FUNDAMENTALS OF ELECTRONICS

WEEK 6: DESCRIPTION AND APPLICATIONS OF ACTIVE DEVICES/ PART 1: DIODES

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- **Identification of different types of diodes**
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Definition of Active Devices

An **active device** is any type of circuit component with the **ability to electrically control electric charge flow** (electricity controlling electricity).

In order for a circuit to be properly called electronic, it must contain at least one **active device**.

Definition of Diode

- A diode is a two-terminal electronic component that conducts current primarily in one direction; it has low resistance in one direction, and high resistance in the other.

- The most common **function** of a diode is to allow an electric current to pass in one direction (called the diode's forward direction), while blocking it in the opposite direction (the reverse direction). As such, the diode can be viewed as an electronic version of a check valve.

How do diodes work?

- Before knowing the uses of diodes, we should know that an ideal diode is enclosed in a plastic or glass case to mark the cathode side of it. There are two ways a diode functions, either it is a forward-biased or it is reverse-biased.

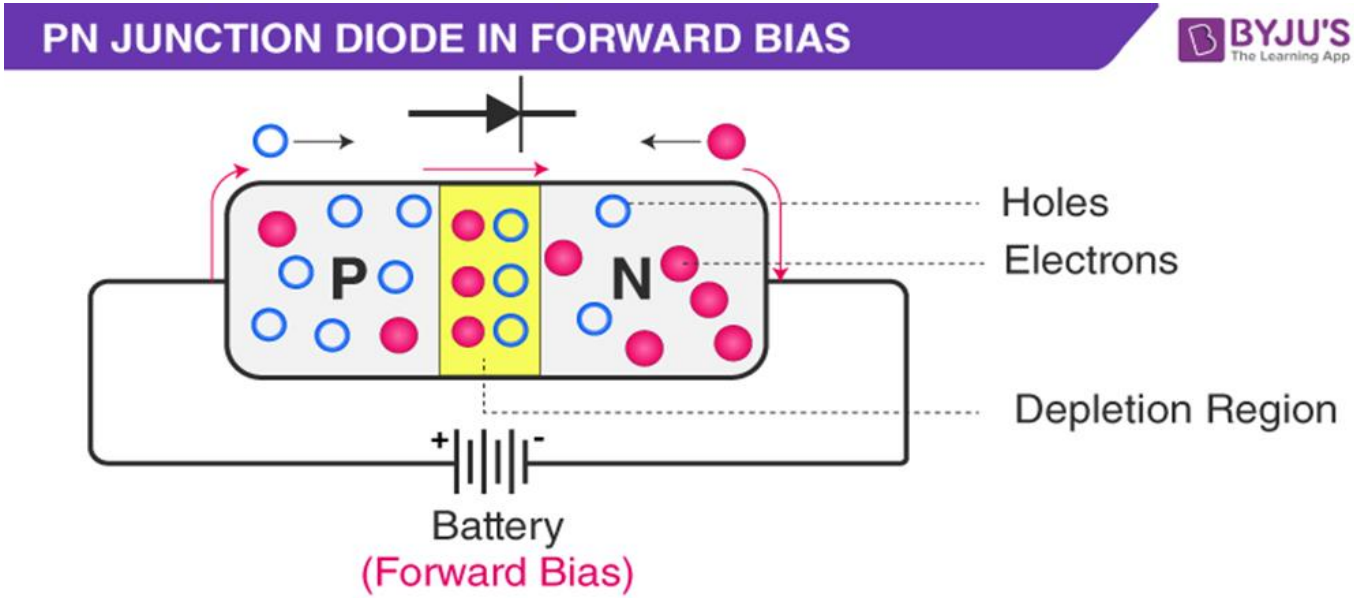
FORWARD-BIASED	**REVERSE-BIASED**
Current flows from anode to cathode.	Current flows from cathode to anode

Let us consider a P-N junction type diode;

- If the diode is in **forward bias**, **the P-type region is connected with the positive terminal of the voltage source and N-type to the negative terminal.** Electrons will get attracted to this terminal and will form a covalent bond with the P-type material.

How do diodes work? Cont'

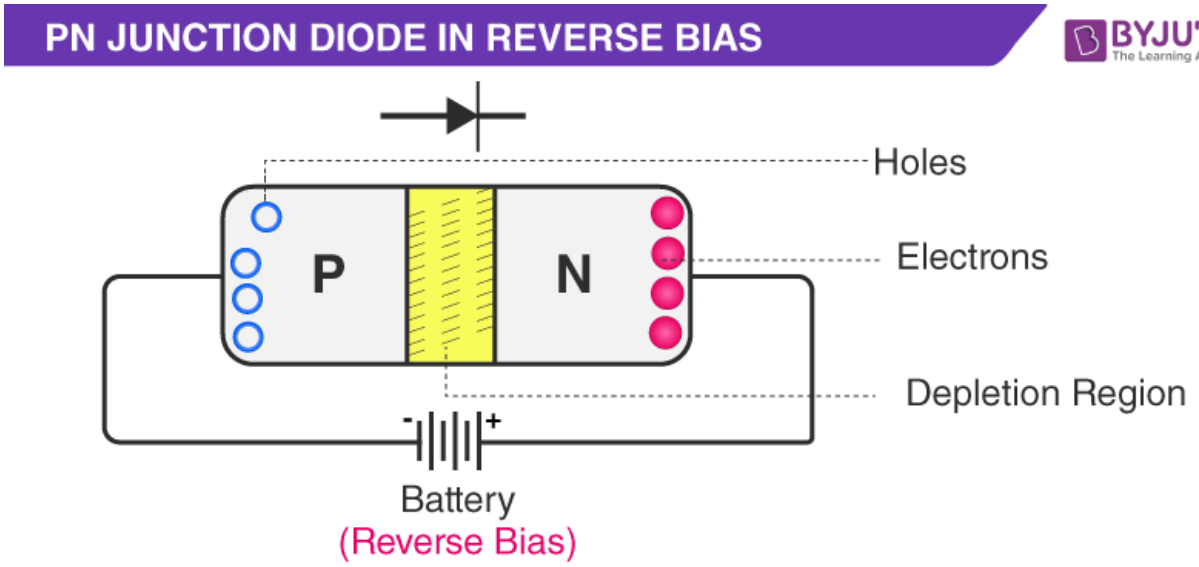
- So, without any hindrance, the **PN-junction diode** will behave as a short circuit.



Source: https://byjus.com/physics/uses-of-diode/

How do diodes work? Cont'

- When the diode is in **reversed bias**, the **P-type region is connected to the negative terminal and the N-type region is connected to the positive terminal of the source.** Because the positive terminal is connected to N-type, the free electrons are attracted towards that region due to the presence of positive terminal.



Source: https://byjus.com/physics/uses-of-diode/

Identification of different types of diodes

Ordinary diode

- An **ordinary diode** is designed to be used as a rectifier and not for operating in reverse breakdown. Consequently, a will not be able to reliably handle much current before the junction is damaged permanently.

Source: https://byjus.com/physics/uses-of-diode/

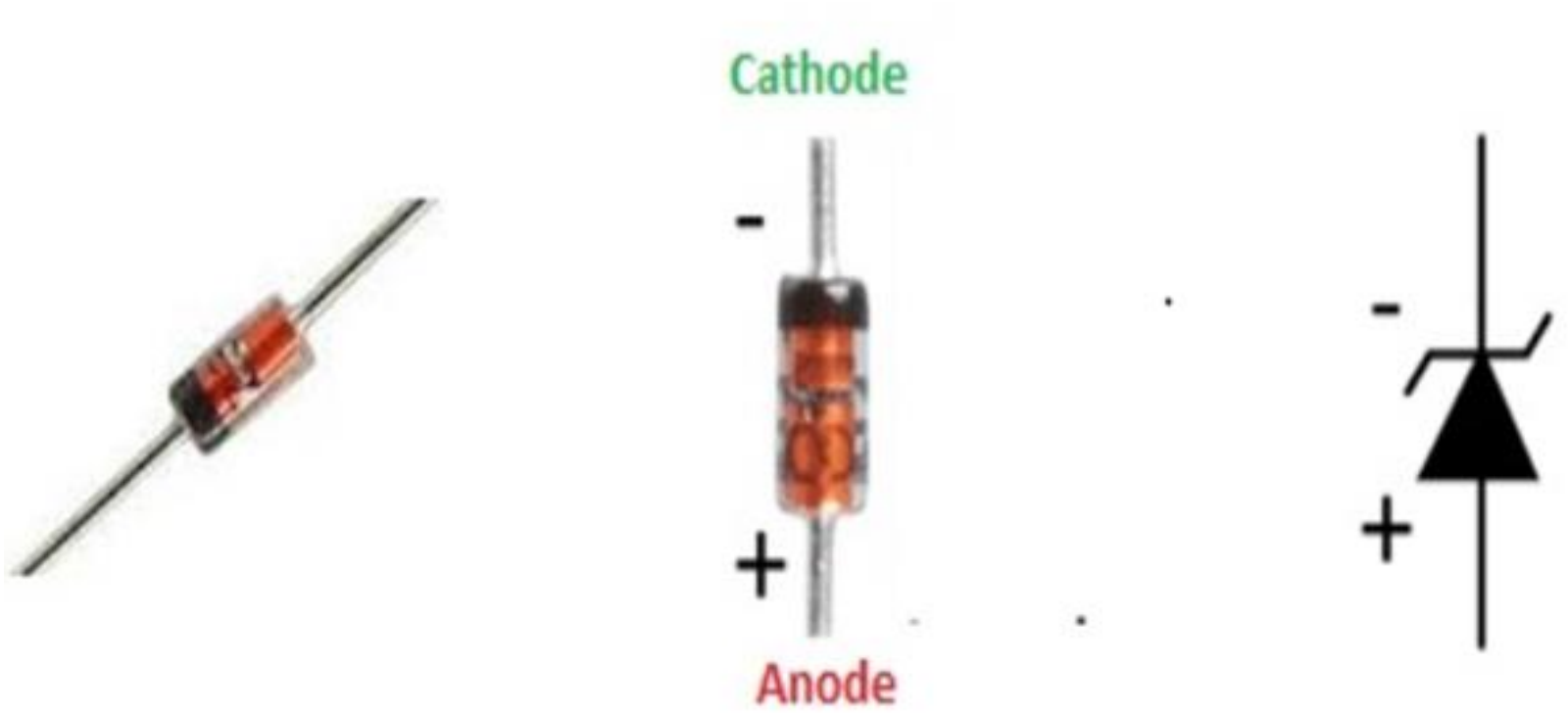
Zener Diode

- **Zener diode** is a special type of diode designed to reliably allow **current** to flow "backwards" when a certain set reverse voltage, known as the *Zener voltage*, is reached.
- Zener diodes are manufactured with a great variety of Zener voltages and some are even variable. Some Zener diodes have a sharp, highly doped **p-n junction** with a low Zener voltage, in which case the reverse conduction occurs due to electron **quantum tunnelling** in the short space between p and n regions – this is known as the **Zener effect**, after Clarence Zener.
- Diodes with a higher Zener voltage have a more gradual junction and their mode of operation also involves **avalanche breakdown**.

Zener Diode

- Both breakdown types are present in Zener diodes with the Zener effect predominating at lower voltages and avalanche breakdown at higher voltages.
- Zener diodes are widely used in electronic equipment of all kinds and are one of the basic building blocks of **electronic circuits**.
- They are used to generate low-power stabilized supply rails from a higher voltage and to provide reference voltages for circuits, especially stabilized power supplies. They are also used to protect circuits from **overvoltage**, especially **electrostatic discharge** (ESD).

Figure: Zener Diode



Source: https://www.theengineeringprojects.com/2019/09/what-is-the-zener-diode.html

Zener Diode cont'

Zener Effect

- Zener Effect is the category of the electric failure (breakdown) that exits in reverse biasing PN junction the strong statice field allow the electrons to move from the valance band to the conductive band of a semiconductor.
- Its name is due to the use of this factor in the operation of the Zener diode.

Applications of Zener Diode

It is commonly used as a voltage reference device.

- It used in voltage regulators.
- It used for switching purposes.
- Zener diode is an important part of the clamp and clipping circuitries.
- It used in many security circuitries.
- It also used in electronic devices like mobile laptops, computers, etc.

Light-Emitting Diode

A light-emitting diode (LED) is a semiconductor device that emits light when an electric current is passed through it. Light is produced when the particles that carry the current (known as electrons and holes) combine together within the semiconductor material. Since light is generated within the solid semiconductor material, LEDs are described as solid-state devices.

The term solid-state lighting, which also encompasses organic LEDs (OLEDs), distinguishes this lighting technology from other sources that use heated filaments (incandescent and tungsten halogen lamps) or gas discharge (fluorescent lamps).

Main LED materials

The main semiconductor materials used to manufacture LEDs are:

- **Indium gallium nitride (InGaN):** blue, green and ultraviolet high-brightness LEDs
- **Aluminum gallium indium phosphide (AlGaInP):** yellow, orange and red high-brightness LEDs
- **Aluminum gallium arsenide (AlGaAs):** red and infrared LEDs
- **Gallium phosphide (GaP):** yellow and green LEDs

Source: https://byjus.com/physics/uses-of-diode/

LED Con't

Working principle of LED

- When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons.

- This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

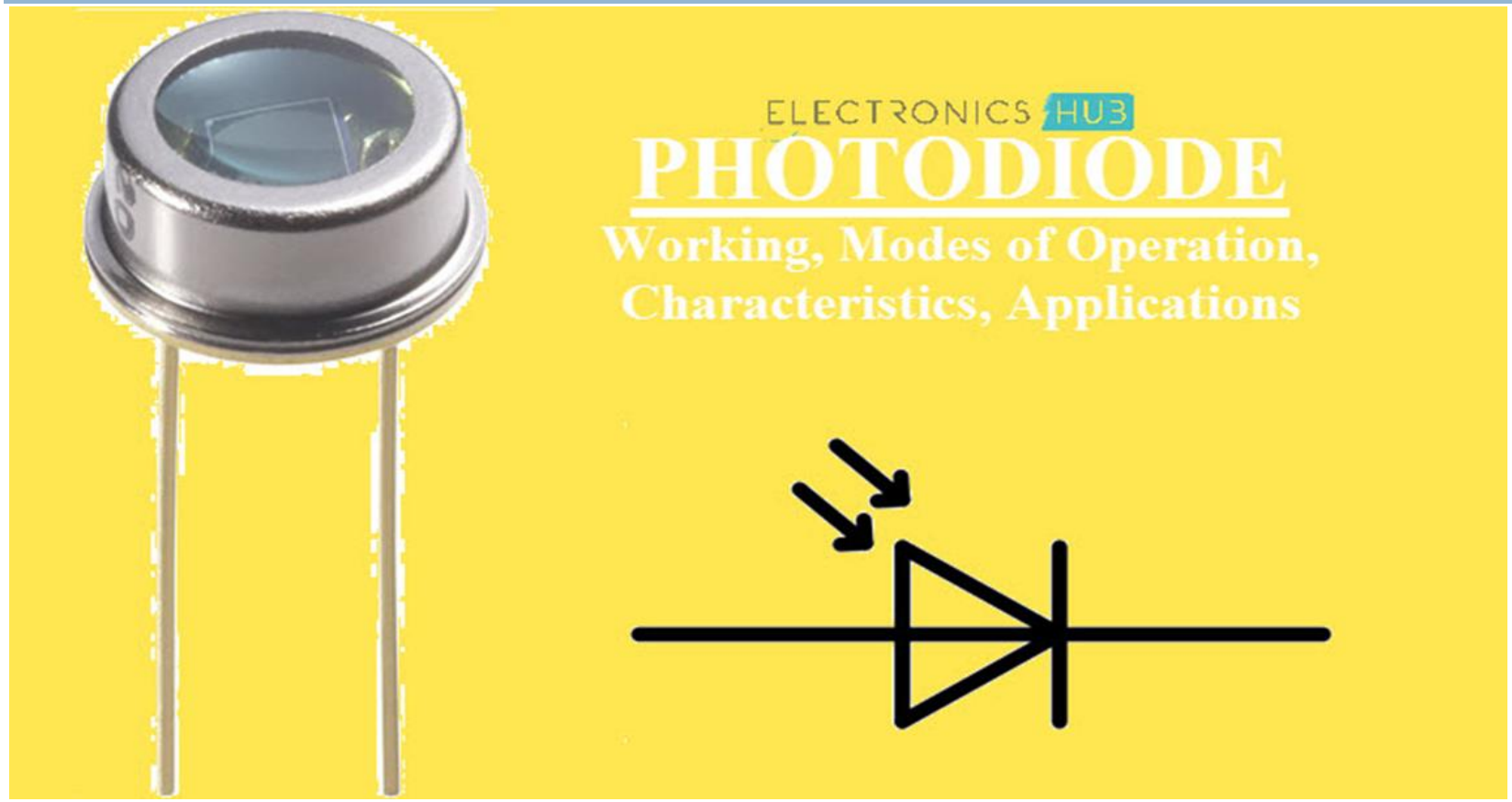
Photodiode

A **photodiode/photodetector** is a semiconductor p-n junction device that converts light into an electrical current. The current is generated when photons are absorbed in the **photodiode.**

The **operating principle** of the **photodiode** is such that when the junction of this two-terminal semiconductor device is illuminated then the electric current starts flowing through it. Only minority current flows through the device when the certain reverse potential is applied to it.

Note: A **photon** is a tiny particle that comprises waves of electromagnetic radiation. As shown by Maxwell, **photons** are just electric fields traveling through space. **Photons** have no charge, no resting mass, and travel at the speed of light.

Figure: Image and symbol for photodiode



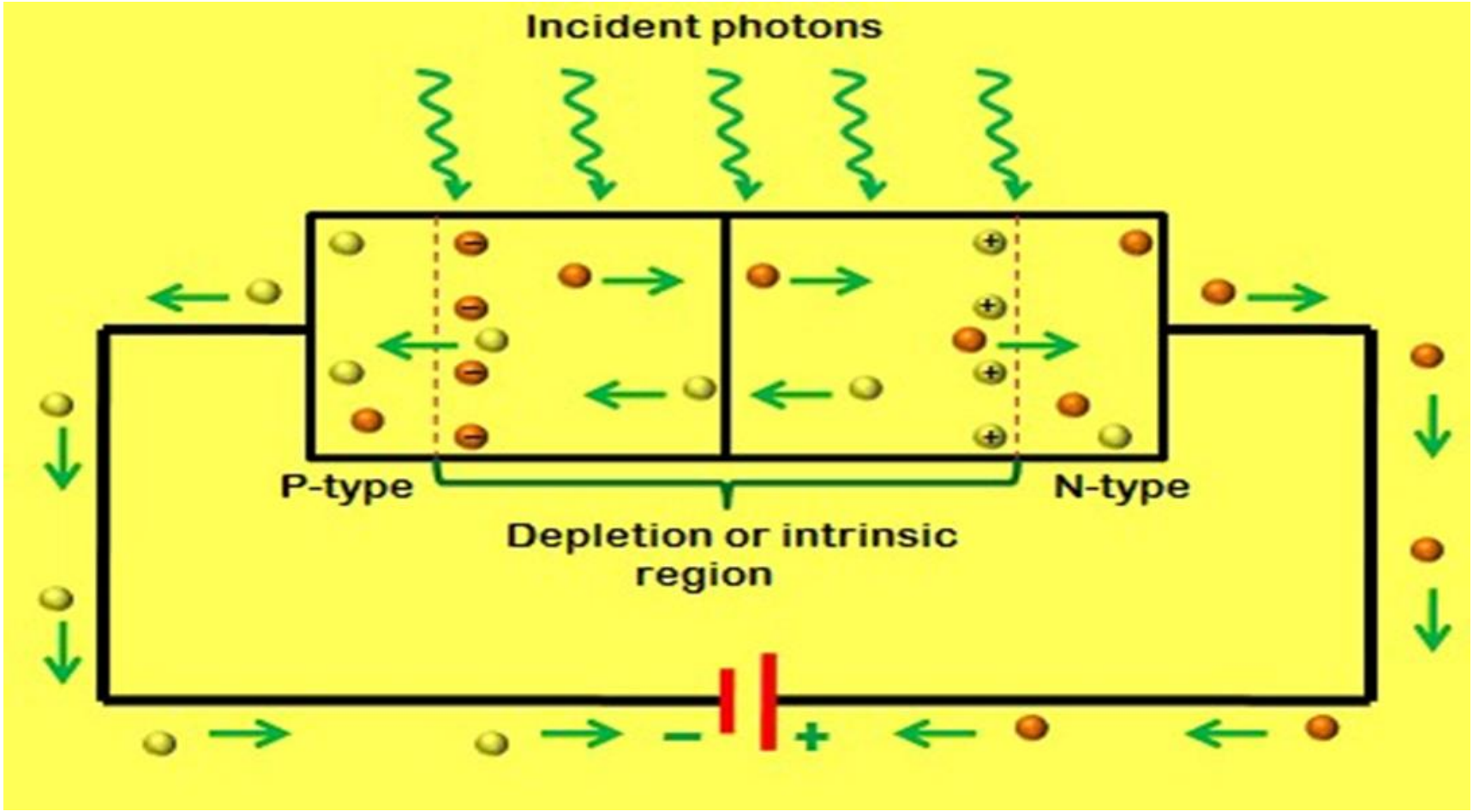
Source: https://www.electronicshub.org/photodiode-working-characteristics-applications/

Working of a photodiode

- Generally, when a light is made to illuminate the PN junction, covalent bonds are ionized. This generates hole and electron pairs. Photocurrents are produced due to generation of electron-hole pairs. Electron hole pairs are formed when photons of energy more than 1.1eV hits the diode.

- When the photon enters the depletion region of diode, it hits the atom with high energy. This results in release of electron from atom structure. After the electron release, free electrons and hole are produced.

Figure: Working of photodiode

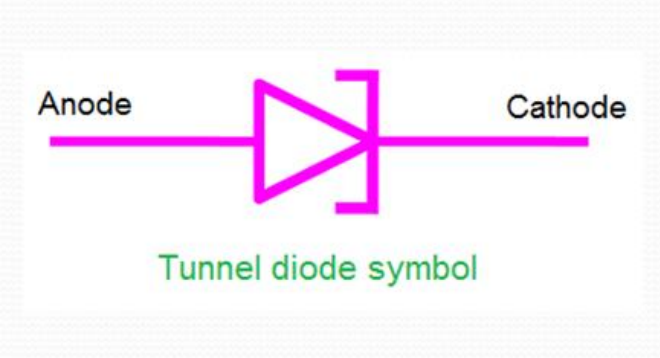


Source: https://www.electronicshub.org/photodiode-working-characteristics-applications/

TUNNEL DIODE

A **tunnel diode** (also known as a Esaki **diode**) is a type of semiconductor **diode** that has effectively "negative resistance" due to the quantum mechanical effect called **tunneling. Tunnel diodes** have a heavily doped pn junction that is about 10 nm wide.

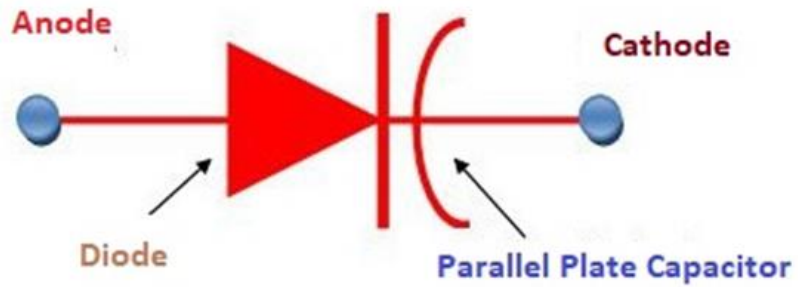
Quantum tunnelling or **tunneling** (US) is the quantum mechanical phenomenon where a wavefunction can propagate through a potential barrier. The transmission through the barrier can be finite and depends exponentially on the barrier height and barrier width.



Source: https://www.physics-and-radio-electronics.com/

Varactor diode

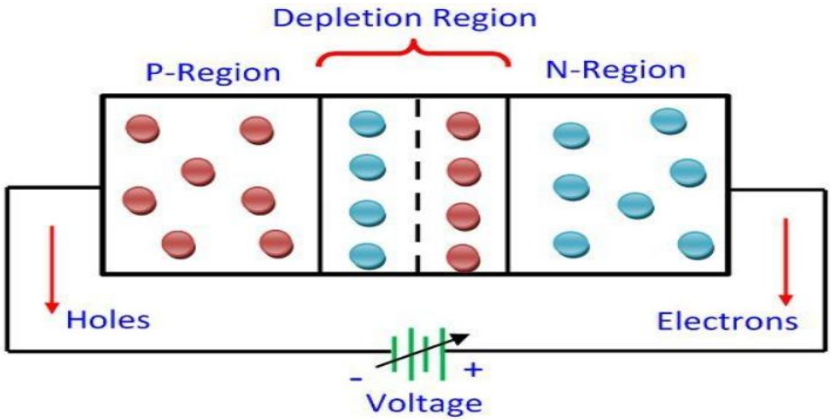
- **Varactor Diode Varactor diode** is a type of **diode** whose internal capacitance varies with respect to the reverse voltage. It always works in reverse bias condition and is a voltage-dependent semiconductor device.
- **Varactor diode** is known by several names as **Varicap**, Voltcap, Voltage variable capacitance, or Tunning **diode**.



Source: https://circuitglobe.com/varactor-diode.html

Working of Varactor Diode

- The Varactor diode is made up of n-type and p-type semiconductor material. In an n-type semiconductor material, the electrons are the majority charge carrier and in the p-type material, the holes are the majority carriers. When the p-type and n-type semiconductor material are joined together, the p-n junction is formed, and the depletion region is created at the PN-junction. The positive and negative ions make the depletion region. This region blocks the current to enter from the PN-region.



Depletion Region in a Reverse Biased P-N junction

Source: https://circuitglobe.com/varactor-diode.html

Working of Varactor Diode cont'

- The varactor diode operates only in reverse bias. Because of reverse bias, the current does not flow. If the diode is connected in forward biasing the current starts flowing through the diode and their depletion region become decreases. The depletion region does not allow the ions to move from one place to another.

- **The Varactor diode is used for storing the charge not for flowing the charge**. In the forward bias, the total charge stored in the diode becomes zero, which is undesirable. Thus, the Varactor diode always operates in the reverse bias.

Selection of Diode based on Coding

The European System(ES) Diode Code

Identification consists of an alphanumeric code as per below:

[1] Two letters and three figures.

[2] Three letters and two figures.

The first naming method is for General purpose diodes and the second option is for special purpose diodes. As shown in the above figure, mostly cathode terminal is identified with the help of marking of the stripe.

First letter = Semiconductor material

A – Germanium

B – Silicon

C – Gallium Arsenide

D – Photodiodes

Selection of Diode based on Coding cont'

Second Letter = Application

A – General Purpose diode

B – Variable capacitance diode

E – Tunnel diode

P – Photo diode

Q – Light Emitting Diode

T – Controlled Diode

X – Varactor Diode

Y – Power rectifier

Z – Zener Diode

Third letter – The third letter does not have any particular significance. The letter is used to mention the specialized application of the diode.

Selection of Diode based on Specifications and Ratings

- **Semi conductor material:** Silicon & Germanium
- **Diode type:** PN junction, etc
- **Forward voltage drop** is the **voltage drop** across the diode when it is **forward** conduction. For silicon diodes $V_f = 0.6$ V. Zener Diodes. Zener diodes have all the same characteristics of normal diodes.
- **Peak inverse voltage** or **Peak Reverse Voltage** (PRV) refer to the maximum **voltage** a diode or other device can withstand in the **reverse**-biased direction before breakdown. Also may be called **Reverse** Breakdown **Voltage**.
- **Reverse breakdown voltage** is the **reverse** anode **voltage** at which the diode conducts a specified amount of **reverse** current. Since it's the **reverse** current across a junction, IR exhibits a knee shaped rise, increasing rapidly once **breakdown** occurs.

Selection of Diode based on Specifications and Ratings cont'

- **Maximum forward current:** The Maximum value of the forward current that a PN junction or diode can carry without damaging the device is called its **Maximum Forward Current.** The rating of a PN junction or a diode is specified by the manufacturer in its datasheet.

- **Junction operating temperature:** The **junction temperature** refers to the **temperature** of the silicon die within the package of the device when the device is powered. The **junction temperature** can also be referred to as the **operating temperature.**

Selection of Diode based on Specifications and Ratings Cont'

- **Junction-to-ambient thermal resistance** (θJA) is defined as the **thermal resistance** from the semiconductor **junction** to the **ambient** air (**junction-to-ambient**). θJA is a measure of the ability of a device to dissipate heat from the surface of the die to the **ambient** air via all paths.

- **Leakage current:** the current that the diode will leak when a reverse voltage is applied to it.

Selection of Diode based on Specifications and Ratings Cont'

Even though diodes are one-way devices, and they are only supposed to conduct current through them when they receive forward voltage (positive voltage to the anode), they will still conduct a small amount of current, called leakage current, when connected in reverse biased (positive voltage) to the cathode.

- **Junction capacitance:** Junction capacitance of a PN junction diode: **capacitance** which must be added to the circuit model of a **p-n diode**. The **capacitance** associated with the charge variation in the depletion layer is called the. **junction capacitance**, while the **capacitance** associated with the excess carriers in the quasi-neutral region is called the diffusion **capacitance**.

DIODES RATING

ELECTRICAL CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)						
PARAMETER	**TEST CONDITION**	**SYMBOL**	**MIN.**	**TYP.**	**MAX.**	**UNIT**
Forward voltage	I_F = 10 mA	V_F			1000	mV
Reverse current	V_R = 20 V	I_R			25	nA
	V_R = 20 V, T_j = 150 °C	I_R			50	µA
	V_R = 75 V	I_R			5	µA
Breakdown voltage	I_R = 100 µA, t_p/T = 0.01, t_p = 0.3 ms	$V_{(BR)}$	100			V
Diode capacitance	V_R = 0 V, f = 1 MHz, V_{HF} = 50 mV	C_D			4	pF
Rectification effiency	V_{HF} = 2 V, f = 100 MHz	η_r	45			%
Reverse recovery time	I_F = I_R = 10 mA, i_R = 1 mA	t_{rr}			8	ns
	I_F = 10 mA, V_R = 6 V, i_R = 0.1 x I_R, R_L = 100 Ω	t_{rr}			4	ns

ABSOLUTE MAXIMUM RATINGS (T_{amb} = 25 °C, unless otherwise specified)				
PARAMETER	**TEST CONDITION**	**SYMBOL**	**VALUE**	**UNIT**
Repetitive peak reverse voltage		V_{RRM}	100	V
Reverse voltage		V_R	75	V
Peak forward surge current	t_p = 1 µs	I_{FSM}	2	A
Repetitive peak forward current		I_{FRM}	500	mA
Forward continuous current		I_F	300	mA
Average forward current	V_R = 0	$I_{F(AV)}$	150	mA
Power dissipation	l = 4 mm, T_L = 45 °C	P_{tot}	440	mW
	l = 4 mm, $T_L \leq$ 25 °C	P_{tot}	500	mW

Source: https://www.electricalclassroom.com/diode-ratings-diode-datasheet/

DIODES RATING Cont'

- **Forward voltage drop (V_f)**

The voltage drop measured across a forward-biased diode during conduction is known as **forward voltage drop**. A silicon diode has a forward voltage drop of **0.6V** and a germanium diode has a forward voltage drop of **0.7V**.

- **Peak Inverse Voltage (PIV)**

Peak Inverse Voltage refers to the maximum reverse bias voltage a diode withstands without damaging itself, before breakdown. The peak inverse voltage is also known as **peak reverse voltage.** The peak inverse voltage rating of a diode increases and decreases with temperature. A typical diode used in rectifiers has a **PIV** rating of at least 50Vdc at room temperature.

- **Maximum repetitive reverse voltage (V_{RRM})**

The maximum reverse voltage a diode can withstand in the form of repetitive pulses is known as Maximum repetitive reverse voltage (V_{RRM}). In other words, it is the maximum reverse voltage that a diode can withstand when applied repeatedly. It is a very important diode rating, that is taken into account while selecting a diode for rectifiers.

DIODES RATING Cont'

- **Maximum DC reverse voltage, V_R**

Maximum DC reverse voltage, V_R, is defined as the maximum continuous reverse-biased voltage a diode can withstand. The maximum DC reverse voltage is also known as the maximum DC blocking voltage (V_{DC}).

- **Forward Viltage V_F:**

A certain amount of voltage is required to trigger conduction in the forward direction. Forward voltage can be defined as the minimum voltage that when applied across diode triggers conduction in the diode. For silicon diodes, the typical forward voltage is around 0.7V and for germanium diode, the typical forward voltage is around 0.3V.

DIODES RATING Cont'

- **Repetitive Peak Forward Surge Current – I_{FRM}**

The repetitive peak forward surge current is the maximum current surge the diode can handle as repetitive pulses without damaging itself.

- **Maximum reverse current or leakage current – I_R**

The maximum amount of current the diode can conduct during reverse bias is known as reverse leakage current or leakage current. It is negligible when compared to the forward continuous current. For an ideal diode, the leakage current assumed to be zero.

- **Maximum power dissipation – P_{Dmax}**

Maximum power dissipation is the maximum possible power dissipation in the diode when operating in forward bias. It is typically the multiplication of forward voltage by the forward continuous current. The P-N junction offers a resistance to the current flow resulting in power loss in the form of heat across the junction.

Selection of Diode based on Applications

Diodes are selected according to the following applications:

- Limiters
- Clippers
- Logic gates
- Rectifiers
- Gain control
- Amplifiers
- Etc.

This is because in each application we can choose a diode which can fit.

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