What is a diode?

General description of diodes and our diode products

Contents

1. Description

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

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

- **Selection Guides**
  https://www.semicon.sanken-ele.co.jp/common/pdf/selectionguide/sge0006.pdf

2. Diodes

2.1. What Is a Diode?

A diode is a semiconductor device, allowing the flow of current in one direction. If you compare electric current to the flow of water, a diode works like a “valve”.

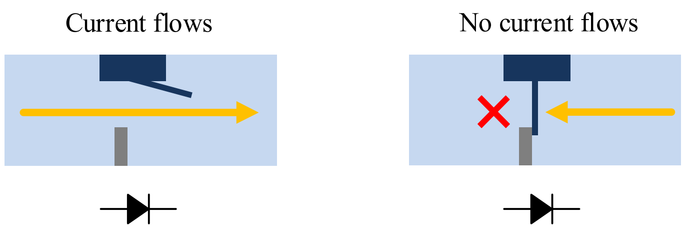

Figure 2-1. Schematic View of Diode

Figure 2-2 shows the examples of actual diodes. Each diode is marked on the cathode side. See Section 2.3 for cathode.

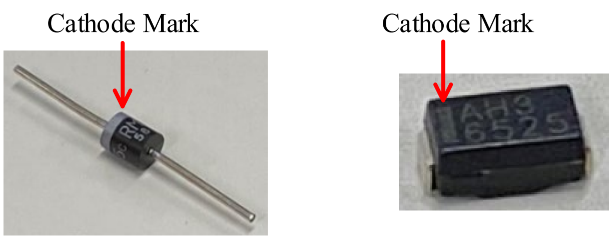

Figure 2-2. Examples of Diodes

2.2. Diode Applications

● **Rectification**

Diodes allow the current to pass in one direction only. This is called rectification. Figure 2-3 shows a full-wave rectifier circuit that uses the diode rectification. Full-wave rectifier circuits are often used in power supply circuits, and are combined with capacitors to convert alternating current to direct current.

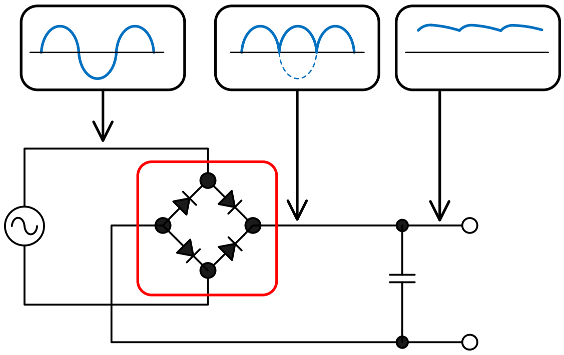

Figure 2-3. Full-wave Rectifier Circuit

● **Reverse direction current prevenction**

Diodes protect circuits and circuit components by preventing current from flowing in the reverse direction.

● **Overvoltage protection**

Diodes protect circuits and circuit components from overvoltage.

2.3. Diode Structure

Diode junction structures are classified into PN junctions and Schottky junctions.

● **PN junctions**

Semiconductors whose charge carriers are holes are called P-type semiconductors. Semiconductors whose charge carriers are electrons are called N-type semiconductors. A structure in which a P-type semiconductor and an N-type semiconductor are joined is called a PN junction. Rebonding (carriers disappearing when electrons fill holes) occurs at the junction, creating a region no charge carriers are present. This is called the depletion layer.

The terminal on the P-type semiconductor side is called anode, and the terminal on the N-type semiconductor side is called cathode.

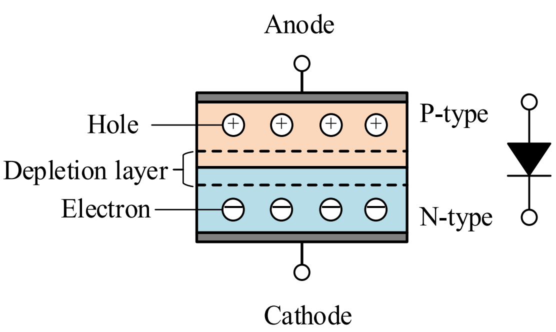

Figure 2-4. PN Junction

The N-layer of an actual diode consists of an N+ layer and an N− layer. The breakdown voltage of the diode is determined by the thickness of the N− layer and the carrier concentration. The thicker the N− layer and the lower the carrier concentration, the higher the breakdown voltage. However, there is a trade-off relationship between breakdown voltage and resistance, thus, increasing the breakdown voltage also increases the resistance.

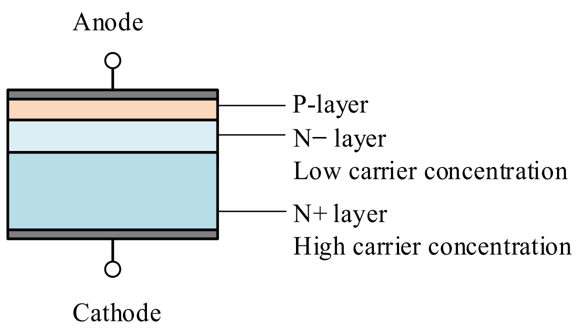

Figure 2-5. PN Junction (P-layer / N-layer)

- **Schottky junction**

A structure in which metal and a semiconductor (generally an N-type semiconductor) are joined is called Schottky junction. A Schottky barrier is created at the junction. The terminal on the metal side is called the anode, and the terminal on the N-type semiconductor side is called the cathode. Since P-type semiconductors are not used, holes are not used as carriers.

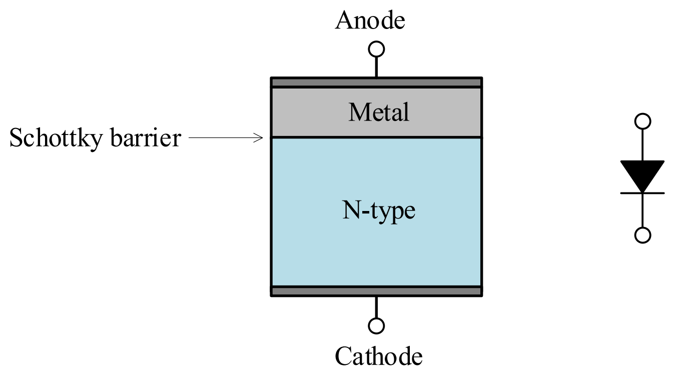

Figure 2-6. Schottky Junction

A diode allows the current to flow when a voltage is applied in the forward direction (positive voltage to the anode and negative voltage to the cathode). Even if voltage is applied in the reverse direction, no current flows.

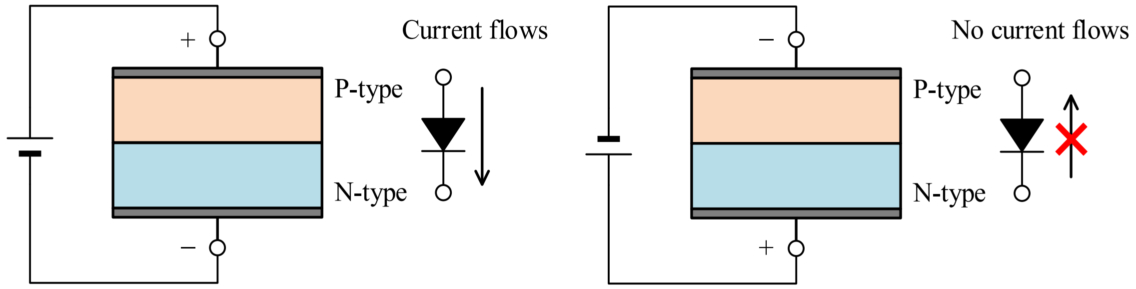

Figure 2-7. Direction to Apply Voltage

2.4. Why Does the Current Flow in One Direction?

The current flow is described using a PN junction diode as an example.

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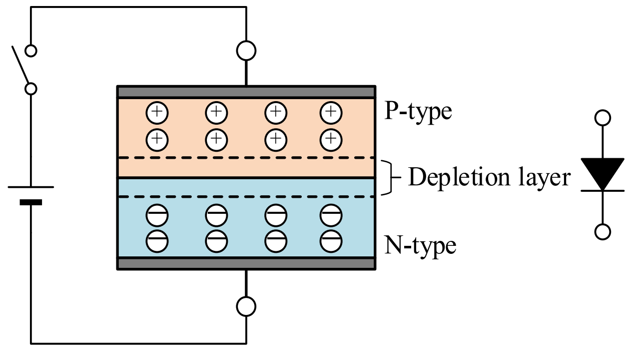
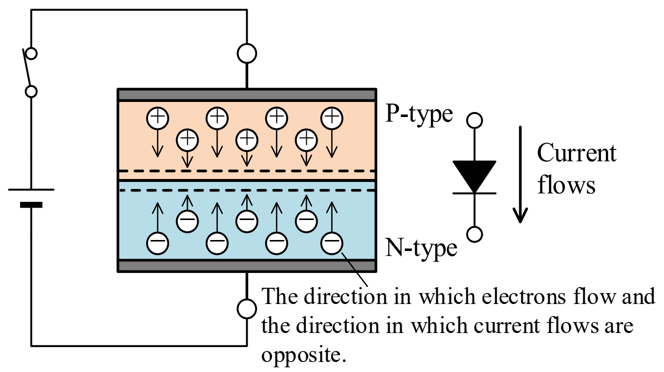
<tr>
<td>
</td>
<td>No voltage applied
Holes and electrons are in equilibrium.</td>
</tr>
<tr>
<td>
</td>
<td>Voltage applied in the forward direction
When a voltage is applied in the forward direction, the depletion layer narrows, and holes and electrons repeatedly recombine. Holes and electrons continue to move in the direction of the arrow (i.e., the current flows.)</td>
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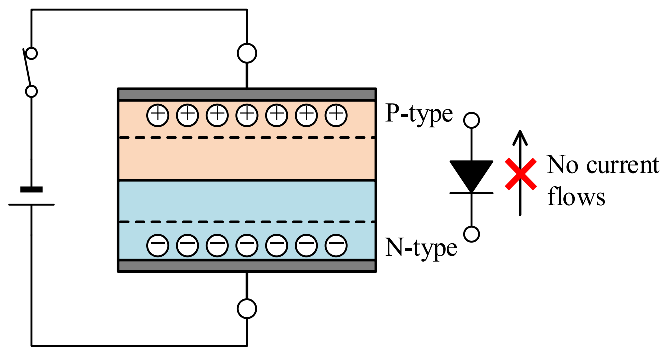
<td>
</td>
<td>Voltage applied in the reverse direction
When a voltage is applied in the reverse direction, the depletion layer expands, and holes and electrons do not move (i.e., no current flows.)</td>
</tr>
</table>

2.5. Electrical Characteristics

This section describes the electrical characteristics of diodes.

2.5.1. Static Characteristics

Figure 2-8 shows the static characteristic of diodes.

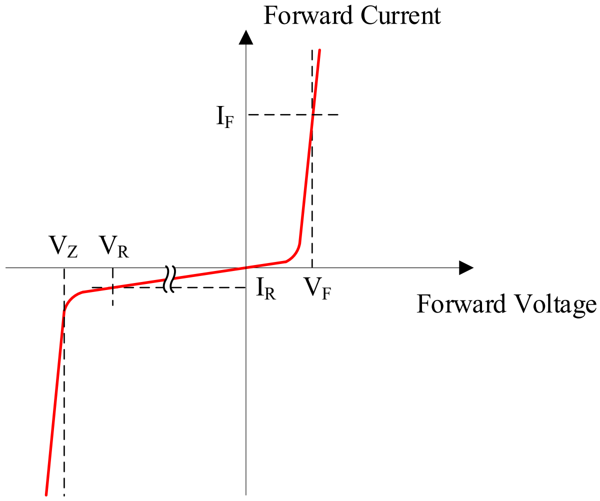


Figure 2-8. Static Chracteristics of Diodes

- Forward Voltage Drop, V_F, and Forward Current, I_F
  The current that flows when a voltage is applied in the forward direction is called the forward current, I_F. The voltage when I_F flows is called the forward voltage drop, V_F.
  When comparing the I_F – V_F characteristics of diodes, the lower the V_F required to flow the same amount of I_F, the lower the power loss and the better the characteristics.
  V_F has a negative temperature characteristic and thus the higher the temperature, the lower the V_F.
- Reverse Voltage, V_R, and Reverse Leakage Current, I_R
  The current that flows when a voltage is applied in the reverse direction is called the reverse leakage current, I_R. The voltage when I_R flows is called the reverse voltage, V_R.
  When a voltage is applied in the reverse direction, a slight leakage current, I_R, flows. A diode with a smaller I_R has less power dissipation and can prevent thermal runaway.
  I_R has positive temperature characteristics, and thus the higher the temperature, the higher the I_R.
- Breakdown Voltage, V_Z
  When the reverse voltage, V_R, is increased, the reverse leakage current, I_R, increases sharply at a certain voltage. This voltage is called the breakdown voltage, V_Z. The breakdown voltage is also called the Zener voltage.

2.5.2. Switching Characteristic

As shown in Figure 2-9, the recovery current flows when the reverse voltage is applied from the state where the forward voltage is applied by turning the switch. The time from when the recovery current flows until the recovery current decreases is called the Reverse Recovery Time, t_{rr}. The larger the forward current, I_F, the longer the t_{rr}. Since the recovery current causes noise and power loss, the shorter the t_{rr}, the better the characteristics.

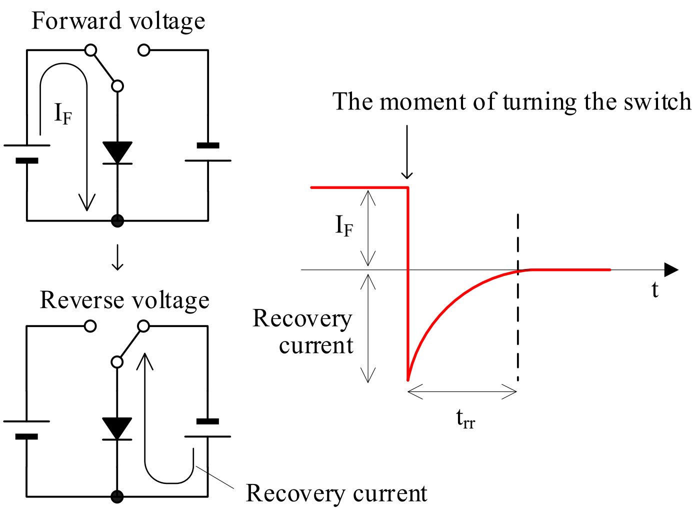
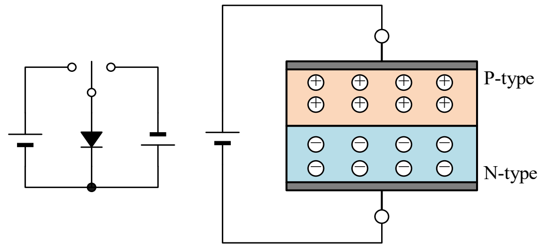
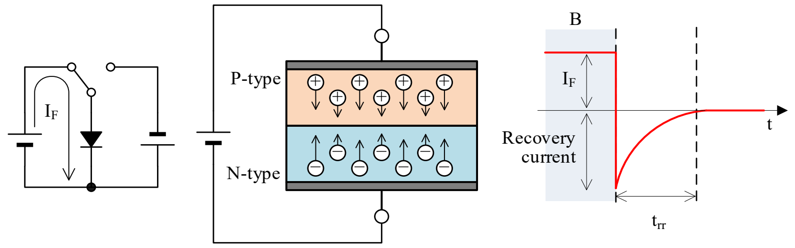
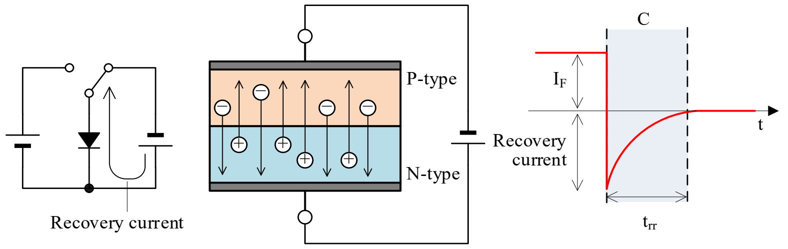
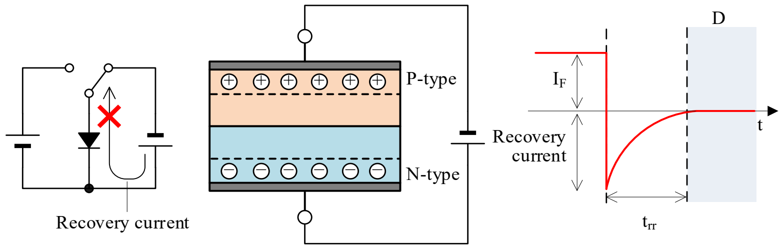


Figure 2-9. Reverse Recovery Time, t_{rr}

The following describes the reason why the recovery current flows when a voltage changes from the forward voltage to the reverse voltage.

	**A: When no voltage applied** Holes and electrons are in equilibrium.
	**B: When forward voltage applied** Electrons move to P-type semiconductors and holes move to N-type semiconductors (i.e., I_F is flowing).
	**C: The moment when the reverse voltage is applied** At the moment the switch is turned, a reverse voltage is applied to the diode, and the directions of movement of electrons and holes are reversed. The current that flows at this time is the recovery current.
	**D: When reverse voltage applied** After a moment, the depletion layer expands, and holes and electrons do not move. The time from C to D is t_{rr}.

3. Types of Diodes

Table 3-1 shows the types of our diodes. This section describes the applications and features of each type of diode.

Table 3-1. Types of Diodes

Junction Type	Diode Type	Product List
PN Junction	General-purpose Rectifier Diodes	URL
	Fast Recovery Diodes	URL
	High Voltage Rectifier Diodes	URL
	Snubber Diodes	URL
	TVS Diodes	URL
	Alternator Diodes	URL
Schottky Junction	Schottky Diode	URL

3.1. General-purpose Rectifier Diodes

General-purpose rectifier diodes are used for commercial power supply rectification (50 Hz / 60 Hz) and reverse connection protection circuits. These diodes have high breakdown characteristics.

3.2. Fast Recovery Diodes

A fast recovery diode (FRD) is used for rectifying high frequencies (several tens to hundreds of kHz) such as switching power supplies. Compared with general-purpose rectifier diodes, the reverse recovery time, t_{rr}, is shorter. While t_{rr} of a general-purpose rectifier diode is several µs to several tens of µs, t_{rr} of an FRD is several tens to several hundreds of ns.

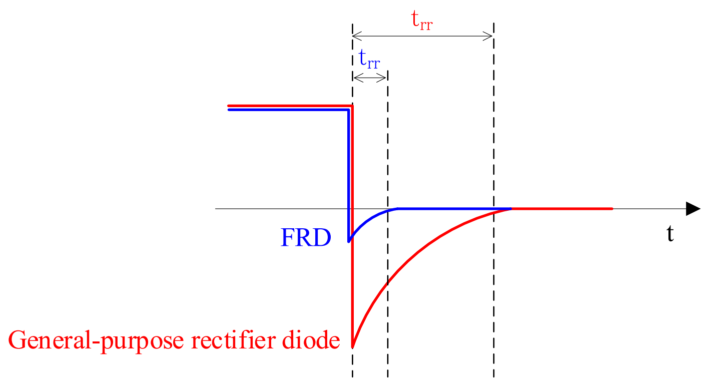


Figure 3-1. Comparison of Reverse Recovery Time, t_{rr}

The reverse recovery time, t_{rr}, of an FRD is short because holes are captured by carrier traps near the junction. As shown in Figure 3-2, when holes that have penetrated to the N-layer move to the P-layer, the carrier traps in the N-layer capture the holes and quickly eliminate the holes to shorten t_{rr}.

However, there is a trade-off relationship between t_{rr} and the forward voltage drop, V_F. Thus, providing a carrier trap structure to shorten t_{rr} increases V_F. Conversely, lowering the V_F increases t_{rr}.

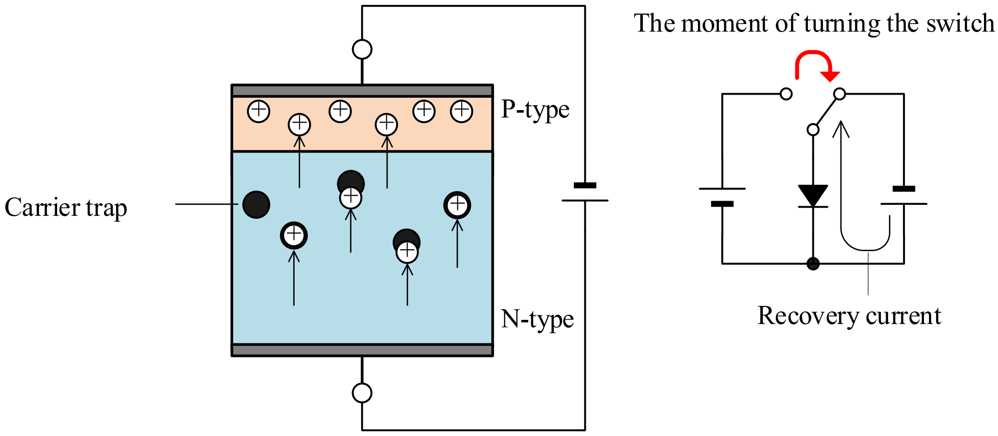


Figure 3-2. Carrier Trap

Since the FRD recovery current causes power loss, the peak value of the recovery current should be small. When the recovery current recovers abruptly, a ringing occurs and may thus cause noise. Therefore, the FRD with a smaller recovery current and a softer recovery has better characteristics (see Figure 3-3).

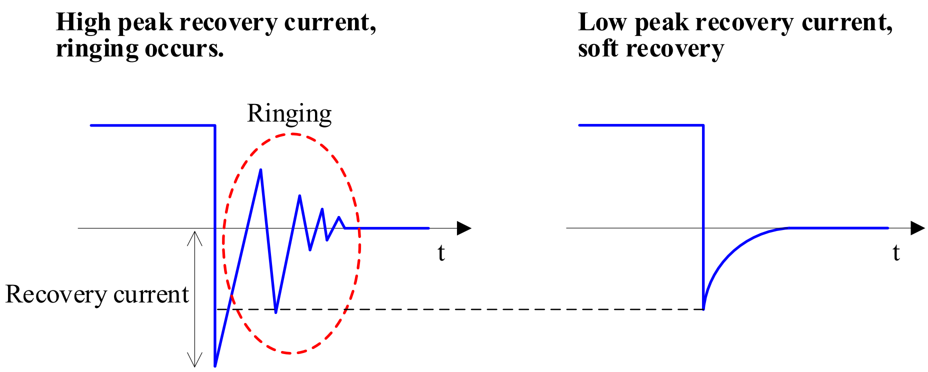


Figure 3-3. FRD Reverse Recovery Time, t_{rr}

3.3. High Voltage Rectifier Diodes

High-voltage rectifier diodes for consumer use are used in microwave oven inverter circuits and high-voltage circuits. Automotive high voltage rectifier diodes are used for ignition coils of fuel injection systems.

3.4. Snubber Diodes

Snubber diodes are auxiliary switch diodes especially designed for snubber circuits, which are used in the primary-side of flyback switching power supplies. They reduce the ringing voltage generated at power MOSFET turn-off, contributing to improvement of the efficiency of switching power supplies and noise reduction.

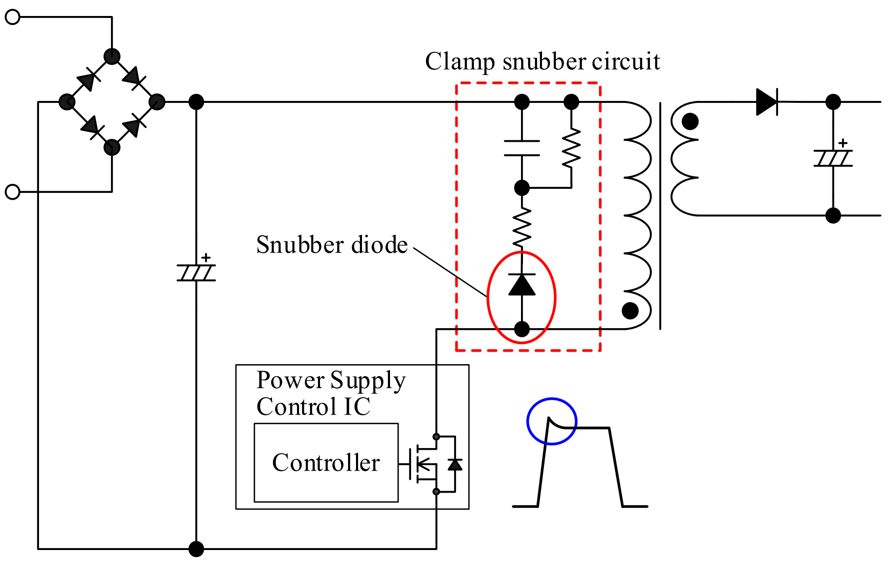


Figure 3-4. Clamp Snubber Circuit

3.5. Alternator Diodes

Alternator diodes can withstand the harsh environments of automotive engine rooms. They are available in surface mount and pressfit type packages.

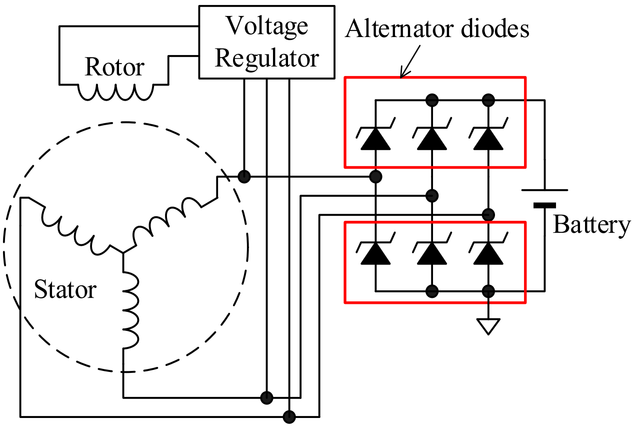


Figure 3-5. Alternator

3.6. TVS Diodes

Transient voltage suppressor (TVS) diodes are used to protect circuits and devices from overcurrent, overvoltage, and surges. The reverse voltage of the TVS diodes during breakdown is almost constant regardless of the current flowing (see Figure 3-6). TVS diodes use the reverse characteristic to protect circuits and devices.

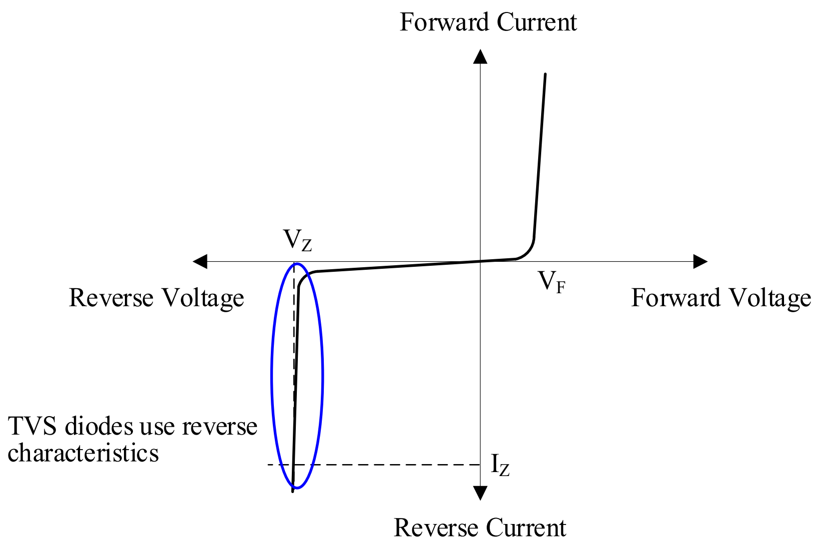


Figure 3-6. Diode Static Characteristics

3.7. Schottky Diode

Schottky diodes use the barriers created by Schottky junctions. Compared with PN junction diodes, Schottky diodes have a lower forward voltage drop, V_F, and a shorter reverse recovery time, t_{rr}, making them suitable for high-speed switching. t_{rr} has no temperature dependence and thus t_{rr} is the same at all temperatures.

However, compared with PN junction diodes, Schottky diodes have a larger reverse leakage current, I_R, and higher power loss ($I_R \times V_R$). The higher the temperature, the higher the power loss. Hence, it is required to design the heat dissipation so that thermal runaway does not occur.

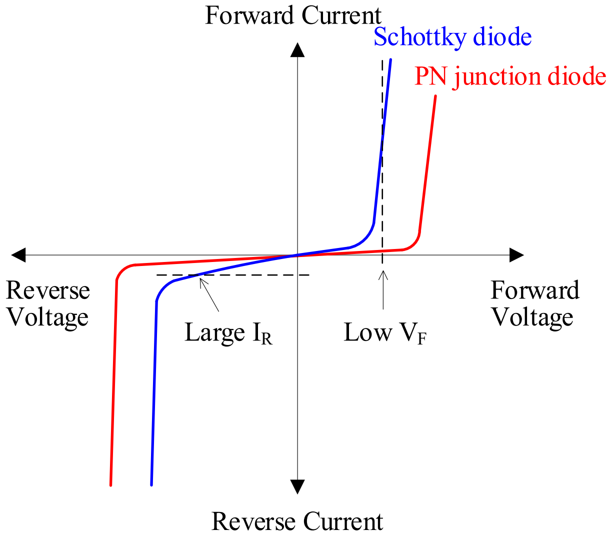


Figure 3-7. Static Characteristics Comparison

The breakdown voltage of Schottky diodes is lower than that of PN junction diodes, and it is difficult to achieve high breakdown voltage (generally up to 150 V). As shown in Figure 3-8, the breakdown voltage is increased by thickening the N-layer and lowering the carrier concentration. However, this also increases resistance and V_F. As a result, increased loss leads to the diode performance deviating from its practical use range. At Sanken Electric, we have recently been developing SiC Schottky diodes with high breakdown voltage and practicality by using the next-generation power semiconductor material, SiC.

Next-generation power semiconductors: https://www.semicon.sanken-ele.co.jp/en/guide/GaNSiC.html

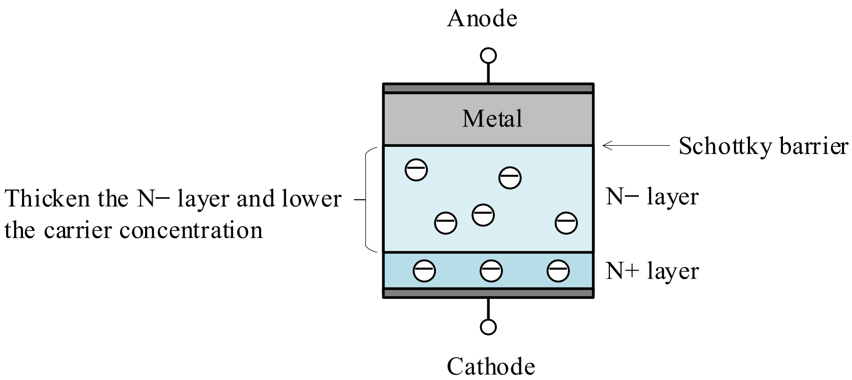


Figure 3-8. Schottky Junction

The height of the Schottky barrier depends on the type of metal connected to the semiconductor. The electrical characteristics are different depending on the type of metal. As shown in Figure 3-9, there is a trade-off relationship between the forward voltage drop, V_F, and the reverse leakage current, I_R, depending on the type of metal. Select the metal according to the target characteristics.

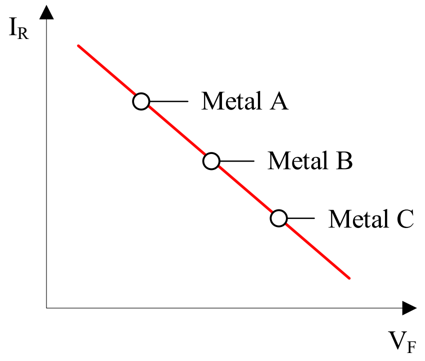


Figure 3-9. Characteristics Depending on the Metals

4. Diode Ratings and Characteristics

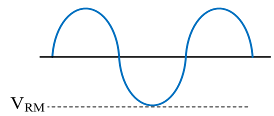
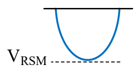
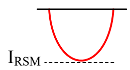
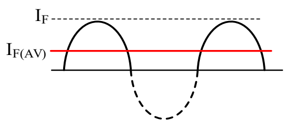
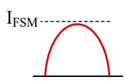
Absolute maximum ratings and electrical characteristics are described in the data sheet. This section describes the ratings and characteristics described in our data sheet.

4.1. 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 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. As a result, semiconductors may not withstand long-term use.

The parameters specified in the absolute maximum ratings are listed below. The parameters of absolute maximum ratings listed depend on the diode type.

Parameter	Symbol	Unit	Description	Schematic Waveform
Repetitive Peak Reverse Voltage	V_{RM}	V	Maximum reverse voltage (AC) that can be applied repeatedly	
Nonrepetitive Peak Reverse Voltage	V_{RSM}	V	The maximum reverse voltage that can be applied without repetition	
Peak Pulse Reverse Current	I_{RSM}	A	The maximum leakage current that can flow in the reverse direction without repetition	
Power Dissipation	P_D	W	The maximum power dissipation that the product can maintain its function	
DC Blocking Voltage	V_{DC}	V	The maximum reverse voltage (DC) that can be applied repeatedly	
Peak Pulse Reverse Power	P_{RSM}	W	The maximum power dissipation that can be permitted in the reverse direction without repetition	
Average Forward Current	$I_{F(AV)}$	A	Average forward current, I_F	
Surge Forward Current	I_{FSM}	A	The maximum current that can flow in the forward direction without repetition	
I^2t Limiting Value	I^2t	A^2s	I_{FSM} limit value that can flow with a pulse width of 1 ms $\leq t_P <$10 ms	
Junction Temperature	T_J	°C	Temperature of semiconductor junction in the product	
Storage Temperature	T_{STG}	°C	Temperature at which the product can be stored when the device is not operating	

4.2. Electrical Characteristics

Electrical characteristics show the performance of a product by specifying conditions such as temperature, voltage, and current. The parameters of electrical characteristics to be listed depend on the type of diode.

Parameter	Symbol	Unit	Description
Forward Voltage Drop	V_F	V	Voltage drop that occurs when a current flows in the forward direction
Forward Current	I_F	A	Current that flows when a voltage is applied in the forward direction
Reverse Voltage	V_R	V	Voltage drop that occurs when a current flows in the reverse direction
Reverse Leakage Current	I_R	µA	Leakage current that flows when a voltage is applied in the reverse direction
Reverse Leakage Current under High Temperature	$H{\cdot}I_R$	mA	Leakage current that flows when a voltage is applied in the reverse direction at high temperature
Breakdown Voltage	V_Z	V	Voltage when a voltage is applied in the reverse direction and current flows rapidly
Reverse Current	I_Z	A	Current that flows when reverse breakdown voltage, V_Z, is applied
Thermal Resistance	$R_{th(J\text{-}C)}$	°C/W	Thermal resistance between semiconductor junction and case
	$R_{th(J\text{-}L)}$	°C/W	Thermal resistance between semiconductor junction and lead
Breakdown Voltage Temperature Coefficient	r_Z	mV/°C	The coefficient that shows the relationship between V_Z and temperature
Breakdown Region Equivalent Resistance	R_Z	Ω	A value that shows the relationship between V_Z and current
Reverse Recovery Time	t_{rr}	µs	The time from when the recovery current flows until the recovery current decreases
Pulse Width	t_P	ms	Time of current flowing through the product and the applied voltage
Case Temperature	T_C	°C	Product case temperature
Lead Temperature	T_L	°C	Product lead temperature
Ambient Temperature	T_A	°C	Ambient temperature of the product

4.3. Mechanical Characteristics

These are the mechanical characteristics of a product. The parameters of mechanical characteristics to be listed depend on the type of diode.

Parameter	Unit	Description
Heatsink Mounting Screw Torque	N·m	Maximum tolerance of heatsink mounting screw torque
Package Weight	g	Product weight

Important Notes

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- No anti-radioactive ray design has been adopted for the Sanken Products.
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