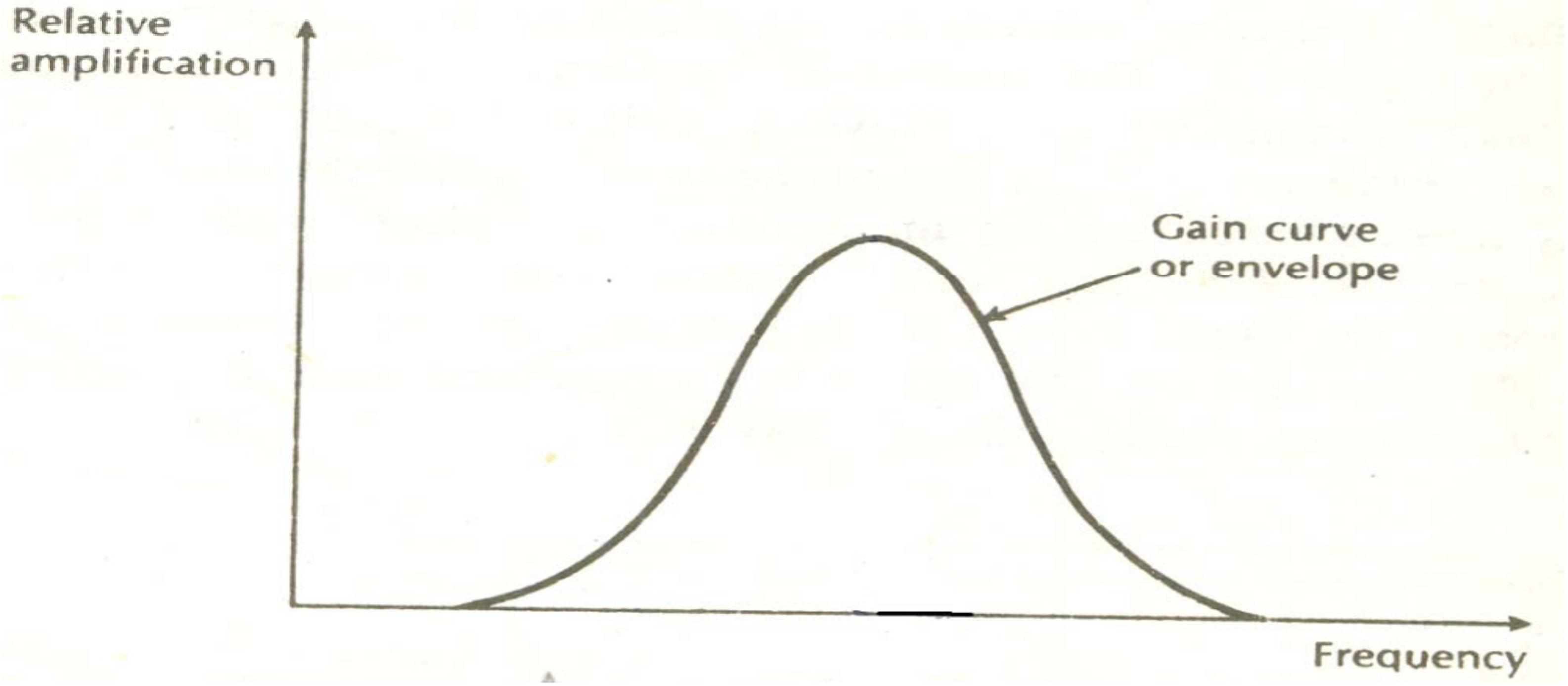
LASER & STRUCTURES

LASER OSCILLATION

- 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



.

- 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

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

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

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 ϕ/dt = ϕ(Cn –1/ τph) when δ =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/ τph ≥ 0

Therefore n has a threshold value which satisfies

above = n

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

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

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

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

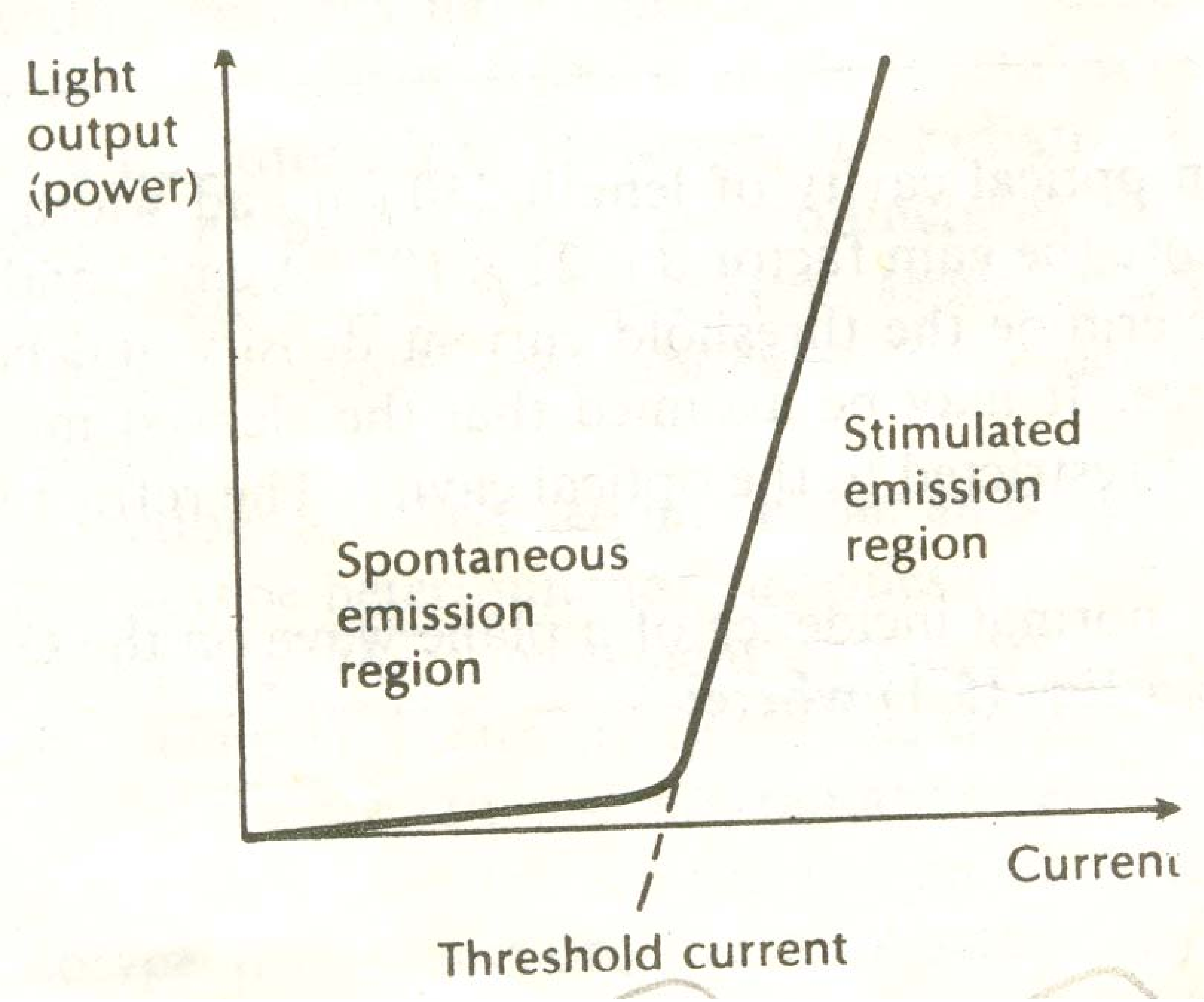
Substituting (C) in (A), to find steady state photon density (ϕs)

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

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

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

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



Characteristics (Light o/p vs Current)

EFFICIENCY OF SEMICONDUCTOR LASER

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

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

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%

η_i = Internal Quant. Efficiency =

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

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

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

$I > I_{th}$ (normally)

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

External power η(device η)

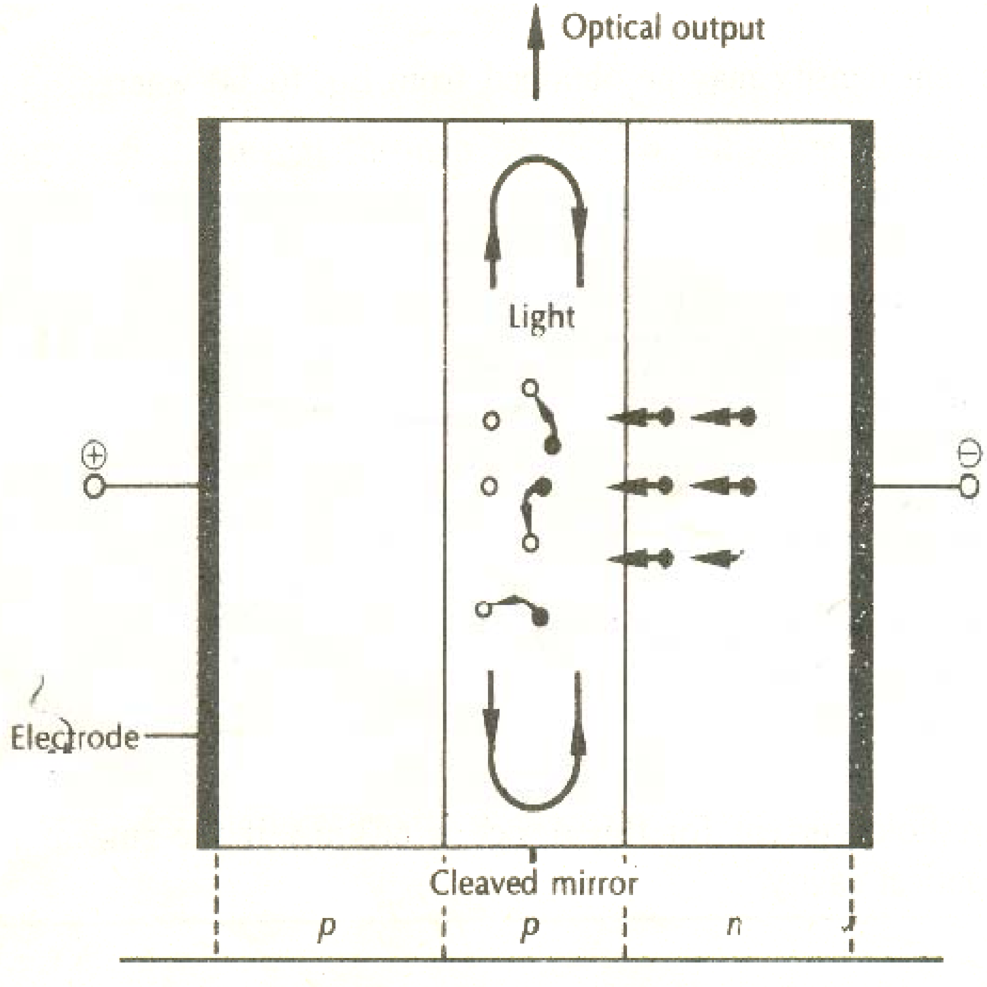
$\eta_{ep} = (Pe\ (o/p))/\ P(i/p) \times 100 = Pe\ /IV \times 100\%$

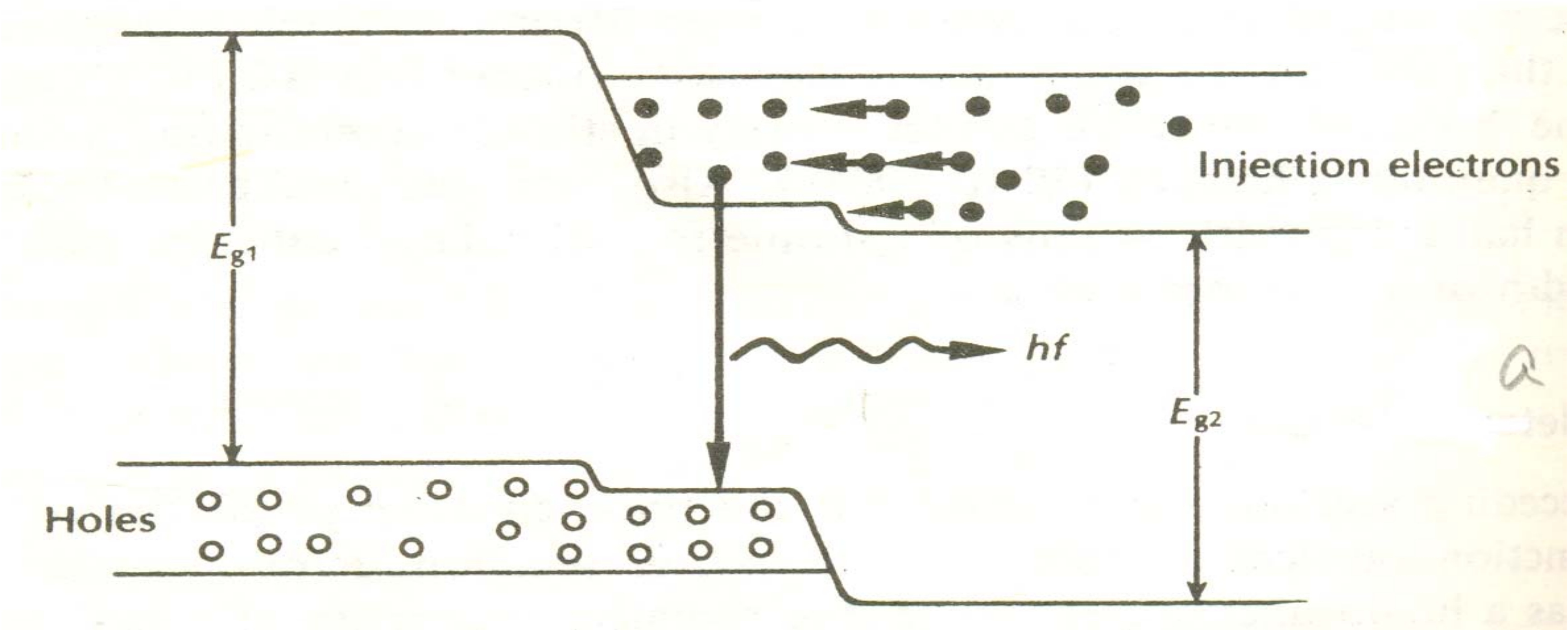
Where P= IV = DC elect. Input power

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

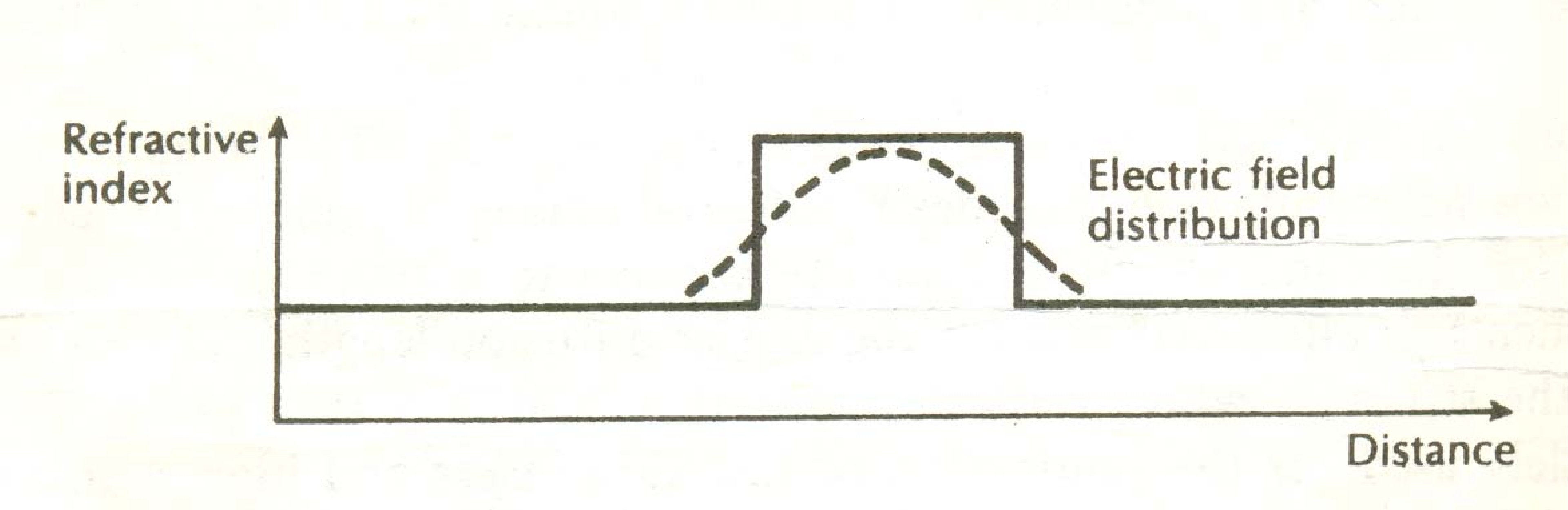
DOUBLE HETRO JUNCTION INJECTION LASER

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 (iso type) or p – n (an-isotype)

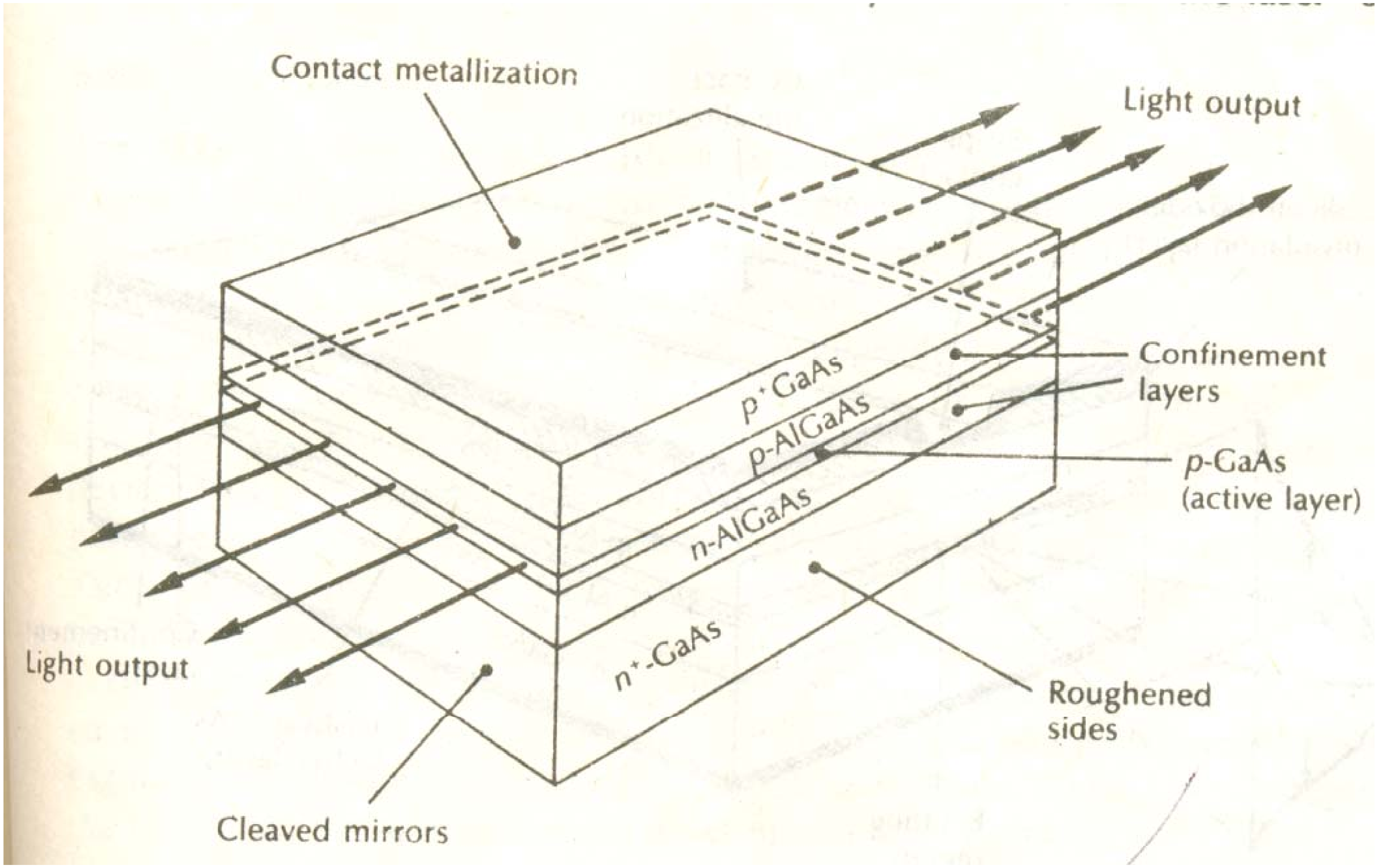
Iso type HJ helps in carrier confinement to a small active region, there by reducing the vol. where rad. recomb. take place.

An-isotype 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

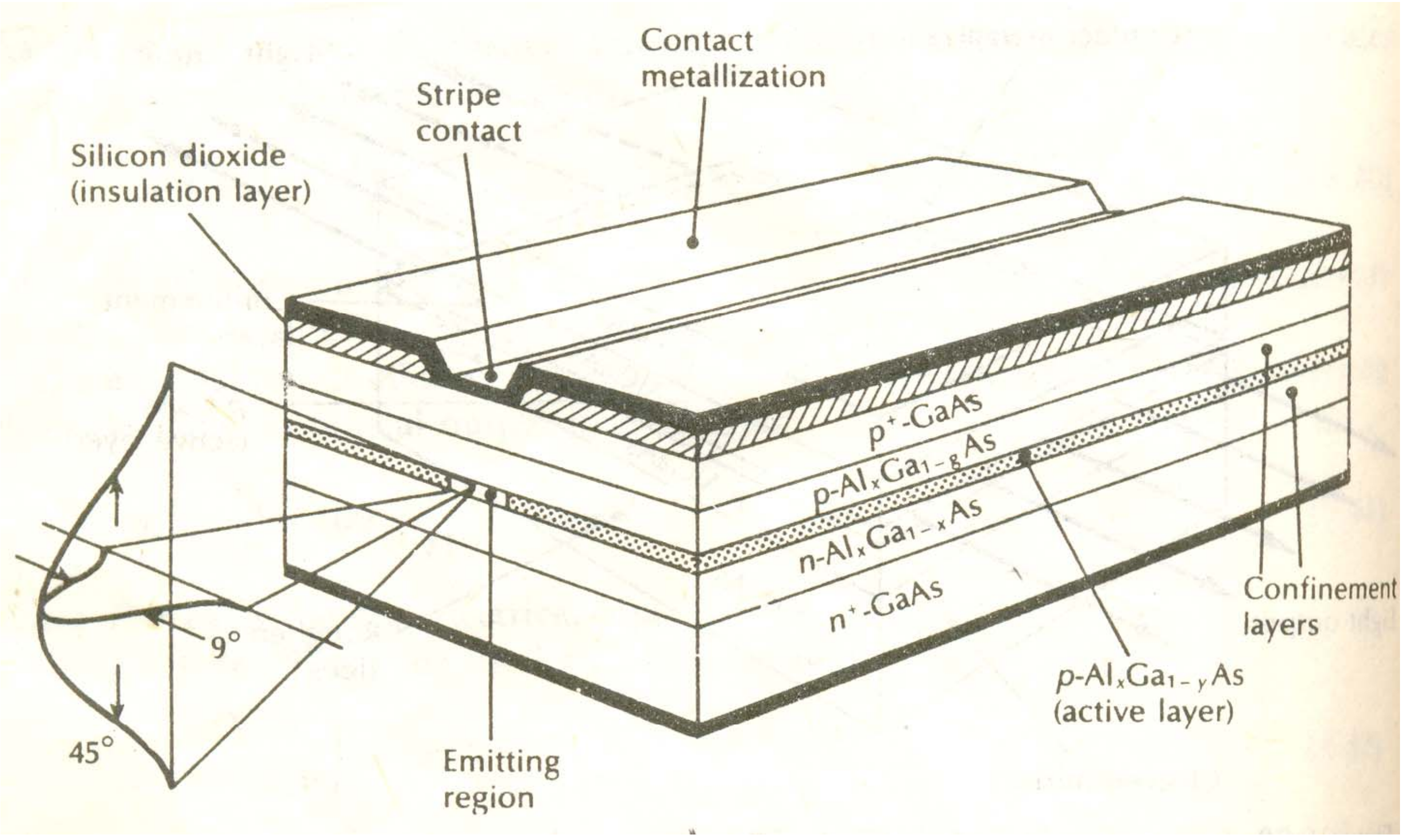
-Major current flow thr’ the device and hence the active region is within the stripe.

-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

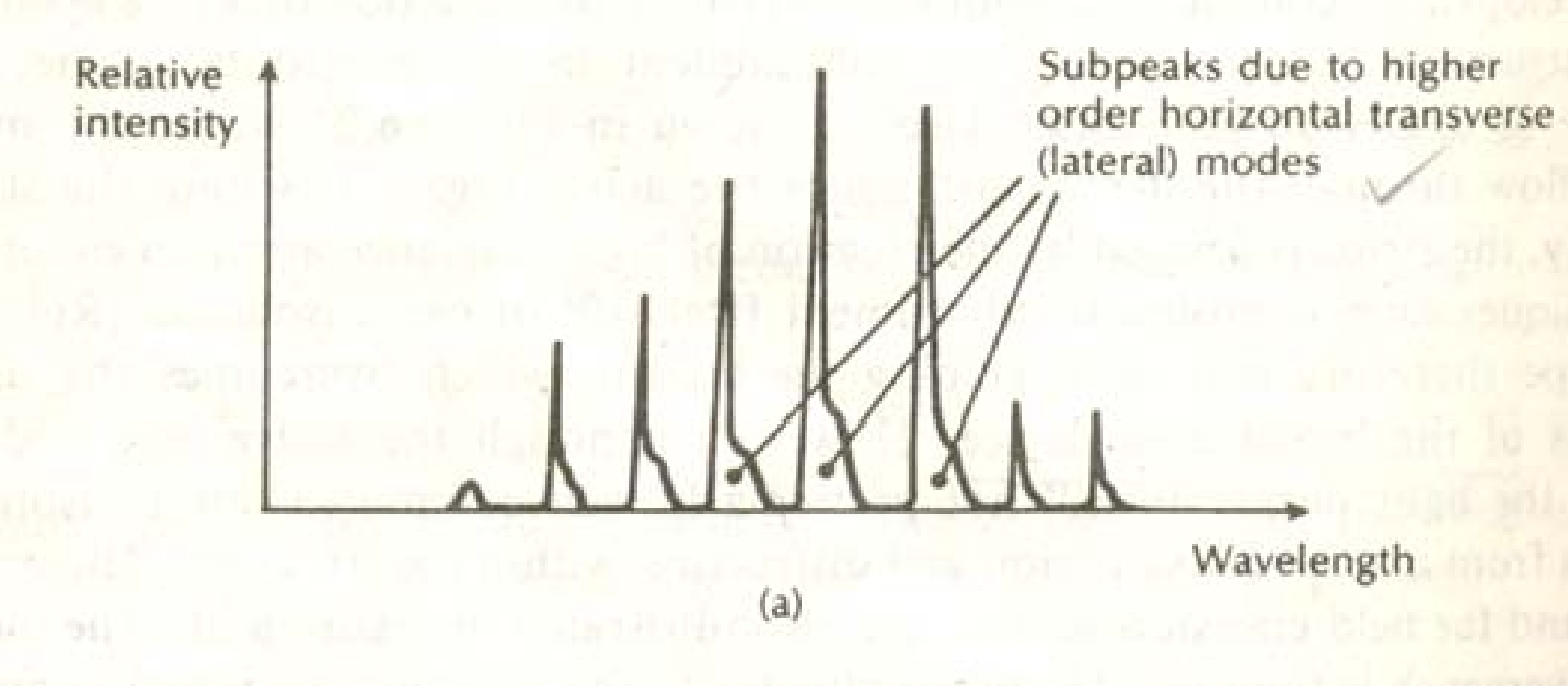


An oxide stripe AlGaAs DH injection laser.

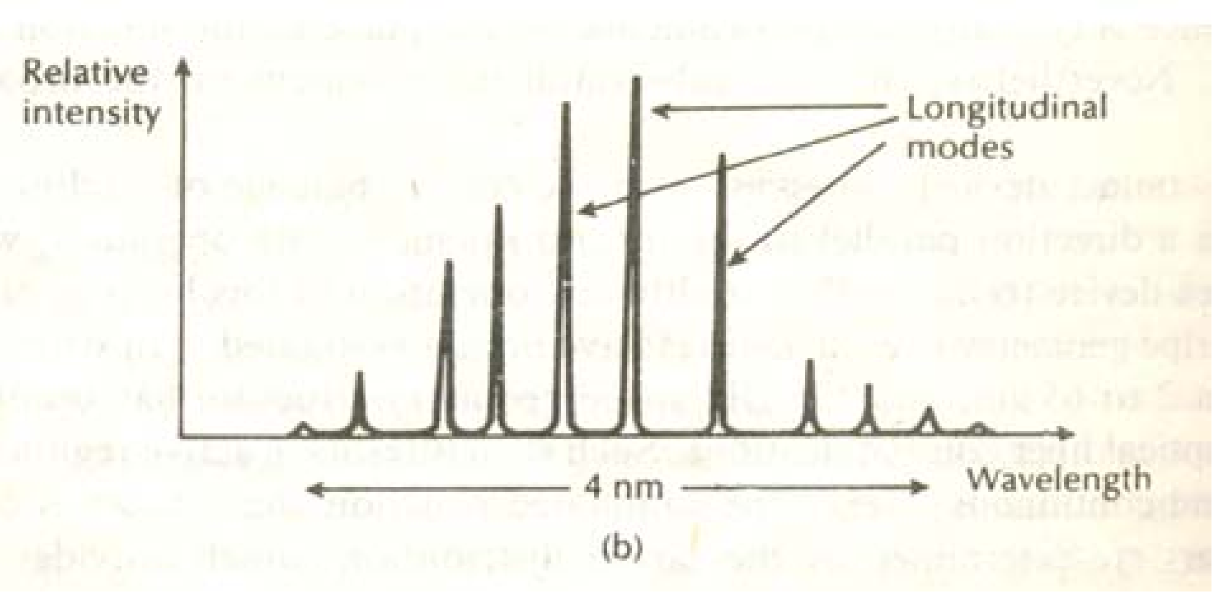
Typical stripe width range = 2 – 65 µm

DH structure gives active regions which are planar & continuous.

OUTPUT SPECTRA FOR MULTIMODE INJECTION LASER



Broad area device with multi-transverse modes



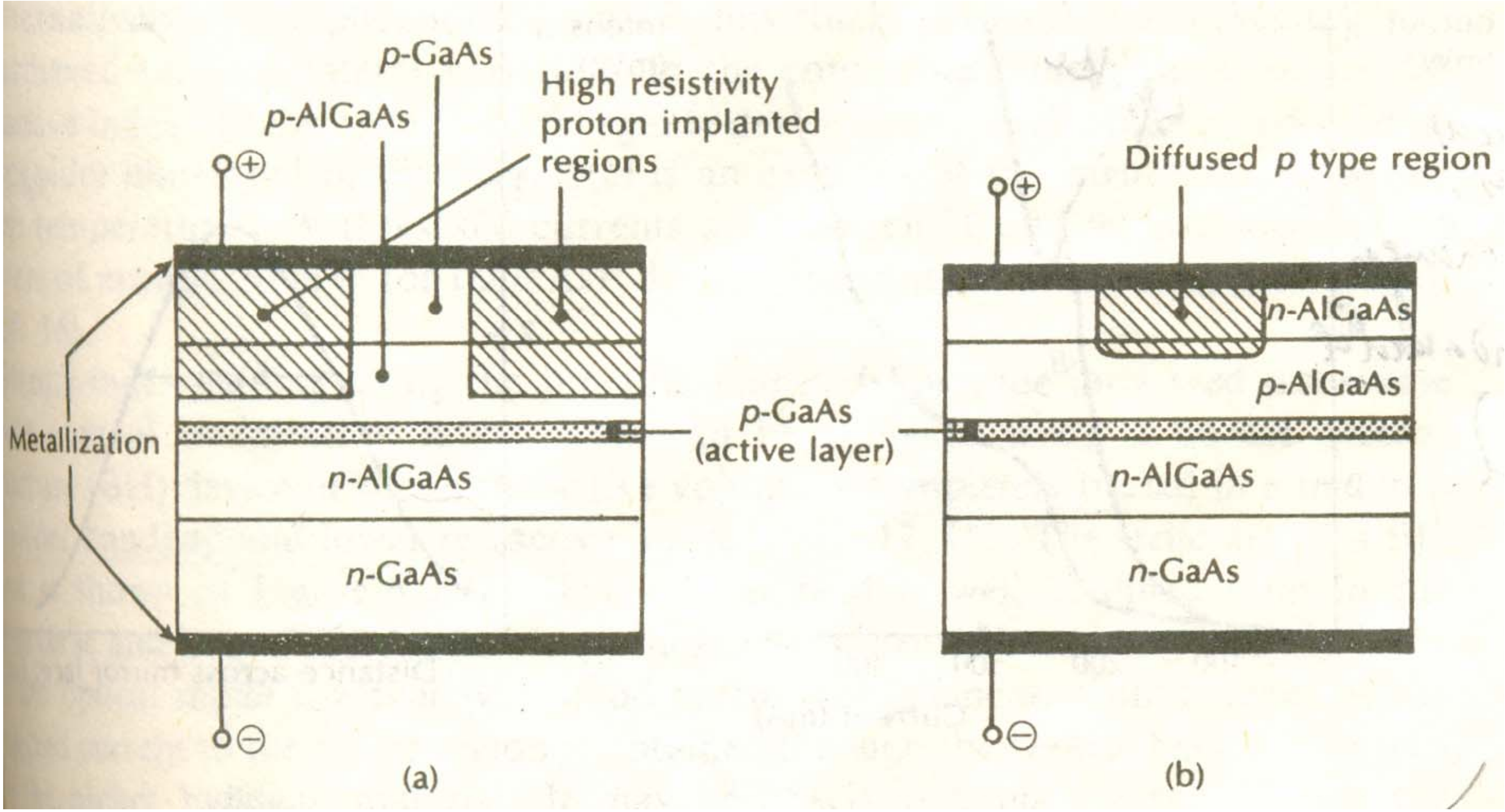
(b)

(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/AlGaAs laser;

(b) p—n junction isolated (diffused planar stripe) GaAs/AlGaAs 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.

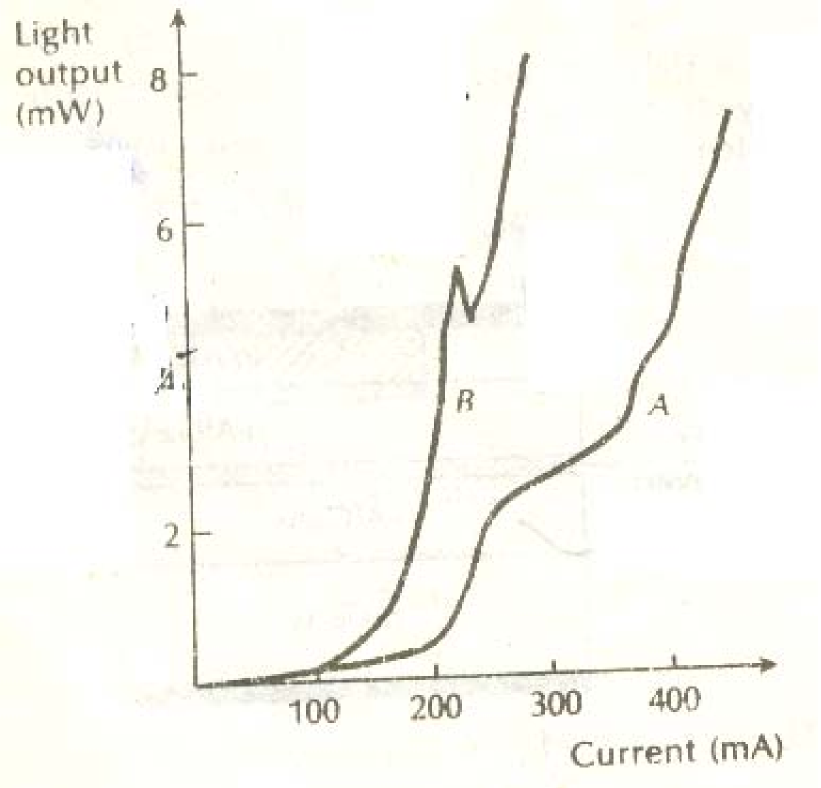
Radiation & current is not confined to stripe region and spreading occurs on both sides of the stripe.

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

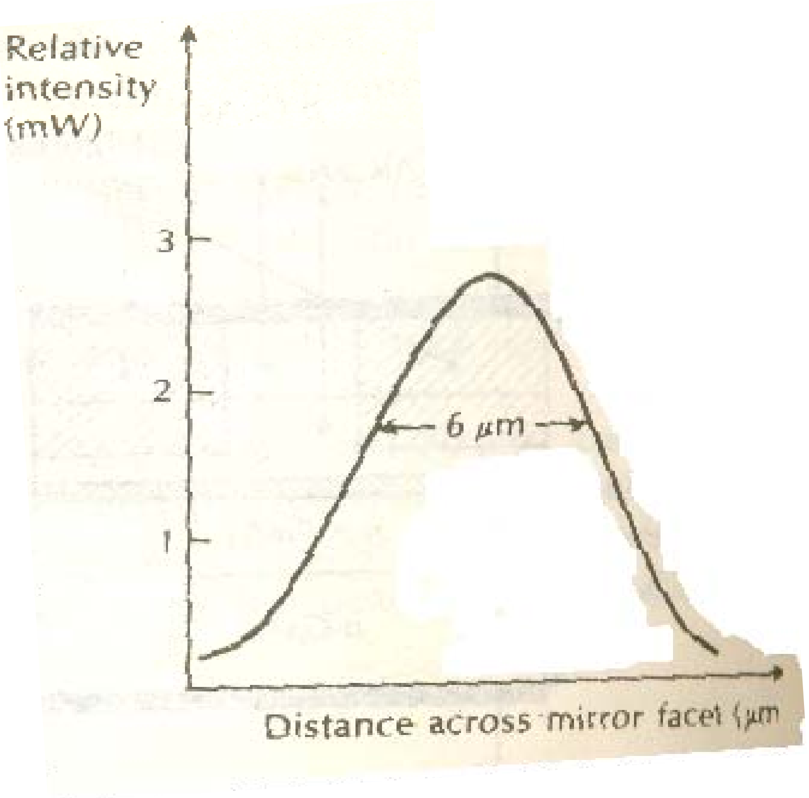
Gain guided injection lasers have higher threshold currents (100 – 150 mA) as well as low differential quantum η.



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.

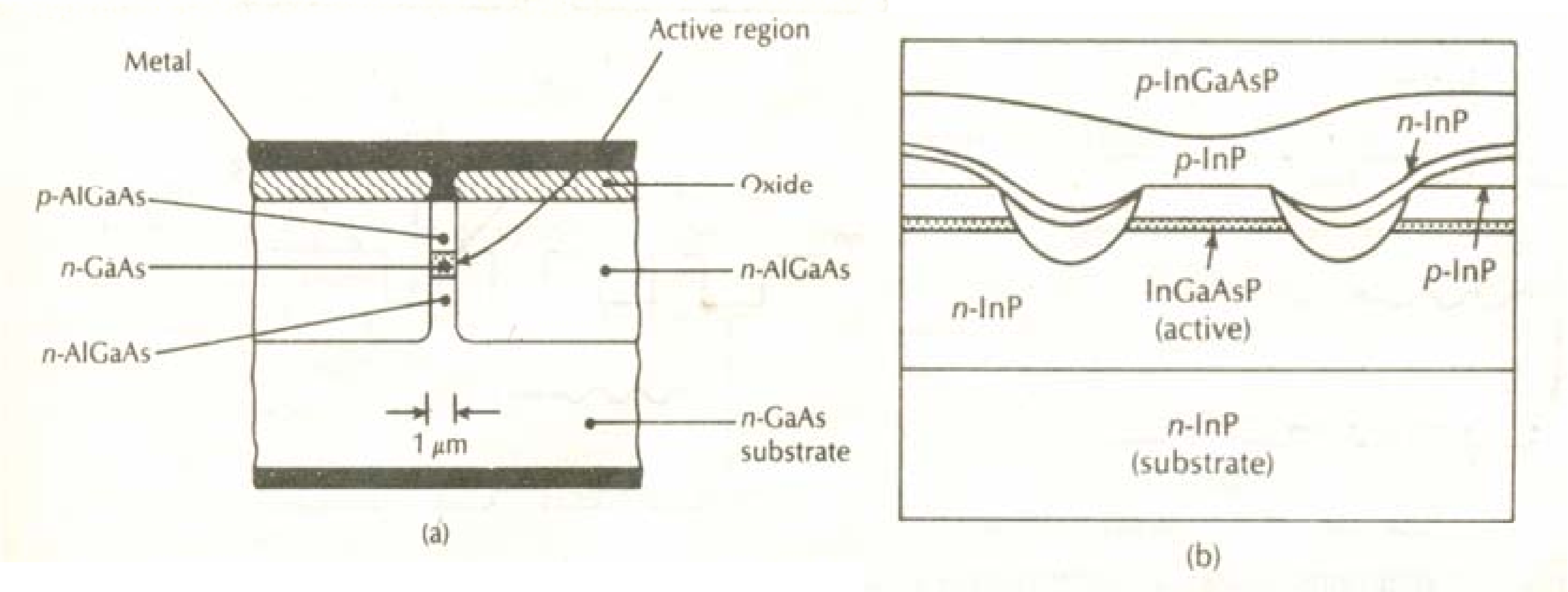
For narrow stripe devices (< 10 µm) the fundamental lateral mode dominates.

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.

Assignment

- Obtain Rate equations for electron & photon density
- Describe all in detail –

a) Buried hetro-structure laser structures.

b) Gain guided lasers

c) Oxide stripe AlGaAs DH injection laser

d) Double hetro-junction injection laser