ISSN (ONLINE) : 2395-695X
ISSN (PRINT) : 2395-695X
Available online at www.ijarbest.com
International Journal of Advanced Research in Biology, Ecology, Science and Technology (IJARBEST)
Vol. 1, Issue 7, October 2015

UNIT -IV

SPECIAL SEMICONDUCTOR DEVICES

Metal - Semi conductor junction - MESFET, Schottky barrier diode, Zener diode, Varactor diode - Tunnel diode - Gallium Arsenide device, LASER diode, LDR.

IMPORTANT ANNA UNIVERSITY QUESTIONS

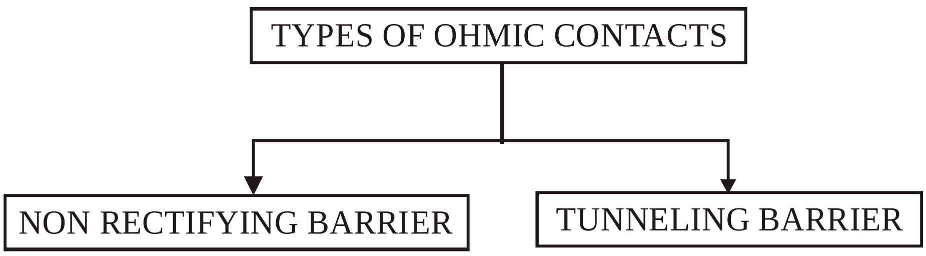
* Zener diode - Characteristics, Breakdown, Applications - 8 Marks
* Tunnelling - 2 Marks
* Tunnel diode - 16 Marks
* Zener Effect - 2Marks
* Applications of Varactor diode - 2 Marks
* MESFET - 2 Marks
* Schottky Barrier diode - 8 Marks

4.1 METAL SEMICONDUCTOR JUNCTIONS

4.1.1 INTRODUCTION

→ Contact between Semiconductor devices or IC's with the outside world are made through **metal - semiconductor junctions** or **ohmic contacts**.

→ **OHMIC CONTACT** → Low resistance junction providing current conduction in both direction between metal and semiconductor.



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1) NON RECTIFYING BARRIER:

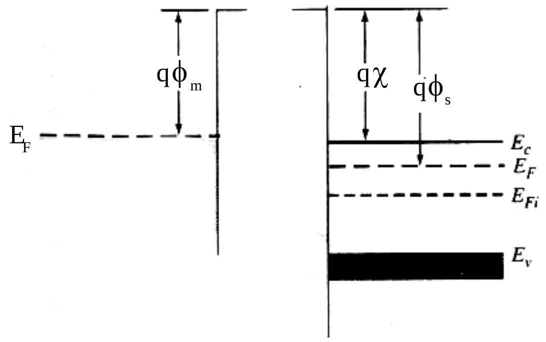

Fig 4.1ENERGY BAND DIAGRAM BEFORE CONTACT FOR METAL - n-SEMI CONDUCTOR JUNCTION FOR $\phi_m < \phi_s$

(May/June - 2014 - 2Marks)

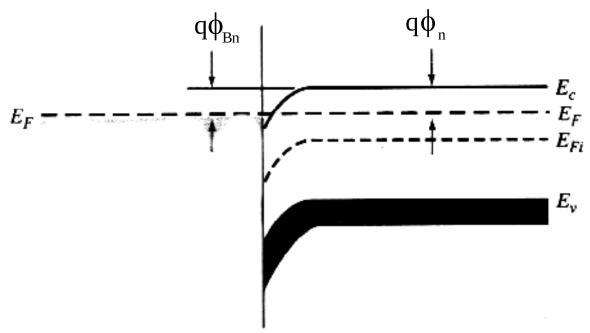

Fig 4.2 ENERGY BAND DIAGRAM AFTER CONTACT FOR METAL - n - SEMICONDUCTOR JUNCTION FOR $\phi_m < \phi_s$

(May/June - 2014 - 2Marks)

* To achieve thermal equilibrium in this junction, electrons will flow from metal into lower energy states in semiconductor. This makes the surface of the semiconductor **more n- type**
* If positive voltage is applied to metal, there is no barrier to electrons from semiconductor into metal.
* If positive voltage is applied to semiconductor, Barrier height for electrons flowing from metal to semiconductor will be $\boxed{\phi_{Bn} = \phi_n}$

2) ENERGY BAND DIAGRAM OF METAL - n - SEMICONDUCTOR OHMIC CONTACT (a) WITH POSITIVE VOLTAGE APPLIED TO METAL AND (b) WITH POSITIVE VOLTAGE APPLIED TO SEMICONDUCTOR:

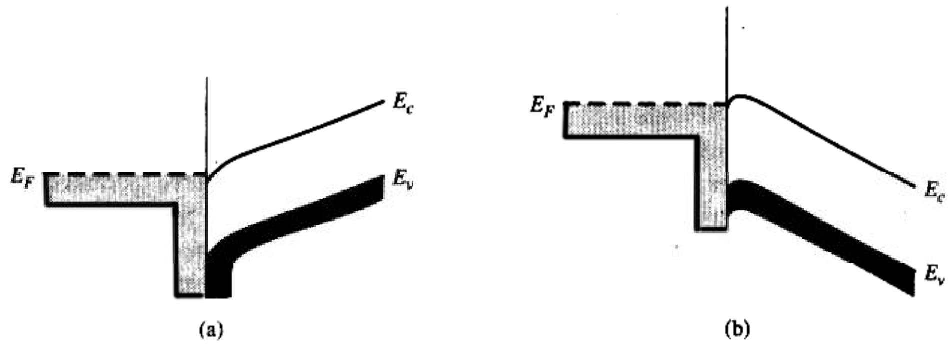

Fig. 4.3 ENERGY BAND DIAGRAM OF (a) AND (b)

* When non rectifying contact is made between metal and p-type semiconductor, electrons from semiconductor will flow into metal to achieve thermal equilibrium which leaves behind more empty states (holes)
* Excess concentration of holes at surface makes surface of semiconductor more p-type.
* Electrons from metal can move into empty states in semiconductor.
* Charge movement corresponds to holes flowing from semiconductor into metal.
* If $\phi_m < \phi_s$ for metal - n -type semiconductor contact and if $\phi_m > \phi_s$ for metal - p- type semiconductor contact, good ohmic contact may not be formed.

4.1.2 TUNNELING BARRIER:

* Space charge width in **rectifying** metal semiconductor contact is inversely proportional to square root of semiconductor doping.
* When width of depletion region decreases, doping concentration in semiconductor increases. So probability of tunneling through barrier increases.

Tunneling current density

$$J_t \alpha \exp\left(\frac{-q\phi_{Bn}}{E_{00}}\right)$$

4.1.3 SPECIFIC CONTACT RESISTANCE:

Specific Contact Resistance is defined as reciprocal of derivative of current density with respect to voltage evaluated at zero bias.

Specific contact Resistance $$R_C = \left(\frac{\partial J}{\partial V}\right)^{-1}\Bigg|_{V=0} \Omega cm^2$$

Current density $$J_n = A^* T^2 \exp\left(\frac{-q\phi_{Bn}}{KT}\right)\left(\exp\left(\frac{qV}{KT}\right) - 1\right)$$

For thermionic emission,

$$R_C = \frac{\frac{KT}{q}\exp\left(\frac{q\phi_{Bn}}{KT}\right)}{A^* T^2}$$

* For forming a good ohmic contact, a low barrier should be created and highly doped semiconductor at surface should be used.
* The formation of tunneling junction requires diffusion, ion implantation or epitaxial growth.
* Very **good processing** is required for forming a good ohmic contact.

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4.2 MESFET

* MESFET $\rightarrow$ Metal - Semiconductor field Effect transistor
* Thin epitaxial layer of GaAs is used for active region.
* The subtrate is a very high resistivity GaAs material called as **SEMI - INSULATING SUBSTRATE.**

4.2.1 ADVANTAGES:

* High electron mobility
* Small transit time
* Faster response
* Decreased parasitic capacitance

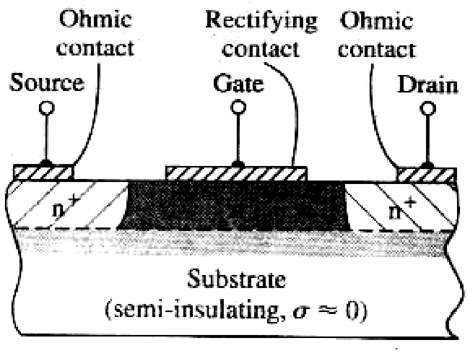

Fig 4.4 CROSS SECTION OF n- CHANNEL MESFET WITH SEMI - INSULATING SUBSTRATE

* Reverse bias **gate-to-source** voltage induces space charge region under metal gate which modulates channel conductance.

* Space charge region reaches substrate if applied negative gate voltage is large. This is known as "**PINCH OFF** "

* Since there is a potential barrier between channel and substrate & between channel and metal, majority carrier electrons are confined to channel region. This is shown in energy band diagram shown below:

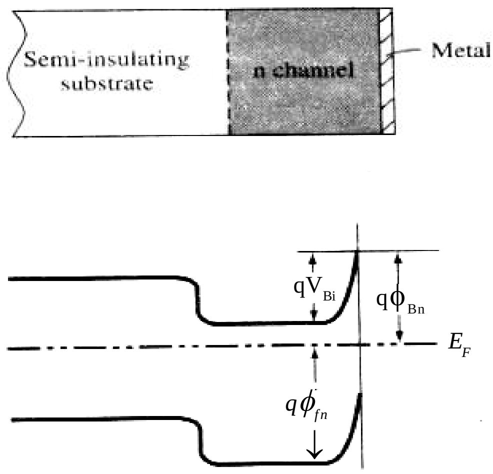

Fig 4.5 ENERGY BAND DIAGRAM OF SUBSTRATE - CHANNEL - METAL IN n - CHANNEL MESFET

4.2.2. CIRCUIT SYMBOLS OF MESFET:

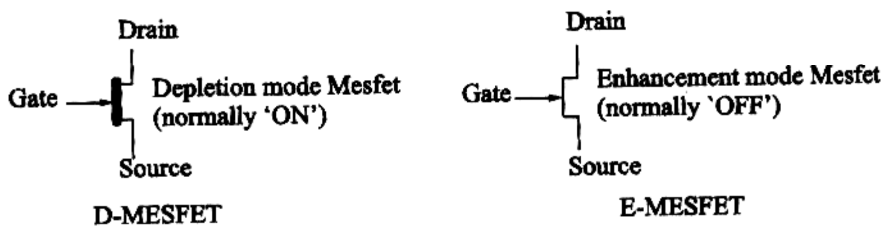

Fig 4.6 a) D - MESFET b) E - MESFET

4.2.3 CHANNEL SPACE CHARGE REGION OF E- MESFET FOR (a) V_{GS}=0 (b)V_{GS}=V_T and (c) V_{GS} > V_T :

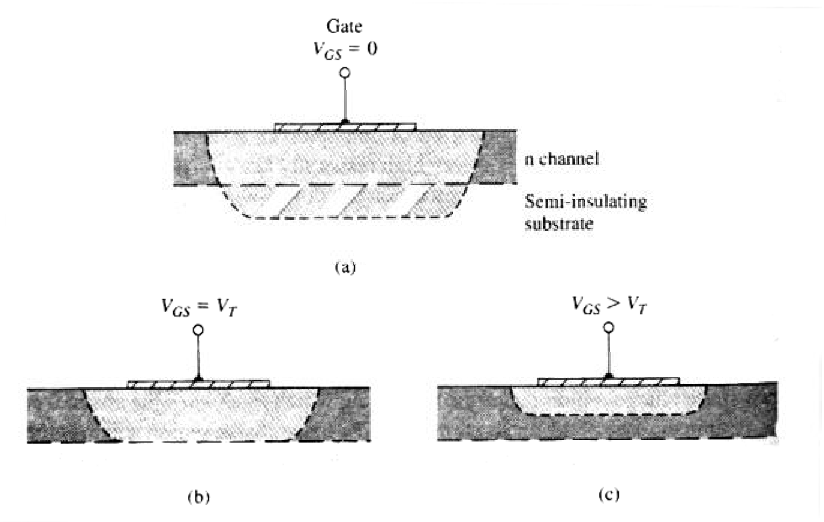

Fig 4.7 CHANNEL SPACE CHARGE REGION OF E - MESFET FOR (a) AND (b)

* When slightly forward bias voltage is applied, depletion region extends through the channel. This is known as "**THRESHOLD**"

Threshold Voltage $V_T = V_{bi} - V_{p0}$

where V_{bi} = Built- in potential

V_{p0} = internal pinch off voltage.

4.2.4 APPLICATIONS:

→ Satelite Communications

→ As Power oscillator

→ As Power amplifier for output stage of microwave links.

→ Military communications

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4.3 SCHOTTKY BARRIER DIODE (May /June 2010 - 8 Marks)(May /June 2014 - 8 Marks)

* Schottky Barrier diode (also known as point contact diode) was made from metal - semiconductor rectifying contact.

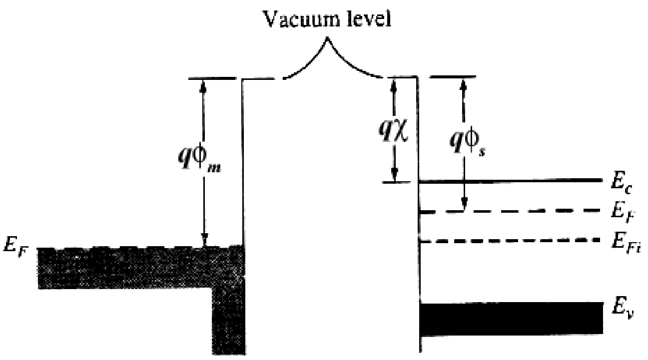

Fig 4.8 (a) ENERGY BAND DIAGRAM OF METAL AND SEMICONDUCTOR BEFORE CONTACT

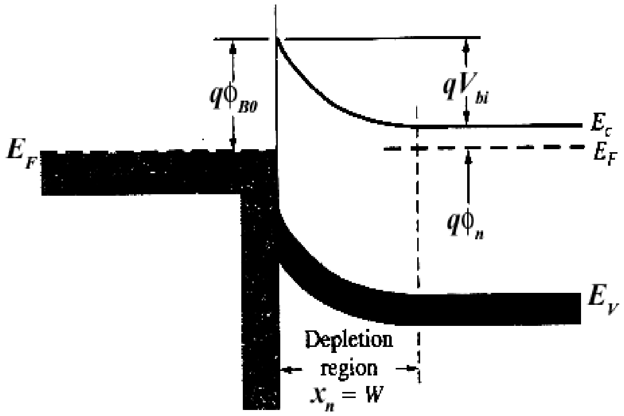

Fig 4.8 (b) ENERGY BAND DIAGRAM OF METAL - n - SEMICONDUCTOR JUNCTION FOR $\varphi_m > \varphi_s$

* Vacuum level $\rightarrow$ Reference level.
* $\phi_m \rightarrow$ metal work function (in volts)
* $\phi_s \rightarrow$ semiconductor work function
* $\chi \rightarrow$ electron affinity
* Before contact, fermi level was above the semiconductor in the metal.
* To make Fermilevel a "constant", electrons from semiconductor flows into lower energy states in metal.
* Positively charged donor atoms remain in semiconductor creating space charge region.
* $\phi_{B0} \rightarrow$ideal barrier height of semiconductor contact (also known as **SCHOTTKY BARRIER**)

$$\phi_{B0} = (\phi_m - \chi)$$

Built in potential barrier in semiconductor $V_{bi} = \phi_{B0} - \phi_n$

4.3.1 DETERMINATION OF ELECTROSTATIC PROPERTIES:

From Possion's equation,

$$\frac{dE}{dx} = \frac{\rho(x)}{\xi_S} \rightarrow ①$$

where $\rho(x)$ $\rightarrow$ space charge volume density

ξ_S $\rightarrow$ permittivity of semiconductor

Integrating ①,

$$E = \int \frac{\rho(x)dx}{\xi_S}$$

$$\rho(x) = qN_D$$

$$\therefore E = \int \frac{qN_D}{\xi_S} dx$$

$$= \frac{qN_D x}{\xi_S} + C_1$$

where C_1 $\rightarrow$integration constant

At **space charge edge** in semiconductor,

E = 0

$$So\ 0 = \frac{qN_D x}{\xi_S} + C_1$$

$$C_1 = \frac{-qN_D x_n}{\xi_S}$$

$$\therefore E = \frac{+qN_D}{\xi_S}(x - x_n)$$

$$\boxed{E = \frac{-qN_D}{\xi_S}(x_n - x)}$$

Space charge Width $\boxed{W = x_n = \left[\frac{2\xi_S(V_{bi} + V_R)}{qN_D}\right]^{1/2}}$

Junction capacitance = $\left[\frac{1}{C'}\right]^2 = \frac{2(V_{bi} + V_R)}{q\xi_S N_D}$

where C' = Junction capacitance = Capacitance per unit area.

4.3.2 SYMBOL

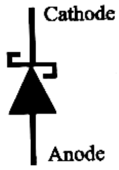

Fig 4.9 SYMBOL

SCHOTTKY BARRIER DIODE	pn JUNCTION DIODE
$\rightarrow$ Reverse saturation current density $J_{ST} = A^* T^2 \exp\left(\frac{-q\phi_{Bn}}{KT}\right)$ $\rightarrow$ Current is determined by thermionic emission of majority carriers.	$\rightarrow$ Reverse saturation current density $J_S = \frac{qD_n n_{p0}}{L_n} + \frac{qD_p p_{n0}}{L_p}$ $\rightarrow$ Current is determined by diffusion of minority carriers.

4.3.3 ADVANTAGES

→ Low turn on voltage (between 0.2 and 0.3V)
→ Low junction capacitance
→ Fast recovery time.

4.3.4 APPLICATIONS:

* RF mixer and detector diode
* Power rectifier
* Power OR circuits
* Solar Cell applications
* Clamp diode

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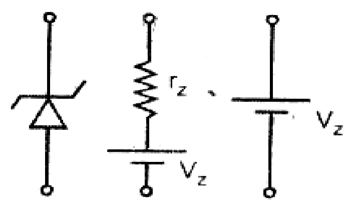
4.4 ZENER DIODE

(May /June 2010 - 16 Marks) (Nov / Dec 2012 - 16 Marks)(Nov - Dec 2009-8 Marks) (May / June 2009-8 Marks) (May /June 2014 -8 Marks)

→ Zener diode is a pn junction device which is designed to operate in **reverse breakdown** region.
→ Heavily doped than ordinary pn junction diode.
→ Breakdown voltage of Zener diode is set by controlling doping level.
→ Operation of Zener diode in forward biased condition is same as pn junction diode.

4.4.1 SYMBOL, PRACTICAL AND IDEAL EQUIVALENT CIRCUIT OF ZENER DIODE:



(a) (b) (c)

Fig 4.10 (a) Symbol b) Practical Equivalent Circuit c) Ideal Equivalent Circuit

4.4.2 V-I CHARACTERISTICS OF ZENER DIODE:

* Resistance 'R' limits current through Zener diode.

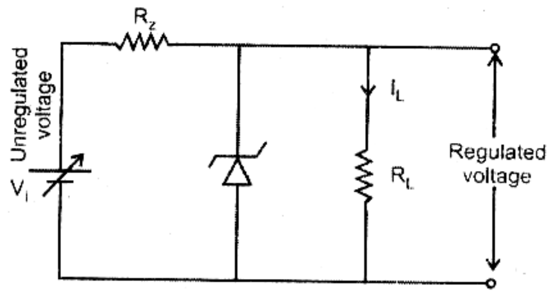


Fig 4.11 CIRCUIT ARRANGEMENT - VI CHARACTERISTICS

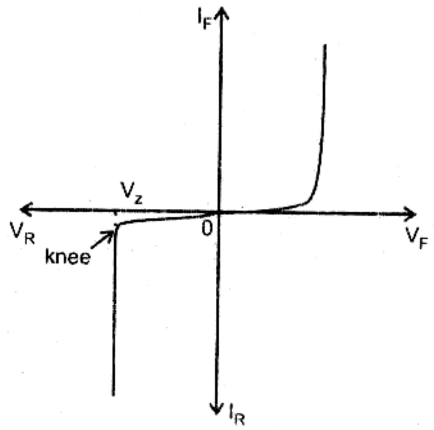
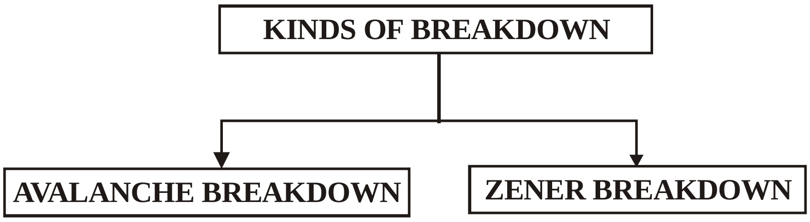


Fig 4.12 V -I CHARACTERISTICS OF ZENER DIODE

* **Forward bias** characteristics of Zener diode is same as that of ordinary pn junction diode.
* In **Reverse bias,** when reverse voltage (V_R)is increased, reverse saturation current (I_R)remains extremely small upto knee of curve.
* If reverse voltage is increased further, breakdown occurs and current increases rapidly.
* Reverse voltage at which breakdown occurs is called **"REVERSE BREAKDOWN VOLTAGE"**

4.4.3 BREAKDOWN MECHANISMS IN ZENER DIODES:
(Nov /Dec 2010 - 8 Marks)



1) AVALANCHE BREAKDOWN:

→ Under reverse biased condition, small amount of reverse saturation current flows. This current is due to temperature. So when temperature is constant, current is constant.

→ When reverse voltage is increased, width of depletion layer increases. At the same time, electrons acquire some high velocity and during their motion inside diode, they collide with electrons which are in covalent bonds of crystal.

→ These 2 charges get sufficient velocity and again collide with electrons in covalent bonds of crystal.

→ Due to this multiplication process, large current flows and this kind of breakdown is called "**AVALANCHE MULTIPLICATION**"or Avalanche breakdown. When breakdown occurs, diode gets damaged.

2) **ZENER BREAKDOWN :**

→ When doping is heavy, in reverse bias, ever before minority charge carriers acquire sufficient velocity, breakdown occurs. This breakdown is called "**ZENER BREAKDOWN**" **(May /June 2012 - 2Marks)**

4.4.4 **APPLICATIONS:**

→ Voltage regulator

→ Square Wave generator

→ Clippers in wave - shaping circuits.

4.4.5 **ZENER DIODE AS VOLTAGE REGULATOR**

* Voltage regulator → Circuit which maintains output voltage of DC power supply constant against variations in input AC voltage and load current.

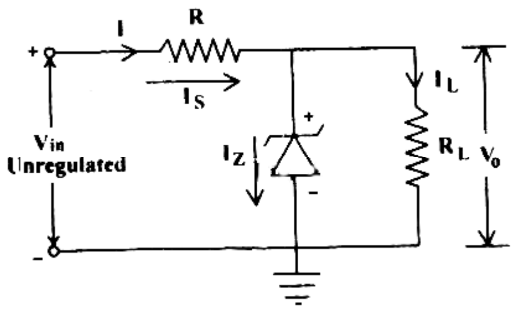


Fig 4.13 ZENER REGULATOR WITH VARYING VOLTAGE REGULATOR

* When R_L increases, $I_{L(min)}$ decreases which increases $I_{Z(max)}$

$$I_{L(min)} = I - I_{Z(max)}$$

* When R_L decreases, $I_L(max)$ increases which decreases $I_{Z(min)}$

$$I_{L(max)} = I - I_{Z(min)}$$

* Maximum power dissipation

$$P_D = V_Z I_{Z(max)}$$

$$I = \frac{V_{in} - V_z}{R}$$

x

4.5 VARACTOR DIODE **(May /June 2014 - 8 Marks)**

→ Specially manufactured reverse biased PN junction diode with suitable impurity concentration.

→ When reverse bias is applied to pn junction, holes in p-region move away from junction and are attracted to postive terminal and electrons in n-region move away from junction and attracted to negative terminal.

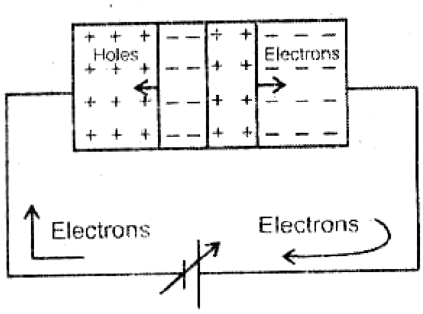


Fig 4.14 VARACTOR DIODE

* Flow of holes and electrons away from junction increase depletion layer.
* Depletion region →Region with no current carriers and acts as an insulator.
* Depletion region can be controlled using reverse bias voltage.
* pn junction can be thought of as a parallel plate capacitor where p and n regions act like plates of capacitor.

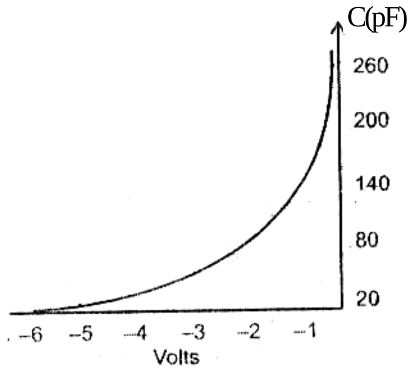


Fig.4.15 C-V Characteristics of varactor diode

* Depletion region increases as reverse voltage applied to diode increases.
* Since Capacitance varies inversely as dielectric thickness; junction capacitance will decrease as voltage across pn junction increase.

$$C_T = \frac{\xi A}{W}$$

→As W increases, C decreases.

* At low frequencies, capacitance is negligible as diode appears essentially open because $R_R \to \infty$
* At high frequencies, Voltage controlled capacitor becomes **dominant.**
* Varactor diode is also known as **"VARICAP"** or **"VOLTACAP".**

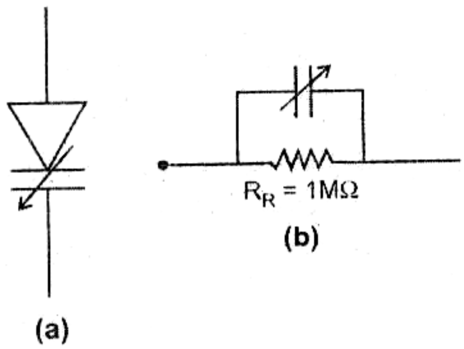


Fig 4.16(a) SYMBOL (b) EQUIVALENT CIRCUIT

4.5.1 CHARACTERISTICS - VARACTOR DIODE

* Diode conducts normally in forward direction.
* At relatively low voltage, reverse current saturates and remains constant.

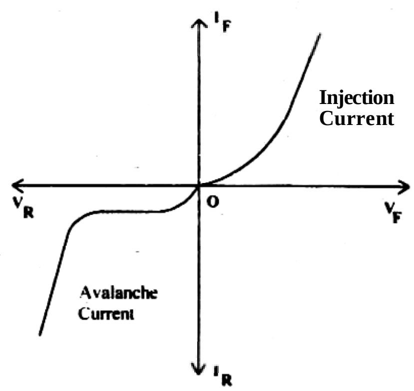


Fig 4.17 V - I CHARACTERISTICS

* At the same time, it rises rapidly at avalanche point.
* At saturation point, maximum junction capacitance is obtained. At a point above avalanche minimum junction capacitance is obtained.

4.5.2 APPLICATIONS (Nov /Dec 2008-2 Marks)

* In Frequency modulation
* In high frequency multipliers
* Used in phase locked loop (PLL)and frequency locked loops (FLL)
* Very low noise microwave parametric amplifiers.

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4.6 TUNNEL DIODE

(Nov / Dec 2008 - 16 Marks) (Nov/ Dec 2010-16 Marks) (May /June 2010 - 16Marks)

→ Processes that an electron from n-side of pn diode directly penetrates through the junction into p-side of diode is called "**TUNNELLING**"**(Nov/ Dec 2012-2 Marks) (May /June 2012 - 2 Marks)**

→ Also known as **ESAKI DIODE**

→ Impurity concentration is about 1 in 10^3 and width of depletion layer is 10^{-6} cm.

→ Decrease in depletion layer reduces height of potential energy barrier.

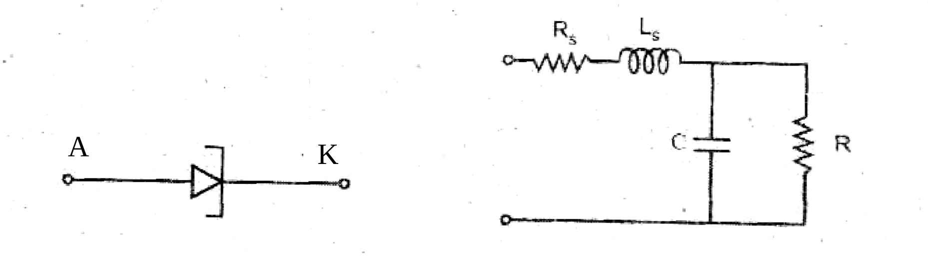


Fig 4.18 (a) SYMBOL (b) EQUIVALENT CIRCUIT

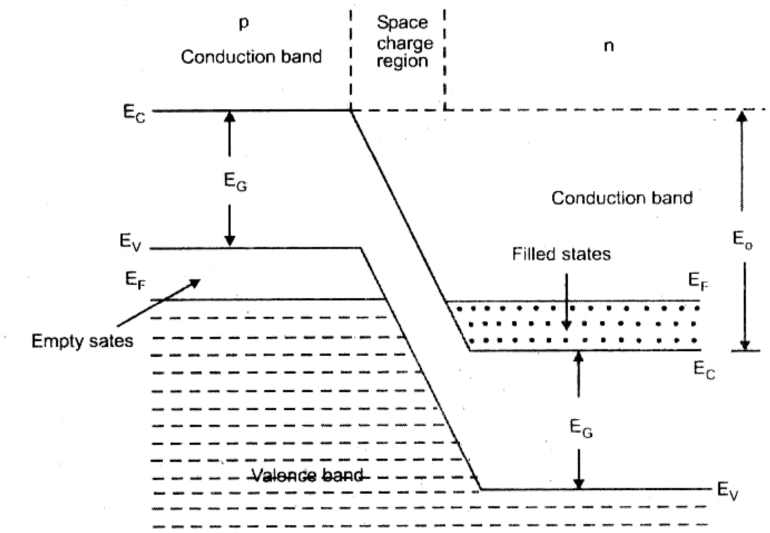


Fig 4.19 (a) ENERGY BANDS IN HEAVILY DOPED pn DIODE (UNDER OPEN CIRCUIT CONDITIONS)

* In Slightly doped pn junction diodes ($N_D < N_C$), fermi level lies inside forbidden energy gap.

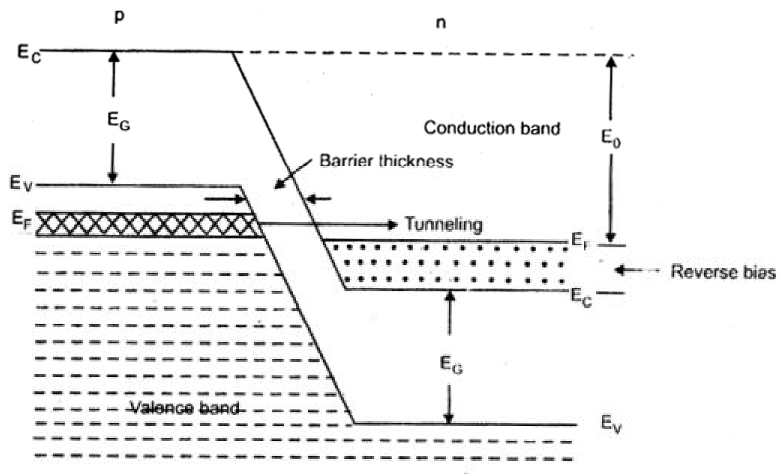


Fig 4.19(b) ENERGY BANDS IN HEAVILY DOPED p-n DIODE WITH REVERSE BIAS

$$E_F = E_C^{'} - KT \ln \frac{N_C}{N_D}$$

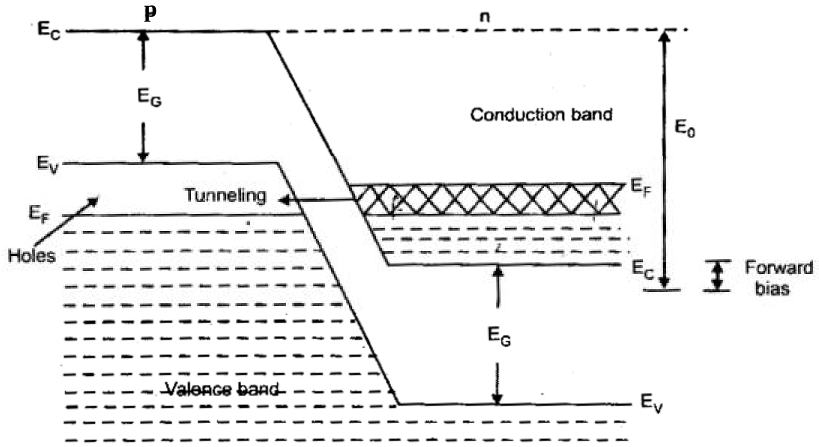


Fig 4.19 (c) ENERGY BANDS IN HEAVILY DOPED p-n DIODE WITH FORWARD BIAS

* In highly doped diodes ($N_D > N_C$), $\ln\left(\frac{N_C}{N_D}\right) \rightarrow$ negative and $E_F > E_C$.
* Fermi level in n-type material lies in conduction band.
* Similarly for heavily doped p- type material ($N_A > N_V$), fermi level lies in valence band.
* Under Open circuit conditions, energy band in heavily doped pn- diode is shown in Fig 4.19 (a) in which there is no flow of charge in either direction across junction.
* Contact difference of potential energy $E_O > E_G$ (forbidden energy gap voltage)

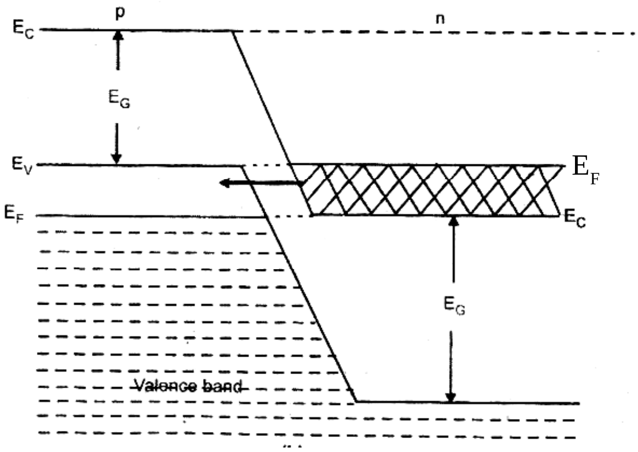
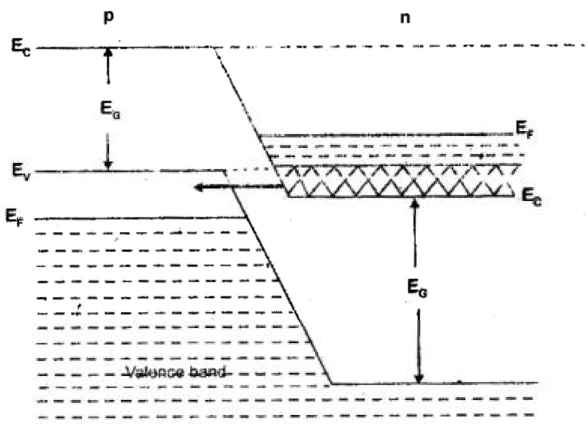


Fig 4.19 (d) ENERGY BANDS IN HEAVILY DOPED p-n DIODE WITH FORWARD BIAS

* When reverse bias is applied to tunnel diode, n-side energy levels shift downward w.r.t. p-side as shown in fig 4.19 (b)
* Electrons will tunnel from p-side to n-side. This gives rise to reverse diode current.
* If reverse bias is increased, reverse current also increases.
* When forward bias is applied to diode(Fig 4.19 (c)), n-side energy level shift upward w.r.t p-side energy level.
* Electron will tunnel from n-side to p-side.



4.19(e) ENERGY BAND DIAGRAM IN HEAVILY DOPED pn DIODE WITH INCREASED FORWARD BIAS

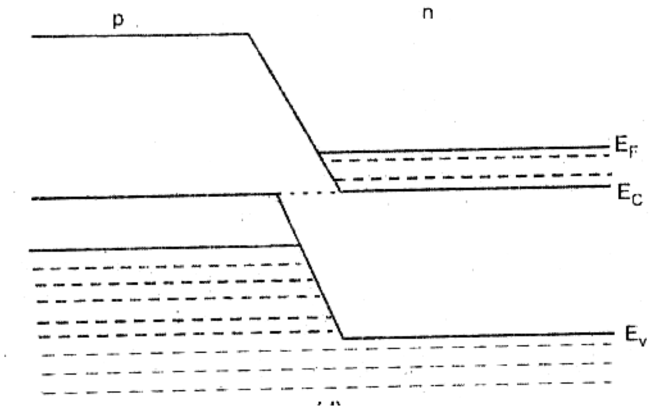


Fig 4.19 (f) ENERGY BAND DIAGRAM IN HEAVILY DOPED pn DIODE WITH INCREASED FORWARD BIAS

* If forward bias is further increased, (as shown in fig 4.19 (f)) tunnelling current decreases.
* At forward voltage, tunnelling current decreases and drops to 0.

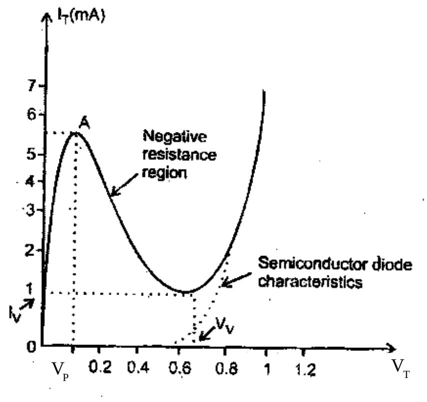


Fig 4.20 V- I CHARACTERISTICS

* Portion OA of characteristics is due to tunnelling phenomena.
* Current increases with increasing forward bias and reaches peak value I_p at forward voltage V_p.
* If V is increased beyond V_p, current decreases and reach minimum value I_v called **"VALLEY CURRENT"**
* Forward bias voltage at valley current I_v is called **"VALLEY VOLTAGE".**
* Tunnel diode exhibits negative resistance characteristic between peak current and valley current.

* For **forward bias** voltage above valley voltage, tunnel diode behaves like an ordinary diode.
* For **reverse bias,** tunnel diode conducts such that there is no breakdown effect.
* Reverse characteristics are similar to characteristics of resistor.

4.6.1 **APPLICATIONS: (May / June 2010 - 2 Marks)(May/June -2014-2Marks)**

* Relaxation Oscillators
* Microwave Oscillators
* Amplifiers
* Storage devices
* Pulse generator

4.6.2 **ADVANTAGES:**

→ Low cost
→ High speed
→ Low noise

4.6.3 **DISADVANTAGES**

* No isolation between input and output
* Low output voltage swing.

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4.7 LASER DIODE

(May /June 2010 - 2 Marks) (May /June 2014-8 Marks)

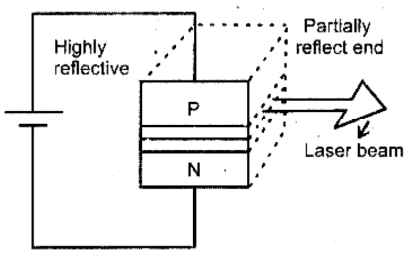

Fig 4.21 LASER DIODE

* LASER → **LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION**
* Laser diodes → Semiconductors which convert electrical signal to light.
* Constructed from **GaAlAs** (Gallium Aluminium Arsenide) for short wavelength devices and **InGaAsP**(Indium Gallium Arsenide Phosphide) for long wavelength devices.
* Conversion of electric current into light is efficient because it generates **little heat** compared to incandescent lights.
* This configuration is called as **MONOJUNCTION** since there is only one PN junction.

* **HETEROJUNCTION** is also possible if there are several closely spaced junctions formed by layers of P and N materials
* In the diagram, two ends of structure is flat and parallel with one end mirrored (highly reflective) and another end partially reflective.
* Length of the junction is related to wavelength of light to be emitted.
* Electrical input to laser diode is provided by special current controlled DC power supply.
* When junction is **forward biased**, recombination of free electrons with holes emits photons.
* Photons reflect back and forth between mirror surfaces.
* Region between mirror ends act like cavity which filters light and purifies its colour.
* Photons which bounce back and forth induce more recombinations which emits new photons. These new photons again induce more recombinations which emits more new photons. This creates **avalanche effect.**
* All photons which are generated emerge like a beam from partially reflected end.
* When temperature increases, threshold current increases.

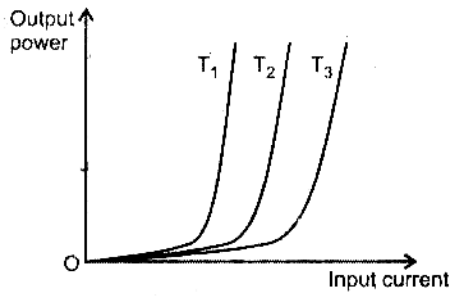

Fig 4.22 CURRENT -POWER CHARACTERISTICS

4.7.1 ADVANTAGES:

→ Compact
→ Efficient when compared to gas lasers
→ Long life

4.7.2 DISADVANTAGES:

* Require great care in drive electronics.
* Coherence length and monochromaticity are inferior.
* Most laser diodes are not suitable for holography.

4.7.3 APPLICATIONS:

* Used in CD players opearating at 780 nm (GaAs Laser diode)
* Used as Laser printers operating at 675 nm (AlGaAs Laser diode)
* Used in Super market checkout, UPC scanners, barcode scanners, CT and MRI scanners.

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4.8 LDR (LIGHT DEPENDENT RESISTOR

→ 2 terminal semiconductor device whose resistance varies as a function of intensity of incident light.

→ Also known as **"PHOTOCONDUCTOR".**

→ When there is no light, resistance of LDR is maximum.

→ This resistance **(DARK RESISTANCE)** is of the order of $100K\Omega$

→ When light intensity increases, LDR resistance decreases.

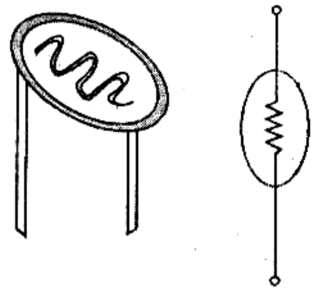

Fig 4.23 (a) CONSTRUCTION (B) SYMBOL

* Light sensitive material is arranged in zig-zag fashion on disc shaped base.
* Glass or plastic covers light sensitive material. Connections are made to lead pins at each end.

4.8.1 **WORKING :**

→ Valence and Conduction bands in semiconductor material are close to each other.

→ When light falls on semiconductor material, electrons are excited from valence band to conduction band.

→ Free electrons therefore increases and terminal resistance decreases.

Relation between resistance and illumination:

$$R = AE^{\alpha}$$

where $\alpha, A \rightarrow$ constants

E $\rightarrow$ Illumination

R $\rightarrow$ Resistance

4.8.2 LDR - CHARACTERISTICS:

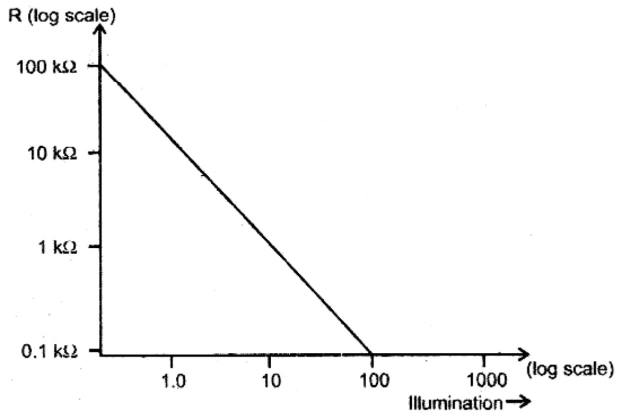

Fig 4.24 LDR CHARACTERISTICS

DISADVANTAGES:

→ Non Linearity
→ Poor sensitivity
→ Narrow Spectral response

4.8.3 **APPLICATIONS:**

* Shutter control in cameras
* Brightness control in TV receivers
* Control relays

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4.9 GALLIUM ARSENIDE (GaAs) DEVICE:

* Injection of electrons into the diode alters refractive index of active layer.
* Injected carriers creates weak, complex waveguide that confines light laterally. This device is called **"GAIN - GUIDED LASER"**
* Dielectric waveguide structures are fabricated in lateral direction.
* Variation in refractive index of various materials control **lateral modes** in laser. So they are called **"INDEX GUIDED LASERS"**
* If particular index - guided laser supports only fundamental transverse mode and fundamental longitudinal mode, it is known as **SINGLE -MODE LASER**

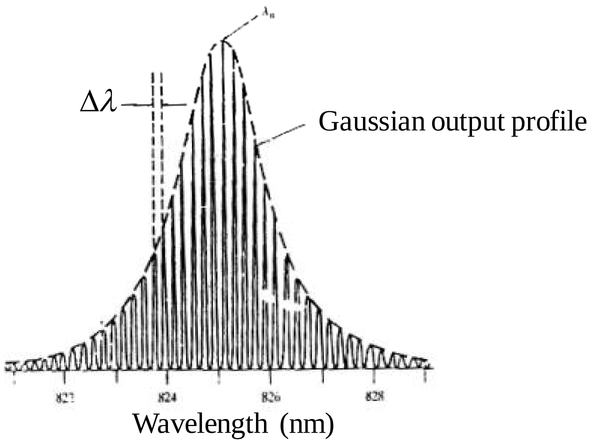
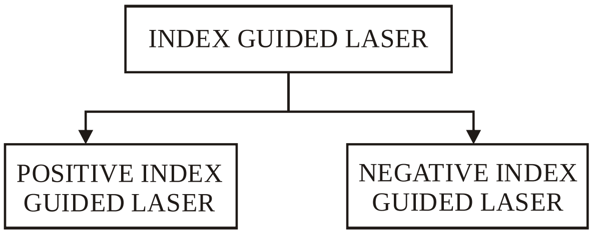


Fig 4.25 SPECTRUM FROM GAIN GUIDED GaAs LASER DIODE



* Central region has high refractive index than outer regions. * All of the guided light is reflected at dielectric boundary as that at the core - cladding interface.	* Central region of active layer has lower refractive index than outer region. * Part of the guided light is reflected at dielectric boundary and the rest is refracted into surrounding material and is lost.

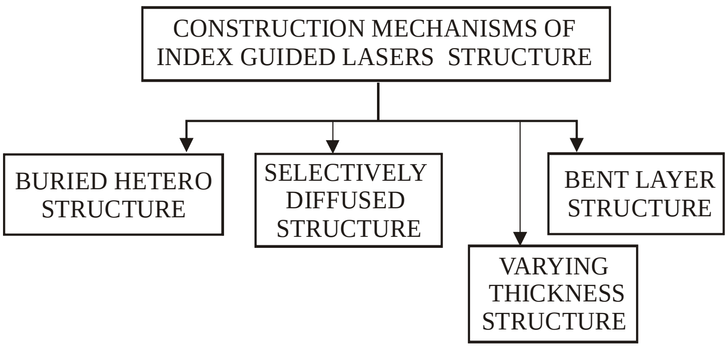


Fig 4.26 Short Wavelength (800-900 nm) GaAlAs & Long Wavelength InGaAsP buried heterostucture

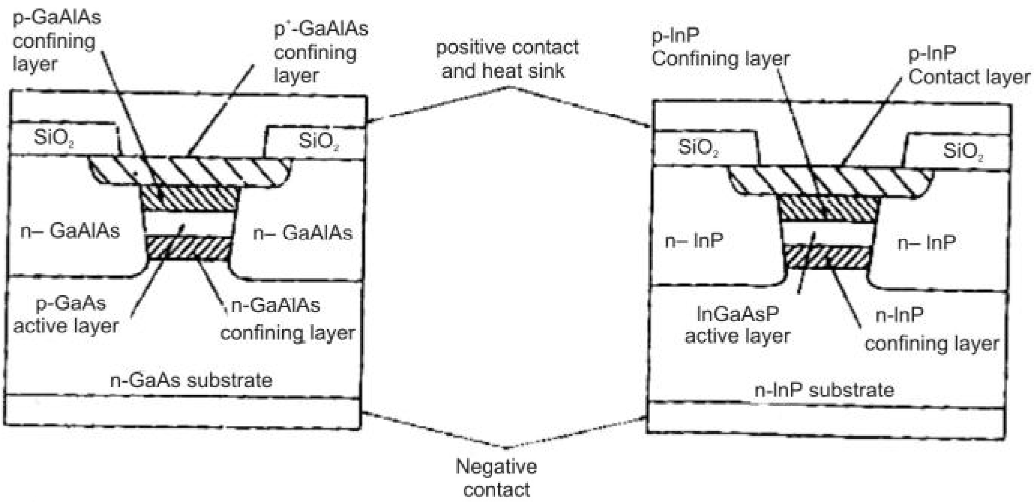


Fig 4.27 CONSTRUCTION MECHANISMS

* In **Selectively diffused construction**, Chemical dopant (**Zinc** for GaAlAs lasers and **Cadmium** for InGaAsP Lasers) is diffused into active layer below metallic contact stripe.
* Dopant changes refractive index of active layer to form lateral waveguide channel.
* In **Varying thickness structure,** channel is etched into substrate. This creates variations in thickness of active and confining layers.
* In **bent layer structure**, mesa is etched into substrate.
* When optical wave travels along flat top of mesa in active area, lower index material outside the bends confines the light along the lateral channel.

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REFERENCES
[1] Christo Ananth, S.Esakki Rajavel, S.Allwin Devaraj, P.Kannan. "Electronic Devices.", ACES Publishers, Tirunelveli, India, ISBN: 978-81-910-747-6-5, Volume 2,December 2014, pp:1-300.
[2] Christo Ananth, Vivek.T, Selvakumar.S., Sakthi Kannan.S., Sankara Narayanan.D, "Impulse Noise Removal using Improved Particle Swarm Optimization", International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE), Volume 3, Issue 4, April 2014, pp 366-370
[3] Christo Ananth, W.Stalin Jacob, P.Jenifer Darling Rosita. "A Brief Outline On ELECTRONIC DEVICES & CIRCUITS.", ACES Publishers, Tirunelveli, India, ISBN: 978-81-910-747-7-2, Volume 3,April 2016, pp:1-300.
[4] Christo Ananth, "Monograph On Semi Conductor Diodes", International Journal of Advanced Research in Biology, Ecology, Science and Technology (IJARBEST), Volume 1,Issue 3,June 2015, pp:40-63.
[5] Christo Ananth, "Monograph On Bipolar Junctions", International Journal of Advanced Research in Biology, Ecology, Science and Technology (IJARBEST), Volume 1,Issue 4,July 2015, pp:28-93.