IGBT

Surge Voltage Suppression at Turn-off

Introduction

This document describes the surge voltage suppression mechanism used at turn-off in Renesas IGBT products.

Contents

1. Overview

In the IGBT switching operation, a surge voltage occurs at turn-off.

When gate resistance (Rg off) is small or di/dt is high, surge voltage increases.

A common solution is to increase gate resistance (Rg off). However, this is not optimal as the potential for switching failure increases as gate resistance (Rg off) increases.

Renesas IGBTs offer the unique characteristic of suppressing surge voltage when gate resistance is decreased to within a set value (such as in the example conditions shown in Figure 1, where Rg_off = 4 ohm or less at 25℃). Renesas refers to this mechanism as the “self-clamping mode,” as explained in the following sections.

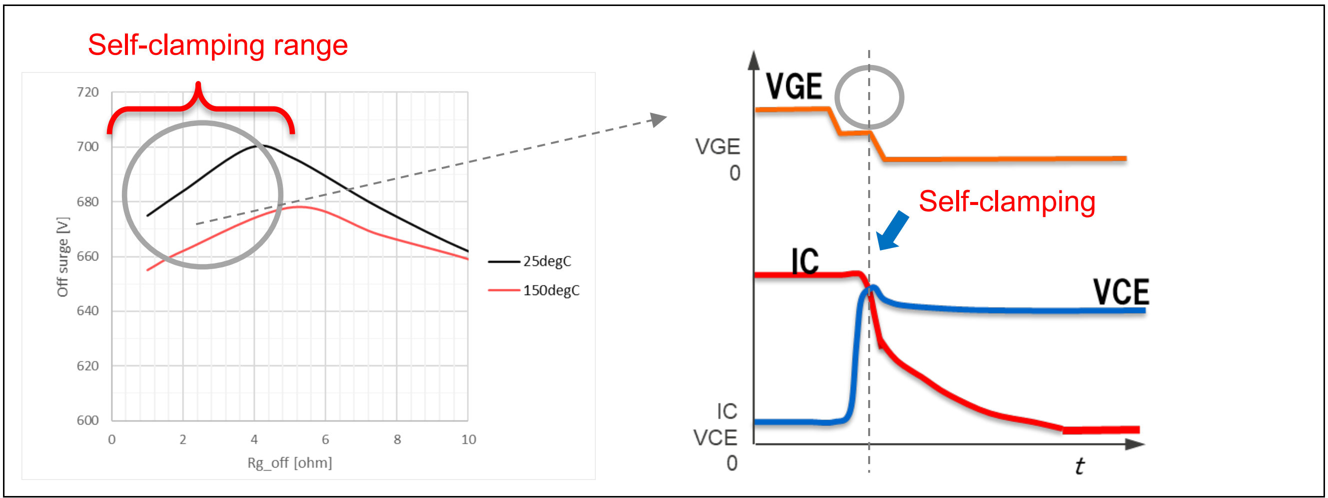

Figure 1 Rg off: Surge Characteristics and Turn-off Waveform (AE5 IGBT 750V/300A)

2. Mechanism

2.1 Channel Closure

When Rg off is small, the channel rapidly closes, suddenly stopping the supply of electrons.

2.2 Hole Carrier Increase

The hole carriers increase and combine with the shutdown electrons to maintain the inductive current in the circuit.

2.3 Hole Carrier Disappearance

The remaining hole carriers gradually disappear. As a result, di/dt decreases, and the tail current causes the VCE to clamp.

Renesas designs and tunes their IGBTs with a carrier concentration that promotes this type of self-clamping mechanism.

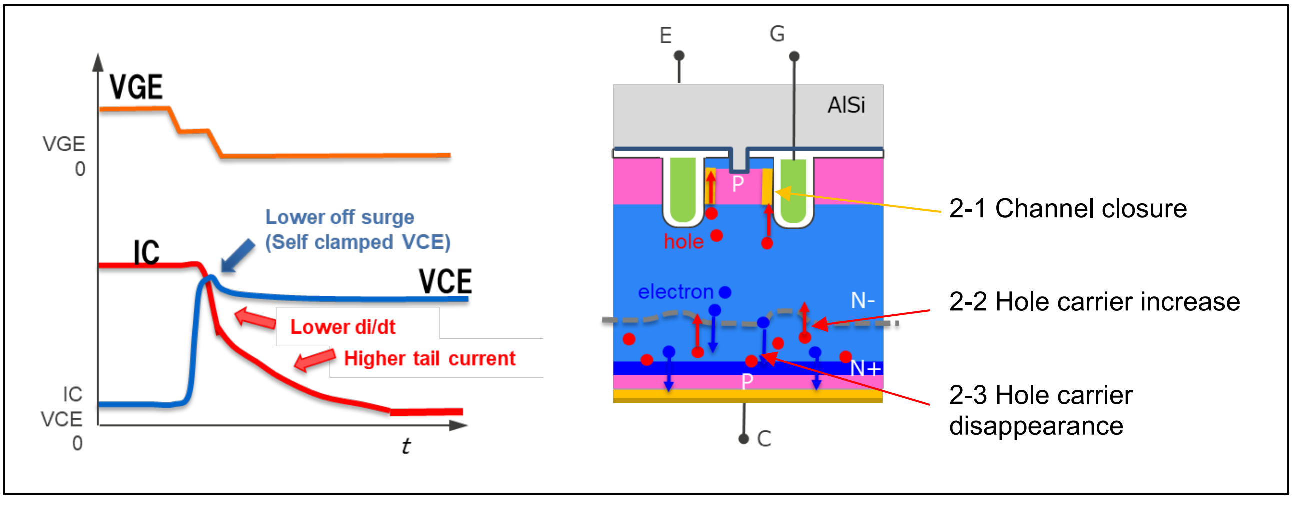

Figure 2 Waveform and Carrier Operation at Turn-off

3. Ensuring Robustness

Normally, when gate resistance (Rg off) is small or the circuit's parasitic inductance is large, the surge voltage during turn-off goes high, which tends to narrow the RBSOA (Reverse Bias Safe Operating Area).

However, as noted in the previous section, Renesas designs and tunes their IGBT's to feature a self-clamping mode that suppresses the surge voltage even when gate resistance is small.

Figure 3 shows the waveform and locus curve that confirm the RBSOA at low gate resistance (Rg off = 3.3 ohm) in the Renesas IGBT AE5. Even under conditions of three times the rated current, safety is ensured at turn-off in self-clamp mode, demonstrating that IGBTs were designed to ensure robustness.

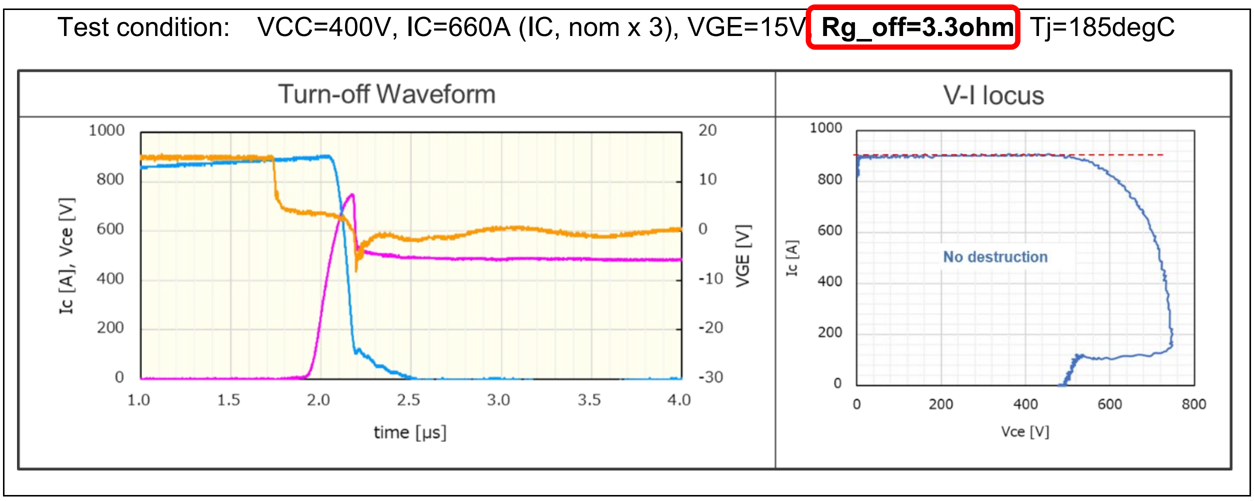

Figure 3 RBSOA Test in Self-clamping Mode (AE5 IGBT 750V/300A)

APPENDIX: Definition of Terms

Switching Characteristics

IGBTs are used as switches in power conversion.

Switching characteristics are measured using the switching characteristic measurement circuit shown in Figure 4.

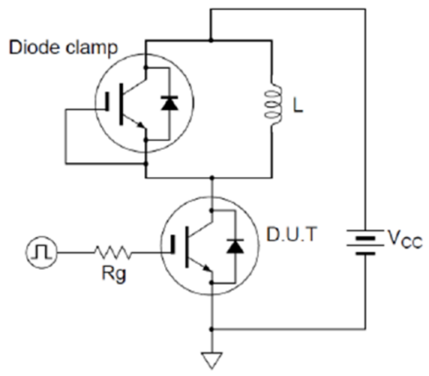

Figure 4 Switching Characteristics Measurement Circuit

The following describes important parameters in the switching characteristics.

Switching Characteristics (switching time)

- td(on): Turn-on Delay Time
  Time for the gate-emitter voltage to rise from 10% of the forward-bias voltage to 10% of the collector current.
- tr: Rise Time
  Time for the collector current to rise from 10% to 90%.
- td(off): Turn-off Delay Time
  Time for the gate-emitter voltage to fall from 90% of the forward-bias voltage to 90% of the collector current.
- tf: Fall Time
  Time for the collector current to fall from 90% to 10%.

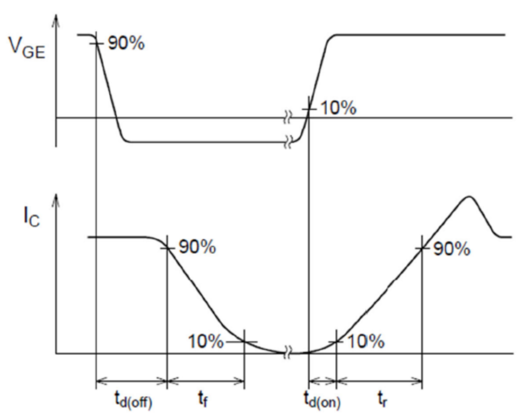

Figure 5 Switching Waveforms

Switching Characteristics (switching loss)

Switching loss is shown in Figure 6.

Off-period loss can be calculated as VCE x IC.

Calculating IGBT loss is extremely important for estimating the application's power consumption and junction temperature Tj.

Turn-on loss energy	Eon	Integral value of collector loss that occurs from the start of turn-on until the collector-emitter voltage reaches the specified value.
Turn-off loss energy	Eoff	Integral value of collector loss that occurs from the start of turn-off until the collector-emitter voltage reaches the specified value.
Switching loss energy	Etotal	Sum of Eon and Eoff.

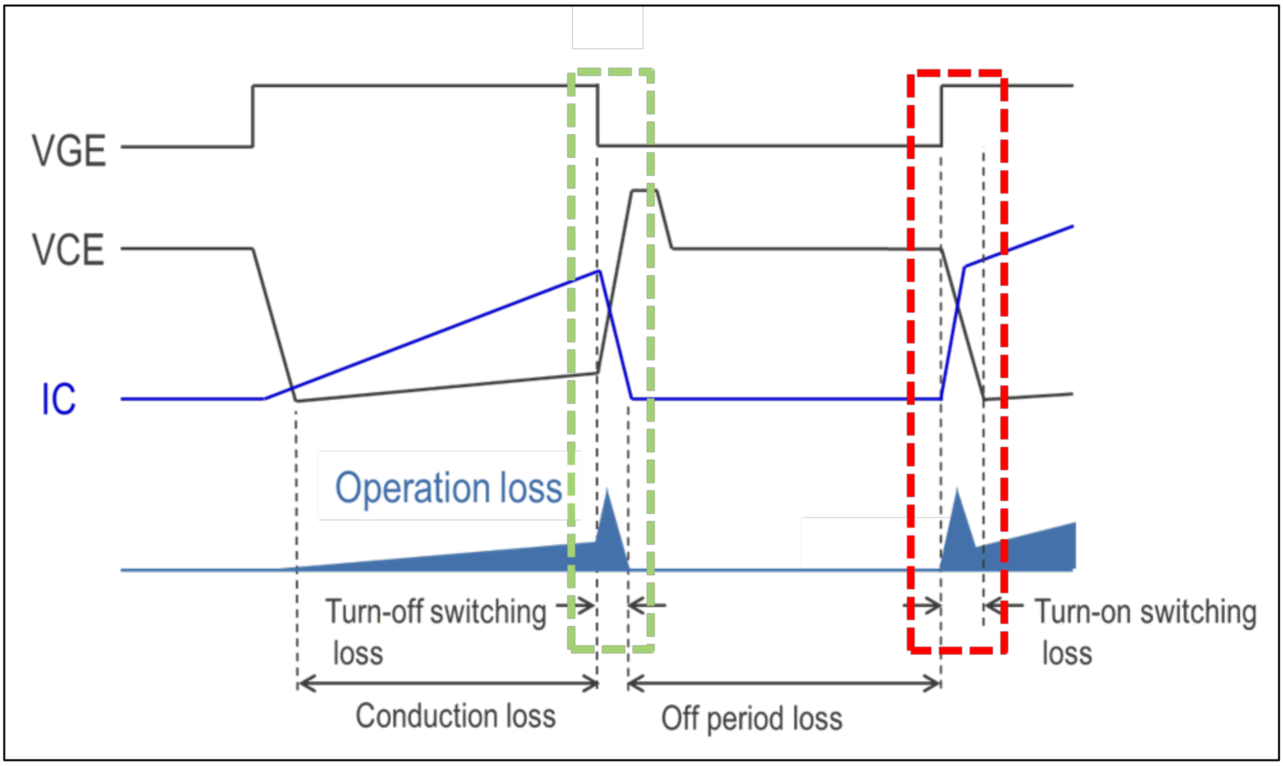

Figure 6 Switching Loss

di/dt and Surge Voltage

di/dt refers to the amount of change in current during the switching transition period.

At turn-off, the collector current converges rapidly, and the steep di/dt causes a surge voltage in the parasitic inductance.

Vsurge = L x di/dt

Note that the surge voltage caused by high voltage and high current is significant and can cause damage to the product if the rated value is exceeded.

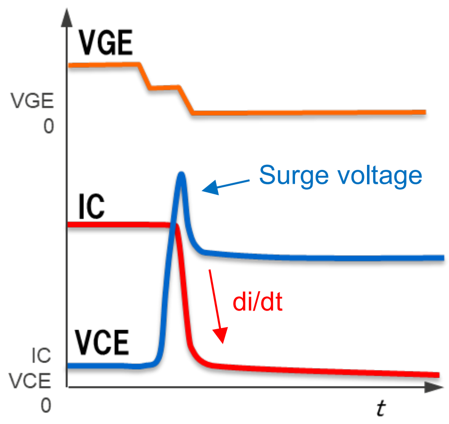

Figure 7 Surge Voltage and di/dt

Revision History

Rev.	Date	Description	
		Page	Summary
0.10	July 31, 2024	-	First edition

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