Power Diodes

Descriptions of Electrical Characteristics and Usage

Introduction

This application note describes the diode characteristics and basic usage method focusing on the contents covered in the diode datasheet. The term “Diode” in this application note refers primarily to FRDs (First Recovery Diodes).

Contents

1. What is Power Diode?

A diode is a semiconductor device with rectifying action (in which current flows in only a certain direction). Depending on the application, a diode is used alone or connected in parallel with an IGBT.

2. Terminology

2.1 Absolute Maximum Ratings

Absolute maximum ratings are rated vales set to ensure safe usage of diodes.

Exceeding absolute maximum ratings even instantaneously may lead to deterioration or destruction of the circuit, so always use diodes within the maximum ratings.

Table 1 Absolute Maximum

Term	Symbol	Definition
Reverse voltage	V_R, V_{RM}	Maximum voltage that can be applied between cathode and anode
Forward current	I_F	Maximum current allowed at anode terminal
	$I_{F(pulse)}$, I_{FSM}	Maximum current allowed at anode terminal during pulsed operations
Internal diode forward current	I_F	Maximum current allowed in internal diode
	$I_{F(peak)}$	Maximum current allowed in internal diode during pulsed operations
Junction-to-case thermal resistance	$R_{th(j-c)}$	Thermal resistance from element junction to case
Junction temperature	T_j	Maximum temperature of element junction to ensure normal operations
Storage temperature	T_{stg}	Temperature range for storage when power is not applied

Usage Notes

Even if the usage conditions (operating temperature / current / voltage etc.) are within the absolute maximum ratings, if the diode is used continuously under high load (high temperature, large current/high voltage application, large temperature change etc.), the reliability may decrease significantly. Please check the Renesas Semiconductor Reliability Handbook (handling precautions, usage notes, requests and derating concepts and methods) and individual reliability data (reliability test reports, estimated failure rates, etc.), and always design for reliability.

2.2 Electrical Characteristics

Table 2. Electrical Characteristics

Term	Symbol	Definition
Forward voltage	V_F	Voltage between anode and cathode at specified diode current
Reverse current	I_R	Cathode current when specified voltage is applied between cathode and anode
Reverse recovery time	t_{rr}	Time from the point at which the diode current switches from forward to reverse and the reverse recovery current begins to flow, until the straight line that connects 90% and 50% of the reverse recovery current peak value crosses the time axis.
Reverse recovery current	I_{rr}	Current flowing in the reverse direction transiently when switching from the state when the diode current is flowing to the off state.
Reverse recovery charge	Q_{rr}	Total charge dissipated during reverse recovery operation

3. Electrical Characteristics

3.1 Static Characteristics

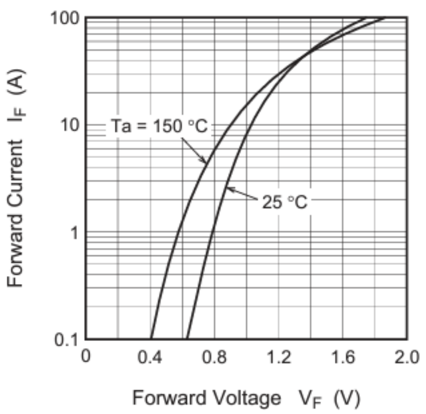


Figure 1 Forward Voltage Characteristics

Figure 1 shows the forward voltage characteristics.

Diode forward voltage V_F is the voltage drop that occurs when diode current I_F flows in the diode forward direction. In motor applications, the lower the V_F, the better, as V_F is the characteristic that determines loss during free-wheel regeneration. Also, positive and negative temperature characteristics depend on diode forward current I_F.

3.2 Switching Characteristics

IGBTs are used as switches for power conversion.

Switching characteristics are measured by the switching characteristics measurement circuit as shown in Figure 2.

Since the diode clamp is connected in parallel with inductive load L, the IGBT turn-on time (turn-on loss) is also affected by the diode's recovery characteristics.

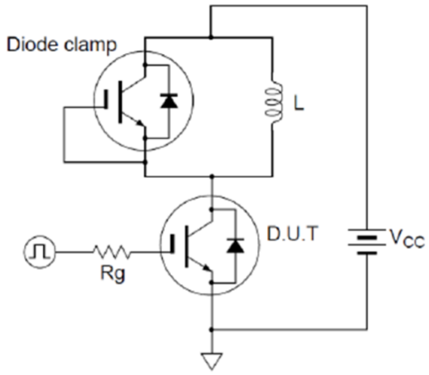


Figure 2 Switching Characteristics Measurement Circuit

Figure 2 Switching Characteristics Measurement Circuit

3.2.1 Reverse Recovery Characteristics

Accumulated minority carriers are emitted when switching from the state where forward current flows through the diode to the state of reverse element. The time required for these minority carriers to be completely emitted is called the reverse recovery time (trr), the current during this time is called reverse recovery current (Irr), and the integral value of these two periods is called the reverse recovery charge (Qrr).

$$Qrr = 1/2\ Irr \times trr$$

Since the trr period is equivalently short circuited, it entails a large loss. In addition, it limits the frequency during the switching operation. Therefore, in general, fast trr and small Irr (small Qrr) is considered optimal. These characteristics are highly dependent on forward bias current IF, diF/dt, and junction temperature

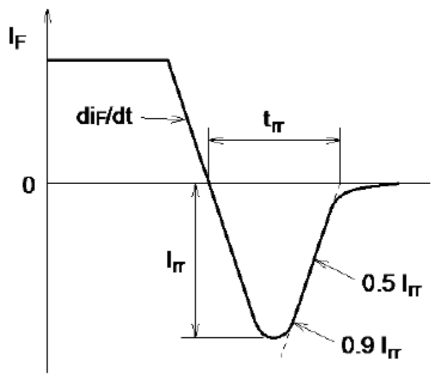


Figure 3 Reverse Recovery Characteristics

Figure 3 Reverse Recovery Characteristics

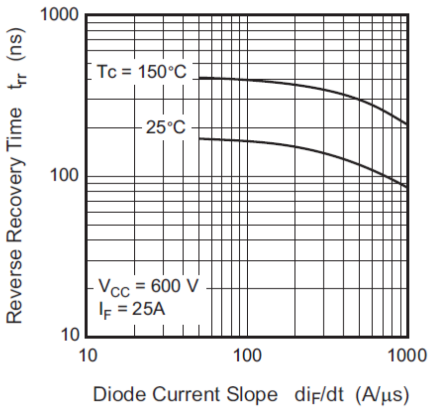


Figure 4 Reverse Recovery Time vs. diF/dt Dependency

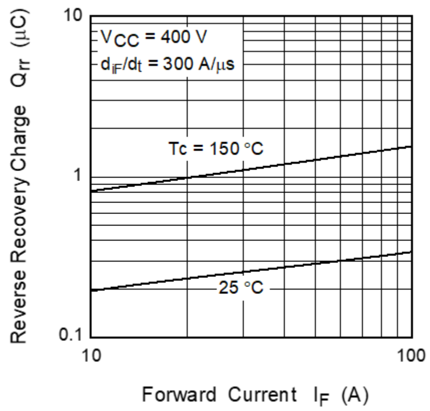


Figure 5 Reverse Recovery Time vs. Forward Current Dependency

However, when trr becomes faster, diF/dt becomes steeper at recovery timing, as does the corresponding collector-emitter voltage dv/dt, which increases the tendency for noise generation. Examples of noise countermeasures are provided below

1) Reduce diF/dt (slow down IGBT turn-on time).
2) Add a snubber capacitor between the IGBT collector and emitter to mitigate collector-emitter voltage dv/dt.

   Figure 5 Reverse Recovery Time vs. Forward Current Dependency

3) Change the built-in power diode to a soft recovery.
   The reverse recovery characteristic greatly depends on the withstand voltage and the capacity of the device. This characteristic can be improved with lifetime control, heavy metal diffusion, and other methods.

3.2.2 Surge Voltage and di/dt

di/dt indicates the amount of change in the current during switching transition.

During FRD operations, the recovery current converges suddenly, and the parasitic inductance caused by the steep di/dt generates surge voltage.

$$V_{surge} = L \times di/dt$$

This is an important point, as a surge voltage generated by high voltage and large current may exceed ratings and result in damage or destruction of the product.

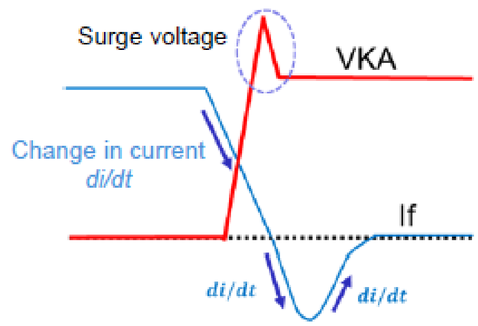


Figure 6 Surge Voltage and di/dt

3.2.3 Ringing

Ringing refers to the phenomenon of a waveform that oscillates in comparison to an ideal signal, as shown in Figure 7,

Although there are several causes of ringing, this section discusses only ringing caused by parasitic components and diode recovery operations.

- Ringing caused by parasitic components
  Ringing is caused by parasitic inductance in conductors and parasitic capacitance in IGBTs (Figure 8). To avoid this, it is necessary to design the wiring as short as possible and take other countermeasures. Click here for information on ringing that occurs in parallel operations, referred to as “gate oscillation”.
- Ringing caused by diode recovery operation at low current
  At low current, recovery current is generated during the diode recovery operation, and ringing occurs due to steep current convergence (Figure 9).

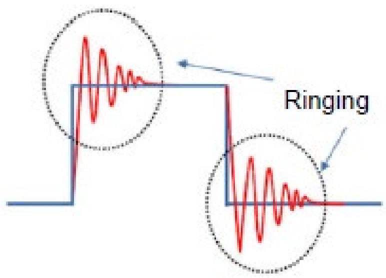


Figure 7 Ringing

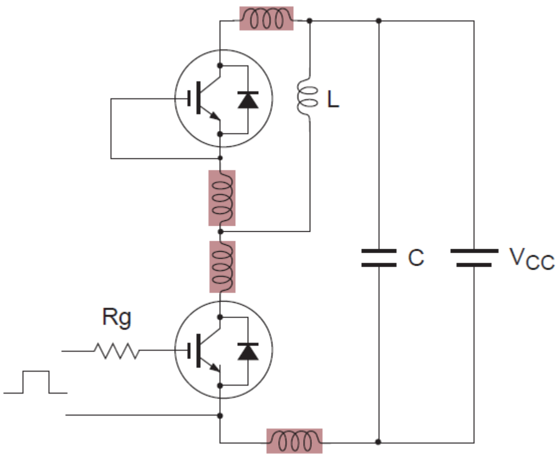


Figure 8 Parasitic Components of Circuit

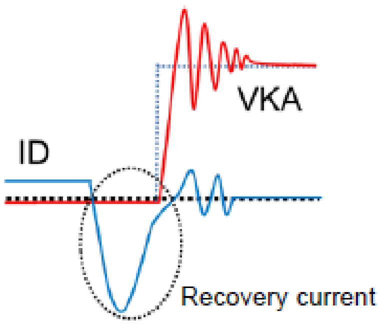


Figure 9 Ringing Due to Recovery Current at Low Current

Figure 10 shows a comparison of ringing due to the recovery current at low current between the Renesas AE5 and competitors' products.

Even when operating at 5A with a rated voltage of 750V/300A, ringing did not occur in the AE5, whereas competitors' products experienced a surge voltage of about 160V as well as ringing.

Although surge voltage and ringing can be suppressed by increasing the IGBT's Rg_on, Renesas AE5 diodes are superior in this respect, allowing us to keep Rg_on smaller than that of the competition.

Ultimately, users only need to be concerned about setting Rg in consideration of EMI noise.

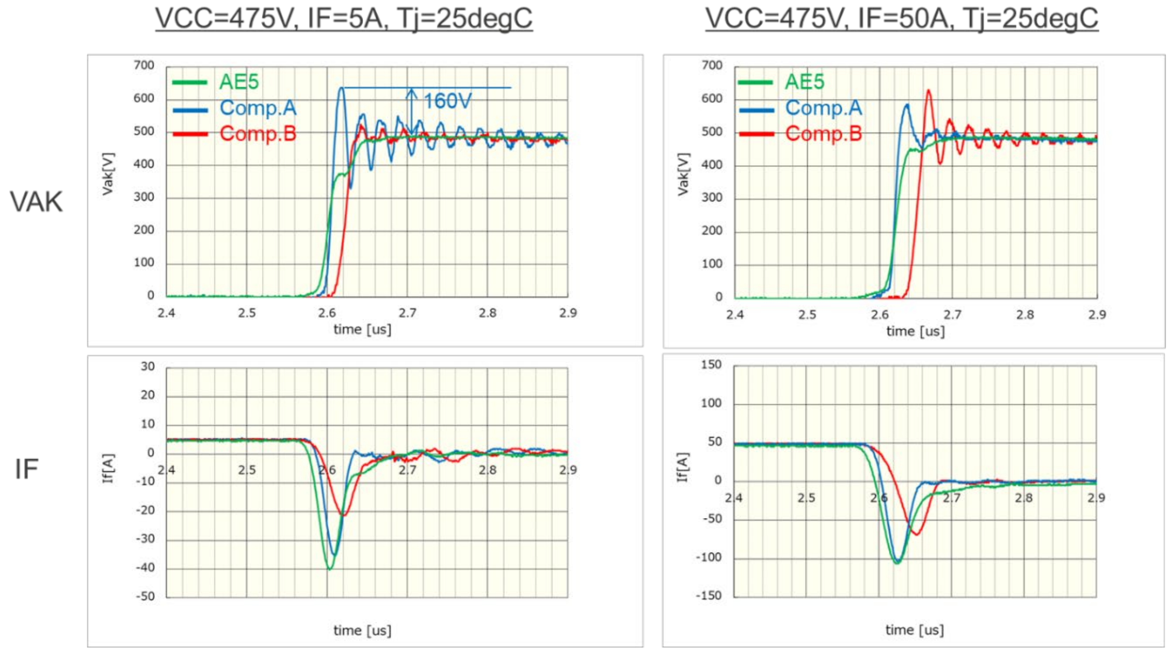


Figure 10 Manufacturer Comparison:

Ringing due to recovery current at low current List end

Ringing is more likely to occur in low temperature environments. The AE5 suppresses ringing even in such environments.

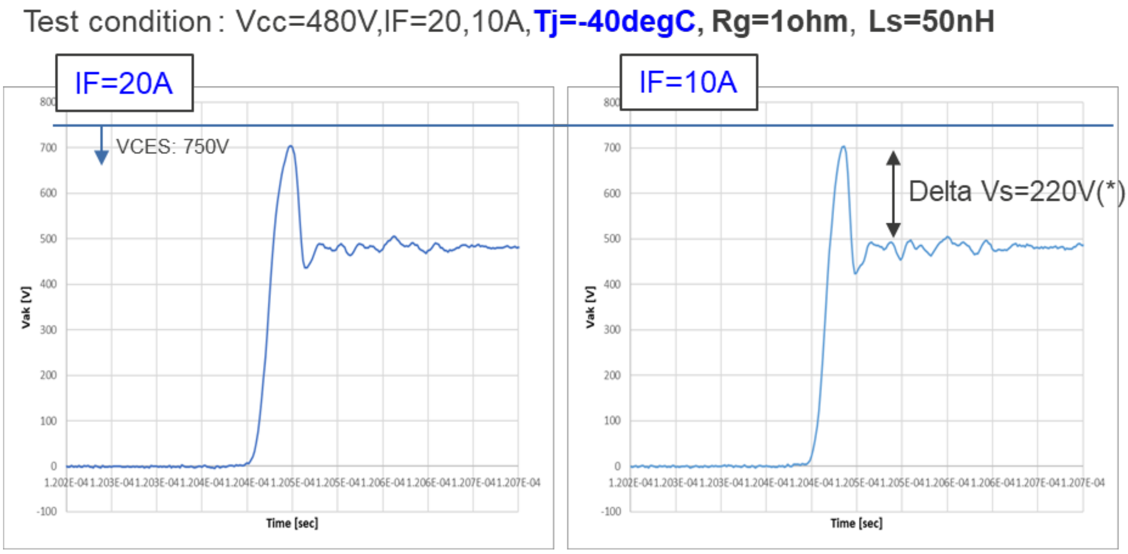
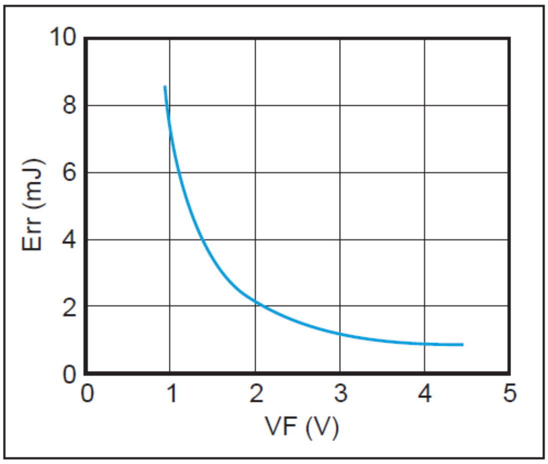


Figure 11 Ringing Suppression in Low Temperature Environments

3.2.4 Trade-off Relationship between VF and Err



When combining diodes with IGBTs for switching operations, conduction loss due to V_F and switching loss due to E_{rr} occur.

There is a tradeoff between the two. Product specifications with a smaller V_F will result in a larger E_{rr}.

The optimum balance of characteristics depends on the actual application and usage conditions.

Renesas diodes offer characteristics suitably balanced to match application specifications.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Nov.13.2024	-	First edition

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