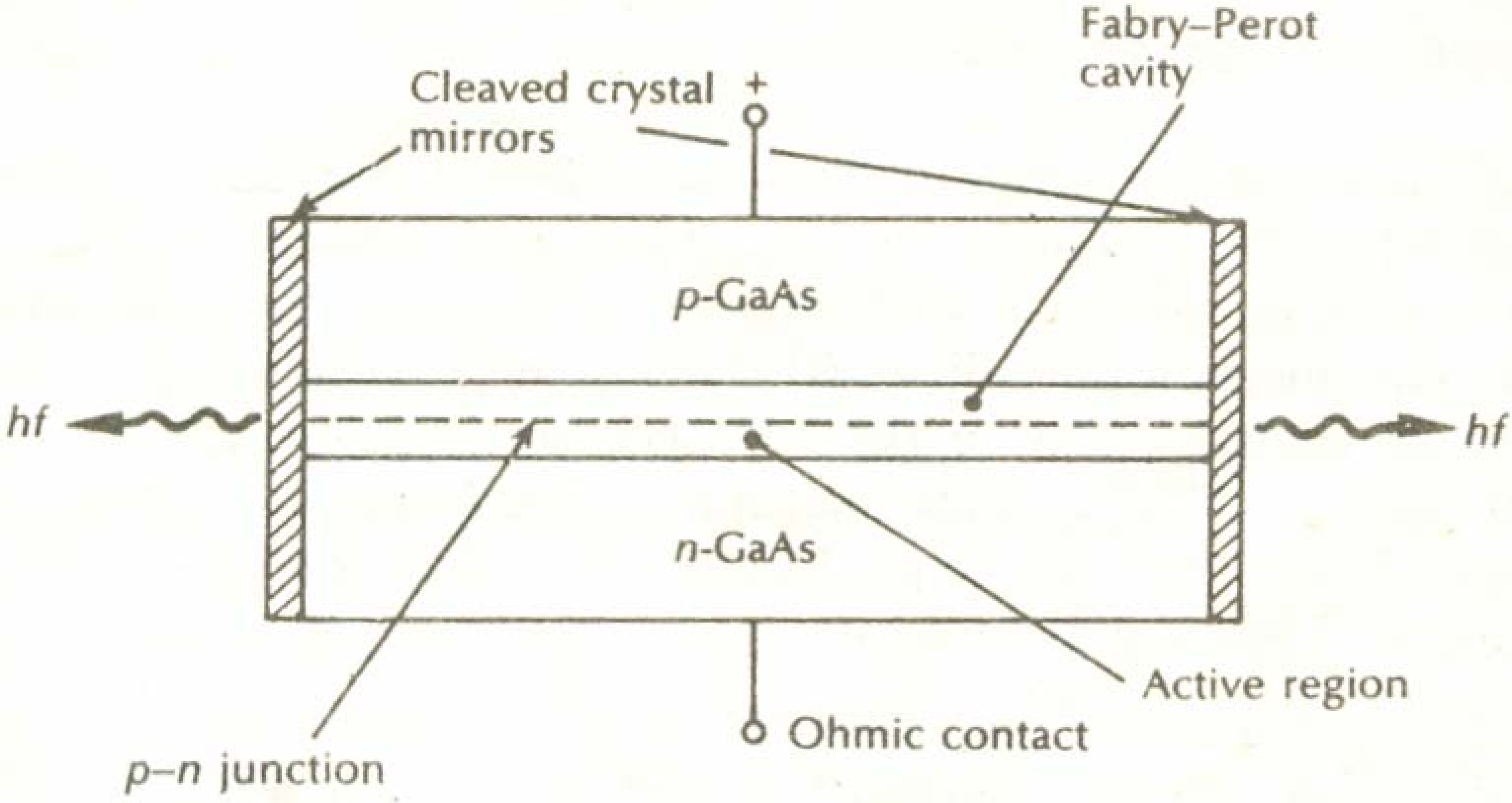
SEMI CONDUCTOR INJECTION LASER DIODE

Principle : Stimulated emission by recombination of injected carriers by provision of an optical cavity to provide the feed back of photons

Advantages of ILD :

1. High radiance (due to amplifying effect of stimulated emission).
2. Narrow line width (1 nm) & so less dispersion.
3. Better modulation capabilities.
4. More coherent & hence better focusing capability.
5. Better coupling efficiency of output power into optical fiber



GaAs homojunction injection laser with a Fabry – Perot cavity

EINSTEIN RELATIONS– LASER

- Atomic system is in thermal equilibrium, i.e. the rate of upward transitions must be equal to rate of downward transitions

N_1, N_2 = density of atoms in energy levels E_1 & E_2

g_1, g_2 = corresponding degeneracies (no of sub levels within energy levels E_1 , E_2)

$$N_1 / N_2 = g_1 e^{-E_1/KT} / g_2 e^{-E_2/KT}$$

$$= g_1/g_2\, e^{(E_2 - E_1)/KT} = g_1/g_2\, e^{hf/KT} \qquad (1)$$

where $E_2 - E_1$ = hf = energy of 1 photon

K- Boltzmann's constant, T= abs. temp.

ρf – spectral density, B_{12} – Einst. coefft. of absorption

R_{12} = rate of upward transition = $N_1 \rho f B_{12}$

$(R_{12} \propto N_1 \rho f)$

R_{21} = downward transition rate = sum of spontaneous and stimulated contributions

$$R_{21} = N_2 A_{21} + N_2 \rho f B_{21}$$

where A_{21}= Einst. Cofft.of spontaneous emission = $1/t_{21}$

t_{21} = spontaneous life time

For thermal equilibrium, $R_{12} = R_{21}$

$$N_1 \rho f B_{12} = N_2 A_{21} + N_2 \rho f B_{21}$$

$$\rho f (N_1 B_{12} - N_2 B_{21}) = N_2 A_{21}$$

$$\rho f = N_2 A_{21} / N_1 B_{12} - N_2 B_{21} = (A_{21} / B_{21}) / (N_1 B_{12} / N_2 B_{21}) - 1$$

Putting $N_1/N_2 = g_1/g_2\ e^{hf/Kt}$ from = n(1)

$\rho f = (A_{21}/\ B_{21})/(g_1\ B_{12}/g_2 B_{21})\ e^{hf/Kt}\ -1$

$\rho f= (A_{21}/B_{21})/[\ (g_1 B_{12}/g_2\ B_{21}) e^{hf/Kt}\ ] - 1$ = radiation density from a black body.

Radiation density for a black body (Planck's Result)

$\rho f = 8\pi\ hf^3/c^3(1/\ e^{hf/\ KT} - 1\ )$ (A)

Comparing the above two results

$(A_{21}/B_{21})/(g_1 B_{12}/g_2\ B_{21}) e^{hf/KT} - 1 = 8\pi\ hf^3/c^3\ (1/\ e^{hf/\ KT} - 1)$

$A_{21}/B_{21} = 8\ \pi\ hf^3/\ c^3$ **(B)**

$(g_1 B_{12}/g_2\ B_{21}) e^{hf/KT} - 1 = e^{hf\ /Kt} - 1$

$(g_1 B_{12}/g_2\ B_{21}) = 1$ or $B_{12} = (g_2/g_1)\ B_{21}$

If $g_1 = g_2$, $B_{12} = B_{21}$

Einstein Coefft. of absorption = Einstein coefft of stimulated emission

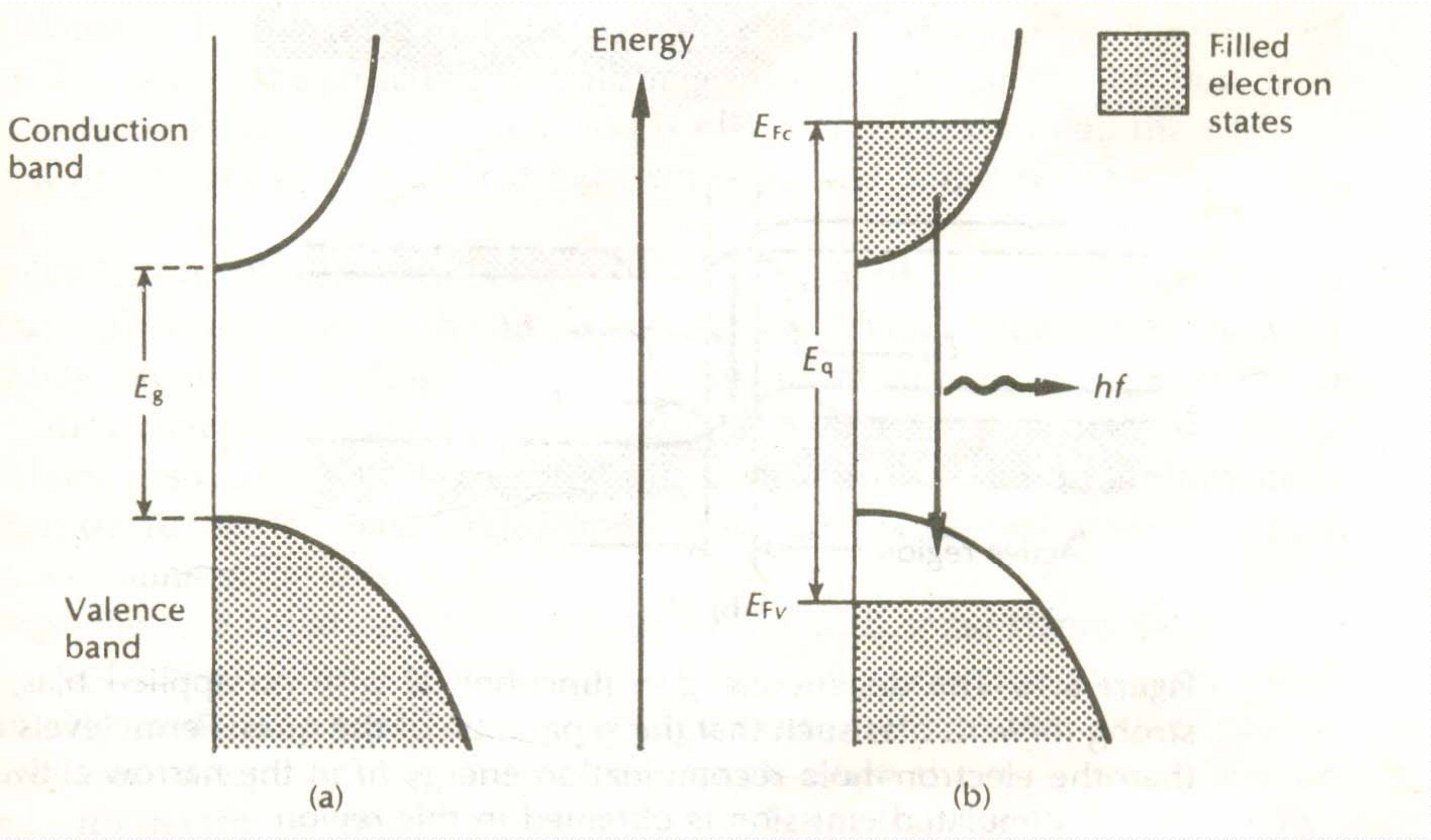
From = n A and= n B

$\rho f = A_{21}/ B_{21} (1/ e^{hf /KT} - 1)$

Or $B_{21} \rho f / A_{21} = (1/ e^{hf / KT} - 1)$

= stimulated emission rate / spontaneous emission rate

STIMULATED EMISSION & LASING:



The filled electron state for an intrinsic direct band gap semiconductor at absolute zero (a) in equilibrium (b) with higher carrier injection

At Abs. zero temperature, conduction band contains no electrons.

Incident photons with energy Eg (< Efc – Efv) can't be absorbed

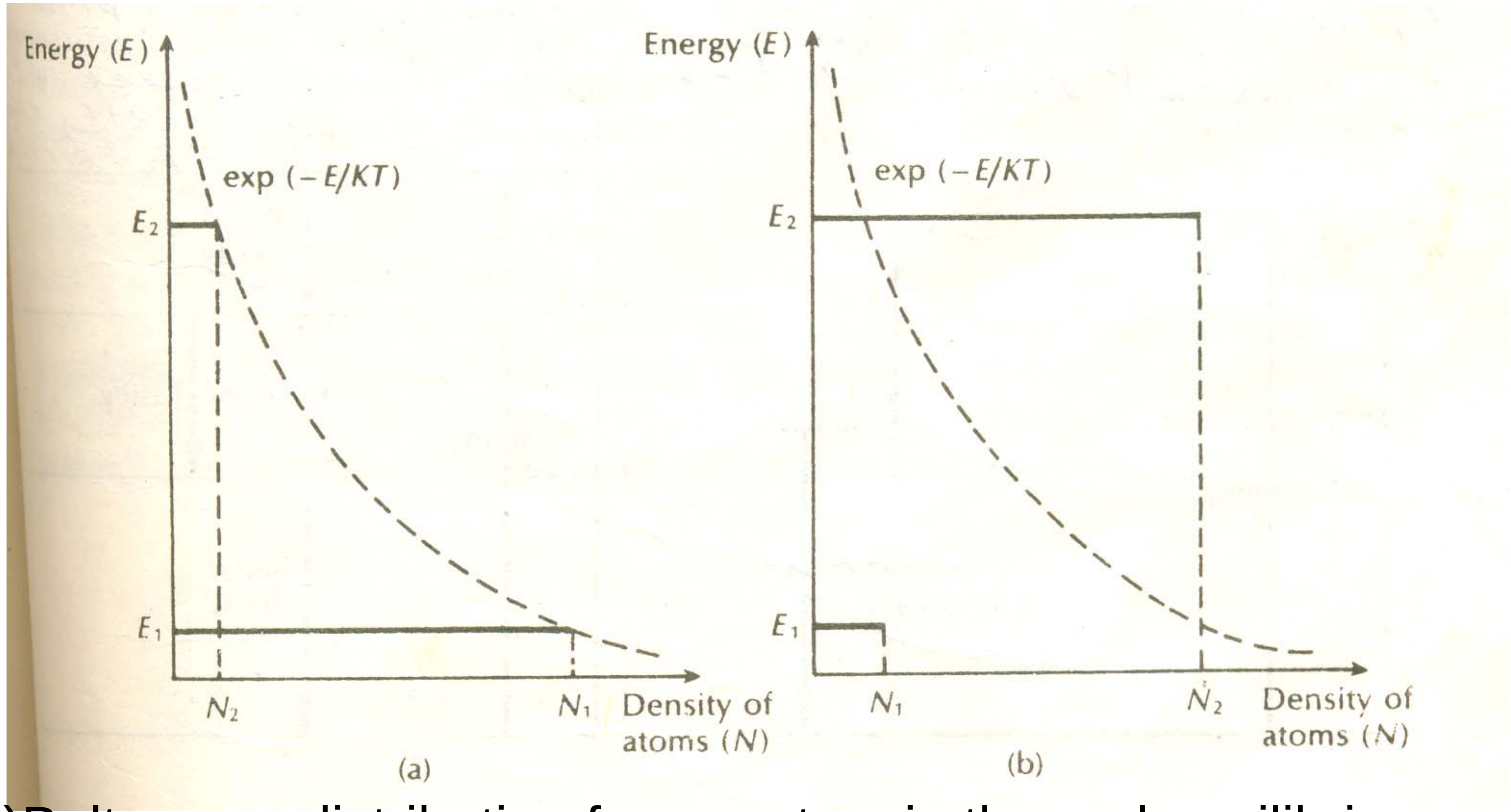
These photons induce downward transition of an electron and thus stimulated emission of another photon.

Basic condition for stimulation : $E_{fc} - E_{fv} > hf > Eg$

Heavy doping satisfies the above condition in a p-n junction thereby providing stimulated emission whereas in a normal p-n junction only spontaneous emission takes place **(LED**).

Another condition (for pn diode) to establish lasing is the provision of optical feedback to give laser oscillation (Fabry – Perot Cavity)

POPULATION INVERSION



(a)Boltzmann distribution for a system in thermal equilibrium;
(b) a nonequilibrium distribution showing population inversion

FOR OPTICAL **AMPLICATION** : $N_2 > N_1$

(to increase the rate of stimulated emission.)

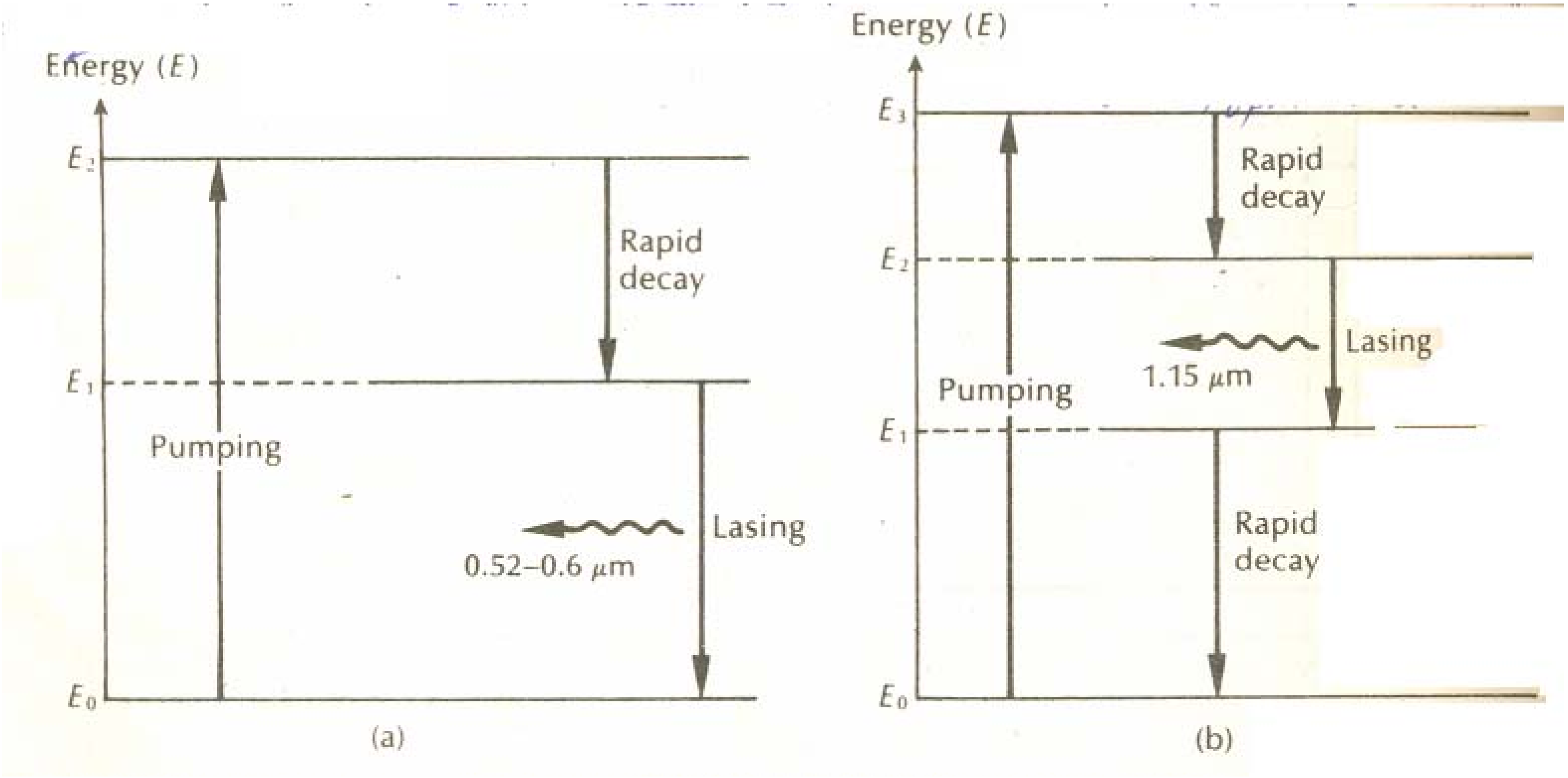
PUMPING :An external energy source is used to excite atoms into the upper energy state, thereby obtaining condition of population inversion.

- Intense radiation from a HF radio field or an optical flash tube is applied.
- The two level system does not lend itself to suitable population inversion.
- From = n $B_{12} = (g_2/g_1)B_{21}$

At best $B_{12} = B_{21}$(when $g_1 = g_2$) which means prob. of absorption and stimulated emission are equal ($N_1 = N_2$)

- Hence the necessity to use three or four energy level to obtain population inversion.

THREE AND FOUR LEVEL SYSTEMS - POPULATION INVERSION



Energy level diagrams showing population inversion and lasing for two non-semiconductor lasers: (a) three level system — ruby (crystal) laser; (b) four level system — He—Ne (gas) laser.

Both systems display a central metastable state in which atoms spend an usually long time.

Stimulated emission (lasing) takes place from this metastable state.

With pumping, electrons move from E_0 to E_2 state.

Electrons rapidly decay by non- radiative process to either E_1 or E_0, providing empty states in E_2.

Thus density of atoms in metastable state N_1 increases above the ground state N_0.

$N_1 > N_0$ (population inversion) – LASING

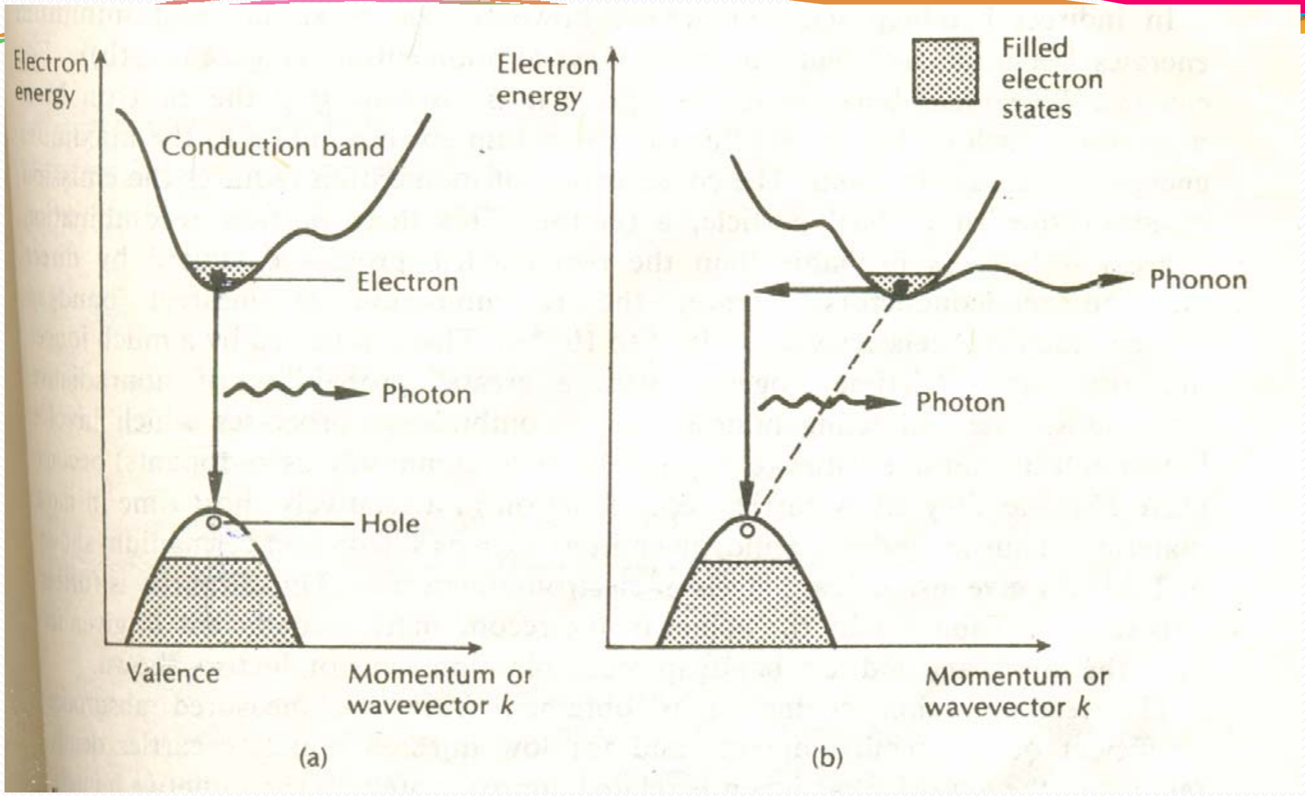
- *Three level system requires high pump powers*

Four level system

- Pumping excites atoms from E_0 to E_3, and they decay rapidly to meta stable level E_2

Since population of E_3 and E_1 remain essentially unchanged a small increase in no of atoms in E_2 creates population inversion hence lasing takes place between E_2 & E_1

- **FOUR LEVEL SYSTEM HAS MUCH LOWER PUMPING REQUIREMENTS**



Energy — momentum diagrams a) direct bandgap semiconductor
; (b) indirect bandgap semiconductor.

Recombination is slow in indirect BG semiconductor

Thus competing non – radiative recombination process becomes more likely(due to impurities/ defects)

DIRECT & INDIRECT BANDGAP SEMICONDUCTORS

Therefore indirect band gap materials give insignificant levels of electroluminescence

$p= 2\pi hk$

Avg minority carrier lifetime$=10^{-8}$ to 10^{-10} sec(DBGSC)

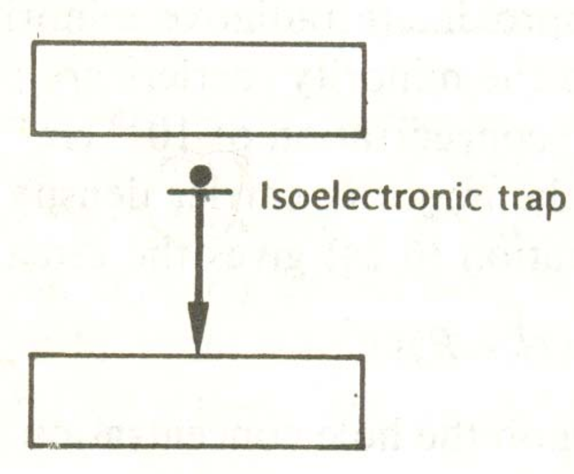
$=10^{-2}$ to 10^{-4} sec(IDBGSC)

Material	Energy Band gap (eV)	Recom.coefft.	
GaAs	Direct: 1.43	7.21 × 10-10	cm3s-1
GaSb	Direct : 0.73	2.39×10^{-10}	
InAs	Direct : 0.35	8.5×10^{-11}	
InSb	Direct : 0.18	4.58×10^{-11}	
Si	Indirect : 1.12	1.79×10^{-15}	
Ge	Indirect : 0.67	5.25×10^{-14}	
GaP	indirect : 2.26	5.37×10^{-14}	

Addition of impurity center (N_2) to GaP, indirect BG material converts it into a direct BG material

Nitrogen :- ISOELECTRONIC IMPURITY

(As it has the same no of valance electrons as Phosphorus)



Nitrogen impurity center captures an electron and acts as an ISOELECTRONIC trap which has a large spread of momentum.

Nitrogen :- ISOELECTRONIC IMPURITY

- This trap attracts the oppositely charged carrier (hole) and a direct transition takes place between impurity centre and valence band. **GaP + N_2 becomes an efficient light emitter**. The carrier lifetime is effectively reduced.

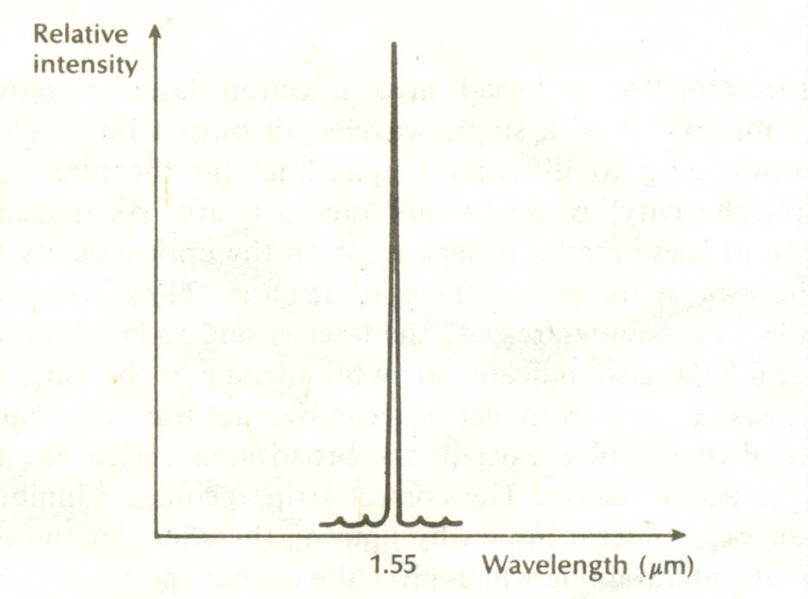
SINGLE MODE OPERATION :

The spectral width of the emission from the single mode device is far smaller than the broadened transition line width, which occurs due to

a) emission over a small frequency band instead on a single frequency.

b) frequency variations due to thermal motion of atoms -Doppler broadening

c) due to atomic collisions



Typical single longitudinal mode output spectrum from a single-mode injection laser.

OBTAINING A SINGLE MODE OPERATION .

This can be done by reducing the length of the cavity, L until frequency of separation $\delta f = c/2nL$ is larger than the laser transition line width or gain curve. Then only the single mode which falls within the transition line width can oscillate within the laser cavity.

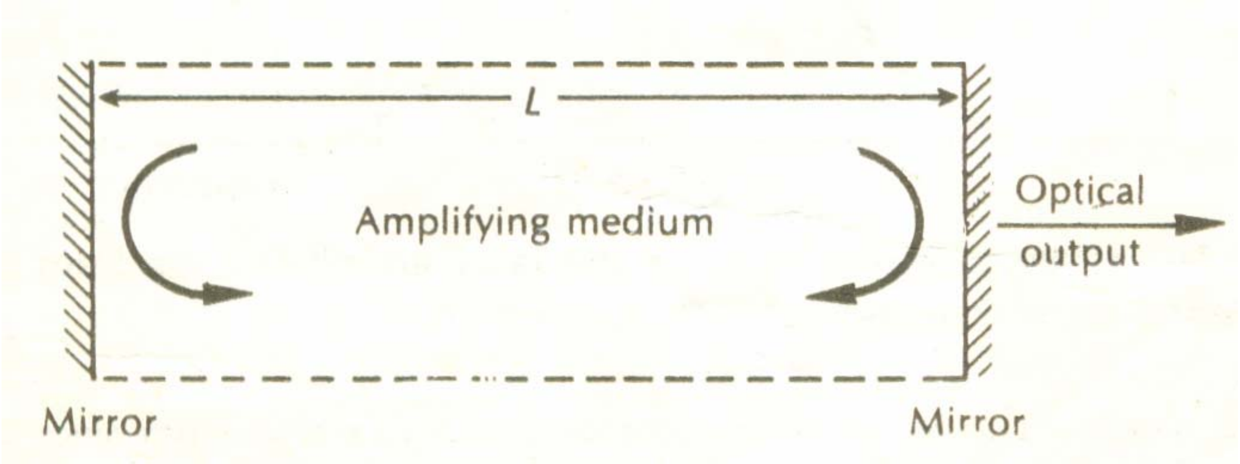
Note : Injection lasers with short cavity lengths (=50 μm) are difficult to handle and have not been very successful.

OPTICAL FEEDBACK AND LASER OSCILLATION

Light amplification in laser occurs due to a photon colliding with an atom (in the excited energy state) to cause stimulated emission of a second photon. Then both these photons release two more.

CONTINUATION OF THIS PROCESS CREATES AVALANCHE MULTIPLICATION.

When em waves associated with these photons are in phase, amplified coherent emission is obtained.



The basic laser structure incorporating plane mirrors

The optical cavity formed provides positive feedback of photons by reflection at the mirrors. The structure acts as a FABRY – PEROT resonator.

One mirror is made partially transmitting for useful radiation to escape from cavity.

THRESHOLD CONDITION FOR LASER OSCILLATION

CONDITIONS FOR LASER OSCILLATION

- Population inversion
- Threshold gain within the amplifying medium (to initiate and sustain the laser oscillation).

Let α = loss coefficient per unit length.

r_1, r_2 = reflectivities of two mirrors.

Fractional loss incurred on each round trip of the beam = $r_1 r_2 e^{-2 \alpha L}$

Fractional gain = e^{2gL} (due to stimulated emission)

where g = gain coefficient per unit length

Hence $e^{2gL} \times r_1 r_2 \, e^{-2\alpha L} = 1$

$r_1 r_2 \, e^{2L(g-\alpha)} = 1$

Or $e^{2L(g-\alpha)} = 1/r_1 r_2$ or $2L\,(g-\alpha) = \log 1/r_1 r_2$

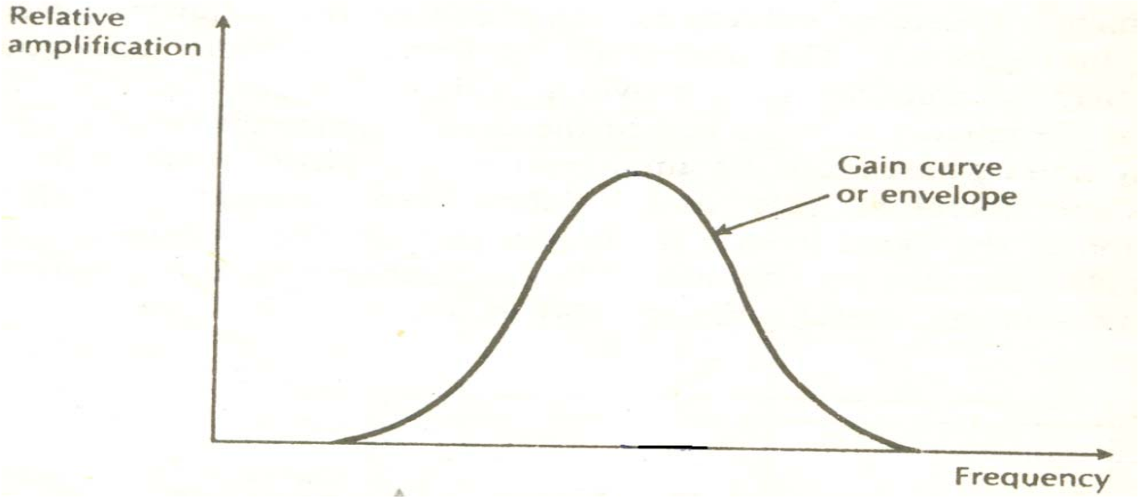
$(g-\alpha) = 1/2L[\log 1/r_1 r_2]$

$g = l/2L\,[\log 1/r_1 r_2] \qquad + \alpha$

(trans. loss thr’ mirrors)

LASER OSCILLATION (contd)

- O/P is stable when gain matches losses
- Losses – Absorption & scattering in amp. medium as well as mirrors.
  - Diffraction & other losses (non- useful transmission) thr' mirrors.
- The laser emits over a narrow spectral band



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- LASER OSCILLATION (contd)

- Standing waves are formed between mirrors which exist when distance between mirrors is an integral no of $\lambda/2$
- $L = q\,\lambda/2n = qc/2nf$ [n – ref. index, q – an integer]
- Or $f = qc/2nL$ [various q values correspond to each resonance/mode]
- **Mode separation** $\boldsymbol{\delta f = c/2nL}$ $\{q=1\}$
- $\boldsymbol{\delta\lambda} = \lambda\,\delta f/f = \lambda^2\,\delta f/c = \boldsymbol{\lambda^2/2nL}$

RATE EQUATIONS FOR ELECTRON & PHOTON DENSITY

$dn/dt = (J/ed) - (n/\tau sp) - Cn\,\phi$ ($m^{-3}\,s^{-1}$)---- A

$d\phi/dt = Cn\phi + \delta . n/\tau sp - \phi/\tau\, ph$ ($m^{-3}\,s^{-1}$)---- B

where τsp = spontaneous emission life time($\cong \tau_{21}$)

C= coefficient. (eqvt. to B coefficients)

δ= fractional value

τ ph = photon life time

Eq A : first term indicates increase in electron concentration as the current flows. Second and third terms refer to lost electrons due to spontaneous and simulated transitions.

- Eq B : First term depicts stimulated emission. Second term is due to photons (fraction only) due to spontaneous emission. The third term refers to the **Decay** in the number of photons **due to losses in the optical cavity**.

For steady state dn/dt & d ϕ/dt should be zero.

From = n (B) d $\phi/dt = \phi(Cn - 1/\tau ph)$ when $\delta = 0$

d ϕ/dt must be positive when ϕ is small.

Note : ϕ represents the field in the optical cavity which must build up from small initial values

$\therefore Cn - 1/\tau ph \geq 0$

Therefore n has a threshold value which satisfies

above = n

n (threshold) = 1/C τph (m^{-3}) ---- = n (1)

= n(A) $\mathbf{dn/dt = J/ed - n / \tau_{sp} - Cn\phi}$

For steady state (when $\phi = 0$) at threshold current

$\mathbf{0 = J_{th}/ed - n_{th} / \tau_{sp}}$ or $\mathbf{J_{th} / ed = n_{th} / \tau sp}$ –©

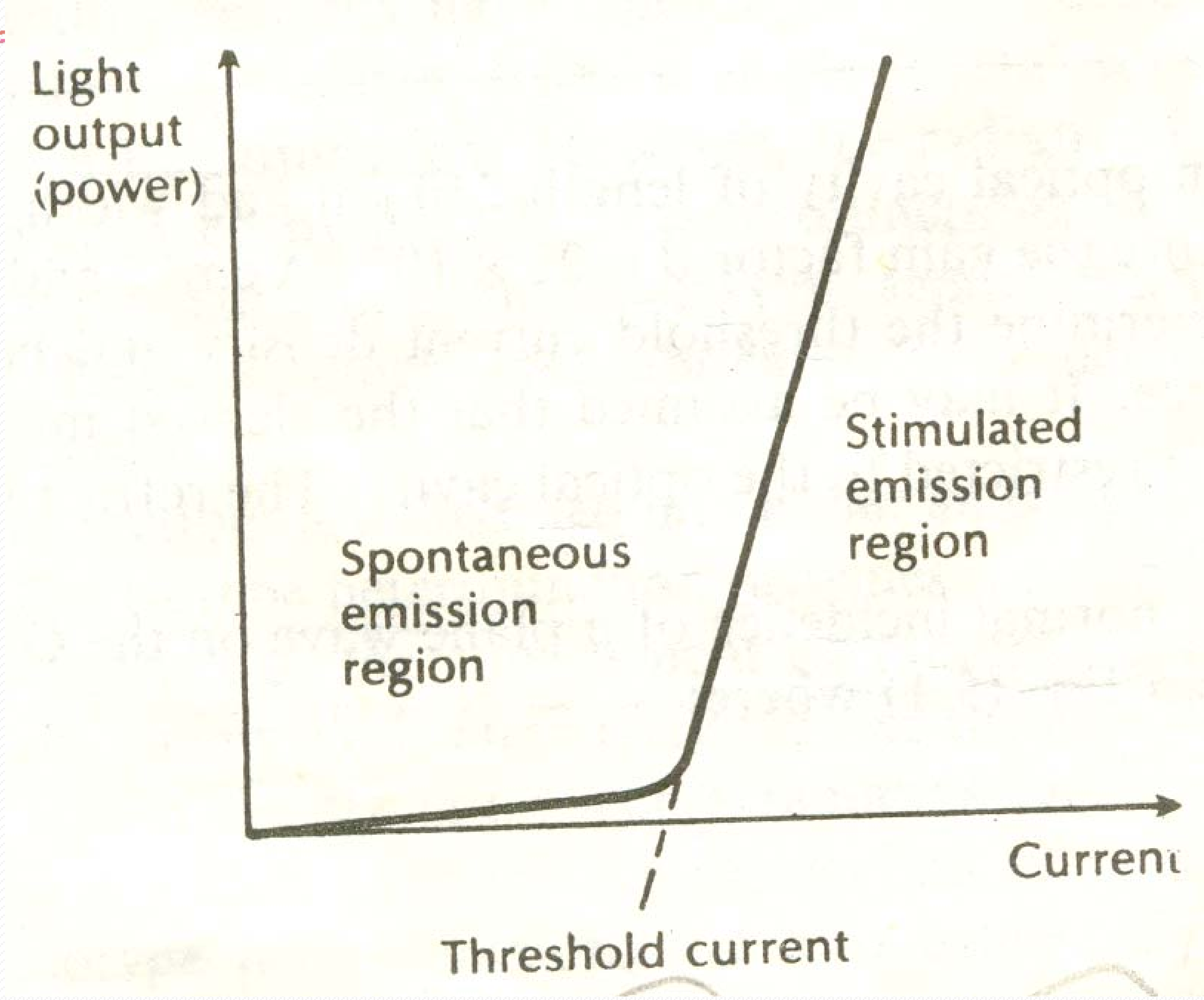
Substituting (C) in (A), to find steady state photon density (ϕs)

$\mathbf{0 = J/ed - J_{th}/ed - Cn_{th}\phi s}$

$\mathbf{\therefore \phi s = [J - J_{th}]/ed . 1/C n_{th}}$

But $\mathbf{C n_{th} = 1/ \tau_{ph}}$ from = n (1)

$\mathbf{\phi s = \tau_{ph}(J - J_{th})/ed}$ (m^{-3})



Characteristics (Light o/p vs Current)

EFFICIENCY OF SEMICONDUCTOR LASER

Differential Quant. $\eta_D = \dfrac{\text{increase in photon output rate}}{\text{(given) increase in no. of inj. electrons}}$

$$= \mathbf{(d\ Pe\ /\ hf\ )/\ d\ (I/e)}$$

η_D is a measure of rate of change of opt. o/p power with current and hence defines the slope of output characteristic .

η_D = slope quantum η= 40 to 60%

ηi =Internal Quant. Efficiency=

$\dfrac{\text{no .of photons produced in laser cavity}}{\text{no of injected electrons}}$

Total η(Ext. quant. η)= $\dfrac{\text{total no of output photons}}{\text{total no of inj electrons}}$

\-

$= (Pe/ hf)/ I/e = Pe/I\ Eg$ (A)

$I > I_{th}$ (normally)

$\eta t = \eta d[\,1- I_{th} / I\,] = \eta\, d[$ when $I >> I_{th}]$

External power η(device η)

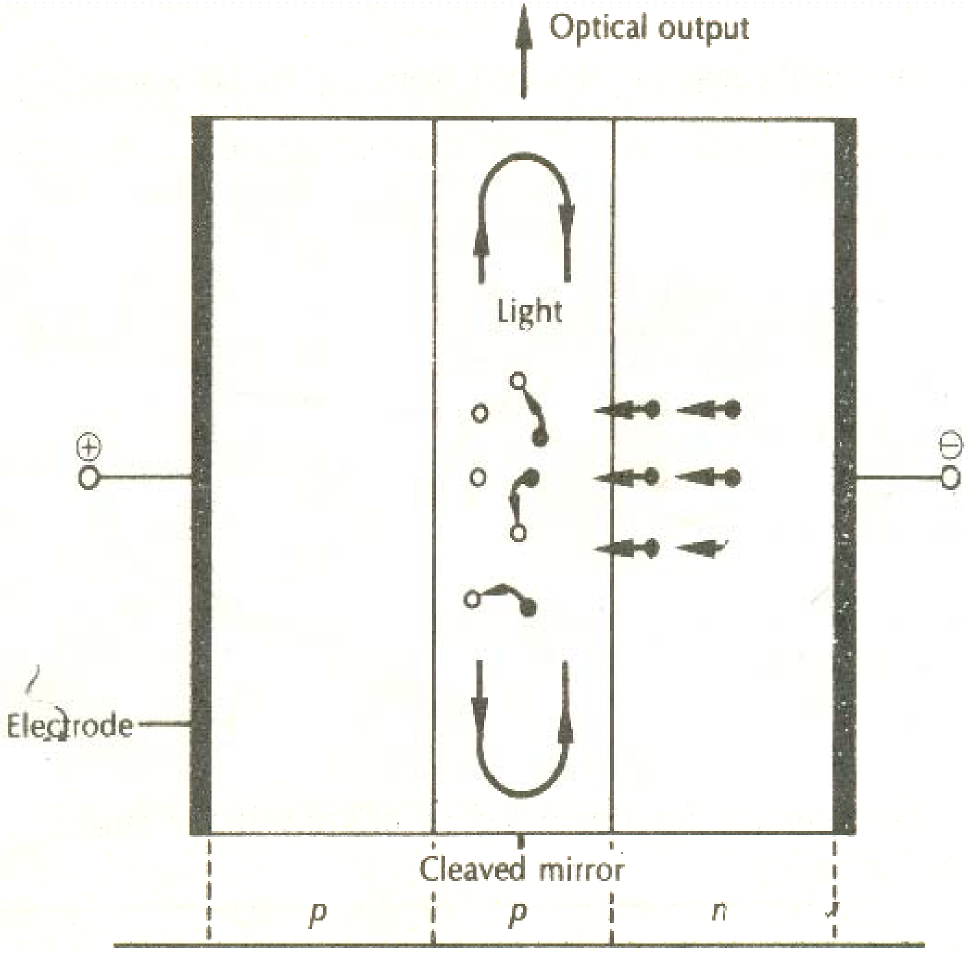
$\eta_{ep} = (Pe\ (o/p))/ P(i/p) \times 100 = Pe /IV \times 100\%$

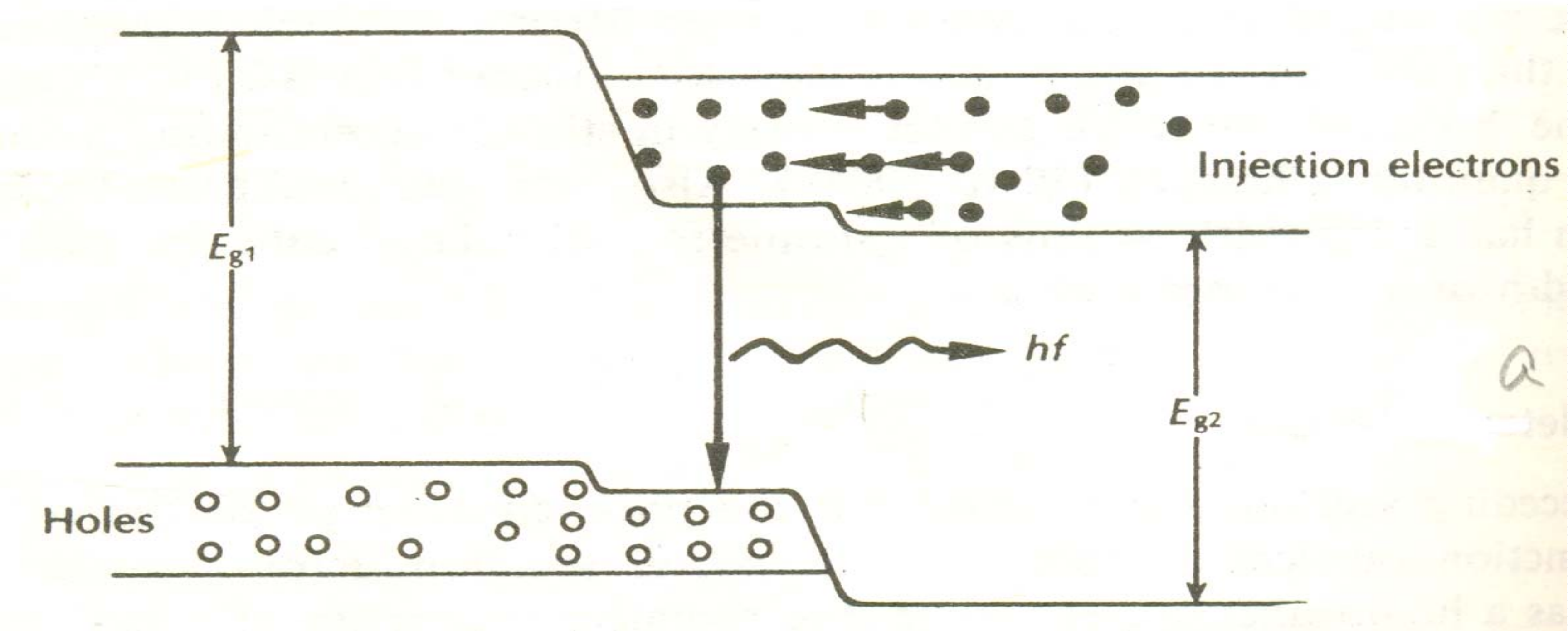
Where $P= IV$ = DC elect. Input power

Using (A) $\boldsymbol{\eta_{ep} = \eta t\ (Eg/V) \times 100\ \%}$

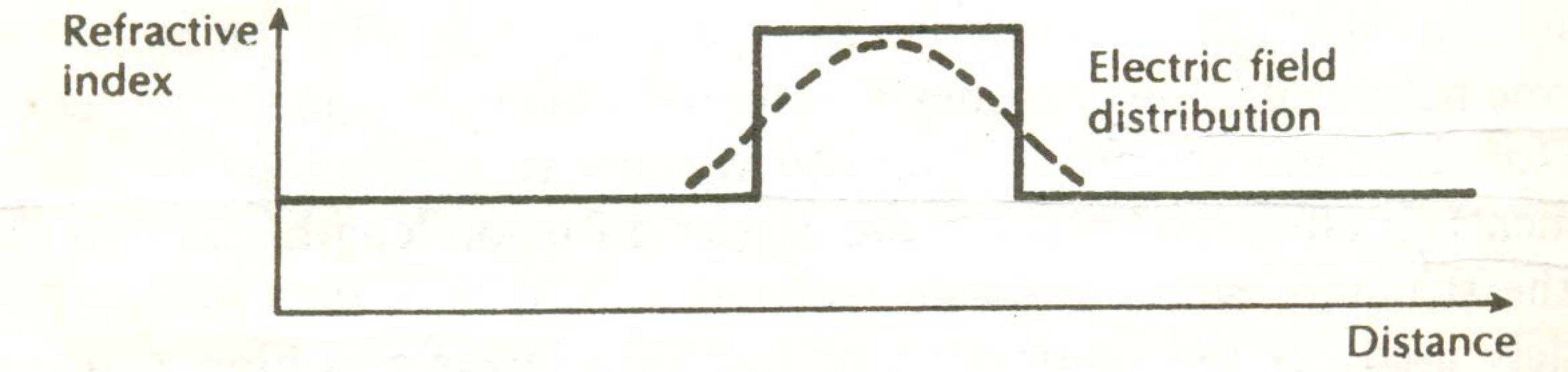
DOUBLE HETRO JUNCTION INJECTION LASER

HETRO JUNCTION : Hetro junction is an interface between two adjoining single crystal semi conductors with different band gap energies.





Energy band diagram indicating p-p heterojunction on the left and p-n heterojunction on the right.



The corresponding refractive index diagram and electric field distribution.

HETRO JUNCTION may be n-n or p-p (isotype) or p – n (anisotype)

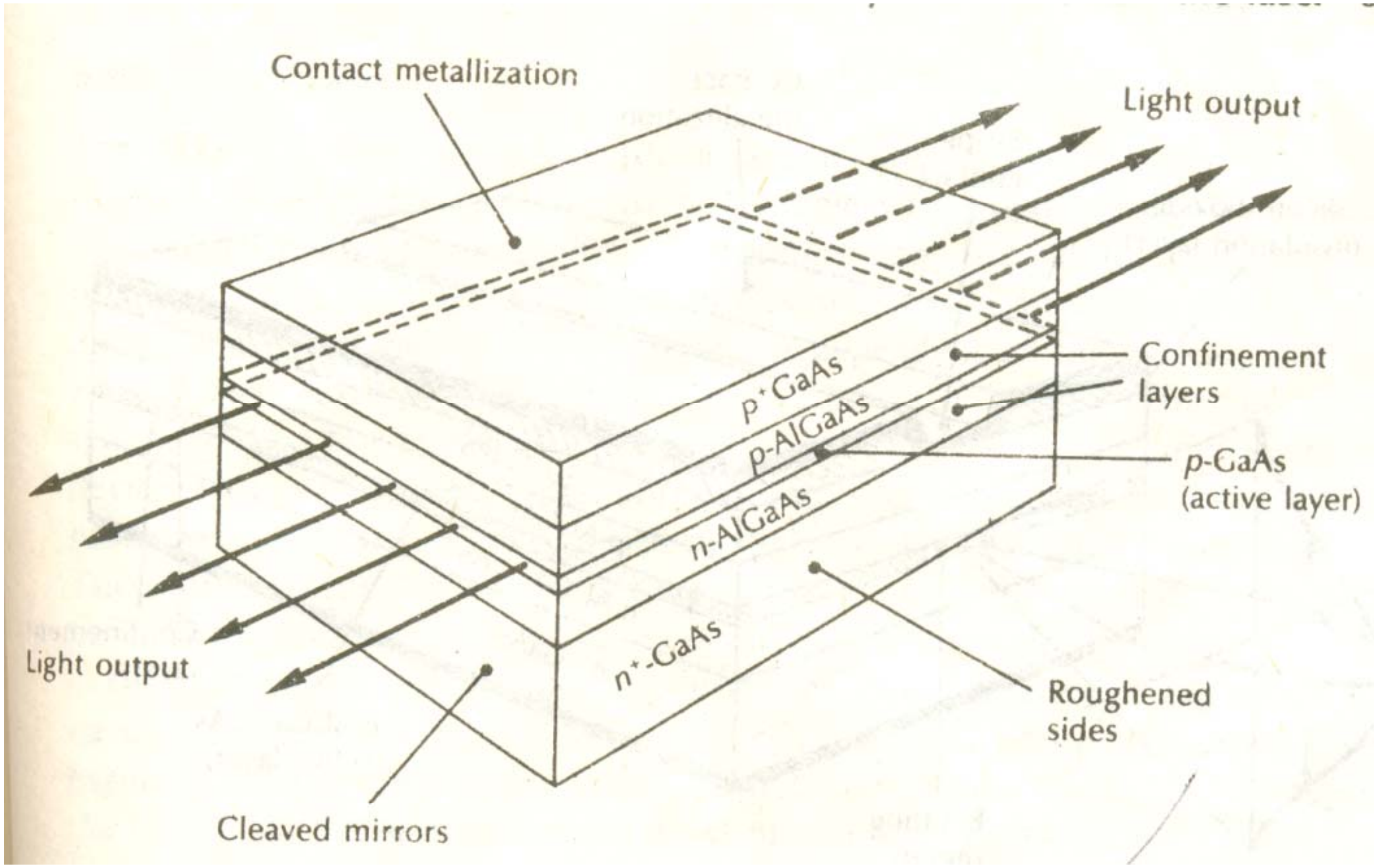
Isotype HJ helps in carrier confinement to a small active region, there by reducing the vol. where rad. recomb. take place.

Anisotype HJ improves the injection η of electrons / holes

Both type of HJ provide a di-electric step due to diff. refractive indices at either side of the junction.

Double hetro junction structure (a) reduces the threshold current necessary for lasing (50-200 mA)

(b) prevents losses due to lack of wave guiding



A broad area GaAs/AlGaAs DH inj. Jaser.

- Lasing takes place across whole width
- DH structure provides optical confinement

  thr' ref. index step at hetro junction interfaces (in vertical direction)

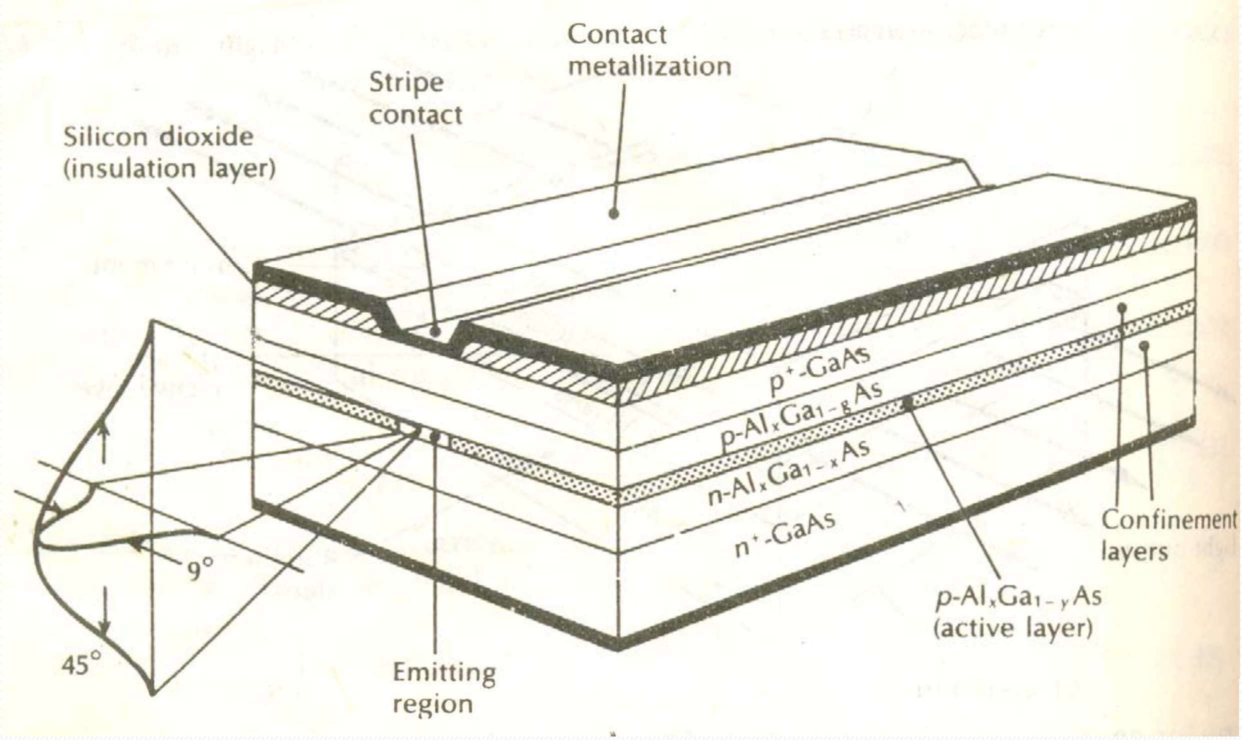
DISADVANTAGES - BROAD AREA DEVICE

- **Difficult heat sinking.**
- **Lasing from wide area.**
- **Difficulty in efficient coupling to fibers.**
- **These problems have been overcome in laser structures in which the active region does not extend to the edges of the device.**
- **Introduction of Stripe geometry structure provides optical containment in the horizontal plane.**

OXIDE STRIPE AL GaAs DH INJECTION LASER

- Major current flow thr’ the device and hence the active region is within the stripe.
- The stripe acts as a guiding mechanism which overcomes the major problems of the broad area device.
- Output beam divergence is 45^0 perpendicular to the plane of the Junction & 90^0 parallel to it.
- Stripe contact device gives single mode operation whereas broad area device gives multimode operation.–

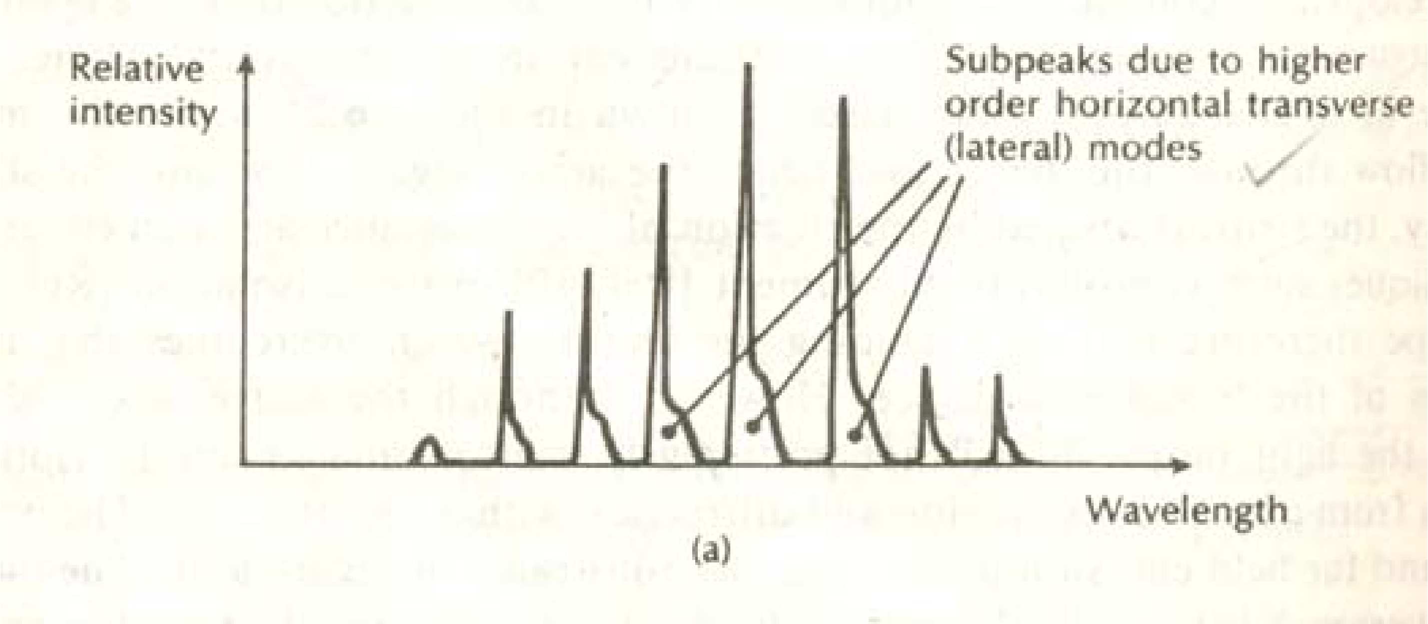
OXIDE STRIPE ALGAAS DH INJECTION LASER



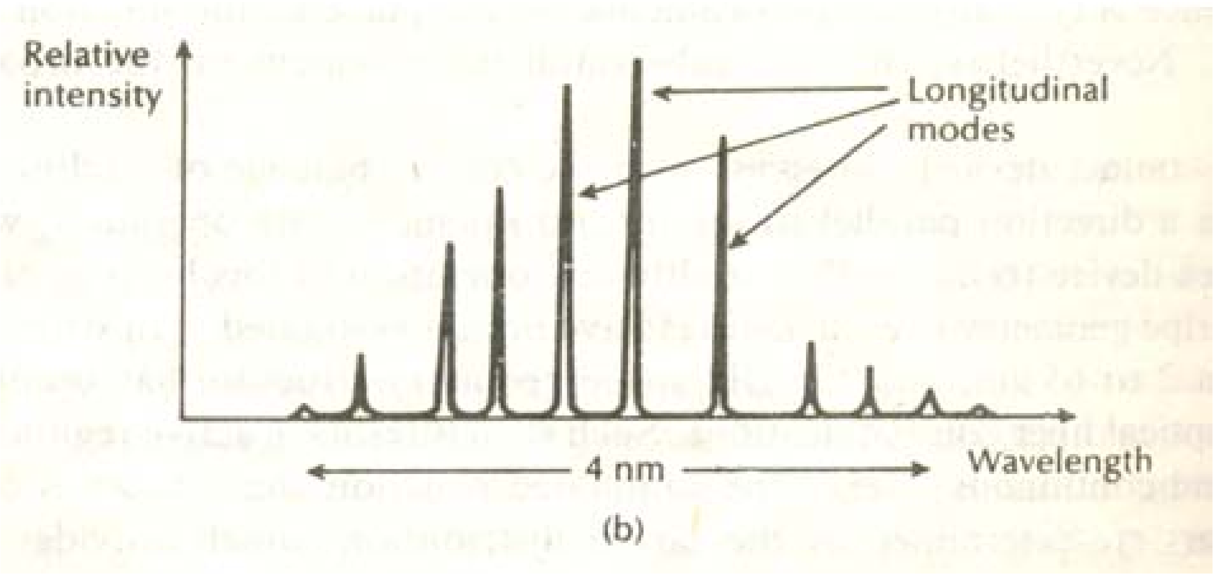
An oxide stripe AlGaAs DH injection laser.

Typical stripe width range = 2 – 65 µm
DH structure gives active regions which are planar & continuous.

OUTPUT SPECTRA FOR MULTIMODE INJECTION LASER



Broad area device with multitransverse modes

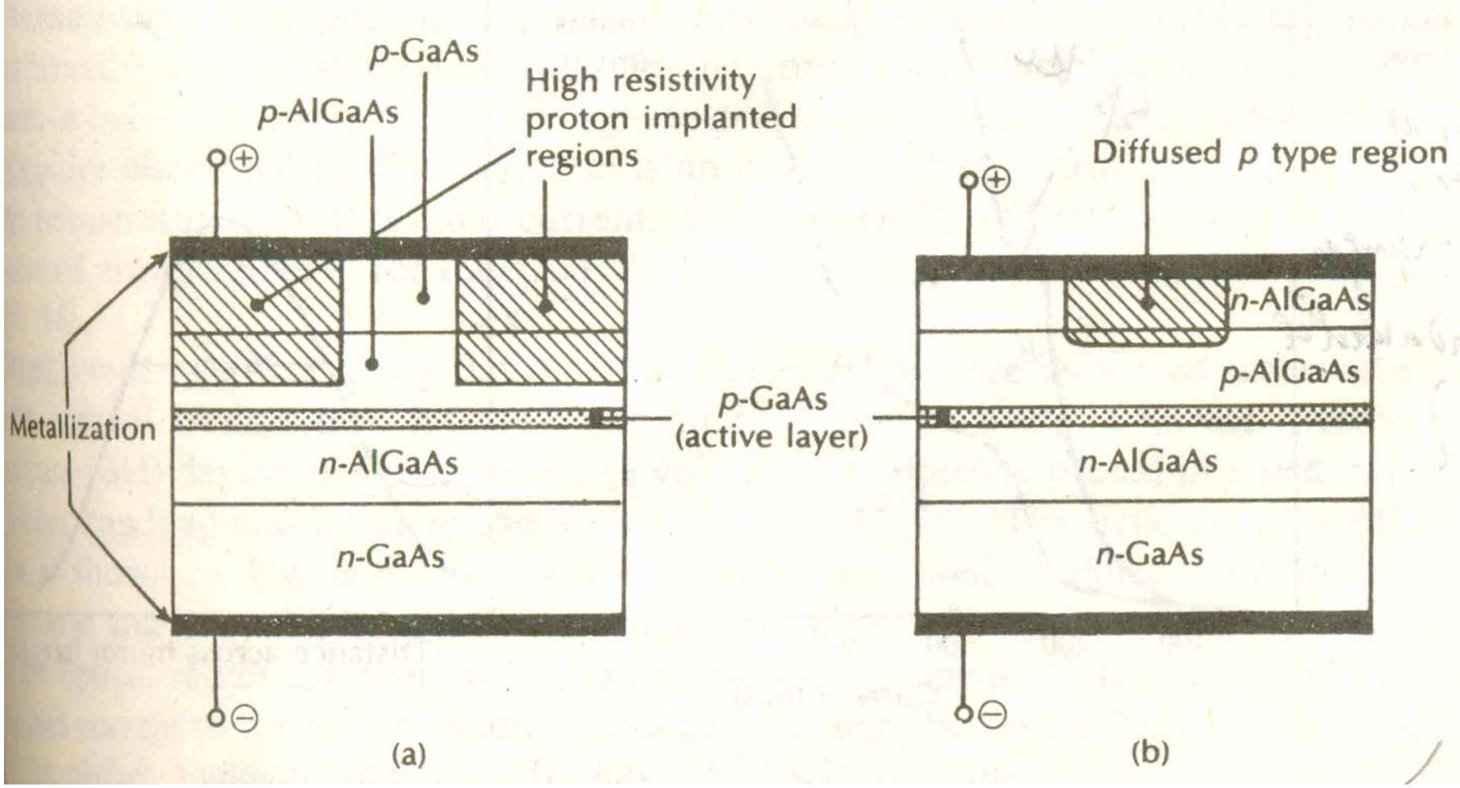


(b) **stripe geometry device with single transverse mode**.

The correct stripe geometry inhibits the occurrence of higher order lateral modes by limiting the width of the optical cavity leaving only a single lateral mode, which gives the output spectrum as shown above.

Note : Transverse modes are perpendicular to the junction plane.

- Laser modes : Spacing of modes depend on optical cavity length.
- Modes are separated generally by a few tenths of a nm.
- Higher order modes are due to unrestricted width of active region in Broad Area Device :



Structures for stripe geometry injection lasers:
(a) proton isolated stripe GaAs/AIGaAs laser; (b) p—n junction isolated (diffused planar stripe) GaAs/AIGaAs laser.

GAIN GUIDED LASERS-STRIPE GEOMETRY

The resistive region formed by proton bombardment gives better current confinement and has superior thermal properties due to absence of SiO_2 layer.

p-n junction isolation involves a selective diffusion thr' the n type surface region in order to reach the p- type layers.

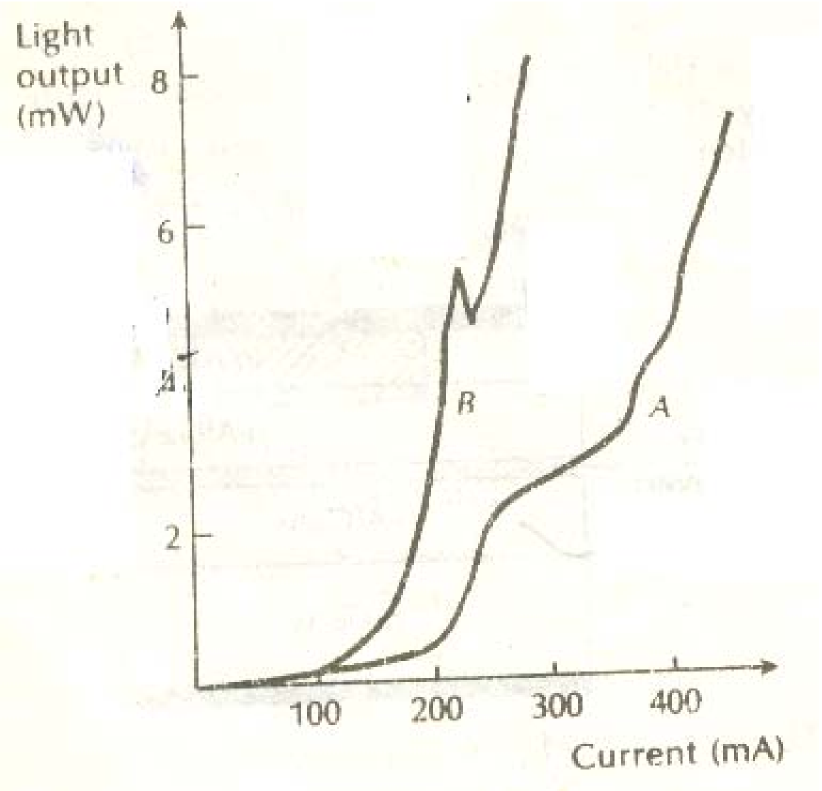
Radiation & current is not confined to stripe region and spreading occurs on both sides of the stripe.

GAIN GUIDED LASERS (contd)

With stripe width of 10 µm or less, such planar stripe lasers provide highly efficient coupling into multimode fibers.

Coupling η is lower for small core dia single mode fibers

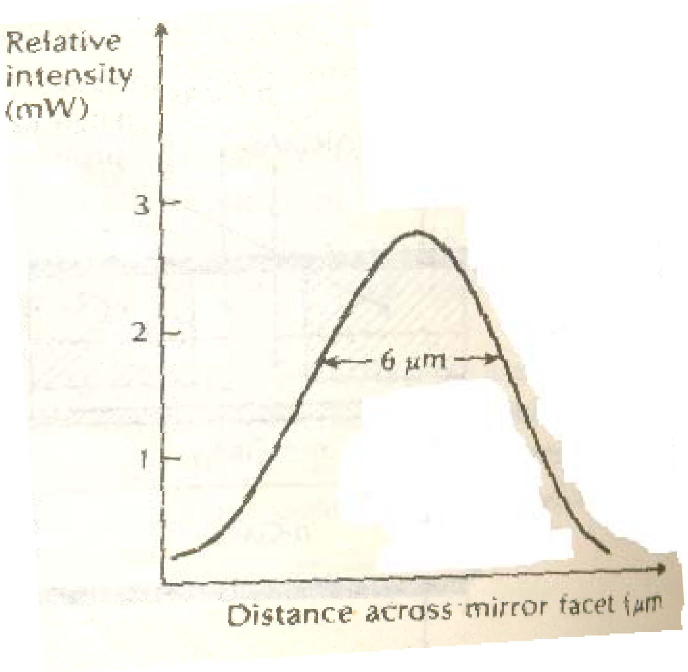
Gain guided injection lasers have higher threshold currents (100 – 150 mA) as well as low differential quantum η.



Curve A: **lasing from the device changes from a fundamental lateral mode to a higher order mode in a current region corresponding to change in slope**.

Curve B**: these spikes are associated with defects within the crystal structure**

Both type of kinks affect near and far field intensity distribution.



A typical near field intensity distribution (pattern) in the plane of the junction..

FIG shows the typical near field intensity distribution (pattern) in the plane of junction for the injection laser.

The single intensity max. indicates that fundamental lateral mode is dominant.

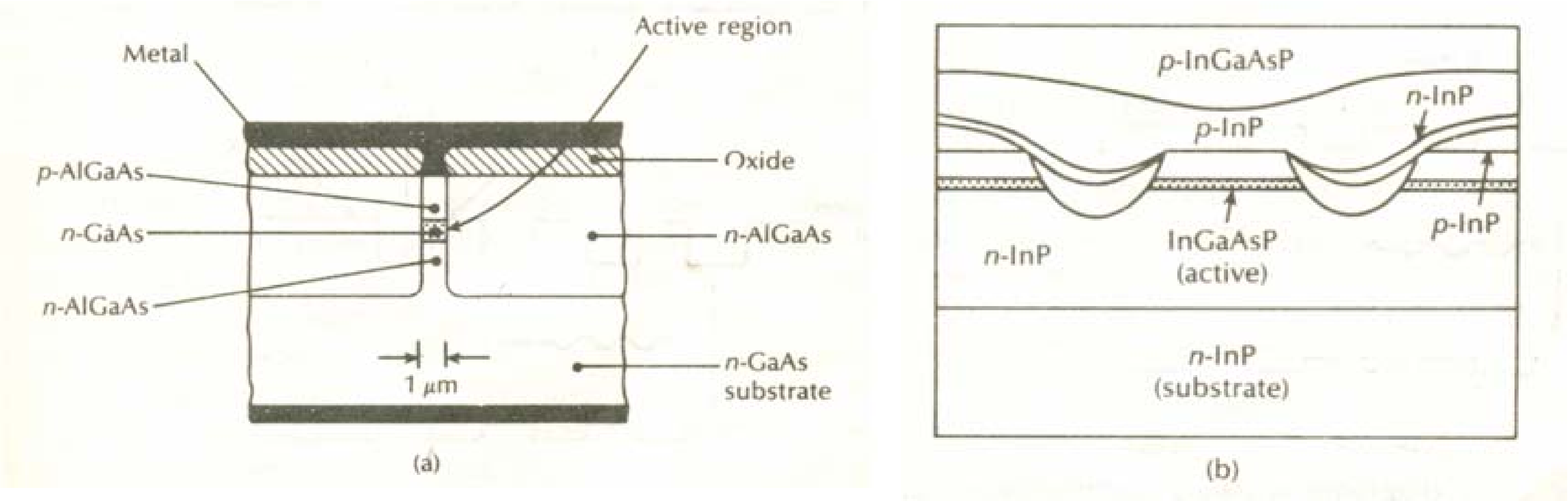
For narrow stripe devices (< 10 μm) the fundamental lateral mode dominates.

DISADVANTAGES OF GAIN GUIDED LASERS.

- Non linearity (kinks)
- High threshold current(100 to 150 mA)
- Low differential quantum efficiency.

BURIED HETROSTRUCTURE LASER STRUCTURES.

This structure provides improved transverse mode control thr' strong index guiding along Junction plane.



(a) GaAs/AlGaAs BH device;

(b) InGaAsP/InP double channel planar BH device.

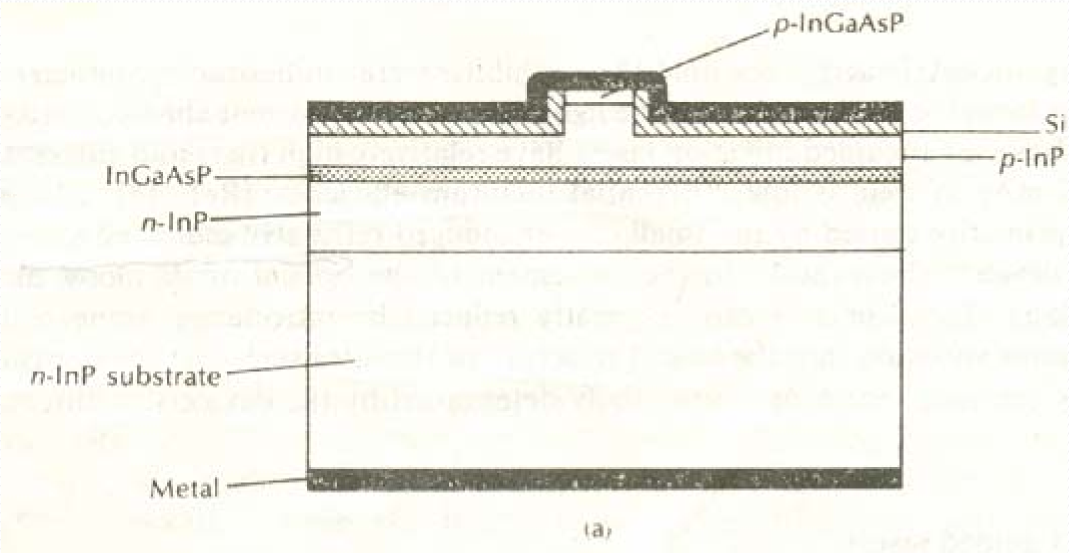
BURIED STRUCTURE LASERS (contd)

- Active volume is completely buried in a material of wider band gap and lower ref. index.
- Carrier confinement is improved and so the opt. field thr. RB junction of higher band gap energy
- These structures offer multimode and single mode operation.

BURIED STRUCTURE LASERS (contd)

- I_{TH} =10 to 20 mA.
- Power o/p= 40mW at 15 to 20 mA at room temp.
- (DCPBH)-active region (0.3 μm^2) provides fundamental mode of operation.
- Modulation speed achievable > 20 GHz.

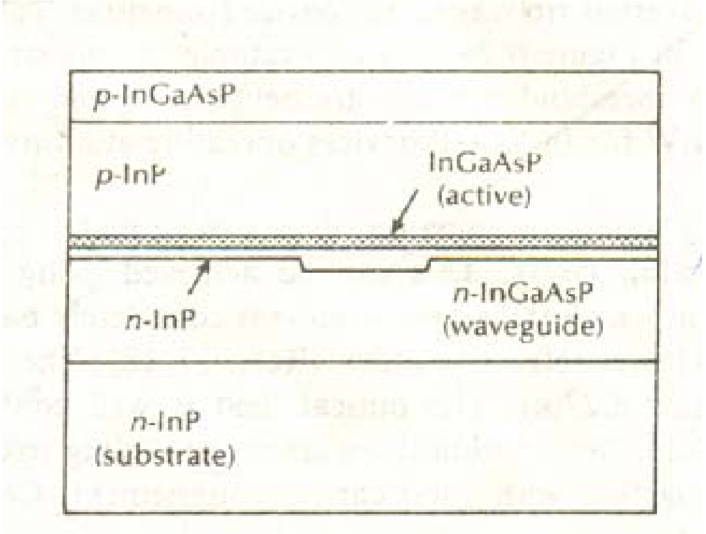
INDEX GUIDED LASERS:



A: Ridge acts as narrow current confining stripe.
I th = 40 to 60 mA (Typical)

-Can operate with single lateral mode

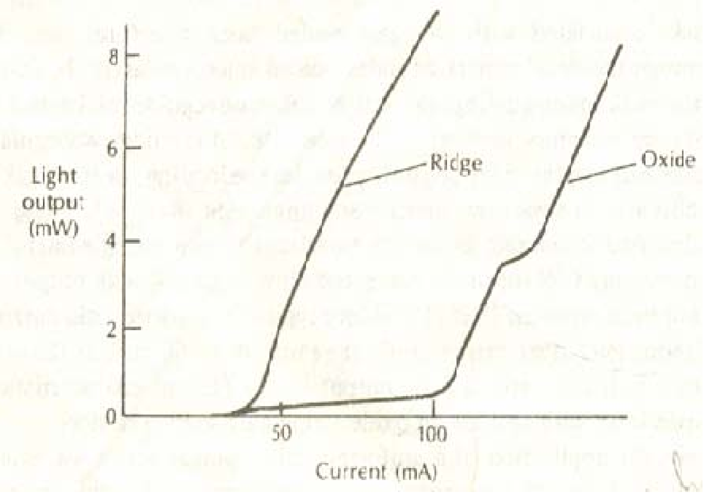
POWER O/P=25 mW (at Ith=18 mA at room temp.)



B: This structure provides variation in current confinement layer thickness (refractive index variation)

I th =70 to 90 mA

P output=20mW(at Ith at room temp) at 1.3 µm wavelength

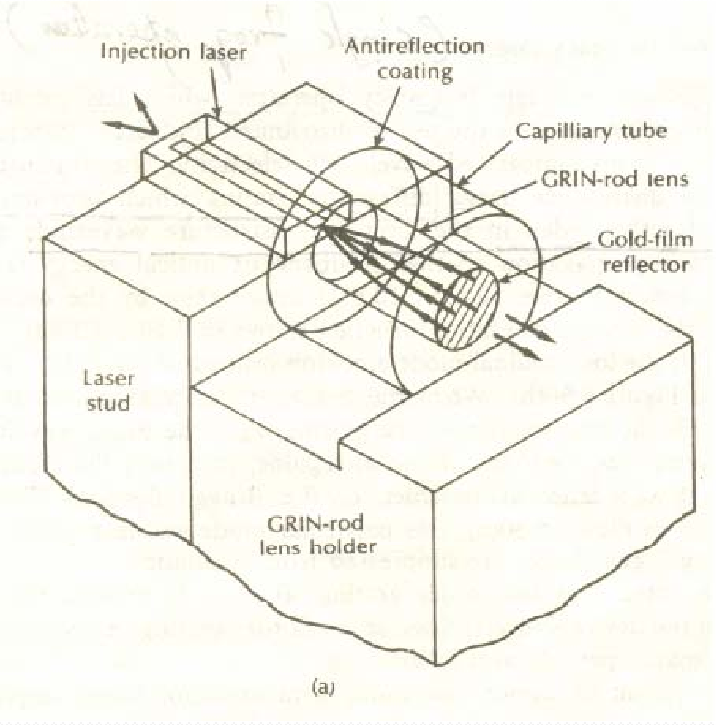


COUPLED CAVITY LASER

Single mode operation is achieved by shortening the length of the cavity so that only a single longitudinal mode falls within the gain bandwidth of the device.

Shortening the length from 250 to 25 µm will have the effect of increasing the mode spacing from 1 to 10 nm.

FIG : **grin rod lens is used to enhance coupling to an external mirror**



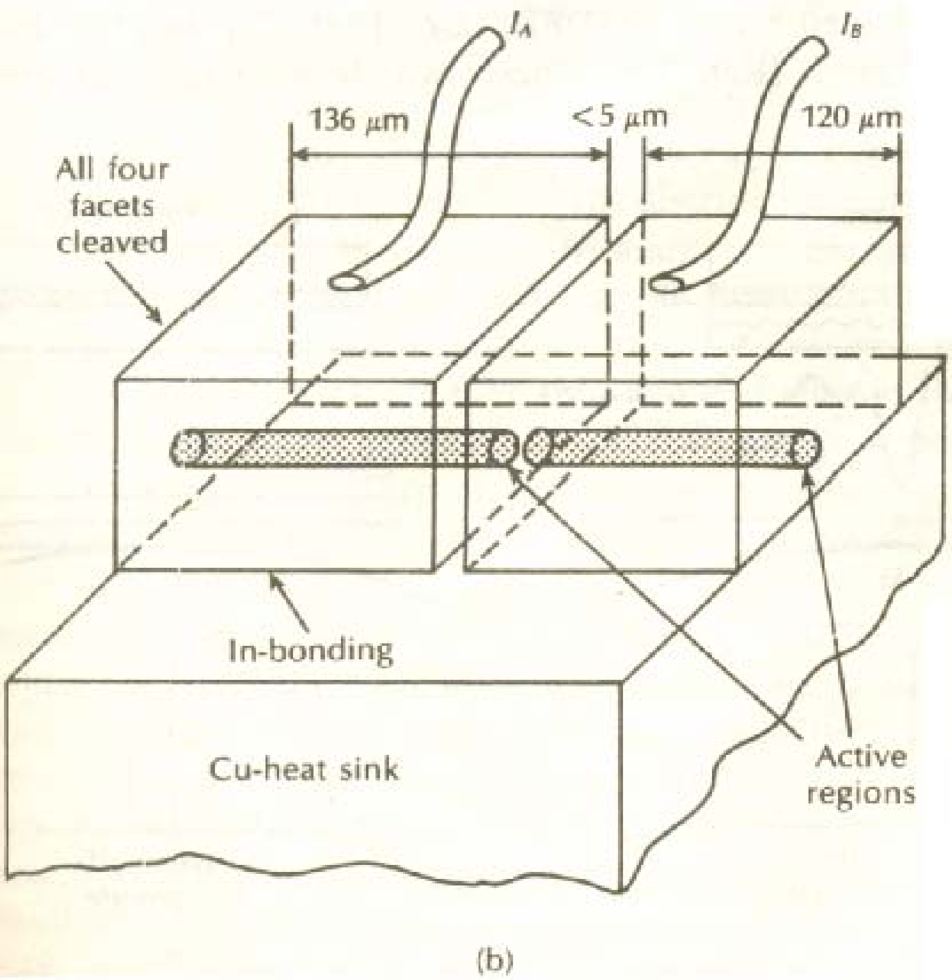
SHORT EXT. CAVITY LASER USING GRIN ROD LENS

COUPLED CAVITY LASER

- Conventional cleaved mirror structures are difficult to fabricate with cavity lengths below 50 µm.
- Configurations employing resonators have been utilized.
- Such resonators form a short cavity length of 10 to 20 µm thereby providing single mode operation.
- Both the cavities shown in the three mirror resonator (previous slide) are in resonance

FIG B: two active laser sections are separated by a λ gap.

It yields **cleaved coupled cavity (C3) laser**.



CLEAVED COUPLED CAVITY LASER (contd)

This four mirror resonator device provides single mode operation with side mode suppression achieved thr’ control of magnitude & phases of two Inj. Currents as well as temp.

Single freq. emission can be tuned over a range of some 26 nm by varying the current thr’ one section.

NON- SEMICONDUCTOR LASER

The Nd: YAG laser

Nd: YAG structure-(YTTRIUM-ALUMINIUM-GARNET) = $Y_3 Al_5O_{12}$

DOPED WITH NEODYMIUM(Nd^{3+}),

(RARE EARTH METAL ION)

Max doping level=1.5 %

PROPERTIES :

1) Suitable source for single mode systems (near 1.064 & 1.32 μm wavelength)
2)Narrow line width (<0.01 nm). So less dispersion
3)Long life time
4)Reduced size (dimension)

DRAW BACKS :

1)external Opt. modulator is necessary
2) Technology not developed fully as in semiconductors
3) High Cost due to pumping & modulation

END PUMPED Nd : YAG LASER

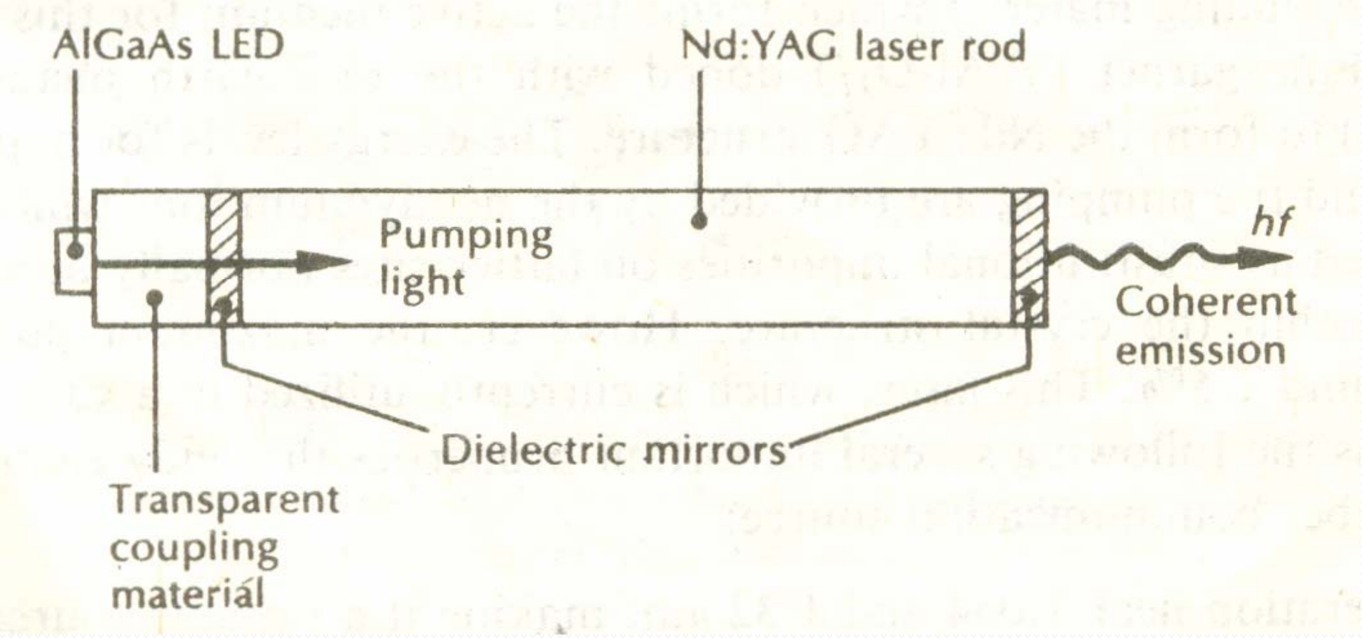


Diagram of an end pumped Nd:YAG laser.

END PUMPED Nd : YAG LASER(contd)

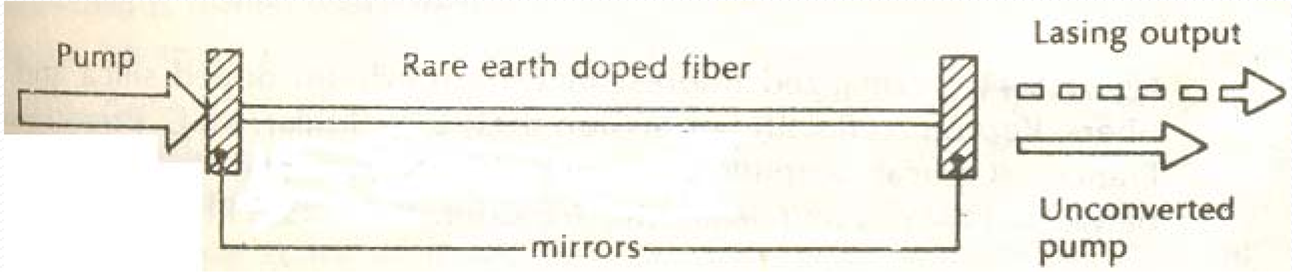
One mirror is fully reflecting , other is 10% transmitting.

Nd: YAG laser is a four level system.

-Strongest pumping bands at wavelengths of 0.75 & 0.81 µm, giving major useful lasing transitions at 1.064 & 1.32 µm.

-Single mode operation possible when L is about 1 cm

GLASS – FIBER LASER :-



Opt fiber core doped with rare earth ions forms the laser cavity. (Fabry-Perot cavity).

Rare earth elements Lanthanum (La), atomic no.57

Lutetium- atomic no 71

Major dopants: Neodymium(Nd 3+) Erbium (Er 3+)

La provides a 4 level scheme o/p at 0.90, 1.06 & 1.32 μm

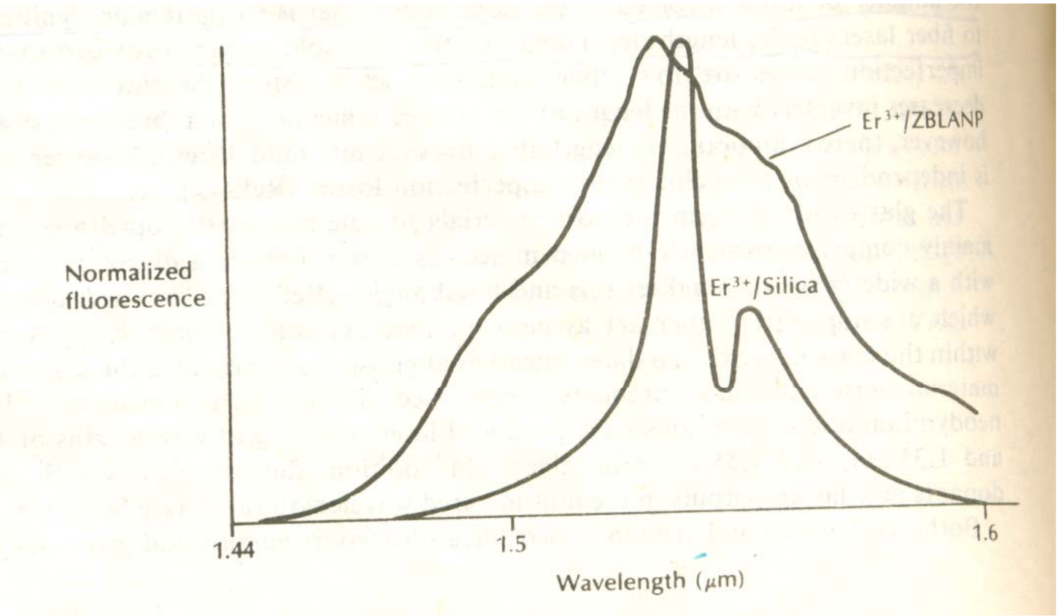
Lutetium provides a 3 level scheme, o/p at(0.80,0.98 & 1.55 μm)

Threshold power depends on length of cavity

Host material :Glass, silica based glass, fluoride glass.

Codopants : phosphorus pentoxide (P_2O_5)
germania (GeO_2, $GeCl_4$)Alumina (Al_2O_5)

Dopant level: 400 parts per million (Low) to avoid crystallisation within the glass structure



Significant spectral broadening of curve occurs due to host glass materials (in contrast to Nd : YAG laser)

ZBLANP(fluorozirconate) fiber has lead fluoride added to glass to raise the relative ref. index

GLASS – FIBER LASER(contd)

LIMITATIONS

- Launching of light from mirror end can cause damage to the mirror coating
- Reduction in launch efficiency
- Gain spectrum extends over 50 nm wavelength but output is between 10 -15 nm
- This linewidth is too narrow for broadband operation but too wide for single freq output

RELIABILITY (LASERS)

Degradation (in behavior)

1)catastrophic 2)gradual

catastrophic degradation could be due to mech. damage of the mirror faces; leading to partial or complete laser failure.

The operation may be limited to low opt. power levels.

Gradual Degradation could be due to

a) Defect formation in the active region
b)Degradation of current confining junctions

a) & b) lead to higher threshold currents thereby lowering the ext. quantum efficiency.

a) Could be due to

i) High density of recombining holes. Non radiative electron – hole recombinations cause point defects (**due to possible strain, thermal gradients) at the active region**, called **Dark Spot Defects(DSD)**

ii) **Mobile impurites in the active region(O_2, Cu, Beryllium or Zinc atoms)**, can cause high local absorption of photons causing dark lines in the o/p spectrum, called **Dark Line defects (DLD)**

b) This is due to increase in leakage current which increases the device threshold and reduces the ext. quantum η.

<u>Use of substrates & treating of mirror faces reduces these defects.</u>

Mean life time (injection laser)≈ 10^6 hours (100 yrs) at op.temp of 50°c

LASER CHARACTERISTICS

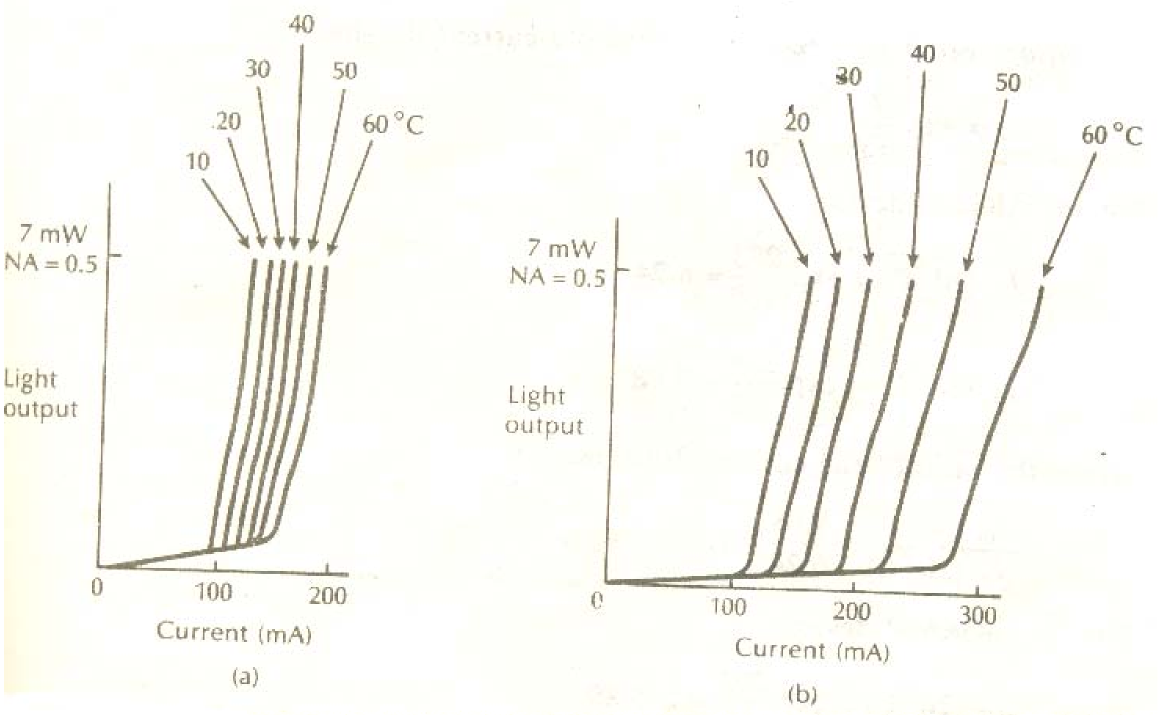
Threshold current temp. dependance

Jth α e^{T/T_0} where T – Device abs. temp

T_0 - Threshold temp coefft. (depending upon quality of material/structure of device)=120 to 190 K for (a) and 40 to75 K for (b)

Stripe width

= 20 µm



Variation in threshold current with temperature for gain-guided injection lasers: a) AlGaAs device; (b) InGaAsP device.

LASER CHARACTERISTICS (CONTD)

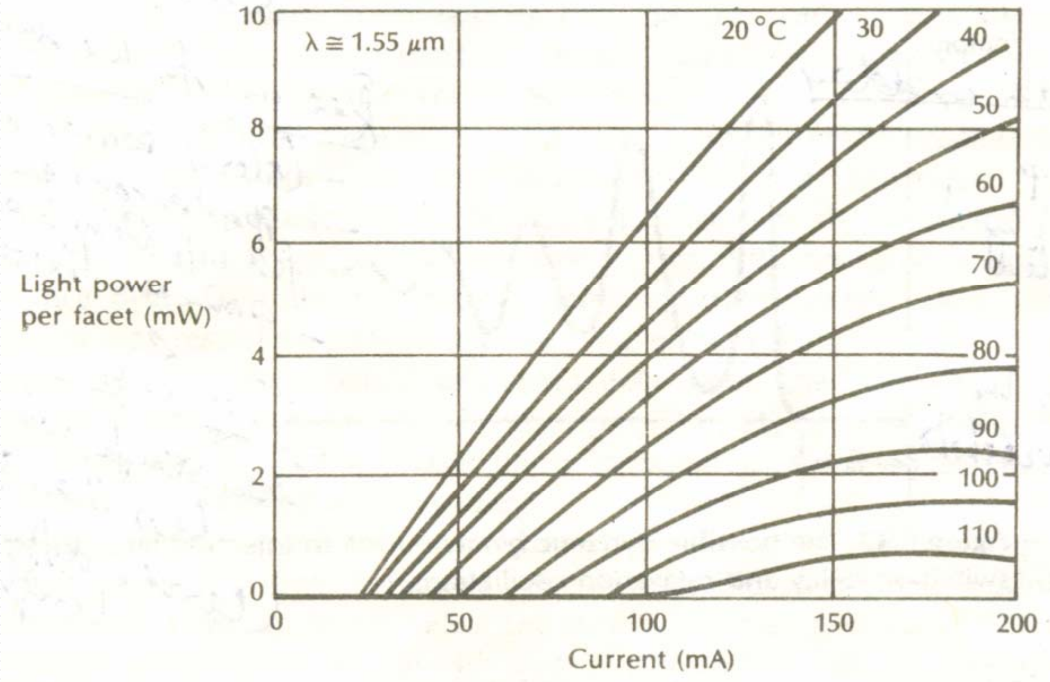
- There is stronger temp. dependence in InGa As P devices due to increasing energy spread of electrons & holes.
- Intrinsic physical properties of InGaAsP material system (carrier leakage effects, band absorption etc) may cause its higher temp sensitivity.

Note : Higher the value of To, less will be the temp dependence.

Light o/p vs current for a plannar BH In GaAsP laser

(At λ=1.55μm)- Index guided laser

Substantial attention should be paid to **Thermal dissipation to provide efficient heat sinking arrangements to achieve low operating currents**



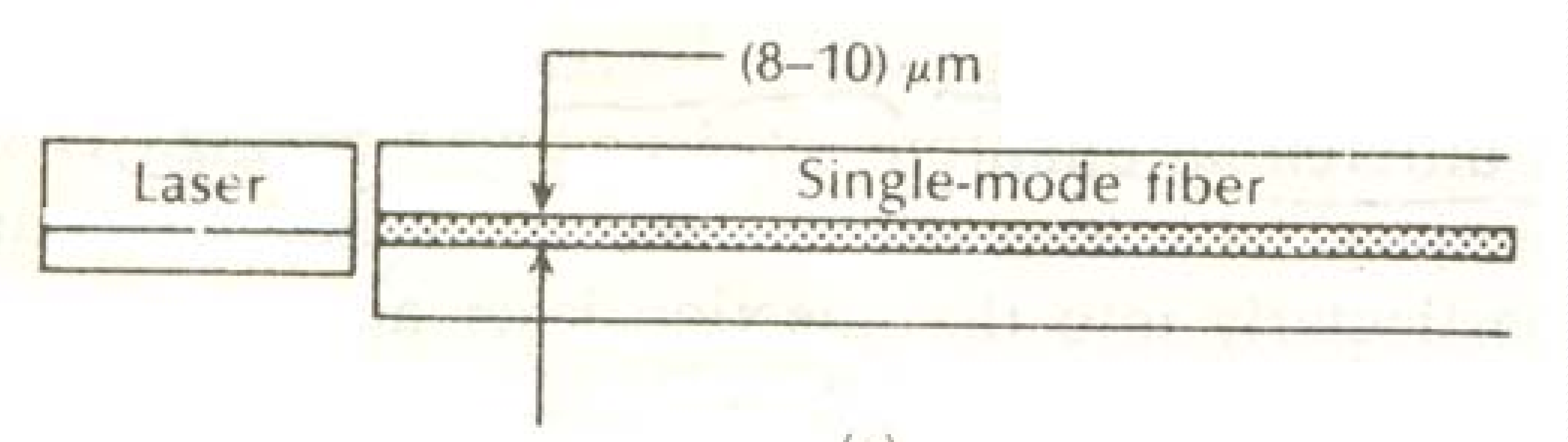
Light output versus current characteristics at various temperatures for a InGaAsP double channel planar BH laser emitting at a wavelength of 1.55 μm.

INJECTION LASER TO FIBER COUPLING

Light needs to be efficiently coupled between laser & optical fiber (Lasers have diverging o/p fields)

Single mode fibers have narrow acceptance angles, small core dia. & low NA

COUPLING TECHNIQUES - (a) BUTT COUPLING

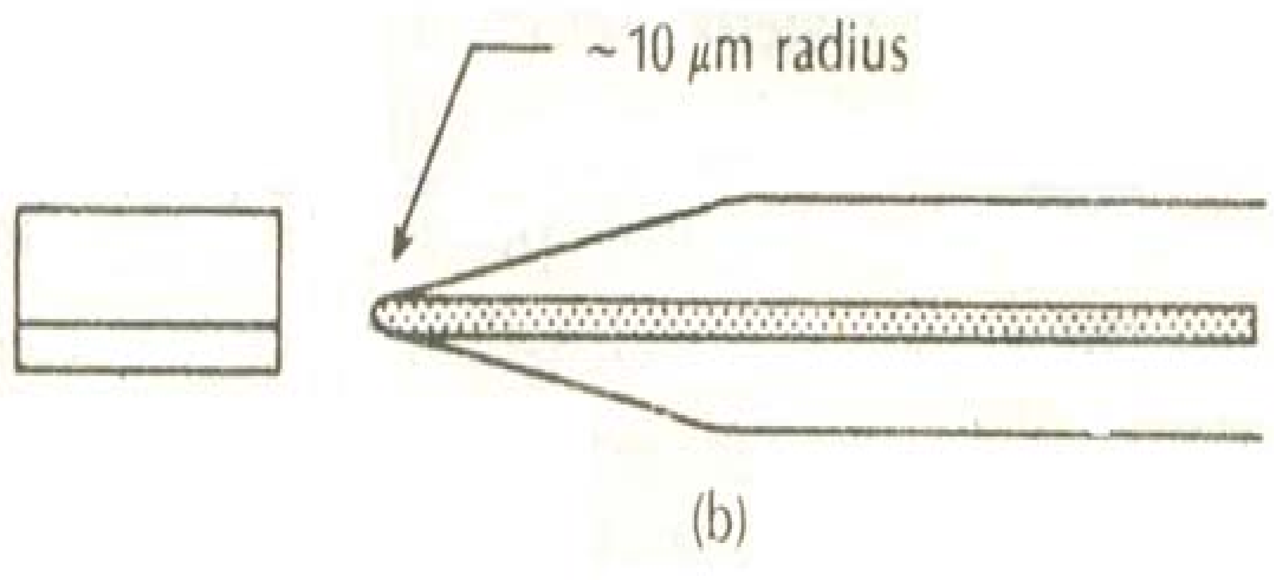


(a)

Disadvantage : Back reflection from fiber, produce noise at output resulting in degradation in performance

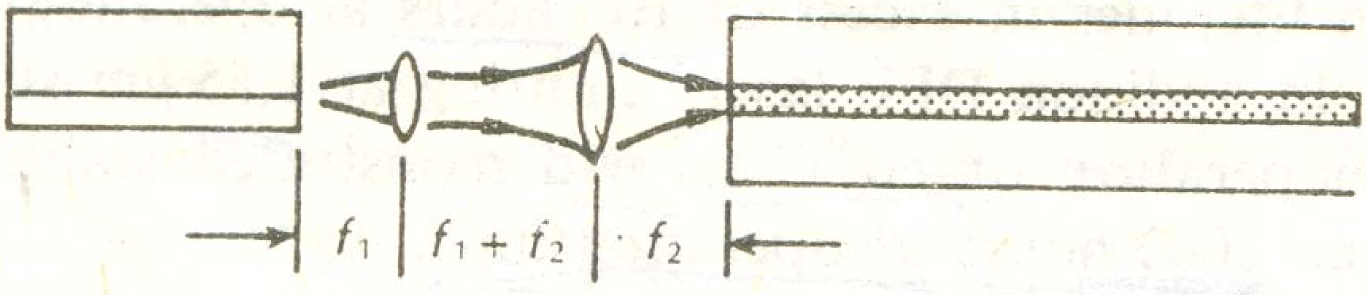
b) TAPERED HEMISPHERICAL COUPLING

o/p field from laser is matched to o/p field of fiber.



Hemispherical lens (10 μm radius) formed on the end of tapered opt. fiber.

CONFOCAL LENS SYSTEM



(c)

Use of lens provides relaxation in alignment tolerance

Efficiency=40 % (with spherical/ grin rod lens)

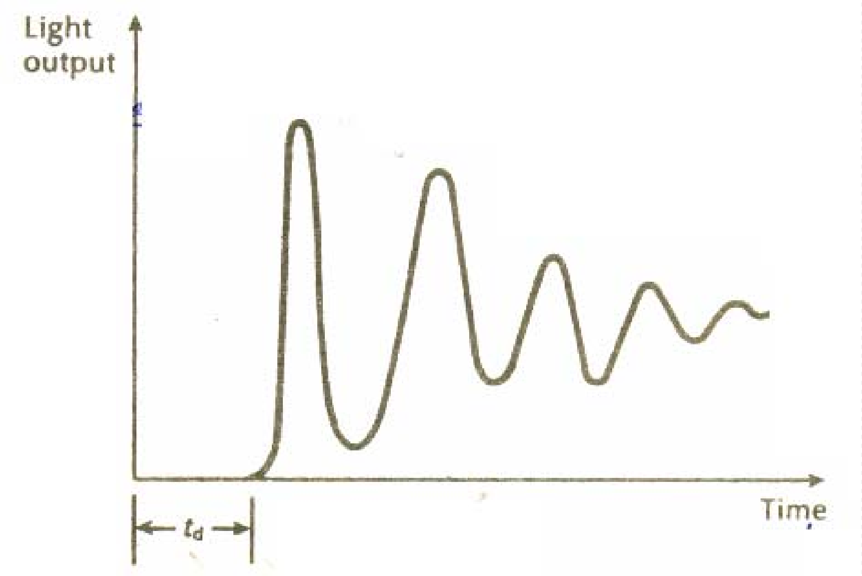
=49 – 55 % (Grin rod lens with one convex surface and with a silicon plano -convex lens)

=70 % (silicon lens with a confocal system)

DYNAMIC RESPONSE (INJ. LASER)

This behavior is critical, esp. at high bit rate (wideband)

The application of current results in switch-on delay, followed by HF (≈ 10 GHz or so) damped oscillations known as **relaxation oscillations (RO) .**This is a transient phenomena.



The possible dynamic behavior of an injection laser showing the switch-on delay and relaxation oscillations.

DYNAMIC RESPONSE(contd)

The inj. Laser o/p comprises several pulses as the electron density is repetitively built up and quickly reduced, causing RO's

$t_d \approx 0.5$ ns, RO = twice the t_d approx

At data rates above 100 M bits/sec, a serious deterioration in the pulse shape is produced

-these transient phenomena occur while electron and photon population come into equilibrium

DYNAMIC RESPONSE (contd)

Hence reducing t_d and damping RO is highly desirable.

- The **switch on delay**, which is caused by initial build up of photon density is related to minority carrier lifetime & current thr’ the device

This delay is reduced by biasing the laser near threshold (pre-biasing)

- **RO damping is obtained in DH / BH structures with stripe widths less than 3 µm (carrier diff. length).This also helps in giving fast response**

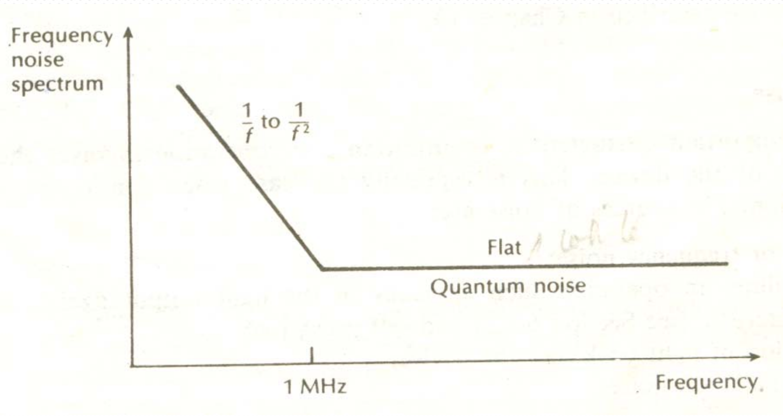
NOISE - ILD (esp. when considering analog transmission)

SOURCES OF NOISE :-

a. **Phase/freq. noise.(Intrinsic property of lasers)**
b. **Instabilities in operation (kinks)**
c. **Reflection of light back into device**
d. **Mode partition noise**

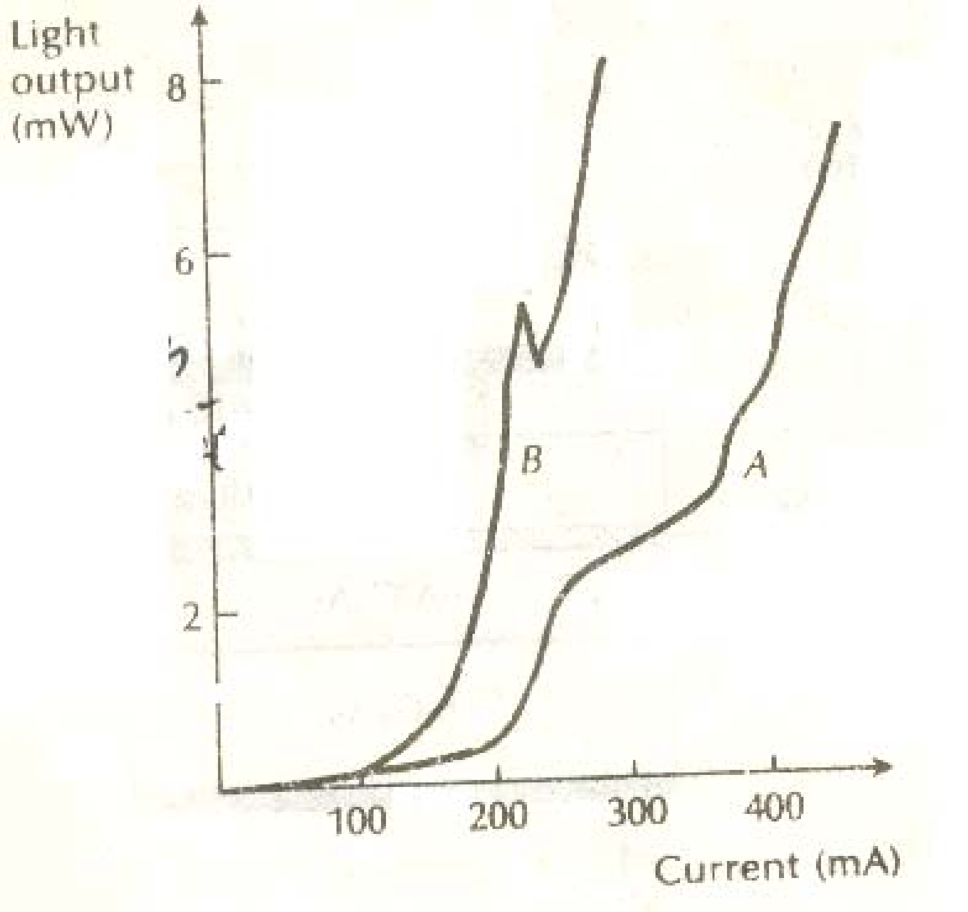
a) PHASE NOISE :- Inevitable aspect of laser emission

Exists in all types of lasers due to intensity fluctuation in opt. emission



Spectral characteristic showing injection laser phase noise.

b) KINKS :-



The light output against current characteristics for an injection laser with nonlinearities or a kink in the stimulated emission region

Single mode lasers have demonstrated greater noise immunity. (by as much as 30db when $I > I_{th}$)

c) Affects the intensity & freq. stability of SC laser.

d) **MODE PARTITION NOISE**

This occurs in multimode semiconductor lasers (modes not well stabilised) .Temp changes also affect the output.

Note 1 :- At freq above 1 MHz, noise spectrum is flat or white and is known as Quatum noise.

Note 1 :- **Quantum noise is a principle cause of line width broadening,** within semiconductor lasers.

Note 2 :- Below 100 MHz –Quant. Noise ↓ between 200 MHz & 1GHz –Quant. Noise ↑

COMPARISON – LED VS LASER

		LED	LASER
1.	Power/J	Low	High
2.	Coherence	Poor/low	High
3.	Mode of operation	multimode source (with multimode fiber)	Single mode source (with single mode fiber)
4.	Amplification	No	Yes
5.	Light emission process	Spontaneous	Stimulated

COMPARISON – LED VS LASER

	LED	LASER
6. Line width	30 to 40 nm	1 nm or so
7. Light focusing capability	Poor	Good

8. **Performance** – Laser has improved performance over LED due to use of stripe geometry/BH/DH , better carrier confinement and faster response

COMPARISON – LED VS LASER

		LED	LASER
9.	Mean life time	>10^6-10^7 hrs(100-1000 yrs) AlGaAs >10^9 hrs for surface emitting LED (InGaAsP)	10^6hrs (100yrs- at 1.55µm λ (temp 50°c)
10.	Coupling η	upto 15% (with lens)	upto 65%
11.	Int. Quantum η	50%	60 to 80 %

COMPARISON – LED VS LASER

		LED	LASER
12.	Modulation bandwidth	Low	High
13.	Cost	Low	High
14.	Construction	Simple fabrication (no mirrors, no cavity, no stripe geometry)	Relatively complex fabrication
15.	Reliability	not subject to catastrophic degradation and are much less sensitive to gradual degradation	subject to catastrophic degradation and are more sensitive to gradual degradation

COMPARISON – LED VS LASER

		LED	LASER
16.	Temp Dependence	Less	More (Raising temp increases Threshold current)
17.	Drive circuitry –	simple	Complex
18	Linearity	Yes	No

Note : Advantages of LED over LASER (SI NO 13 to 18) combined with high radiance development and possible use of high BW devices have ensured that LED remains an extensively used source for OFC.