Basics of Diodes
(Types and Overview of Diodes)

Outline:

Diodes are used in a wide range of equipment for various applications such as rectification, reverse-current blocking, and circuit protection. In addition to silicon (Si) pn diodes, various other types of diodes are available, including Schottky barrier diodes (SBDs), transient voltage suppressor (TVS) diodes (also known as ESD protection diodes), and Zener diodes. Toshiba's product portfolio also includes state-of-the-art silicon carbide (SiC) SBDs fabricated using a compound semiconductor. This application note provides an overview of the classification and operation of diodes.

Table of Contents

List of Figures

List of Tables

1. Types of diodes

1.1. Classification of diodes according to their applications and characteristics

Different types of diodes are available for various applications. Diodes are broadly classified into two types: pn diodes that are based on the pn junction formed by p-type and n-type semiconductors and metal-semiconductor diodes (commonly known as Schottky barrier diodes or SBDs for short) that are formed by the junction of a metal with either an n-type or p-type semiconductor. Figure 1.1 shows the classification of diodes according to their applications and characteristics.

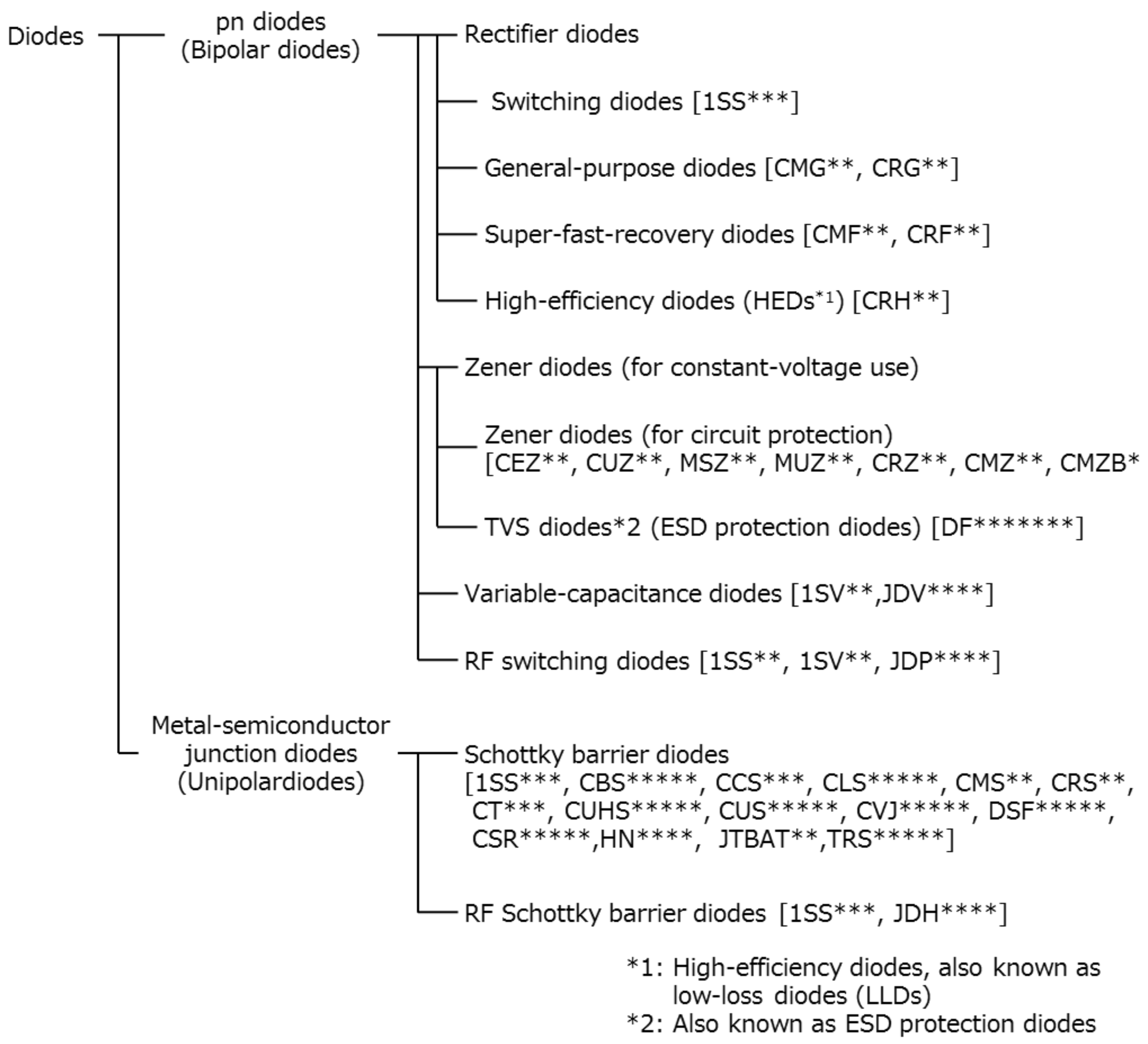


Figure 1.1 Types of diodes

Figure 1.2 shows the classification of diodes according to their internal connections.

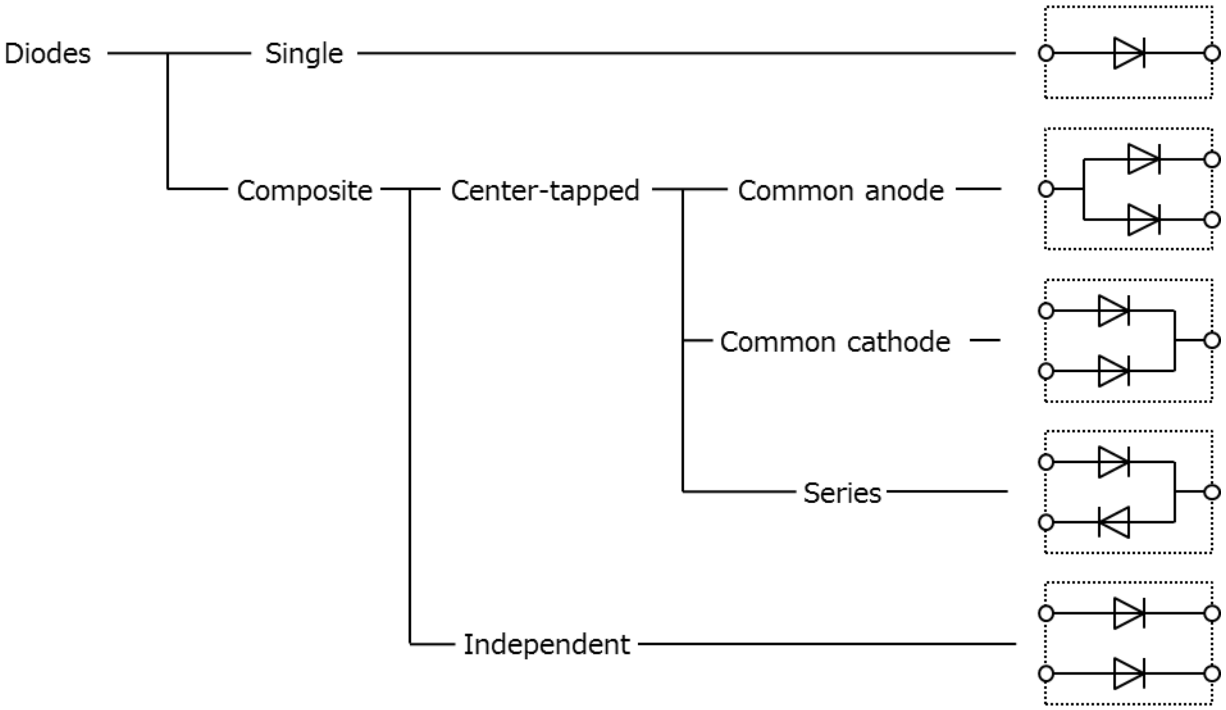


Figure 1.2 Classification of diodes according to their internal connections

2. Overview of various types of diodes

2.1. pn diodes

2.1.1. What is a pn junction?

A pn junction is an interface between two types of semiconductor materials, p-type and n-type, maintaining their orderly crystal lattice arrangements. These semiconductors have different Fermi levels. The Fermi level of the p-type region is close to the highest energy level of a valence band whereas the Fermi level of the n-type region is close to the lowest energy level of a conduction band.

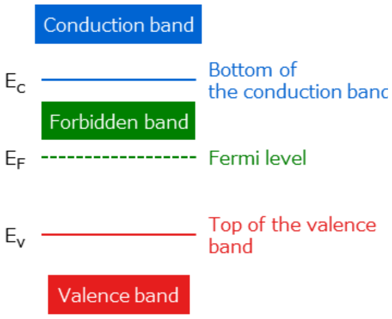


Figure 2.1 Fermi level of intrinsic semi-conductors

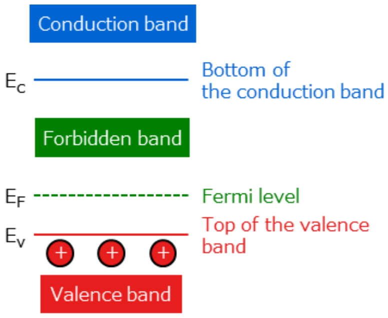


Figure 2.2 Fermi level of p-type semi-conductors

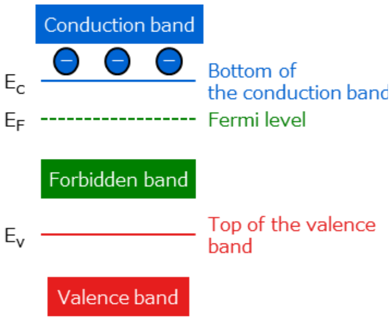


Figure 2.3 Fermi level of n-type semi-conductors

2.1.2. pn junction in an unbiased state

Electrons in the n-type semiconductor close to the pn junction diffuse into the p-type semiconductor and recombine with holes there. Conversely, holes in the p-type semiconductor diffuse into the n-type semiconductor and recombine with electrons there. The recombination of carriers (free electrons and holes) causes a region where no carriers exist to be formed as shown in Figure 2.5. This region is called a depletion layer.

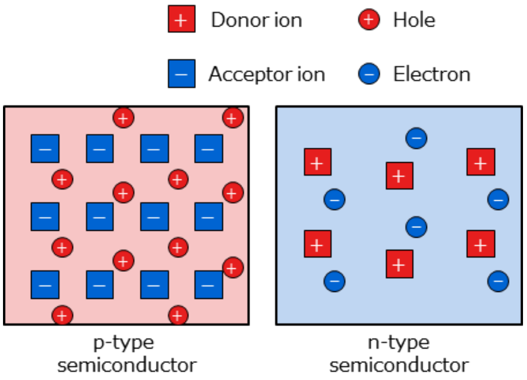


Figure 2.4 P-type and n-type semiconductors before they are joined together

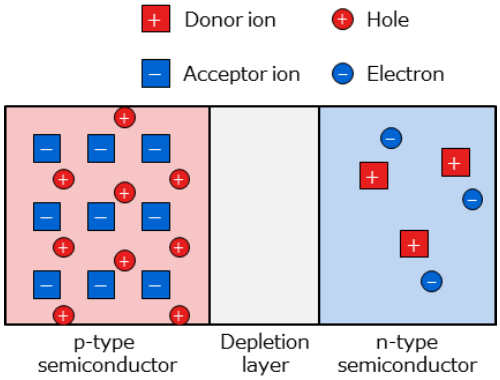


Figure 2.5 P-type and n-type semiconductors after they are joined together

When p-type and n-type semiconductors are joined together, carrier diffusion causes the Fermi level of the p-type semiconductor to move upwards and that of the n-type semiconductor to move downwards, resulting in the formation of new Fermi levels as shown in Figure 2.6. The decrease in the Fermi level in the conduction band is equal to the work function of the p-type and n-type regions. As a result, a diffusion potential (qV_D) appears between them.

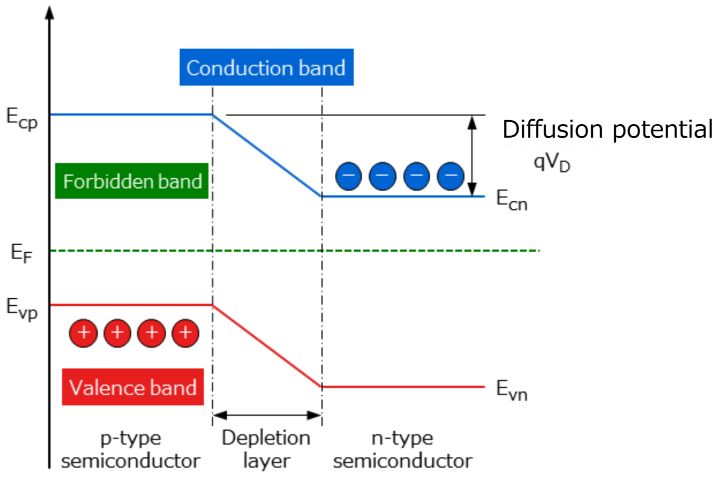


Figure 2.6 Band diagram of a pn junction

Figure 2.7 shows the electron and hole densities in the p-type and n-type semiconductors when the pn junction is unbiased. Electrons in the n-type semiconductor that have energy higher than E_{cp} can move into the p-type semiconductor. Likewise, holes in the p-type semiconductor that have energy lower than E_{vn} can move into the n-type semiconductor. At this time, the electron densities in the n-type and p-type semiconductors (n_n and n_p) become almost equal. When $n_n \approx n_p$, the movement of electrons stops, reaching an equilibrium state. The hole densities in the n-type and p-type semiconductor (p_n and p_p) have the same relationship.

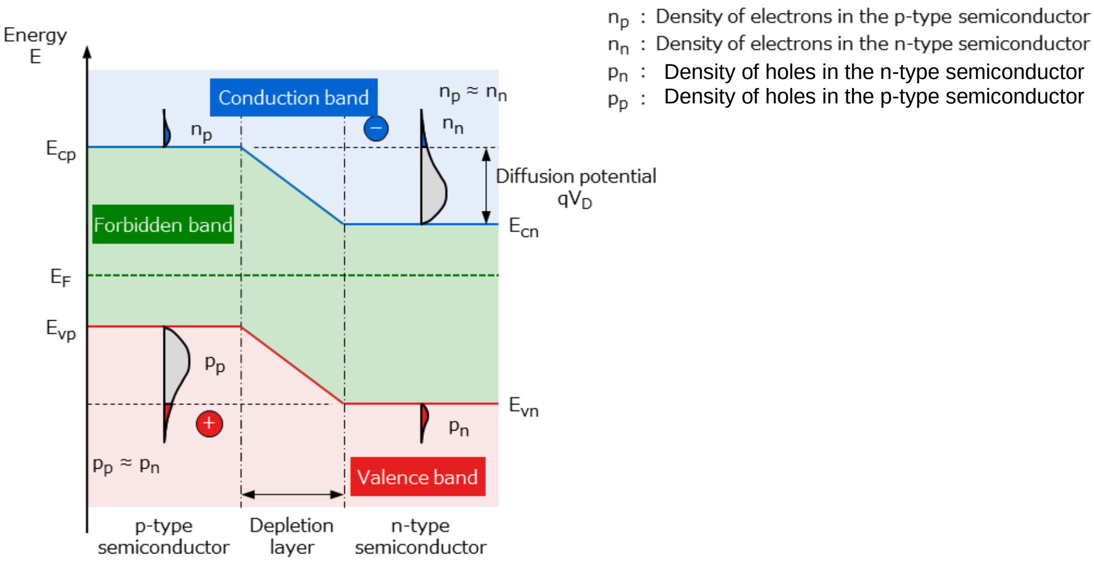
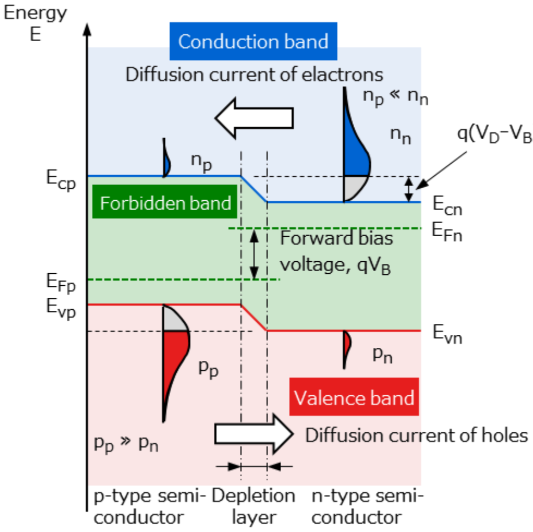


Figure 2.7 Band diagram of a pn junction in an unbiased state

2.1.3. pn junction in the forward-biased state

When a forward bias of qV_B is applied across the pn junction (with the p-type semiconductor being more positive than the n-type semiconductor), its diffusion potential decreases from qV_D in the unbiased state to $q(V_D\text{-}V_B)$. As a result, the density of electrons in the n-type semiconductor that have energy higher than E_{cp} becomes higher than the electron density in the p-type semiconductor, causing a huge amount of electrons to move from the n-type semiconductor to the p-type semiconductor. At the same time, a multitude of holes in the p-type semiconductor diffuse into the n-type semiconductor. Therefore, electric current flows.

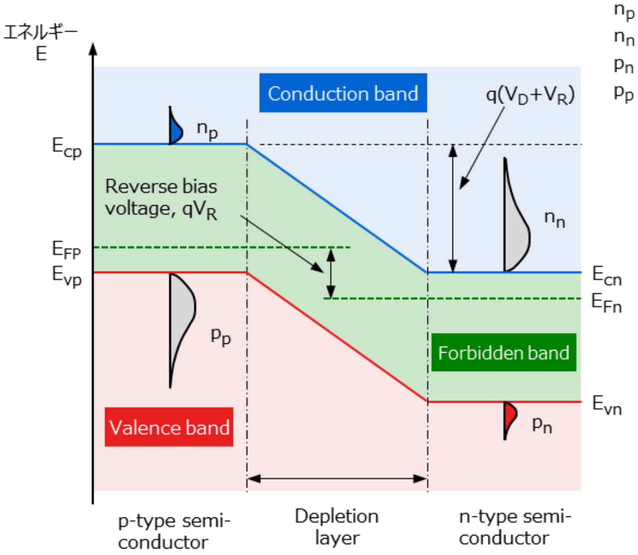


n_p : Density of electrons in the p-type semiconductor
n_n : Density of electrons in the n-type semiconductor
p_n : Density of holes in the n-type semiconductor
p_p : Density of holes in the p-type semiconductor

Figure 2.8 Band diagram of a pn junction in the forward-biased state

2.1.4. pn junction in the reverse-biased state

When a reverse bias of qV_R is applied across the pn junction (with the p-type semiconductor being more negative than the n-type semiconductor, the p-type semiconductor is applied negatively and the n-type semiconductor is applied positively), the diffusion potential increases from qV_D in the unbiased state to $q(V_D+V_R)$. As a result, the density of electrons in the n-type semiconductor that have energy higher than E_{cp} becomes almost zero. Likewise, holes in the p-type semiconductor that can diffuse into the n-type semiconductor almost disappear, causing the current flow to stop.



n_p : Density of electrons in the p-type semiconductor
n_n : Density of electrons in the n-type semiconductor
p_n : Density of holes in the n-type semiconductor
p_p : Density of holes in the p-type semiconductor

Figure 2.9 Band diagram of a pn junction in the reverse-biased state

2.1.5. Electric characteristics of pn diodes

In the case of a diode formed by a pn junction, the forward current (I_F) is expressed by Equation 2-1. This equation applies to the low-current region, but not to the high-current region because the internal resistance of a diode causes a voltage drop in the high-current region.

$$I_F = I_S \cdot \left(e^{\frac{q \cdot V_F}{K \cdot T}} - 1\right) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (2\text{-}1)$$

I_F : Forward current (A)
I_S : Saturation current (A)
q : Electron charge (1.602×10^{-19}) (C)
V_F : Forward voltage (V)
K : Boltzmann constant (1.381×10^{-23}) ($J \cdot K^{-1}$)
T : Junction temperature (in Kelvin) (K)

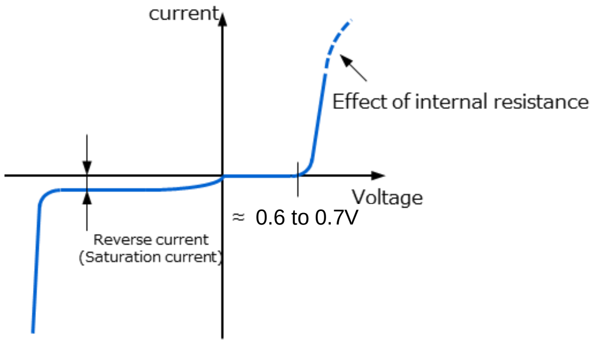


Figure 2.10 Current-voltage curve of a pn diode

Figure 2.10 shows the current-voltage curve of a pn diode. When a forward bias of 0.6 to 0.7 V is applied across a Si diode, its forward current rises suddenly.

The forward voltage (V_F) of the Si diode has a temperature coefficient of roughly -2 mV/°C. However, the temperature coefficient decreases in the high-current region because a voltage drop due to internal resistance has a positive temperature coefficient.

The current that flows through a diode when it is reverse-biased is called reverse current (I_R)[*3] or saturation current (I_S). I_R is approximated by Equation 2-2:

[*3] Also called leakage current

$$I_R = I_{R0} \cdot e^{k(T-T_0)} \qquad \cdots\cdots\cdots \qquad (2\text{-}2)$$

I_R	:	Reverse current at temperature T	(A)
I_{R0}	:	Reverse current at the reference temperature (T_0)	(A)
k	:	Constant determined by the semiconductor material used (approximately 0.1/°C in the case of Si)	
T	:	Temperature	(°C)
T_0	:	Reference temperature	(°C)

Figure 2.11 shows an example of the I_R curve over temperature. In this example, I_R exhibits a double-digit increase over a temperature increase (ΔT_a) of 75°C.

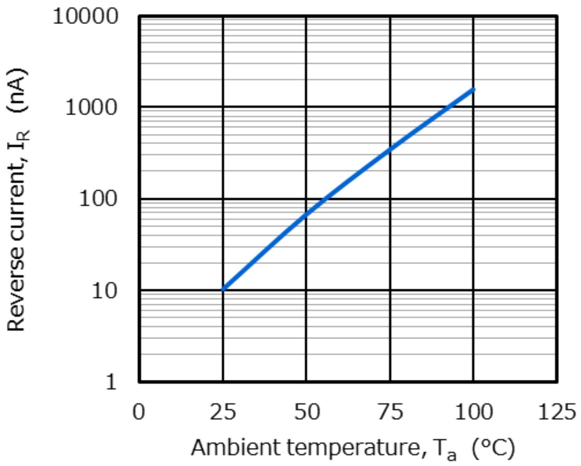


Figure 2.11 Example of a pn diode's reverse current-vs-ambient temperature curve

2.1.6. PIN diode

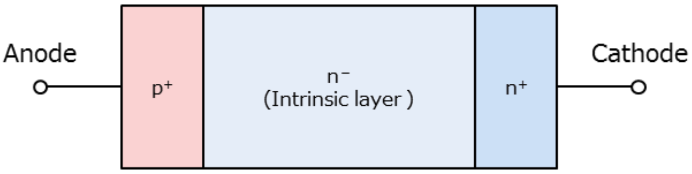


Figure 2.12 Structure of a PIN diode

Typical Si diodes using a pn junction have a thick n^- layer*4 with a low dopant concentration between p^+ and n^+ layers as shown in Figure 2.12. The n^- layer is called an intrinsic layer because it has a dopant concentration close to that of an intrinsic semiconductor. Since this diode has a p-i-n structure, it is called a PIN diode. The PIN diode has unique characteristics described below.

*4 The n$^-$ layer is also called a high-resistance layer or a drift layer.

1) Increase in breakdown voltage

When the pn junction is reverse-biased, a depletion layer expands in the intrinsic layer. The electric field increases the most at the pn junction. When it exceeds the maximum electric field strength, either avalanche or Zener breakdown occurs. The breakdown voltage of the pn junction is determined by the triangular area shown in Figure 2.13. Therefore, the breakdown voltage can be increased by decreasing the dopant concentration of the n$^-$ layer to make the slope of the electric field strength shallow and by increasing the thickness of the n$^-$ layer.

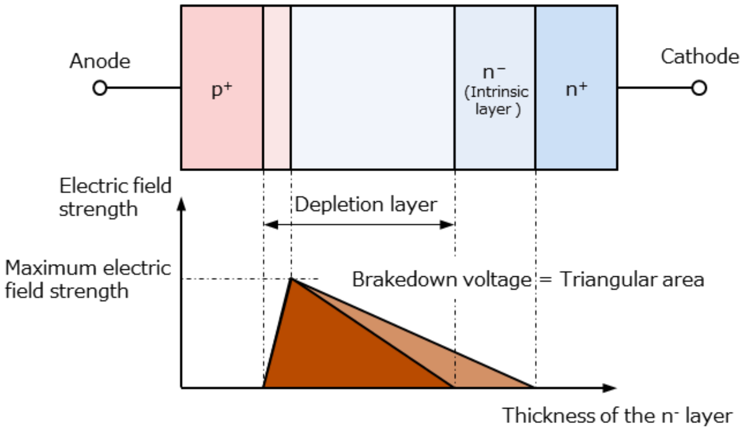


Figure 2.13 Increasing the breakdown voltage of a PIN diode

2) Low conduction resistance

When the pn diode consisting of a p$^+$ and an n$^-$ layer conducts, holes are injected from the p$^+$ layer into the n$^-$ layer. Conversely, electrons are injected from the n$^+$ layer into the n$^-$ layer, causing the carrier density in the n$^-$ layer to exceed its dopant concentration. As a result, the resistance of the n$^-$ layer decreases when the pn diode conducts. The phenomenon that an increase in the number of carriers in the n$^-$ layer causes a decrease in conduction resistance is called conductivity modulation.

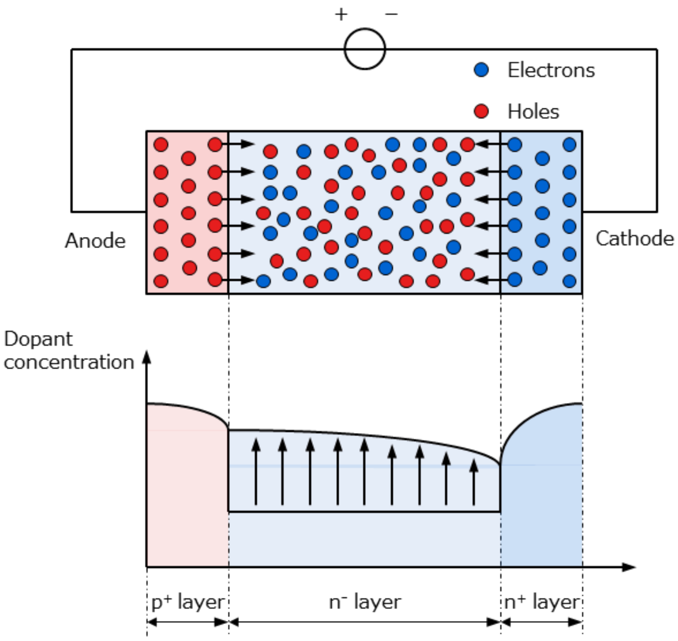


Figure 2.14 Change in the dopant concentration of the n⁻ layer due to conductivity modulation

2.2. Schottky barrier diodes

2.2.1. Schottky junction

Figure 2.15 shows the structure of a Schottky barrier diode. A Schottky barrier diode is a type of diode formed by the metal-to-semiconductor junction that behaves as a rectifier. The Schottky barrier diode (SBD) is named after Walter Hans Schottky. In an SBD, a Schottky junction is formed by a deposited metal and an n-type semiconductor.

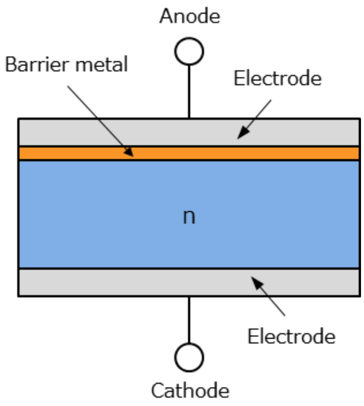


Figure 2.15 Example of a structure of a Schottky barrier diode

A metal has a Fermi level between valence and conduction bands and does not have a forbidden band (i.e., a bandgap) as shown in Figure 2.16. Therefore, a metal has a huge amount of holes in a valence band and a huge amount of electrons in a conduction band.

Figure 2.17 shows a band diagram of an n-type semiconductor. The n-type semiconductor has a forbidden band between valance and conduction bands in which no electron states can exist. The Fermi level is located within the forbidden band.

A Schottky junction is formed when an n-type semiconductor is joined with a metal that has a lower Fermi level than that of the n-type semiconductor. The Schottky junction behaves as a rectifier. In contrast, an ohmic junction is formed when an n-type semiconductor is joined with a metal that has a higher Fermi level than that of the n-type semiconductor. The ohmic junction behaves as a resistor.

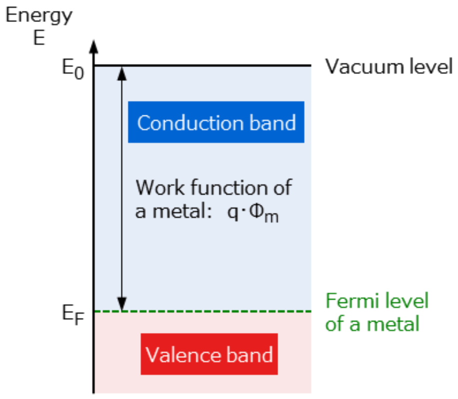


Figure 2.16 Band diagram of a metal

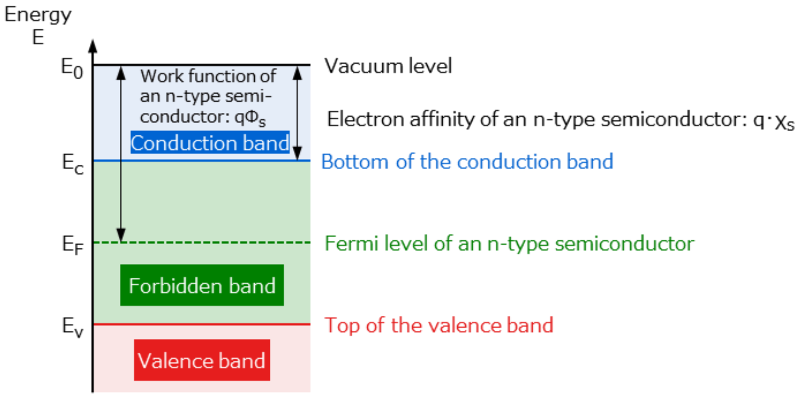


Figure 2.17 Band diagram of an n-type semiconductor

When a metal and an n-type semiconductor are joined together, some electrons diffuse into the metal from the n-type semiconductor, making their Fermi level constant. At the same time, the lowest energy level in the conduction band (E_C) and the highest energy level in the valence band (E_V) of the n-type semiconductor change as shown in Figure 2.18. At this time, diffusion energy of $q\Phi_{bi}=q(\Phi_m-\Phi_s)$ is generated between the metal and the n-type semiconductor, causing a depletion layer to be formed by positive ions on the n-type semiconductor side. A depletion layer hardly expands into the metal even when electrons flow into it from the n-type semiconductor because the metal has a huge amount of electrons. When the Schottky junction is unbiased, no current flows because electrons cannot exceed the diffusion energy level of the depletion layer, $q(\Phi_m-\Phi_s)$.

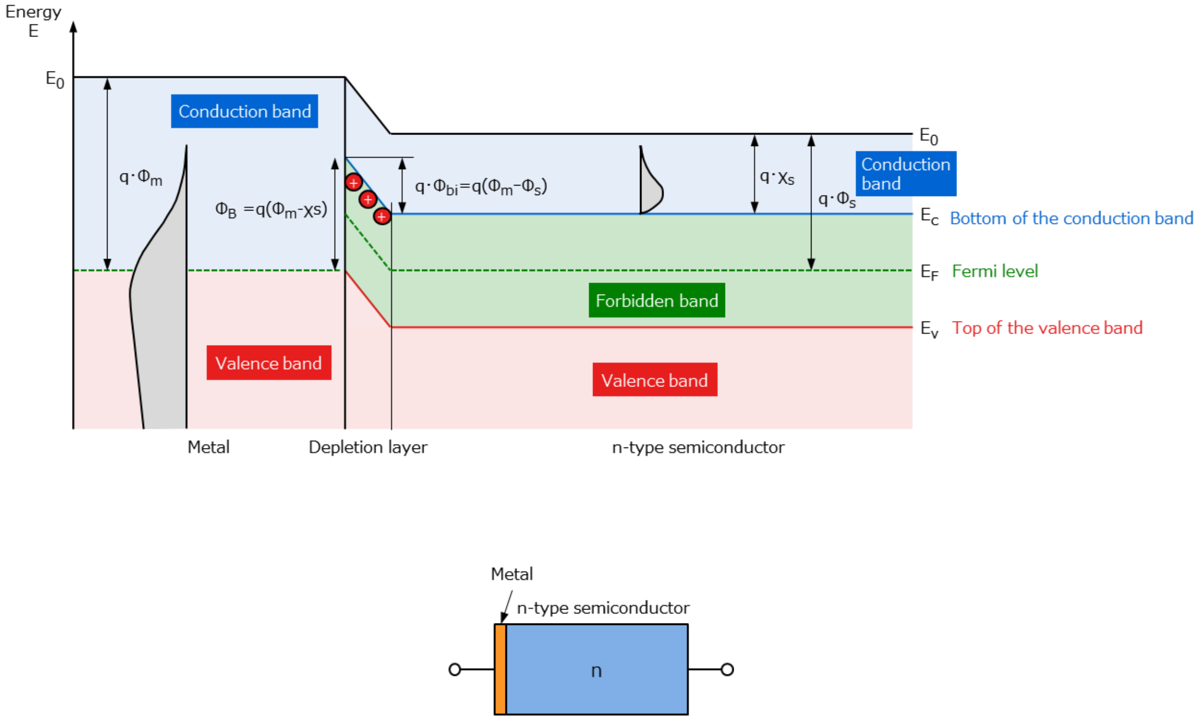


Figure 2.18 Band diagram of a Schottky junction in an unbiased state

When a forward bias of V_B is applied across the Schottky junction, the energy level of the n-type semiconductor rises, increasing the number of electrons that exceed the diffusion energy, $q(\Phi_m - \Phi_s - V_B)$. These electrons move into the metal, allowing current to flow.

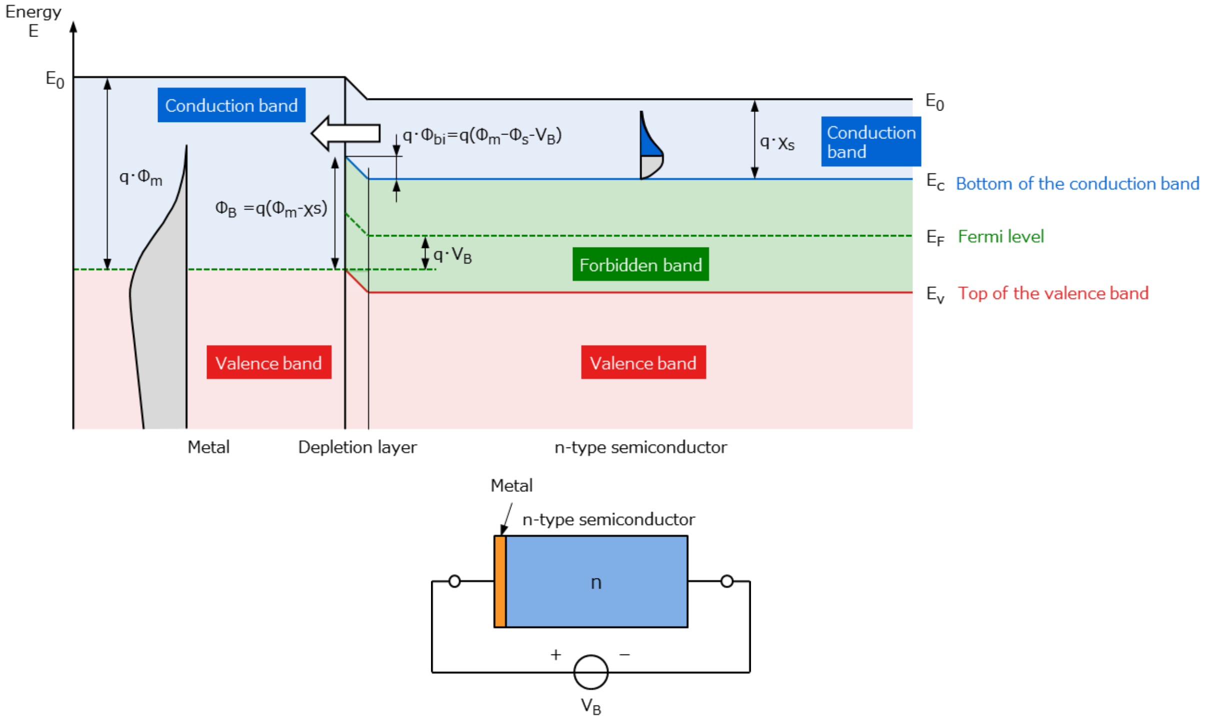


Figure 2.19 Band diagram of a Schottky junction in the forward-biased state

When a reverse bias of V_R is applied across the Schottky junction, the energy level of the n-type semiconductor drops. Therefore, few electrons can exceed the diffusion energy, $q(\Phi_m- \Phi_s+V_R)$, causing the current flow to stop.

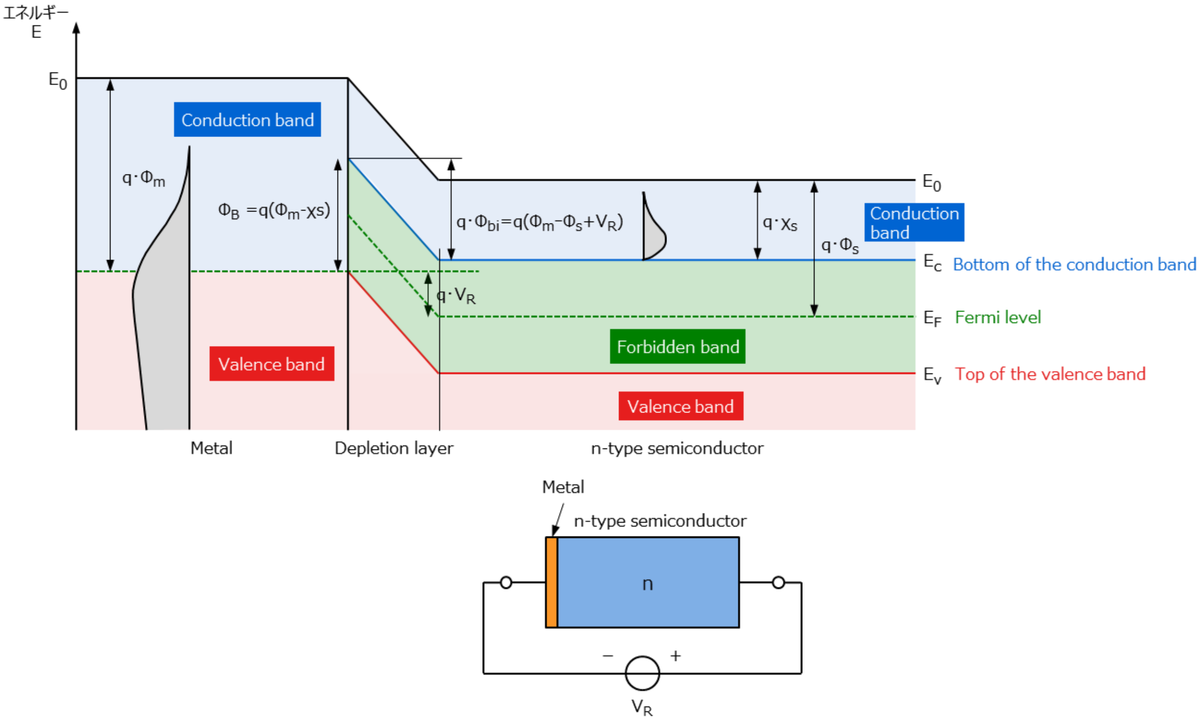


Figure 2.20 Band diagram of a Schottky junction in the reverse-biased state

Typically, molybdenum (Mo), titanium (Ti), and vanadium (V) are used as a barrier metal forming a Schottky junction. A major characteristic of the SBD is that its current rises at a voltage lower than the Si diode.

The diffusion potential of vanadium (V) and titanium (Ti) is lower than that of molybdenum (Mo). Therefore, SBDs using vanadium and titanium have lower metal-to-semiconductor barrier potential than those using molybdenum and tend to exhibit larger reverse current. SBDs with large reverse current cause an increase in junction temperature because of power dissipation equal to reverse voltage multiplied by reverse current. Reverse current has a positive temperature coefficient. In other words, reverse current increases as junction temperature increases. As junction temperature increases, reverse current, in turn, increases, eventually leading to thermal runaway and ultimately to destruction or degradation of the device. Therefore, care should be taken as to the reverse bias voltage applied, ambient temperature, and other usage conditions when using SBDs.

2.2.2. JBS structure

Despite low forward voltage (V_F), an SBD exhibits large reverse current. Since reverse current has a positive temperature coefficient, it increases as temperature increases. A rise in temperature, in turn, causes an increase in reverse current, eventually leading to thermal runaway, depending on the reverse voltage applied, ambient temperature, and other usage conditions. Thermal runaway might cause device destruction or degradation. Toshiba's product portfolio includes diodes designed with a Junction Barrier Schottky (JBS) structure to reduce reverse current.

Figure 2.21 shows the cross-sectional view of an SBD with the JBS structure, which has p-type layers buried in the n layer. When an SBD is reverse-biased, depletion layers begin to expand across the n and diffused p layers. As the reverse bias voltage is increased, adjacent depletion layers merge, suppressing an increase in reverse current.

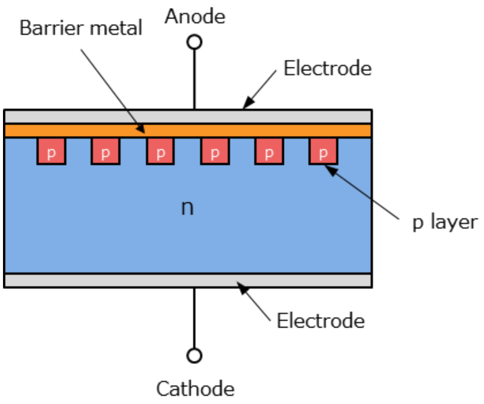


Figure 2.21 JBS structure

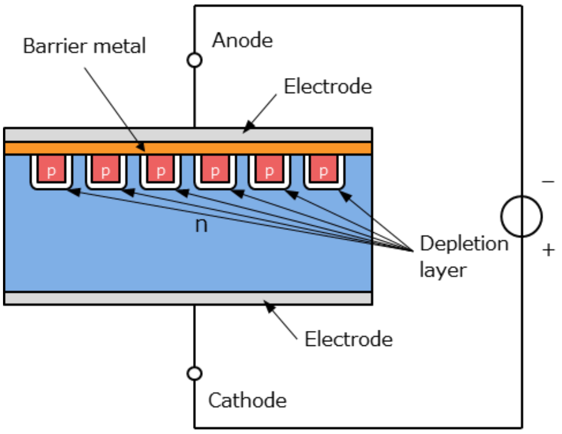


Figure 2.22 Formation of depletion layers by the application of a reverse bias across the Schottky junction

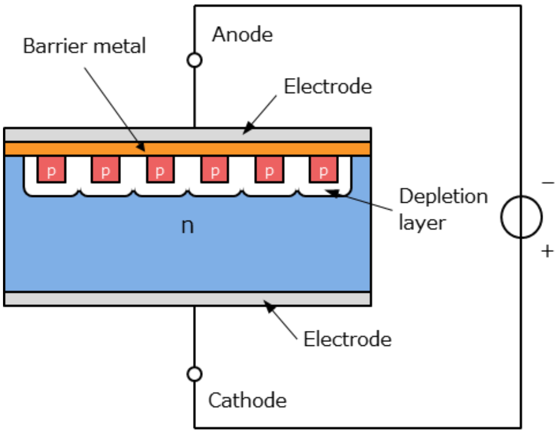


Figure 2.23 Expansion of depletion layers by an increase in reverse bias across the Schottky junction

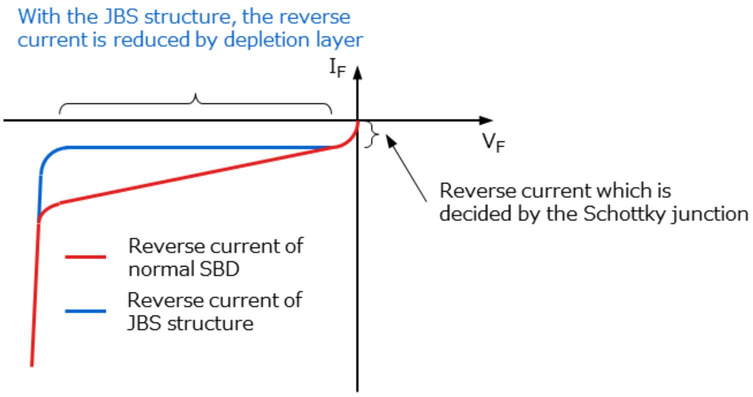


Figure 2.24 Comparison of the reverse current characteristics of SBDs with typical and JBS structures

2.3. SiC Schottky barrier diodes

2.3.1. What is SiC?

Silicon carbide (SiC) consists of silicon (Si) and carbon (C) atoms. Each atom is surrounded by four different atoms in the form of a regular tetrahedron. SiC is the compound semiconductor with the densest tetrahedral arrangement. SiC has many crystalline structures called polytypes that exhibit different physical properties because of periodic differences in the overlap of tetrahedrons.

Compared to silicon, SiC has a wider energy gap where no electron states can exist (called a bandgap, E_g) between valence and conduction bands. A wide bandgap provides a strong atomic bond and therefore a high electrical breakdown field. SiC has an electrical breakdown field that is roughly ten times that of silicon. Because of a strong atomic bond, SiC has greater lattice vibration and consequently conducts energy more easily than silicon. Therefore, SiC is a semiconductor material with good thermal conduction. The polytypes of SiC include 4H-SiC and 6H-SiC that are hexagonal crystal structures and 3C-SiC that is a cubic crystal structure. Table 2-1 compares the physical properties of silicon and other semiconductor materials. 4H-SiC is commonly used as a semiconductor material because it provides a better balance among electron mobility, electrical breakdown field, saturation electron drift velocity, and other physical properties than other polytypes of SiC.

Table 2-1 Physical properties of typical semiconductor materials

Property	Symbol	Unit	Si	4H-SiC	6H-SiC	3C-SiC	GaN	GaAs	ダイヤモンド
Bandgap	E_g	eV	1.12	3.26	3.02	2.23	3.39	1.43	5.47
Electron mobility	μ_e	cm^2/Vs	1400	1000/1200	450/ 100	1000	900	8500	2200
Hole mobility	μ_h		600	120	100	50	150	400	1600
Electric breakdown field	E_c	V/ cm	3.0×10^5	2.8×10^6	3.0×10^6	1.5×10^6	3.3×10^6	4.0×10^5	1.0×10^7
Thermal conductivity	λ	W/ cm·K	1.5	4.9	4.9	4.9	2.0	0.5	20
Saturation electron drift velocity	V_{sat}	cm/ s	1.0×10^7	2.2×10^7	1.9×10^7	2.7×10^7	2.7×10^7	2.0×10^7	2.7×10^7
Relative dielectric constant	ε_r	-	11.8	9.7/ 10.2	9.7/ 10.2	9.7	9.0	12.8	5.5

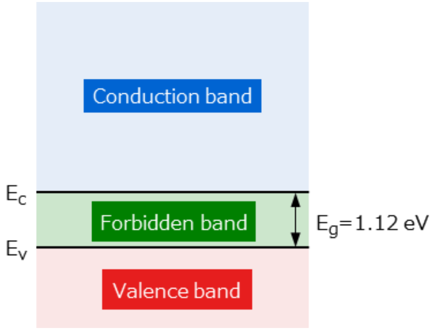


Figure 2.25 Bandgap of Si

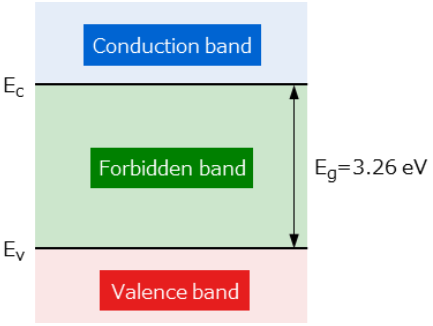


Figure 2.26 Bandgap of SiC

High-voltage Si power devices have low electric breakdown field. In order to achieve high breakdown voltage, it is necessary to provide a wide n^- layer with low dopant concentration as shown in Figure 2.27. However, a lightly doped n^- layer has large resistivity, causing the conduction resistance of a diode to increase.

Since the electric breakdown field of SiC is nearly 10 times that of silicon, SiC makes it possible to increase the dopant concentration and reduce the thickness of the n^- layer in order to obtain the breakdown voltage equivalent to that of Si diodes.

Electron and hole mobilities (μ) characterize how quickly an electric field can accelerate the velocity of an electron or a hole [(velocity = mobility (μ) × electric field (E)]. A higher carrier mobility (μ) means that an electric current flows more easily with less resistance. Since SiC provides a higher saturation electron drift velocity (i.e., a higher limit to μ) than Si, SiC makes it possible to create high-performance devices.

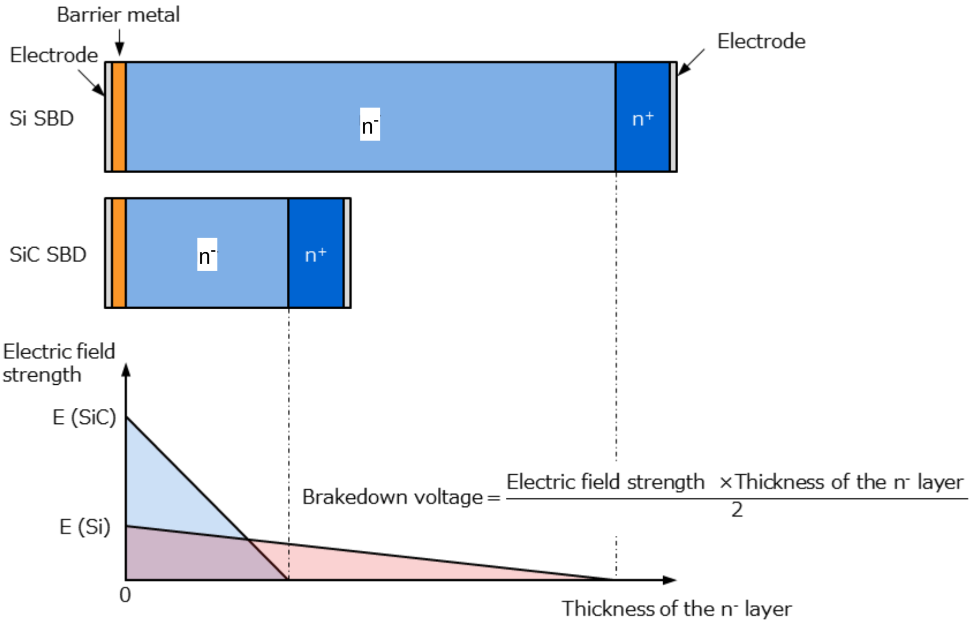


Figure 2.27 Comparison of electric fields in Si and SiC SBDs

2.3.2. SBD with an improved JBS structure

Large current flows through SiC and other types of rectifier diodes when charging a capacitance load. Therefore, high forward pulse current capability (I_{FP} or I_{FSM}) is required for these diodes.

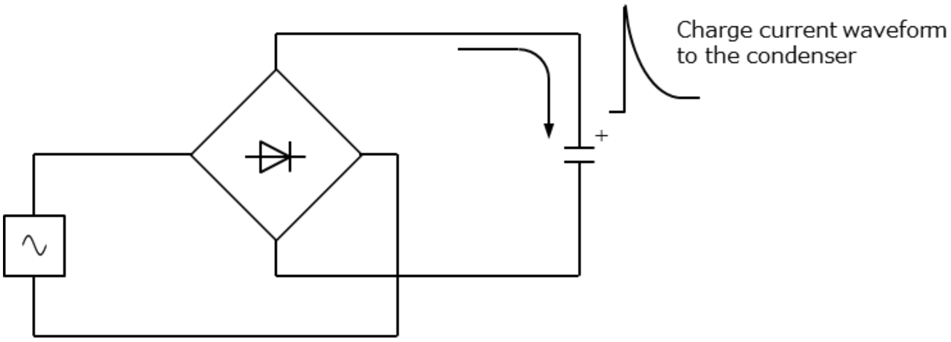


Figure 2.28 Example of a waveform of a charging current flowing to a capacitor for full-wave rectification

To meet this requirement, Toshiba has developed new SiC SBDs with an improved JBS structure incorporating the concept of the Merged PIN Schottky (MPS) structure.

The MPS structure has p^+ layers buried in the n^- layer of an SBD as shown in Figure 2.29. (Toshiba's MPS structure replaces some of the p layers in a JBS structure with p^+ layers.) When large current flows through an SBD, the pn diode formed by the p^+ and n^- layers conducts in addition to the Schottky junction. At this time, the p^+ layers provide holes for the n^- layer while the n^+ layer provides electrons for the n^- layer. This causes conductivity modulation, increasing the carrier concentration in the n^- layer (see section 2.1.6). Conductivity modulation reduces the resistance of the n^- layer, making it possible to conduct large current and increase allowable peak forward surge current.

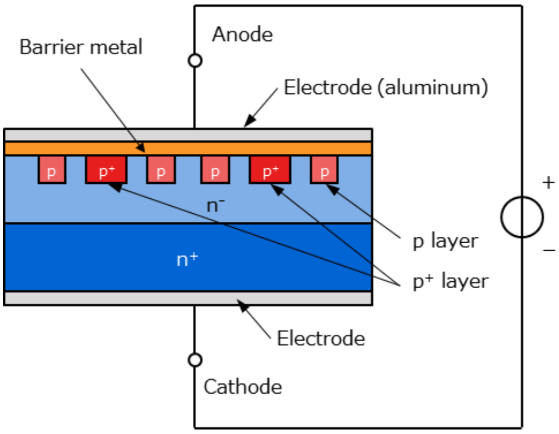


Figure 2.29 Cross-sectional view of an SBD with an improved JBS structure

Figure 2.30 shows the forward current-vs-forward voltage curve of an SBD with an improved JBS structure. This SBD provides high pulse current capability as well as low forward voltage even in the high-current region.

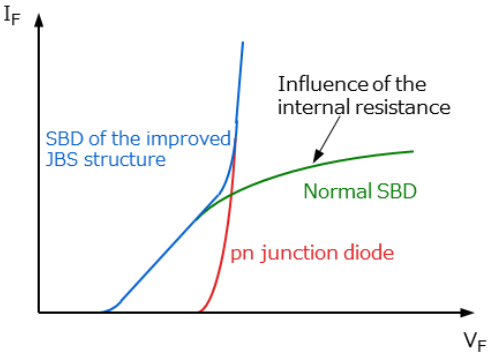


Figure 2.30 Forward current-vs-forward voltage curves of a typical SBD, a pn diode, and an SBD with an improved JBS structure

2.4. Zener diodes

Zener diodes differ from typical rectifier and switching diodes in that they are used in the breakdown region in which the reverse characteristics of the pn junction are stable. Typical diodes cannot be used in the reverse breakdown region unless it is specifically noted that it is permissible. Using typical diodes in the reverse breakdown region causes a local breakdown phenomenon, which might cause current concentration, resulting in the destruction of the pn junction. In contrast, Zener diodes are designed in such a manner that current does not concentrate locally at the pn junction.

The breakdown characteristics of a Zener diode are determined by the dopant profile in the vicinity of the pn junction as well as its shape and surface conditions. Therefore, Zener diodes with different breakdown voltages can be designed by changing these conditions.

2.4.1. Zener breakdown and avalanche breakdown

The operation of a Zener diode can be explained by two phenomena: Zener breakdown and avalanche breakdown.

2.4.1.1. Zener breakdown

As the reverse bias voltage across the pn junction is increased, bonding in a crystal lattice is broken because valence electrons (i.e., electrons in the outermost shell) comprising the crystal lattice in the depletion layer are exposed to a high electric field. As a result, free electrons are created. These free electrons jump by tunneling from the valence band to the conduction band. As electrons and holes are attracted to the electrodes of a diode, current flows suddenly. If a diode is heavily doped, a depletion layer does not expand easily even when the pn junction is reverse-biased. In such cases, Zener breakdown occurs. Zener breakdown is predominant for low-voltage Zener diodes in which a breakdown occurs at a voltage lower than 5 to 6 V.

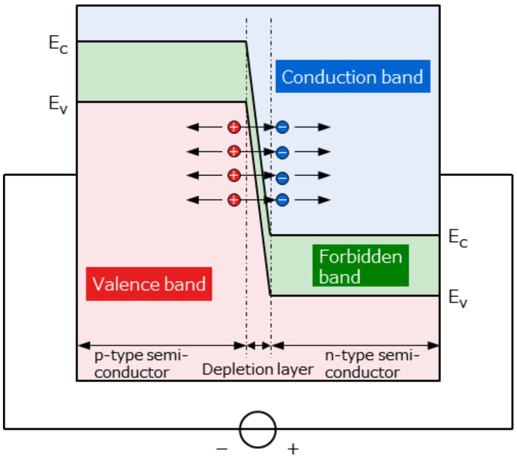


Figure 2.31 Zener breakdown

2.4.1.2. Avalanche breakdown

Avalanche breakdown is also called electron avalanche breakdown. As the reverse bias voltage across the pn junction is increased, thermally generated electrons and holes are accelerated by the high electric field in the depletion layer and collide with the atoms in crystal, knocking valence electrons free and thus creating electron-hole pairs. As these electron-hole pairs are also accelerated by the high electric field, they collide with other atoms, creating more electron-hole pairs. This leads to further knocking-out processes, attracting electrons and holes to the electrodes of a Zener diode and causing current to flow suddenly. Called avalanche breakdown, this effect becomes predominant at a voltage higher than 5 to 6 V.

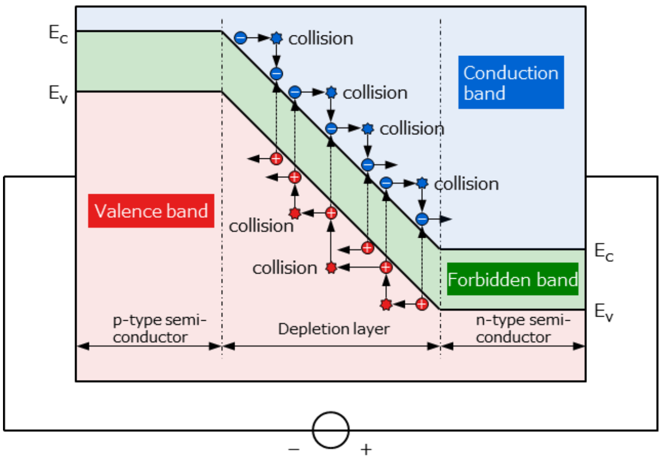


Figure 2.32 Avalanche breakdown

Zener breakdown and avalanche breakdown exhibit different temperature characteristics because of the difference in their mechanisms. The Zener breakdown voltage decreases as temperature increases whereas the avalanche breakdown voltage increases as temperature increases.

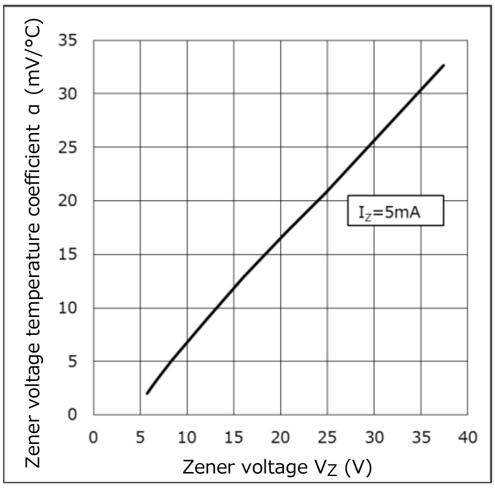


Figure 2.33 Example of Zener voltage temperature coefficient vs Zener voltage

2.4.2. Forward characteristics of Zener diodes

As is the case with typical pn diodes, the forward current of a Zener diode in the low-current region is expressed by Equation 2-3:

$$I_F = I_S \cdot \left(e^{\frac{q \cdot V_F}{K \cdot T}} - 1\right) \quad \cdots\cdots \quad (2\text{-}3)$$

I_F : Forward current (A)
I_S : Saturation current (A)
q : Electron charge (1.602×10^{-19}) (C)
V_F : Forward voltage (V)
K : Boltzmann constant (1.381×10^{-23}) ($J\cdot K^{-1}$)
T : Junction temperature (in Kelvin) (K)

2.4.3. Reverse characteristics of Zener diodes

The voltage that is sufficient to allow a Zener diode to conduct in the reverse direction is called Zener voltage (V_Z), which is determined by the dopant concentration of the n-type semiconductor and the dopant concentration profile of the pn junction. Figure 2.34 show an example of the I_Z–V_Z curves at different Zener voltages. Since Zener voltage (V_Z) depends on Zener current (I_Z), I_Z should be set appropriately according to V_Z.

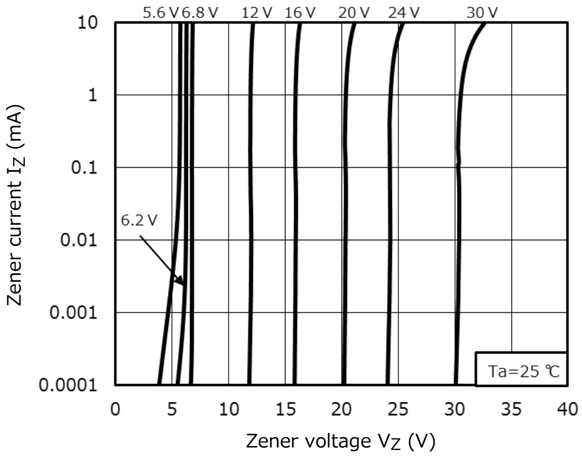


Figure 2.34 Example of I_Z-V_Z curves at different Zener voltages

To perform a parametric search of switching diodes → Click Here

To perform a parametric search of rectifier diodes → Click Here

To visit a web page on Schottky barrier diodes → Click Here

To perform a parametric search of Schottky barrier diodes → Click Here

To visit a web page on SiC Schottky barrier diodes → Click Here

To perform a parametric search of SiC Schottky barrier diodes → Click Here

To visit a web page on TVS (ESD protection) diodes → Click Here

To perform a parametric search of TVS (ESD protection) diodes → Click Here

To visit a web page on Zener diodes → Click Here

To perform a parametric search of Zener diodes → Click Here

To download the application note “SiC Schottky Barrier Diodes” → Click Here

To download the application note “SiC Schottky Barrier Diodes:
Absolute Maximum Ratings and Electrical Characteristics” → Click Here

To download the application note “Selecting Schottky Barrier Diodes
for Voltage Boost Circuits” → Click Here

To download the application note “Basics of ESD Protection (TVS) Diodes” → Click Here

To download the application note “Zener and
ESD Protection Diodes Suitable for Overvoltage Protection” → Click Here

To visit an FAQ web page on diodes → Click Here

Reference Design Center → Click Here

RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA".
Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**

Toshiba Electronic Devices & Storage Corporation
https://toshiba.semicon-storage.com/