POWER ELECTRONICS

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POWER ELECTRONICS

- Power Electronics refers to the process of controlling the flow of current and voltage and converting it to a form that is suitable for user loads. The most desirable power electronic system is one whose efficiency and reliability is 100%.
- Power electronics is a specialized field of electrical engineering that focuses on the control, conversion, and management of electrical power using electronic devices. It deals with the design, analysis, and implementation of circuits and systems that manipulate electrical energy to meet specific requirements.
- power electronics enables the efficient conversion of electrical power between different forms, such as AC (alternating current) and DC (direct current), and at different voltage and current levels. This technology is fundamental to a wide range of applications, including renewable energy systems, electric vehicles, industrial automation, consumer electronics, and power supplies.
- Key components of power electronics systems include semiconductor devices like diodes, transistors (such as MOSFETs and IGBTs), and thyristors, as well as various types of power converters and control circuits. These components are used to regulate voltage and current, control power flow, and convert between AC and DC power.
- Overall, power electronics plays a crucial role in shaping modern technology and industries by providing efficient and reliable solutions for power management and control, contributing to energy efficiency, sustainability, and innovation.

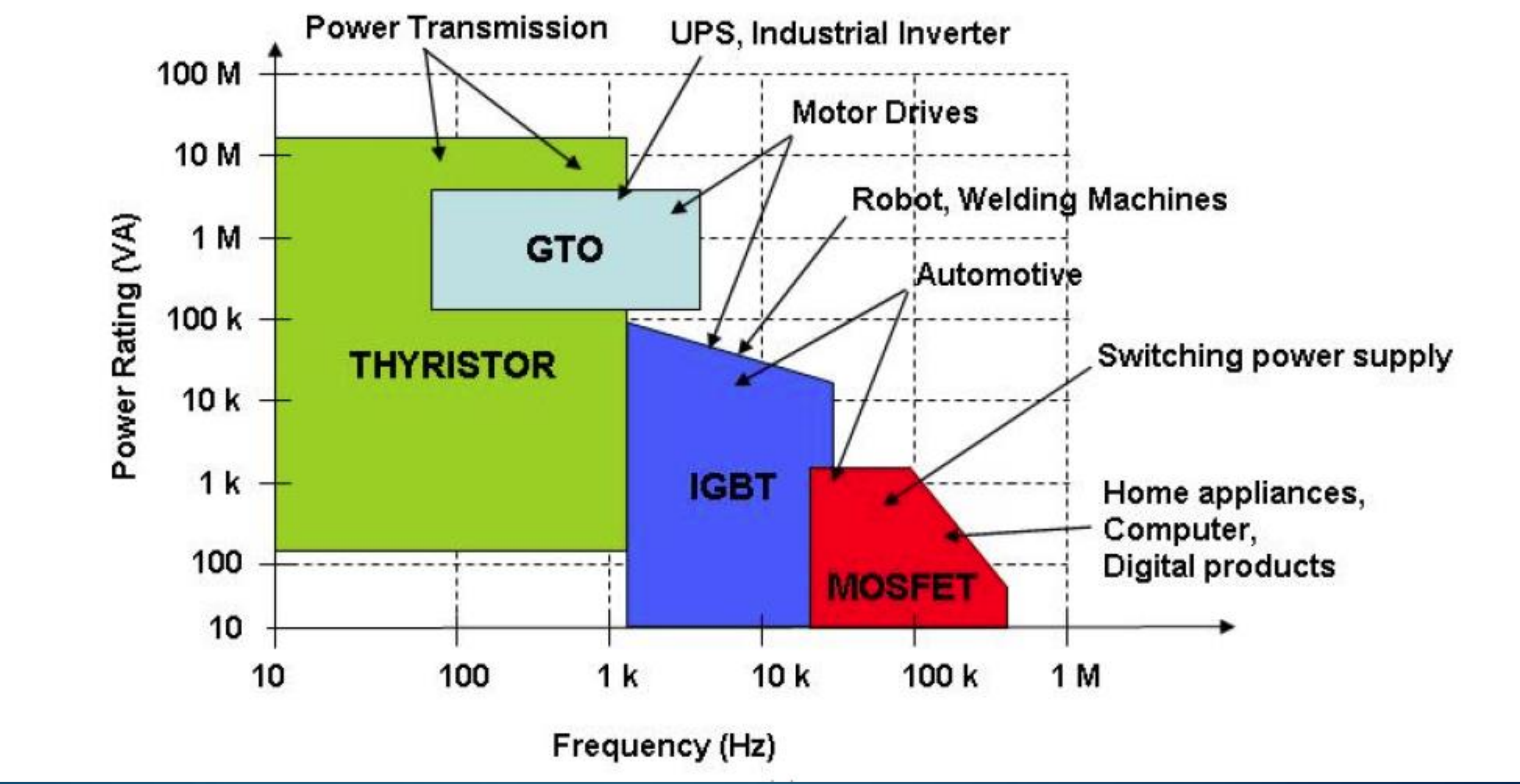
POWER ELECTRONICS IMPORTANCE IN MODERN TECHNOLOGY AND INDUSTRIES

- **Energy Efficiency: Power electronics technology facilitates efficient energy conversion and utilization, leading to reduced energy consumption and lower operational costs across various sectors. This is particularly vital in energy-intensive industries such as manufacturing and transportation.**
- **Renewable Energy Integration: With the growing focus on renewable energy sources like solar and wind, power electronics plays a critical role in integrating these intermittent energy sources into the grid. Power converters enable the efficient conversion of DC power generated by renewables into AC power compatible with existing grid infrastructure.**
- **Electric Vehicles (EVs): Power electronics is fundamental to the operation of electric vehicles, from controlling motor speed and torque to managing battery charging and discharging. Advanced power electronic systems contribute to extending EV range, improving performance, and enhancing overall driving experience.**
- **Industrial Automation: In industrial automation and robotics, power electronics drives the precise control of motors and actuators, enabling efficient and precise movement in manufacturing processes. This leads to increased productivity, reduced downtime, and enhanced product quality.**
- **Consumer Electronics: Power electronics is ubiquitous in consumer electronics devices, such as smartphones, laptops, and household appliances.**

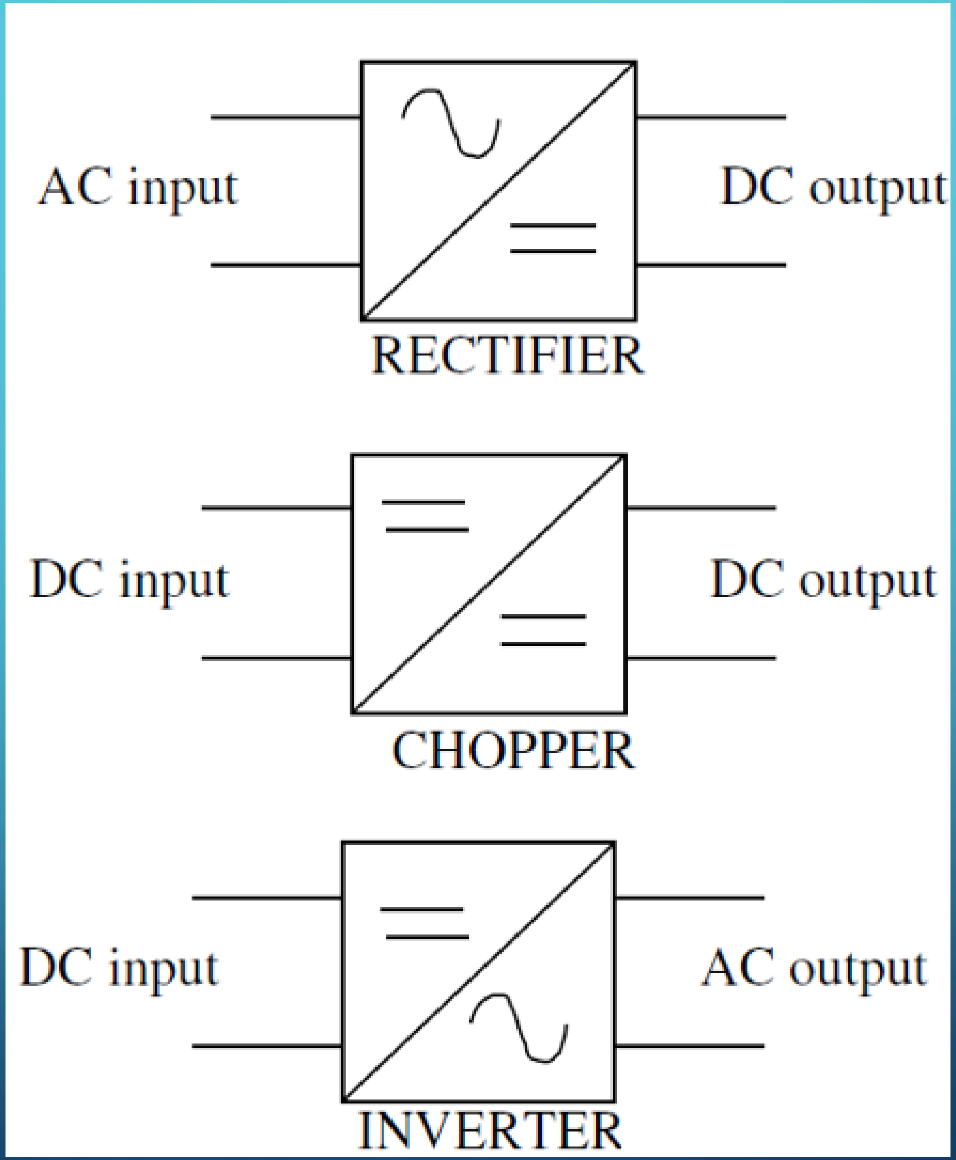
POWER ELECTRONICS IMPORTANCE IN MODERN TECHNOLOGY AND INDUSTRIES

- **Consumer Electronics: Power electronics is ubiquitous in consumer electronics devices, such as smartphones, laptops, and household appliances. Switching power supplies and voltage regulators ensure stable and efficient power delivery, prolonging device lifespan and improving user experience.**
- **Grid Stability and Power Quality: Power electronic devices and systems help maintain grid stability by providing reactive power compensation, voltage regulation, and frequency control. They also mitigate power quality issues such as harmonics and voltage fluctuations, ensuring reliable and high-quality electrical supply.**
- **Data Centers: In data centers and telecommunications facilities, power electronics equipment such as uninterruptible power supplies (UPS) and voltage converters ensure continuous and reliable power supply, safeguarding critical operations and data integrity.**
- **Smart Grids and Energy Management: Power electronics technology plays a crucial role in the development of smart grids and advanced energy management systems. Smart grid components, including grid-tied inverters, enable bidirectional power flow, demand response, and integration of distributed energy resources.**

POWER ELECTRONICS SWITCHING DEVICES



POWER ELECTRONICS CONVERTERS



POWER SEMICONDUCTOR DEVICES

The power semiconductor devices can be classified into three categories according to their controllability

1. Uncontrolled turn-on & off devices (eg. diode)
2. Controlled turn-on & Uncontrolled turn off devices (eg. SCR)
3. Controlled turn-on & off devices (eg. BJT's, MOSFET, GTO, IGBT, SIT'S,MCT's)

The different power semiconductor devices which are commonly used in different applications are as follows :

- Power Diodes.
- Power Transistors (BJT's).
- Power MOSFETS.
- IGBT's (Insulated Gate Bilateral Transistors)
- Thyristors

THYRISTORS

- The term thyristor is used to indicate a family of semiconductor devices used for power control .
- A thyristor is a four layer, semiconductor of p-n-p-n structure with three p-n junctions. It has three terminals, the anode, cathode and the gate.
- The word thyristor is coined from thyratron and transistor. It was invented in the year 1957 at Bell Labs. The Different types of Thyristors are
  - Silicon Controlled Rectifier (SCR).
  - TRIAC (Tiode for Alternating Current)
  - DIAC (Diode for Alternating Current)
  - Gate Turn Off Thyristor (GTO)

THYRISTORS

- The term "thyristor" is indeed derived from combining "thyratron" and "transistor." It reflects the functionality and characteristics of these two electronic devices.

Thyratron: Thyratrons are gas-filled tubes capable of controlling the flow of electrical current. They were widely used in early electronic applications for switching and amplification.

Transistor: Transistors are solid-state semiconductor devices that can amplify or switch electronic signals. They revolutionized electronics by replacing bulky, less reliable vacuum tubes like thyratrons.

- A thyristor combines elements of both thyratrons and transistors. Like thyratrons, thyristors are capable of controlling large currents and voltages. However, they operate on solid-state principles like transistors, offering advantages such as smaller size, faster switching speeds, and greater reliability.
- The term "thyristor" thus signifies a semiconductor device that shares characteristics of both thyratrons and transistors, offering a solid-state alternative to thyratrons for high-power switching applications. Thyristors are widely used in various applications, including power control, motor drives, lighting control, and voltage regulation.

SILICON CONTROLLED RECTIFIER (SCR)

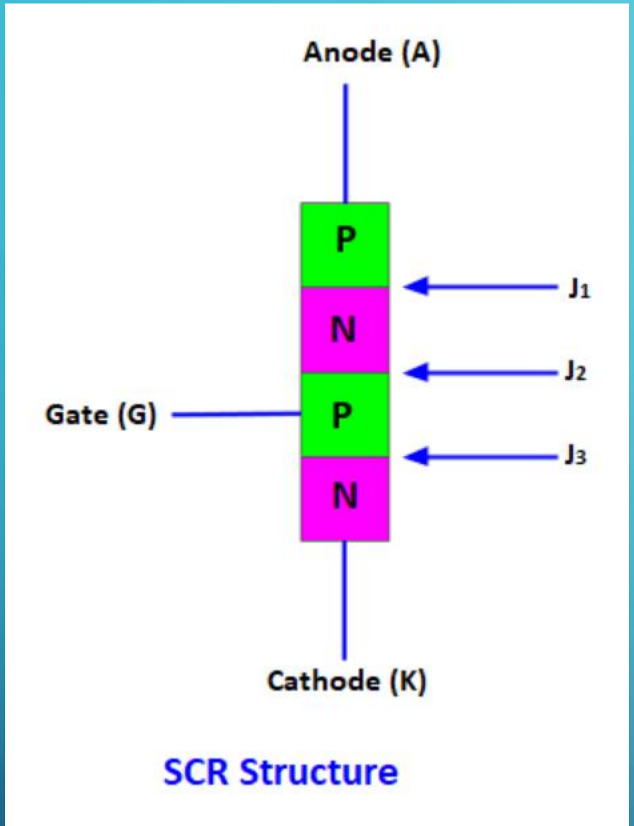
- A Silicon-Controlled Rectifier (SCR), also known as a thyristor, is a semiconductor device used in power electronics circuits for controlling the flow of electrical current. It acts as a high-speed switch that can handle large power levels.
- **Structure:** An SCR consists of three semiconductor layers - an N-type semiconductor layer sandwiched between two P-type semiconductor layers. This structure forms a P-N-P-N configuration.
- **Operation:** The SCR behaves like a diode until a specific trigger voltage, called the gate voltage, is applied to the gate terminal. Once the gate voltage surpasses the threshold level, the SCR enters the conducting state, allowing current to flow from the anode to the cathode. Once triggered into conduction, it remains in the conducting state even if the gate voltage is removed until the anode current falls below a certain threshold called the holding current or the polarity of the anode-cathode voltage is reversed.

SILICON CONTROLLED RECTIFIER (SCR)

- **Applications:** SCR finds extensive use in various applications, including motor speed control, power regulation, AC power control, voltage regulation, and inverter circuits. It's commonly used in industries where high-power switching is required, such as in industrial automation, motor drives, heating systems, and electric vehicle charging stations.
- **Advantages:**
- High current and voltage handling capability.
- Fast switching speed.
- Simple and rugged construction.
- Low forward voltage drop when conducting.
- **Disadvantages:**
- Unidirectional conduction (current can only flow in one direction).
- Once triggered into conduction, it remains conducting until the current falls below a certain level or the voltage polarity reverses.
- Requires careful triggering to ensure proper operation.

SILICON CONTROLLED RECTIFIER (SCR)

- **SCR structure:**



A silicon controlled rectifier is made up of 4 semiconductor layers of alternating P and N type materials, which forms NPNP or PNPN structures. It has three P-N junctions namely J_1, J_2, J_3 with three terminals attached to the semiconductors materials namely anode (A), cathode (K), and gate (G). Anode is a positively charged electrode through which the conventional current enters into an electrical device, cathode is a negatively charged electrode through which the conventional current leaves an electrical device, gate is a terminal that controls the flow of current between anode and cathode. The gate terminal is also sometimes referred to as control terminal.

The anode terminal of SCR diode is connected to the first p-type material of a PNPN structure, cathode terminal is connected to the last n-type material, and gate terminal is connected to the second p-type material of a PNPN structure which is nearest to the cathode.

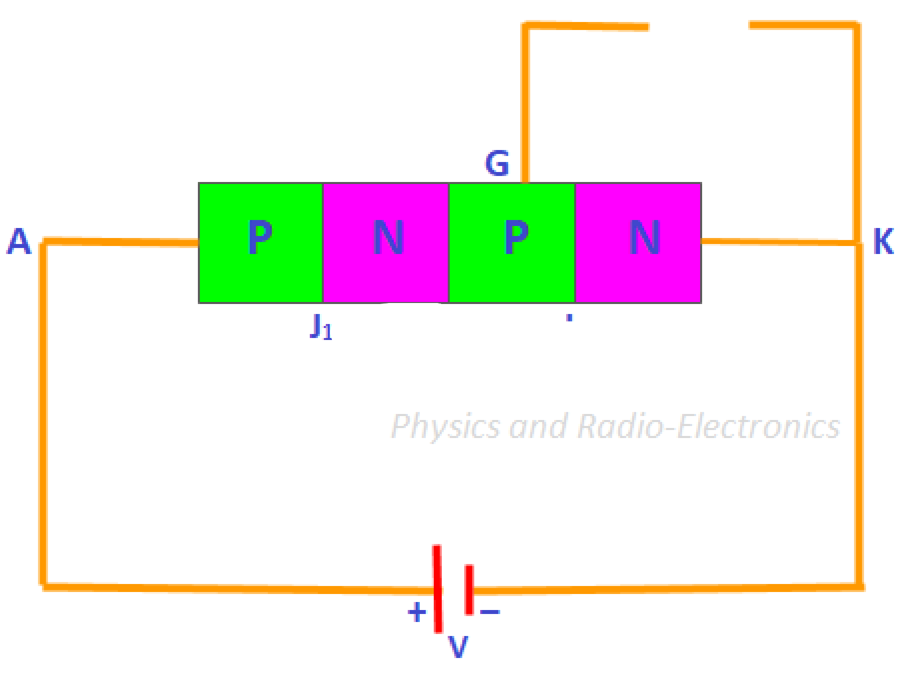
SILICON CONTROLLED RECTIFIER (SCR)

- **SCR Modes of Operation:** There are three modes of operation for a Silicon Controlled Rectifier (SCR), depending upon the biasing given to it.

1) **Forward Blocking Mode (Off State)**

2) **Forward Conducting Mode (On State)**

3) **Reverse Blocking Mode (Off State)**



Forward Blocking Mode of SCR

Forward Blocking Mode (Off State) In this mode of operation, the positive voltage (+) is given to anode A (+), negative voltage (-) is given to cathode K (-), and gate G is open circuited as shown in the below figure. In this case, the junction J1 and junction J3 are forward biased whereas the junction J2 becomes reverse biased. Due to the reverse bias voltage, the width of depletion region increases at junction J2. This depletion region at junction J2 acts as a wall or obstacle between the junction J1 and junction J3. It blocks the current flowing between junction J1 and junction J3. Therefore, the majority of the current does not flow between junction J1 and junction J3. However, a small amount of leakage current flows between junction J1 and junction J3.

When the voltage applied to the SCR reaches a breakdown value, the high energy minority carriers causes avalanche breakdown. At this breakdown voltage, current starts flowing through the SCR. But below this breakdown voltage, the SCR offers very high resistance to the current and so it will be in off state.

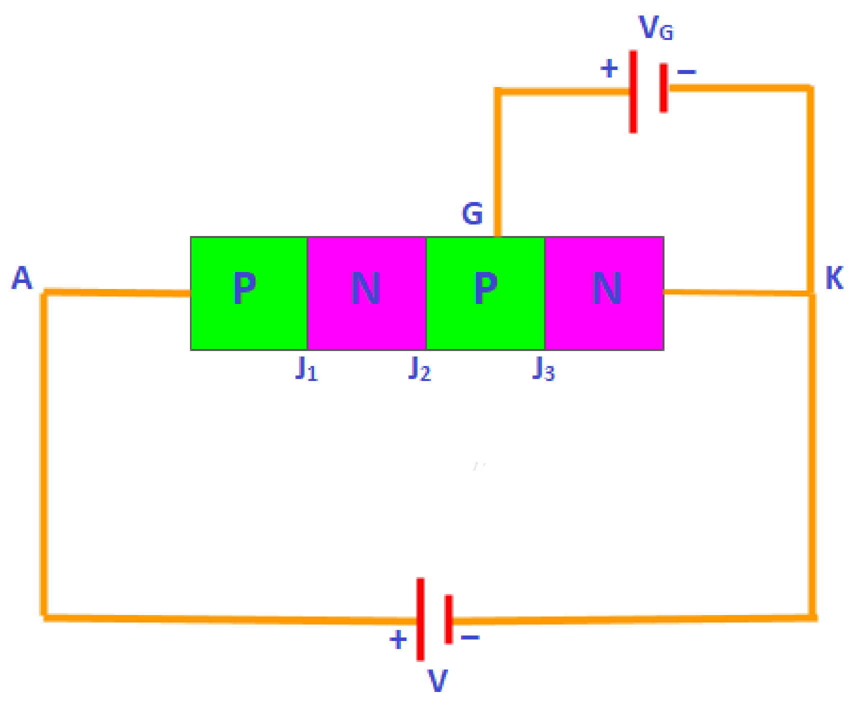
In this mode of operation, SCR is forward biased but still current does flows through it. Hence, it is named as Forward Blocking Mode.

SILICON CONTROLLED RECTIFIER (SCR)

- **Forward Conducting Mode (On State)** The Silicon Controlled Rectifier can be made to conduct in two ways:

1. By increasing the forward bias voltage applied between anode and cathode beyond the breakdown voltage
2. By applying positive voltage at gate terminal.

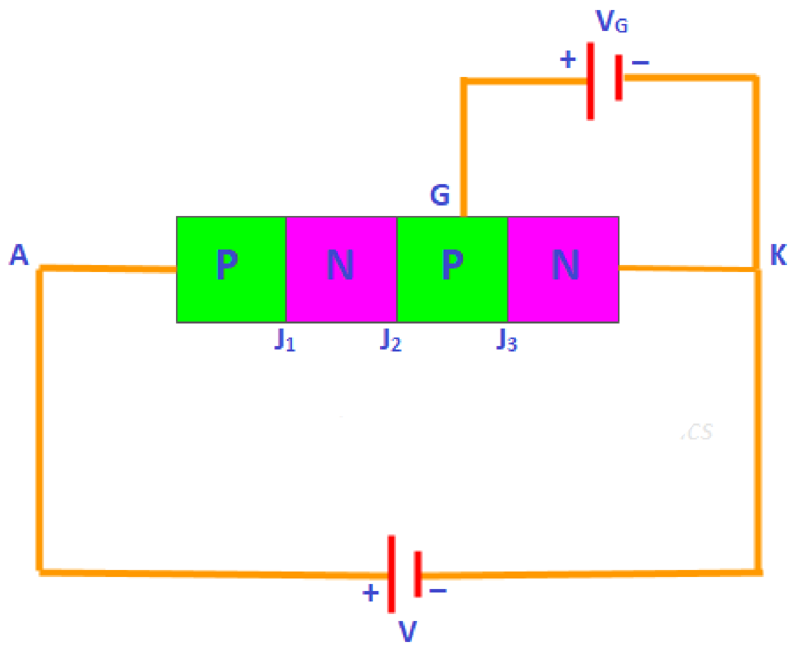
- In the first case, the forward bias voltage applied between anode and cathode is increased beyond the breakdown voltage, the minority carriers (free electrons in anode and holes in cathode) gains large amount of energy and accelerated to greater velocities. This high speed minority carriers collides with other atoms and generates more charge carriers. Likewise, many collisions happens with other atoms. Due to this, millions of charge carriers are generated. As a result depletion region breakdown occurs at junction J_2 and current starts flowing through the SCR. So the SCR will be in On state. The current flow in the SCR increases rapidly after junction breakdown occurs.



Forward Conducting Mode of SCR

SILICON CONTROLLED RECTIFIER (SCR)

- **Forward Conducting Mode (On State)** In the second case, a small positive voltage V_G is applied to the gate terminal. As we know that, in forward blocking mode, current does not flows through the circuit because of the wide depletion region present at the junction J_2. This depletion region was formed because of the reverse biased gate terminal. So this problem can be easily solved by applying a small positive voltage at the Gate terminal. When a small positive voltage is applied to the gate terminal, it will become forward biased. So the depletion region width at junction J_2 becomes very narrow. Under this condition, applying a small forward bias voltage between anode and cathode is enough for electric current to penetrate through this narrow depletion region. Therefore, electric current starts flowing through the SCR circuit.



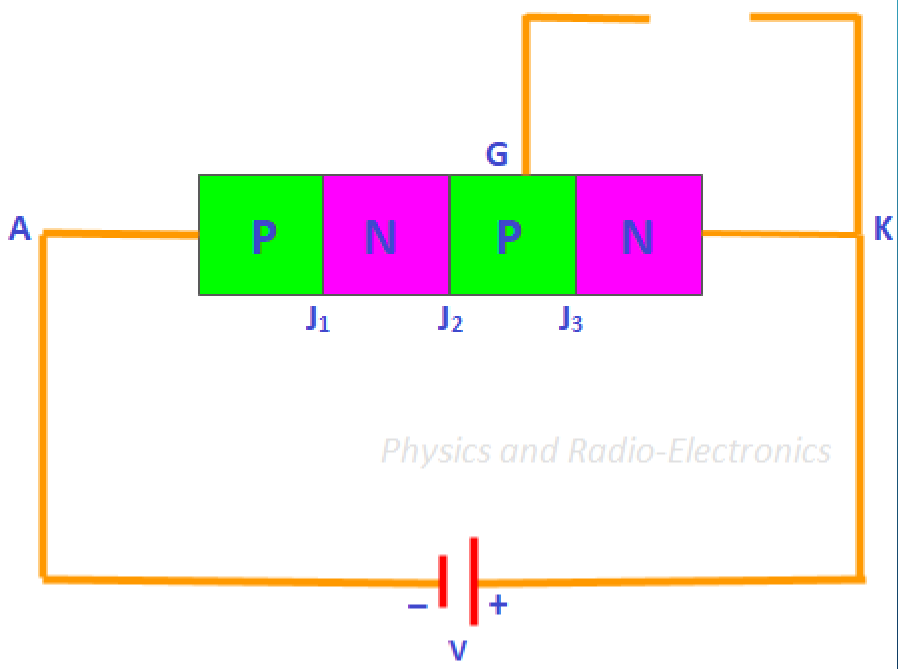
Forward Conducting Mode of SCR

- In second case, we no need to apply large voltage between anode and cathode. A small voltage between anode and cathode, and positive voltage to gate terminal is enough to brought SCR from blocking mode to conducting mode.
- In this mode of operation, SCR is forward biased and current flows through it. Hence, it is named as Forward Conducting Mode.

SILICON CONTROLLED RECTIFIER (SCR)

Reverse Blocking Mode (On State) In this mode of operation, the negative voltage (-) is given to anode (+), positive voltage (+) is given to cathode (-), and gate is open circuited as shown in the below figure. In this case, the junction J_1 and junction J_3 are reverse biased whereas the junction J2 becomes forward biased.

As the junctions J1 and junction J3 are reverse biased, no current flows through the SCR circuit. But a small leakage current flows due to drift of charge carriers in the forward biased junction J2. This small leakage current is not enough to turn on the SCR. So the SCR will be in Off state.



Reverse Blocking Mode of SCR

SILICON CONTROLLED RECTIFIER (SCR)

V-I Characteristics of SCR The V-I characteristics of SCR is shown in the below figure. The horizontal line in the below figure represents the amount of voltage applied across the SCR whereas the vertical line represents the amount of current flows in the SCR.

V_A = Anode voltage, I_A = Anode current, $+V_A$ = Forward anode voltage, $+I_A$ = Forward anode current, $-V_A$ = Reverse anode voltage, $+I_A$ = Reverse anode current

The V-I characteristics of SCR is divided into three regions:

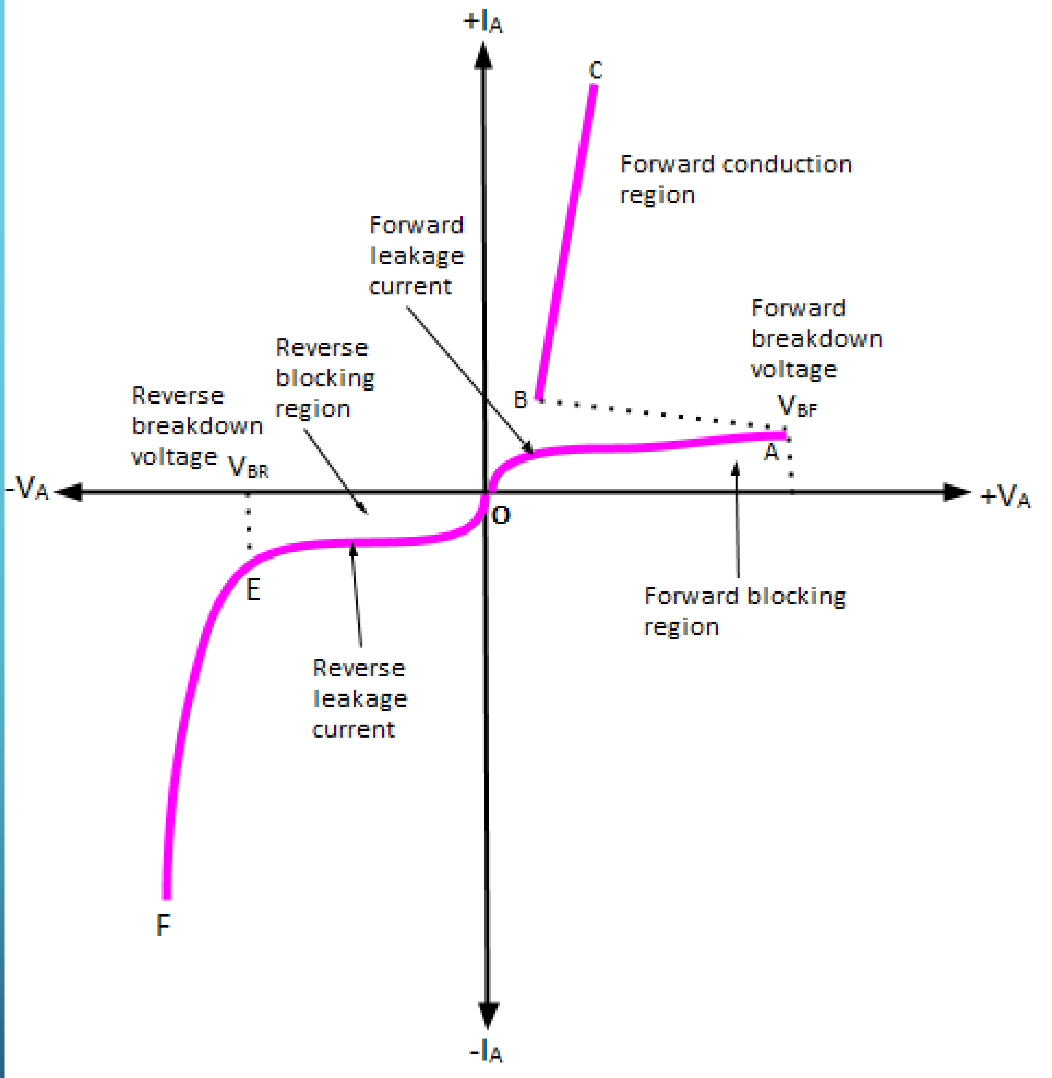
- Forward blocking region
- Forward conduction region
- Reverse blocking region

SILICON CONTROLLED RECTIFIER (SCR)

•**Forward blocking region**

In this region, the positive voltage (+) is given to anode (+), negative voltage (-) is given to cathode (-), and gate is open circuited. Due to this the junction J_1 and J_3 become forward biased while J_2 become reverse biased. Therefore, a small leakage current flows from anode to cathode terminals of the SCR. This small leakage current is known as forward leakage current.

The region OA of V-I characteristics is known as forward blocking region in which the SCR does not conduct electric current.



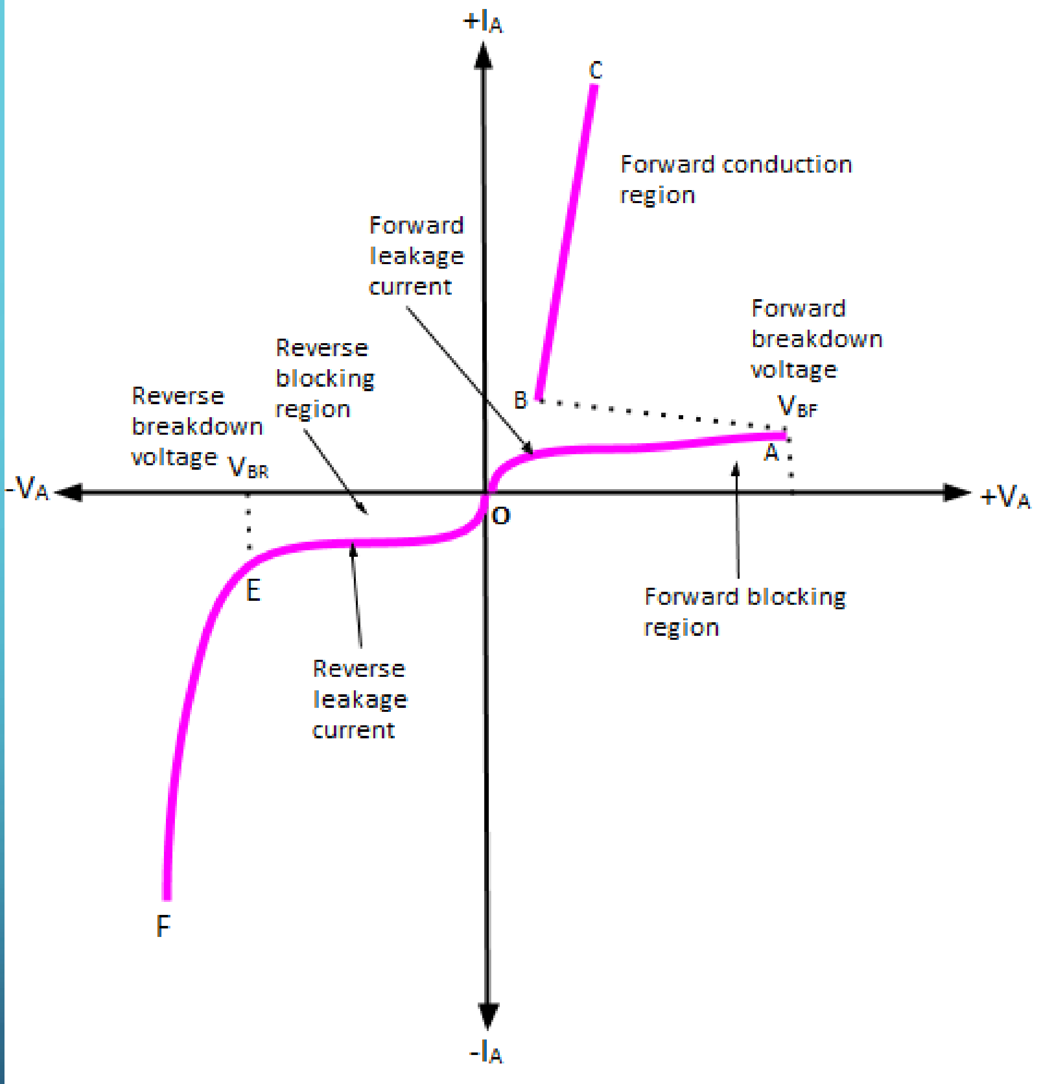
V-I Characteristics of SCR

SILICON CONTROLLED RECTIFIER (SCR)

- **Forward Conduction region**

If the forward bias voltage applied between anode and cathode is increased beyond the breakdown voltage, the minority carriers (free electrons in anode and holes in cathode) gains large amount of energy and accelerated to greater velocities. This high speed minority carriers collides with other atoms and generates more charge carriers. Likewise, many collisions happens with atoms. Due to this, millions of charge carriers are generated. As a result depletion region breakdown occurs at junction J_2 and current starts flowing through the SCR. So the SCR will be in On state. The current flow in the SCR increases rapidly after junction breakdown occurs.

The voltage at which the junction J_2 gets broken when the gate is open is called forward breakdown voltage (V_{BF}).



V-I Characteristics of SCR

SILICON CONTROLLED RECTIFIER (SCR)

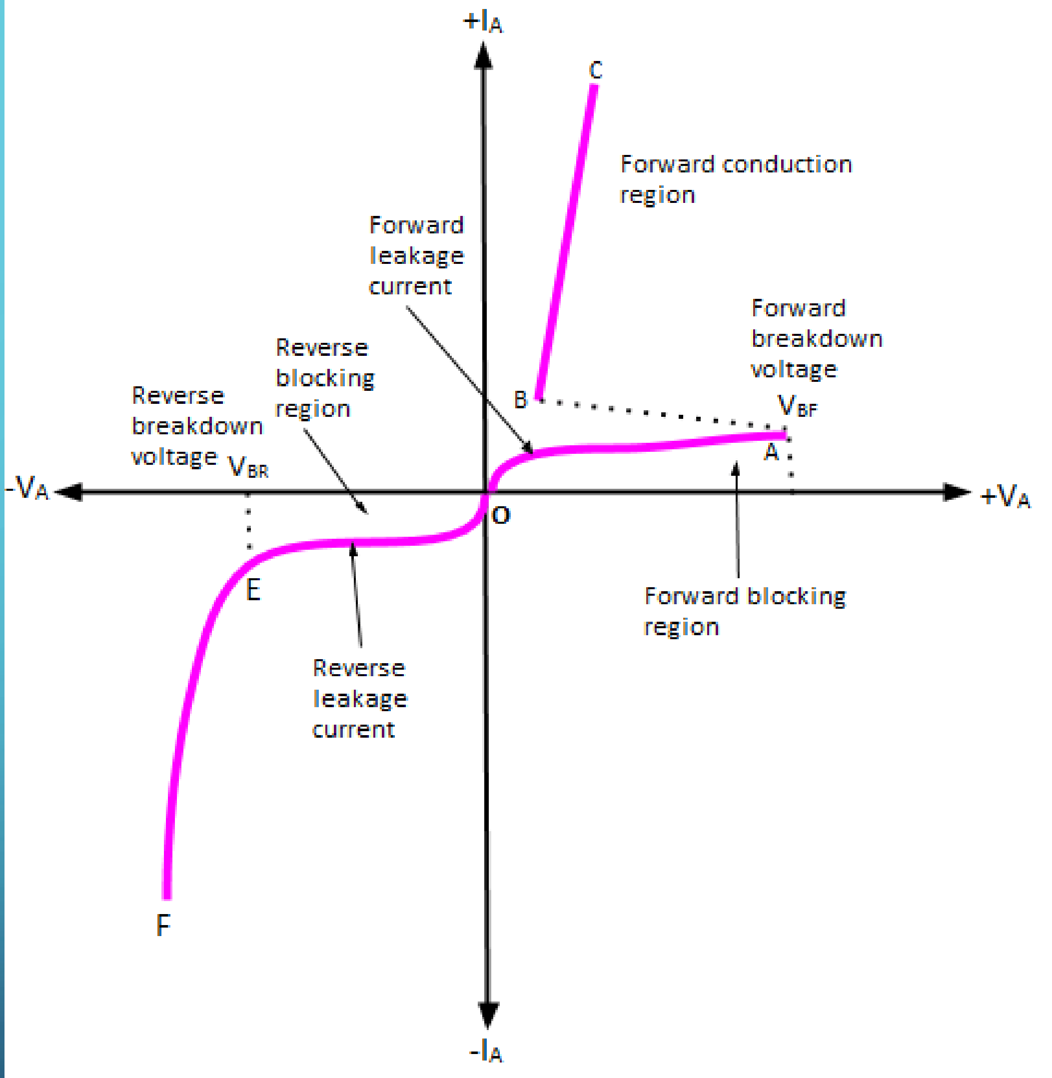
•Forward Conduction region

The region BC of the V-I characteristics is called conduction region. In this region, the current flowing from anode to cathode increases rapidly. The region AB indicates that as soon as the device becomes on, the voltage across the SCR drops to some volts.

•Reverse Blocking Region

In this region, the negative voltage (-) is given to anode (+), positive voltage (+) is given to cathode (-), and gate is open circuited. In this case, the junction J_1 and junction J_3 are reverse biased whereas the junction J2 becomes forward biased.

As the junctions J_1 and junction J_3 are reverse biased, no current flows through the SCR circuit. But a small leakage current flows due to drift of charge carriers in the forward biased junction J_2. This small leakage current is called reverse leakage current. This small leakage current is not sufficient to turn on the SCR.

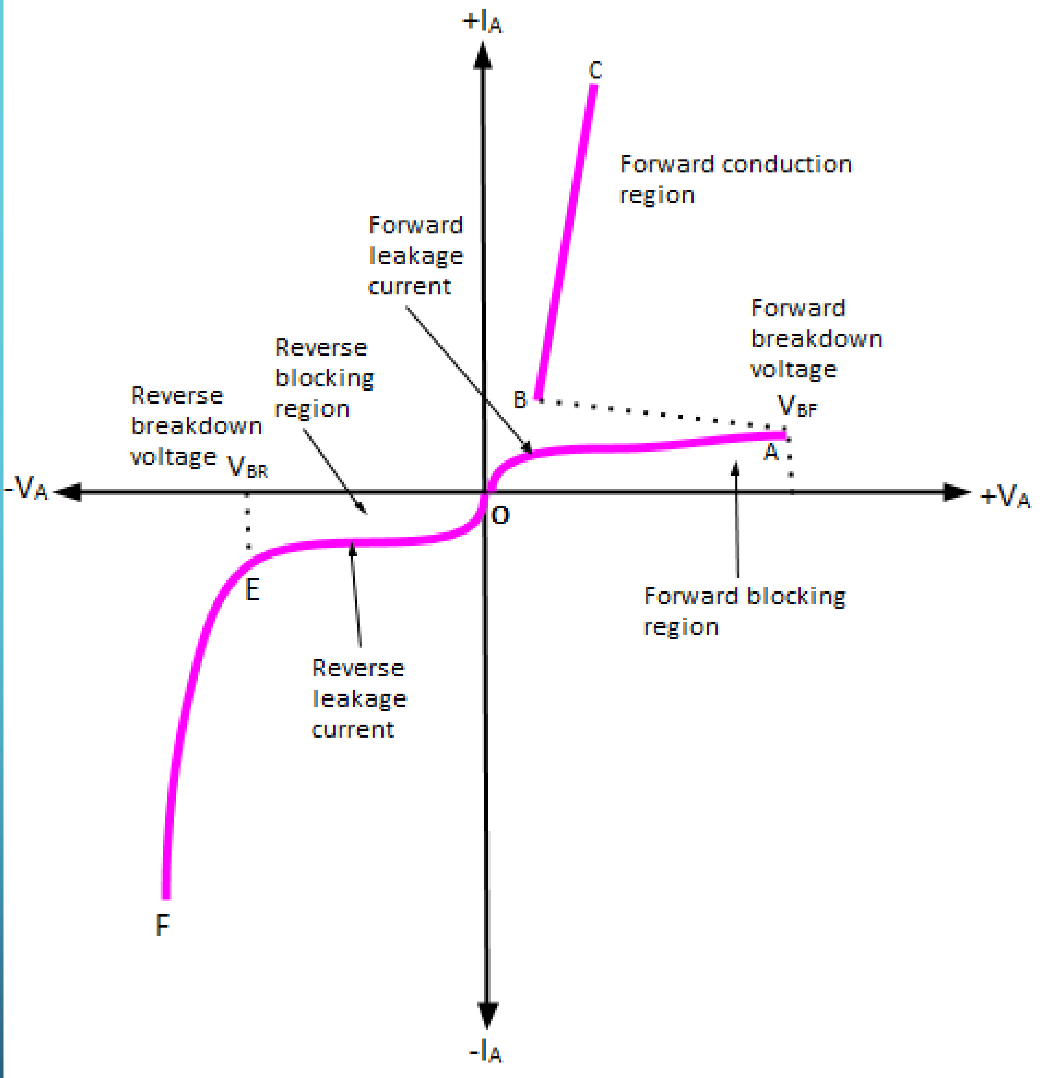


V-I Characteristics of SCR

SILICON CONTROLLED RECTIFIER (SCR)

- **Reverse Blocking Region**

If the reverse bias voltage applied between anode and cathode is increased beyond the reverse breakdown voltage (V_{BR}), an avalanche breakdown occurs. As a result, the current increases rapidly. The region EF is called reverse avalanche region. This rapid increase in current may damage the SCR device.



V-I Characteristics of SCR

SILICON CONTROLLED RECTIFIER (SCR)

Q1. An SCR with a rated voltage (Vak) of 600 V and a rated current (Iak) of 50 A is connected in series with a load. The SCR has a gate triggering voltage (Vgt) of 1 V. Determine whether the SCR will turn on when a gate voltage of 1.5 V is applied.

Solution: To determine whether the SCR will turn on, we need to compare the gate triggering voltage (Vgt) to the applied gate voltage (Vg). If the applied gate voltage exceeds the gate triggering voltage, the SCR will turn on.

Given:

- Vgt = 1 V
- Vg = 1.5 V

Since the applied gate voltage (Vg = 1.5 V) exceeds the gate triggering voltage (Vgt = 1 V), the SCR will turn on.

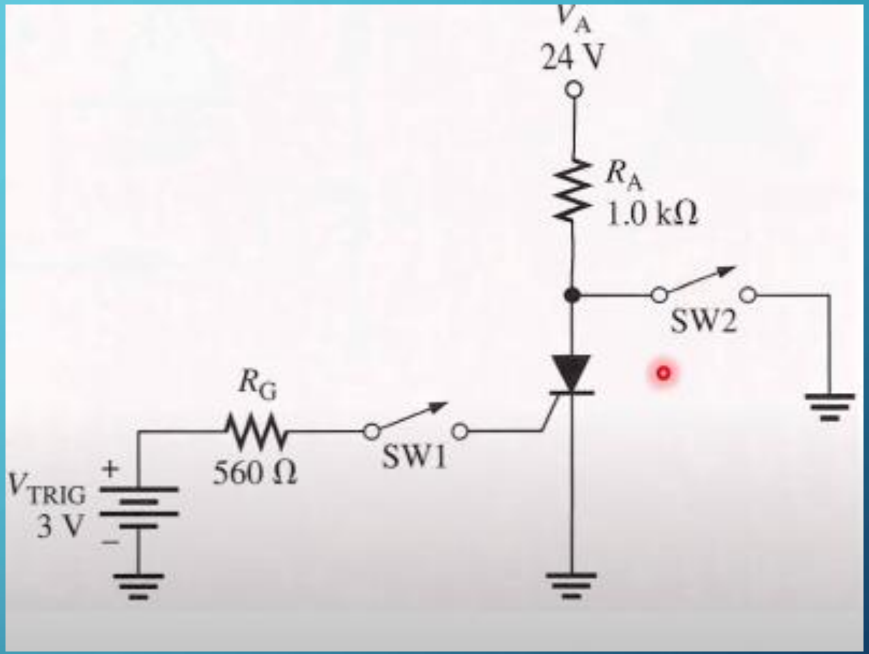
This is a basic illustration of SCR operation. In practical applications, other factors such as gate current, forward voltage drop, and load characteristics need to be considered for proper SCR operation and control.

SILICON CONTROLLED RECTIFIER (SCR)

Q2. determine Ig and Ia when SW1 is momentarily closed. Assume Vak= .8V, Vgk= 0.7V and Ih=20mA. What is the state of the SCR if va is reduced to 12V? Why?

$$I_G = \frac{V_{TRIG} - V_{GK}}{R_G} = \frac{3-.7}{560} = 4.1mA$$

$$I_A = \frac{V_A - V_{AK}}{R_A} = \frac{24-0.8}{1000} = 23.2mA$$



Since the anode current is less than the holding current (20mA), so the SCR will be in OFF state.

POWER DIODE

A power diode is a semiconductor device used in power electronics circuits to control the flow of electrical current. It operates similarly to a standard diode but is designed to handle higher currents and voltages.

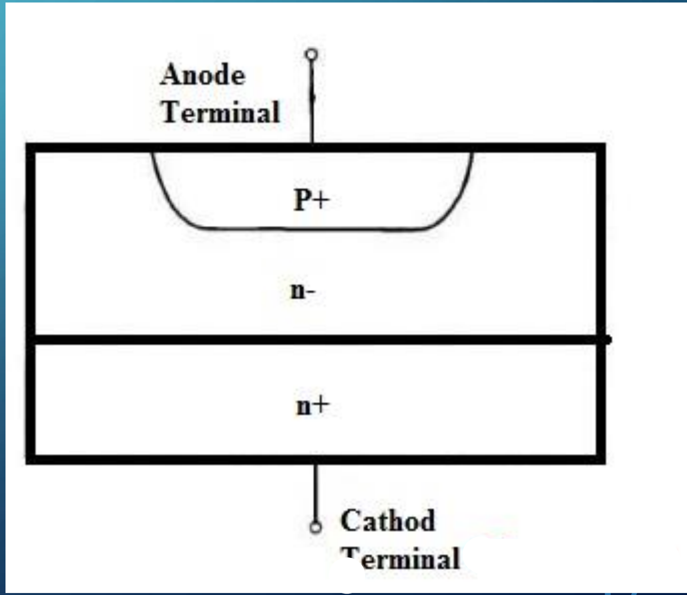
- In power electronic circuits, this diode plays an essential role. It can be used as a rectifier in converter circuits, voltage regulation circuits, flyback / freewheeling diode, reverse voltage protection, etc.

- These diodes are related to signal diodes except for a slight disparity in its construction. The doping level in signal diode for both P-layer & N-layer is the same whereas, in power diodes, the junction can be formed among a heavily doped P+ layer & lightly doped N– layer.

Construction

The construction of this diode includes three layers like the P+ layer, n– layer and n+ layer. Here the top layer is the P+ layer, it is heavily doped. The middle layer is n– layer, it is lightly doped and the last layer is n+ layer, and it is heavily doped.

Here p+ layer acts as an anode, the thickness of this layer is 10 µm, The n+ layer acts as a cathode, the thickness of this layer is 250-300 µm. The n- layer acts as a middle layer/drift layer, the thickness of this layer mainly depends on the breakdown voltage. Once this layer width increases then breakdown voltage will be increased.



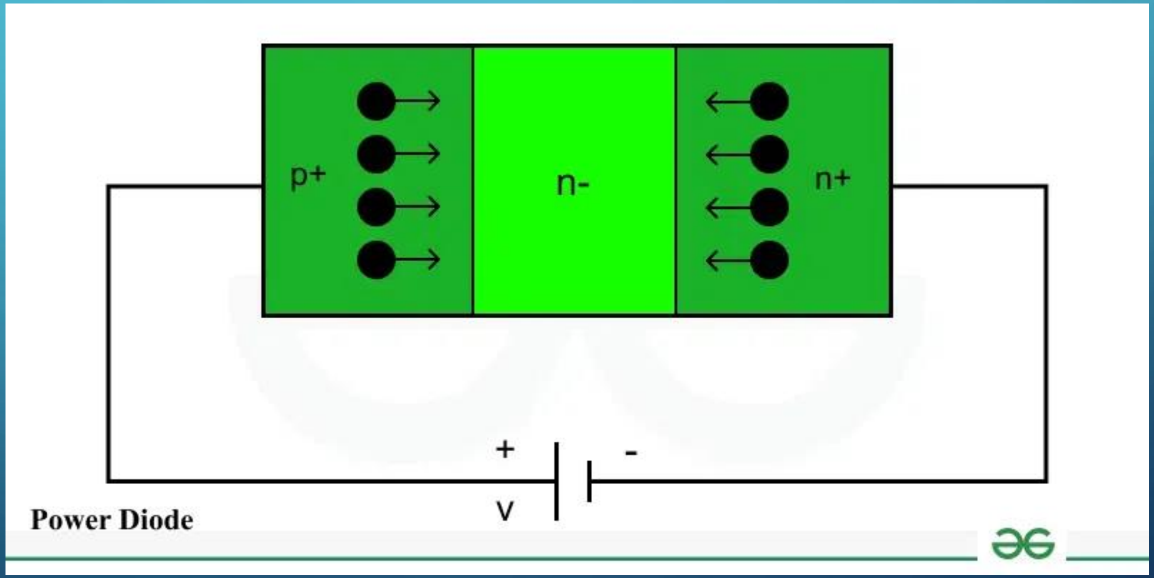
POWER DIODE

Working Principle of Power Diode

•The power diode consists of two region, P-type semiconductor region and an N-type semiconductor region joined together to form a P-N junction interface.

•It starts operating in forward bias, when a positive voltage (anode) is connected to the P-side and a negative voltage (cathode) is connected to the N-side, due to which the barrier potential across the junction reduces and the current starts flowing easily across the diode.

•Due to this application of voltage the holes start to flow from p-side to n-side and the electrons flows from n-side to p-side enabling the diode to conduct effectively and act as closed switch for current flow.



POWER DIODE

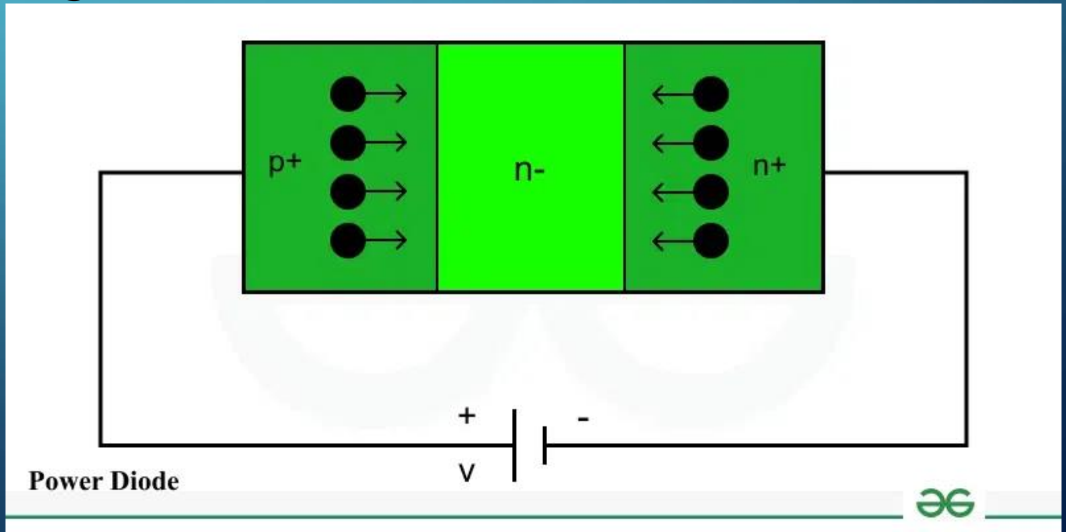
Working Principle of Power Diode

•On applying a reverse voltage (positive to the N-type material and negative to the P-type material) the barrier potential across the junction is increased. This blocks the flow of current in the reverse direction, and the diode acts as an open switch, allowing only a tiny leakage current due to minority carriers.

•The diode enters breakdown region, at a specific reverse voltage called the breakdown voltage. This phenomenon can be interpretated as either Zener breakdown or avalanche breakdown, which allows the diode to conduct in the reverse direction beyond this threshold without damaging the diode.

•The recombination of charges takes place Due to dual injection of positive and negative charge carries, hence the diode starts to conduct.

•The n+ region is responsible for the recombination. Thus, due to this recombination the resistance in n- drift region decreases, and the diodes begins to conduct.



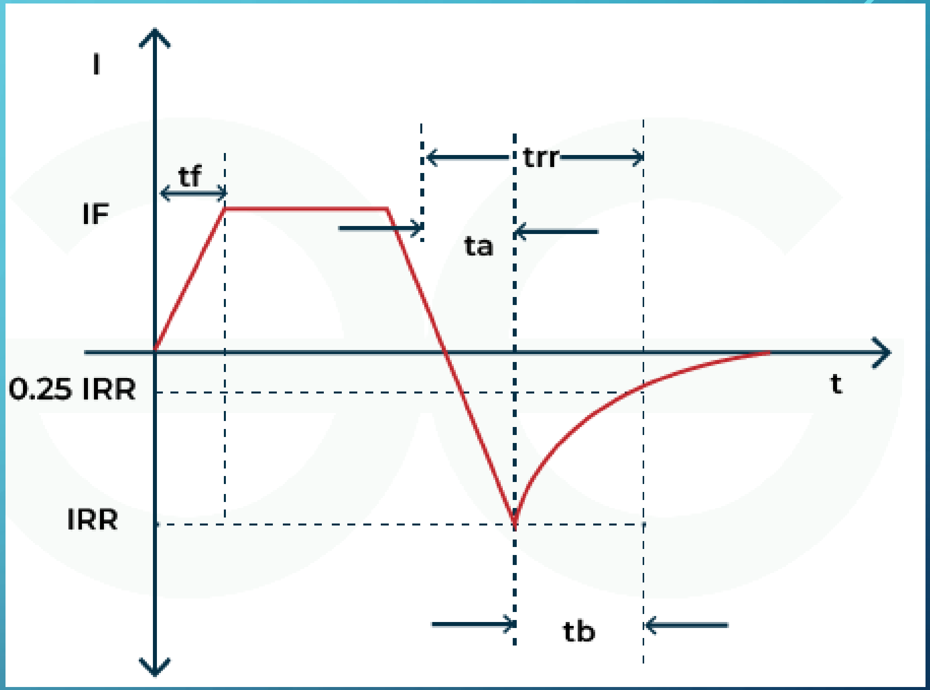
REVERSE RECOVERY TIME

Reverse recovery time is an important characteristic of semiconductor diodes, including power diodes. It refers to the time it takes for a diode to switch from conducting in the forward direction to blocking in the reverse direction after the applied forward voltage is suddenly reversed.

When a diode is conducting in the forward direction and the voltage polarity across it is reversed, the diode initially continues to conduct in the forward direction for a short period. This is because charge carriers (electrons and holes) that were injected into the semiconductor material during forward conduction need to be removed or neutralized before the diode can block the reverse voltage effectively.

The reverse recovery time is typically measured from the instant when the forward current reaches zero to the instant when the reverse current reaches a specified level (often 25% or 50% of the peak reverse current).

A shorter reverse recovery time is desirable in many power electronics applications, especially in high-frequency switching circuits, as it reduces the switching losses and improves the efficiency of the circuit. Fast recovery diodes are specifically designed to minimize the reverse recovery time and are often used in applications where rapid switching is required, such as in inverters, motor drives, and power supplies.



POWER DIODE

Types of Power Diode

Diodes are classified on the basis of their reverse recovery characteristics, speed of operation, current and Voltage handling capacity. There are mainly three types of power diode

- General Purpose Diodes
- Fast Recovery diodes
- Schottky Diodes

General Purpose Diodes

These diodes have huge reverse recovery time around 25μs; therefore they are applicable in low frequency (up to 1 kHz) & low-speed operations (up to 1- kHz).

Fast Recovery Diodes

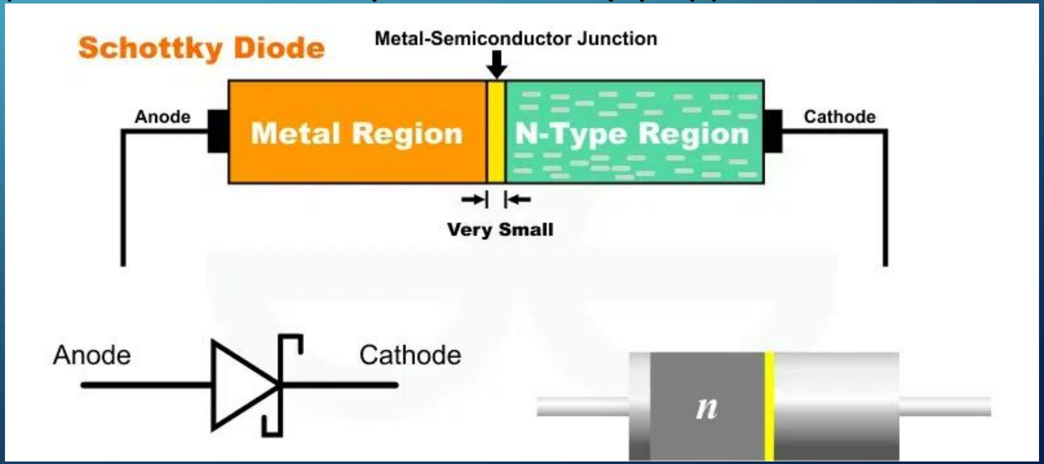
These diodes have quick recovery act due to their very small reverse recovery time less than 5μs, used in high-speed switching applications

Schottky Diodes

Schottky diode is another type of power diode which is also known as Schottky barrier diodes (SBDs).SBDs are used due to its fast switching speed, low forward voltage drop, and high efficiency. These diodes are formed by the junction of a metal electrode (usually made of platinum or tungsten) and a semiconductor material (typically silicon) instead of a traditional p-n junction .given below is the circuit diagram of the Schottky Diodes.

POWER DIODE

- Unlike a P-N junction like regular diodes, Schottky diode consists of Metal-Semiconductor interface junction.
- They have a lower forward voltage drop (0.3V to 0.4V) which is responsible for their reduced power loss and faster switching. Their low forward voltage drop improves the efficiency, making them suitable in power supply and rectification circuits.
- They have a faster recovery time as compared to other types of power diodes.
- Very less ON state voltage drop (0.3 to 0.4 V).
- High Reverse Leakage Current.
- Lower peak inverse voltage (PIV): 50 V to 100 V.
- Due to their construction, Schottky diodes have a faster switching speed, making them suitable for high-frequency applications.
- **Applications:** It is commonly used in higher power applications where good efficiency is required such as high precision rectifiers, SMPS (Switch Mode power supply) circuits, Radio-Frequency mixers, detector circuits.



POWER DIODE

PARAMETER	POWER DIODE	SIGNAL DIODE
Purpose	Used in high-power applications, rectification, etc.	Used in low-power applications, signal processing.
Current handling Capacity	Higher current handling capabilities.	Lower current handling capabilities.
Voltage handling capacity	Typically, higher voltage ratings.	Lower voltage ratings.
Reverse Recovery Time	Longer Reverse Recovery Time.	Shorter Reverse Recovery Time.
Switching speed	Slow as compared to signal diode.	Faster as compared to power diode
Forward Voltage Drop	Higher as compared to signal diode.	Lower as compared to power diode.

Thank You!