MAJOR REQUIREMENTS - OPTICAL FIBER EMITTER

1. LIGHT 0/P SHOULD BE HIGHLY DIRECTIONAL.
2. SOURCE SHOULD BE ‘LINEAR’ (MIN. DISTORTION AND NOISE)
3. SHOULD EMIT LIGHT AT WAVELENGTHS WHERE THE FIBER HAS LOW LOSSES & LOW DISPERSION.
4. SHOULD BE CAPABLE OF SIMPLE SIGNAL MODULATION OVER A WIDE BW (AUDIO TO GHz)
5. MUST COUPLE SUFFICIENT OPTICAL POWER INTO THE OFC.

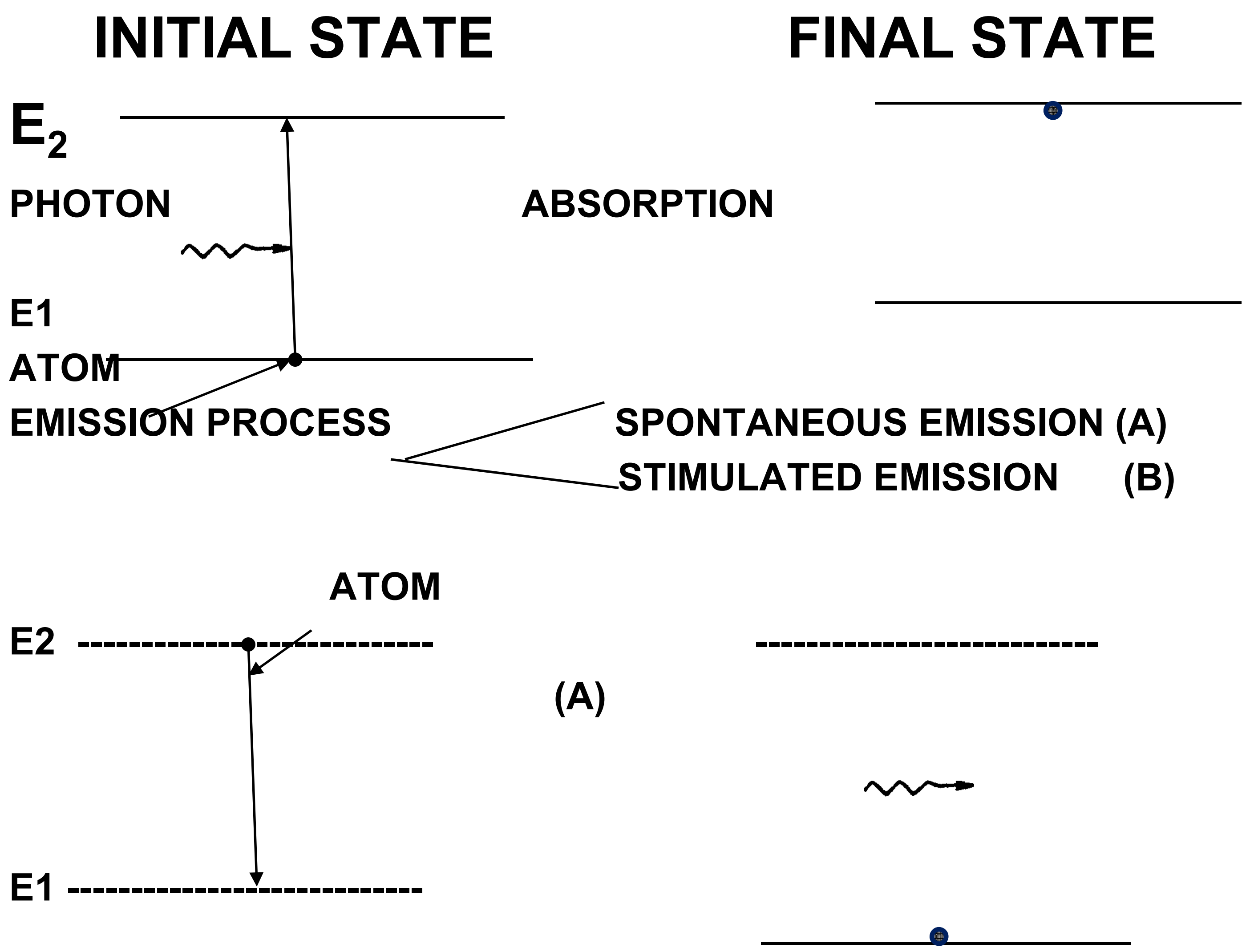
6. SHOULD HAVE A NARROW LINEWIDTH (SO AS TO MINIMISE DISPERSION IN THE FIBER)

7. 0/P SHOULD NOT BE TEMP DEPENDENT.

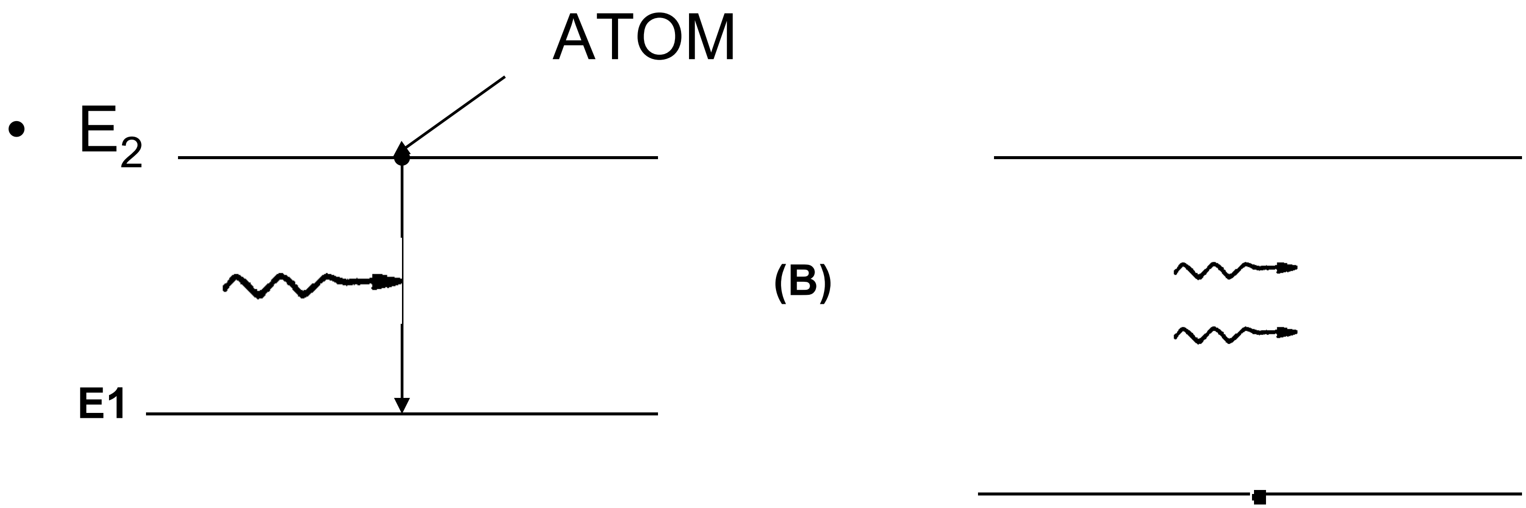
8. SOURCE SHOULD BE CHEAPER & RELIABLE.

- **FIRST GENERATION OPTICAL SOURCES - 0.85 μm (WAVELENGTH) .**
- **SECOND GENERATION OPTICAL SOURCES - 1.1 to 1.6 μm (WAVELENGTH) •**

ENERGY STATE DIAGRAM



- ATOM RETURNS TO LOWER ENERGY STATE IN AN ENTIRELY RANDOM MANNER (INCOHERENT LIGHT RADIATION)----LED !



A PHOTON HAVING AN ENERGY EQUAL TO (E2 –E1) INTERACTS WITH THE ATOM (IN UPPER ENERGY STATE) CAUSING IT TO RETURN TO LOWER STATE WITH THE CREATION OF A SECOND PHOTON – (LASER !)

→ **COHERENT RADIATION !**

OPTICAL SOURCE - 'LED'

- OPTICAL SOURCE CONVERTS ELECTRICAL ENERGY (CURRENT) INTO OPTICAL ENERGY (LIGHT).
- THREE TYPES OF OPTICAL SOURCES

- WIDEBAND CONTINUOUS SPECTRA SOURCES (**INCANDESCENT LAMP**).

- MONOCHROMATIC INCOHERENT SOURCES (**LEDs)**

- MONOCHROMATIC COHERENT SOURCES (**LASERS**).

LED'S ADVANTAGES :-

- SIMPLE CONSTRUCTION & OPERATION
- LOWER COST
- TROUBLE FREE LIFE (HIGH RELIABILITY)
- . LESS TEMP DEPENDANCE
- LINEARITY

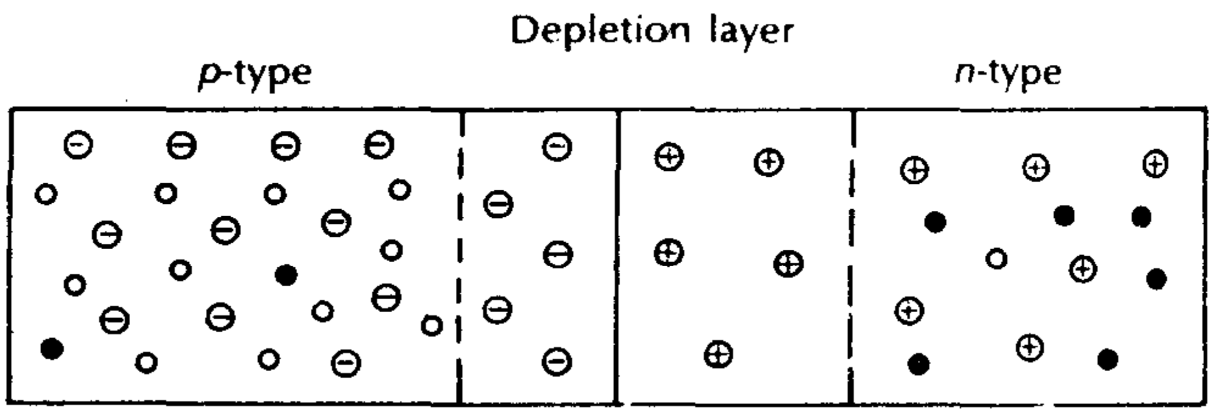
DISADVANTAGES:-

- LOWER OPT POWER CAN BE COUPLED INTO OFC
- LOWER MODULATION BANDWIDTH
- HARMONIC DISTORTION

HOWEVER,LEDs CONTINUE TO REMAIN A PROMINENT OPTICAL FIBER COMMUNICATION SOURCE FOR MANY SYSTEM APPLICATIONS.

OPT. EMISSION FROM SEMICONDUCTOR

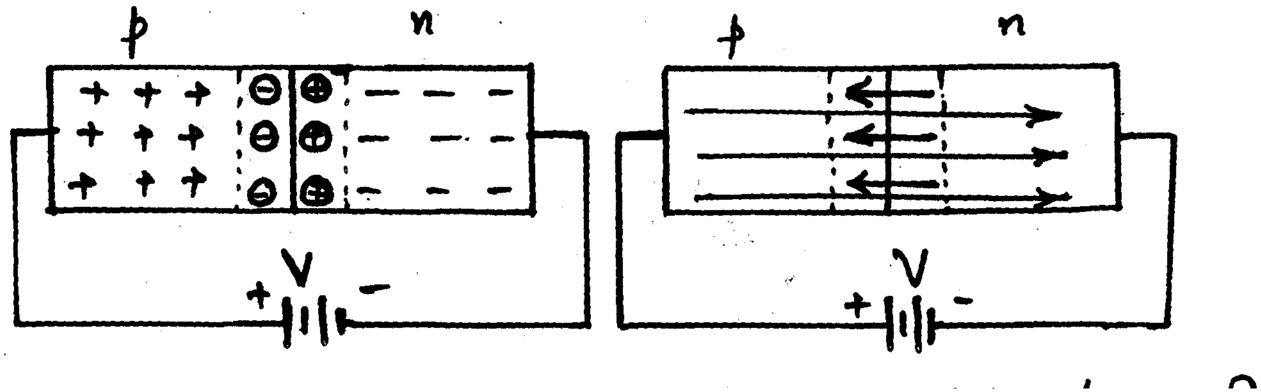
THE P-N JUNCTION



Impurities and charge carriers at the PN junction

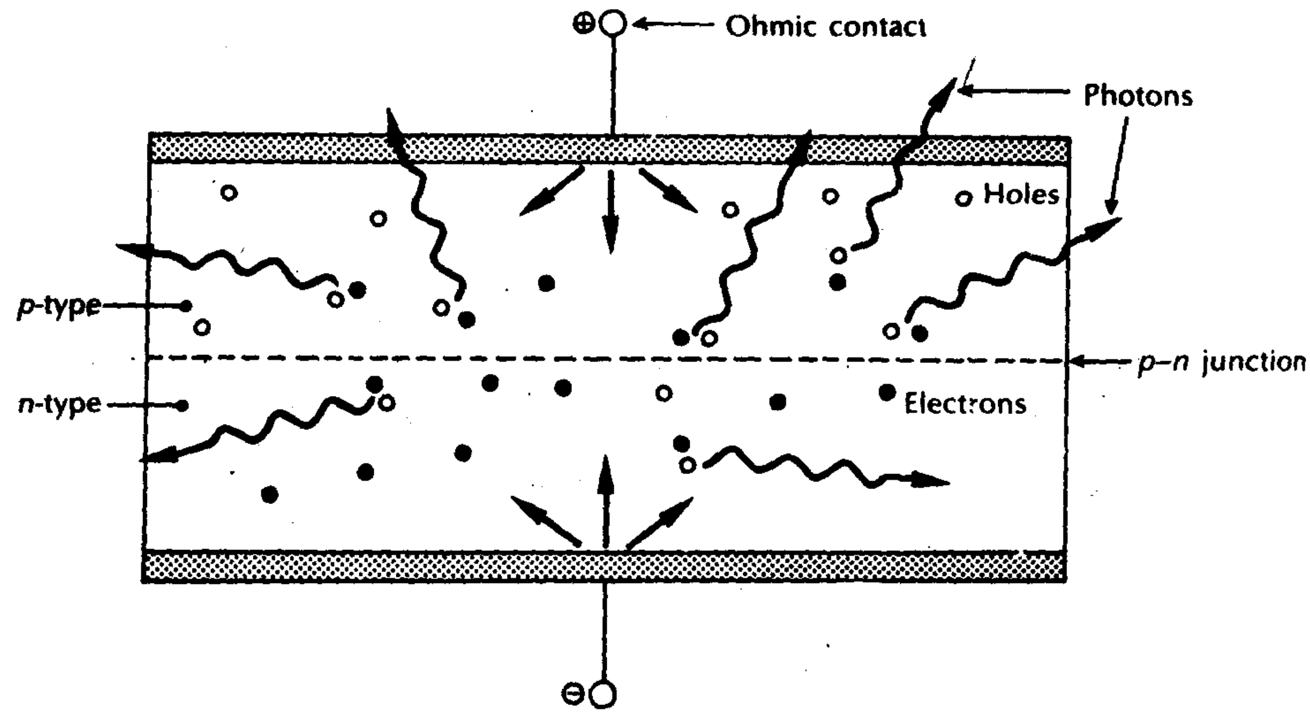
BARRIER POTENTIAL : 0.3V (Ge), 0.7V (Si) AT 25^0C

FORWARD BIAS



- THE APPLIED FIELD OPPOSES THE DEPLETION LAYER FIELD .
- THUS IT PUSHES ELECTRONS & HOLES TOWARDS THE JUNCTION.
- EDGES OF DEPLETION LAYER GET DE-IONISED .
- THIS NARROWS THE DEPLETION LAYER.
- THUS GREATER THE EXTERNAL VOLTAGE NARROWER THE DEPLETION LAYER.
- **RECOMBINATION BETWEEN ELECTRONS AND HOLES OCCUR AROUND THE JUNCTION**.

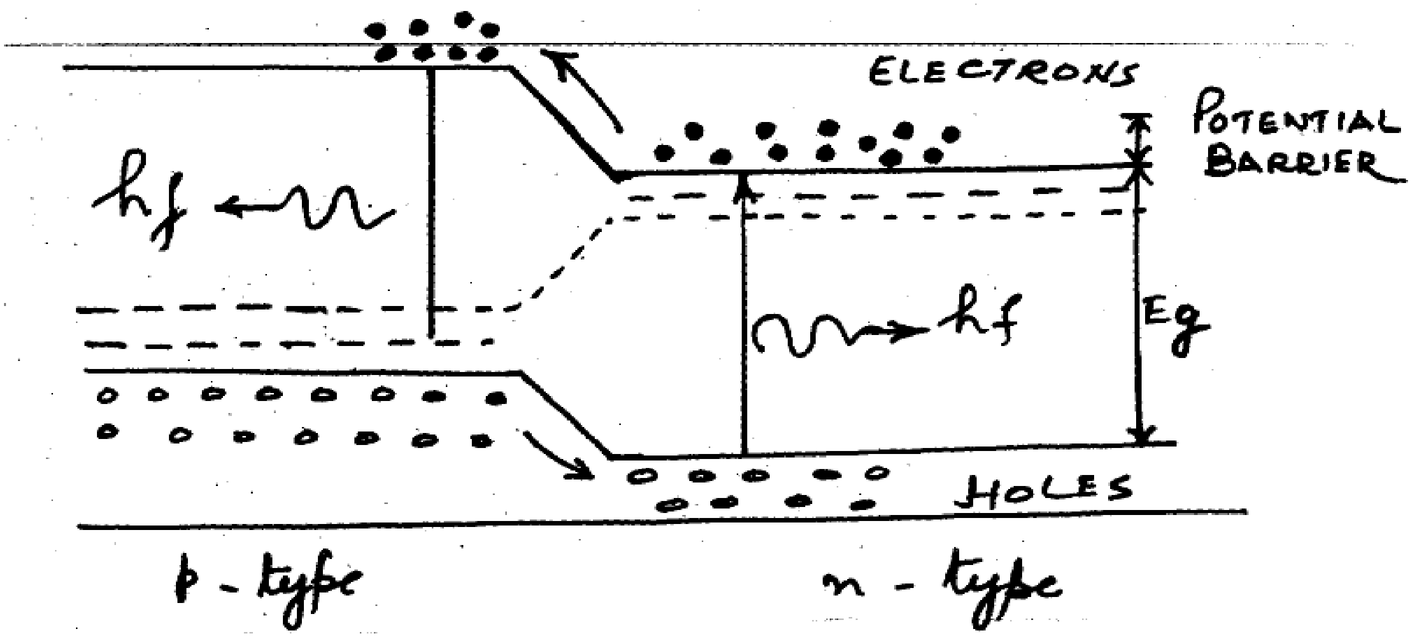
CARRIER COMBINATION GIVING SPONTANEOUS EMISSION OF LIGHT



An illustration of carrier recombination giving spontaneous emission of light in a p—n junction diode.

THE AVERAGE TIME THE MINORITY CARRIER REMAINS IN A FREE STATE BEFORE RECOMBINATION IS SHORT, 10^{-8} TO 10^{-10} SEC. (MINORITY CARRIER LIFETIME)

PRINCIPLE OF OPERATION – LED



PN JUNCTION WITH FORWARD BIASING

- **INCREASED CONCENTRATION OF MINORITY CARRIERS IN THE OPPOSITE TYPE REGION IN FORWARD BIASED P-N DIODE LEADS TO RECOMB1NATION OF CARRIERS.**

- ENERGY RELEASED BY ELECTRON HOLE RECOMBINATION IS APPROX. EQUAL TO BAND GAP ENEGY Eg.

- **ENERGY IS RELEASED WITH THE CREATION OF A PHOTON.**

  Eg= hf = hc/λ WHERE $h=6.626 \times 10^{-34}$ J **(PLANCK'S CONSTANT)**

THIS SPONTANEOUS EMISSION OF LIGHT FROM DIODE IS CALLED- **ELECTROLUMINESCENCE.**

LED'S POWER & EFFICIENCY

INTERNAL QUANTUM η = NO OF PHOTONS GENERATED / NO OF ELECTRONS INJECTED

RECOMBINATION
- RADIATIVE (PHOTON IS GENERATED)
- NON-RADIATIVE(ENERGY RELEASED IN THE FORM OF HEAT)

INTERNAL QUANTAM η = RADIATIVE RECOMBINATION RATE / TOTAL RECOMBINATION RATE

$$= r_r/r_r + r_{nr} \qquad = r_r/r_t$$

NON-RADIATIVE RECOMBINATION TAKES PLACE WITHIN THE STRUCTURE DUE TO CRYSTALLINE IMPERFECTIONS AND IMPURITIES GIVING AN EFFICIENCY OF 50% (MAX)

- **<u>LED'S POWER & EFFICIENCY (contd)</u>**

- THE ENERGY RELEASED BY THIS ELECTRON – HOLE RECOMBINATION IS APP. EQUAL TO BANDGAP ENERGY $E_g = hf$.
- LET Δn = EXCESS DENSITY OF ELECTRONS IN p – TYPE MATERIAL .

  Δp = EXCESS DENSITY OF HOLES IN n- TYPE MATERIAL.

  $\Delta n = \Delta p$ (FOR CHARGE NEUTRALITY)

RATE = n FOR CARRIER RECOMBINATION

$d/dt\,(\Delta n) = J/ed - \Delta n/\tau \quad (m^{-3}s^{-1})$

At equilibrium ,rate of change of density = 0

or $J/ed = \Delta n/\tau$ or $\Delta n = J\tau/ed \; (m^{-3})$ (1)

=n(1) GIVES STEADY STATE ELECTRON DENSITY WHEN A CONSTANT CURRENT IS FLOWING INTO JUNCTION

AT STEADY STATE,TOTAL NO OF CARRIER RECOMBINATIONS PER SECOND, = $r_t = J/ed = r_r + r_{nr}$

RATE = n FOR CARRIER RECOMBINATION

- $\Delta n = \Delta n(o)\, e^{-t/\tau}$
- WHERE $\Delta n(o)$= Initial injected excess electron density :

  τ = total carrier recombination life time.

At equilibrium (constant current flows into junction diode)

TOTAL RATE (carrier generation)= EXT SUPPLIED + THERMALLY GENERATED

Let J = CURRENT DENSITY (amp/m^2)

= J/ed= ELECTRONS PER CUBIC METRE PER SEC.

(where d = thickness of recombination region)

FURTHER, R_t = total number of recombinations per sec= i/e (i = forward bias current)

LED INTERNAL QUANTAM EFFICIENCY

$$\eta\ int = \frac{\text{Radiative Recombination rate}}{\text{Total recombination rate}} = \frac{r_r}{rt} = \frac{r_r}{r_r + r_{nr}}$$

$= R_r / R_t$

Or $R_r = \eta$ int x R_t = **η int x i/e**

= total no of photons generated per sec.

ENERGY IN EACH PHOTON Eg = hf joules

OPT POWER GENERATED BY LED (P_{int})

= No of photons generated x energy /photon

= η_{int} x i/e x hf Watts

$P_{int} = \eta_{int} \times hci/e\lambda$

NOW τ_r = RADIATIVE MINORITY CARRIER LIFE TIME.

$= \Delta n / r_r = \dfrac{\text{electrons /m3}}{\text{electrons /m3 /sec.}}$

$\tau_{nr} = \Delta n / r_{nr}$

$\eta_{int} = r_r / r_r + r_{nr}$

$\eta_{int} = r_r / r_r + r_{nr} = 1/1+(r_{nr} / r_r) = 1/1+(\tau_r / \tau n_r)$

$r_{nr} / r_r = \Delta n / \tau_{nr} \times \tau_r / \Delta n = \tau_r / \tau_{nr}$

Hence $\eta_{int} = 1/1+(\tau_r / \tau_{nr})$

Also τ = Total recomb.life time $= \Delta n/r_t$

$= \Delta n/ r_r+r_{nr} \quad = \Delta n/ (\Delta n/ \tau_r) + (\Delta n/ \tau_{nr})$

$= 1/ (1/ \tau_r) + (1/ \tau_{nr})$

$1/ \tau = 1/ \tau_r + 1/ \tau_{nr}$

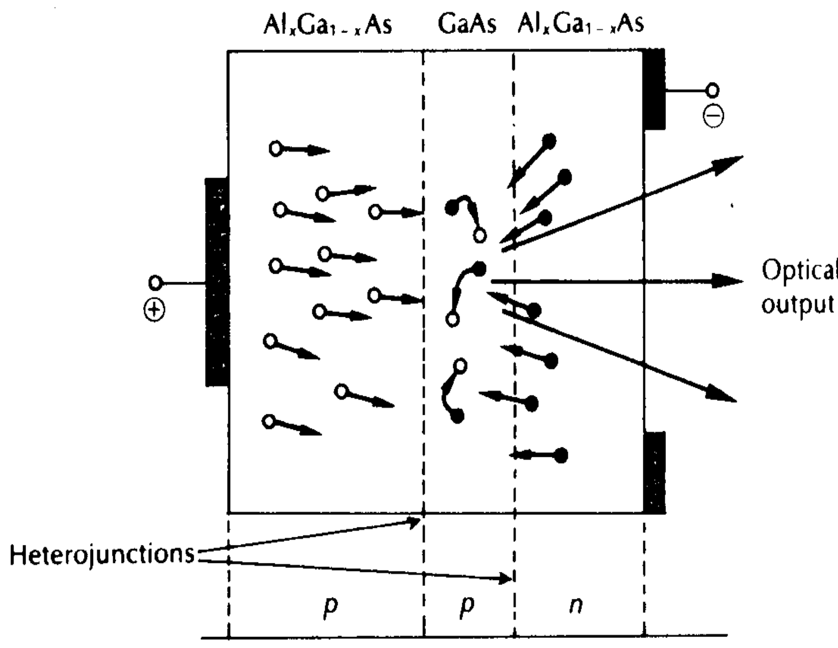
Further $\eta_{int} = r_r / r_r + r_{nr}$

$= r_r / r_t$

$= \dfrac{(\Delta n / \tau_r)}{(\Delta n/ \tau)} = \tau/\tau_r$

Hence $\eta_{int} = \tau/\tau_r$

THE DOUBLE HETROJUNCTION LED



Layered Structure With Applied Forward Bias

THE DOUBLE HETROJUNCTION LED

- p- TYPE GaAs IS SANDWITCHED BETWEEN A p–TYPE Al Ga As AND AN n- TYPE Al Ga As .

- **ON APPLICATION OF FORWARD BIAS**

- ELECTRONS FROM n TYPE ARE INJECTED THR'

  p-n JUNCTION, INTO p TYPE GaAs LAYER.
- THESE MINORITY CARRIERS RECOMBINE WITH MAJORITY CARRIERS (HOLES).
- PHOTONS ARE PRODUCED WITH ENERGY CORRESP TO BAND GAP ENERGY OF p- TYPE GaAs LAYER.
- THE INJECTED ELECTRONS ARE INHIBITED FROM

  DIFFUSING INTO p – TYPE Al Ga As LAYER BECAUSE OF POTENTIAL BARRIER PRESENTED BY p-p HETROJUNCTION

THE DOUBLE HETROJUNCTION LED(contd)

  - THUS ELECTRO LUMINESCENCE OCCURS ONLY IN GaAs LAYER PROVIDING GOOD INTERNAL QUANTUM EFFICIENCY AND' HIGH RADIANCE EMISSION.

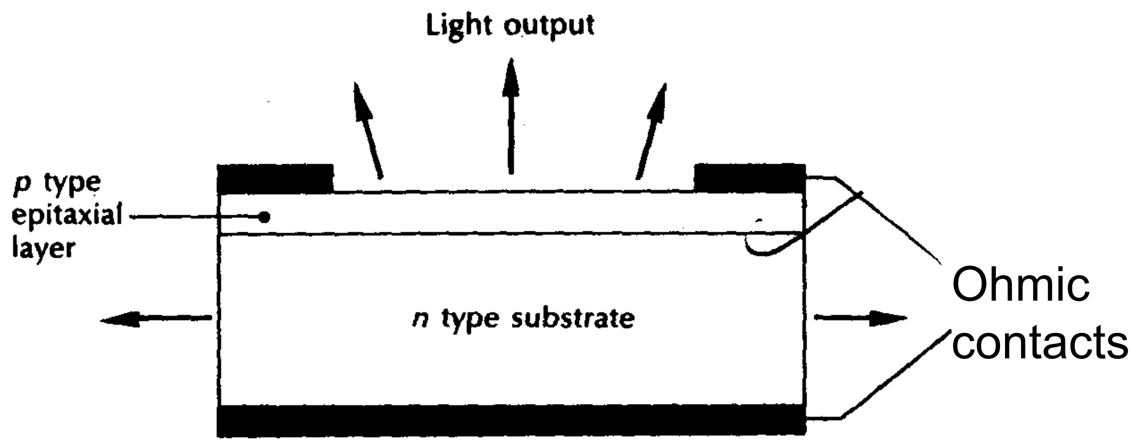
- **THE DH STRUCTURE IS MOST EFFICIENT INCOHERENT SOURCE FOR OPT.FIBER COMM.**

LED STRUCTURES

FIVE MAJOR TYPES OF LED STRUCTRE

- PLANNAR LED'S
- DOME LED'S
- SURFACE EMITTER LED'S
- EDGE EMITTER LED'S
- SUPER LUMINESCENT LED'S

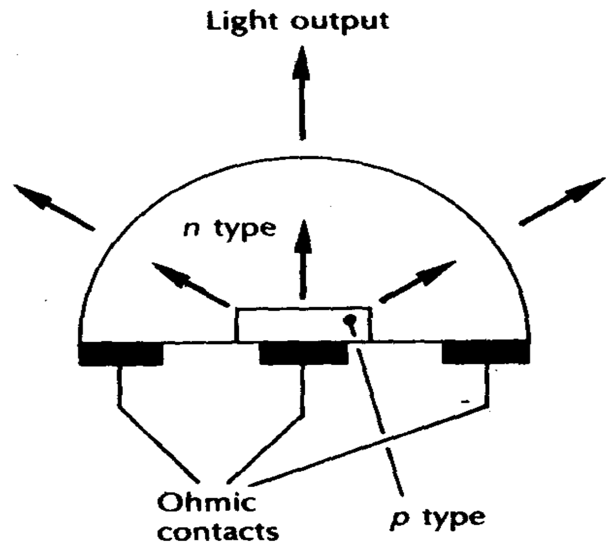
PLANAR LED



The structure of a planar LED showing the emission of light from all surfaces.

-P TYPE DIFFUSION OCCURS INTO N TYPE SUBSTRATE
-FORWARD CURRENT FLOWS THR' JUNCTION AND DEVICE EMITS LIGHT .
-HOWEVER, RADIANCE IS LOW (light emitted from entire surface)

DOME LED



- DIA OF DOME IS SO CHOSEN TO MAXIMISE AMOUNT OF INTERNAL EMISSION REACHING THE SURFACE (WITHIN CRITICAL ANGLE OF GaAs- AIR INTERFACE).

- HIGHER EXT EFFICIENCY THAN PLANAR LED

- **DOME SIZE IS FAR GREATER THAN THE ACTIVE RECOMBINATION AREA .** SO EFFECTIVE EMISSION AREA IS GREATER ,THEREBY REDUCING THE RADIANCE.

SURFACE EMITTER LED (SLED)

• **GIVES HIGH RADIANCE**

- DUE TO LOW INTERNAL ABSORPTION
- HIGHER REFLECTION COEFFICIENT AT BACK CRYSTAL FACE (GIVING GOOD FORWARD RADIANCE)

• POWER COUPLED INTO MULTIMODE STEP INDEX FIBER.

$$P_c = \pi(1-r)A\,R_D(NA)^2 \quad \text{— (1)}$$

r-FRESNEL COEFFICIENT AT FIBER SURFACE

A-EMISSION AREA OF THE SOURCE

R_D- RADIANCE OF THE SOURCE

POWER COUPLED ALSO DEPENDS UPON

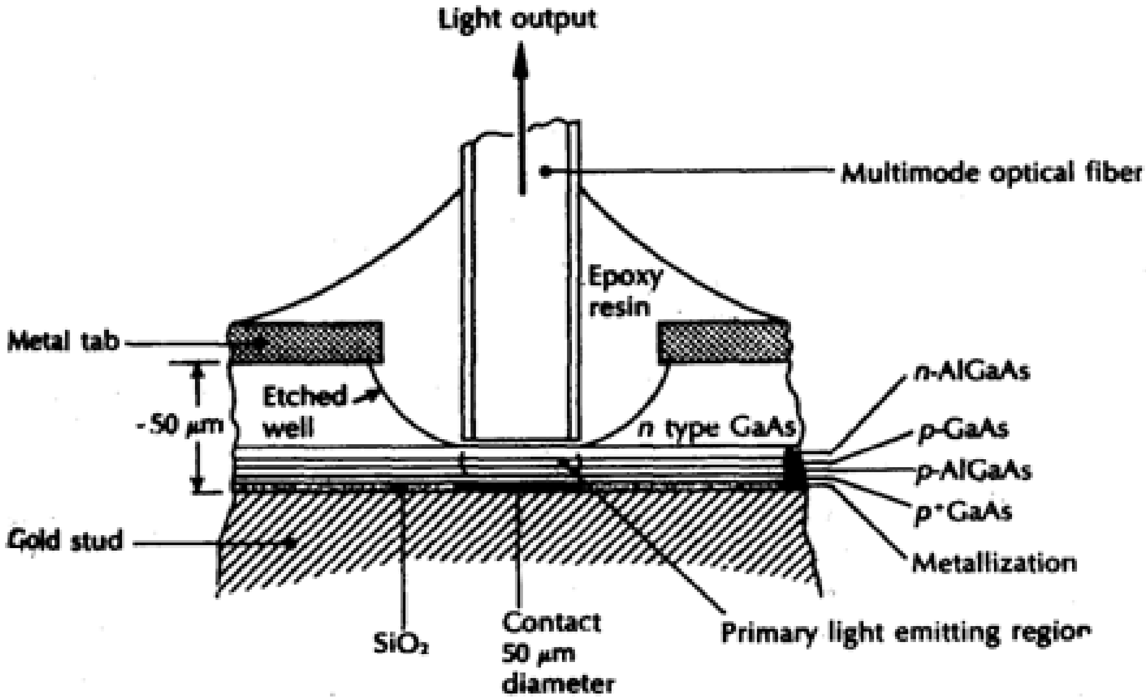
- **DISTANCE AND ALIGNMENT** BETWEEN EMISSION AREA & FIBER
- SLED EMISSION PATTERN
- MEDIUM BETWEEN EMITTING AREA & FIBER

- **DOUBLE HETROJUNCTION LED SURFACE EMITTERS GIVE MORE COUPLED OPTICAL POWER THAN GIVEN BY =n(1)**

SLED (contd)

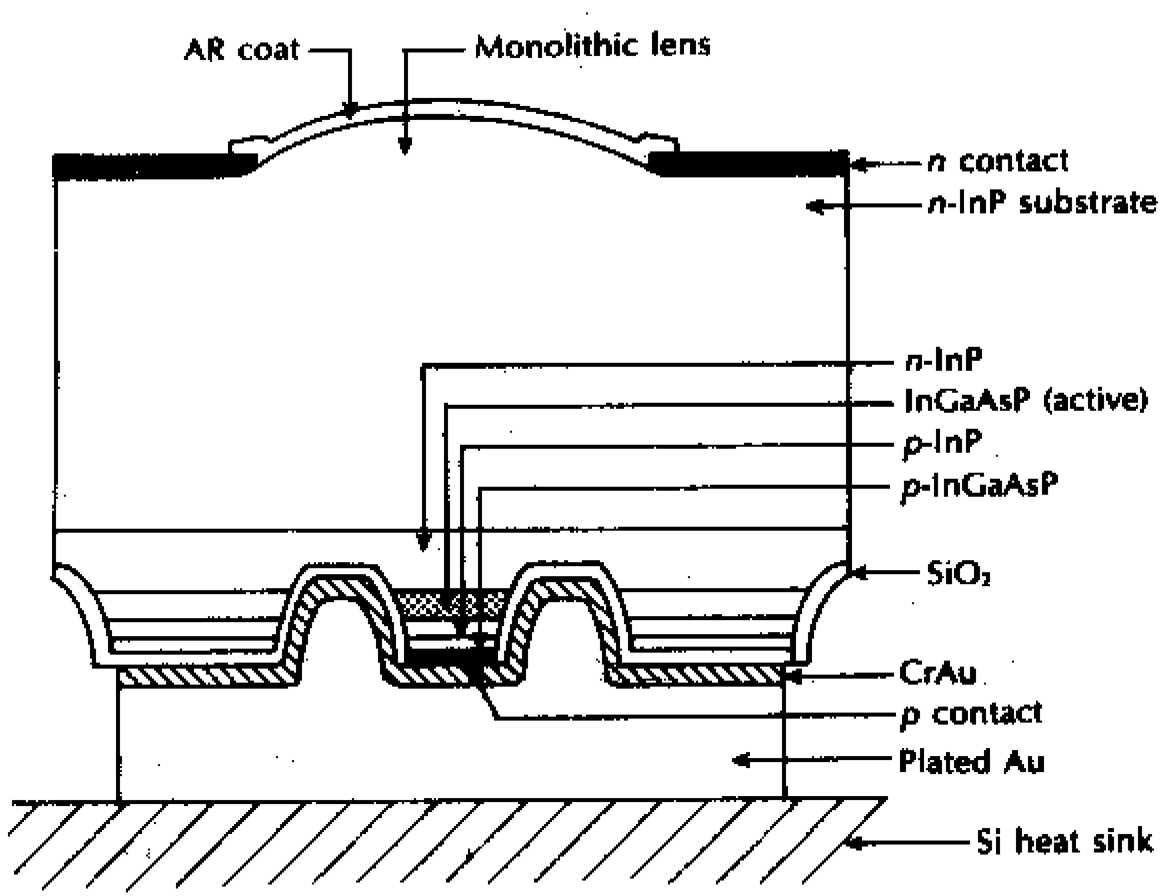
- MUCH OF THE LIGHT COUPLED INTO A MM FIBER FROM A LED IS LOST WITHIN A FEW HUNDRED METRES.
- HENCE **MORE POWER IS COUPLED INTO SHORTER LENGTH THAN LONGER LENGTH**.
- **THE SLED'S SUFFER FROM CURRENT SPREADING RESULTING IN REDUCED CURRENT DENSITY** & EFFECTIVE EMISSION AREA GREATER THAN CONTACT AREA.

Al Ga As DH SURFACE EMITTING LED (0.8-0.9 μm WAVE LENGTH)



The structure of an AlGaAs DH surface-emitting LED (Burrus type)

- INTERNAL ABSORPTION OF THIS DEVICE IS LOW DUE TO LARGE BAND GAP CONFINING LAYERS.
- THE ADDITION OF EPOXY RESIN IN THE ETCHED WELL TENDS TO REDUCE THE REFRACTIVE INDEX MISMATCH AND INCREASE THE EXTERNAL POWER EFFICIENCY OF THE DEVICE.

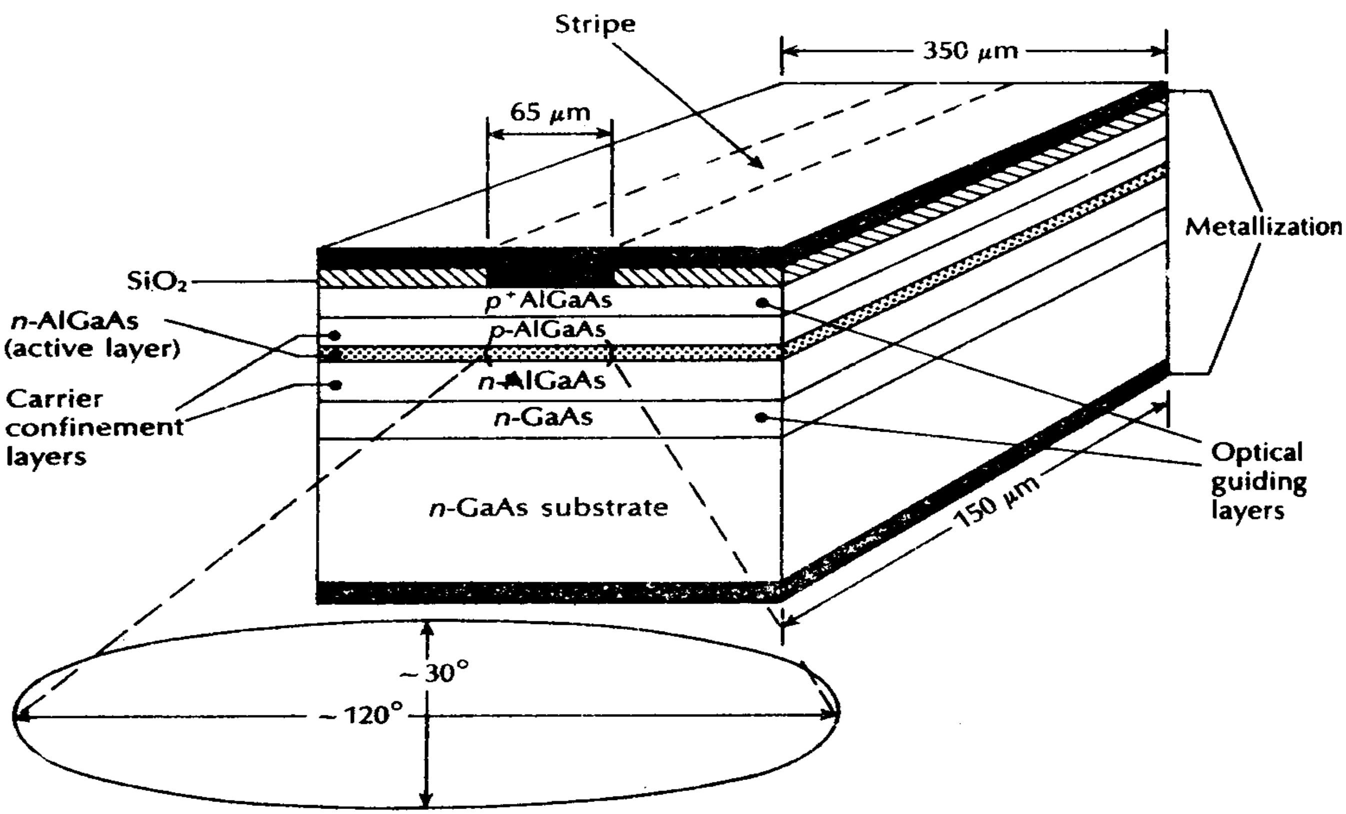


Small area InGaAsP mesa-etched surface-emitting LED structure

In Ga As P MESA ETCHED SELED STRUCTURE(contd)

- **MESA STRUCTURE** (mesa dia 20 to 25 μm at the active layer) REDUCES THE CURRENT SPREADING
- WAVE LENGTH = 1.3 μm
- THE STRUCTURE IMPROVES THE COUPLING η DUE TO FORMATION OF INTEGRAL LENS AT EXIT FACE.
- **TYPICAL DATA** : WITH A DRIVE CURRENT OF 50 mA, IT COUPLES 2 μw POWER INTO A SINGLE MODE FIBER.
- COUPLING η UPTO 15% CAN BE ACHIEVED WITH OPTIMISED DEVICES.

EDGE EMITTING LED'S (ELED)

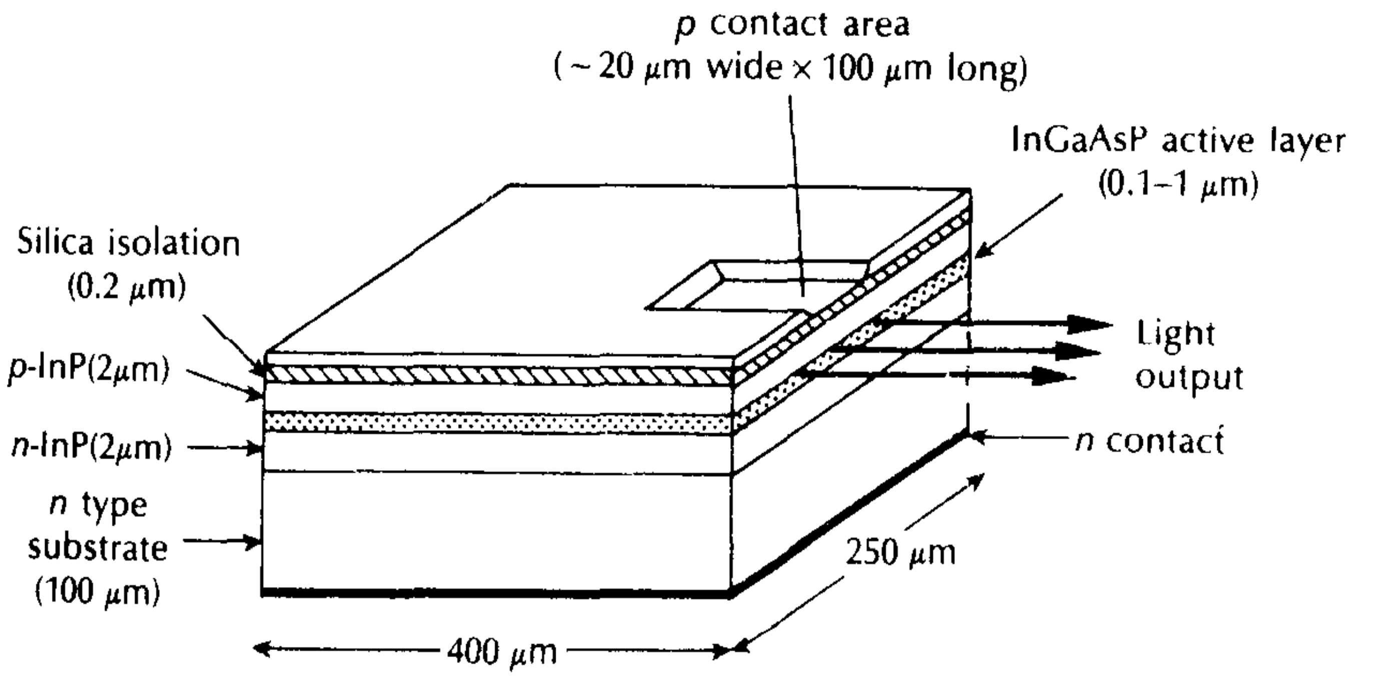


Stripe Geometry DH AlGaAs Edge Emitting LED

ELED (contd)

- ACTIVE LAYER (50 TO 100 μm) WITH TRANSPARENT GUIDING LAYERS REDUCES SELF ABSORPTION IN THE ACTIVE LAYER.
- O/P WITH HALF POWER WIDTH OF 30º & 120º
- MOST OF LIGHT EMISSION IS AT ONE END FACE ONLY
- EDGE EMITTERS COUPLE MORE OPTICAL POWER INTO LOW NA < 0.3 THAN SELED, AND OPPOSITE IS TRUE FOR NA > 0.3.
- **COUPLING η IS 3.5 to 6 TIMES THAN SELED**.
- USE OF LENS COUPLING INCREASES COUPLING η (5 TIMES).
- EDGE EMITTERS ALSO **GIVE BETTER MODULATION BW** (HUNDREDS OF MHz) THAN COMPARABLE SELED WITH THE SAME DRIVE LEVEL.
- ELED'S HAVE **LESSER SPECTRAL LINE WIDTH** THAN SELED.

TRUNCATED STRIPE In Ga As P EDGE EMITTING LED



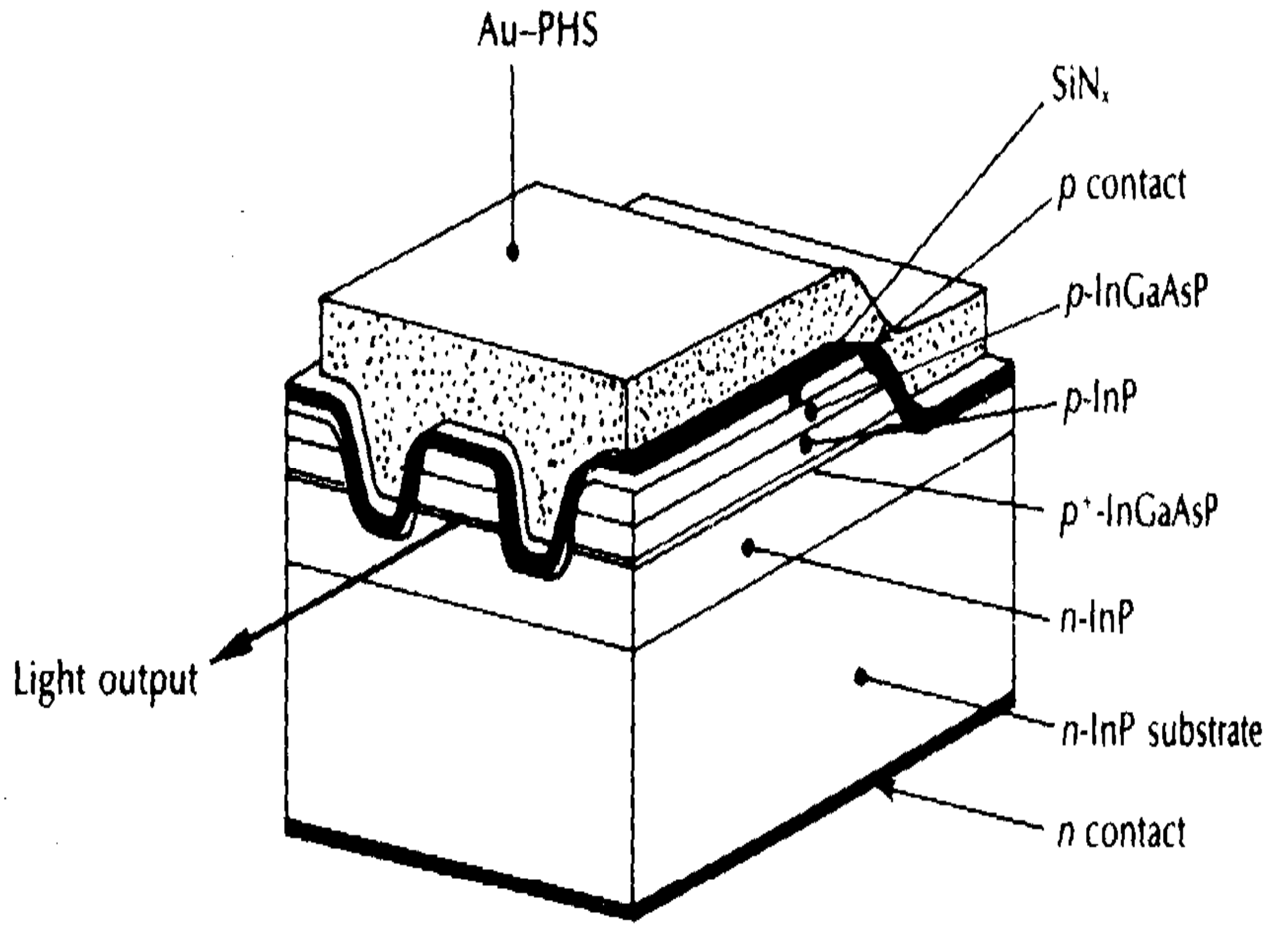
Truncated Stripe InGaAsP Edge Emitting LED

- **TRUNCATED STRIPE In Ga As P EDGE EMITTING LED (Contd**)

- OPERATING WAVE LENGTH = 1.3 μm.
- THE DEVICE IS DH EDGE EMITTING LED HAVING RESTRICTED LENGTH ,STRIPE GEOMETRY p – CONTACT ARRANGEMENT.
- THE EXTERNAL EFFICIENCY OF THE ELED IS HIGHER DUE TO LESSER INTERNAL ABSORPTION OF CARRIERS.
- SILICA LAYER GIVES THE ISOLATION BETWEEN THE p TYPE LAYERS.
- STRIPE 100 μm LENGTH

  20 μm WIDTH

HIGH SPEED In Ga As EDGE EMITTING LED'S



Mesa Structure High Speed LED

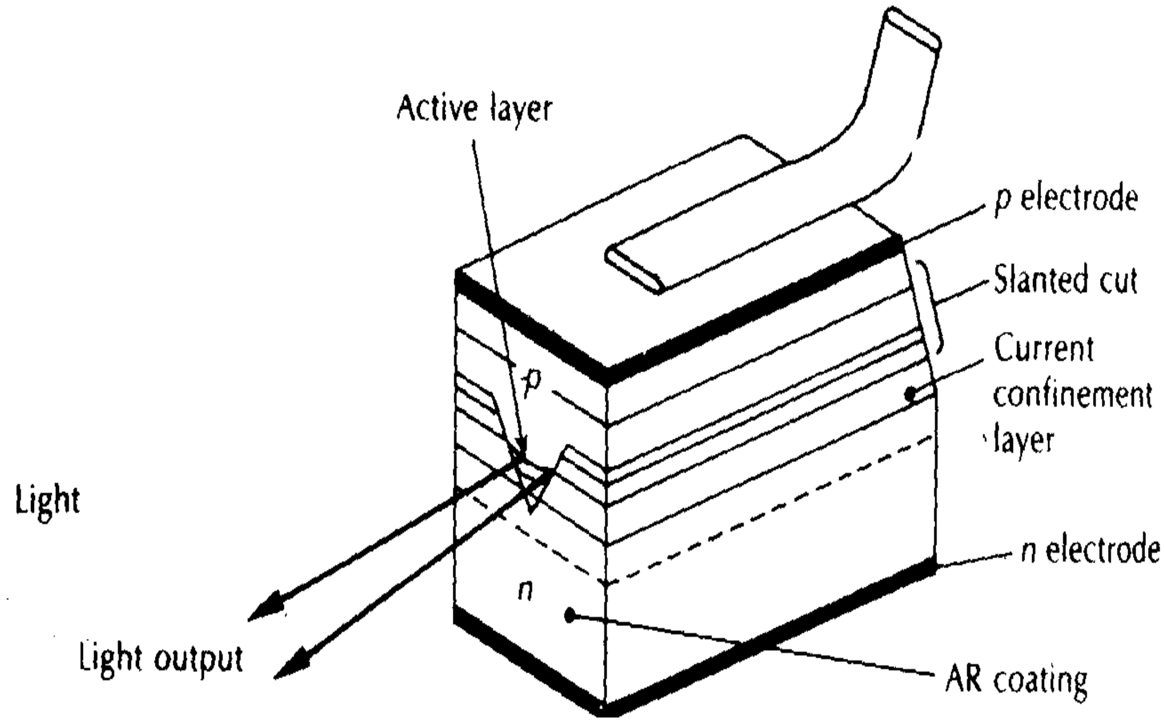
HIGH SPEED In Ga As EDGE EMITTING LED'S

- MESA STRUCTURE (8 µm WIDTH x 150 µm LENGTH FOR CURRENT CONFINEMENT).
- TILTED BACK FACE TO AVOID LASING ACTION .
- ACTIVE LAYER IS HEAVILY DOPED (WITH Zn) TO REDUCE MINORITY CARRIER LIFE TIME & IMPROVE MODULATION BW.
- MODULATION BW OF 600 MHz IS POSSIBLE .

HIGH SPEED In Ga As EDGE EMITTING LED'S

- 4 μw to 6 μw POWER CAN BE LAUNCHED AT *100 m*A AND 240 mA DRIVE CURRENT RESPECTIVELY INTO A SINGLE MODE FIBER.
- 7μw POWER IN BURIED HETROSTRUCTURE WITH 20 mA DRIVE CURRENT LAUNCHED INTO SM FIBER

V-GROOVED SUBSTRATE BH ELED



V-grooved substrate BH ELED

V-GROOVED SUBSTRATE BH ELED

FRONT FACE IS AR COATED

REAR FACE ETCHED SLANTLY TO SUPPRESS LASING

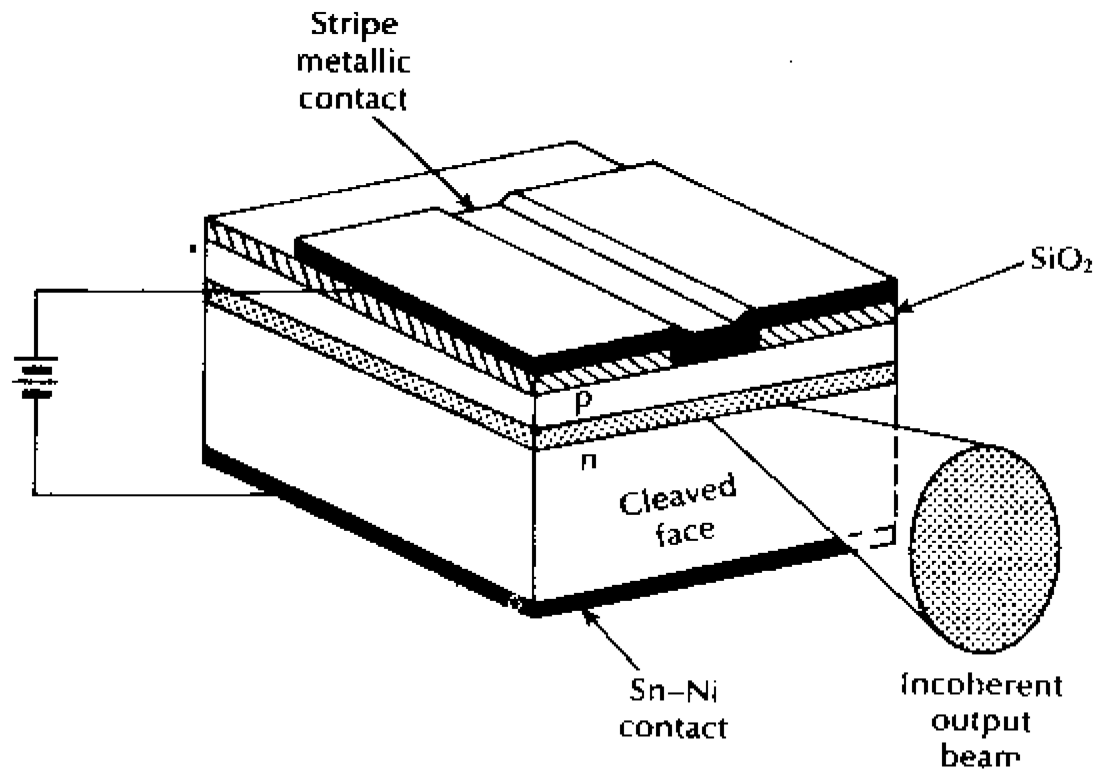
$\lambda \rightarrow 1.3$ μm, 3dB Mod BW ≈ 350 MHz

OPT. POWER ≈ 30 μW (INTO SINGLE MODE FIBER)

BY LENS COUPLING, POWER **UPTO 200 μw** CAN BE LAUNCHED WITH DRIVE CURRENT OF 100 mA.

SPECTRAL WIDTH = 50 nm (narrow)

Al Ga As CONTACT STRIPE SLD



AlGaAs contact stripe SLD

Al Ga As CONTACT STRIPE SLD (contd)

PROVIDES SIGNIFICANT BENEFITS OVER ELED & SLED

Advantages :

1. HIGH OUTPUT POWER
2. DIRECTIONAL BEAM
3. NARROW SPECTRAL LINE WIDTH
4. HIGHER MODULATION BW.

Al Ga As CONTACT STRIPE SLD(contd)

- p- n JUNCTION IN THE FORM OF A LONG RECTANGULAR STRIPE .
- ONE END OF THE DEVICE IS MADE LOSSY IN A MANNER TO PREVENT REFLECTIONS (TO SUPRESS LASING)
- .OUTPUT IS FROM THE OTHER END.DEVICE GIVES PEAK O/P POWER OF 60 mw AT 0.87 µm WAVELENGTH
- ANTI REFLECTION COATING APPLICATION REDUCES LASER RESONANCE POSSIBILITY
.

Al Ga As CONTACT STRIPE SLD(contd)

- **DEVICE PARAMETERS**
- 550 µw POWER – 50 µm DIA MMGI FIBER-25O mA
- 250 µw POWER – SINGLE MODE FIBER – 100 mA
- **LINEWIDTH :** 30 TO 40 nm COMPARED TO 60 TO 90 nm ASSOCIATED WITH CONVENTIONAL ELED'S

InGaAsP / InP SLD

- STRUCTURE EMITS AT 1.3 μm

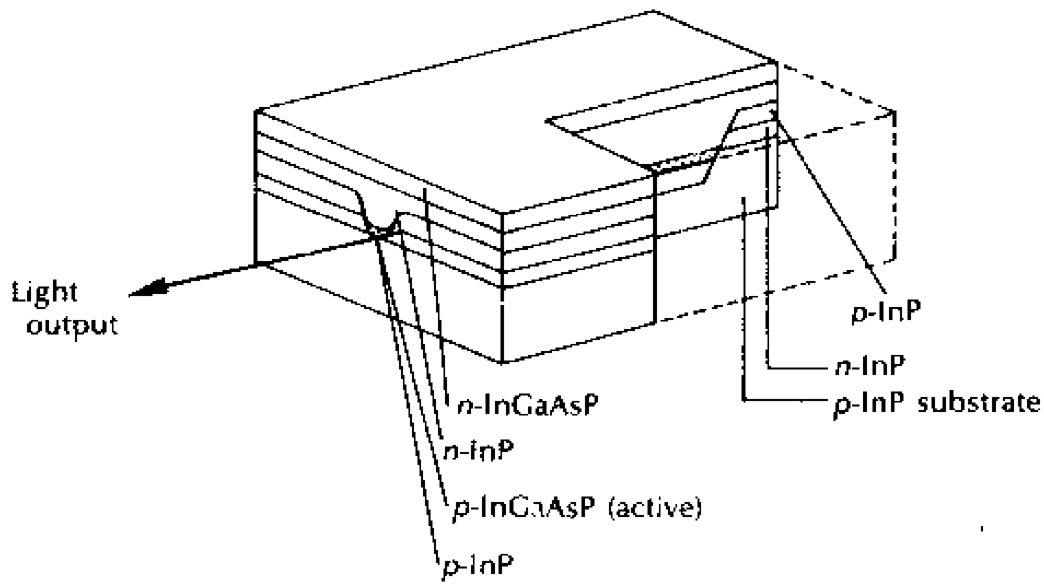
- BURRIED ACTIVE LAYER WITHIN V-SHAPED GROOVE ON p - TYPE InP SUBSTRATE.

- LOW LEAKAGE CURRENT

- A LIGHT DIFFUSION SURFACE IS PLACED WITHIN THE DEVICE WHICH SCATTERS THE BACKWARD LIGHT.THIS SCATTERING FROM THE ACTIVE LAYER DECREASES FEEDBACK INTO THIS LAYER

- AN AR COATING IS PROVIDED ON THE 0/ P FACET.
- HIGH 0 / P POWER OF 1 mw CAN BE COUPLED INTO A SINGLE MODE FIBER.

InGaAsP SLD / InP SLD



High output power InGaAsP SLD

DRAWBACKS - SLD

-HIGH DRIVE CURRENT

-NON – LINEAR O/P CHARACTERISTIC.

-INCREASED TEMP. DEPENDECE OF O/P POWER.

LENS COUPLING TO FIBER

COUPLING η = $\dfrac{\text{POWER COUPLED (INTO THE FIBRE)}}{\text{TOTAL POWER EMITTED}}$

COUPLING EFFICIENCY IS GENERALLY POOR (1 T0 2%)

USE OF LENSES IMPROVES THE COUPLING EFFIIENCY BY 2 TO 5 TIMES.

FOR BETTER COUPLING FIBER CORE DIA >> WIDTH OF EMISSION REGION.

LENS COUPLING CONFIGURATIONS

.a)SPHERICAL POLISHED STRUCTURES

b) SPHERICALLY ENDED OR TAPERED FIBER COUPLING

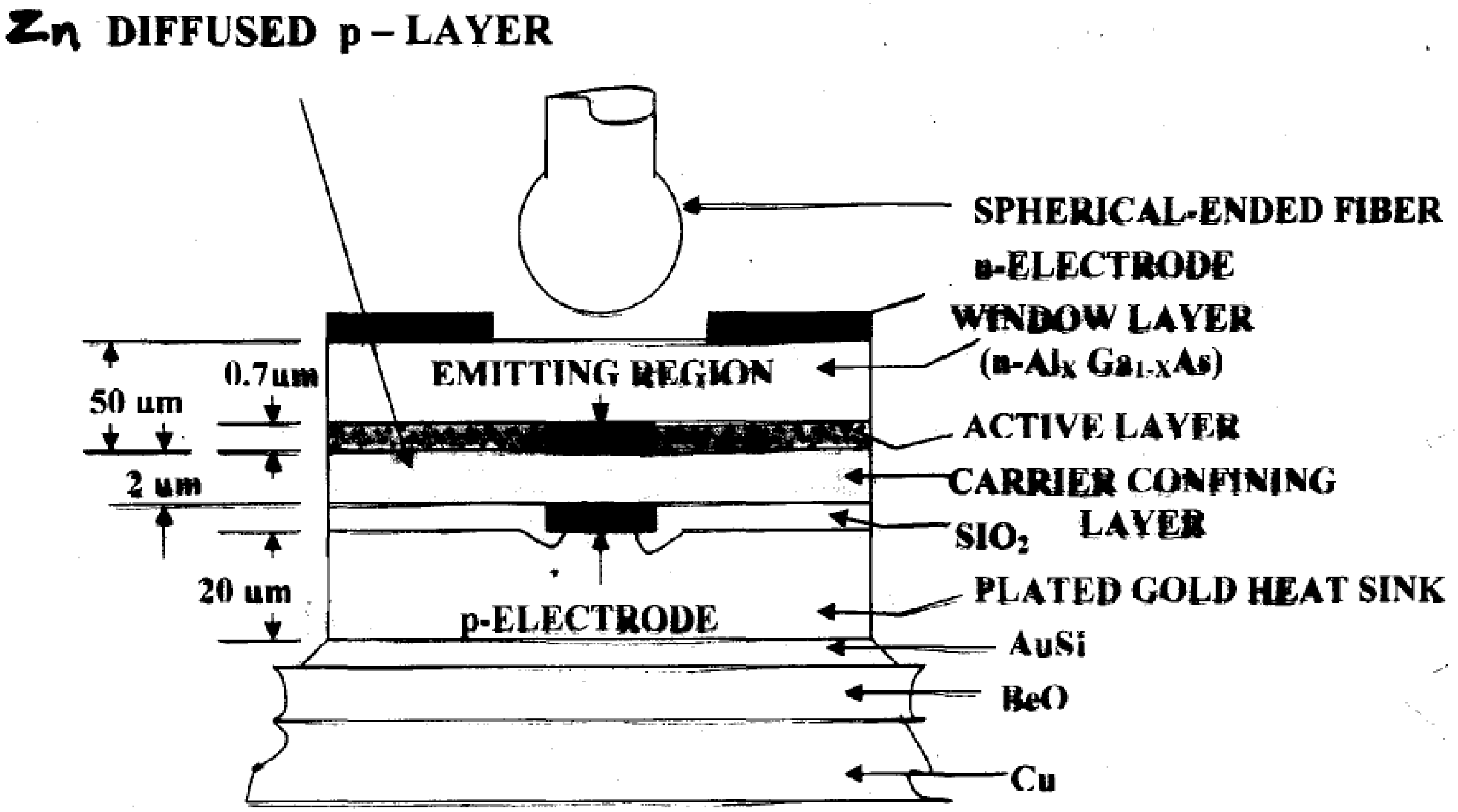
c) TRUNCATED MICROLENSES

d)GRIN-ROD LENSES

e) INTEGRAL LENS STRUCTURE

Note :LED output is not fully coupled into the fiber because of narrow acceptance angle of the fiber.

Spherical-Ended Fiber Coupled AlGaAs LED



SPHERICALLY ENDED FIBER COUPLED Al Ga As LED

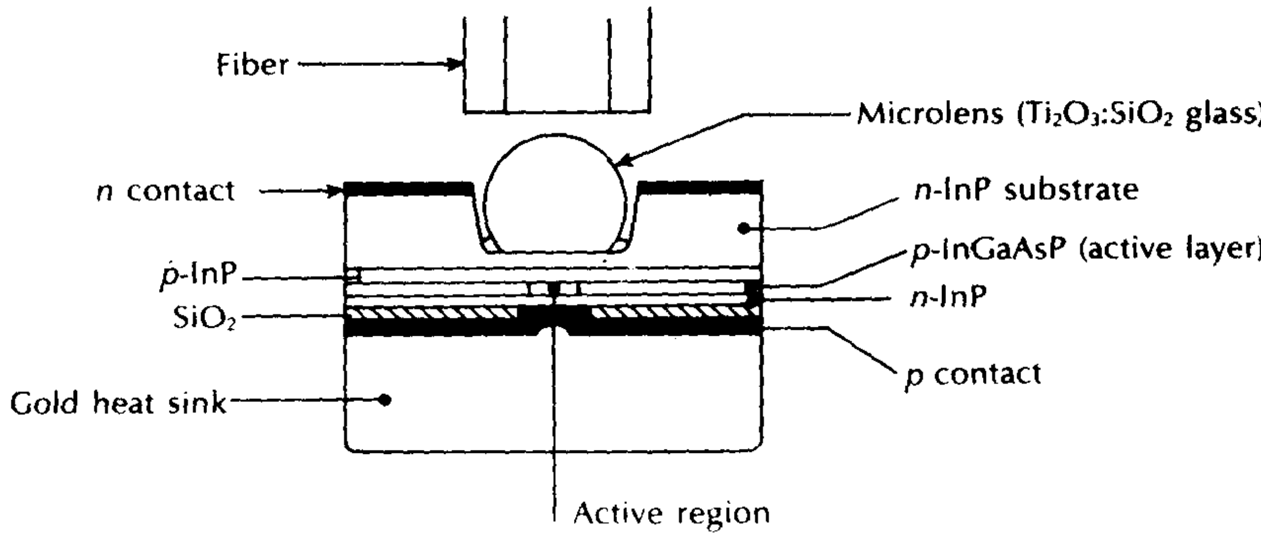
- EMITTING DIA = 35 µm
- CORE DIA (OF FIBER)= 75 – 110 µm

} RATIO OF 1: 2 (min)

- **COUPLING EFFICIENCY OF 2 TO 5 TIMES CAN BE ACHIEVED THR THE USE OF SPHERICAL FIBER LENS.**

- THE DEVICE IS A PLANAR SURFACE EMITTING STRUCTURE WITH THE SPHERICAL ENDED FIBER ATTACHED TO THE CAP BY EPOXY RESIN.
- **COUPLING EFFICIENCY = 6 %**

USE OF TRUNCATED SPHERICAL MICROLENS FOR COUPLING THE EMISSION FROM AN InGaAsP surface EMITTING LED



- OPERATING wave length = 1.3 μm
- EMISSION REGION DIA SHOULD BE MUCH SMALLER THAN CORE DIA OF THE FIBER.
- **TYPICAL VALUES (for a step Index fiber**)
- ACTIVE DIA : 14 μm
- CORE DIA : 85 μm

  NUM APERTURE : 0.16

COUPLING η INCREASED BY A FACTOR OF 13.

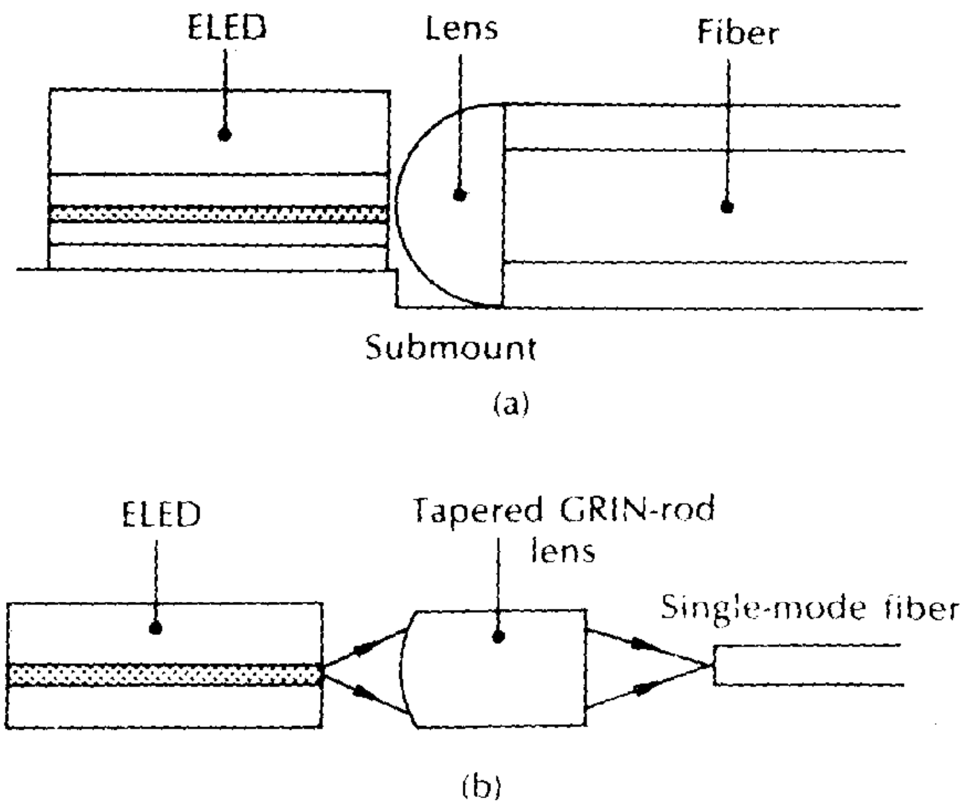
OVERALL POWER CONVERSION EFFICIENCY (η PC)

$$= \left(\frac{\text{OPT POWER COUPLED INTO FIBER}}{\text{ELECT. POWER APPLIED AT TERMIALS}} \right)$$

IS STILL LOW= **0.4%**

NOTE : THEORY SUGGESTS POSSIBLE INCREASE OF UPTO 30 TIMES IN THE COUPLING η)

LENS COUPLING WITH EDGE EMITTING LED'S



Lens coupling with edge-emitting LEDs: (a) lens-ended fiber coupling; (b) tapered (plano-convex) GRI N-rod lens coupling to single-mode fiber.

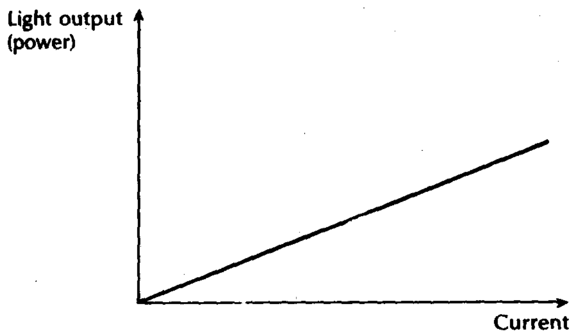
LENS COUPLING WITH EDGE EMITTING LED’S

- HIGHER POWER CAN BE COUPLED INTO SINGLE MODE FIBERS IN CASE OF EDGE EMITTING LED’S THAN SELED’S.
- **TAPERED FIBER – LENSES YIELD A COUPLING EFFICIENCY OF 15%**
- **COUPLING** $\eta = \dfrac{\textbf{COUPLED POWER}}{\textbf{TOTAL EMITTED POWER}}$

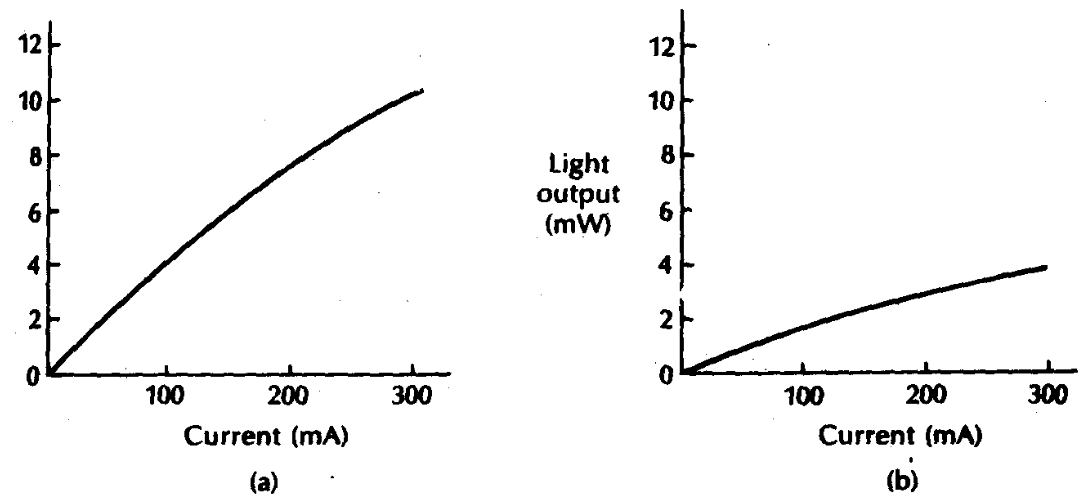
A) LENS – ENDED FIBER COUPLING

B) TAPERED(PLANO - CONVEX) GRIN – ROD LENS COUPLING TO SINGLE MODE FIBER.

LED CHARACTERISTICS



An ideal light output against current



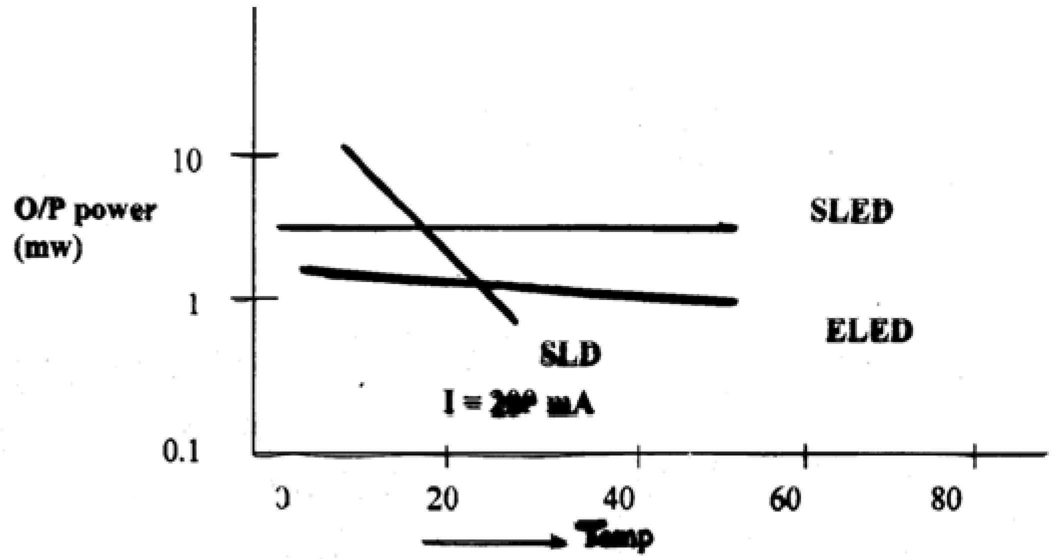
(a) an AlGaAs **surface emitter** with a 50 μm diameter

(b) an AlGaAs **edge emitter** with a 65 μm wide stripe and 100 μm length.

<u>SURFACE EMITTER LED RADIATES SIGNIFICANTLY MORE OPTICAL POWER THAN EDGE EMITTER LED</u>.

BOTH ARE REASONABLY LINEAR AT MODERATE CURRENTS

LIGHT OUTPUT TEMP DEPENDENCE-LED

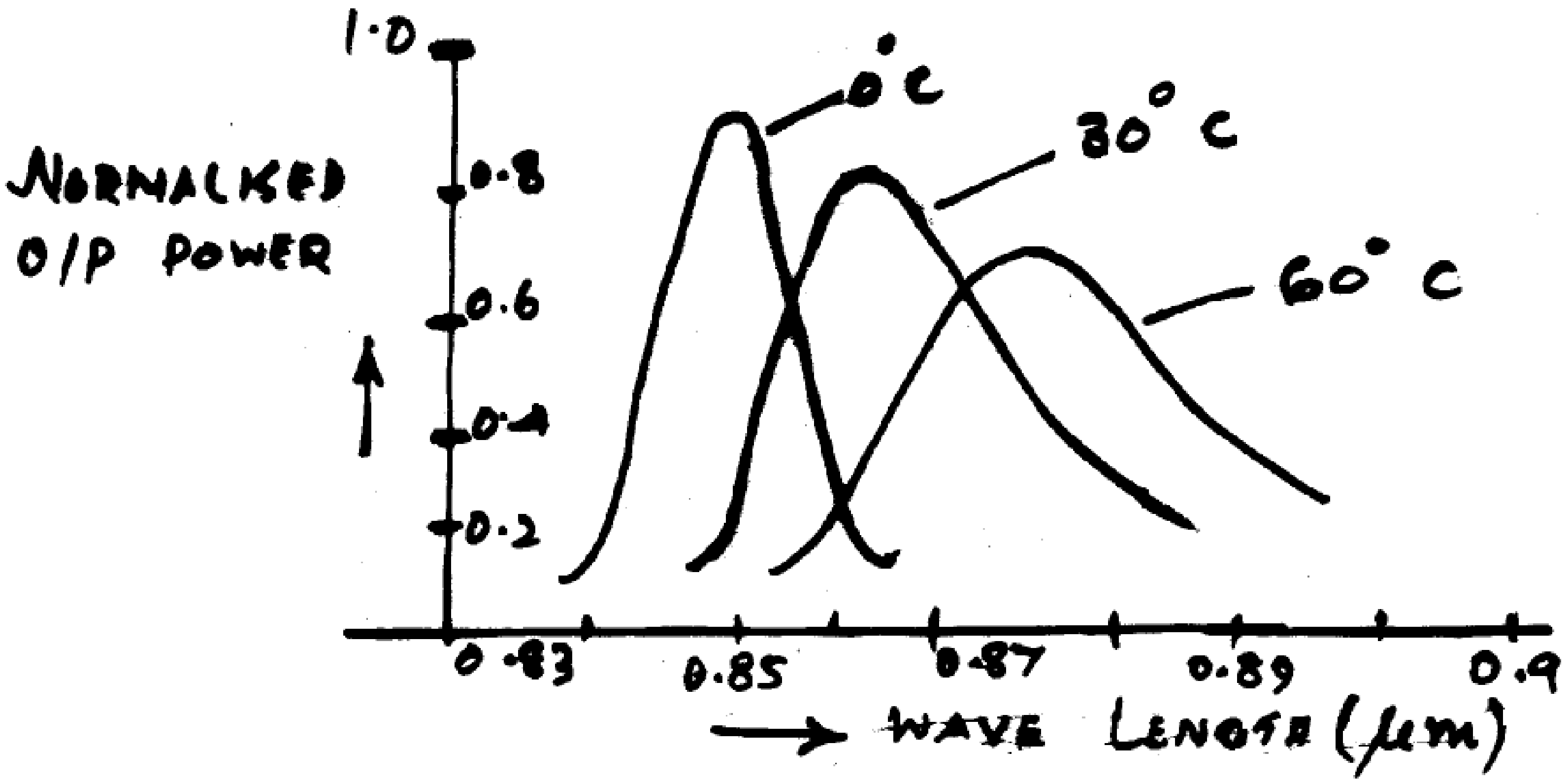


- THE INTERNAL QUANTUM EFFICIENCY OF LED'S DECREASES EXPONENTIALLY WITH INCREASING TEMPERATURE & SO THE LIGHT OUTPUT DECREASES AS P-N JUNCTION TEMPERATURE INCREASES.

- **ELED EXHIBITS GREATER TEMPERATURE DEPENDENCE THAN SLED**

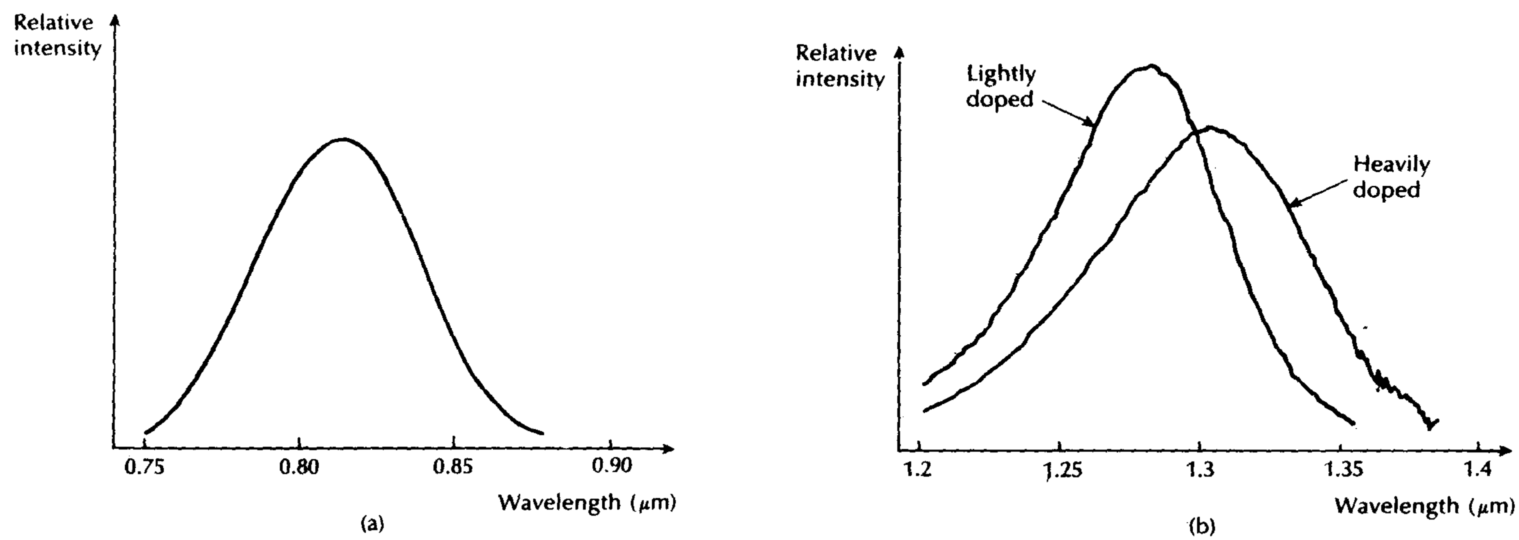
- **OUTPUT OF SLD WITH ITS STIMULATED EMISSION IS STRONGLY DEPENPANT ON THE JUNCTION TEMPERATURE**.

CURVES FOR AN Al Ga AS SURFACE EMITTING LED



OUTPUT SPECTRA TENDS TO BROADEN AT A RATE **0.1 TO 0.3 nm/deg** INCREASE IN TEMP. (DUE TO GREATER ENERGY SPREAD IN CARRIER DISTRIBUTIONS)

OUTPUT SPECTRUM



LED output spectra: (a) for an AlGaAs surface emitter with doped active region .(b) for an InGaAsP surface emitter showing both the lightly doped and heavily doped cases.

-SPECTRAL LINEWIDTH OF LED OPERATING AT ROOM TEMP IN THE 0.8 TO 0.9 μm WAVELENGTH BAND IS 25 – 40 nm AT HALF POWER POINTS . **LINE WIDTH INCREASES DUE TO INCREASED DOPING LEVELS**.

-TYPICAL VALUES FOR ELED & SLED IS 75 nm & 125 nm RESP at 1.3 μm

MODULATION

- TO TRANSMIT INFORMATION ,IT IS NECESSARY TO MODULATE A PROPERTY OF THE LIGHT ,WITH THE INFORMATION SIGNAL.
- **PROPERTY : INTENSITY , FREQUENCY, PHASE , POLARISATION (DIRECTION)**

INTENSITY MODULATION (IM) OF THE SOURCE IS THE MAJOR MODULATION STRATEGY.

- IM IS EASY TO IMPLEMENT (variation of drive current of the source)
- ANALOG INTENSITY MODULATION IS USUALLY EASIER TO APPLY BUT REQUIRES LARGE S/N RATIO , AND HENCE LIMITED TO SHORT DISTANCE APPLICATIONS (NARROW BW).
- **DIGITAL INTENSITY MODULATION GIVES IMPROVED NOISE IMMUNITY , BUT REQUIRES WIDER BW'S.** IDEALLY SUITED FOR OFC, AS LARGE BW IS AVAILABLE .

MODULATION BANDWIDTH

ELECTRICAL DEFINITION :

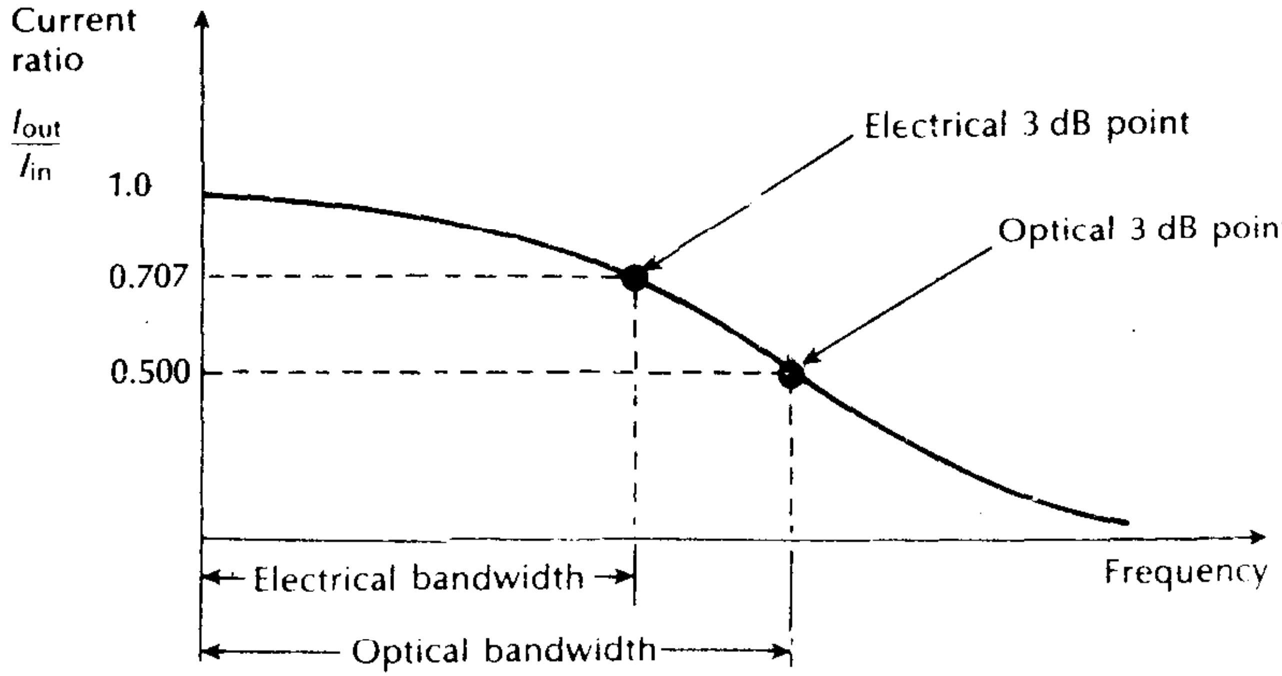
ELECT SIGNAL POWER HAS DROPPED TO HALF ITS CONSTANT VALUE DUE TO MODULATED PORTION OF THE OPTICAL SIGNAL (3 DB DOWN). **THIS CORRESPONDS TO THE FREQ AT WHICH ELECT POWER IS REDUCED BY 3 db wrt I/P ELECT POWER ie WHEN OUTPUT CURRENT HAS DROPPED TO 0.707 OF INPUT CURRENT.**

MODULATION BANDWIDTH

MODULATION BANDWIDTH (OPTICAL) : FREQUENCY RANGE BETWEEN ZERO AND THIS HIGH FREQUENCY 3 DB POINT **WHEN OUTPUT CURRENT HAS DROPPED TO 0.5 OF THE INPUT CURRENT**.

OPTICAL BANDWIDTH IS NORMALLY $\sqrt{2}$ TIMES GREATER THAN THE ELECTRICAL BANDWITH.

MODULATION BANDWIDTH (ELECT & OPTICAL)



RATIO OF ELECT. O/P POWER TO ELECT I/P POWER IN db = RE db

R E db = 10 Log_{10} Elect POWER OUT (DET)/ Elect POWER IN(SOURCE)

α10 Log_{10} [Iout/I in]^2 AT 3db (Iout/I in)^{2}= ½

Iout/I in = 1/√2 = 0.707

$$RO = 10 \log_{10} \frac{\text{OPT power out (DET)}}{\text{OPT power in (SOURCE)}}$$

$$= 10 \log_{10} \frac{I\ out}{I\ in} \qquad \text{At 3 db} \quad \frac{I\ out}{I\ in} = 1/2$$

(Due to linear light/ current relationship) of the source and detector

Opt. BW = √ 2(Elect BW)

RELIABILITY OF LED’S

- LED’S EXHIBIT **GRADUAL DEGRADATION** IN ADDITION TO **RAPID DEGRADATION**.
- **RAPID DEGRADATION IS DUE TO GROWTH OF DISLOCATIONS AND PRECIPITATE – TYPE DEFECTS IN ACTIVE REGION** (CALLED **DLDs & DSDs**)
- **THESE DEFECTS DEPEND UPON INJECTION CURRENT DENSITY, TEMP & IMPURITY CONCENTRATION** .
- **LONG TERM DEGRADATION COULD BE DUE TO MIGRATION OF IMPURITIES INTO THE ACTIVE REGION**.

RELIABILITY(contd)

- <u>Output power</u>

Pout : INITIAL O/P POWER

β_r : DEGRADATION RATE = β_0e-Ea/KT

Where β_0 – PROPORTIONALITY CONSTANT

K- BOLTZMAN'S CONSTANT

OPT. POWER O/P Pe(t) = Pout $e^{-\beta_r t}$

T- ABS. TEMP. OF THE EMITTING REGION.

Ea – ACTIVATION ENERGY ≈ 0.56 TO 1.0 ev FOR SLED'S (dependant upon material and structure of device)

AVG. LIFE OF SLED'S

-10^6 TO 10^7 HOURS(100 TO 1000 YRS)

(FOR CW OPERATION AT ROOM TEMP FOR AlGaAs DEVICES)

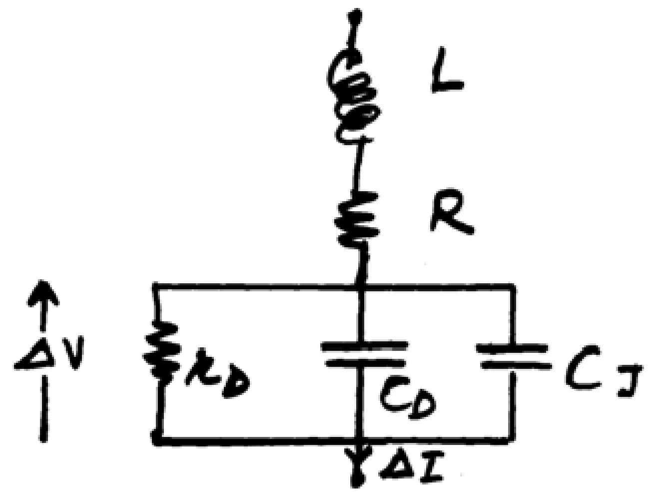
- IN EXCESS OF 10^9 HRS FOR SURFACE EMITTING InGaAsP LED'S.

- **DEVICE LIFE TIME IS OFTEN DETERMINED FOR A 50% DROP IN LIGHT OUTPUT FROM THE DEVICE**

- **JUNCTION TEMP, EVEN FOR A DEVICE OPERATING AT ROOM TEMP. IS LIKELY TO BE WELL IN EXCESS OF ROOM TEMP, WHEN SUBSTANTIAL DRIVE CURRENTS ARE PASSED**

BEHAVIOUR AT HIGH FREQUENCIES –LED'S.

To study the behavior at high freq, let us consider eqvt. circuit of a LED.



L,R (INDUCTANCE & RESISTANCE OF SEMICONDUCTOR)

C_J = JUNCTION CAPACITANCE

C_D=diff. capacitance

R_d=shunt resistance

rd,cd & cj are non-linear components

$Cj=\Delta Q/\Delta V$

Where Q=charge stored in depletion layer

<u>BEHAVIOUR AT HIGH FREQUENCIES –LED'S (contd)</u>

$C_J=C_0/(1-V/V_d)^{1/2}$

Where C_0 =cap.of unbiased junction

V=applied voltage

V_d=diffusion potential

Y_d=admittance of forward biased diode =1/rD+jw C_d=J1A/$V_=$ $I_{1/V1}$

Where A=junction area

I_1=AC Component of current

We need to find values of rD $_\&$ Cd to know behavior of LED at high freq.

BEHAVIOUR AT HIGH FREQUENCIES – LED'S(contd)

$Y_D=1/r_D+j\ w\ C_D$

There is time varying diffusion length ,that is a complex function of freq.

Similarly there are time varying components of current density J1 and optical o/p power density P1, that result from sinusoidal component of driving voltage V1.

$J1= J0(1+jwt)^{1/2}$ ev1/KT

- Admittance $Yd=J1A/V1=J0(1+jwt)^{1/2}eA/KT=eJ0A/KT(1+jwt)^{1/2}$
- Putting $I_0=J0A$ & squaring both sides
- $YD2=1/rD2+j2wcD/rD-w2cD2=(eI0/KT)2(1+jwt)$
- Equating real parts
- $1/rD^2-w^2cD^2=(eI_0/KT)^2$
- Neglecting w^2cD^2(being very small)

- $rD = KT/eI_0$
- Equating imaginary parts $2c_D/rD = J(eI_0/KT)^2$

$2cD = rD \, .J(eI_0/KT)^2$

$= KT/eI_0.J(eI_0/KT)^2 = J.(eI_0/KT)$

$C_d = J/2rD$

AT HIGH FREQ., Cd FALLS [$C_d \, \alpha \, 1/\omega^2$], JN BEHAVIOUR BECOMES DOMINATED BY DEPLETION LAYER CAPACITANCE

THE TOTAL OPTICAL POWER DENSITY

= TOTAL NO OF RADIATIVE RECOMBINATIONS PER SEC PER UNIT AREA MULTIPLIED BY MEAN PHOTON ENERGY.

$P = {}_0\int^X Eph(dn/dt)r\ dx$

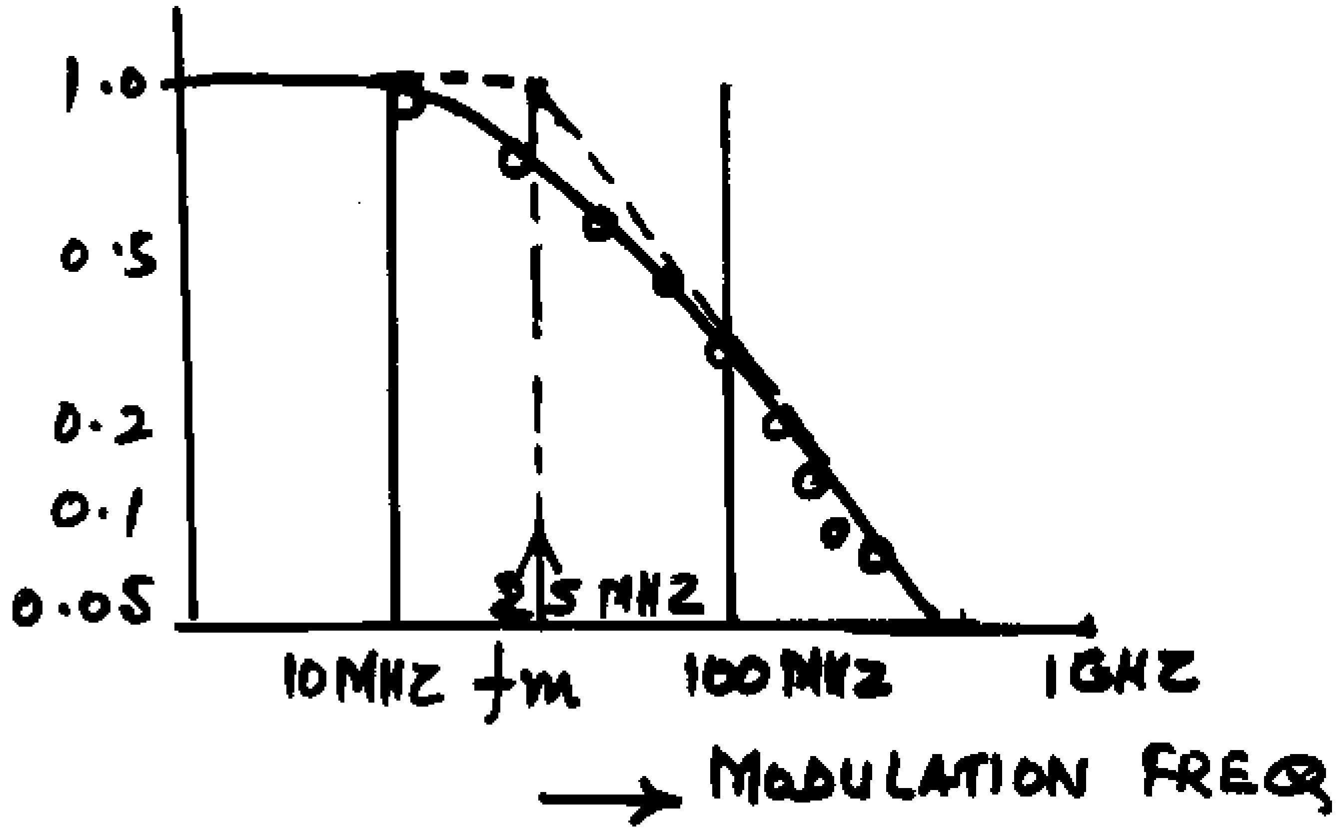
P_o(ss comp) + P_1 (time varying comp)

BY INTEGRATION & SUBSTITUTION

$|P_1/J_1 = | P_o/J_o * 1/(1+\omega 2\ \ J2)^{1/2}$

PLOT OF THE ABOVE =n

I1 THE CURRENT FLOWING IN rd & Cd VARIES WITH FREQUENCY AND FALL IN OPT. POWER ABOVE FREQ. OF ½πJ IS SNPERIMPOSED ON THIS CKT RESPONSE.



- AT FREQUENCIES ABOVE fm=1/2πj, SOURCE η FALLS.

-DECREASING t INCREASES THE UPPER CUT OFF FREQ.

-REDUCING RADIATIVE LIFE TIME tr, MAXIMISES THE QUANTAM η AT LOW MOD. FREQ. AND HIGH FREQ. CUTOFF.--