn-off Time, $t_{d(OFF)}$**
  Time from 90% of the V_{GE} setting value to 90% of the I_C setting value

- **Turn-off Fall Time, t_f**
  Time from 90% to 10% of the I_C setting value

- **Turn-off Time, t_{OFF}**
  The total time of $t_{d(OFF)}$ and t_f

2.11. Short-circuit Characteristics

Short-circuit current, I_{SC}, is the current that flows when an IGBT is shorted. The higher the gate-to-emitter voltage, V_{GE}, the higher the short-circuit current, I_{SC}, thus causing the short circuit withstand time, t_{SC}, to be decreased. The higher the junction temperature, T_J, the lower the t_{SC}.

2.12. Fast Recovery Diode

Unlike power MOSFETs, IGBTs do not have body diodes. When using an IGBT to control an inductive load such as a motor, using a product that combines an IGBT and a fast recovery diode (FRD) in one package reduces the number of external components, resulting in reliability improvement of the circuit. Refer to the link below for the features of the fast recovery diode.

https://www.semicon.sanken-ele.co.jp/sk_content/an0014_en.pdf

2.13. Factors that Cause IGBT Destruction

The following are typical factors of IGBT destruction.

- Safe Operating Area (SOA) Destruction
- Destruction by ESD
- Destruction by Parasitic Oscillation

2.13.1. Safe Operating Area (SOA) Destruction

The Safe Operating Area (SOA) is divided into a forward bias safe operating area and a reverse bias safe operating area. Exceeding the limited area of the forward bias safe operating area or the reverse bias safe operating area can cause the IGBT to generate abnormal heat, resulting in IGBT destruction. Section 2.13.1.1 and Section 2.13.1.2 describe the two areas, the forward bias safe operating area and the reverse bias safe operating area, respectively.

The data sheet provides the safe operating area graph under the ideal conditions (single pulse, T_C = 25°C, etc.). Use the IGBT within the safe operating area by derating the graph to the actual operating conditions. For derating, refer to the link below.
https://www.semicon.sanken-ele.co.jp/en/support/reliability/4-5.html#sec2

2.13.1.1. Forward Bias Safe Operating Area (FBSOA)

The Forward Bias Safe Operating Area (FBSOA) is the range of current and voltage that an IGBT can be used without deterioration or destruction during the IGBT turn-on. The forward bias safe operating area is divided by the following limits.

(1) The area limited by collector-to-emitter saturation voltage, $V_{CE(SAT)}$
(2) The area limited by the maximum rated value of collector current
(3) The area limited by the maximum rated value of junction temperature (thermally limited area)
(4) The area limited by the maximum rated value of collector-to-emitter voltage, V_{CE}

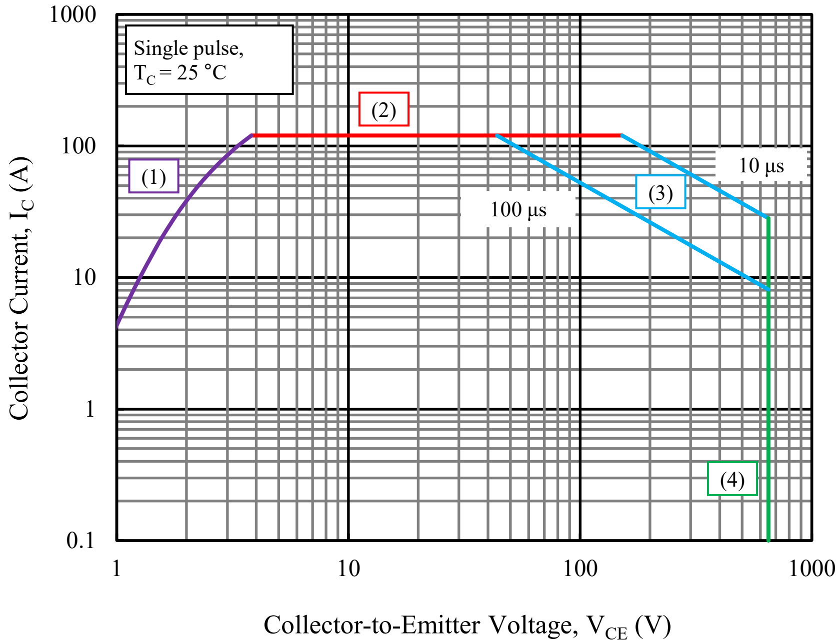


Figure 2-9. Example of Forward Bias Safe Operating Area

2.13.1.2. Reverse Bias Safe Operating Area (RBSOA)

The Reverse Bias Safe Operating Area (RBSOA) is the range of current and voltage that an IGBT can be used without deterioration or destruction during the IGBT turn-off. The reverse bias safe operating area is divided by the following limits.

(1) The area limited by collector-to-emitter saturation voltage, $V_{CE(SAT)}$
(2) The area limited by the maximum rated peak value of collector current
(3) The area limited by characteristics specific to an IGBT
(4) The area limited by the maximum rated value of collector-to-emitter voltage, V_{CE}

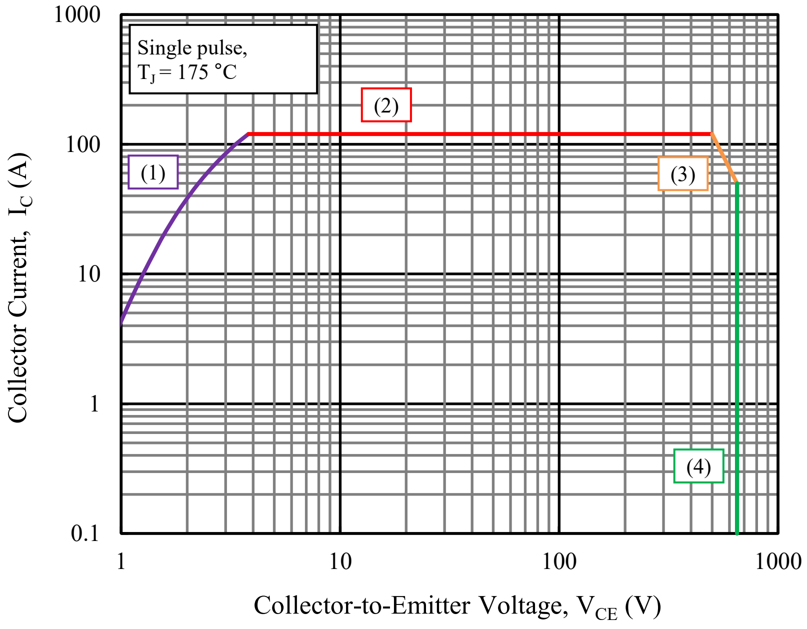


Figure 2-10. Example of Reverse Bias Safe Operating Area

2.13.2. Destruction by ESD

The gate pin is sensitive to static electricity. If a static electricity or surge voltage generated by the human body or mounting equipment is applied to the gate and a static electricity capacitance of the gate is exceeded, the IGBT may be destroyed.

● **Measures**

- Connect the human body to the ground by a conductive strap or the like.
- Use conductive table mats on workbenches.
- Connect the equipment to the ground or the like.

For more details on the measures for electrostatic discharge (ESD), refer to the link below.
https://www.semicon.sanken-ele.co.jp/en/support/reliability/4-9.html#sec1

2.13.3. Destruction by Parasitic Oscillation

For more details, see Section 2.14.

2.14. Notes on Connecting in Parallel

The following are the key considerations and the guidelines for connecting IGBTs in parallel.

- To reduce the variation of the collector current, I_C, in normal operation, use IGBTs with similar values of collector-to-emitter saturation voltage, $V_{CE(SAT)}$.
- PCB layout patterns include parasitic inductance and impedance. To reduce the variation of the current flowing during transients such as turn-on and turn-off, place IGBTs so that there is no variation due to the pattern.
- If the IGBTs connected in parallel are driven by different drivers, the operation of the IGBTs varies due to the effect of the output delay time for each driver. Therefore, drive the IGBTs connected in parallel with one driver as shown in Figure 2-11.
- If IGBTs are connected in parallel without connecting a gate resistor, parasitic oscillation tends to occur. Due to parasitic oscillation, the gate-to-emitter voltage, V_{GE}, exceeds the maximum rated value, or the IGBTs generate heat, which may result in the destruction of the IGBTs. Be sure to connect a gate resistor to each IGBT to suppress parasitic oscillation.

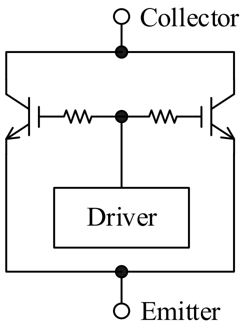


Figure 2-11. Ideal Connection in Parallel

Important Notes

- All data, illustrations, graphs, tables and any other information included in this document (the "Information") as to Sanken's products listed herein (the "Sanken Products") are current as of the date this document is issued. The Information is subject to any change without notice due to improvement of the Sanken Products, etc. Please make sure to confirm with a Sanken sales representative that the contents set forth in this document reflect the latest revisions before use.
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- No anti-radioactive ray design has been adopted for the Sanken Products.
- The circuit constant, operation examples, circuit examples, pattern layout examples, design examples, recommended examples, all information and evaluation results based thereon, etc., described in this document are presented for the sole purpose of reference of use of the Sanken Products.
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