Diode

How to Select Rectifier Diodes

In applications of commercial power supplies and switching power supplies, the diodes primarily used for rectification are general rectifier diodes, fast recovery diodes, Si Schottky barrier diodes, and SiC Schottky barrier diodes. All of them are elements composed of an anode and a cathode, having nearly the same factors indicating essential functions and characteristics. Some electrical characteristics of each diode are optimized differently according to its application. This application note provides a summary of features of the characteristics and suitable applications for each diode. Use this application note as a reference for selecting rectifier diodes.

Comparison of features of rectifier diodes

Here, the rectifier diodes used for power supply circuits are classified into the following four types: general rectifier diodes (REC), fast recovery diodes (FRD), Si Schottky barrier diodes (Si-SBD), and SiC Schottky barrier diodes (SiC-SBD). Table 1 shows a comparison of their features.

RECs are elements primarily intended to rectify an alternate current to a direct current. In addition, they are used for protection to prevent overcurrent from flowing when a power supply or battery is connected in reverse. The forward voltage (V_F) varies with the current to be applied. However, a typical value is about 1 V. Since the diodes are supposed to rectify commercial power supplies at 50 Hz to 60 Hz, the standard characteristics of the reverse recovery time (t_{rr}) are not fast.

FRDs are pn junction diodes as well as high-speed elements with a significant improvement in t_{rr}. Si-SBDs are high-speed elements like the FRDs. Compared with the reverse voltage (V_R) of 200 V or less (breakdown voltage) for the Si-SBDs, the FRDs can achieve a breakdown voltage as high as 800 V. However, V_F is generally high and the standard value is about 2 V for specifications with a high breakdown voltage and large current, although elements with reduced V_F have also been developed (described later). Based on their high breakdown voltage and high-speed performance, they are often used for switching power supplies for AC-DC converters and inverter circuits.

Table 1. Comparison of features of rectifier diodes

Type	Features	Characteristics				Suitable applications
		V_F	I_R	t_{rr}	V_R	
REC	General purposes	★ 1.1 V	★★★ 1 µA - 10 µA	★ 10 µs	★★ 1000 V	Rectification of commercial power supplies Power supply protection against reverse connection
FRD	High speed	★ 0.85 V-3 V	★★★ 1 µA - 10 µA	★★ 20 ns-80 ns	★★ 800 V	AC-DC converters Inverter circuits, PFC circuits
Si-SBD	High speed Low V_F	★★★ 0.3 V-1 V	★ 35 nA-1.2 mA	★★★ None*1	★ 200 V	DC-DC converters Secondary side of AC-DC converters
SiC-SBD	High speed High breakdown voltage	★★ 1.5 V-1.6 V	★★ 11 µA - 400 µA	★★★ None*1	★★★ 1200 V	Inverter circuits, PFC circuits

- REC: General rectifier diode. FRD: Fast recovery diode. Si-SBD: Silicon Schottky barrier diode.
  SiC-SBD: Silicon carbide Schottky barrier diode
- V_F: Forward voltage. I_R: Reverse current. t_{rr}: Reverse recovery time. V_R: DC reverse voltage
- ★ is an indicator of quality. The larger the number of stars, the better the characteristics.
- The numerical values are the maximum values on the data sheets for the ROHM products (as of September 2023).

*1: Although no value exists in principle, the value is determined by the LC resonance composed of the terminal capacitance and the inductance of external wiring.

Si-SBDs use a barrier generated by the junction of a metal and semiconductor (Schottky barrier) instead of the pn junction. Compared with the pn junction diodes, Si-SBDs feature a low V_F and fast switching characteristics. However, the reverse current (I_R, leakage current) is large and care must be taken since thermal runaway may occur depending on the conditions. Products with reduced I_R are listed in ROHM's lineup (described later). Their V_F is about 0.8 V even when a current as large as 10 A is passed and about 0.5 V with a current of several amperes. Furthermore, since the breakdown voltage is also lower than that of FRDs, their typical applications include DC-DC converters and the secondary side of AC-DC converters in which a higher efficiency is required.

SiC-SBDs are elements with the same basic structure as the Si-SBDs in which a junction of a metal and semiconductor is created. Silicon carbide (SiC) is employed as the semiconductor material, realizing a breakdown voltage as high as 1,200 V as well as an excellent high-speed performance. Consequently, although the FRDs with the pn junction structure are currently mainstream for diodes with high speed and high breakdown voltage, the recovery loss during the switching operation can be significantly reduced by replacing the FRDs with SiC SBDs. In addition, the SiC SBDs can be used for applications requiring a high surge tolerance because their breakdown voltage is higher than that of the FRDs.

Comparison of characteristics of FRD, Si-SBD, and SiC-SBD

In Table 1, their features are broadly compared. However, it can be difficult to determine which diode to use for switching circuits. The target characteristics to be focused on depend on the circuit types. Here, the features of the respective characteristics are compared to deepen understanding so that elements with a smaller loss or a higher breakdown voltage can be selected.

Figure 1 shows an image of the V_F and I_R characteristics. V_F is shown in the order of Si-SBD, SiC-SBD, and FRD from the lowest to the highest. I_R is shown in the order of FRD, SiC-SBD, and Si-SBD from the lowest to the highest. It is necessary to select a device with a low V_F to reduce the loss during forward operations and a device with a small I_R to reduce the loss during reverse operations. However, these orders are based on comparisons of standard products, and some products with improved V_F or I_R are also available (described later).

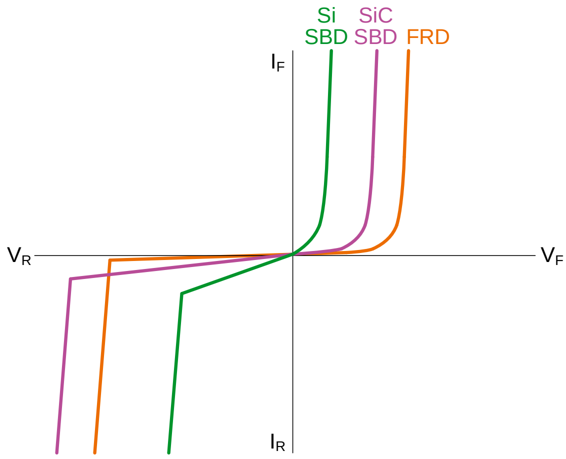

Figure 1. Image of V_F and I_R characteristics

Figure 2 shows an image of the temperature characteristics of V_F and I_R. The left graph shows the characteristics for Si diodes, where V_F is decreased and I_R is increased as the temperature is increased. In addition, since the increase in I_R at higher temperature is especially large for the Si-SBDs, they cannot be used in some applications.

Next, the right graph shows the characteristics for the SiC-SBDs. In contrast to Si, V_F is increased as the temperature is increased. Although I_R is increased similarly to Si, the value is smaller than that of Si-SBDs.

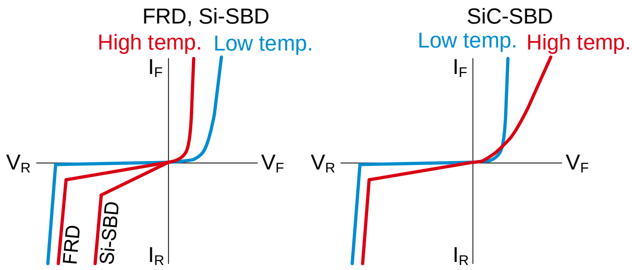

Figure 2. Image of temperature characteristics of V_F and I_R

Figure 3 shows an image of the t_{rr} characteristics. The figure shows that, since the recovery times of the FRDs and SiC-SBDs are at least 100 times faster compared with the general rectifier diodes (REC), the recovery loss during the switching operation (shaded area) can be significantly reduced. The Si-SBDs are not included in the figure because their operating voltage range is different. However, their characteristics are as fast as those of the SiC-SBDs.

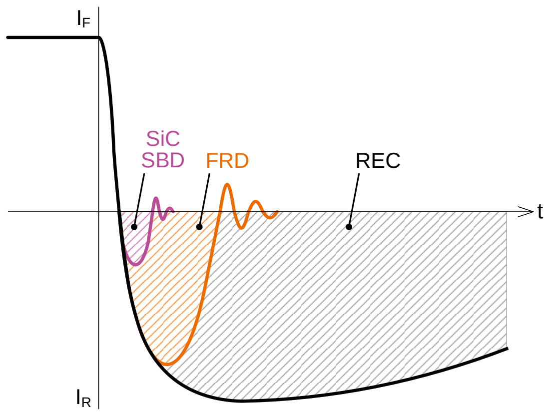

Figure 3. Image of t_{rr} characteristics

Figure 4 shows an image of the temperature characteristics of t_{rr}. For the FRDs, since the carrier concentration is increased as the temperature is increased, the reverse recovery takes longer accordingly. In contrast, for the SiC-SBDs, since SiC itself has only minor temperature characteristics, there is almost no change in the reverse current characteristics.

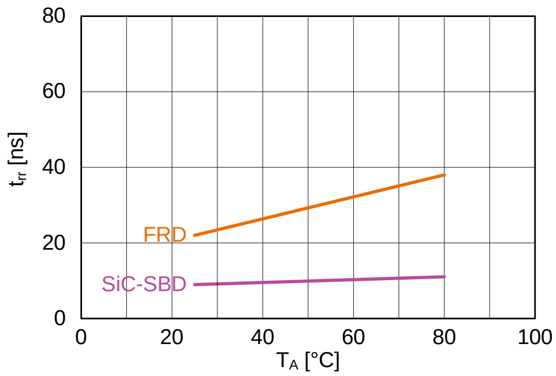

Figure 4. Image of temperature characteristics of t_{rr}

Figure 5 shows a comparison of V_R. For the SBDs focusing on low V_F characteristics, select the Si-SBDs and SiC-SBDs for low-voltage and high-voltage applications, respectively.

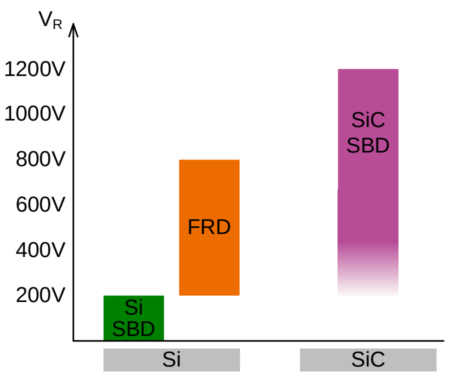

Figure 5. Comparison of V_R

There is a wide overlap between the supported voltage ranges of the FRDs and SiC-SBDs. Since the SiC-SBDs have a smaller recovery loss, they are particularly advantageous in applications where high-speed performance is important. V_F, which acts on the conduction loss, is also lower for the SiC-SBDs. For the FRDs, there is a trade-off relationship between t_{rr} and V_F that affects the recovery loss. In contrast, the SiC-SBDs have no t_{rr} in principle (the value is determined by the LC resonance composed of the terminal capacitance and the inductance of external wiring). Therefore, there is no relationship with V_F. A comparison of the characteristics of both is shown in Figure 6.

Since the cost of elements is high for the SiC-SBDs, select which elements to use while considering the balance with the total cost, including downsizing of devices by increasing the frequency and the heat dissipation design.

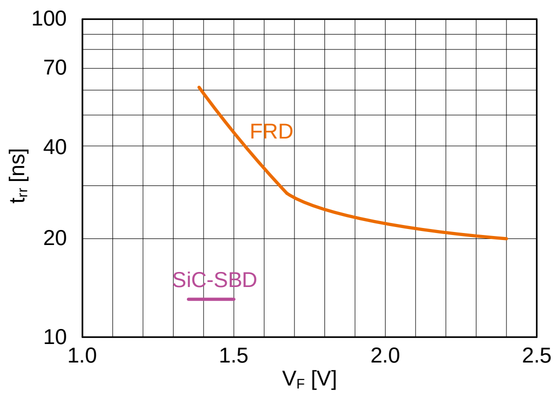

Figure 6. Image of relationship between t_{rr} and V_F

Features and types of FRD

A fast t_{rr} is a feature of the FRDs. Since there is a trade-off relationship between t_{rr} and V_F, the FRDs also feature a high V_F. ROHM has also productized elements with a reduced V_F. You can select the FRD most suitable for each application.

Table 2 shows a summary of the types of FRD and their suitable applications. The high-speed type products have a fast t_{rr}, although V_F is high. Therefore, they are suitable for the continuous current mode (CCM) power factor correction (PFC) in which the efficiency is increased as t_{rr} becomes faster and V_F has basically no effect.

The low V_F type products have a low V_F, although t_{rr} is slow. Therefore, they are suitable for the boundary current mode (BCM) PFC in which the efficiency is increased as the conduction loss of V_F is decreased and t_{rr} has little effect. In addition, they are also suitable for secondary side rectifying circuits in which the efficiency is increased as the conduction loss is decreased.

Table 2. Types of FRD and suitable applications

Type (ROHM series name)	Characteristics			Suitable applications
	V_F	I_R	t_{rr}	
Ultra-high speed (RFV)	★ 2.8 V-3 V	★★★ 10 μA	★★★ 20 ns-40 ns	Continuous current mode (CCM) PFC On-board chargers (OBC) Charging stations
High speed (RFS)	★ 2.3 V	★★★ 5 μA - 10 μA	★★★ 35 ns-55 ns	
Low V_F (RFL)	★★ 1.5 V	★★★ 5 μA - 10 μA	★★ 55 ns-75 ns	Boundary current mode (BCM) PFC Reflux diodes for inverters On-board chargers (OBC) Secondary side rectifying circuits
Ultra-low V_F (RFNL)	★★★ 1.25 V-1.3 V	★★★ 10 μA	★★ 60 ns-70 ns	

- V_F: Forward voltage. I_R: Reverse current. t_{rr}: Reverse recovery time
- ★ is an indicator of quality. The larger the number of stars, the better the characteristics.
- The numerical values are the maximum values on the data sheets for the ROHM products with an average rectified current of 5 A or more at a reverse voltage of 600 V or higher (as of September 2023).

List of FRD products

Features and types of Si-SBD

The Si-SBDs have the lowest V_F with fast switching characteristics when used in circuits of 200 V or lower. Since there is a trade-off relationship between the V_F and I_R characteristics, their I_R is typically large.

ROHM has productized elements with their characteristics optimized for each application. Table 3 shows a summary of the types of Si-SBD and their suitable applications.

The ultra-low V_F type products can realize a reduction in loss in circuits used mainly in the forward direction. They are ideal for rectifier applications in mobile devices where low-voltage operations are performed using a battery, such as in smartphones.

The low V_F type is a general-purpose series in which V_F is reduced by 25% compared with the conventional ROHM products. Since the loss in the forward direction is the smallest, they can be used for automotive applications as protection diodes in in-vehicle infotainment systems and automotive LED lamps in which improvement in efficiency is required.

The small I_R type is a series in which well-balanced characteristics of V_F and I_R are realized. Compared with the conventional ROHM products, the reverse power loss is reduced by 60% or more. Therefore, it is possible to reduce the risk of thermal runaway due to increase in I_R at high temperature. Their suitable applications include rectifiers for engine ECUs where operations in a high-temperature environment are required, protection for high output power LED headlamps, and power supplies for industrial devices in which a large current is passed.

The characteristics of the ultra-small I_R type products enable a reduction in the risk of thermal runaway. This series is ideal for rectifier applications where operations in a high-temperature environment are required, including batteries and ECUs around motors in xEVs, engine ECUs in gasoline-powered vehicles, and transmission ECUs. Products of up to 200 V are listed in the lineup. Since they can replace the rectifier diodes and FRDs, a significant reduction in V_F can be achieved.

Table 3. Types of Si-SBD and suitable applications

Type (ROHM series)	Characteristics				Suitable applications
	V_F	I_R	t_{rr}	High temperature	
Ultra-low V_F (RBS)	★★★ 0.37 V-0.49 V	★ 400 μA - 800 μA	★★★	★	Mobile devices Laptop PCs
Low V_F (RBR)	★★ 0.47 V-0.69 V	★ 50 μA - 800 μA	★★★	★	In-vehicle infotainment systems, automotive LED lamps Automotive ECUs, laptop PCs
Small I_R (RBQ, YQ)	★★ 0.57 V-0.77 V	★★ 70 μA - 450 μA	★★★	★★	xEVs, engine ECUs, high output power LED headlamps Power supplies for industrial devices
Ultra-small I_R (RBxx8)	★ 0.64 V-0.96 V	★★★ 35 nA - 30 μA	★★★	★★★	Battery management systems for xEVs, engine ECUs Inverters for industrial devices

- V_F: Forward voltage. I_R: Reverse current. t_{rr}: Reverse recovery time
- ★ is an indicator of quality. The larger the number of stars, the better the characteristics.
- The numerical values are the maximum values on the data sheets for the ROHM products (as of September 2023).

Comparisons and features of the diode characteristics are explained above. However, it is necessary to understand which target characteristics must be focused on in your application in order to select the most suitable diodes.

List of Si-SBD products

Features and types of SiC-SBD

The features of SiC-SBDs realize a high breakdown voltage while showing an excellent high-speed performance. The breakdown voltage of Si-SBDs can be increased by increasing the thickness of the n$^-$ type layer and decreasing the carrier concentration. However, their characteristics become impractical due to an increase in loss, for example, with an increased resistor value and a higher V_F. Therefore, the breakdown voltage of Si-SBDs is limited to 200 V. In contrast, since the dielectric breakdown field strength of SiC is 10 times higher than that of Si, the breakdown voltage can be increased to 600 V or higher while maintaining practical characteristics. Products of 650 V, 1,200 V, and 1,700 V are listed in ROHM's lineup.

As a result, the recovery loss can be significantly reduced by replacing currently prevailing FRDs with SiC-SBDs. This contributes to improvement in the power supply efficiency, downsizing of passive components including coils by high frequency drive, and noise reduction.

The SiC-SBDs are used to increase the reliability of power conversion systems, including battery chargers, charging circuits in electric and hybrid vehicles, and solar panels.

Currently, ROHM has productized second- and third-generation SiC-SBDs. Table 4 shows the typical electrical characteristics of both product generations. The second-generation SBD has an excellent surge current tolerance (I_{FSM}) and low V_F characteristics. In the third generation, these performances are further improved and I_R is reduced, which has a trade-off relationship with decrease in V_F.

Table 4. Comparison of typical characteristics of SiC-SBD

V_R=650 V, I_F=12 A

Parameter	Second generation SCS212AG	Third generation SCS312AH
Forward voltage V_F (12 A, 25°C)	1.35 V	1.35 V
V_F (12 A, 150°C)	1.55 V	1.44 V
V_F (12 A, 175°C)	1.63 V	1.50 V
Reverse current I_R (25°C)	2.4 µA (600 V)	0.036 µA (650 V)
I_R (150°C)	36 µA (600 V)	2.4 µA (650 V)
I_R (175°C)	84 µA (600 V)	7.2 µA (650 V)
Surge non-repetitive forward current I_{FSM} (150°C)	34 A	81 A

List of SiC-SBD products
List of SiC-SBD bare die products

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