BHARATHIDASAN UNIVERSITY
Tiruchirappalli- 620 024
Tamil Nadu, India

Programme: M.Sc., Medical Physics

Course Title : Electronics and Instrumentation
Course Code : MP104

Unit-I
Semiconductor Devices and IC Fabrication

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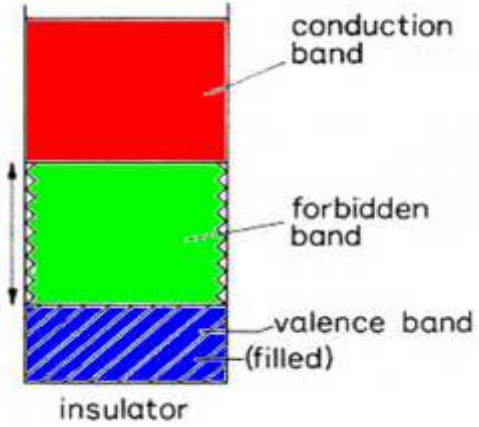
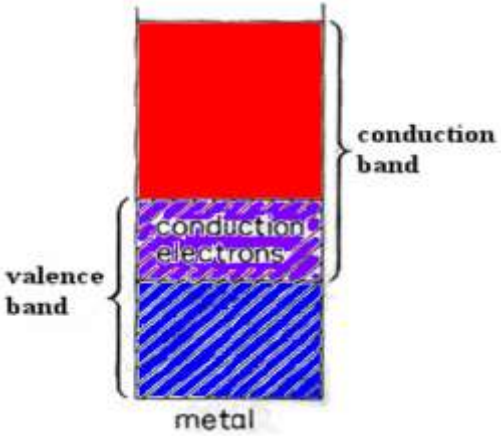
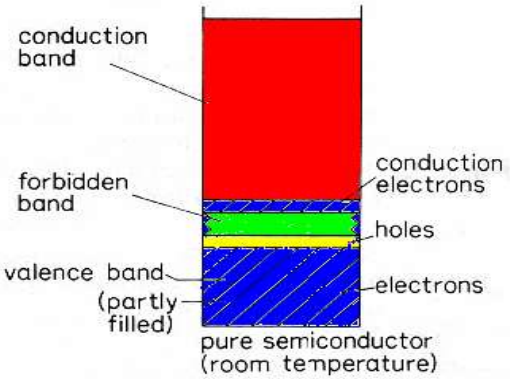
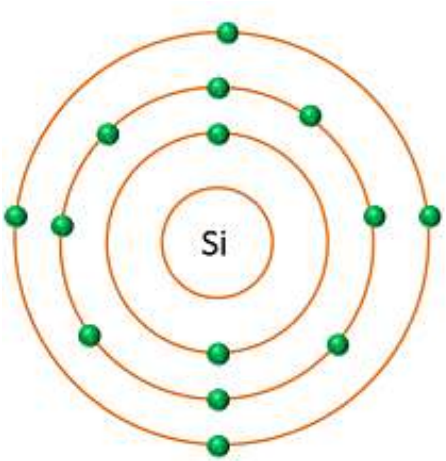
Department of Medical Physics

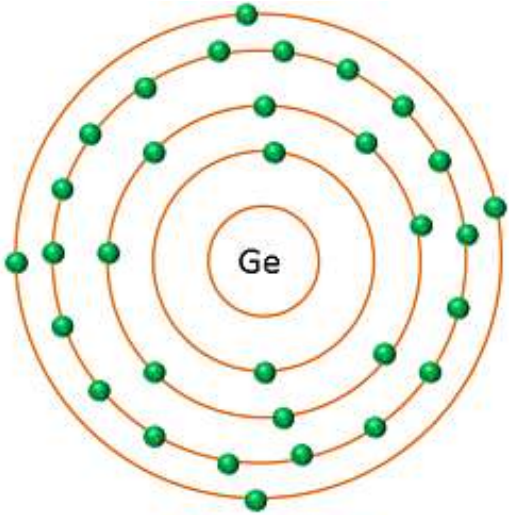
ENERGY BANDS IN INSULATORS, CONDUCTORS & SEMICONDUCTORS



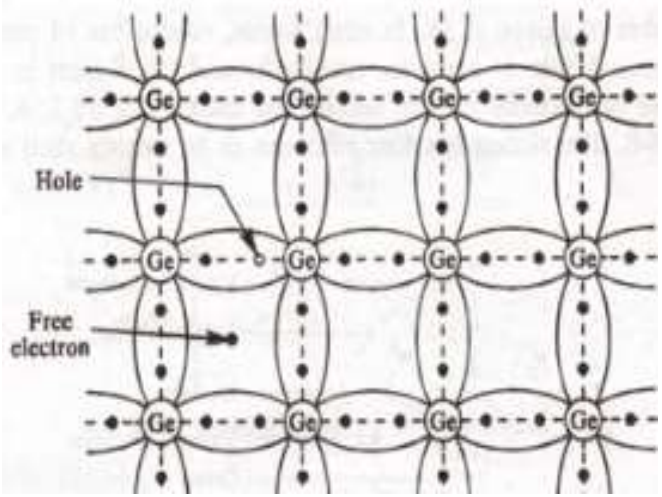


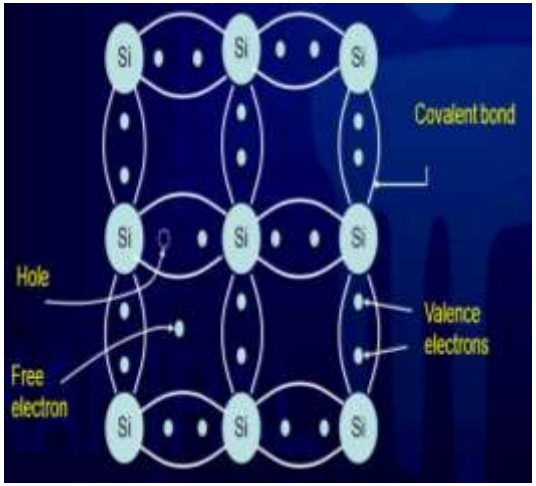




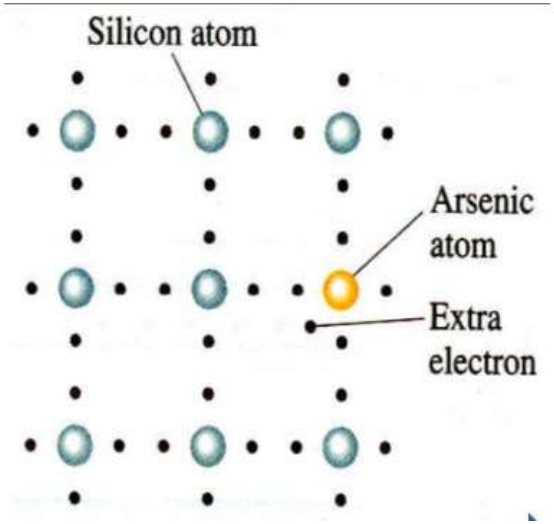


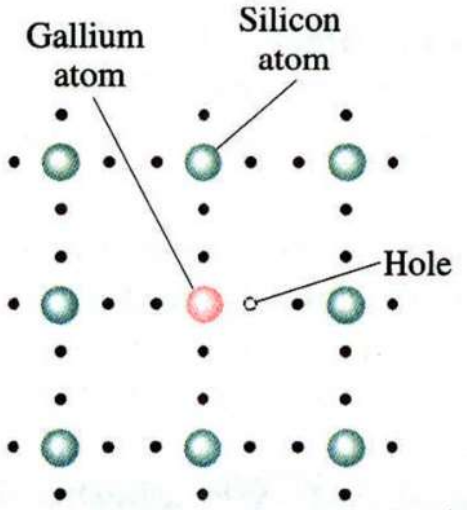
INTRINSIC SEMICONDUCTOR



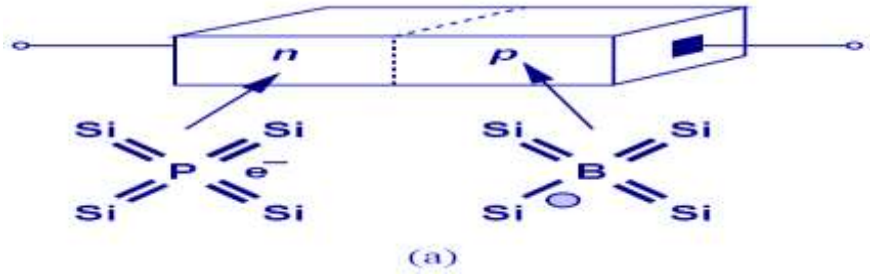


EXTRINSIC SEMICONDUCTORS



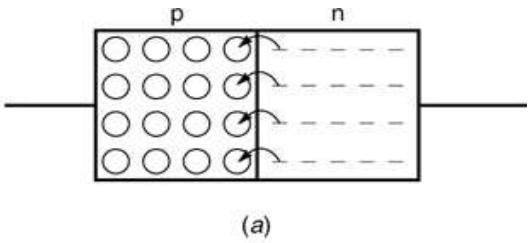


PN Junction (Diode)

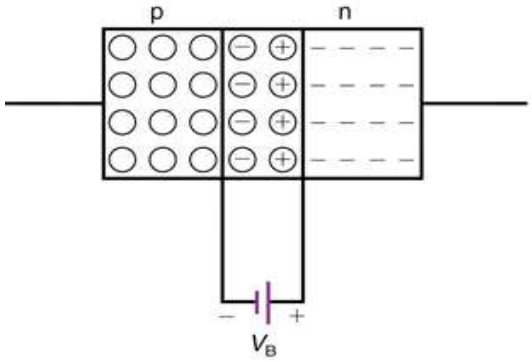


(a)

(b)



(*a*)



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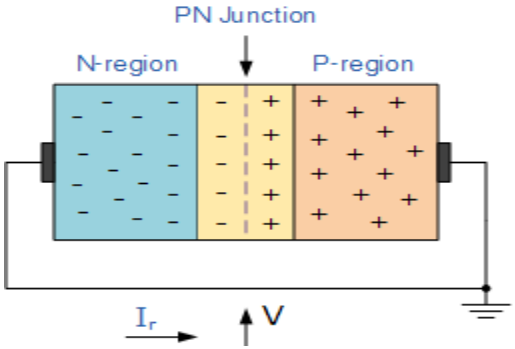
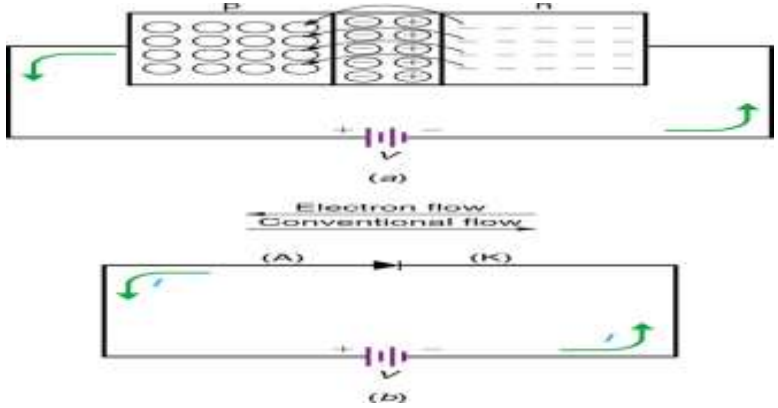
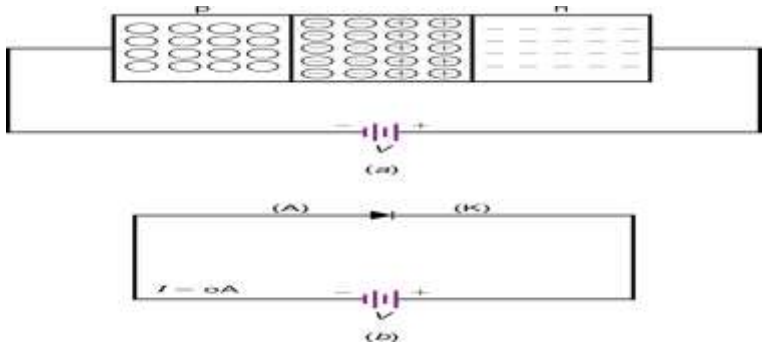
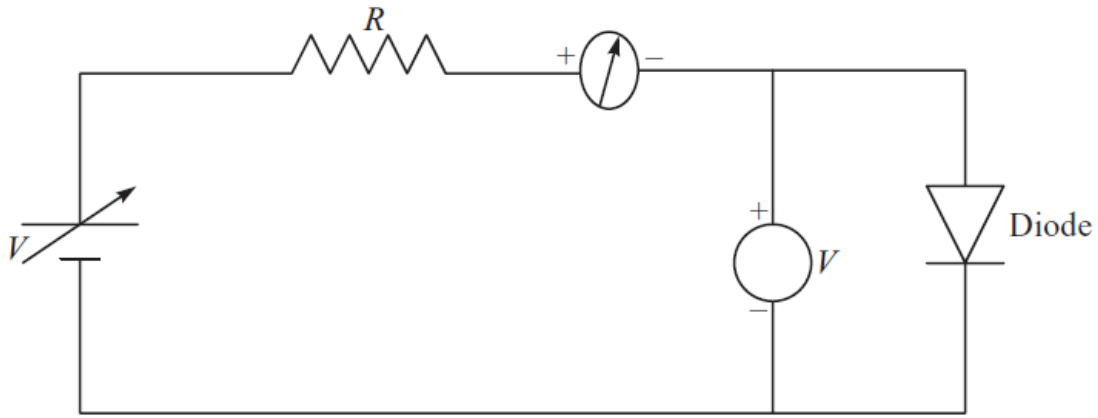


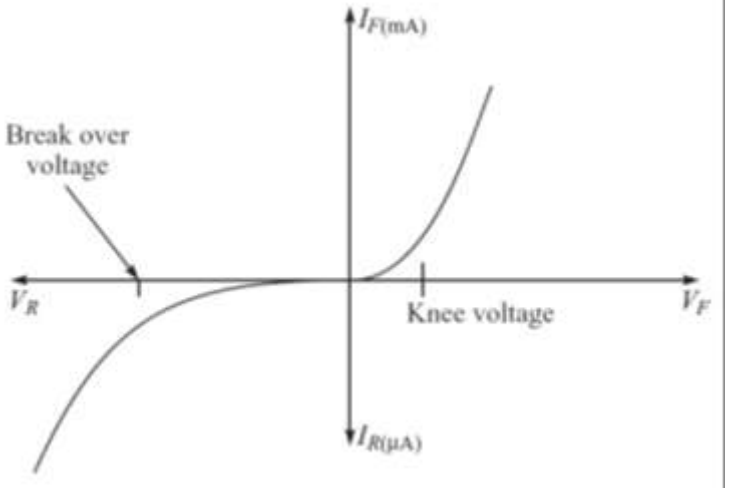
Forward biased:

Reverse biased:









The current in a diode is given by the diode current equation

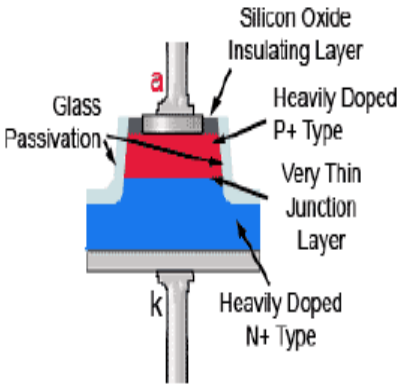
$$I = I_o(e^{V/\eta V_T} - 1)$$

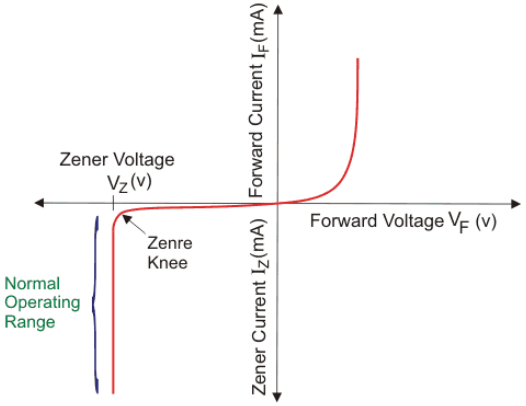
where, I = Diode current
I_o = Reverse saturation current
V = Diode voltage
η = Semiconductor constant
= 1 for Ge
= 2 for Si.
V_T = Voltage equivalent of temperature = $T/11{,}600$ (temperature T is in kelvin)

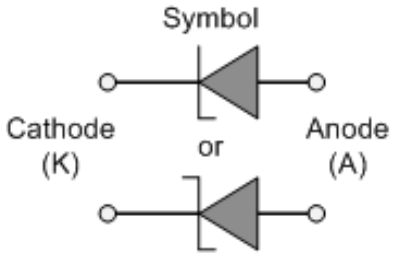
Junction Diode Summary

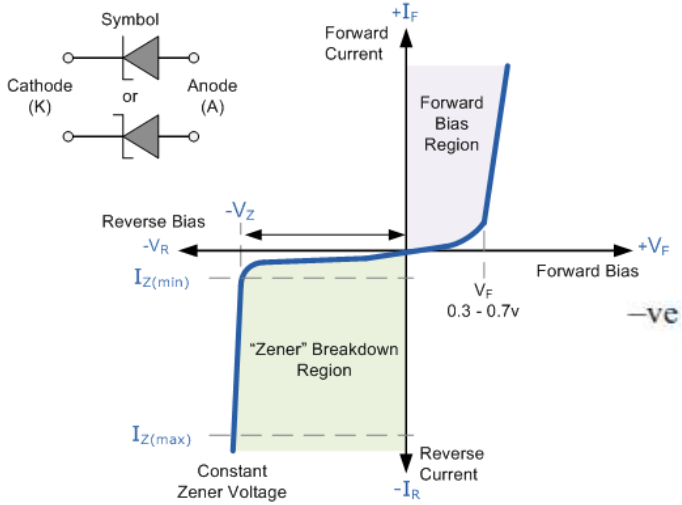
- Semiconductors contain two types of mobile charge carriers, “Holes” and “Electrons”.
- The holes are positively charged while the electrons negatively charged.
- A semiconductor may be doped with donor impurities such as Antimony (N-type doping), so that it contains mobile charges which are primarily 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 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).

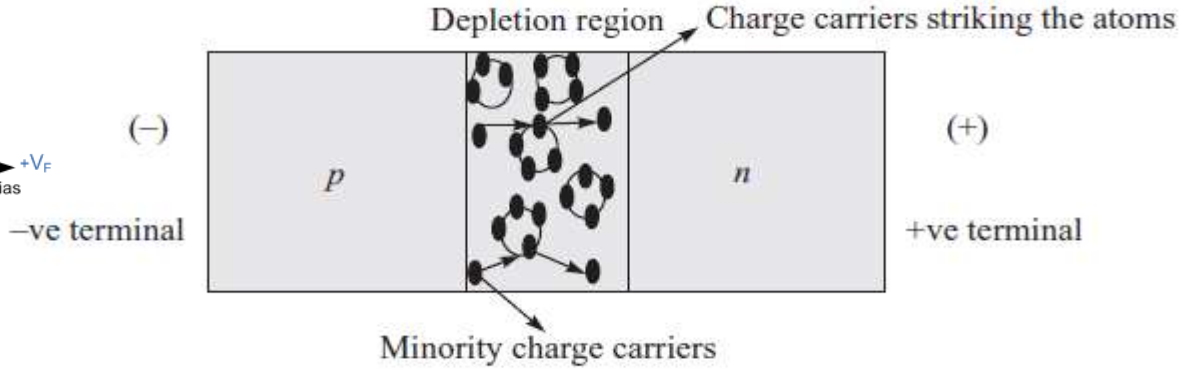
Zener Diode


Silicon Oxide
Insulating Layer
a
Glass
Passivation
Heavily Doped
P+ Type
Very Thin
Junction
Layer
k
Heavily Doped
N+ Type

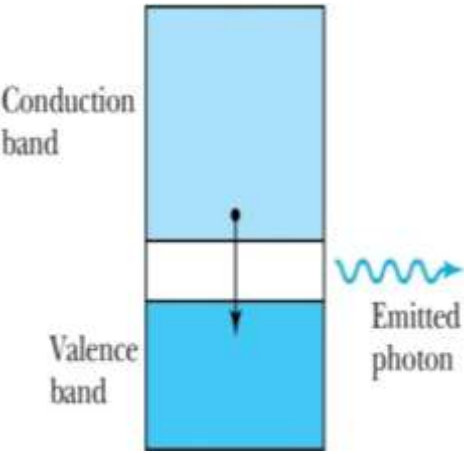

Forward Current I_F(mA)
Zener Voltage
V_Z(v)
Forward Voltage V_F (v)
Zenre
Knee
Normal
Operating
Range
Zener Current I_Z(mA)

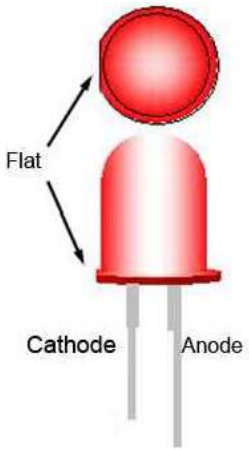

Symbol
Cathode
(K)
or
Anode
(A)

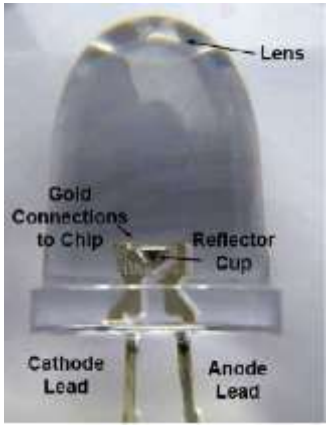

Symbol
Cathode
(K)
or
Anode
(A)
+I_F
Forward
Current
Forward
Bias
Region
Reverse Bias
-V_Z
-V_R
+V_F
Forward Bias
$I_{Z(min)}$
V_F
0.3 - 0.7v
"Zener" Breakdown
Region
$I_{Z(max)}$
Constant
Zener Voltage
Reverse
Current
-I_R

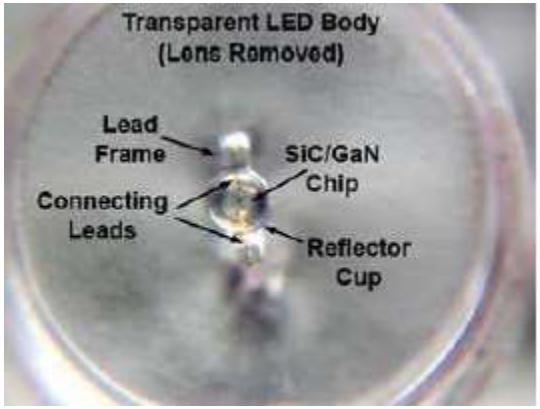

Depletion region
Charge carriers striking the atoms
(–)
p
n
(+)
–ve terminal
+ve terminal
Minority charge carriers

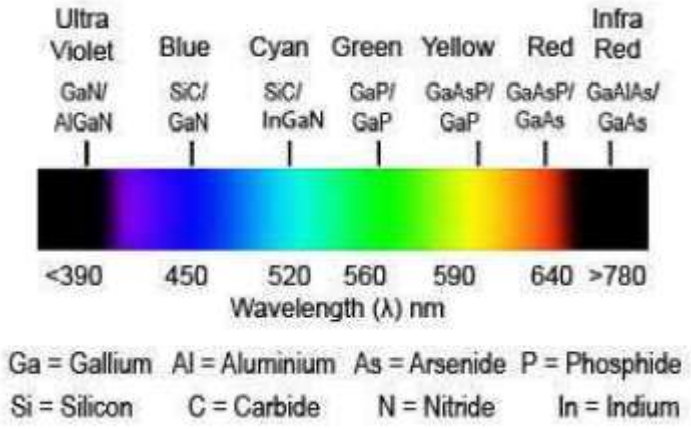
LED

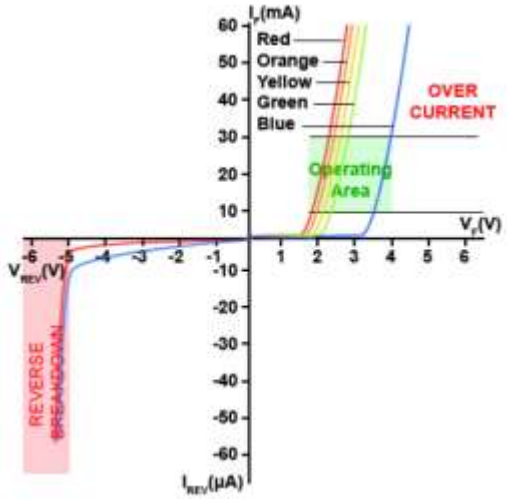

Conduction band
Valence band
Emitted photon


Flat
Cathode
Anode

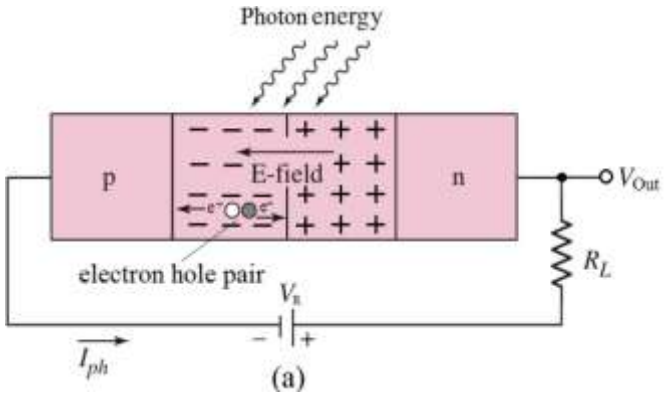

Lens
Gold Connections to Chip
Reflector Cup
Cathode Lead
Anode Lead

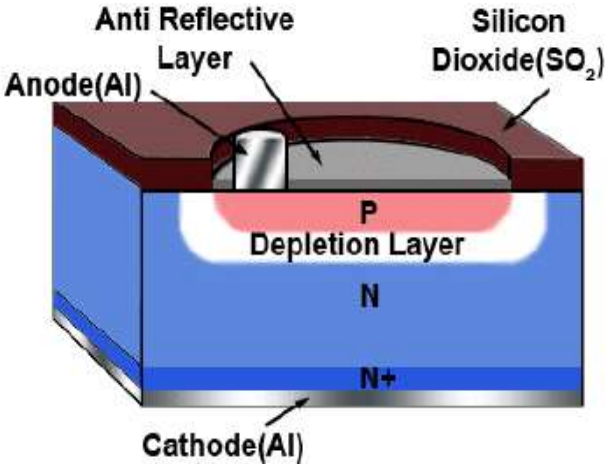

Transparent LED Body (Lens Removed)
Lead Frame
SiC/GaN Chip
Connecting Leads
Reflector Cup

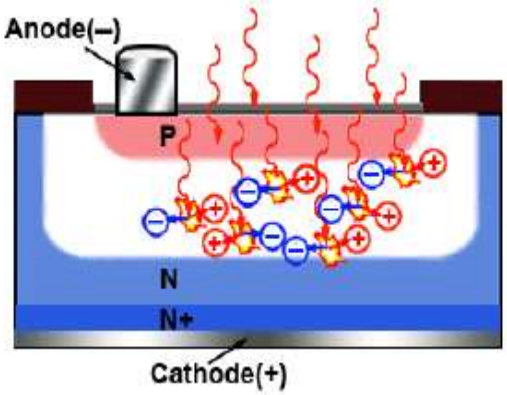

Ultra Violet
Blue
Cyan
Green
Yellow
Red
Infra Red
GaN/ AlGaN
SiC/ GaN
SiC/ InGaN
GaP/ GaP
GaAsP/ GaP
GaAsP/ GaAs
GaAlAs/ GaAs
<390
450
520
560
590
640
>780
Wavelength (λ) nm
Ga = Gallium
Al = Aluminium
As = Arsenide
P = Phosphide
Si = Silicon
C = Carbide
N = Nitride
In = Indium

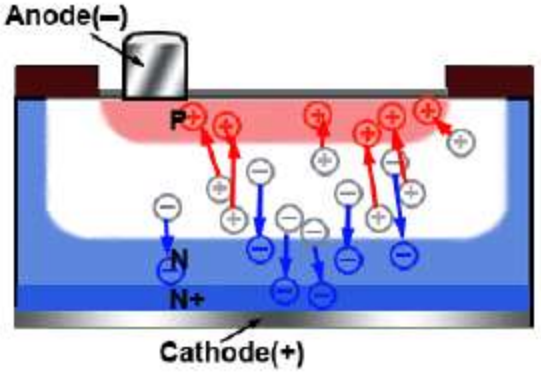

I_F(mA)
Red
Orange
Yellow
Green
Blue
OVER CURRENT
Operating Area
V_F(V)
V_{REV}(V)
REVERSE BREAKDOWN
I_{REV}(μA)

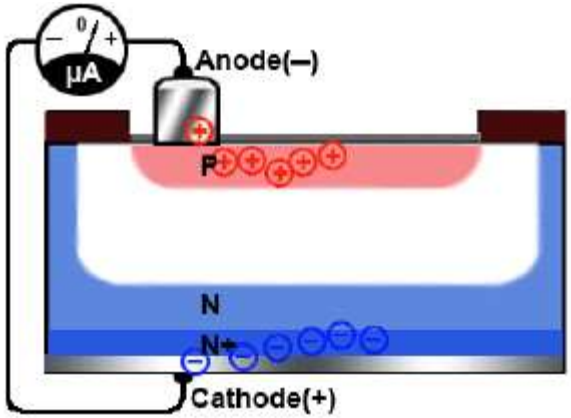
Photodiode

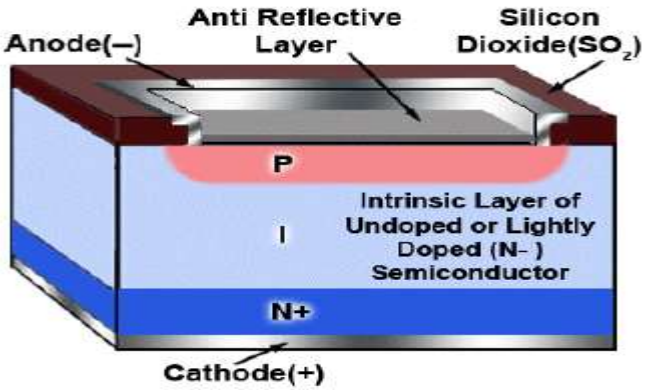

Photon energy
p
E-field
n
V_{Out}
R_L
electron hole pair
V_R
I_{ph}
(a)

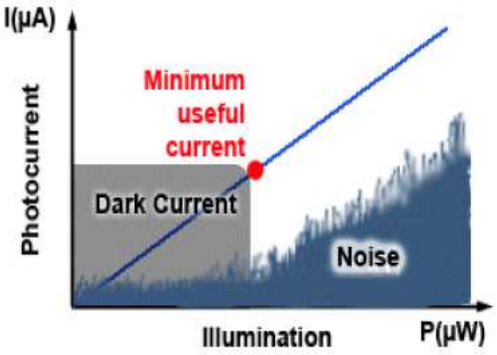

Anti Reflective Layer
Silicon Dioxide(SO_2)
Anode(Al)
P
Depletion Layer
N
N+
Cathode(Al)


Anode(–)
P
N
N+
Cathode(+)

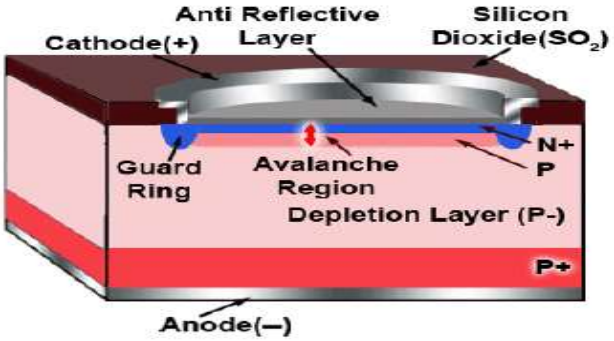

Anode(–)
P
N
N+
Cathode(+)


μA
Anode(–)
P
N
N+
Cathode(+)

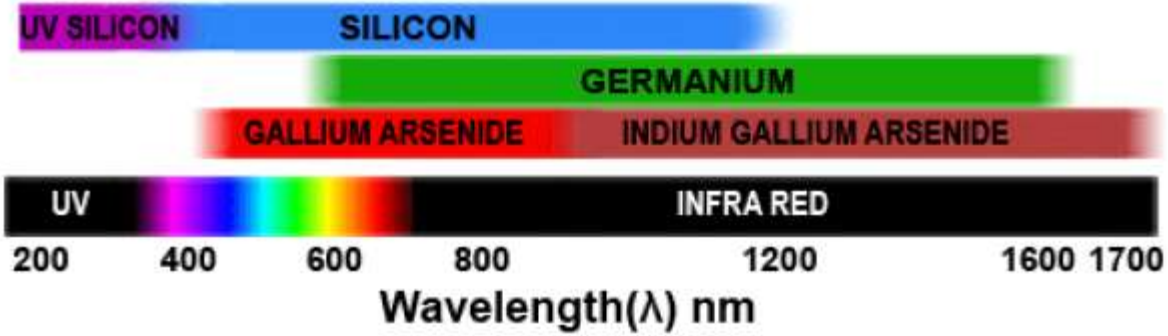

Anode(–)
Anti Reflective Layer
Silicon Dioxide(SO_2)
P
I
Intrinsic Layer of Undoped or Lightly Doped (N-) Semiconductor
N+
Cathode(+)


I(μA)
Photocurrent
Minimum useful current
Dark Current
Noise
Illumination
P(μW)

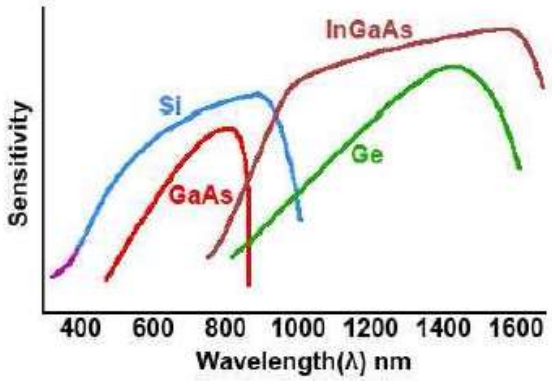
The Avalanche Photodiode



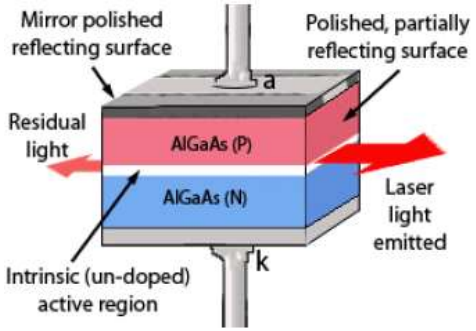
Photodiode Materials

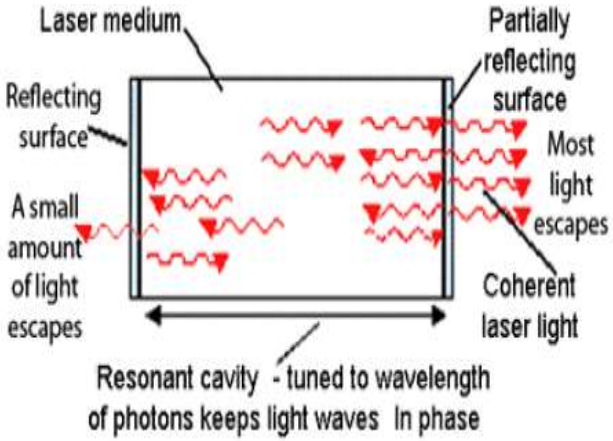


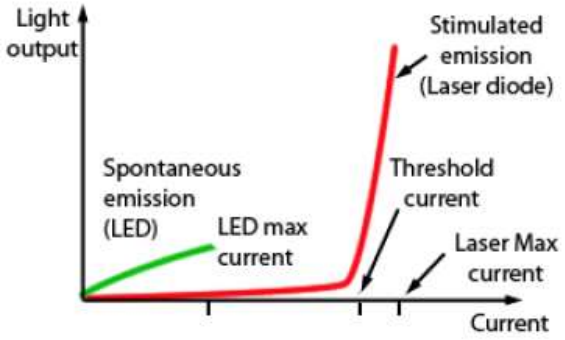
Silicon Photodiodes



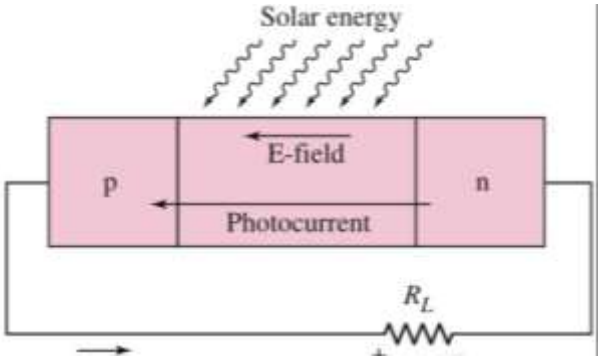
LASER (Light Amplification by the Stimulated Emission of Radiation) Diodes

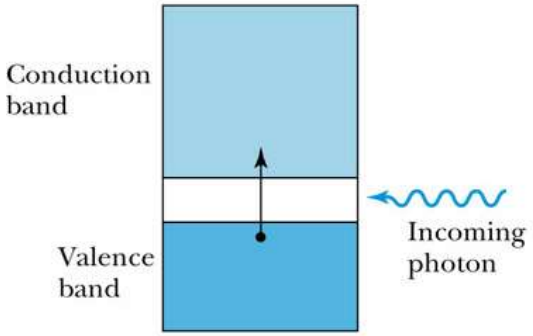


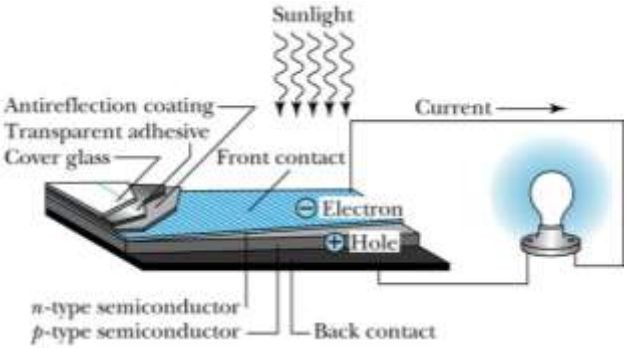




Solar Cell

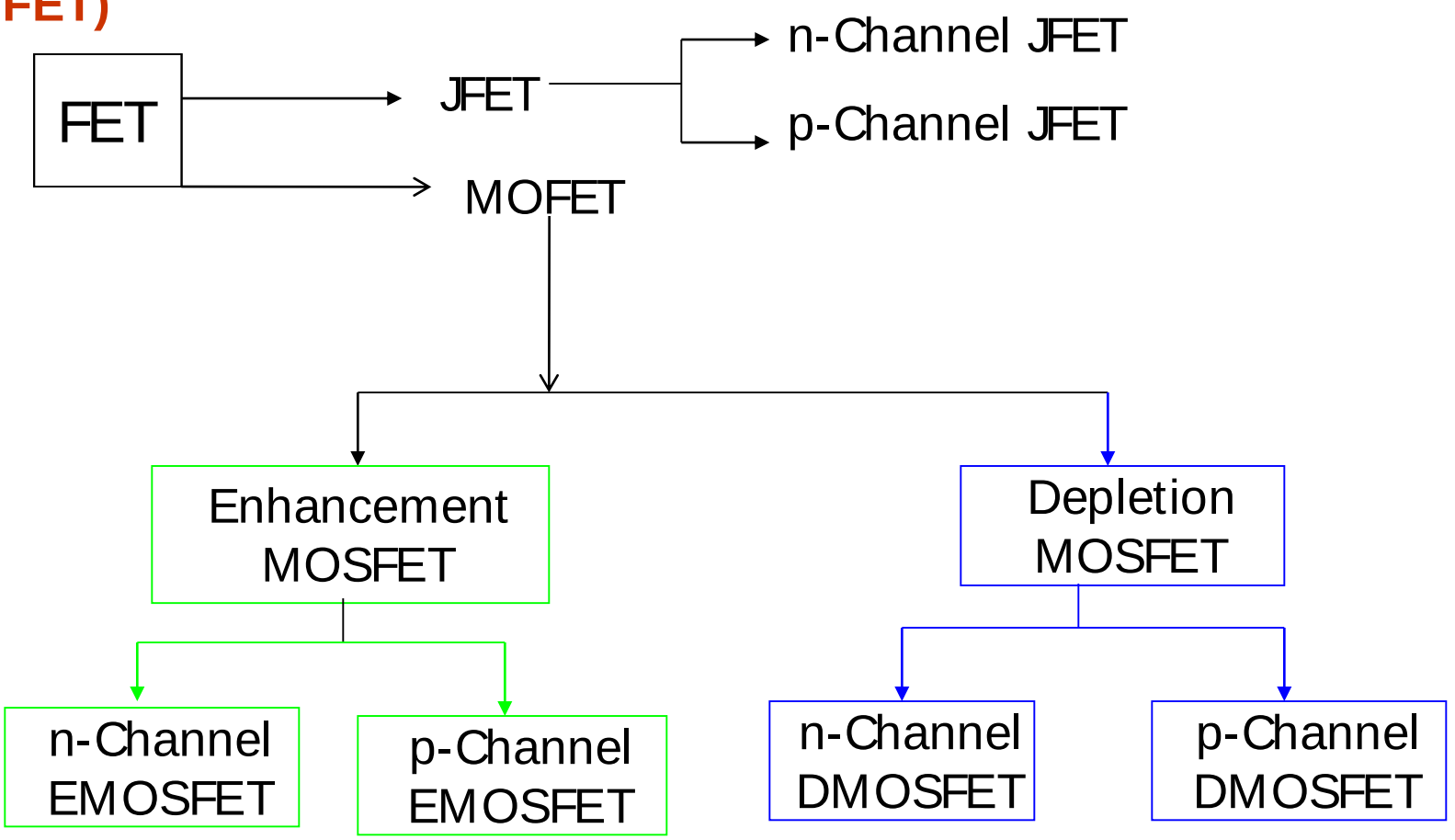




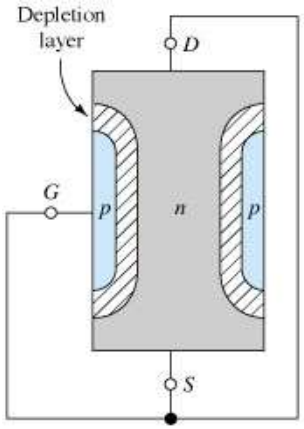


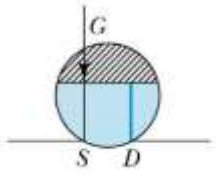
Types of FET

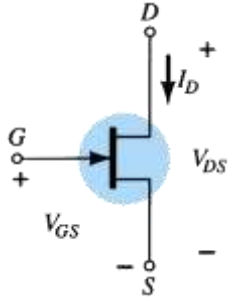
- FET has taken various forms like that
  - Junction field-effect transistor (JFET),
  - Metal semiconductor field-effect transistor (MESFET),
  - Metal-insulator-semiconductor field-effect transistor (MISFET),
  - Metal-oxide-semiconductor field-effect transistor (MOSFET) or **Insulated Gate Field-effect Transistor (IGFET)**

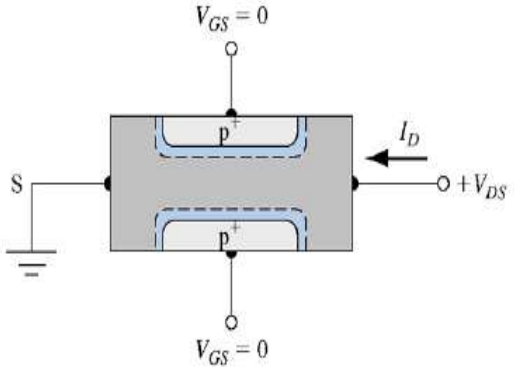


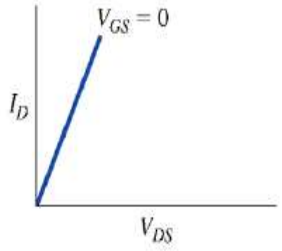
Junction FETs (JFETs)

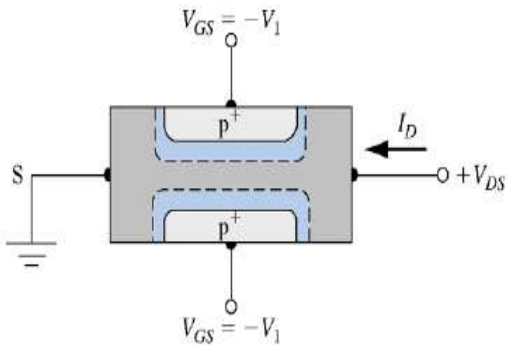


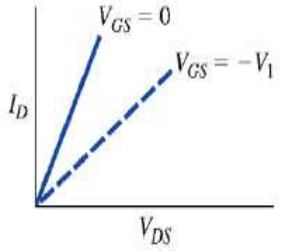


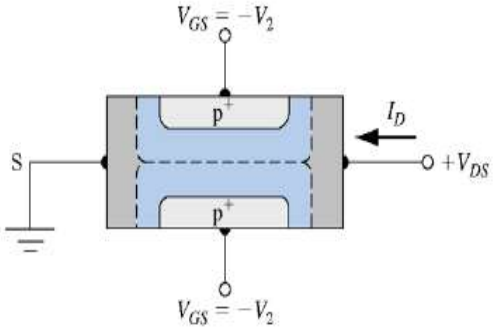


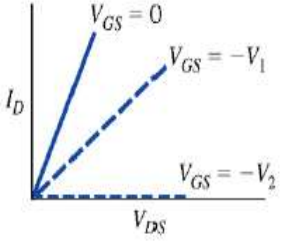






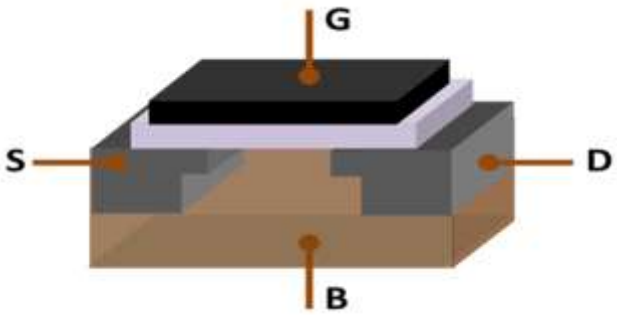


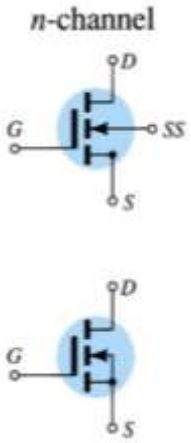


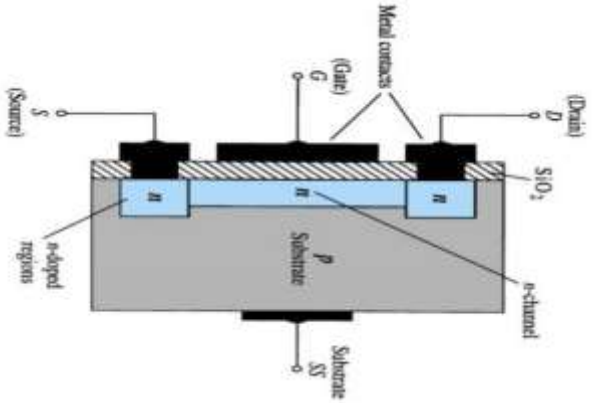


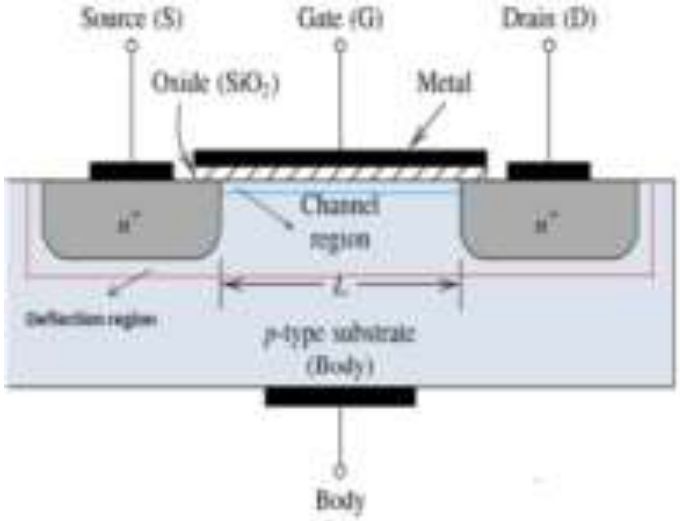
V_G controls the channel width → V_G control I_d

What is a MOSFET

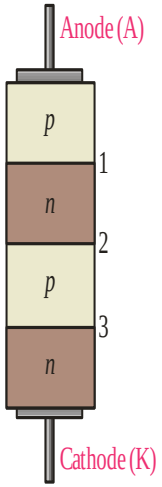


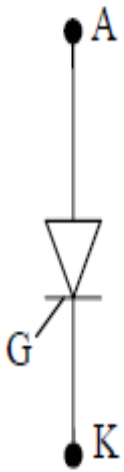


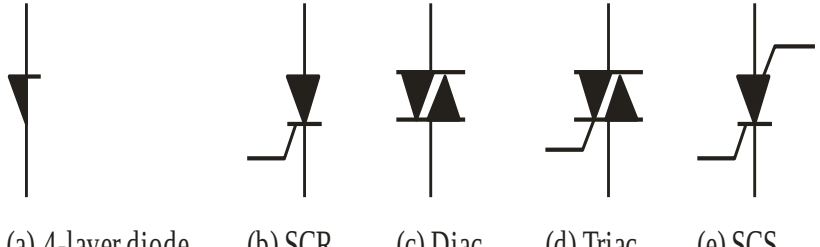


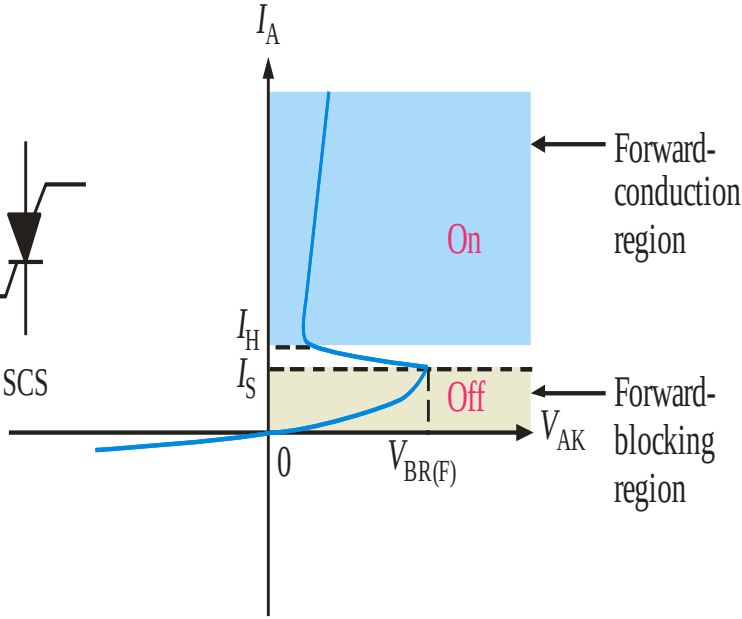


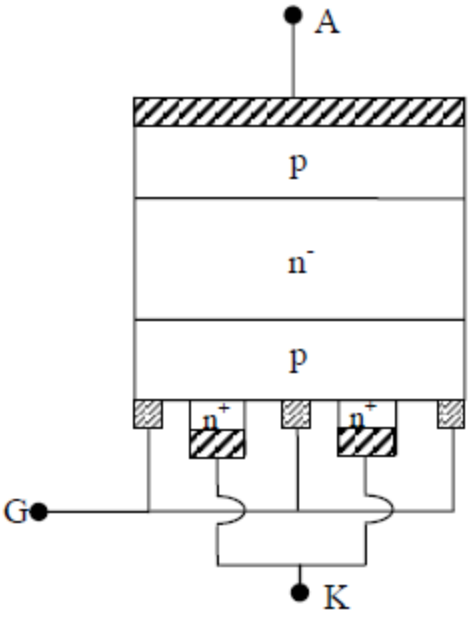
Thyristors

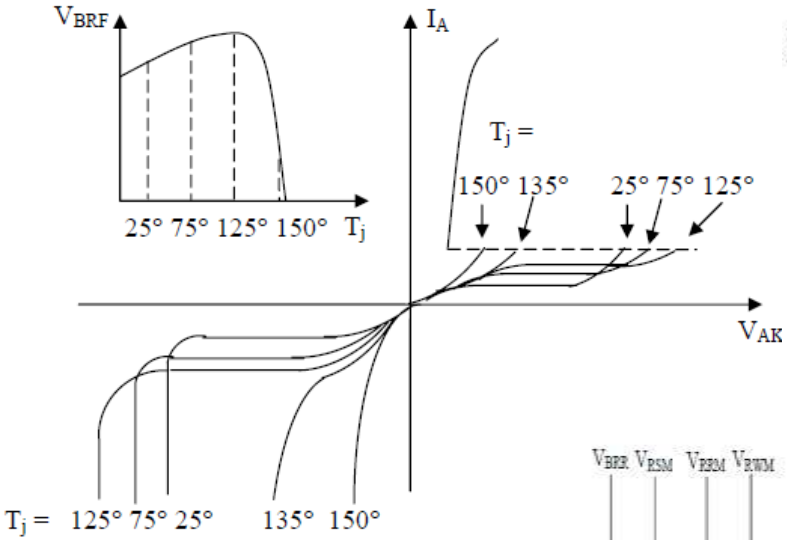

Anode (A)
p
n
p
n
1
2
3
Cathode (K)

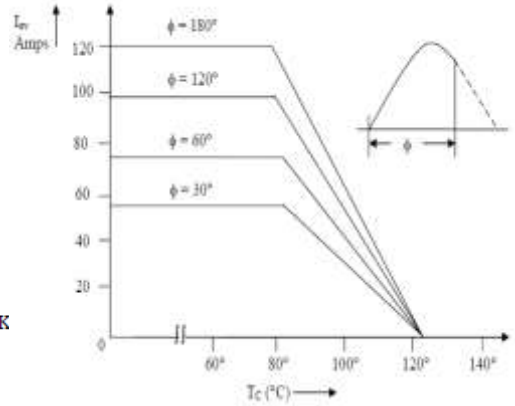

A
G
K

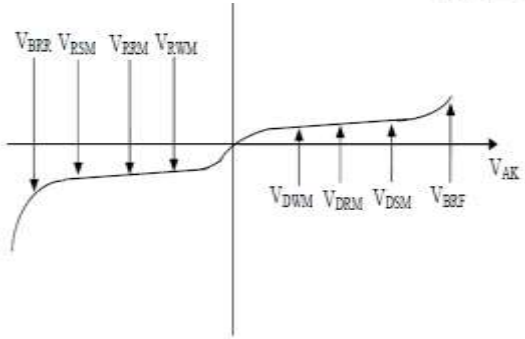

(a) 4-layer diode
(b) SCR
(c) Diac
(d) Triac
(e) SCS


I_A
On
Forward-conduction region
I_H
I_S
Off
Forward-blocking region
V_{AK}
0
$V_{BR(F)}$

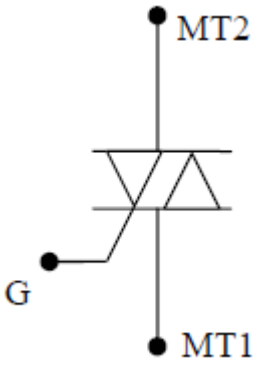

A
p
n⁻
p
n⁺
n⁺
G
K

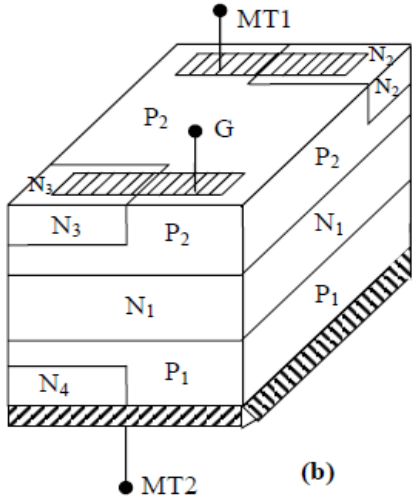

V_{BRF}
I_A
T_j =
25° 75° 125° 150° T_j
150° 135°
25° 75° 125°
V_{AK}
T_j = 125° 75° 25°
135° 150°

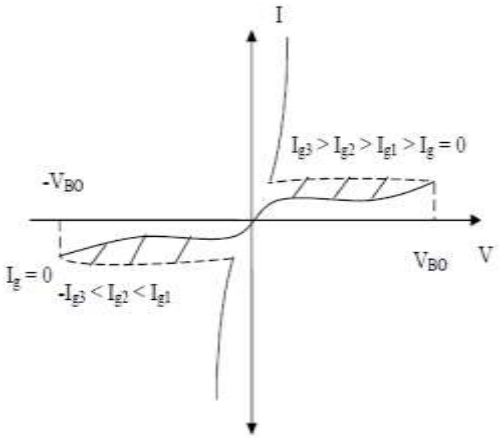

I_T, Amps
ϕ = 180°
ϕ = 120°
ϕ = 60°
ϕ = 30°
120
100
80
60
40
20
0
60°
80°
100°
120°
140°
T_C (°C)

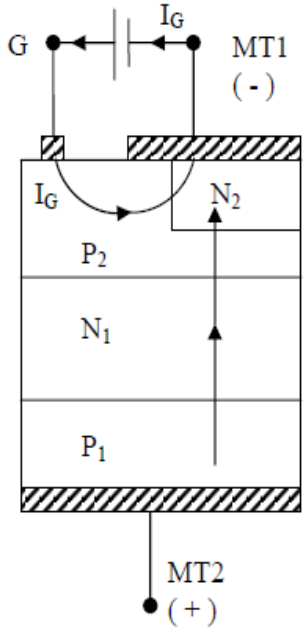

V_{BRR} V_{RSM} V_{RRM} V_{RWM}
V_{AK}
V_{DWM} V_{DRM} V_{DSM} V_{BRF}

Triac: Construction and operating principle

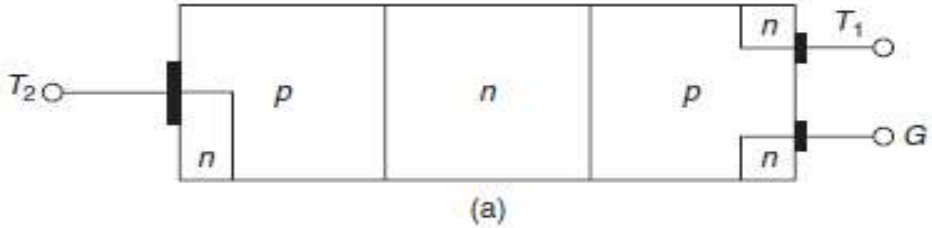


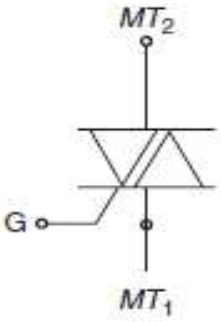


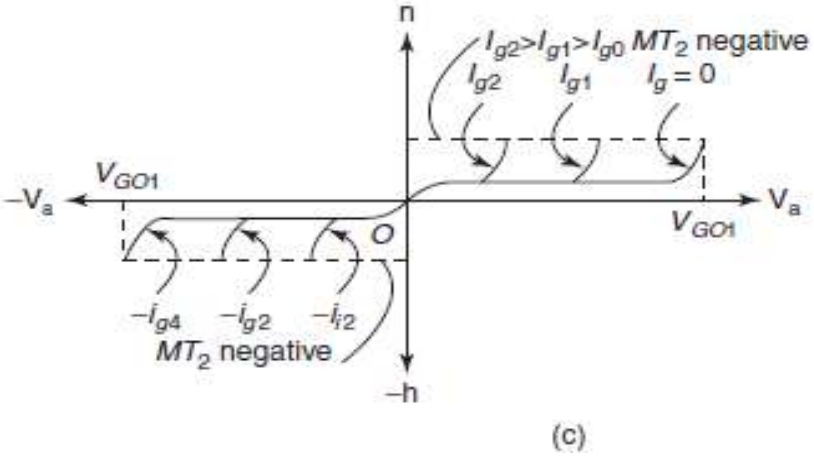


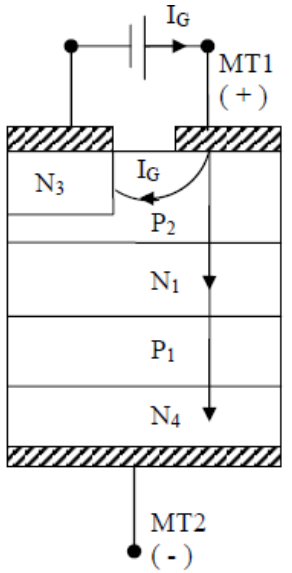


Mode – 1



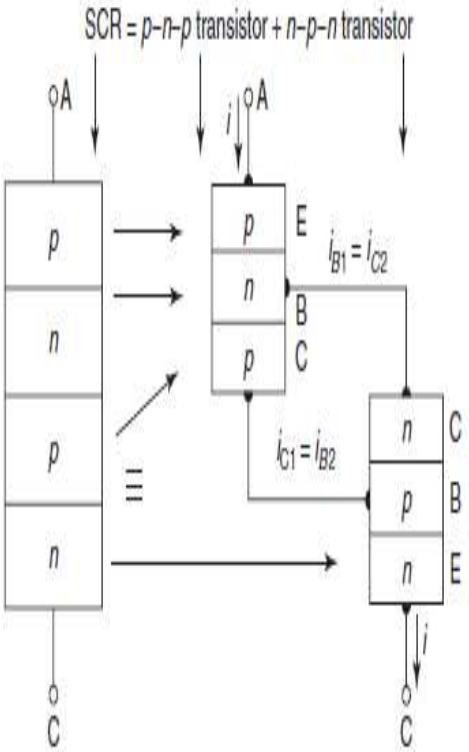


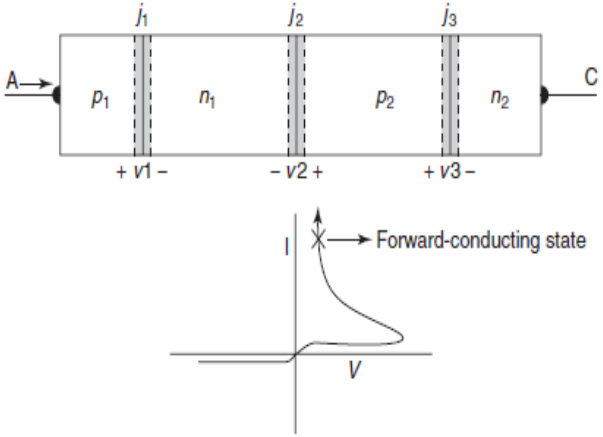


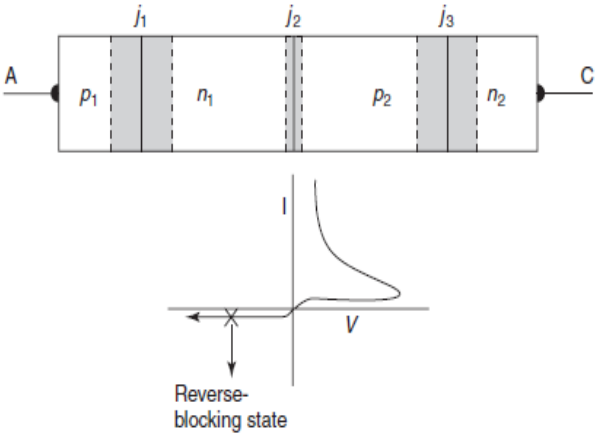


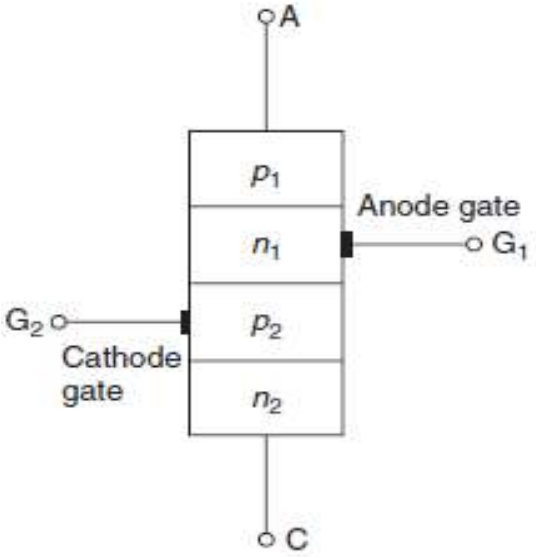
Mode – 3

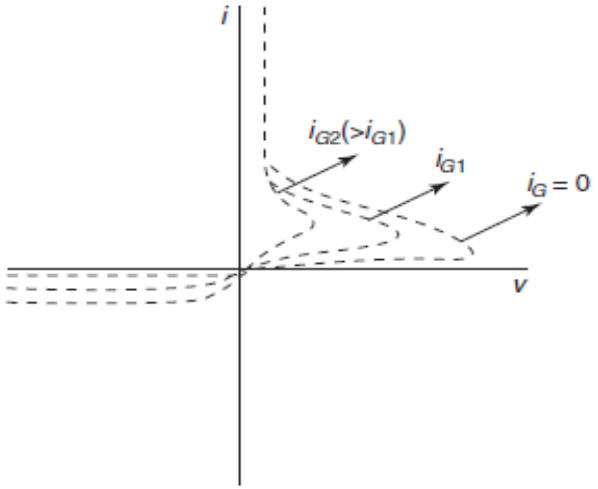
SCR


SCR = p–n–p transistor + n–p–n transistor
A
i
A
p
n
p
n
E
B
C
$i_{B1} = i_{C2}$
$i_{C1} = i_{B2}$
n
p
n
C
B
E
i
C
C

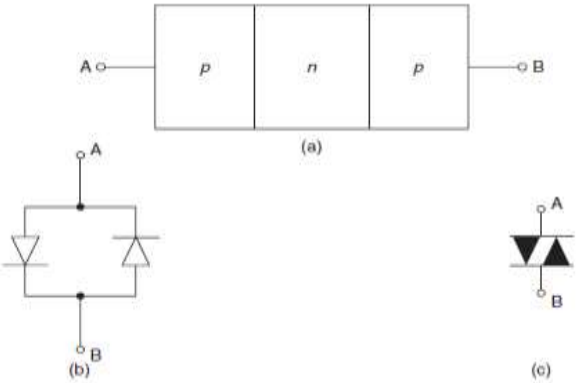

j_1
j_2
j_3
A
p_1
n_1
p_2
n_2
C
+ v1 –
– v2 +
+ v3 –
I
Forward-conducting state
V

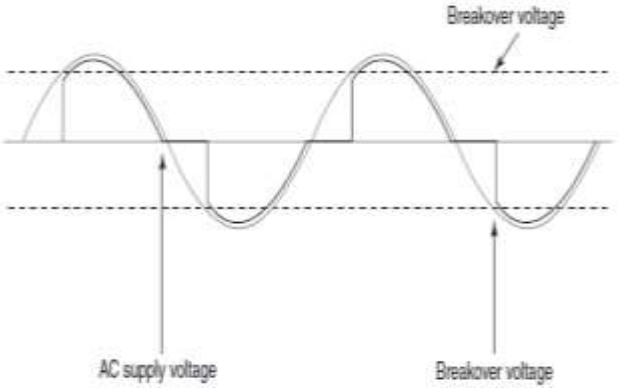

j_1
j_2
j_3
A
p_1
n_1
p_2
n_2
C
I
V
Reverse-
blocking state

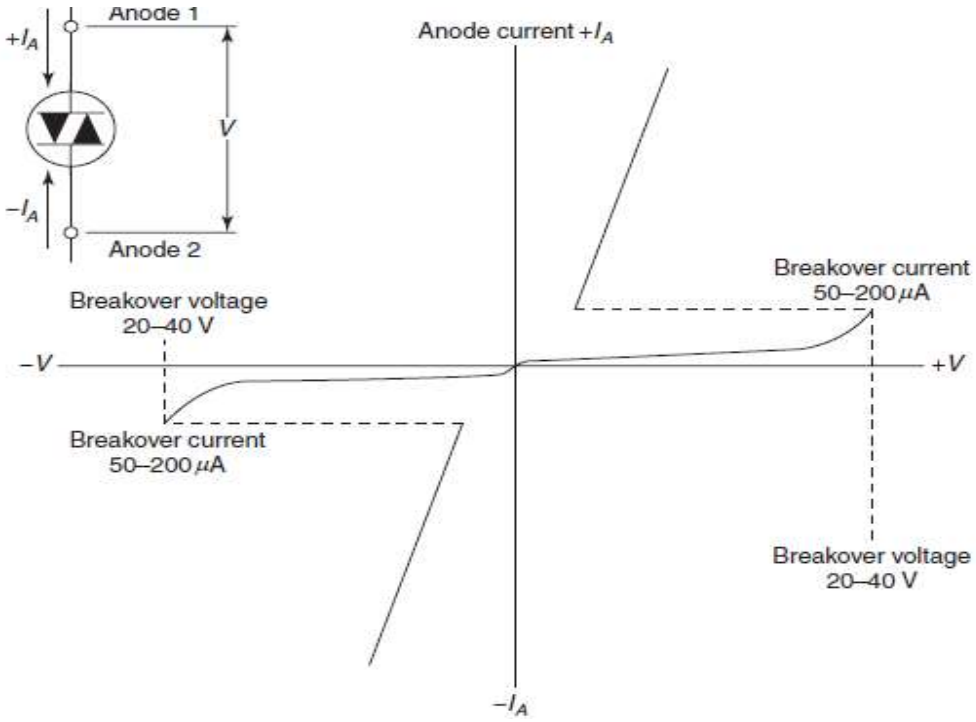

A
p_1
n_1
p_2
n_2
Anode gate
G_1
G_2
Cathode
gate
C


i
$i_{G2}(>i_{G1})$
i_{G1}
$i_G = 0$
v

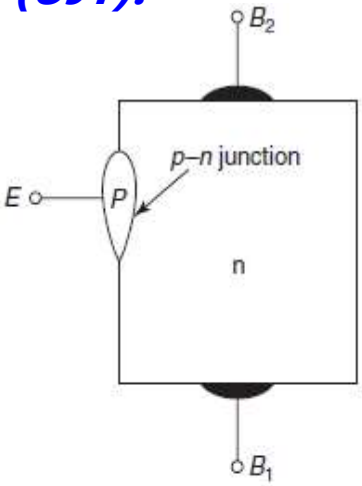
DIODE AC SWITCH (DIAC):

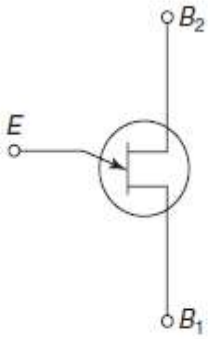


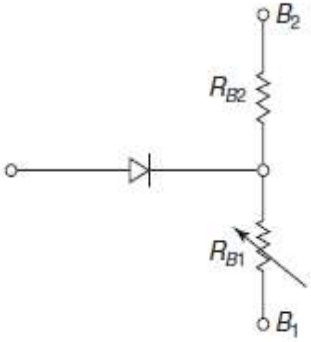


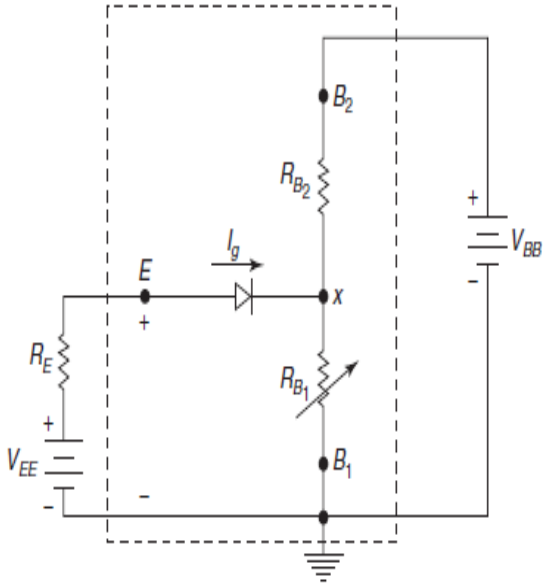


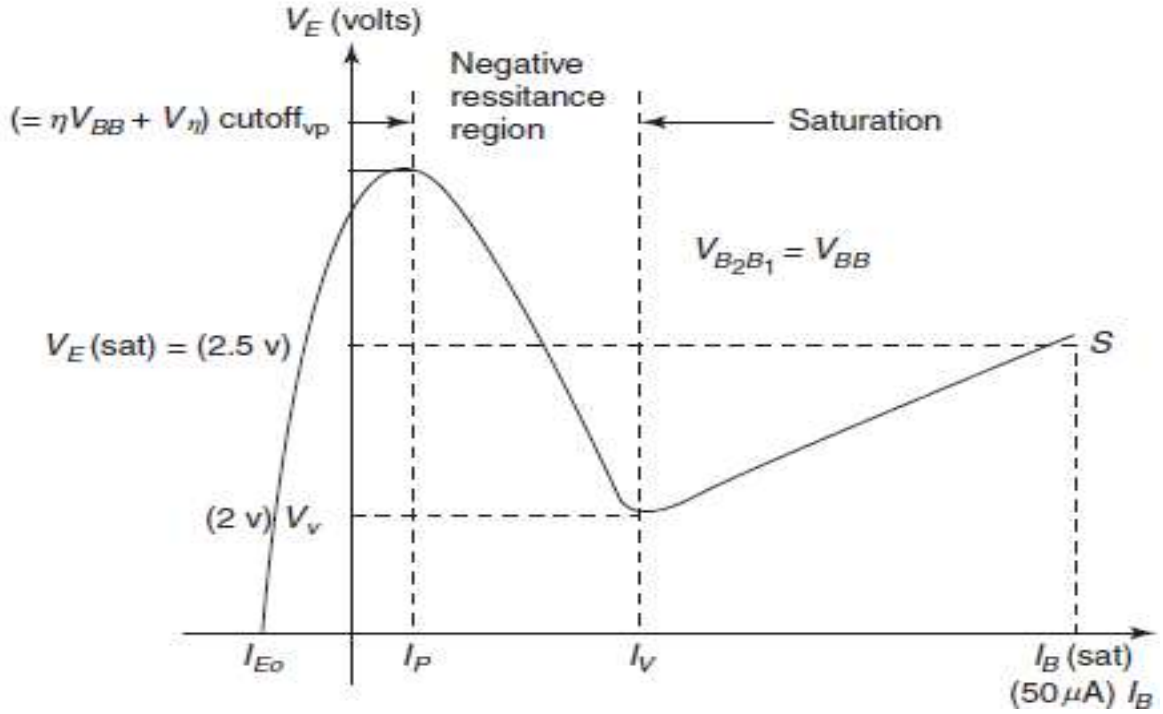
UNIJUNCTION TRANSISTOR (UJT):





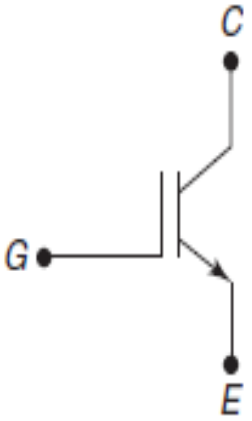


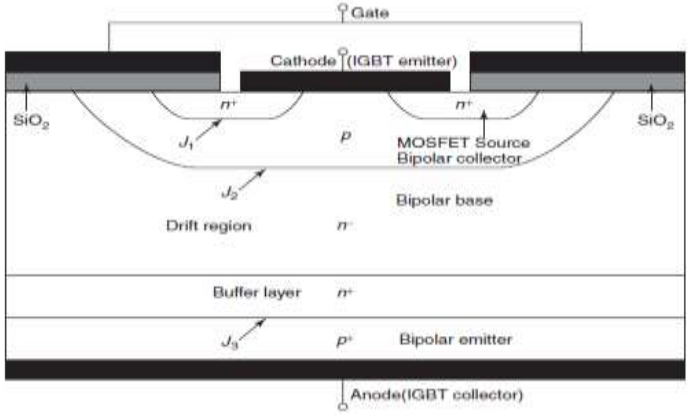


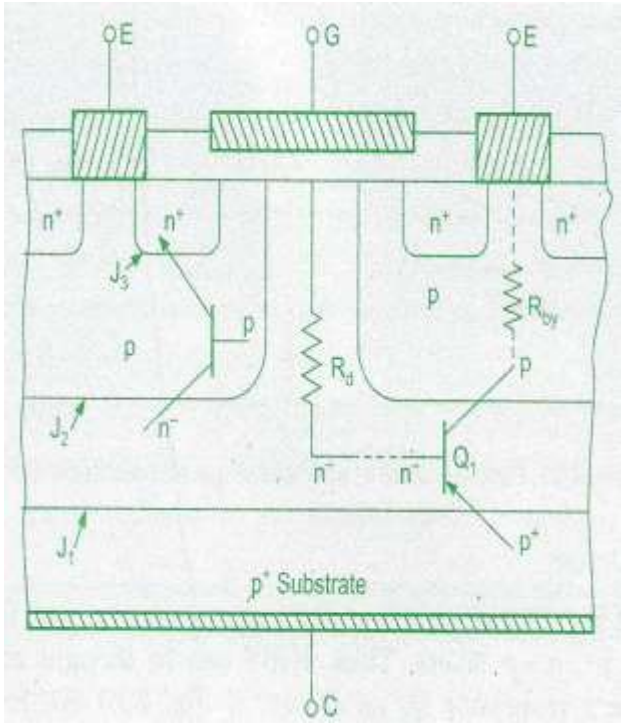


INSULATED-GATE BIPOLAR TRANSISTOR (IGBT):

INSULATED-GATE BIPOLAR TRANSISTOR (IGBT):







POINTS TO REMEMBER:

1. A thyristor is a multilayer p–n terminal electronic device used for bi-stable switching.
2. The SCR has two states: High-current low-impedance ON state and Low-current OFF state
3. Latching current is defined as a minimum value of anode current which is a must in order to attain the turn-on process required to maintain conduction when the gate signal is removed.
4. Holding current is defined as a minimum value of anode current below which it must fall for turning off the thyristor..
5. The TRIAC is a bidirectional thyristor with three terminals. It is used extensively for the control of power in ac circuits.
6. The DIAC is an n–p–n or p–n–p structure with a uniformly doped layer.
7. Applications of the UJT:
   (a) As trigger mechanism in the SCR and the TRIAC
   (b) As non-sinusoidal oscillators
   (c) In saw-tooth generators
   (d) In phase control and timing circuits
8. The UJT operation can be stated as follows:
   (a) When the emitter diode is reverse-biased, only a very small emitter current flows. Under this condition *RB1 is at its normal* high-value. This is the OFF state of the UJT.
   (b) When the emitter diode becomes forward-biased *RB1 drops to a very low value so* that the total resistance between *E and B1* becomes very low, allowing emitter current to flow readily. This is the ON state.
9. The IGBT is mostly used in high-speed switching Devices.

Power supply

An electrical power supply that incorporates a switching regulator to convert electrical power efficiently.

- Power supply convert alternating current to the direct (DC) current mainly convert 110-240v AC
- Three types of power supply:
  - Linear power supply
  - Switched mode (SMPS
  - Uninterrupted (UPS)
  - Power SMPS stands for **Switch Mode Power Supply**.
- This receives **230V AC** and translates it into different DC levels such as **+5V, -5V, +12V, -12V**.

Linear power supply:

- Ttransformer is used to convert voltage.
- Transformer convert the line AC voltage to a smaller peak voltage
- Rectifies AC signal produces large waveforms , capacitor filter is used filter the rectified wave which contain small pulses (ripple).
- Depend on requirements regulator adjust the output voltage.
- Good line and load regulation lower output voltage ripples.

Basics & Working of Switched Mode Power Supply:

- Switch mode power supplies (SMPSs) are used in a range of applications as an efficient and effective source of power.
- This is in major part to their efficiency.
- For anybody still working on a desktop, look for the fan output in the central processing units (CPU).
- SMPS offers advantages in terms of size, weight, cost, efficiency and overall performance.
- These have become an accepted part of electronics gadgets.
- Basically, it is a device in which energy conversion and regulation is provided by power semiconductors that are continuously switching “on” and “off” with high frequency.

The different kinds

- DC to DC converter
- Forward Converter
- Flyback Converter
- Self-Oscillating Flyback Converter

DC-DC converter:

- The primary power received from AC main is rectified and filtered as high voltage DC.
- It is then switched at a huge rate of speed and fed to the primary side of the step-down transformer.
- The step-down transformer is only a fraction of the size of a comparable 50 Hz unit thus relieving the size and weight problems.
- We have the filtered and rectified output at the secondary side of the transformer.
- It is now sent to the output of the power supply.
- A sample of this output is sent back to the switch to control the output voltage.

Forward converter:

- In a forward converter, the choke carries the current when the transistor is conducting as well as when it's not.
- The diode carries the current during the OFF period of the transistor.
- Therefore, energy flows into the load during both the periods.
- The choke stores energy during the ON period and also passes some energy into the output load.

Flyback converter:

- In a flyback converter, the magnetic field of the inductor stores energy during the ON period of the switch.
- The energy is emptied into the output voltage circuit when the switch is in the open state.
- The duty cycle determines the output voltage.

Basic working concept of an SMPS:

- A switching regulator does the regulation in the SMPS.
- A series switching element turns the current supply to a smoothing capacitor on and off.
- The voltage on the capacitor controls the time the series element is turned.
- The continuous switching of the capacitor maintains the voltage at the required level.

Design basics:

- AC power first passes through fuses and a line filter.
- Then it is rectified by a full-wave bridge rectifier.
- The rectified voltage is next applied to the power factor correction (PFC) pre-regulator followed by the downstream DC-DC converter(s).
- Most computers and small appliances use the International Electrotechnical Commission (IEC) style input connector.
- As for output connectors and pinouts, except for some industries, such as PC and compact PCI, in general, they are not standardized and are left up to the manufacturer.

Why SMPS:

- Like every electronic gadget, SMPS also involve some active and some passive components.
- And like each of those gadgets, it has its own advantages and disadvantages.

Operation:

- The **power supplies** used in computers are switched mode power supplies.
- The primary power **received** from **AC** mains is **rectified and filtered** as high-voltage DC.

SMPS

- Switched mode : electronic power supply with **switching regulator**.
- power SMPS stands for **Switch Mode Power Supply**.
  - This receives **230V AC** and translates it into different DC levels such as **+5V, -5V, +12V, -12V**.
- it is switched to a high frequency approximately **10 to 100 KHz** by a bipolar transistor and fed to the primary side (P) of a **step-down transformer.**
- **Uses feedback mechanism**

SMPS working

- Convert AC to DC voltage with rectifier
- Which is unregulated DC voltage sent it to filter
- Inverter convert DC to AC with help of power oscillator.
- Output transformer inverts AC voltage up to down to the required output level.
- Output rectifier and filter : AC output from transformer is rectified.
- For lower voltage uses silicon/schottky diodes used and smoothing the rectified output by using filter.
- This **reduces** the amount of the voltage passed through the transformer.
- So the output voltage will be maintained normally.
- Then it is sent to the **output of the power supply**.
- A sample of this output is sent back as **feedback signal for regulation**.

Power Supply Characteristic

- **Wattage**: The total, maximum output of the power supply in watts,Typical power ranges are from 200W to 500W.
- **Efficiency**: Efficiency=Useful Power Output / Total Electrical Power Consume.
- **Regulation**: The ability of a SMPS to maintain an output voltage within specified limits under varying of input voltage.
- **Ripple**: Also called AC Ripple or Periodic and Random Deviation(PARD) or simply Noise the Power Supply of course produces DC outputs from AC input.
- **Load Regulation:** Sometimes called voltage load regulation. This specification refers to the ability of the power supply to control the output voltage level
- **Line Regulation:** The complement of load regulation, this parameter describes the ability of the power supply to control its output levels

Power Supply problems

- **Blackouts: it** is complete loss of electric power where voltage and current drop to **0**,usually caused by **physical interruption in the power line** due to **accidental damage** by a person or act of nature, **loss of AC** will invariably **shutdown** the computer,**loss of data**, **reduction productivity, corrupt file structure and damage files.**
- **Brownouts (Sag)**: The under voltage condition The high load items like air conditioners, welding machine, motor etc draw to much current that the AC voltage level drops.
- power supply will **fall out which resulting in intermittent system operation**. **file may be lost** or **corrupted on the hard drive**.
- **Surge:** small over voltage conditions that take place over relatively long periods and regulate power to a desired level excess energy must be switched (in SMPS).
- **Spikes:** A spike is a large over voltage condition that occurs in the milliseconds. high energy switches can cause spikes on the AC line. Example equipment like drill machine, grinders, welding equipment etc. can produce power spikes.

IC Basics

IC Basics: Integrated circuits can be defined as:

Integrated circuits (ICs) are, much as their name would suggest, small circuits integrated into a plastic holder/"chip." Many ICs are really fairly simple -- often just consisting of multiple copies of a simple 2- or 3-element circuit, in a small, handy, package.

Integrated circuits:

- The most important use of all these semiconductor devices today is not in discrete components, but rather in **integrated circuits** called **chips**.
- Some integrated circuits contain a million or more components such as resistors, capacitors, and transistors.
- Two benefits: **miniaturization** and **processing speed**.

Integrated circuit (IC) chips:

- Today it is possible to combine arrays of tens of thousands of transistors, diodes, resistors, and capacitors on a tiny chip of silicon that usually measures less than a centimeter on a side. These arrays are called integrated circuits (ICs) and can be designed to perform almost any desired electronic function.
- Integrated circuits have revolutionized the electronics industry and lie at the heart of computers, cellular phones, digital watches, and programmable appliances.