



The effect described in the previous tutorial is achieved without any external voltage being applied to the actual PN junction resulting in the junction being in a state of equilibrium.

However, if we were to make electrical connections at the ends of both the N-type and the P-type materials and then connect them to a battery source, an additional energy source now exists to overcome the potential barrier.

The effect of adding this additional energy source results in the free electrons being able to cross the depletion region from one side to the other. The behaviour of the PN junction with regards to the potential barrier's width produces an asymmetrical conducting two terminal device, better known as the **PN Junction Diode**.

A *PN Junction Diode* is one of the simplest semiconductor devices around, and which has the characteristic of passing current in only one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential current-voltage (I - V) relationship and therefore we can not described its operation by simply using an equation such as Ohm's law.

If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased.

By applying a negative voltage (reverse bias) results in the free charges being pulled away

from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking the flow of current through the diodes pn-junction.

Then the depletion layer widens with an increase in the application of a reverse voltage and narrows with an increase in the application of a forward voltage. This is due to the differences in the electrical properties on the two sides of the PN junction resulting in physical changes taking place. One of the results produces rectification as seen in the PN junction diodes static I-V (current-voltage) characteristics. Rectification is shown by an asymmetrical current flow when the polarity of bias voltage is altered as shown below.

Junction Diode Symbol and Static I-V Characteristics

But before we can use the PN junction as a practical device or as a rectifying device we need to firstly **bias** the junction, that is connect a voltage potential across it. On the voltage axis above, “Reverse Bias” refers to an external voltage potential which increases the potential barrier. An external voltage which decreases the potential barrier is said to act in the “Forward Bias” direction.

There are two operating regions and three possible “biasing” conditions for the standard **Junction Diode** and these are:

1. Zero Bias – No external voltage potential is applied to the PN junction diode.
2. Reverse Bias – The voltage potential is connected negative, (-ve) to the P-type material and positive, (+ve) to the N-type material across the diode which has the effect of **Increasing** the PN junction diode’s width.
3. Forward Bias – The voltage potential is connected positive, (+ve) to the P-type material and negative, (-ve) to the N-type material across the diode which has the effect of **Decreasing** the PN junction diodes width.

Zero Biased Junction Diode

When a diode is connected in a **Zero Bias** condition, no external potential energy is applied to the PN junction. However if the diodes terminals are shorted together, a few holes (majority carriers) in the P-type material with enough energy to overcome the potential barrier will move across the junction against this barrier potential. This is known as the “**Forward**

Current” and is referenced as I_F

Likewise, holes generated in the N-type material (minority carriers), find this situation favourable and move across the junction in the opposite direction. This is known as the **“Reverse Current”** and is referenced as I_R . This transfer of electrons and holes back and forth across the PN junction is known as diffusion, as shown below.

Zero Biased PN Junction Diode

The potential barrier that now exists discourages the diffusion of any more majority carriers across the junction. However, the potential barrier helps minority carriers (few free electrons in the P-region and few holes in the N-region) to drift across the junction.

Then an “Equilibrium” or balance will be established when the majority carriers are equal and both moving in opposite directions, so that the net result is zero current flowing in the circuit. When this occurs the junction is said to be in a state of **“Dynamic Equilibrium”**.

The minority carriers are constantly generated due to thermal energy so this state of equilibrium can be broken by raising the temperature of the PN junction causing an increase in the generation of minority carriers, thereby resulting in an increase in leakage current but an electric current cannot flow since no circuit has been connected to the PN junction.

Reverse Biased PN Junction Diode

When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.

The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator and a high potential barrier is created across the junction thus preventing current from flowing through the semiconductor material.

Increase in the Depletion Layer due to Reverse Bias

This condition represents a high resistance value to the PN junction and practically zero

current flows through the junction diode with an increase in bias voltage. However, a very small **reverse leakage current** does flow through the junction which can normally be measured in micro-amperes, (μA).

One final point, if the reverse bias voltage V_r applied to the diode is increased to a sufficiently high enough value, it will cause the diode's PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in the flow of maximum circuit current, and this shown as a step downward slope in the reverse static characteristics curve below.

Reverse Characteristics Curve for a Junction Diode

Sometimes this avalanche effect has practical applications in voltage stabilising circuits where a series limiting resistor is used with the diode to limit this reverse breakdown current to a preset maximum value thereby producing a fixed voltage output across the diode. These types of diodes are commonly known as Zener Diodes and are discussed in a later tutorial.

Forward Biased PN Junction Diode

When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.

This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this voltage point, called the “knee” on the static curves and then a high current flow through the diode with little increase in the external voltage as shown below.

Forward Characteristics Curve for a Junction Diode

The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the

junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented on the static I-V characteristics curve above as the “knee” point.

Reduction in the Depletion Layer due to Forward Bias

This condition represents the low resistance path through the PN junction allowing very large currents to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at approximately 0.3v for germanium and approximately 0.7v for silicon junction diodes.

Since the diode can conduct “infinite” current above this knee point as it effectively becomes a short circuit, therefore resistors are used in series with the diode to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in a very quick failure of the device.

Junction Diode Summary

The PN junction region of a **Junction Diode** has the following important characteristics:

Semiconductors contain two types of mobile charge carriers, “Holes” and “Electrons”.

The holes are positively charged while the electrons negatively charged.

A semiconductor may be doped with donor impurities such as Antimony (N-type doping), so that it contains mobile charges which are primarily electrons.

A semiconductor may be doped with acceptor impurities such as Boron (P-type doping), so that it contains mobile charges which are mainly holes.

The junction region itself has no charge carriers and is known as the depletion region.

The junction (depletion) region has a physical thickness that varies with the applied voltage.

When a diode is **Zero Biased** no external energy source is applied and a natural **Potential Barrier** is developed across a depletion layer which is approximately 0.5 to 0.7v for silicon diodes and approximately 0.3 of a volt for germanium diodes.

When a junction diode is **Forward Biased** the thickness of the depletion region reduces and the diode acts like a short circuit allowing full circuit current to flow.

When a junction diode is **Reverse Biased** the thickness of the depletion region increases and the diode acts like an open circuit blocking any current flow, (only a very small leakage current will flow).

We have also seen above that the diode is two terminal non-linear device whose I-V characteristic are polarity dependent as depending upon the polarity of the applied voltage, V_D the diode is either *Forward Biased*, $V_D > 0$ or *Reverse Biased*, $V_D < 0$. Either way we can model these current-voltage characteristics for both an ideal diode and for a real silicon diode as shown:

Junction Diode Ideal and Real Characteristics

In the next tutorial about diodes, we will look at the small signal diode sometimes called a switching diode which is used in general electronic circuits. As its name implies, the signal diode is designed for low-voltage or high frequency signal applications such as in radio or digital switching circuits.

Signal diodes, such as the 1N4148 only pass very small electrical currents as opposed to the high-current mains rectification diodes in which silicon diodes are usually used. Also in the next tutorial we will examine the Signal Diode static current-voltage characteristics curve and parameters.



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Virat

An electrical break down occurs in pn junction if in what condition

Posted on January 05th 2021 | 8:08 am

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Jacob Gitalu

Does reversed biased not allow any amount to flow

Posted on December 29th 2020 | 11:29 pm

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Shah Mohammad owes khalid Shah

All goods

Posted on December 23rd 2020 | 5:44 am

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Huziz Khan

In practice, no diode is an Ideal diode, this means neither it acts as a perfect conductor when forward biased nor it acts as an insulator when it is reverse biased so Calculate the apparent resistance of a forward-biased p-n junction at room temperature (300 K) when the current through the junction is 5 mA.

Posted on December 10th 2020 | 3:36 pm

 Reply

Kingsuk Kumar Bandyopadhyay

Well explained but still there is grey area regarding how forward and backward biased voltage is applied the diode and detailed reason why after putting in a specific voltage , there is sudden spurt in generation of electricity.. under what conditions forward biased and backward biased diode would be used.

Posted on November 24th 2020 | 3:59 pm

 Reply

Wayne Storr

Rectification

Posted on November 24th 2020 | 4:28 pm

 Reply

Geoffrey

Well explained.thax

Posted on November 23rd 2020 | 9:50 am

 Reply

Stephen Amoah

Draw and label input-output (I vs V) characteristics of a P-N junction diode

Posted on November 21st 2020 | 9:56 pm

 Reply

Priyanka

Thank you

Posted on November 17th 2020 | 2:01 am

 Reply

Javeria

Good

Posted on November 13th 2020 | 12:58 pm

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Jothimani

It could very nice to explained. thanks a lot

Posted on November 02nd 2020 | 2:30 am

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Sanjana

Thank you so much 

Posted on October 12th 2020 | 1:03 pm

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Naeem akhter

Thanks a lot

Posted on October 05th 2020 | 6:18 pm

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Lahari

Good notes

Posted on October 03rd 2020 | 6:08 am

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L🥰kesh

Kya aap jodpur se h..!

Sorry its not relevent.

Posted on October 30th 2020 | 7:45 am

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Ravneet

Thanks a lot

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Bharath

Sankaran Kovil mook 2th start

Posted on September 14th 2020 | 5:01 am

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Siddharth malhotra

I want to join the class

Posted on August 27th 2020 | 4:18 am

 Reply

Manuel Moreno

inside the diagram “Junction Diode Symbol and Static I-V Characteristics” where is “mA” for the current in the reserve bias voltage region, it should be microAmperes not miliAmperes, as mentioned in the text.

Posted on August 26th 2020 | 5:14 pm

 Reply

More

Nikita kumari

Good👍

Posted on August 16th 2020 | 11:50 am

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Paul

Great lesson. Thanks

Posted on August 05th 2020 | 6:50 pm

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John Mtandiko

Apo good

Posted on July 27th 2020 | 3:05 pm

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