TOSHIBA

e-Learning

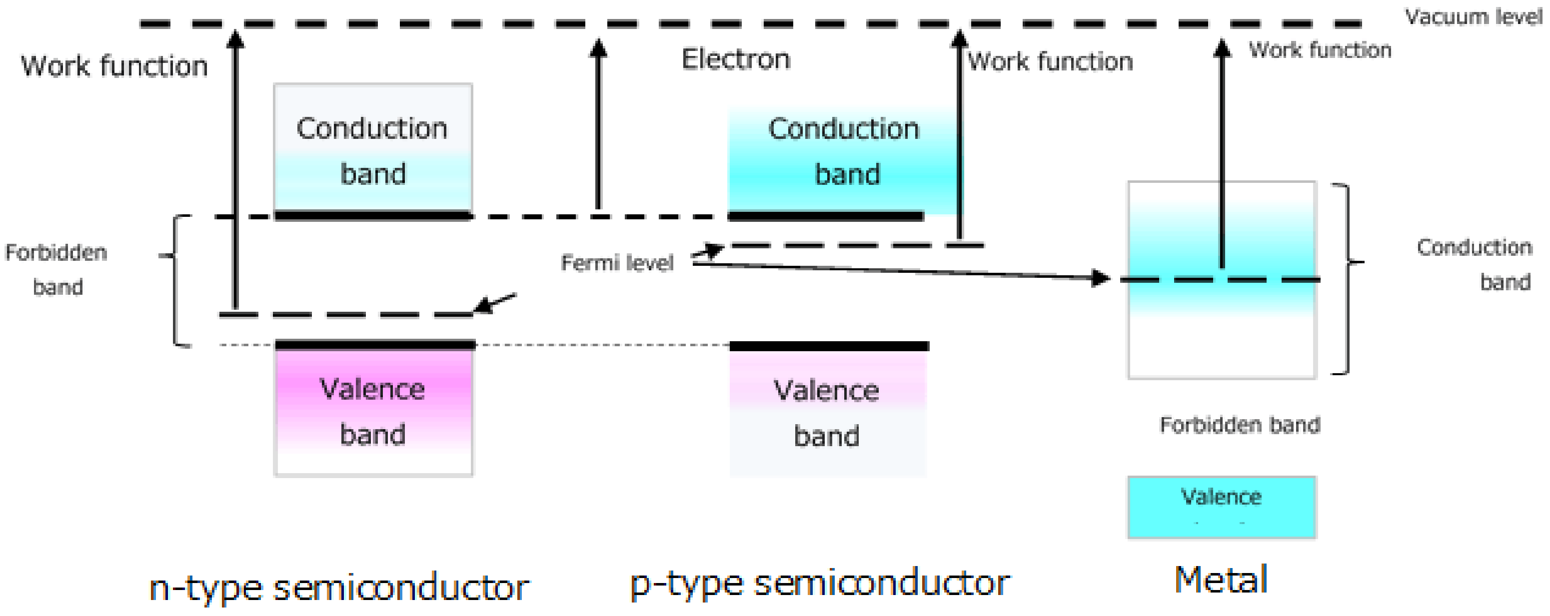
Basics of Schottky Barrier Diodes

Chapter2 Basics of Schottky Barrier Diodes
(Basic of Metal-semiconductor junction)

Toshiba Electronic Devices & Storage Corporation

2. Metal-semiconductor junction

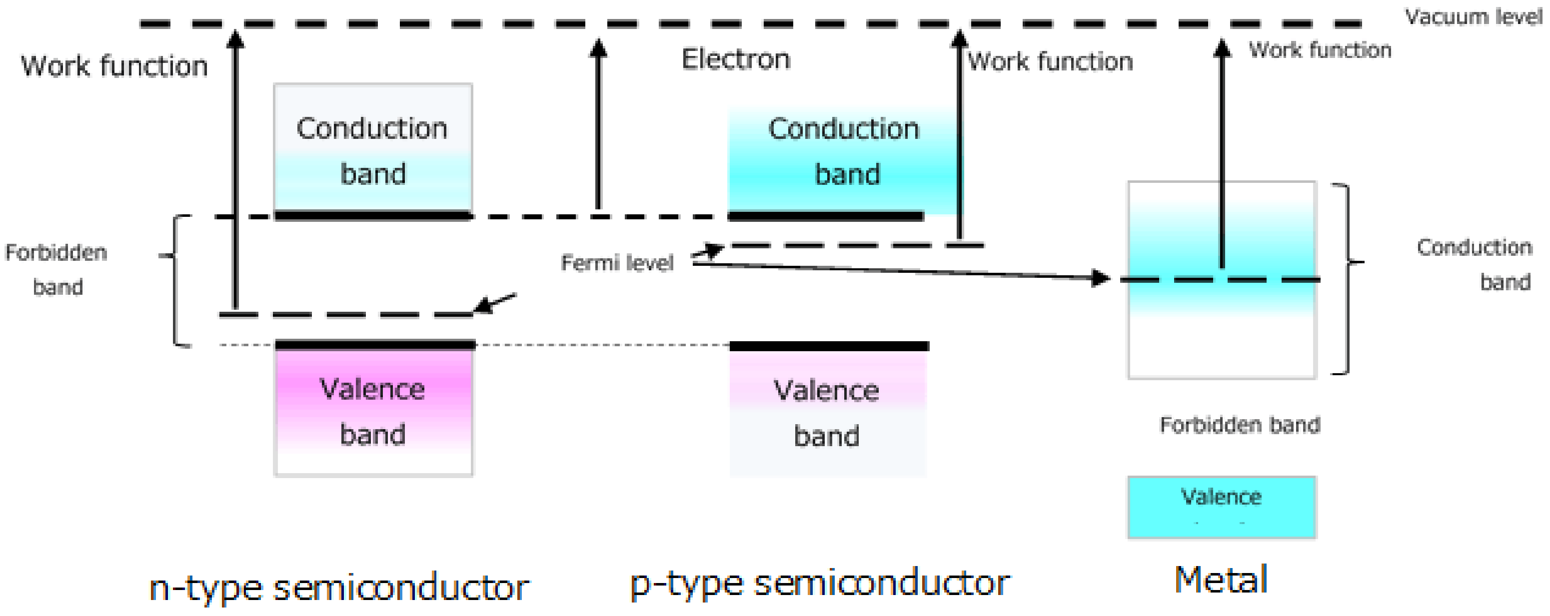
In the previous section, we have discussed the diffusion potential across a pn junction.
You now understand that the Fermi level is the reference energy level for the pn junction.
In the case of a metal-semiconductor junction, a metal and a semiconductor are joined together so that their Fermi levels line up with no external bias. Although the Fermi level is used as a reference point for the diffusion potential (barrier potential) of a pn junction, for a metal-semiconductor junction the work function is used as a reference point. The characteristics of the metal-semiconductor junction depend on whether the work function of the metal is greater or less than that of the semiconductor as described later.



2. Metal-semiconductor junction

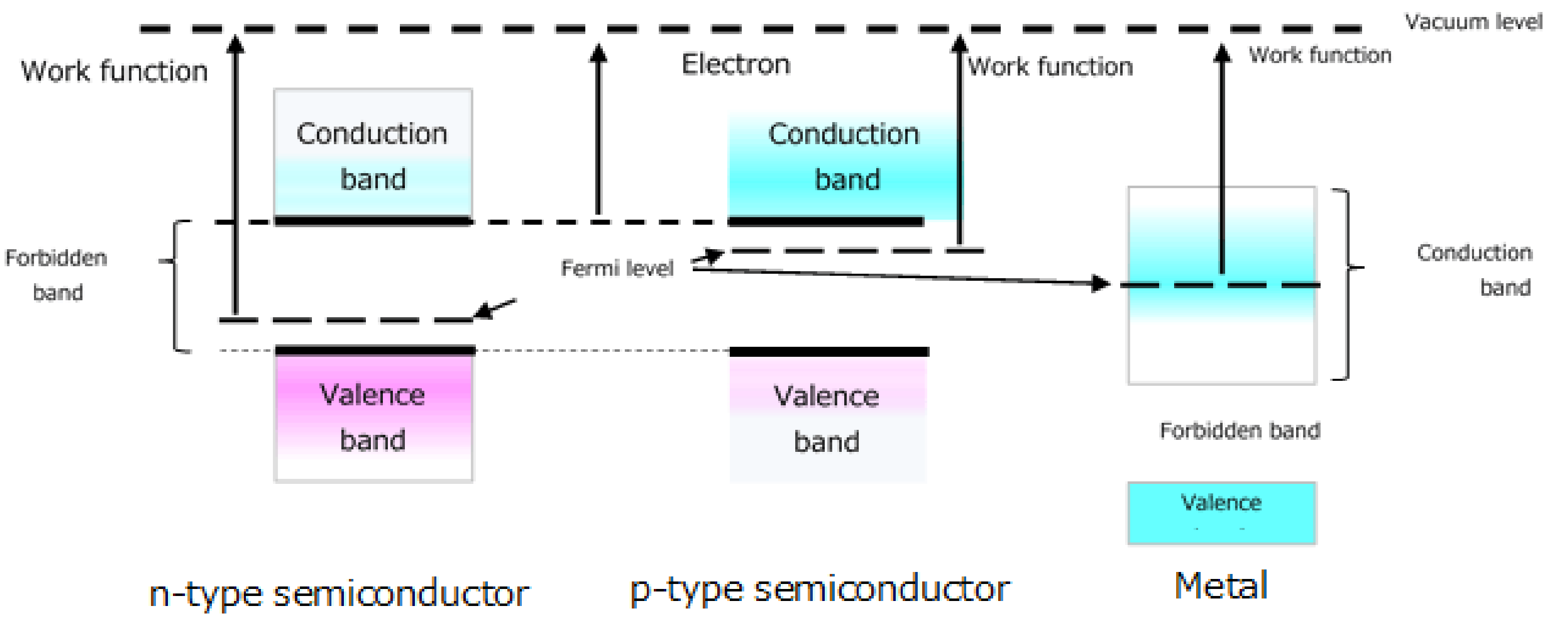
These are some terms used here:

- Electron affinity: Generally, the electron affinity of an atom or a molecule is defined as the amount of energy released when an electron is attached to a neutral atom or molecule. The electron affinity of a semiconductor is a difference between the lowest energy level in the conduction band and the vacuum level. The electron affinity of a metal is equal to its work function.
- Fermi level: The Fermi level is the energy level that has a 50% probability of being occupied by an electron according to the Fermi distribution
- Work function: The work function is the amount of energy needed to remove a free electron from a molecule. It is equal to a difference between the Fermi and vacuum levels.
- Vacuum level: The vacuum level is the energy level of a charged particle (e.g., an electron) when it is in a vacuum with zero kinetic energy.



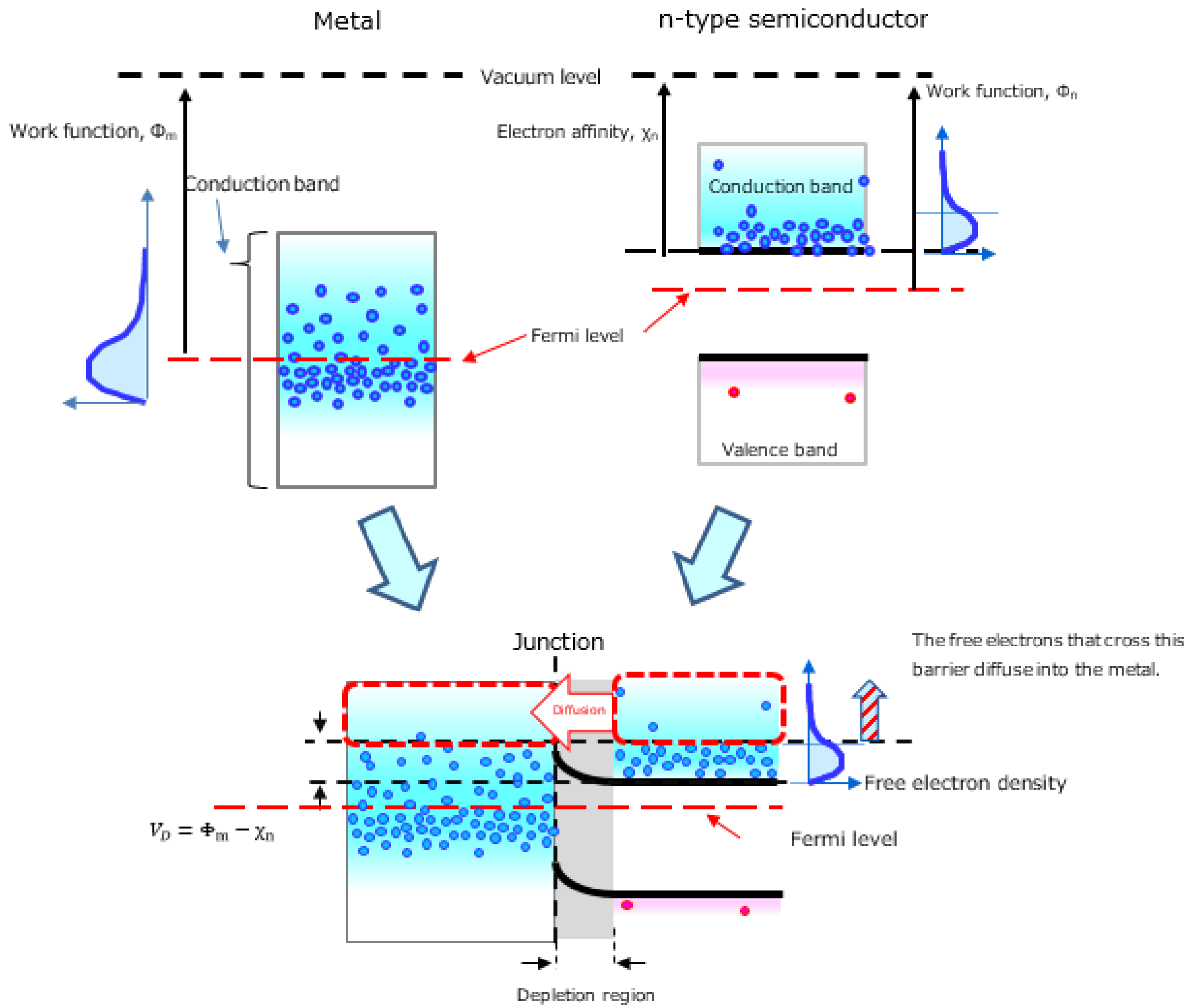
2. Metal-semiconductor junction

When an n-type semiconductor with a work function of Φ_n and a metal with a work function of Φ_m are joined together, the characteristics of the metal-semiconductor junction depend on the difference between Φ_n and Φ_m. A Schottky junction is formed when $\Phi_m > \Phi_n$ whereas an ohmic junction is formed when $\Phi_m < \Phi_n$. The work function of a semiconductor is the Fermi level minus the vacuum level.



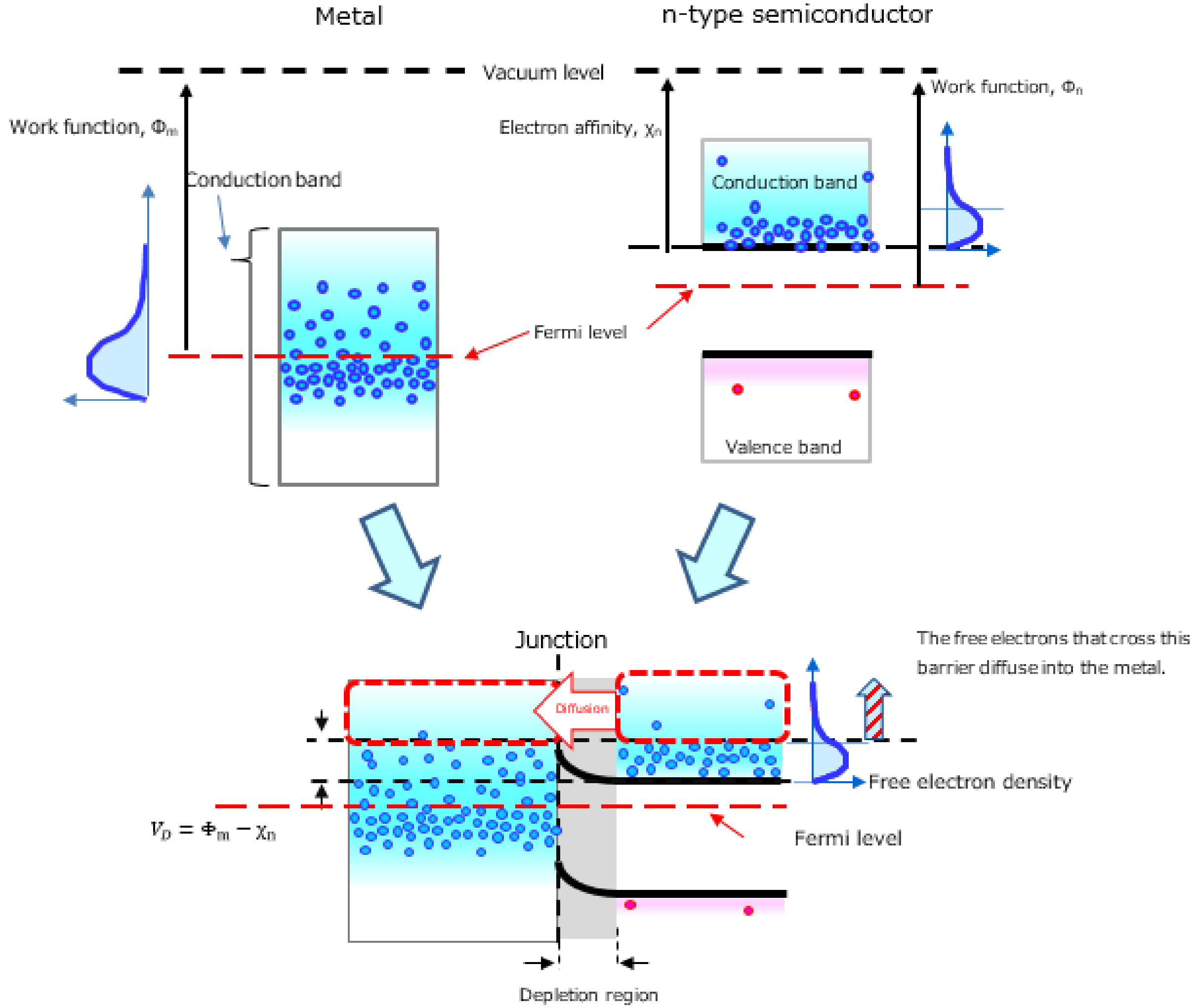
2.1. Schottky contact (Schottky junction) $\Phi_m > \Phi_n$

Let the work function of a metal be Φ_m and that of an n-type semiconductor be Φ_n. When $\Phi_m > \Phi_n$, a Schottky junction is formed when the n-type (or p-type) semiconductor is in contact with the metal. The Schottky junction is used to create Schottky barrier diodes. The following shows the band diagram of a Schottky junction formed by an n-type semiconductor and a metal.



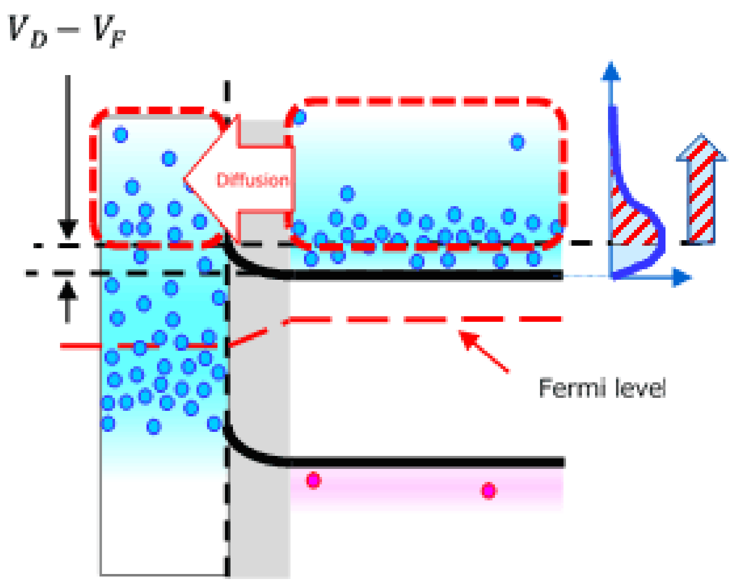
2.1. Schottky contact (Schottky junction) $\Phi_m > \Phi_n$

As electrons move from a higher energy level to a lower energy level, they travel from the conduction band of the semiconductor to that of the metal. As a result, a depletion region extends only into the semiconductor side. As is the case with the pn junction, the Fermi level on the semiconductor side and that on the metal side match. In an equilibrium state, the junction has a diffusion barrier equal to the work function of the metal (Φ_m) minus that of the n-type semiconductor (Φ_n).

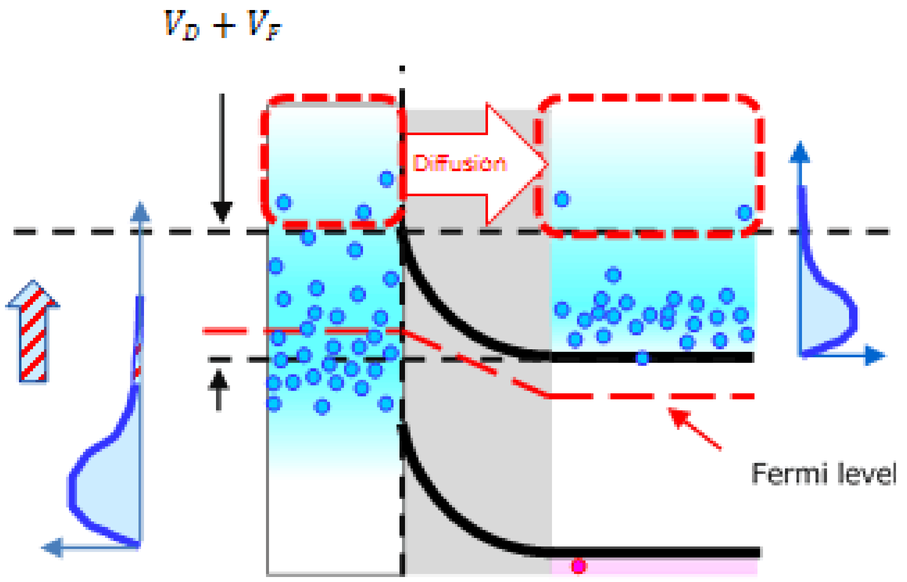


2.1. Schottky contact (Schottky junction) $\Phi_m > \Phi_n$

Free electrons are distributed across the n-type semiconductor according to the Fermi distribution. The electrons that cross the barrier of V_D flow into the metal.
Application of external voltage does not affect the barrier from the metal to the semiconductor, but causes the barrier from the semiconductor to the metal to shift by the applied voltage. This shift in the diffusion barrier causes a change in the current flowing through a Schottky barrier diode.



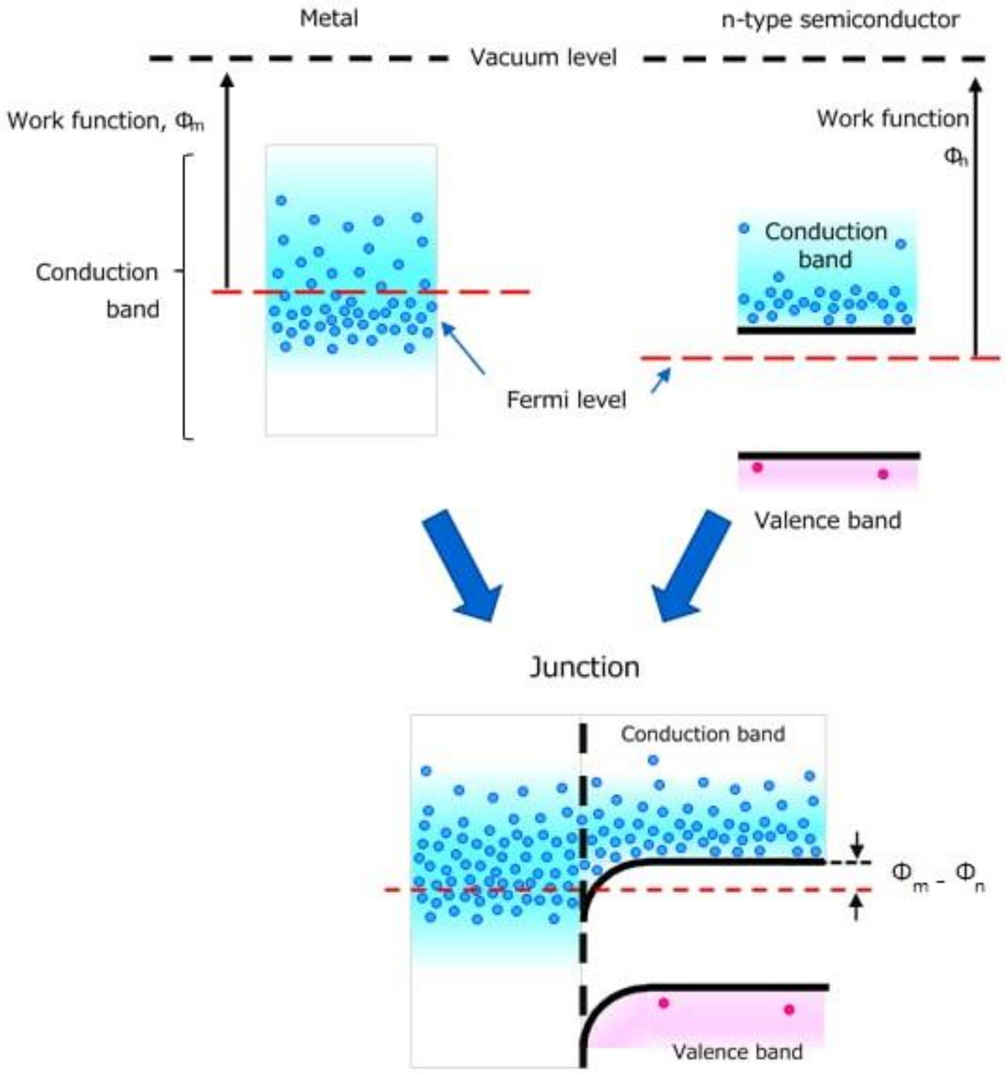
Forward-biased Schottky junction



Reverse-biased Schottky junction

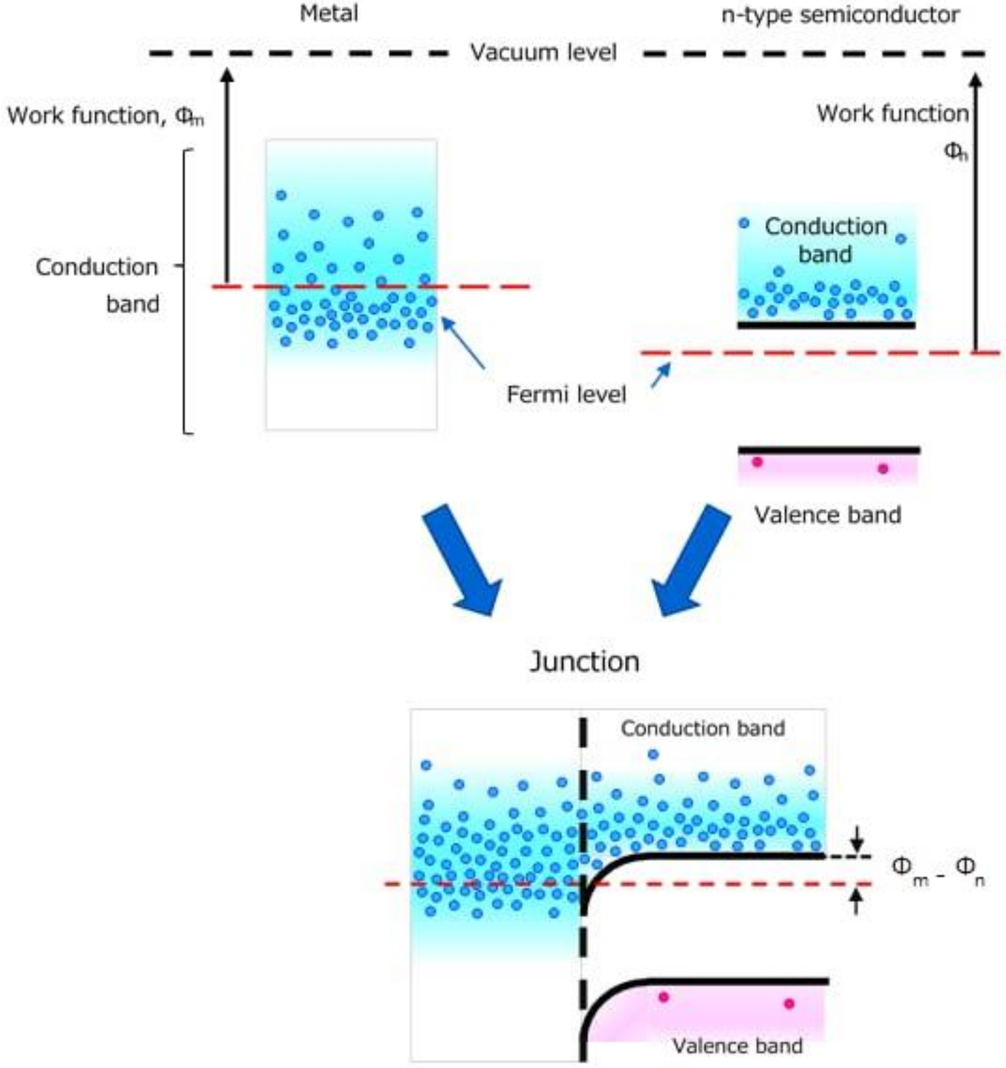
2.2. Ohmic contact (Ohmic junction) $\Phi_m < \Phi_n$

Let the work function of a metal be Φ_m and that of an n-type semiconductor be Φ_n. When $\Phi_m < \Phi_n$, an ohmic junction is formed when the semiconductor is in contact with the metal. Figure shows the band diagram of an ohmic junction formed by an n-type semiconductor and a metal.



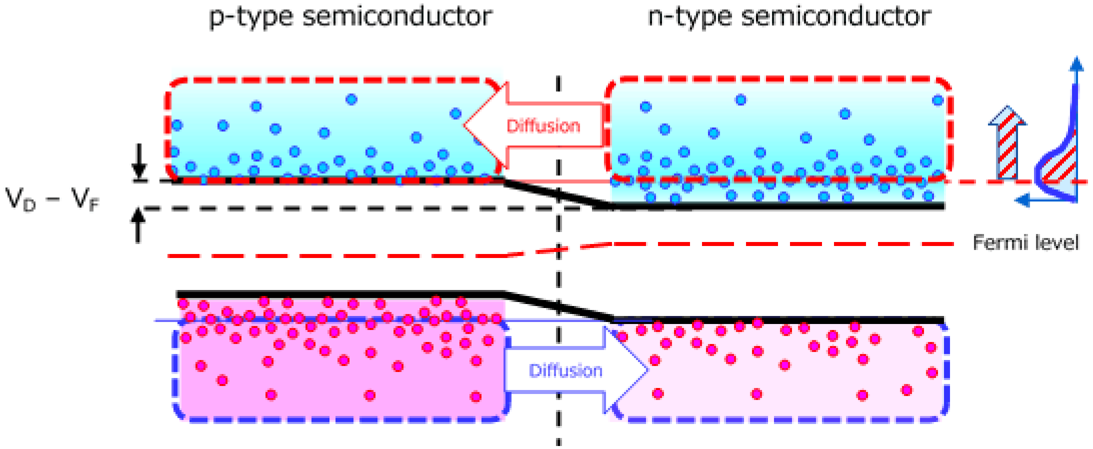
2.2. Ohmic contact (Ohmic junction) $\Phi_m < \Phi_n$

The ohmic junction has no diffusion barrier. Therefore, application of external voltage causes current to flow regardless of its polarity. Unlike the Schottky junction, the ohmic junction does not exhibit diode-like rectifying properties. For example, the ohmic junction is used for bonding pads on a semiconductor chip to create interconnections with its package.

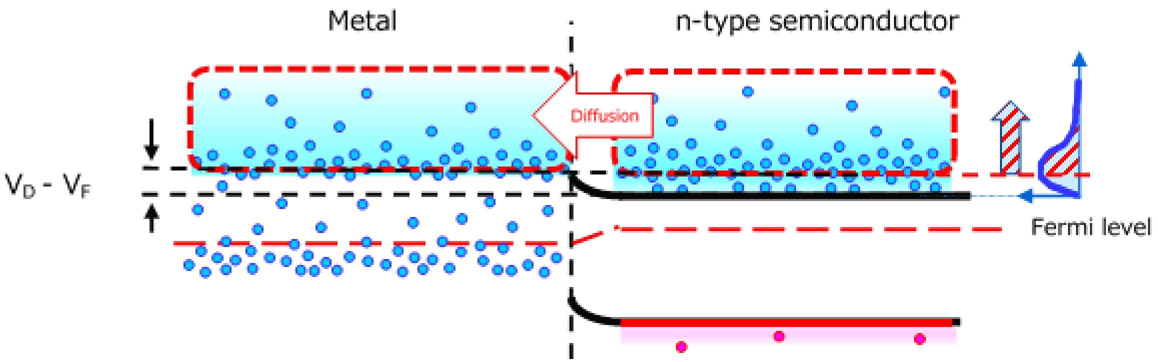


2.3. Conductivity modulation

In the previous subsections, we have discussed the pn and metal-semiconductor junctions. A pn junction is a bipolar junction because both electrons and holes act as charge carriers whereas a metal-semiconductor junction is a unipolar junction (also called a monopolar junction) because either electrons or holes act as charge carriers.



pn junction forward-biased at V_F

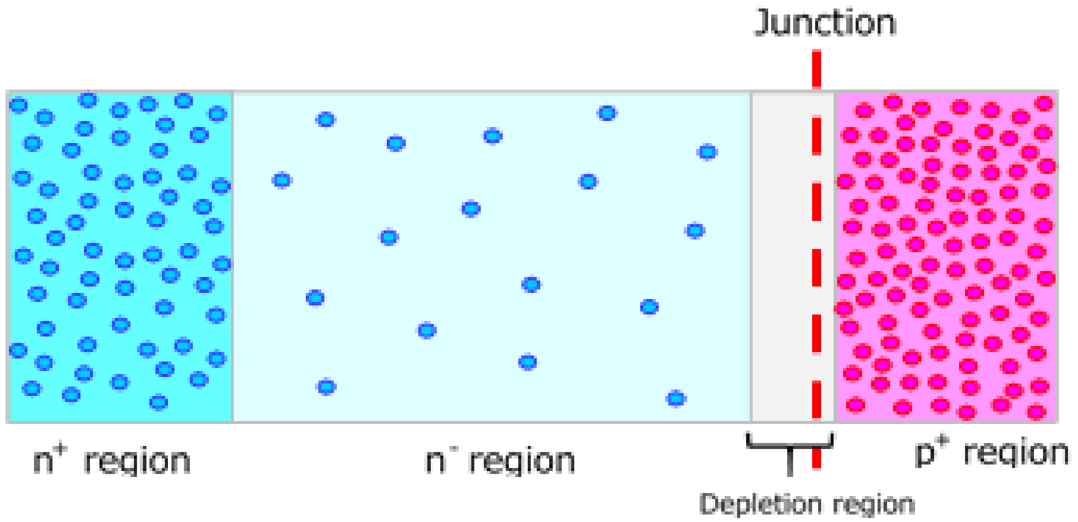


Metal-semiconductor junction forward-biased at V_F

2.3. Conductivity modulation

To create a pn junction, a lightly doped n-type (or p-type) semiconductor substrate is heavily doped with boron (B) or other p-type dopant using a diffusion, epitaxial growth, or ion implantation process. Therefore, the lightly doped n-type (or p-type) substrate acts as a series resistor. Note that the conductivity modulation of the pn junction causes its series resistance to decrease.

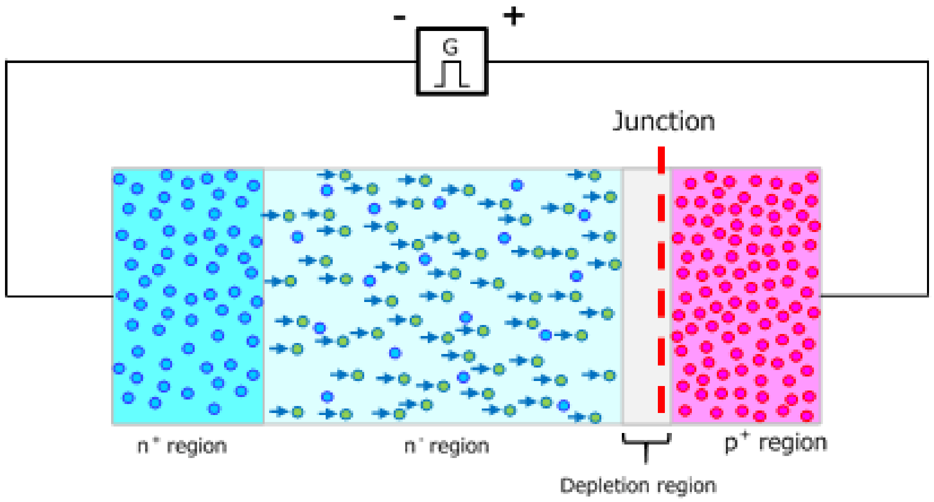
Typical pn junction diodes consist of heavily doped p-type (p^+) and n-type (n^+) regions on either side of a lightly doped n (n^-) region. Diodes with an extremely lightly doped n^- region are called PIN diodes. Typical pn junction diodes have a structure similar to that of PIN diodes although I layers of pn junction diodes are more heavily doped.



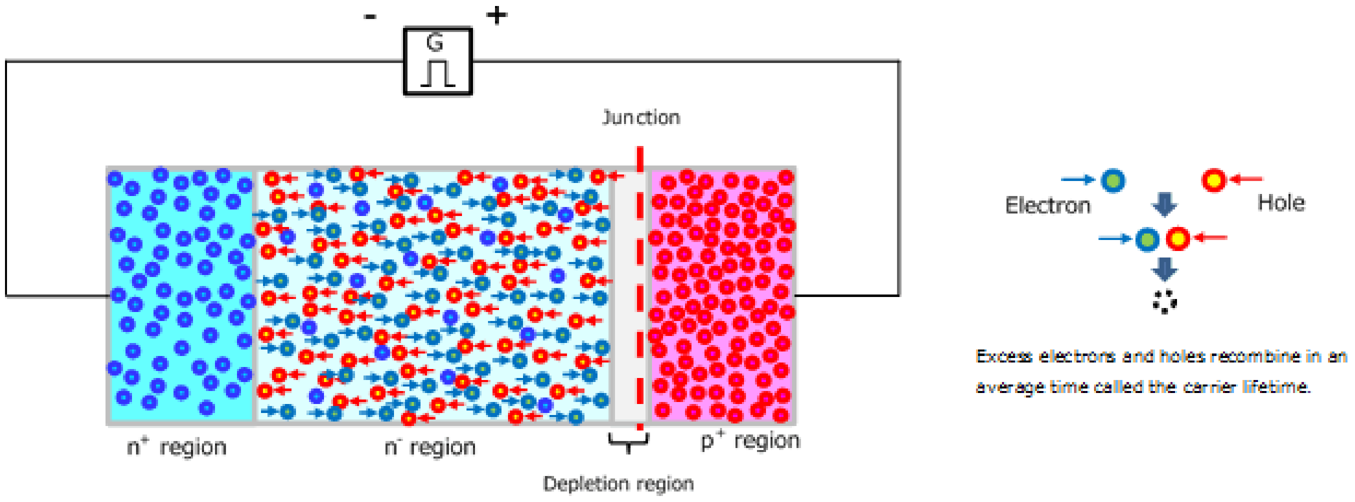
<u>Unbiased pn junction diode</u>

2.3. Conductivity modulation

Electrons from a power supply flow into the n^- region via the n^+ region. To maintain electrical neutrality, holes are injected into the n^- region from the p^+ region. These electrons and holes recombine and disappear ultimately. Carrier lifetime is defined as the average time required for this recombination. Because both electrons and holes exist in the n^- region during this period, it exhibits low resistance as if it were a heavily doped region.



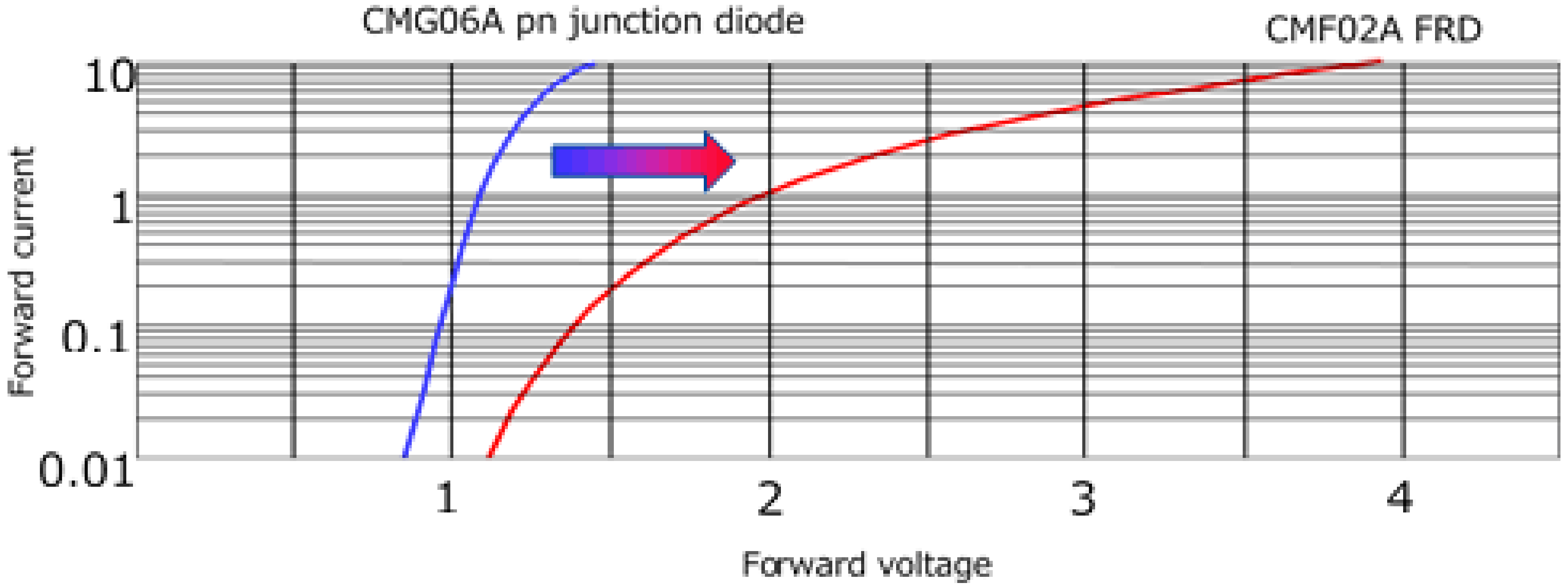
pn junction diode immediately after the application of a forward bias



Forward-biased pn junction diode in a steady state

2.3. Conductivity modulation

The longer the carrier lifetime, the stronger the conductivity modulation effect, yet at the expense of an increase in reverse recovery time (i.e., the time required for a diode to stop conducting). Toshiba provides a type of diodes with a reduced reverse recovery time (i.e., a reduced carrier lifetime) called fast-recovery diodes (FRDs). The FRD has a shallower forward voltage-vs-forward current curve (i.e., higher forward resistance) than the typical pn junction diode as shown in Figure.



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