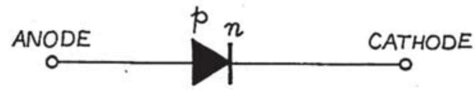
PN JUNCTION

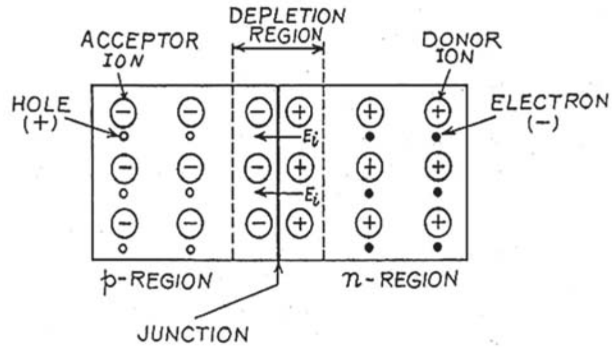
Energy band for n-type and p-type SC

Circuit Symbol for a p-n Junction Diode

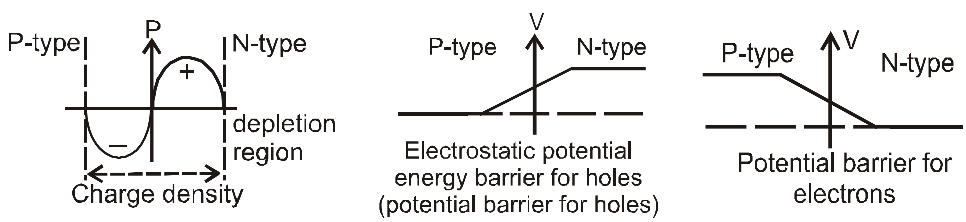
In electronic circuit schematics, semiconductor components are represented by specific symbols. The symbol for the fundamental semiconductor device, the p-n junction diode, is illustrated in the diagram. Within this symbol, an arrowhead designates the p-region, whereas a bar symbolizes the n-region of the diode. The direction of the arrow, extending from p to n, indicates the direction of conventional current flow when the diode is under forward bias. The term 'anode' is assigned to the p-side, while the term 'cathode' is designated to the n-side.



(a) Formation of the p-n Junction: A p-n junction is more than just the interface formed by merging p-type and n-type semiconductor crystals. Instead, it constitutes a unified semiconductor crystal characterized by an abundance of acceptor impurities on one side and donor impurities on the other.



(b) Potential Barrier at the Junction: Formation of the Depletion Region: As depicted in the figure, the p-type region of the p-n junction is primarily composed of positively charged holes as the majority carriers, accompanied by an equal number of immobile negatively charged acceptor ions.
It's important to emphasize that the material as a whole remains electrically neutral. In contrast, the n-type region is comprised of negatively charged electrons as the dominant carriers, alongside an equal number of stationary positively charged donor ions.



The area of the junction that lacks mobile charge carriers is termed the 'depletion region,' as illustrated in the figure. Typically, this region displays a width on the scale of $10^{(-6)}$ meters. The potential difference developed across this depletion region is known as the 'potential barrier.' Specifically, in the case of a germanium p-n junction, this barrier potential is approximately 0.3 volts, whereas for a silicon p-n junction, it's around 0.7 volts. It's important to note that the precise value of the potential barrier depends on the dopant concentration within the semiconductor material. The electric field intensity associated with this barrier, represented as E_i, can be estimated as approximately $E_i \approx 7 \times 10^5$ volts per meter for a silicon junction.

Drift speed for electron and holes

Drift speed refers to the typical velocity achieved by charge carriers within a substance under the influence of an electric field. This concept holds significant importance in comprehending how electrical conduction operates in various materials, especially concerning the flow of current in electronic devices and circuits.
As a consequence of a concentration gradient, holes endeavor to diffuse from the p-side to the n-side.

However, the existence of the depletion layer permits only those holes possessing high kinetic energy to effectively diffuse across from the p-side to the n-side. Similarly, electrons with elevated kinetic energy diffuse from the n-side to the p-side, resulting in a diffusion current that flows from the p-side to the n-side.

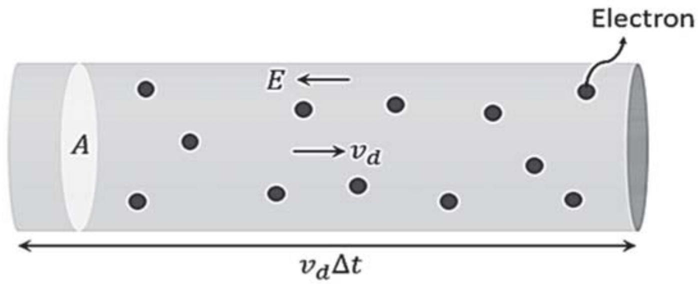
Moreover, owing to thermal collisions or an elevation in temperature, some valence electrons transition into the conduction band. If this occurrence takes place within the depletion region, holes migrate towards the p-side while electrons move towards the n-side, initiating a current from the n-side to the p-side. This phenomenon is termed drift current. In a state of equilibrium, both diffusion and drift currents are balanced and oppositely directed.

The mobility of charge carriers describes the ease with which they traverse through a medium, while drift velocity represents the magnitude of their motion per unit electric field. These concepts are fundamental in understanding how charge carriers move within materials under the influence of an electric field.

$$\mu = \frac{|v_d|}{E}$$

$$\mu = (\frac{e\tau}{m})$$

The mobility of electrons exceeds that of holes.



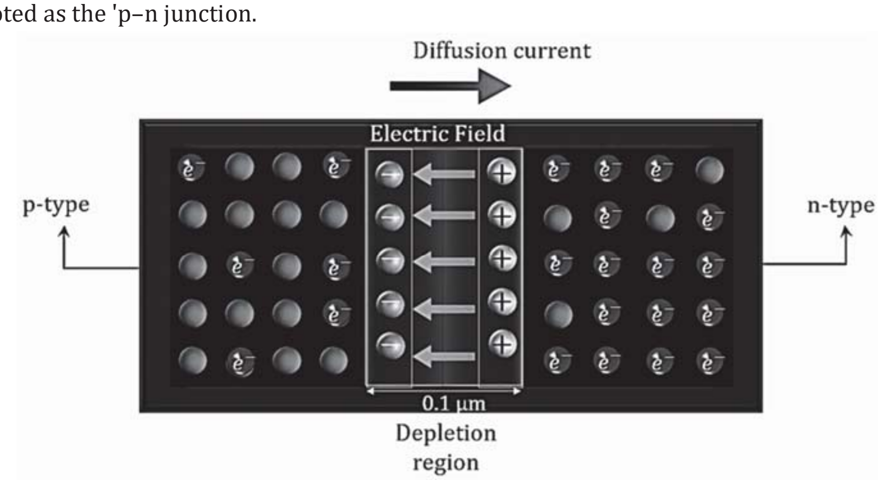
The symbol n represents the number of free electrons per unit volume. The current i is calculated as the product of n, the elementary charge e, the drift velocity vd, and the cross-sectional area A.

In this context, A refers to the area perpendicular to the direction of charge flow. The current density j is given by the ratio of current i to area A,

which can also be expressed as nev_d.

PN JUNCTION

A junction diode, a cornerstone semiconductor component, is crafted from a semiconductor crystal partitioned into two discernible sections. One segment of the crystal is enriched with acceptor impurities, shaping it into a P-type crystal, while the other segment is infused with donor impurities, thereby configuring it as an N-type crystal. The juncture where these two regions meet is denoted as the 'p–n junction.



On the p-side, there is a higher concentration of holes, leading them to diffuse towards the n-side. Conversely, electrons diffuse towards the p-side as the concentration of electrons is greater on the n-side. The resultant current arising from the movement of both holes and electrons is termed diffusion current.

As a consequence of hole diffusion from the p-side to the n-side and electron diffusion from the n-side to the p-side, positive charge accumulates on the n-side while negative charge accumulates on the p-side at the junction. This area at the junction is identified as the depletion region.

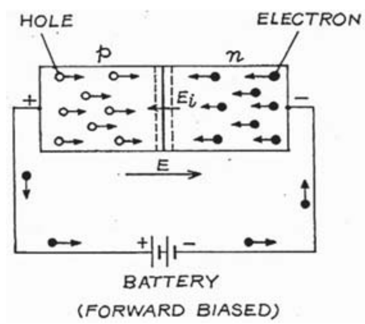
Forward and Reverse Bias of Junction Diode

The junction diode can be connected to an external battery using two different approaches, termed 'forward bias' and 'reverse bias' of the diode. These terms describe how an electromotive force (EMF) source is connected to the P-N junction diode.

These methods are outlined as follows:

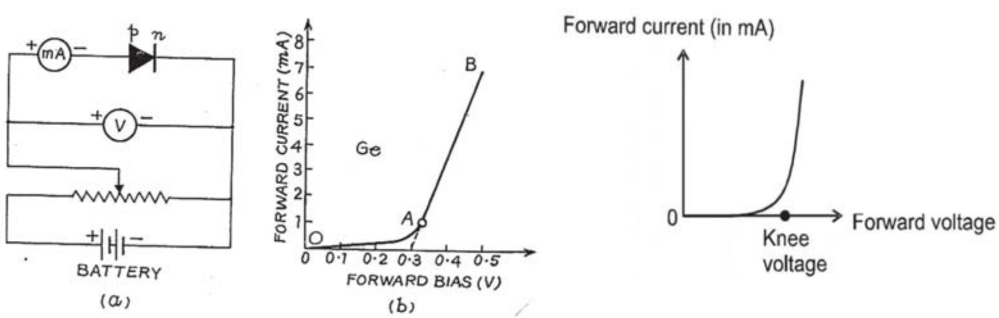
(i) Forward Bias:

A junction diode is considered to be forward-biased when the positive terminal of the external battery is attached to the p-region, and the negative terminal is connected to the n-region of the diode.



Forward-Biased Characteristics:

In the depicted circuit connections (refer to Fig.), the positive terminal of the battery is connected to the p-region, while the negative terminal is linked to the n-region of the junction diode via a potential-divider setup. This configuration enables the adjustment of the applied voltage. Voltage is measured using a voltmeter V, while current is measured with a millimeter mA. Initially, the forward bias voltage is set to a low value and is then incremented step by step, with the corresponding forward current noted at each interval. Subsequently, a graph is plotted to illustrate the relationship between voltage and current. The resulting curve, represented by OAB (as shown in Fig. b), depicts the forward characteristic of the diode.



Initially, when the applied voltage is low, the current passing through the junction diode remains minimal. This is primarily attributed to the existence of the potential barrier, which opposes the applied voltage. The potential barrier typically measures around 0.3 V for a Ge p-n junction and approximately 0.7 V for a Si junction.

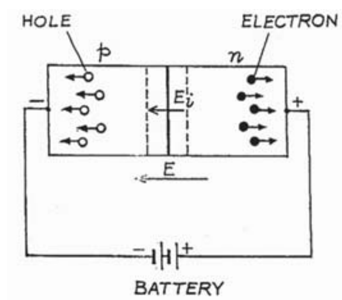
As the applied voltage gradually increases, the current exhibits a slow and nonlinear ascent until it surpasses the potential barrier. This phase is delineated by the segment OA of the characteristic curve. With further increments in the applied voltage, the current experiences a swift and nearly linear augmentation. During this stage, the diode behaves akin to an ordinary conductor, as evidenced by the linear segment AB of the characteristic curve. Extending this straight line backward, it intersects the voltage-axis at the voltage corresponding to the barrier potential.

Note:

- Under forward biasing, the depletion layer's width diminishes.
- The resistance encountered in forward biasing, denoted as Forward RForward, typically falls within the range of 10 ohms to 25 ohms.
- Forward biasing counteracts the potential barrier, and when applied voltages exceed the barrier potential (V > VB), a forward current flows across the junction.
- Cut-in (Knee) voltage: This represents the voltage at which the current initiates a rapid increase. For Ge, this threshold is 0.3 V, while for Si, it stands at 0.7 V.

(ii) Reverse Bias:

When the positive terminal of an external battery is linked to the n-region, and the negative terminal is attached to the p-region of a junction diode, the diode is described as being in a reverse-biased state (as depicted in the figure). In this arrangement, the external electric field E is oriented from the n-region toward the p-region, reinforcing the internal barrier field Ei. As a consequence, both holes in the p-region and electrons in the n-region are pushed away from the junction, preventing their recombination at the junction. Consequently, there is minimal current flow resulting from the movement of majority carriers.



(REVERSE BIASED)

Reverse-Bias Characteristics:

The depicted circuit connections (refer to Fig. a) involve attaching the positive terminal of the battery to the n-region and the negative terminal to the p-region of the junction diode, resulting in a reverse-biased diode state. In this condition, a minute current, typically on the order of microamperes (μA), flows through the junction. This current is generated by the movement of thermally-generated minority carriers—electrons in the p-region and holes in the n-region—facilitated by the applied voltage. The small reverse current remains relatively constant over a sufficiently wide range of reverse bias (applied voltage), displaying minimal augmentation even with an increase in bias. This behavior is illustrated by the segment OC of the reverse characteristic curve (refer to Fig. b).

Note:

- Under reverse biasing, the depletion layer widens.
- The resistance encountered in reverse biasing, labeled as RReverse, is approximately 105 ohms.
- Reverse bias reinforces the potential barrier, impeding current flow across the junction due to majority carrier diffusion.
- While a minuscule reverse current may persist in the circuit due to minority carrier drift across the junction.
- Breakdown voltage signifies the reverse voltage at which semiconductor breakdown occurs. It amounts to 25V for Ge and 35V for Si.