LED

MAJOR REQUIREMENTS - OPTICAL FIBER EMITTER

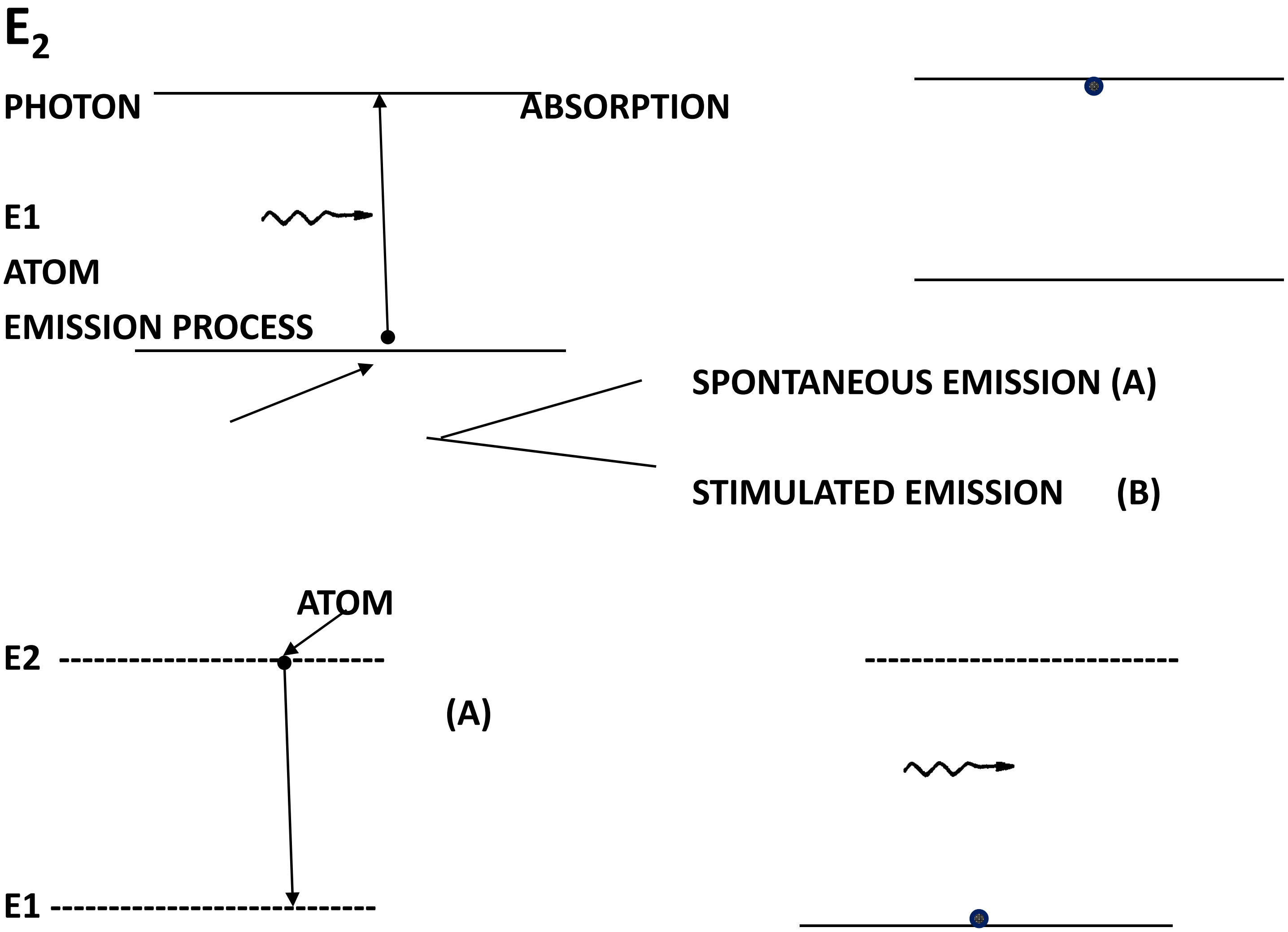
1. LIGHT 0/P SHOULD BE HIGHLY DIRECTIONAL.
2. SOURCE SHOULD BE ‘LINEAR’ (MIN. DISTORTION AND NOISE)
3. SHOULD EMIT LIGHT AT WAVELENGTHS WHERE THE FIBER HAS LOW LOSSES & LOW DISPERSION.
4. SHOULD BE CAPABLE OF SIMPLE SIGNAL MODULATION OVER A WIDE BW (AUDIO TO GHz)
5. MUST COUPLE SUFFICIENT OPTICAL POWER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

INITIAL STATE **FINAL STATE**



E_2

PHOTON

ABSORPTION

E1

ATOM

EMISSION PROCESS

SPONTANEOUS EMISSION (A)

STIMULATED EMISSION (B)

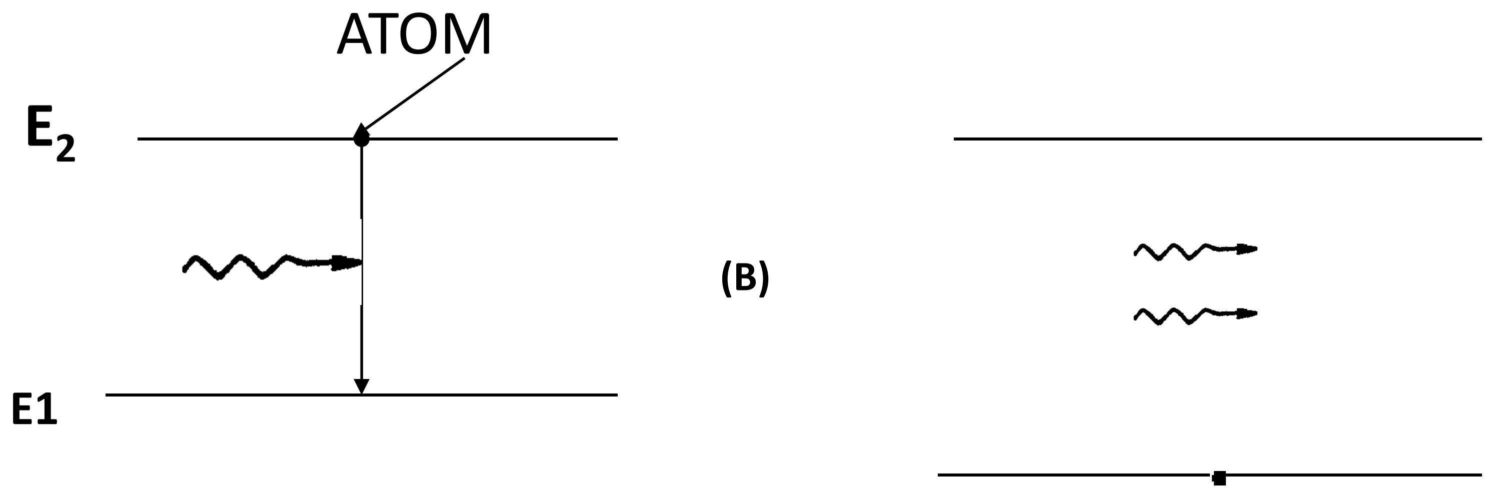
ATOM

E2

(A)

E1

- 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

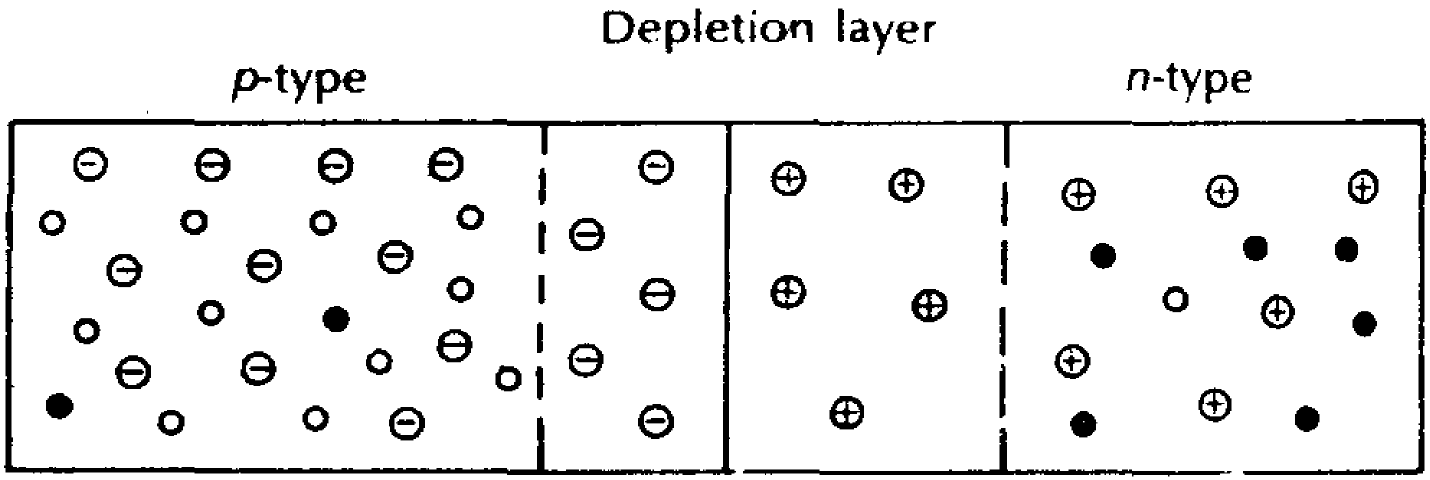
DISADVANTAGES:-

- 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

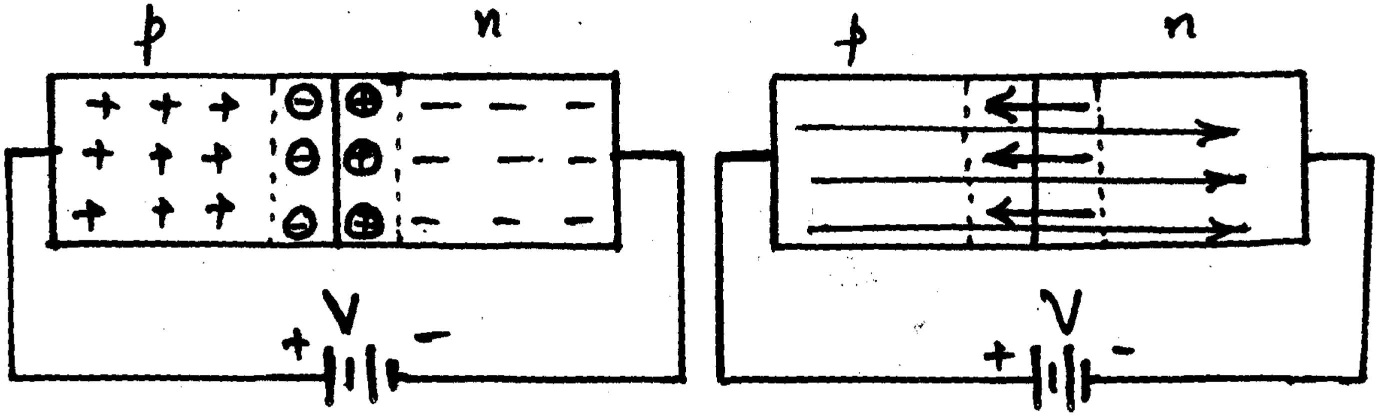
THE P-N JUNCTION



Impurities and charge carriers at the PN junction

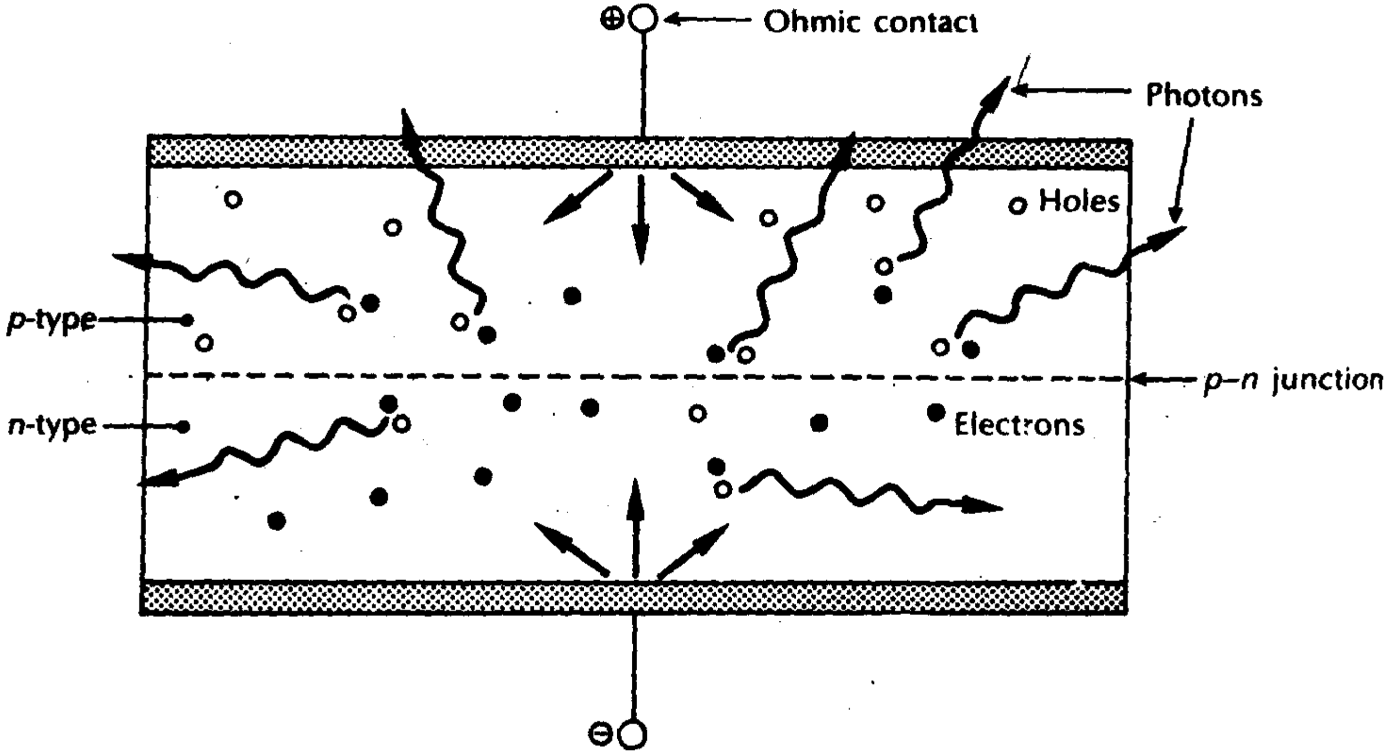
BARRIER POTENTIAL : 0.3V (Ge), 0.7V (Si) AT 25^{0}C

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**.

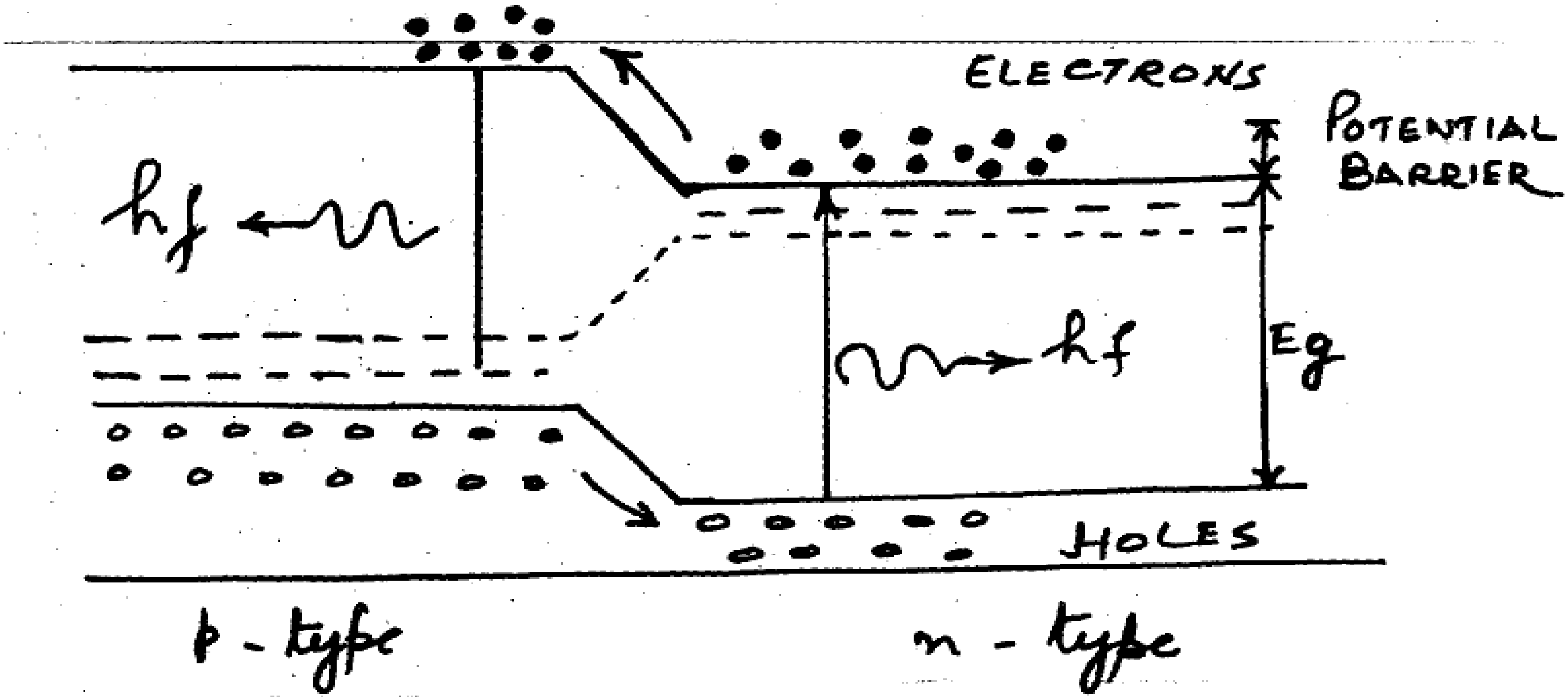
CARRIER COMBINATION GIVING SPONTANEOUS EMISSION OF LIGHT



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 = $\frac{\text{NO OF PHOTONS GENERATED}}{\text{NO OF ELECTRONS INJECTED}}$

RECOMBINATION

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

INTERNAL QUANTAM, η = $\frac{\text{RADIATIVE RECOMBINATION RATE}}{\text{TOTAL RECOMBINATION RATE}}$

$$= r_r / r_r + r_{nr}$$

$$= r_r / r_t$$

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

- **LED’S POWER & EFFICIENCY (contd)**

- 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)

Above equation, GIVES STEADY STATE ELECTRON DENSITY WHEN A CONSTANT CURRENT IS FLOWING INTO JUNCTION

AT STEADY STATE, TOTAL NO OF CARRIER RECOMBINATIONS PER SECOND, = $\mathbf{r_t = J/ed}$

$\mathbf{= r_r + r_{nr}}$

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

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

$$= R_r / R_t$$

Or, $R_r = \eta_{int} \times R_t$ = $\boldsymbol{\eta_{int} \times i/e}$

= total no of photons generated per sec.

ENERGY IN EACH PHOTON $E_g = hf$ 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.

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

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

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

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

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

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

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

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

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

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

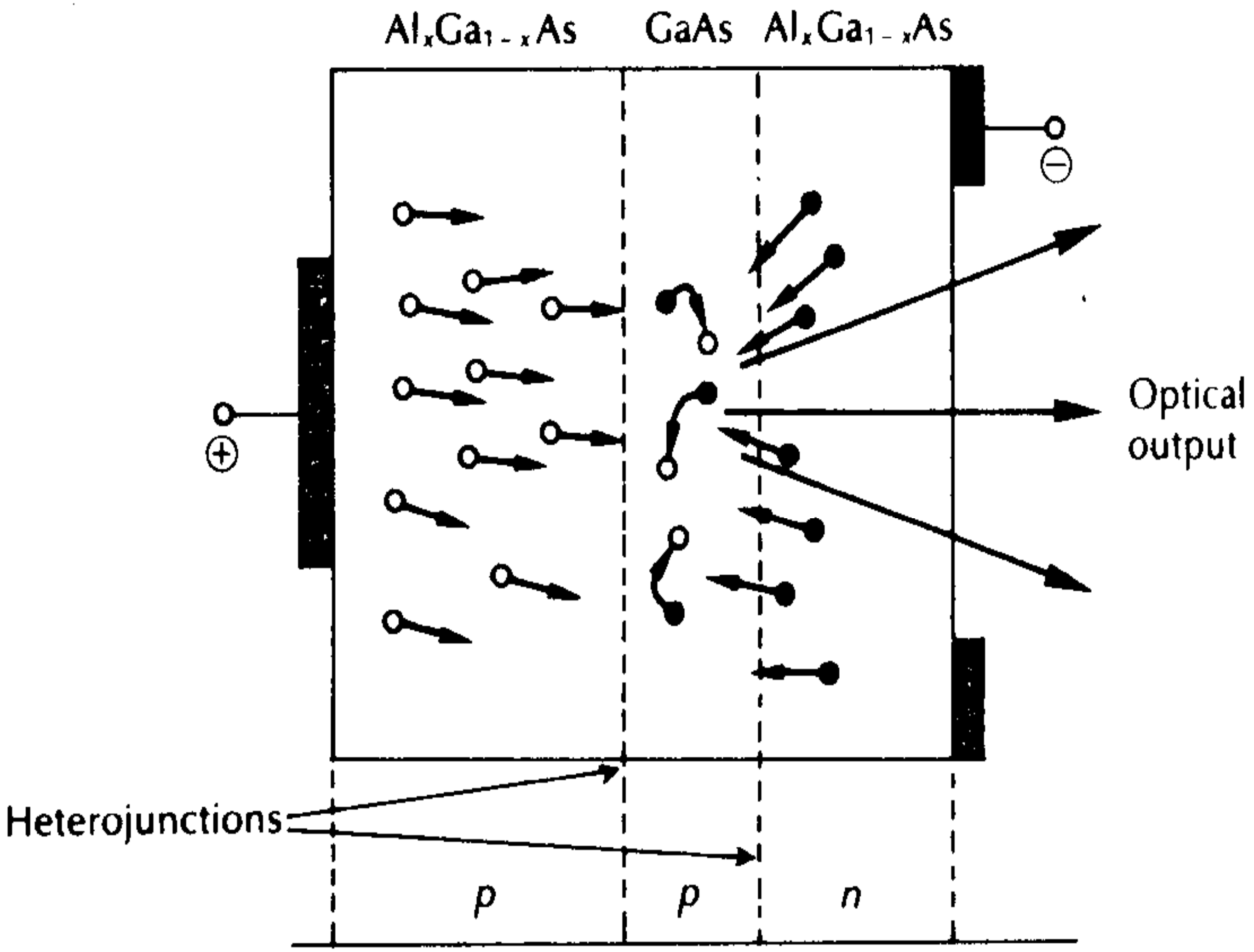
Further $\eta_{int} = r_r / r_r + r_{nr}$

$= r_r / r_t$

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

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.

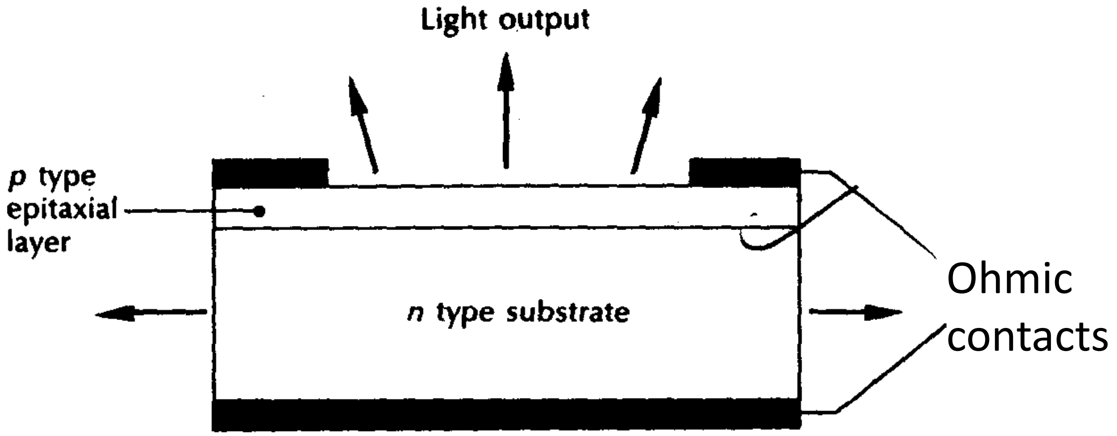
- **THE DH STRUCTURE IS MOST EFFICIENT INCOHERENT SOURCE FOR OPT.FIBER COMM.**

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

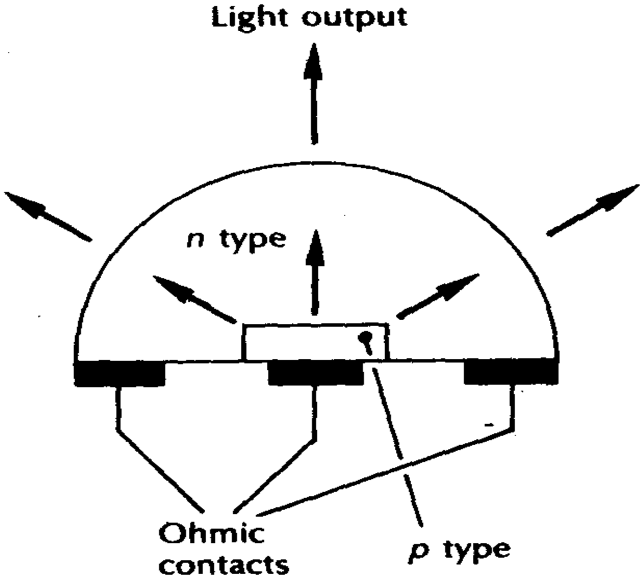
PLANAR LED



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.

$P_c = \pi(1-r)A\, R_D(NA)^2$ .... (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)**

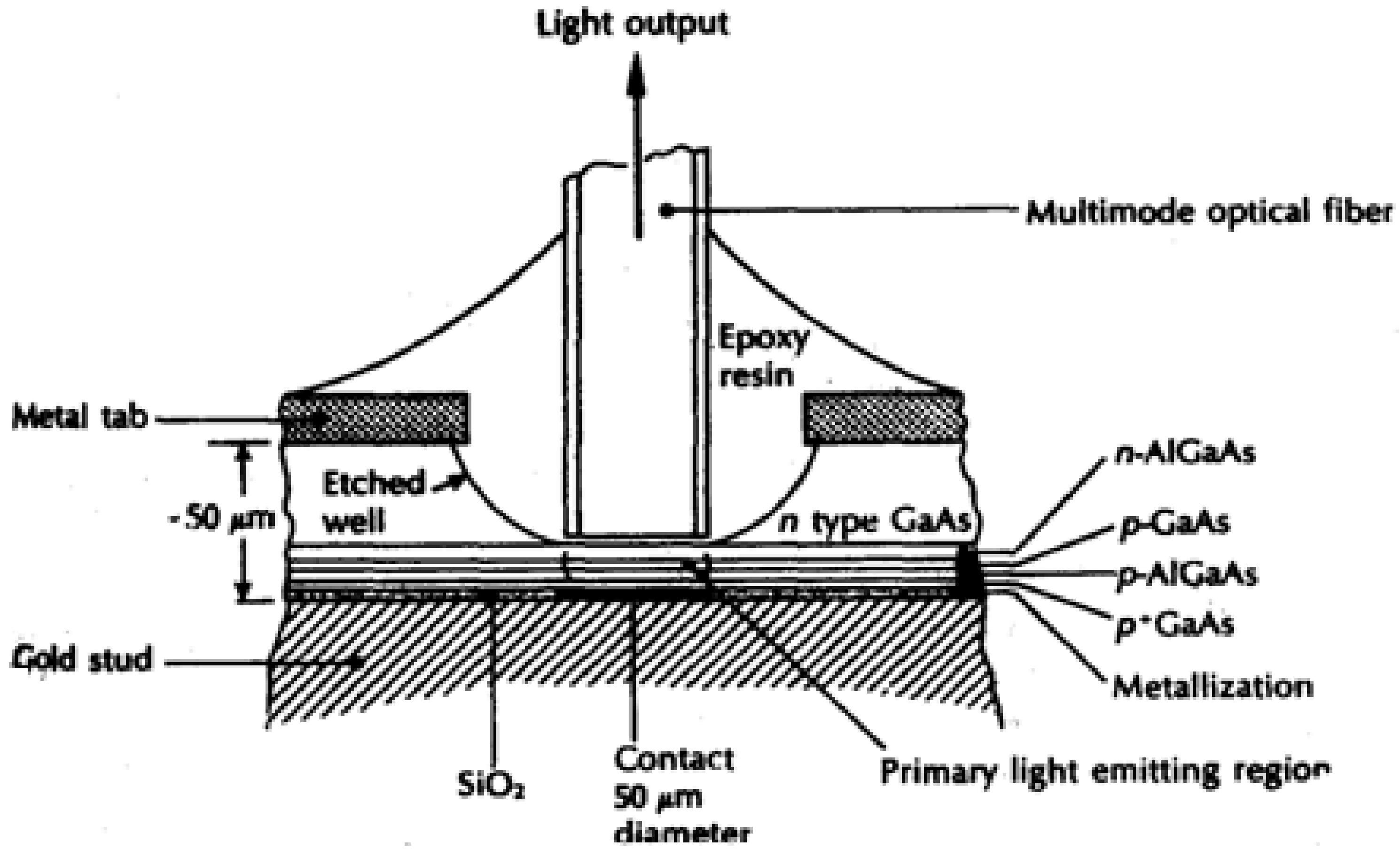
SLED (contd)

- 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.**

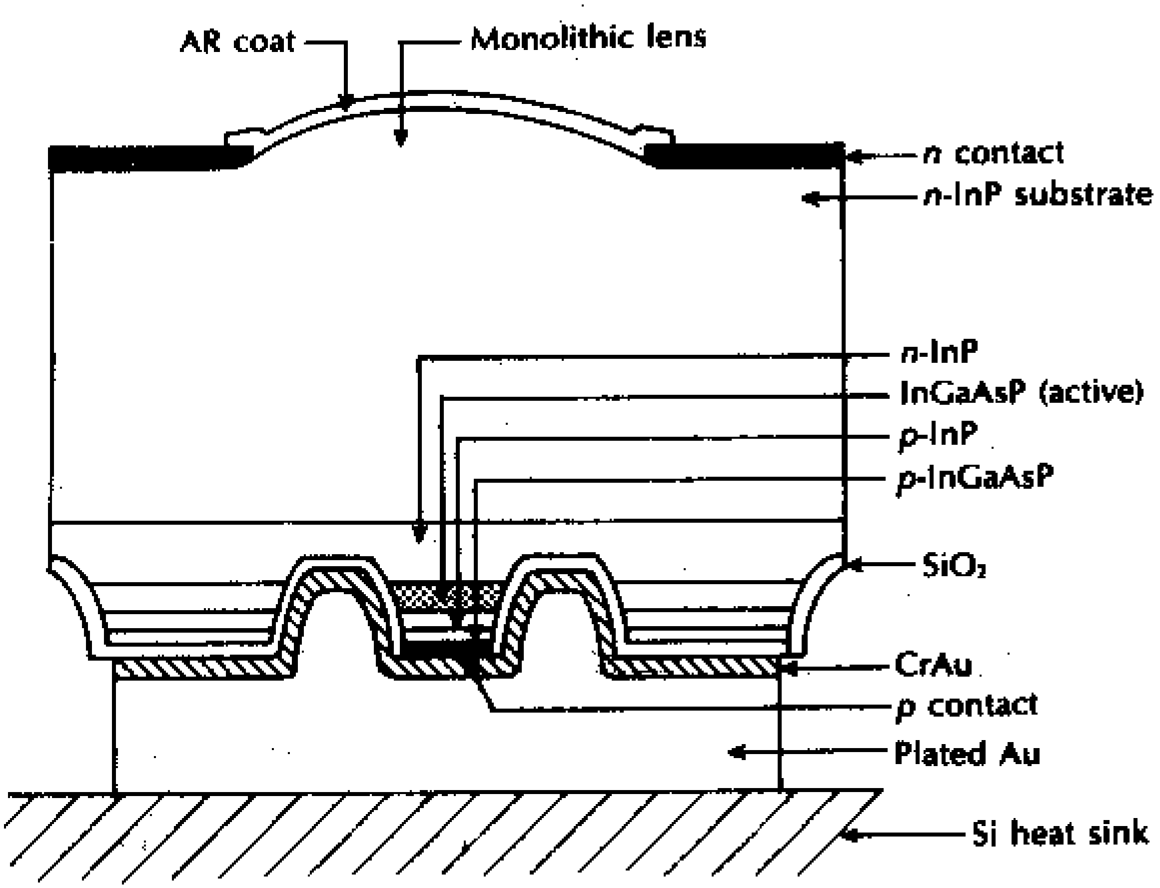
- **THE SLED’S SUFFER FROM CURRENT SPREADING RESULTING IN REDUCED CURRENT DENSITY** & EFFECTIVE EMISSION AREA GREATER THAN CONTACT AREA.

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.

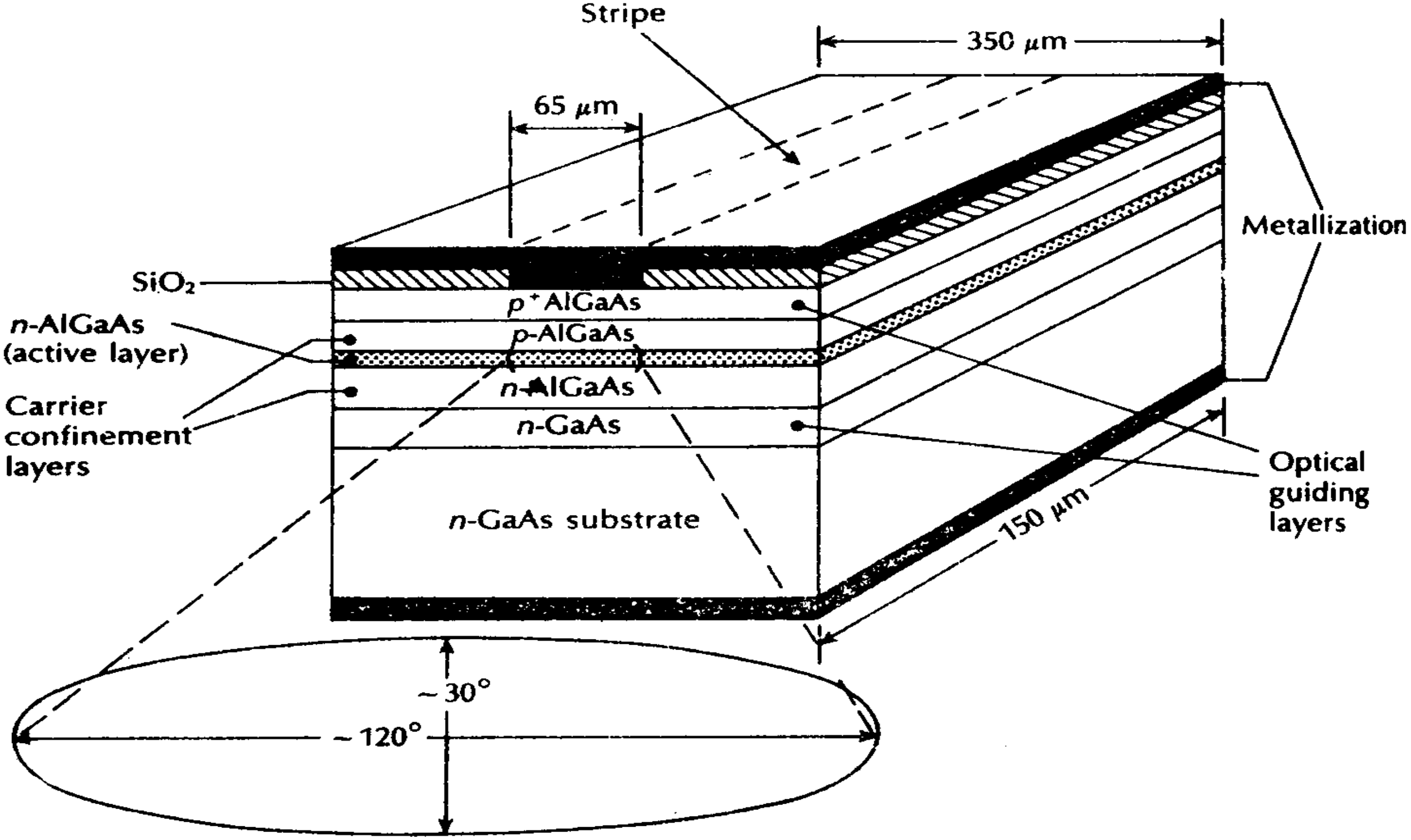


Small area InGaAsP mesa-etched surface-emitting LED structure

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)

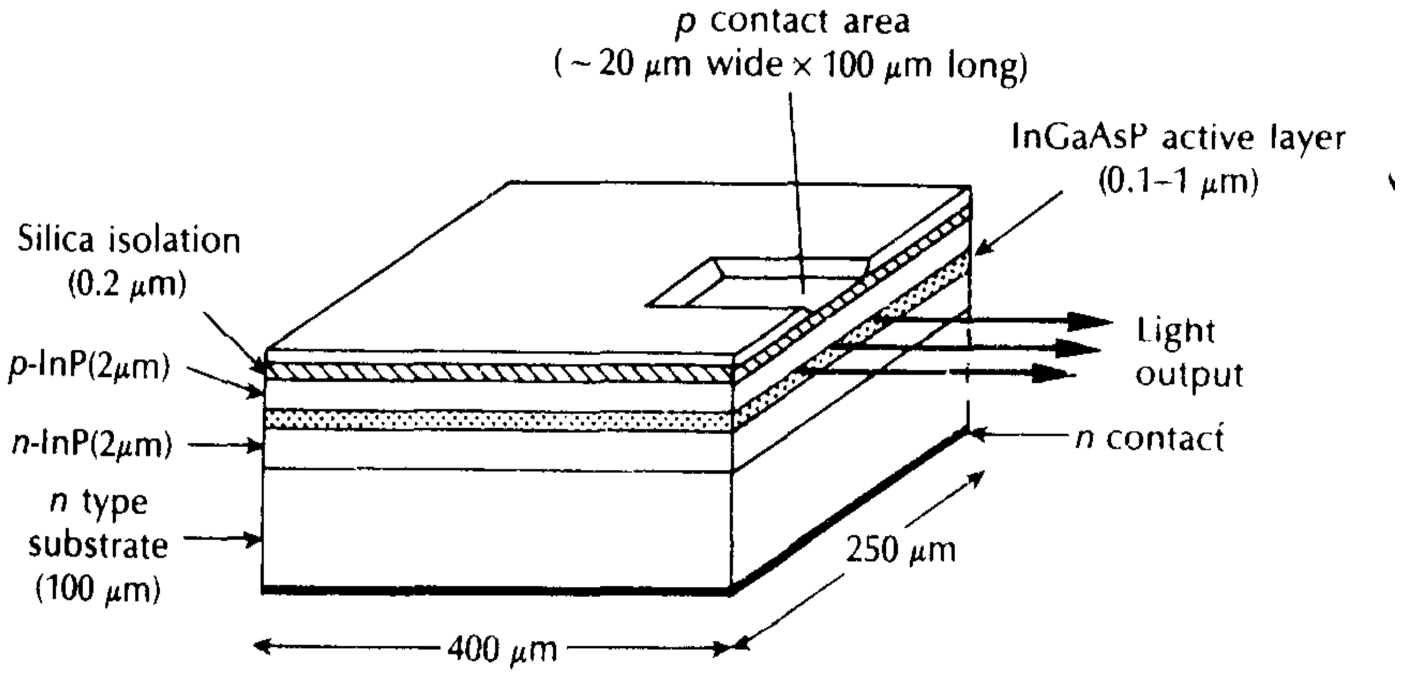


Stripe Geometry DH AlGaAs Edge Emitting LED

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

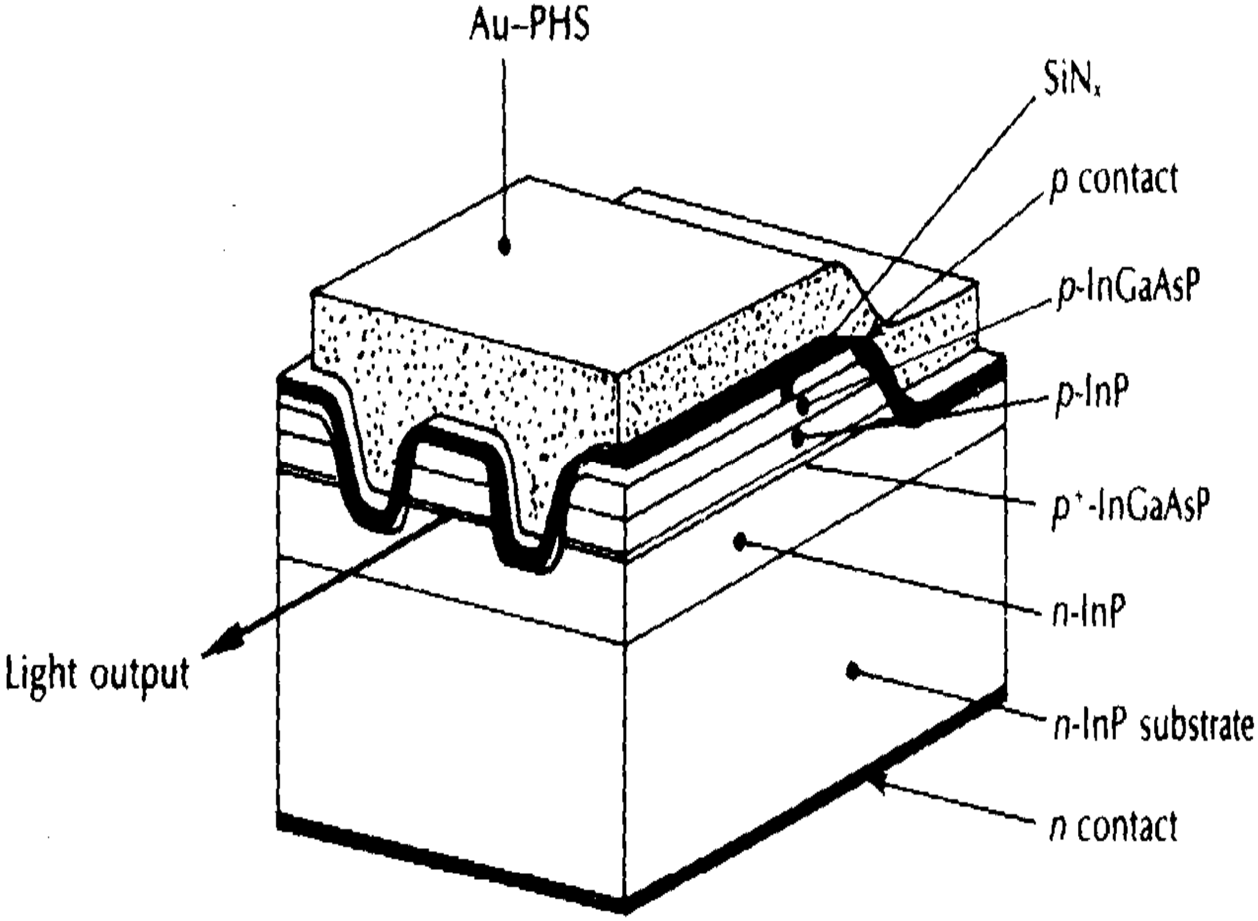


Truncated Stripe InGaAsP Edge Emitting LED

- **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

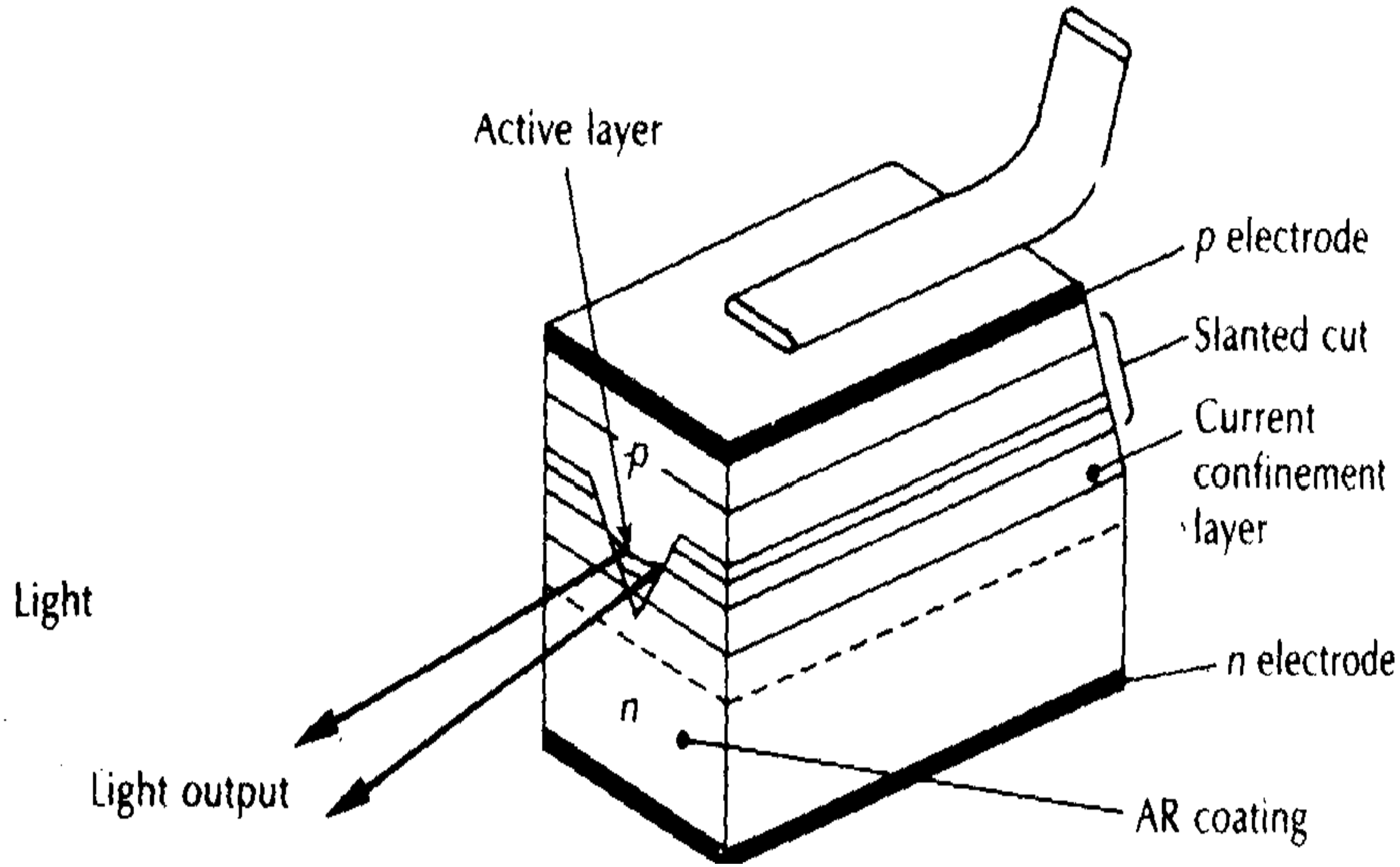
- MESA STRUCTURE (8 μm WIDTH x 150 μm LENGTH FOR CURRENT CONFINEMENT).
- TILTED BACK FACE TO AVOID LASING ACTION .

- 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

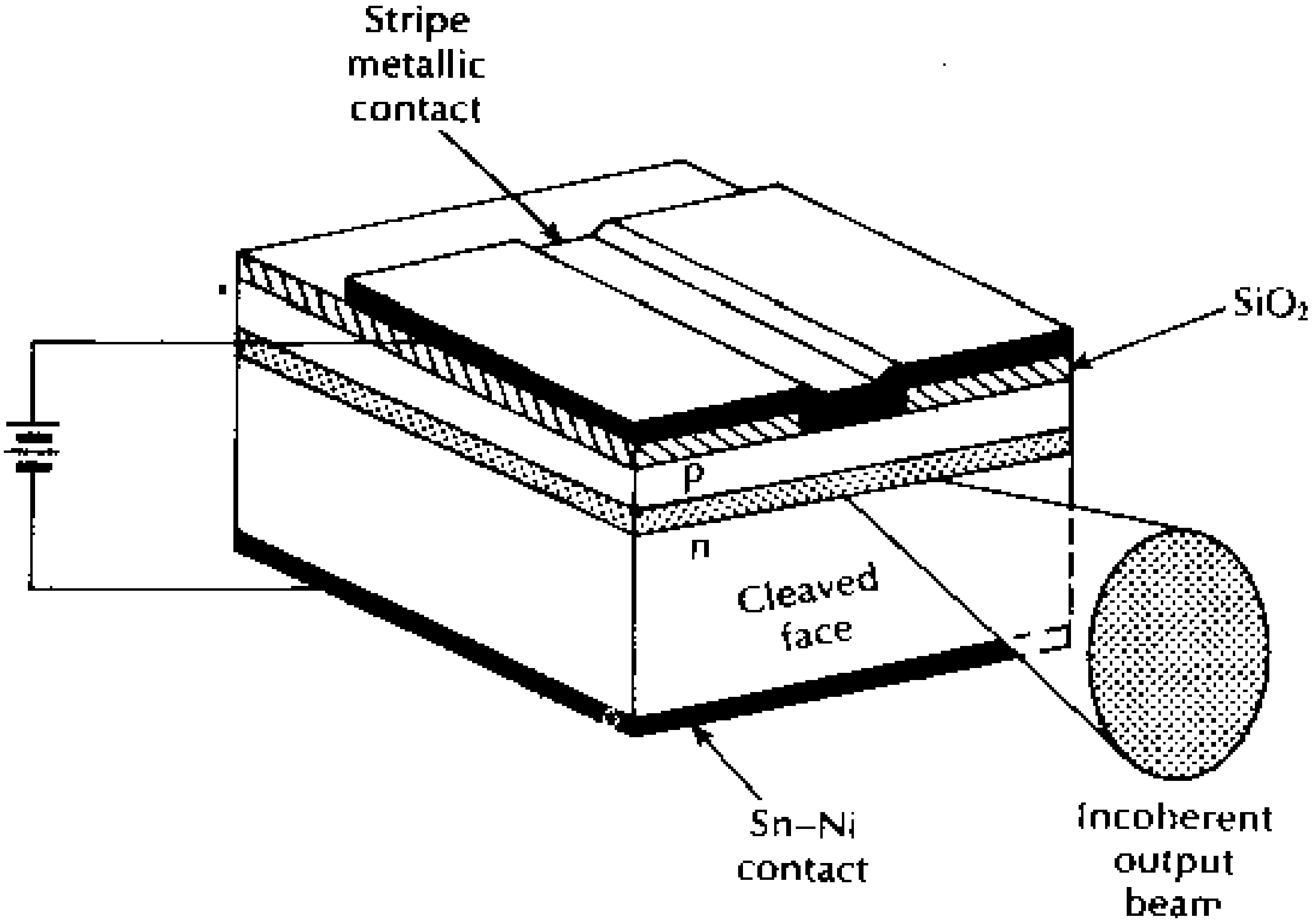
$\lambda \rightarrow 1.3\ \mu m$, 3dB Mod BW ≈ 350 MHz

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

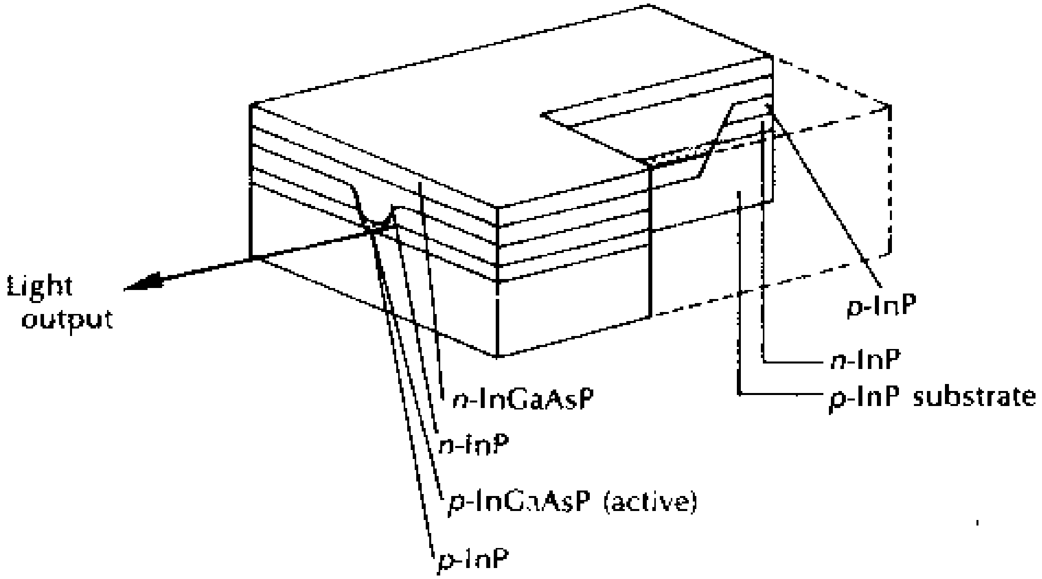
- BURRIED ACTIVE LAYER WITHIN V-SHAPED GROOVE ON p - TYPE InP SUBSTRATE.

- 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 $\eta = \frac{\text{POWER COUPLED (INTO THE FIBRE)}}{\text{TOTAL POWER EMITTED}}$

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.

OS's for Fiber Comm. should satisfy some desirable properties -

- Intensity
- Radiation pattern
- Emission wavelength
- Spectral characteristics
- Response time