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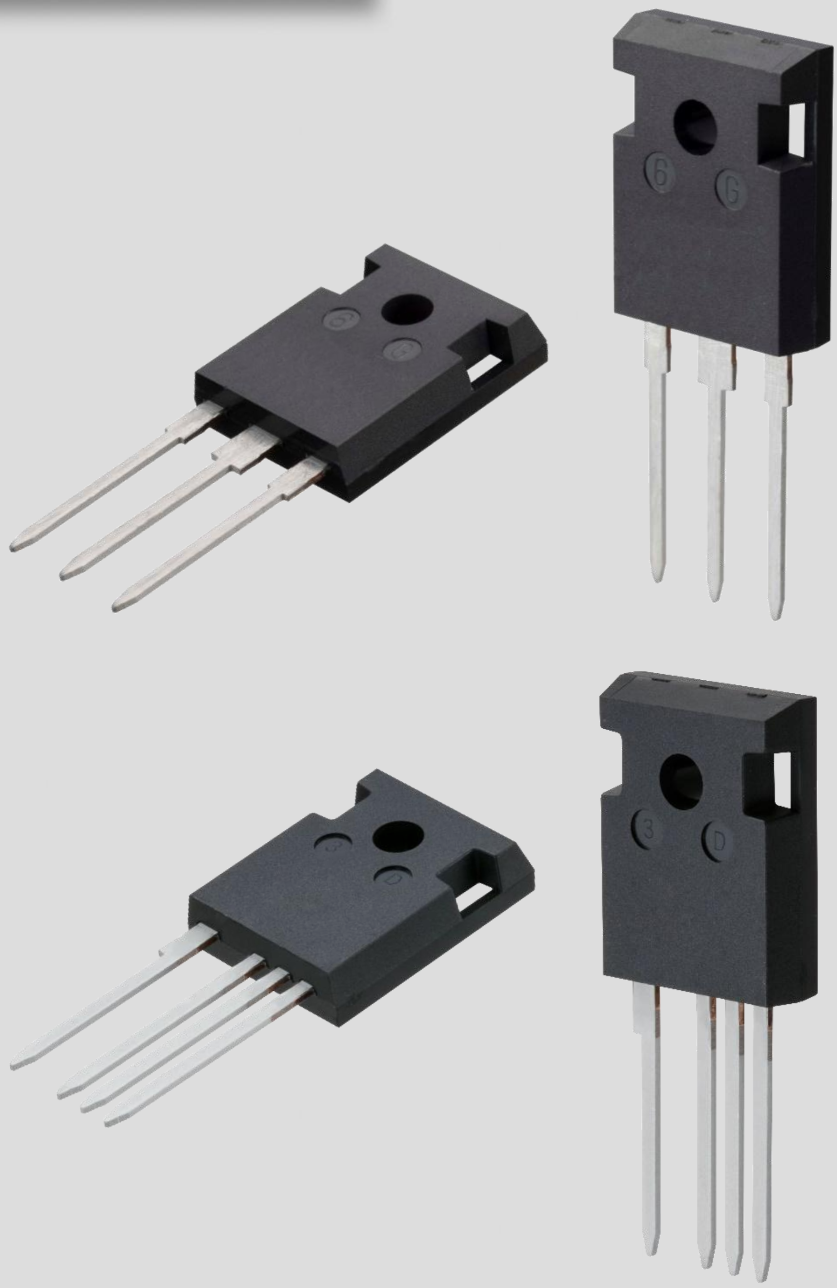

Discrete IGBT

Application Manual

Dec. 2025

Fuji Electric Co.,Ltd.

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⚠ Cautions

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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 3 Discrete IGBT Selection and Application

This chapter describes the precautions when using discrete IGBT and application.

1. Selection of Discrete IGBT

When using discrete IGBTs, it is important to select products with the voltage and current ratings most suited for the intended application.

1.1 Voltage ratings

The voltage rating of a discrete IGBT is determined by the commercial power supply voltage of the equipment in which it is applied and the equipment's DC link voltage. This relationship is shown in Table 3-1. Refer to the table when selecting a device for your application.

Table 3-1 Discrete IGBT voltage rating application example

	IGBT rated voltage	
	650V	1200V
Commercial power supply voltage	～240VAC	～480VAC
DC link voltage	～520VDC	～960VDC

1.2 Current rating

When the collector current I_C of the IGBT increases, both the conduction loss and switching loss increase, resulting in an increase in the device temperature. The virtual junction temperature T_{vj} of the IGBT and FWD must remain below the maximum limit, so choose a current rating that ensures T_{vj} never exceeds its specified maximum rating. Incorrect selection of current rating may lead to device destruction or deterioration of reliability.

Note that in high frequency switching applications, switching loss increases, which increases the device temperature. A common rule of thumb is to select a device which current rating is at least 2~3 times of the operating current. However, the selection of the current rating depends on the operating conditions and heat dissipation conditions of the equipment, thus it is important to select the current rating after checking the power loss and temperature rise in the equipment.

1.3 Maximum rating

Use the device within the maximum ratings (voltage, current, temperature, etc.) described in the specifications. Using the product beyond the maximum rating may destroy the device. Also, the value described in each item of the absolute maximum rating is specified for that item, not for combination of more than one item.

Even if the device is used within the maximum rating, factors such as ambient temperature and operating environment can shorten the product's lifetime. Refer to the absolute maximum ratings, and evaluate and verify the compatibility of the device with the system or equipment.

1.4 RBSOA

Make sure that the IGBT turn-off voltage and current operating locus are within the RBSOA specifications. Using the IGBT beyond the RBSOA region may destroy the device.

2. ESD Protection Measures

Although IGBTs have much higher ESD immunity than small-signal MOSFETs or integrated circuits, they can still be destroyed by static discharges.

As shown in Fig. 3-1, static charge on conductive objects can be safely removed by properly using conductive table mats, wrist straps, and floor mats. The speed at which the charge is discharged depends on the resistance of the discharge path and the capacitance of the charged object. Fig. 3-2 shows the equivalent circuit for a charged conductor with capacitance C and path resistance R. The voltage on the charged object as a function of time is given by the following equation.

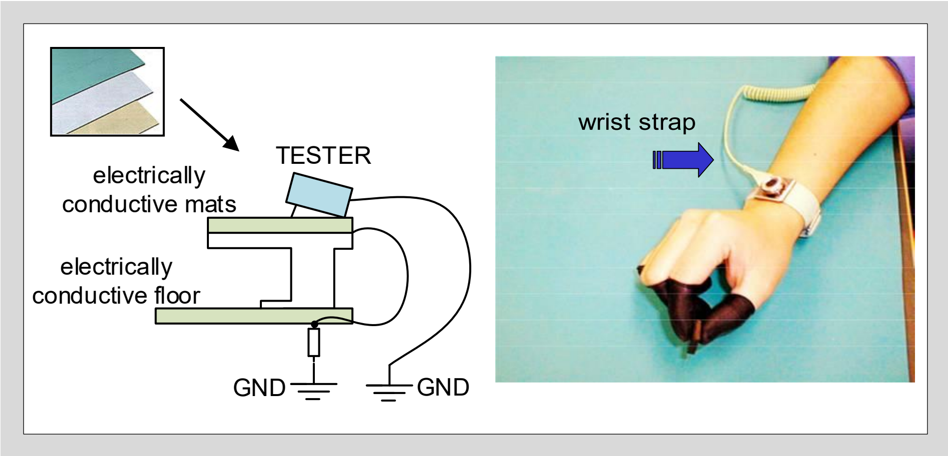

Fig. 3-1 Example of ESD protection measures

$$V(t) = V_0 \cdot \exp\left(-\frac{t}{RC}\right)$$

V : Voltage of charged object at time t [V]
V_0 : Initial voltage of charged object [V]
t : Time [sec]
C : Capacity of charged object [F]
R : Resistance of discharge path [Ω]

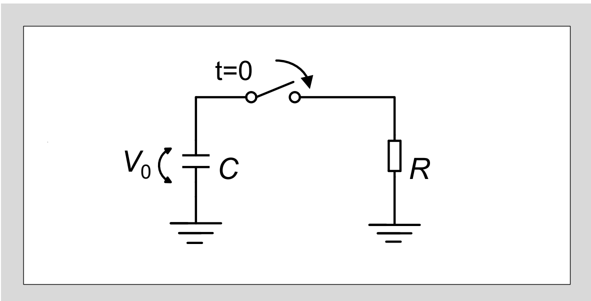

Fig. 3-2 Equivalent circuit of ESD discharge

<Example>

This example shows how to calculate the required resistance to reduce a worker's static electricity to 100V or less in one second.

V = 100V (safe voltage)、V_0 = 10kV (initial voltage of the human body or charged object)、
t = 1s (maximum allowable time to achieve the safe voltage of 100V)、
C = 200pF (average human body capacitance, 100pF～400pF),
R = maximum allowable resistance to ground [Ω]

Substituting these values into the formula,

$$100 = 10 \times 10^3 \cdot \exp\left(-\frac{1}{200 \times 10^{-12} \cdot R}\right)$$

Therefore, $R \cong 1.09 \times 10^9 \Omega$ = 1090MΩ. If the resistor from the table mat, floor, or the wrist strap to ground is 1000MΩ or less, the voltage is discharged to the safety voltage of 100V in less than 1 second.

3. Working Environment

- Workers must be body-grounded. Wear a wrist strap, copper ring or similar device, and connect it to the ground with a resistance of about 1MΩ.
- Equip the workspace with conductive floor mats and/or table mats, all grounded. Also, maintain appropriate humidity.
- When using measuring instruments such as curve tracers, ground the instruments as well.
- When soldering, connect the soldering iron and solder bath to ground so that any leakage voltage from them cannot be applied to the discrete IGBTs.
- Do not touch the terminals directly, always handle the device by its package body.

4. Gate Protection

Applying a voltage between the gate and emitter (G–E) that exceeds the absolute maximum rating can destroy the gate structure of the IGBT. Do not apply any voltage across G–E beyond its absolute maximum rating.

If the G–E path is open (i.e. the gate is floating) while a voltage is applied between the collector and emitter (C–E), the IGBT can also be damaged. This is due to a change in the collector potential induces a leakage current *i* (see Fig. 3-3) from the collector to the gate. This raises the gate potential, inadvertently turns the IGBT on, allows collector current I_C to flow, and causes the device to heat up and fail.

In practice, after you have installed a discrete IGBT into your equipment, a failure or malfunction in the gate drive circuit that leave the gate floating while the main circuit voltage is applied may destroy the IGBT for the reasons above (refer to Chapter 7, section 5.2). To prevent this, we recommend connecting a resistor R_{GE} of about 10 kΩ between gate and emitter.

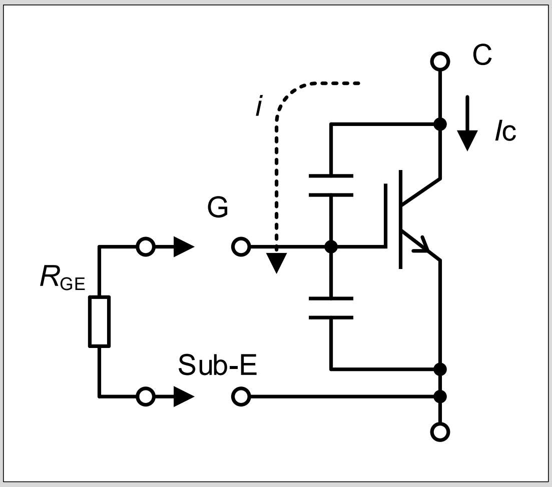

Fig. 3-3 IGBT behavior when G-E is open

5. Protection Circuits Design

Discrete IGBTs can be destroyed by abnormal conditions such as overcurrent or overvoltage. Therefore, it is critically important to design protection circuits that safeguard the device under those conditions. When designing a protection circuit for a discrete IGBT, you must fully understand the IGBT's characteristics (switching speeds, capacitances, thermal limits, etc.) and match the protection circuit's response (timing, thresholds, energy absorption capability) to those device characteristics.

If the protection circuit is not properly matched, the IGBT may still fail even though a protection circuit is present. Common examples of mismatches include:

- Overcurrent protection with too long turn-off delay, allowing excessive energy to flow before cutoff.
- Snubber circuits with capacitances that are too small, resulting in excessive surge voltages.

Detailed methods for overcurrent and overvoltage protection are provided in Chapter 5, "Protection Circuit Design Methods." Please refer to that chapter for design guidelines and examples.

6. Cooling Design

Discrete IGBT have a maximum virtual junction temperature ($T_{vj(max)}$). An appropriate heat sink must be selected to keep the temperature below this value. When designing heat sink, the operating conditions of the Discrete IGBT has to be fully considered.

To perform the cooling design, first calculate the loss generated in the device, and based on those loss select a heat sink that keeps the temperature below the allowable limit. If the cooling design is insufficient, the junction temperature (T_{vj}) may exceed the maximum guaranteed temperature during actual operation, leading to device failure.

For detailed explanations and precautions, refer to Chapter 6, “Cooling Design”

7. Gate Drive Circuit Design

To fully realize the device’s performance, the design of the gate drive circuit is critical. It is also closely related to the design of the protection circuit.

High dv/dt can cause unintended turn-on in the opposing-arm IGBT, gate overvoltage, or noise propagation onto the power-supply lines. Examine optimal drive conditions ($+V_{GE}$, $-V_{GE}$, R_G, C_{GE}) to prevent unintended turn-on, gate overvoltage, and unexpected supply-line noise.

If the wiring between the discrete IGBT and the gate-drive circuit is long, the gate voltage at the device terminals can fluctuate transiently, potentially causing overvoltage failure of the IGBT. To prevent gate overvoltage destruction, implement proper gate-wiring design and verify the gate voltage.

For detailed explanations and precautions, refer to Chapter 7, “Gate Drive Circuit Design”

8. Parallel Connections

When applying discrete IGBTs to high current applications, devices are connected in parallel.

When using parallel connections, it is important to design so that each device carries equal current. If current sharing is unequal, one device may be overloaded and fail.

Current balance in parallel operation depends on device characteristics and wiring methods, so it is necessary to manage and design for matching the C–E saturation voltages $V_{CE(sat)}$ of all parallel devices and to keep the main circuit wiring lengths equal.

For detailed explanations and precautions, refer to Chapter 8, “Parallel Connection of Discrete IGBTs.”

9. Application of TO-247-4

TO-247-4 can reduce loss and suppress ringing by mitigating the effects of inductive voltage (L·dI_C/dt), but this increases the switching speed. In other words, compared with TO-247, dI_C/dt becomes larger, so care must be taken because the surge voltage generated at turn-off is higher. As shown in Fig. 3-4, under the condition I_C = 100 A, with the TO-247 and R_G = 20 Ω, $V_{CE(peak)}$ ≈ 810V. However, to keep the same $V_{CE(peak)}$ with TO-247-4, R_G of approximately 51 Ω must be selected. Also, increasing R_G increases loss, preventing the TO-247-4's low loss feature from being fully realized.

Therefore, for the peripheral circuits of both TO-247 and TO-247-4, select appropriate component values for each device and design the circuit with sufficient margin so that the surge voltage does not exceed the maximum rating.

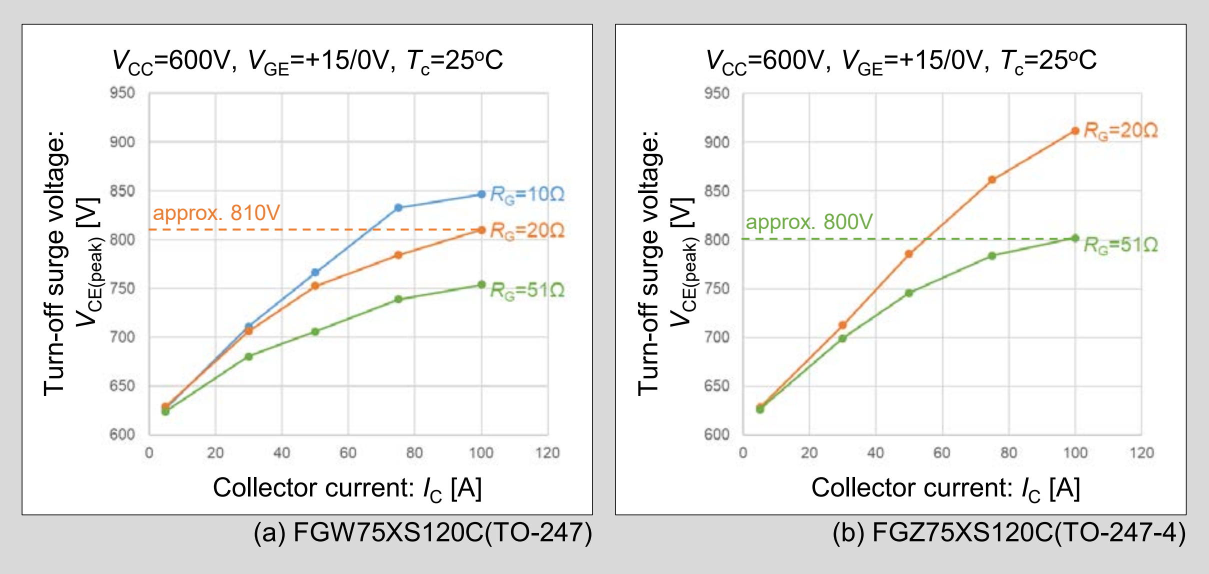

Fig. 3-4 Turn-off surge voltage comparison

By designing a printed circuit board with the layout shown in Fig. 3-5, it is possible to have compatibility between TO-247 and TO-247-4 products. This design makes it easy to replace products and enables two types of packages to be mounted on a single printed circuit board. However, the peripheral circuit constants should be set appropriately for each product.

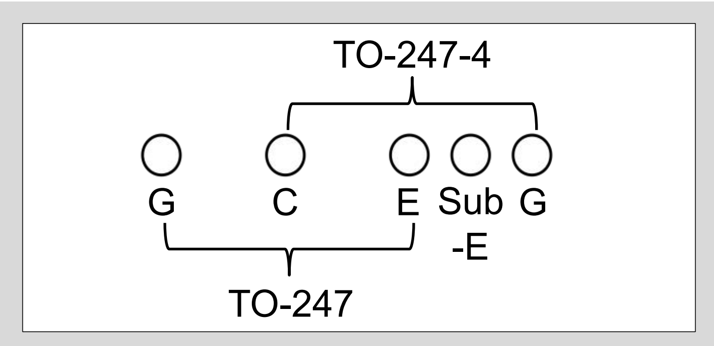

Fig. 3-5 Printed circuit board design example

10. Mounting Notes

When mounting the discrete IGBT to a heat sink, it is recommended to apply thermal grease thinly and evenly between the device and the heat sink to improve thermal conductivity and enhance heat dissipation. Insufficient amount or improper application of thermal grease may prevent it from spreading over the entire device surface, leading to degraded cooling performance and potential thermal failure.

Depending on the type of thermal grease and the application method used, degradation or depletion of the thermal grease can occur during high temperature operation or under temperature cycling, which may shorten the device lifetime. Please pay close attention to the selection of thermal grease and the method of application.

If the tightening torque of the mounting screws is too low, the thermal resistance will increase, increasing the risk of thermal failure. We recommend using torque values within the range specified in Table 3-2.

Table 3-2 Tightening torque of semiconductor device

Package outline	Mounting hole diameter	Screw	Screw torque (N・cm)
TO-247 TO-247-4	φ3.2	M3	40-60

To fill the gap between the device and the insulating sheet, and between the insulating sheet and the heat sink, apply thermal grease in discrete spots to the case area directly beneath the semiconductor-chip mounting section and to the heat sink surface as shown in Fig. 3-6, then secure to the heat sink with screws tightened with the recommended torque. In addition, the heat sink surface must meet the following conditions.

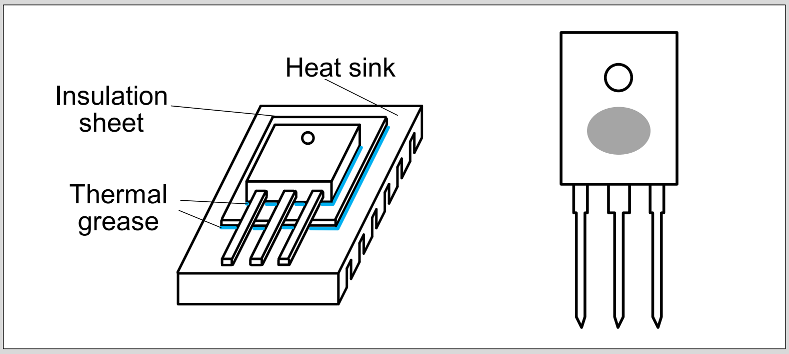

Fig. 3-6 How to apply thermal grease

- Heat sink surface flatness within the contact area of the discrete IGBT: ≤ ±30μm
- Heat sink surface roughness within the contact area of the discrete IGBT: ± 10μm
- Do not taper the screw holes.

11. Soldering

During soldering, heat (temperature) that exceeds the maximum rated storage temperature will normally be applied to the terminals. Please pay attention to the following precautions when soldering.

Table 3-3 Recommended mounting conditions

Package outline	Mounting method				
	Flow solder (total immersion)	Flow solder (Terminal immersion)	Infrared reflow	Hot air reflow	Soldering iron
TO-247 TO-247-4	Not possible	Possible (within 2 times)	Not possible	Not possible	Possible (only 1 time)

Soldering temperature	Immersion time
260±5°C	10±1 sec
350±10°C	3.5±0.5 sec

- Make sure that the immersion depth of the terminal is at least 1.5mm away from the device body.
- Do not immerse the device body in solder when using flow soldering method.
- If flux is used, avoid chlorine-based types and preferably use rosin-based flux.

12. Cleaning

Please note the following when soldering with flux and subsequently cleaning the flux.

12.1 Solvent

- Use a solvent that is non-flammable, non-toxic, and non-corrosive.
- In particular, avoid trichloroethylene-based solvents, as they contain chlorine.

12.2 Cleaning method

Immersion cleaning is recommended. When performing ultrasonic cleaning, take care that discrete IGBTs or printed circuit boards do not come into direct contact with the vibration source.

13. Terminal Processing and Mounting

13.1 Stress to the terminals

Discrete IGBT terminals undergo reliability testing in accordance with JEITA standard ED4701/400A, Test Method 401A. Table 3-4 summarizes the individual test items; for full details, please refer to the JEITA specification.

Note that the following tests apply only to unmounted discrete IGBTs. Any discrete IGBTs that have already been solder-mounted or otherwise installed are excluded from the warranty.

Table 3-4 Test items

Test items	Test methods and conditions	Reference item	Number of samples
Tensile test	Tensile force: 2.2 ± 0.1 N Holding time: 30 seconds	JEITA ED4701/400A 401A Method I	15
Bending test	Bending angle: 15 degrees Bending time: 1 time	JEITA ED4701/400A 401A method III	15
Fatigue test	Bending angle: 15 degrees Bending time: 3 times	JEITA ED4701/400A 401A method V	15

13.2 Precautions for terminals forming

When it is unavoidable to form (bend) the terminals to suit component layouts, observe the following.

Use a special jig that does not apply stress to the internal chip and external package.

- Use a dedicated jig that does not apply stress to the internal chip or the external package.
- For lateral (in-plane) bends, bend at a point at least 4.5 mm away from the package, and limit the bend angle to 30° maximum (see Figure 3-7).
- For right-angle bends (out-of-plane) relative to the package, bend at a point at least 4.5 mm from the package.
- Ensure the bend radius (R) is equal to or greater than the terminal thickness.
- Perform forming at any given location only once. Do not reform or attempt to restore the terminal to its original shape.

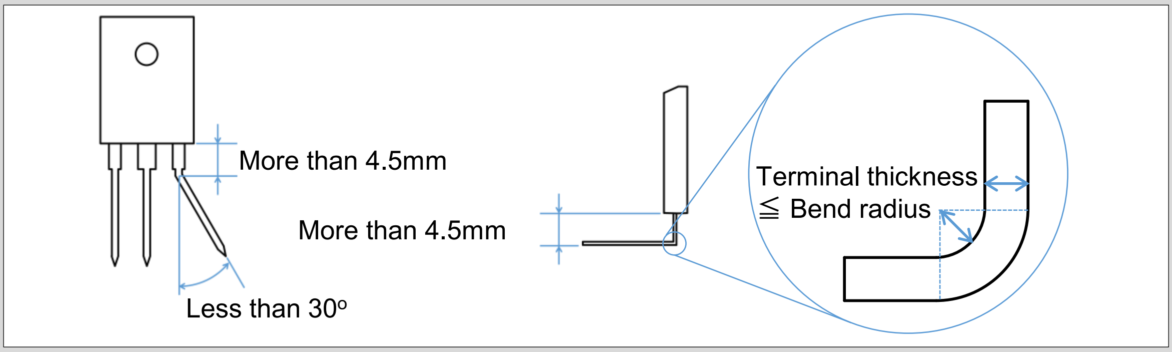

Fig. 3-7 Precautions for terminal forming

13.3 Insertion into printed circuit board

When inserting into the printed circuit board, ensure that the spacing between the terminals matches the spacing of the printed circuit board holes so as not to impose excessive stress on the terminals.

14. Storage

- Devices should be stored at room temperature and normal humidity—avoid extreme temperatures or humidity. As a guideline, maintain 5–35°C and 45–75% RH. In very dry environments, use a humidifier. Do not use tap water (its chlorine content may cause terminal corrosion); instead use purified water or boiled water.
- Avoid areas where corrosive gases are generated or where there is excessive dust.
- Prevent rapid temperature changes that could cause condensation on the devices; choose a location with stable temperature.
- When stacking outer shipment boxes, limit to five boxes high and take measures to prevent collapse or deformation. Do not place heavy objects on top.
- Store the terminals unprocessed to avoid soldering defects due to rust, etc.
- To avoid solderability defects from rust, keep each terminal in unprocessed state.
- All storage shelves should be made of metal and grounded.
- The storage period is one year from the date of delivery, provided that the above points are observed in the storage and packing conditions.

15. Transportation

- Avoid extreme forces such as dropping or shock when transporting the products.
- When transporting several products in the same box or container, insert padding between the products to protect the terminals and to keep the products from shifting.
- Take measures against static electricity from being applied to the gate terminals, such as using antistatic bag or shorting the gate and emitter with aluminum foil when transporting the product.

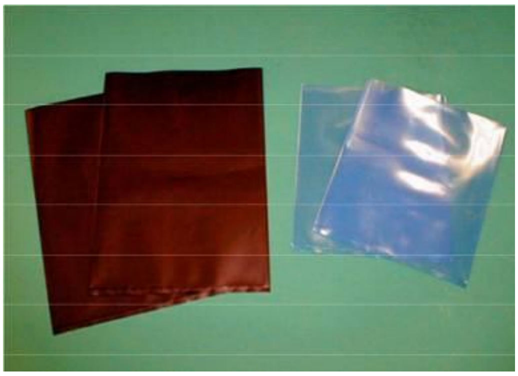

Fig. 3-8 Conductive bag

Fig. 3-9 Conductive foam

16. Precautions for Use

- Do not touch the product terminals or packages directly during operation or while the product is energized. Doing so may result in electric shock or burns.
- Be sure to install fuses, circuit breakers, etc. of appropriate capacity to prevent secondary damage (fire, explosion, etc.) in the event of unexpected device failure.
- The product becomes hot during operation. Although flame-retardant materials are used for the sealing resin of the product, it may cause smoke or fire if the product fails. If the product is used in flammable environment (e.g. environment where flammable gases may leak or accumulate) or near combustible materials, be sure to take fire spread prevention measures at your own responsibility.
- Evaluate the package temperature, junction temperature and terminal temperature rise.
- Do not use the product in environments containing acid, organic matter, or corrosive gas (e.g. hydrogen sulfide, sulfurous acid gas, etc.), as this may cause the product to oxidize or corrode, resulting in failure.
- The product is not designed to be radiation resistant. Avoid using it in environments where it may be exposed to radiation.
- As shown in Fig. 3-10, design and use the device with a steady-state voltage not exceeding 80% of the absolute maximum rated voltage. Even under worst-case conditions, keep the applied voltage within the absolute maximum rated voltage.

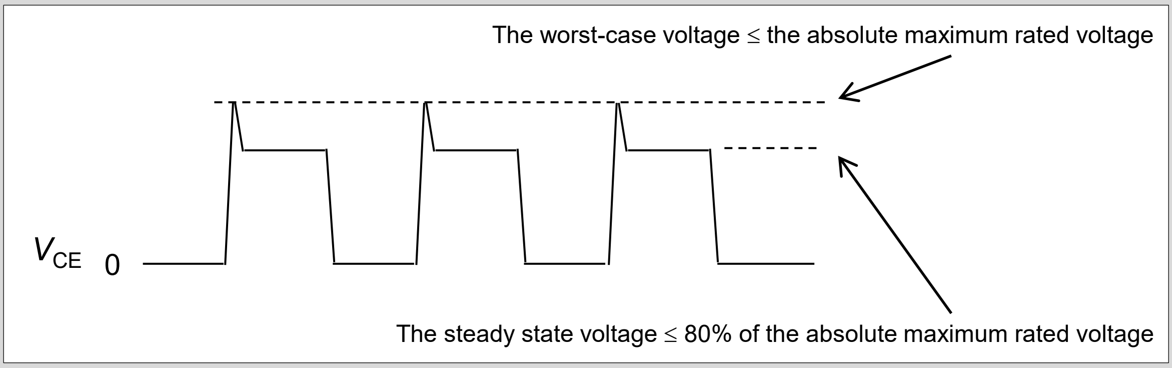

Fig. 3-10 Voltage waveform during switching