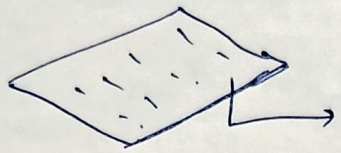
Unit 2 (cont...)

② Passive Display (LCD display) 6m

* LCD molecules → semi solid (pale-yellowish)
molecules arranged in particular direction — Nematic / cholestric



1m
dist b/w 2 plane having same ordering → pitch

Nematic → (can be of diff orientation)

cholestric →

ε → mag of EF. (molecules align acc to EF)

* ε ↑ of solid interface

$\varepsilon < \varepsilon_c$ → critical angle.
↳ no ordering change.

$\varepsilon \geq \varepsilon_c$ → close to critical value
↳ small change in alignment

$\varepsilon >> \varepsilon_c$
↳ complete change in orientation

Polaroid → converts unpolarized to polarized

eg sunglasses.

LED

laser better

* monochromatic
* directional

drawback

* cost
* requires drive ckt & cooling mechanism

LED

* low speed
* can be coupled only with multimode fiber (25-50 mm (MM dia). In single mode fiber dia is smaller than led spectral width)
* wider BW than laser
* moderate power (μW)

Advantages

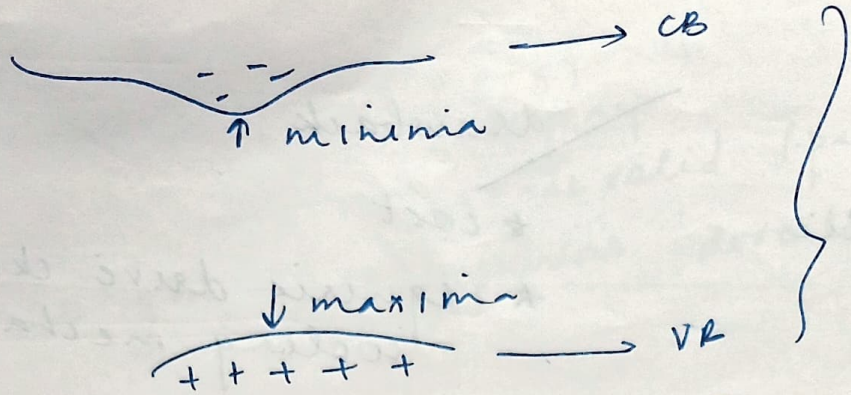
* no drive ckt
* no thermal stabilization
* cheaper.

Material → Indirect Band Gap

Direct Bandgap

~~Indirect~~ (~~not~~ in same plane)

If max of valance band & minima of conduction ~~plane~~ band lies in same plane → Direct



* In ~~in~~ indirect BG, extra energy (transition not easy) needs Phonon.
∴ not used in optical.
→ needs to search for Phonon

* non radiative combination is resulted (heat, vibration)

* Eg Si, Ge
→ not used to fabricate LED, LASER.

* o/p eff less
* Direct ~~Eg~~ (group III (Al, Ga, In), V (P, As, Sb)) → combination of these elements (terenary alloys)
* same plane.
* results in ↑ radiative recombination (light)

* used in fabrication of LED / Lasers
* ↑ efficiency

Source

* uses Direct BG.

* For generation 800 - 900 nm (In Infrared region) shorter.

$Ga_{1-x} Al_x As$

↳ composition (30% - 0.3) percentage.

$\therefore 1-x = 70\%$

$x \longrightarrow$ determines bandgap

Depending on x, peak emission spectrum varies

* For longer λ $\boxed{In_{1-x} Ga_x As_y P_{1-y}}$ (2000-2500 nm)

$$\boxed{\lambda (\mu m) = \frac{1.24}{E_g (eV)}}$$

$\times$ 1m

hc value.

E_g → band gap energy.

λ → peak emission wavelength.

For Si $E_g (Si) = 1.11$

$$\lambda = \frac{1.24}{1.11} = 1.117 \mu m$$

For Ga, Ge As in meq, $\boxed{\lambda \text{ in terms of } (nm) = \frac{1240}{E_g}}$

Spectral width (graph)

half of Max peak, 827 - 789 = 36 nm

$\boxed{\text{* Full width of at half maximum}}$

(causes larger / smaller spot)

Brightness.

Power | unit Area

Response time

↳ how much time taken to convert Electrical → light signal.

Quantum efficiency

↳ how many e^-/h^+ radiatively recombine.

To achieve highest brightness eg quantum eff

↳ use ~~diff~~ double hetro junc structure.

hetro structure → 2 diff bandgap neighbouring material.

LED structure.

* Metal contact → for bias

2 types
- surface emitting (5m)
- Edge emitting (5m)

} ∴ 10 m

Brightness.

Power | unit Area

Response time

↳ how much time taken to convert Electrical → light signal.

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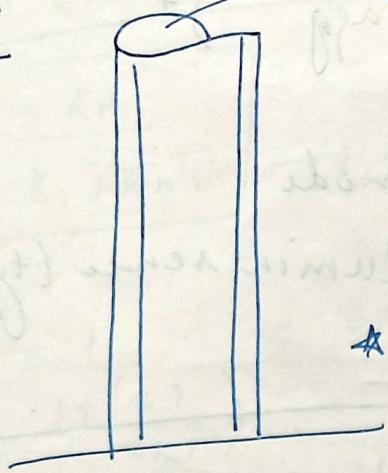
} ∴ 10 m

Surface



→ confine optical fiber and emitted light.

SiO_2 → for isolation.

3 diff confinement layer. (double heterojunction)

* OF to couple emitted light into active region (highest RF)

Active region → light emitted

Emission region (800-900 nm)

In edge

* lower quantum efficiency

* only in 4 μm dia

* Isotropic (120° beam width) lambertian pattern → equal same brightness at any angle close to 120°.

* If θ = 60° power = 50%

* coupling not good

Edge.

* Emitting region is in the edge.

* more directional pattern. (superior O/P pattern)

* reduces self absorption in active layer (due to material being very thin)

* Lambertian (varying as cosθ)

* Better than SLED.

* more coupling efficiency

* narrow spectral width than SLED.

Compare:
→ Hybrid, Monolithic } unit
→ Ramnath, Bragg

→ SLED ELED
→ Singlemode, multimode
→ photo, electro luminiscence (types)
→ PIN, APD

Quantum efficiency of LED power

$n = n_0 \exp(-t/\tau)$

n_0 → initial excess carrier density

t → time

τ → carrier lifetime

→ exponentially decaying wrt time and carrier lifetime.

Externally supplied rate : J/qd (source)

J → current density.

Internally $= n/\tau$ (due to thermal excitation)

$$\boxed{\text{Total rate } \frac{dn(t)}{dt} = \frac{J}{qd} - n/\tau}$$

$$\boxed{n = \frac{J\tau}{qd}}$$

when $\frac{dn(t)}{dt} = 0$ → equilibrium condi

Internal Quantum Efficiency

$$\boxed{\eta_{int} = \frac{R_r}{R_r + R_{nr}}}$$ → non radiative

$$\eta_{int} = \frac{1}{1+\left(\frac{\tau_r}{\tau_{nr}}\right)} = \tau/\tau_r$$

Bulk recombination = $\boxed{1/\tau_r + 1/\tau_{nr}}$

* for 1 e^- 1 photon expected by only 60 - 80 %.
photon for 100 e^-

∴ rest heat

not possible for 100 % QE.

Total Recombination rate :

$$\boxed{R_r + R_{nr} = 1/\tau}$$

$$\boxed{P_{int} = \eta_{int} \frac{1}{q} h\nu} = \cancel{\eta_{int}}$$

→ ~~X~~ 4m problem.

Problem.

4m

$$\boxed{\tau = \frac{\tau_r \tau_{nr}}{\tau_r + \tau_{nr}}}$$

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

$$\boxed{P_{int} = \eta_{int}\left(\frac{hc\, i}{q\lambda}\right)}$$

Ans 29.2 mW

↳ In this only 1.5 - 2 mW recieved externally rest backscattered

External Quantum Eff

$$\eta_{ext} = \frac{\text{no of photons emitted by LED}}{\text{no of photons generated internally}}$$

$$\eta_{ext} = \frac{1}{4\pi} \int_0^{\phi_c} T(\phi)\,(2\pi \sin\phi)\,d\phi$$

$$\boxed{\phi_c = \pi/2 - \theta_c}$$ ~~$\sin^{-1}\left(\frac{n_2}{n_1}\right)$~~

$$\left(\theta_c = \sin^{-1}\frac{n_2}{n_1}\right)$$

$$\boxed{\eta_{ext} = \frac{1}{n(n+1)^2}}$$

→ semiconductor material

~~$P = \eta_{int}$~~

$$\boxed{P = \eta_{int} \times \eta_{ext}}$$

$$\boxed{P = \frac{P_{int}}{n(n+1)^2}}$$

Internal power >>>> Ext power

$\eta_{ext} \approx 1.41\%$

LASER

↳ stimulated emission

photon → 2 photons

∴ multiple photons ~~at~~ in same direction eg phase

↳ population inversion

~~★ due to~~

Population Inversion - X - 4m

★ 2 condn to achieve

atoms should be excited to highest state

★ more atoms in excited state than lower state

★ highest state should be metastable state (3 level state)

transition to

e⁻ stay longer time than excited state

MCQ - X - 1m Lasers cannot be achieved in 2 level inversion rule due to population inversion

Modes of cavity → closed path

- TE
- TM

3 types
- → Lateral (~~length~~ width)
- → Longitudinal (~~width~~ length)
- → Transverse (height)

Lasing → laser light

★ Laser light comes only when population Inversion is achieved

★ stimulated emission ∝ intensity

$$I(z) = I(0) \cdot \exp\{[g(h\nu) - \alpha(h\nu)]z\}$$

gain (g), loss (α), dist of cavity (z), absorption coff, opt confinement factor

★ In laser cavity

Loss → laser hits loss medium

Gain → " "

both present in one round trip

$\boxed{\text{Gain} > \text{loss}}$ → population Inversion takes place and lasing occurs

↓

condn for lasing

~~Fresnels coff~~

$$R = \frac{n_1 - n_2}{n_1 + n_2}$$

R → Reflectivity of mirror

Lasing condn.

For Amp $I(2L) = I(0)$

for phase $\exp[-j2\beta L] = 1$ Resonant freq.

Fabry-Perot cavity → First cavity producing laser pulse (2 mirrors opp with gain medium)

→ closed loop.

Lasing threshold : moment $\boxed{\text{Gain} = \text{Loss}}$

Beyond Lasing threshold : Lasing occurs as Gain > loss.

$g_{th} = \alpha$ → threshold (~~rapid~~

$g \geq g_{th}$ → lasing pulse. (rapid increase in power output)

pumping source → current supplied externally

~~the~~ Below ~~at~~ ~~before~~ I_{th} → acts as LED type emission.

$\boxed{g_{th} = \beta J_{th}}$ → condn for lasing

→ current threshold density.

6m

Derive the condn for Laser threshold condn

External Quantum Eff.

* no of $e^- h^+$ pairs removed after threshold

$$\boxed{\eta_{ext} = \frac{q}{E_g} \frac{dP}{dI}}$$

$$= \boxed{0.8065 \lambda \frac{dP}{dI} \quad \frac{(mW)}{(mA)}}$$

$$\boxed{\eta_{ext} = 15-20\%}$$

~~for~~ Laser Resonant freq → out of portion

Single Mode Laser

* high speed comm system → uses
* one mode → ∴ no dispersion.
* LW is very narrow
* To obtain one mode only
  ↳ restrict length of cavity (not possible)
  ∴ 1m
∴ use VCSEL
  ↳ (diagram) 5m (2m)
  + short note (3m)

Optical Amplifier

Doped Fiber Amplifier

↳ OF (Si) doped with rare earth elements. Er, Yb, Nd, Pr.

↳ OF itself will boost the signal

EDFA boots at 1550nm - X nm

Yb boots at 1060nm

Optical Detectors. (Unit 3)

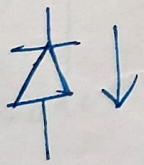
Eg. Solar Panel

characteristics of Detectors

↳ * Quantum Efficiency

* Responsivity → A/W

↳ current generated per unit power



Optical power → current

* optical absorption

Eg PIN ; APD .

Dark current → current gen in absence of light due to random movement of carriers.

Requirements:

→ High sensitivity, ~~quick res~~

→ high fidelity

→ large fast response

→ compactness

→ cost effective

→ insensitive to temp variations

→ small size

Types
- Photomultiplier
- Pyroelectric Detectors
- Phototransistors
- Photodiodes

Photodiodes

PIN → Positive Intrinsic Negative.

APD → Avalanche.

Responsivity (R)

* $\frac{\text{current}}{\text{power}}$ A/W

* ( ) of λ.

$$R = \frac{I_P}{P_{in}}$$ I/P.

2m/4m ☆

$$R = \frac{\eta \lambda}{1240}$$ → Responsivity and quantum efficiency

→ eV/hc.

max R ⇒ $\eta = 1$

Quantum Efficiency 2m/4m

$$\eta = \frac{\text{no of } e^- h^+ \text{ pairs}}{\text{no of incident photons}}$$

$\eta < 1 \longrightarrow$ no $e^- h^+$ pairs generated

Cut off λ ※ 2m/4m

$$\boxed{\lambda_c = \frac{hc}{E_g} = \frac{1.24}{E_g}}$$ (sum)

E_g (Si) = 1.1 μm

→ bandgap energy

PIN (no internal gain)

↳ reverse bias

↳ $e^- h^+$ pairs generated where energy > E_g (photocarriers)

↳ photo current

Op modes — photovoltaic → no bias; very slow (never used)

— photoconductive

↳ reverse bias

↳ current linear with I/P power.

↳ no gain (less sensitivity)

Diffusion length

↳ length of e^- movement.

- carrier Lifetime
  - ↳ time taken for e^- & h^+ recombination

Optical power absorbed

$$P(x) = P_0[1 - \exp(-\alpha(\lambda)x)]$$

→ absorption coeff (varying with λ)

↳ exp decaying

$$\boxed{\lambda_c = \frac{hc}{E_g} = \frac{1.24}{E_g(eV)}}$$

APD

* When high RB applied to PN junction
  - ↳ Zener → direct ionization
  - → Avalanche → impact ionization
  - ↳ has internal gain
  - ↳ reach through APD
  - ↳ ionization rate (e^-, h^+)

$$\boxed{M = \frac{I_M}{I_P}}$$

↳ Avalanche Multiplication

Noise

SNR → ↑ better quality, determines sensitivity

condr

↳ PD have high QE 2m ✗.

↳ PD & Amp noise low

Noise sources ✗ 10m (theory | problem) 8m

↳ RL noise.

↳ ~~johnson~~ Dark leakage noise

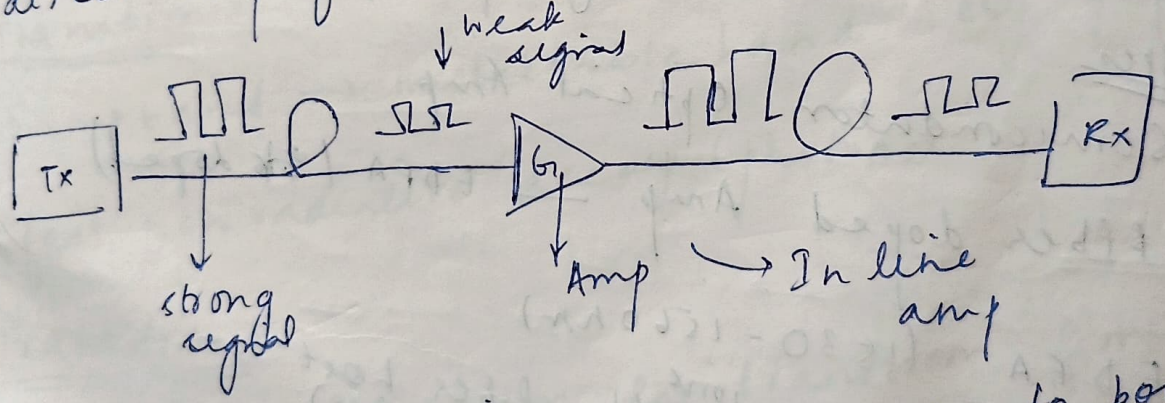
↳ Quantum noise | shot noise

↳ thermal | johnsone noise

Optical Amplifiers (unit2) < SOAs, amp

↳ strengthening the weak signal.

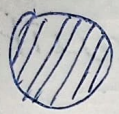
* direct amplification without conversion.



Pre amp → amp just before reciever ckt to boost S/N ratio degraded by the resistors

Power | booster amp → amp just after Tx, to boost Tx power

In line → ↑ transmission dist (b/w Tx & Rx) placed

 → star coupler → used for hub network

Lan booster amp → for LAN network.

Operation

* simulated emission process through pumping
* pumping → supplying external photons
* population inversion.

SOAs
↳ group III / V

* laser without feedback (cavity)
* gain realized through pumping

Types
Semiconductor Optical Amp
Fiber doped Amp → EDFA (~~Er~~ doped)

EDFA (1530 - 1560 nm)
↳ doping Er ions with fiber host (Si)

* mcq
* operates in C band (o/p at 1530 - 1560 nm)

* mcq
* pumping at 980 nm

* sometimes doped with Yb. to ↑ pump eff.

EDFA Energy level diagram (10m)

* Pump band → ~~decay~~ Excited state.

1 process

* SOA's → electrical pumping

OA → optical pumping

* Er ions → Er^{3+}

Raising e^- to higher level — pump / metastable.

Transition 1

Pump → GS to pump level

980nm

Transition 2

pump band → metastable band very quickly

* fast non radiative decay (photons)

Transition 3

* pumping at 1480nm for transition from GS ~~meta~~ to ~~gnd~~ top of metastable state

~~* decays to~~

Transition 4

* decay to highly populated lower metastable level.

pump → highly pop.

meta → top highly populated.

low → highly populated

Transitions

MS → GS (decays on its own)
* random direction → noise

Transition 6

pump – 1550 nm to MS

Transition 7

MS → GS at 1550 nm

EDFA configuration (out of syllabus)

SOAs

* both 1300 - 1550 nm

Fabry Perot Amp

TWA Travelling Wave.

FPA

* FPA cavity → closed loop
2 mirrors → ~~one~~ partially reflecting

* back and forth motion till high intensity is reached

* BW ≈ 10 GHz

TWA

* I/P amp only once (no to & fro motion)
* ~~used feed~~ uses faucets.

Detectors for long λ operation

* For many applications photodetectors should be operated in IR range (5-20 μm)

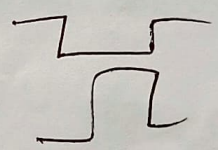
* 2 approaches for long λ detection
  ↳ ~~choose a d~~ detector with small Eg:
  The junction diode and band to band to transition in small energy bandgap

  eg: Antimony, Hg Cd Te, $InAs_{0.5}Sb_{0.5}$

Dis
* Because of small Eg dark currents are very large.

* So, operated in specific temp range

↳ * use quantum wells.



↳ Incident photons should be ⊥ to the device.

* difficult to detect 2D images.

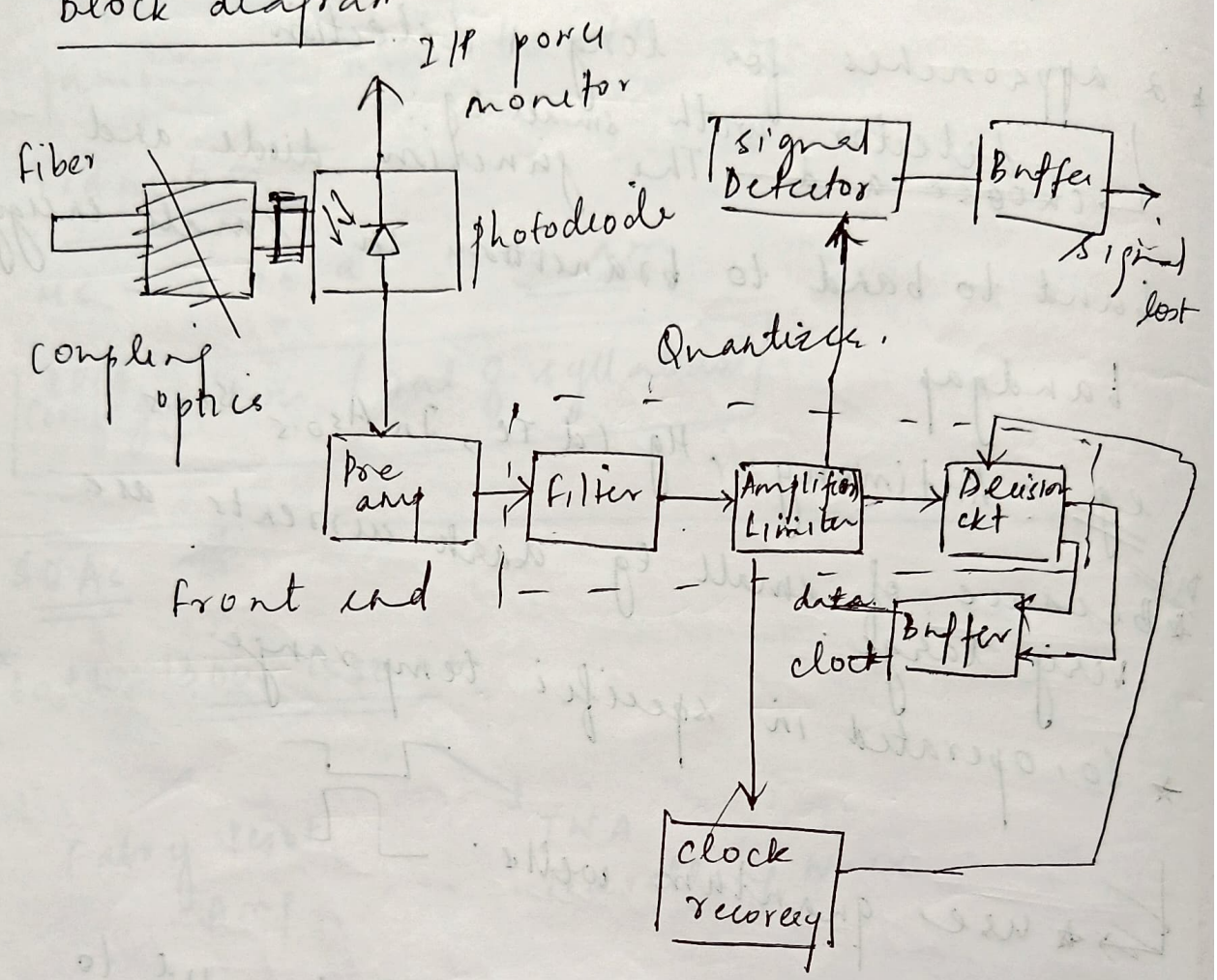
* In this approach tunneling process isn't required as dark current is reduced.

※ 10m

Optical Reciever.

(Refer back notes)

Block diagram



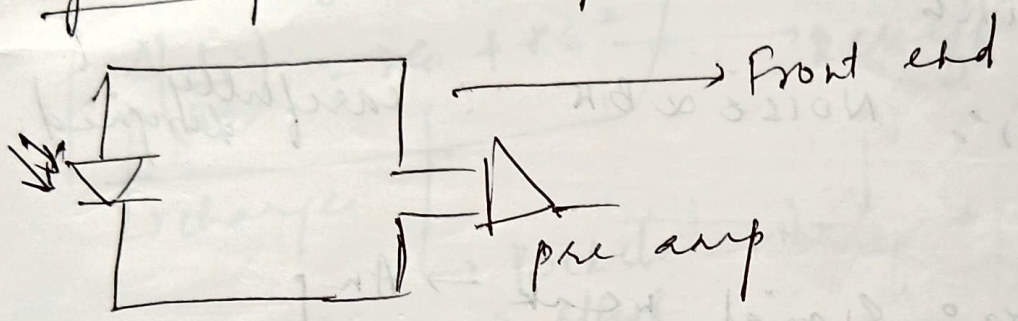
* Photodiode converts light → photo current
* In pre amp photo current converted → voltage and amplified
* Optical front end of the reciever
* photodiode + pre amp → front end

Design types.

Low Impedance Amp

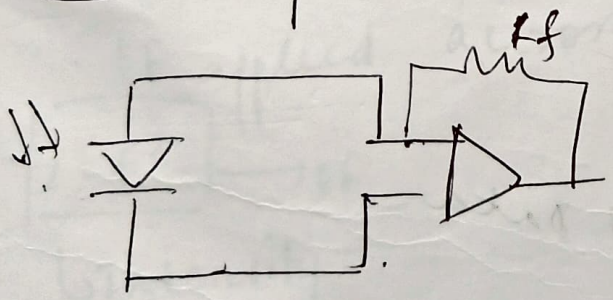
* PD operated with low imp. ~~tg~~ 50 Ω
* more BW less sensitive.
* only one resistor used
* used for short distance.

High Impedance Amp



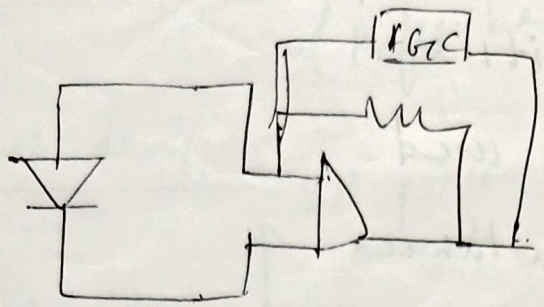
* High I/P imp - MΩ
* $BW \propto \frac{1}{R_L}$

Trans Impedance - (most preferred)



* feedback R
* provides -ve feedback
* gain depends on Rf.
* AGC: Automatic gain controlt can be done with

AGC



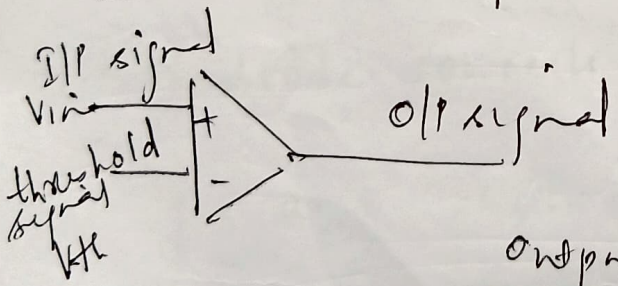
Quantizer

* 3 components

Noise Filter: Noise $\propto$ BW ∴ carefully designed.

Amp | Limiter: Signal weak → Amp
Signal strong → Limiter
* Also includes AGC.

Decision ckt (comparator)



Output Data

$V_{in} > V_{th} \longrightarrow 1$

$V_{in} < V_{th} \longrightarrow 0$

$V_{th} = 1/2$ (desired value)

Unit 4

Modulator
- Electro-optic
- Acousto-optic
- Interferometric

Electro-optic

* apply EF through optical medium
* e^- distorted
* RI changes anisotropically

$$\Delta\left(\frac{1}{n^2}\right) = rE + rE^2$$

rE → pockels effect

rE^2 → kerr effect

* Pockels effect
  - crystal structure
  - material symmetry
* ~~MIQ~~ Linear
* x, y axis → 45° rotation
  EF applied across z direction.

$I = E^2$ → EF

↳ Intensity

* phase ∝ voltage

* Pockel cell modulator (Half wave voltage) 8m

Kerr Modulator

* gradeatio → MCQ

* $RI \propto EF^2$

→ Isotropic media

Acusto - optic

↳ changing RI by sending acusto waves

X: 10m

Ramnath (5m) Bragg (5m) (compare)

* grating thin

* no redistribution

* small beamwidth

X: 1m neg

* grating thick

* redistribution

*

$$\boxed{\text{Bragg angle } \theta_B = \sin^{-1}\left(\frac{\lambda}{2\Lambda}\right)}$$

diagram X for both

Interferometer

↳ phase change

Fabry parot → seq X

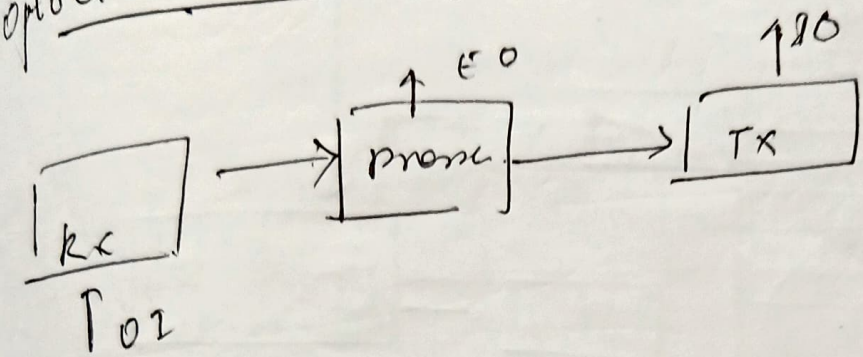
Mach zender → diagram

Opto-electric Integration

↳ electrical + photonic components combined

↳ large BW, speed

Optoelectronic Integration



diff X.

{ Hybrid, Monolithic OEIC and its need } → X questions

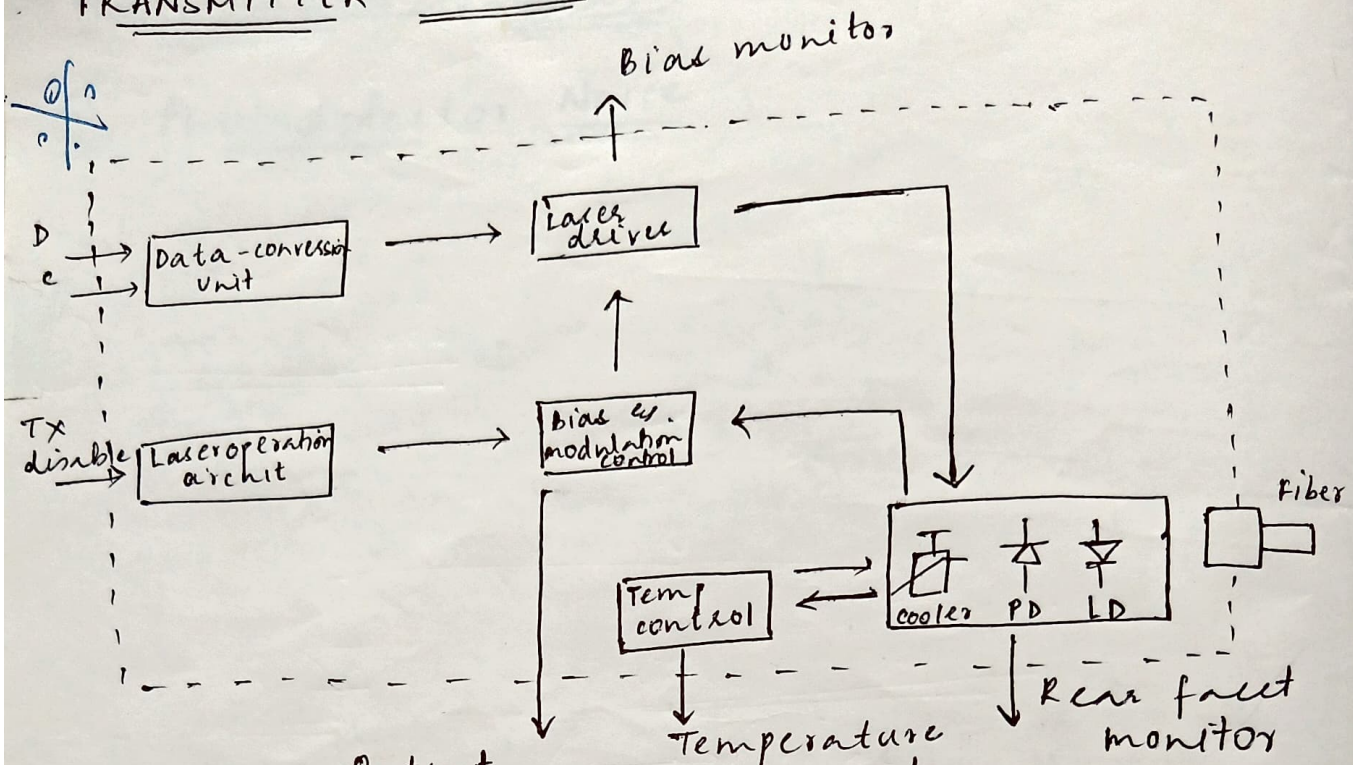
2m

$$P_{out} = \frac{g_{m5}}{2}(V_{g1} - V_{g2})$$

OEIC TX - X.

Unit 2 CT2 preparation

TRANSMITTER MODULE



components
- light source
- coupling optics
- signalling ckt
- power control ckt

Data conversion Unit

* Performs
  - ↳ encoding
  - ↳ piso conversion
  - ↳ data reshaping into electrical format

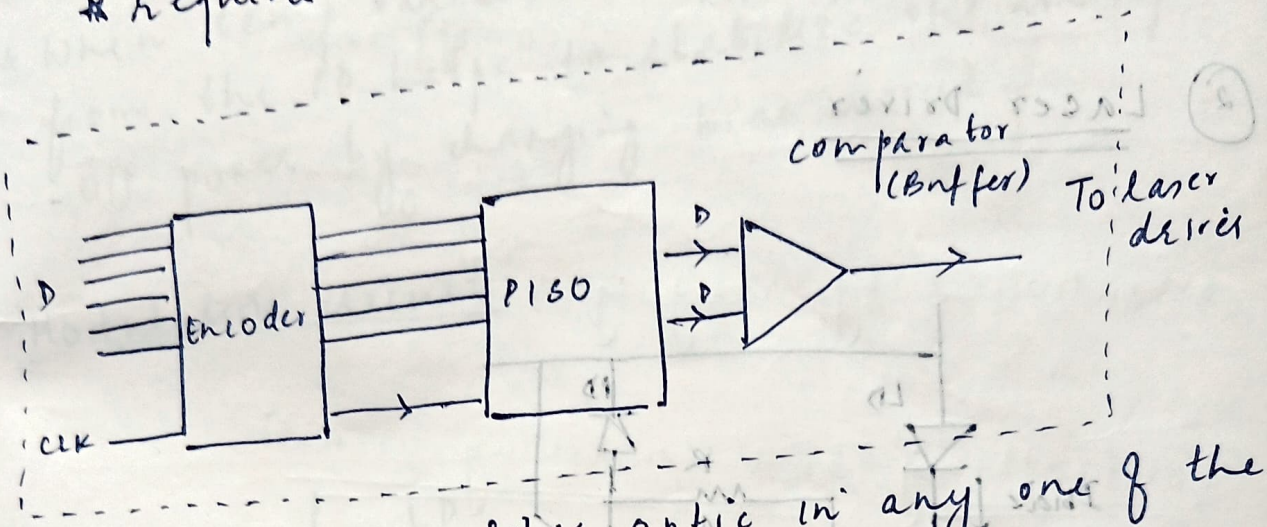
* Encoding - representing data in physical format.
  - ↳ NRZ
  - ↳ Manchester
  - ↳ Return to zero

NRZ → easy, convinient but poor Tx capability

~~do~~ * Tx-Rx consumes more power due to

dc power component.

* ~~NRZ~~ Manchester → transition in middle of clock pulse.
* No dc power component.
* requires twice the BW.



* Data enter the fiber optic in any one of the code but output represents.
  - ↳ 1 → flash of light
  - ↳ 0 → period of darkness.

* For reshaping of the signal a comparator or buffer is used

* A comparator compares 2 signals — Data / complementary
  - ↳ If complementary higher → zero
  - ↳ If data higher → Vcc

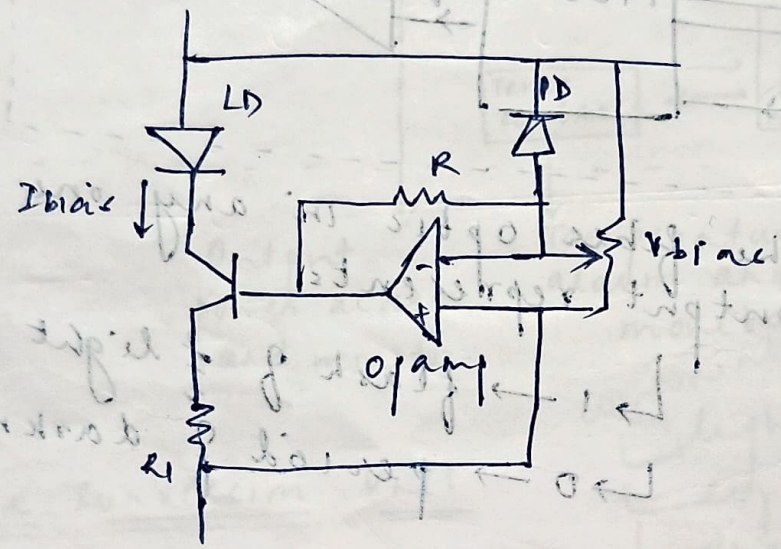
* This circuit has high impedance which makes it compatible with the mux

* Buffer is a device that isolates the I/P from the O/P and amp the current,

transferring the I/P → O/P unchanged.

* Fiber optic Tx uses ECL → high speed, low noise
* Other logics — TTL
  — CMOS

② Laser Driver



* It converts outside voltage → currents needed to drive the laser

* Driving current has to ~~be~~ bias a laser diode to provide a bias current.

* Bias current has to be very stable with the threshold or else error occurs.

* Main factor changing Threshold current is Temperature.

* The feedback signal from the temp sensor reaches the laser ~~diode~~ driver through the bias control

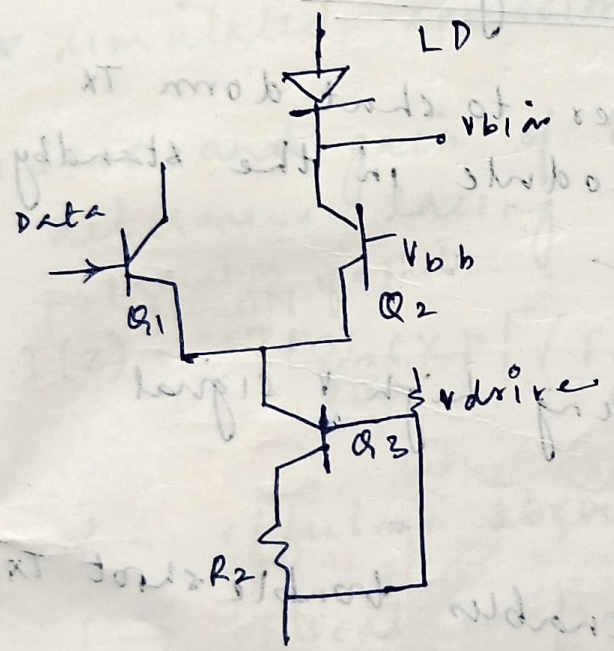
~~loop~~ circuit and closes the control loop.

* R depends only on I/P voltage and not on load resistance.

~~Modulation~~

* When temp varies, the feedback signal obtained from the PD helps to stabilize the average O/P power by changing bias current.

Modulation circuit



* Controlled by changing the driving current from bias level to maximum.

* $V_{Data} > V_{BB}$ → Q_1 conducts → Laser off

* $V_{data} < V_{BB}$ → Q_2 → ON

* V_{BB} must be kept at ± 400mV to keep transistor Q_1 & Q_2 out of saturation.

* switching b/w Q_1 & Q_2 occurs very fast.

* Q_3 controlled by vdrive.

* Duty cycle should be 50%.

* Important concern → control of extinction or on-off ratio
  ratio of max-min light power.

* controlled by varying I

Controlling and Monitoring circuits

* Tx disable - allows user to shut down Tx keeping module in the standby mode

* can be done by placing high V signal at base of Q_1.

* Monitoring signal enables troubleshoot Tx

* Temp sensor → monitor ambient temp

* OLT provide alarm to signal if any parameters deviate.

Derive the condn for Lasing threshold

Lasing

* To determine lasing condn, we focus on the optical wave propogation along z-axis.

* EMW in terms of Ef,

$$\boxed{E(z,t) = I(z)\, e^{j(\omega t - \beta z)}}$$

* Lasing condition occurs only when population inversion is achieved.

* similated emission $\propto$ Intensity.

* Loss and gain of the optical field determine lasing condn $(G > L)$

$$\underbrace{I(z)}_{\text{Radiation Intensity of a photon}} = \underbrace{I(0)}_{R_1 R_2} \exp\left[\left(\Gamma g(h\nu) - \bar{\alpha}(h\nu)\right) z\right]$$

energy

$\bar{\alpha} \rightarrow$ effective absorption coefficient

$\Gamma \rightarrow$ optical confinement factor.

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

$\rightarrow$ Reflectivity of the mirror.

$\therefore$

Lasing condn

For amp : $I(2L) = I(0)$

For phase : $\exp(-j2\beta L) = 1$

Lasing threshold

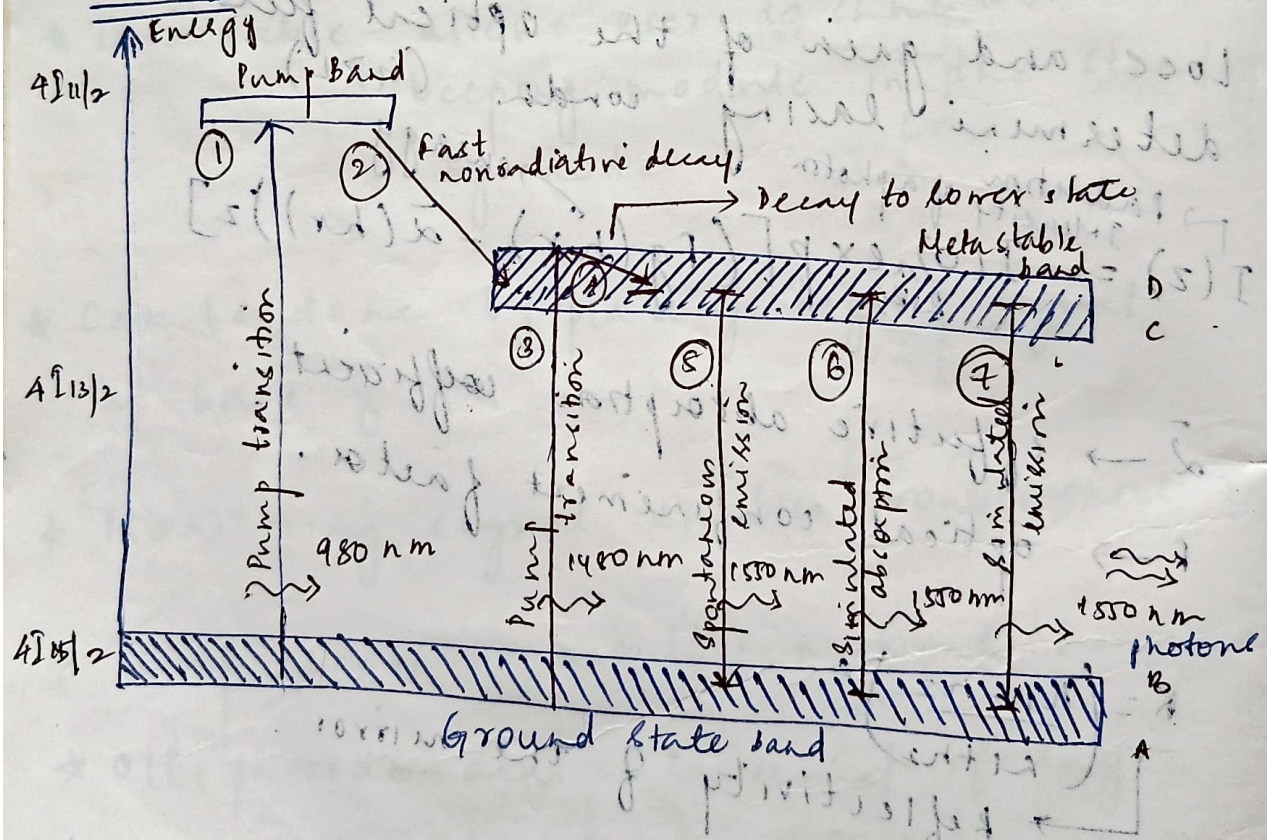
* Beyond lasing threshold lasing occurs

$\Rightarrow \boxed{g > g_{th}}$

$\boxed{\therefore g_{th} = \beta J_{th}}$ → threshold current density

* When $g \geq g_{th}$, the power output ↑ rapidly.

EDFA



* Silica doped with Erbium
* It operates in C band (1530-1560 nm) and pumping is at 960 nm. (980

2 levels — metastable.
— Pump

Transition 1

* pump → GS to pump band energy 980 nm λ.
* ~~Fast radioactive decay~~

Transition 2

* From pump band → metastable band
* Fast non radioactive decay
* ~~energy corresponds to 1480 nm~~

Transition 3

* pumping at 1480 nm from GS to metastable top ? state

Transition 4

* decays to highly populated lower metastable level.

Transition 5

* decays on its own (spontaneous emission) from MS → GS. ~~at~~
* energy - 1550 nm.

Transition 6

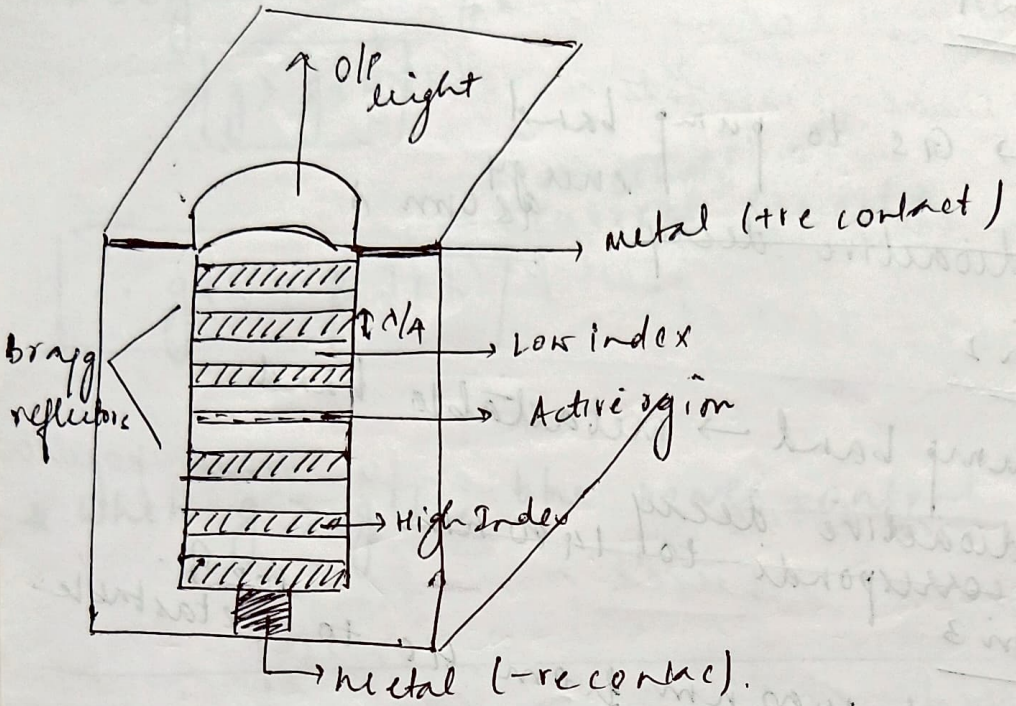
* pumping at 1550 nm to MS state from GS

Transition 7

* MS → GS at 1550 nm

VCSEL

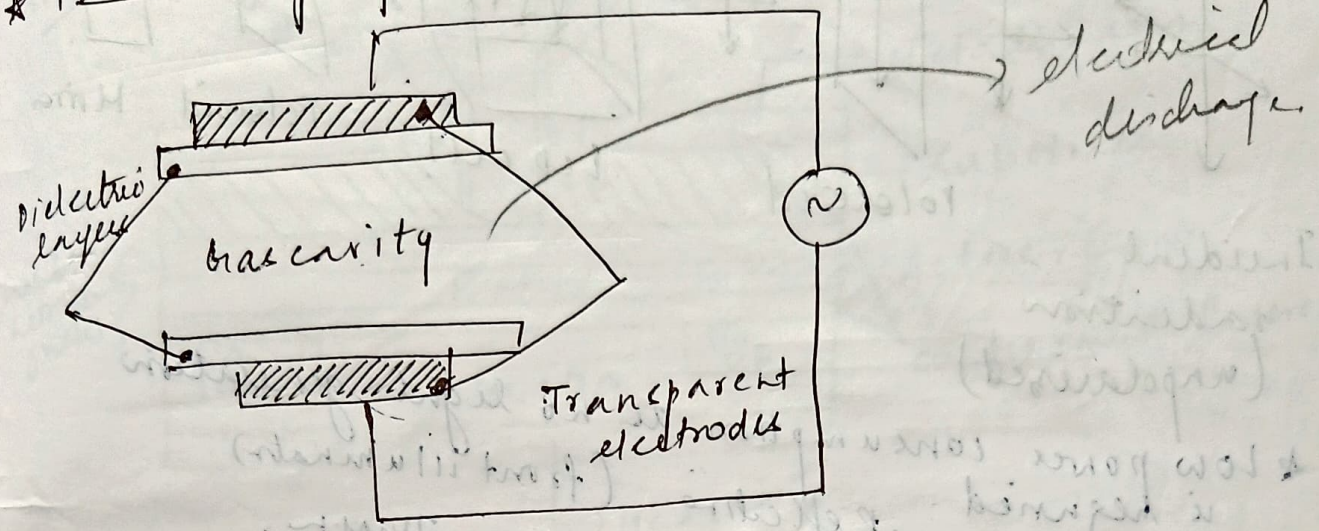
vertical cavity SEL



* cavity proving lasing feedback is arranged in the vertical direction.
* laser beam ⊥ to the wafer.
* several quantum wells are made in active region to enhance light gain.
* placed b/w Bragg reflector
  → (stack of alternate high, low RI layers)
* Each layer is λ/4 thick.
* works like high reflective mirror providing feedback.

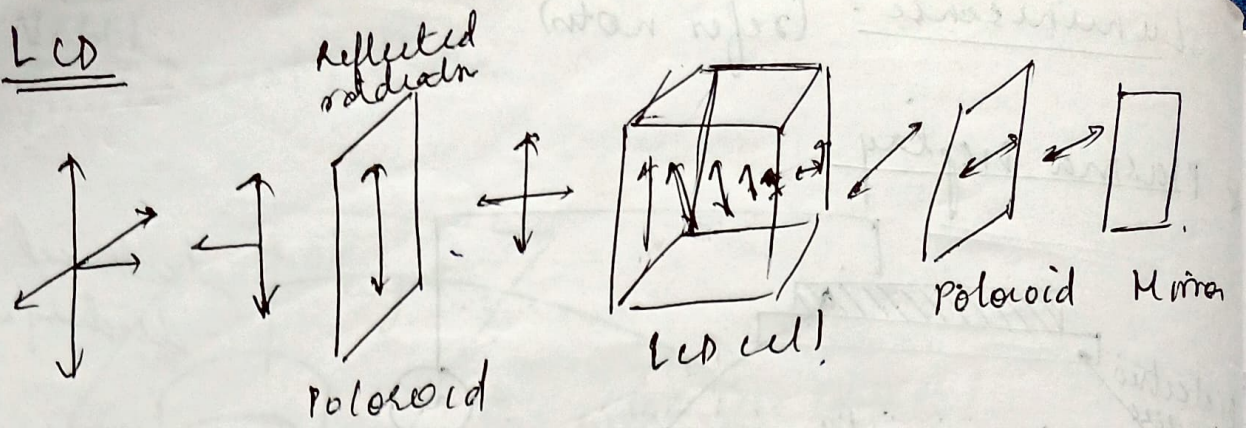
Luminiscence - (refer notes)

* Plasma Display



* AC Current is passed into the gas cavity through the electrodes.
* electrical discharge takes place in the gas and glow is produced due to ionization of gas particles.
* Free e^- obtain KE, collide with gas atoms, transfer energy to the atoms, exciting them to levels above the GS.
* AC or DC can be used
  if DC → electrodes inside cavity
* Discharge initiated by applying a firing voltage
* After discharge there is a ~~sustained~~ reduced voltage.

LCD



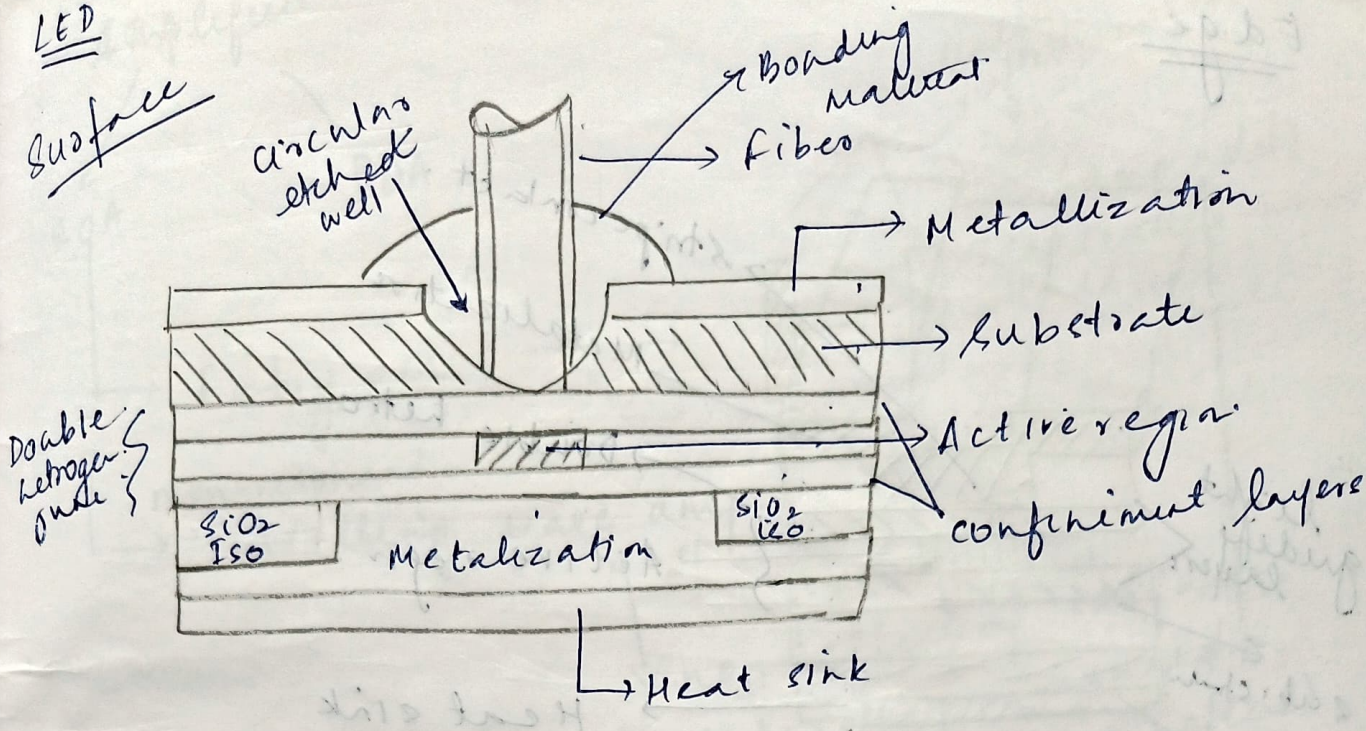
* Low power consumption as no light generation is required.
* Two types — Reflective (front illumination); transmissive (rear illumn.)
* LCD – 2 glass plates + conductive coating filled with
* Liquid crystal material
* Liquid crystal state — low temp – solid; high temp – liquid; within range – milky yellow appearance
* rod shaped – molecules.
* Diff orientation in liquid crystal surface

Nematic	Cholestric	Smectic
↓	↓	
‖l to each other, free to move	large no of planes having nematic like struc	

* Dist b/w 2 planes having same ordering → pitch 'p'. (temp depend.)

LED

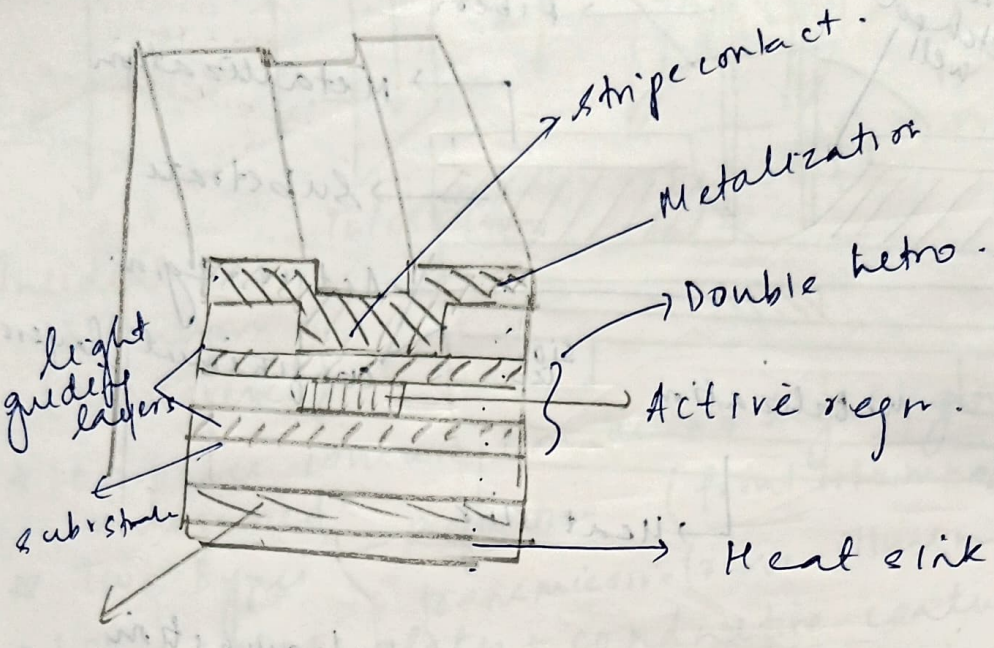
Surface



Construction

* In surface LED, 3 different hetrojunction layer with different materials (diff RI) are used.
* SiO_2 is used for isolation.
* The Active layer has the highest RI
* Plane of light emitting region ⊥ to axis of fiber.
* Fiber well etched in the substrate
* Active region - 50 μm dia, 2.5 μm thickness.
* Isotropic pattern - 120° half power beam width.
* called lambertian pattern.

Edge



* Active region - source of incoherent light and two guiding layers.

* Guiding layer k_I > Active
  < surrounding

* contact stripes - 50 - 70 μm
  Dia - 100 - 150 μm

* more directional emission pattern.

* ~~ISO~~ plane ∥ to junction, Lamberation pattern with 120° half power beam width.

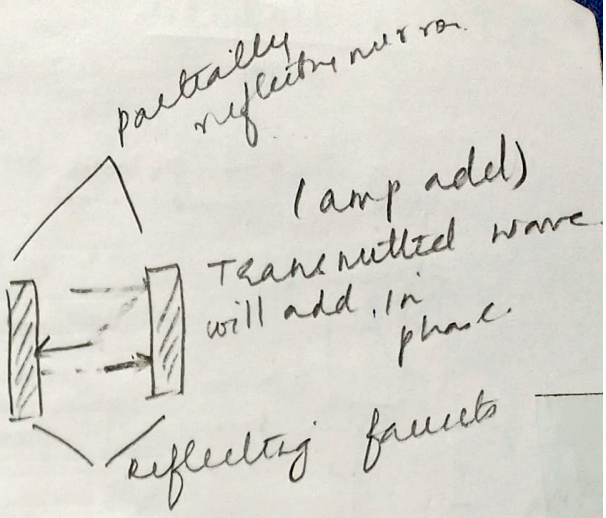
  ⊥ - 25° - 35°

Amplifier

SOA

EDA

Faby perot →

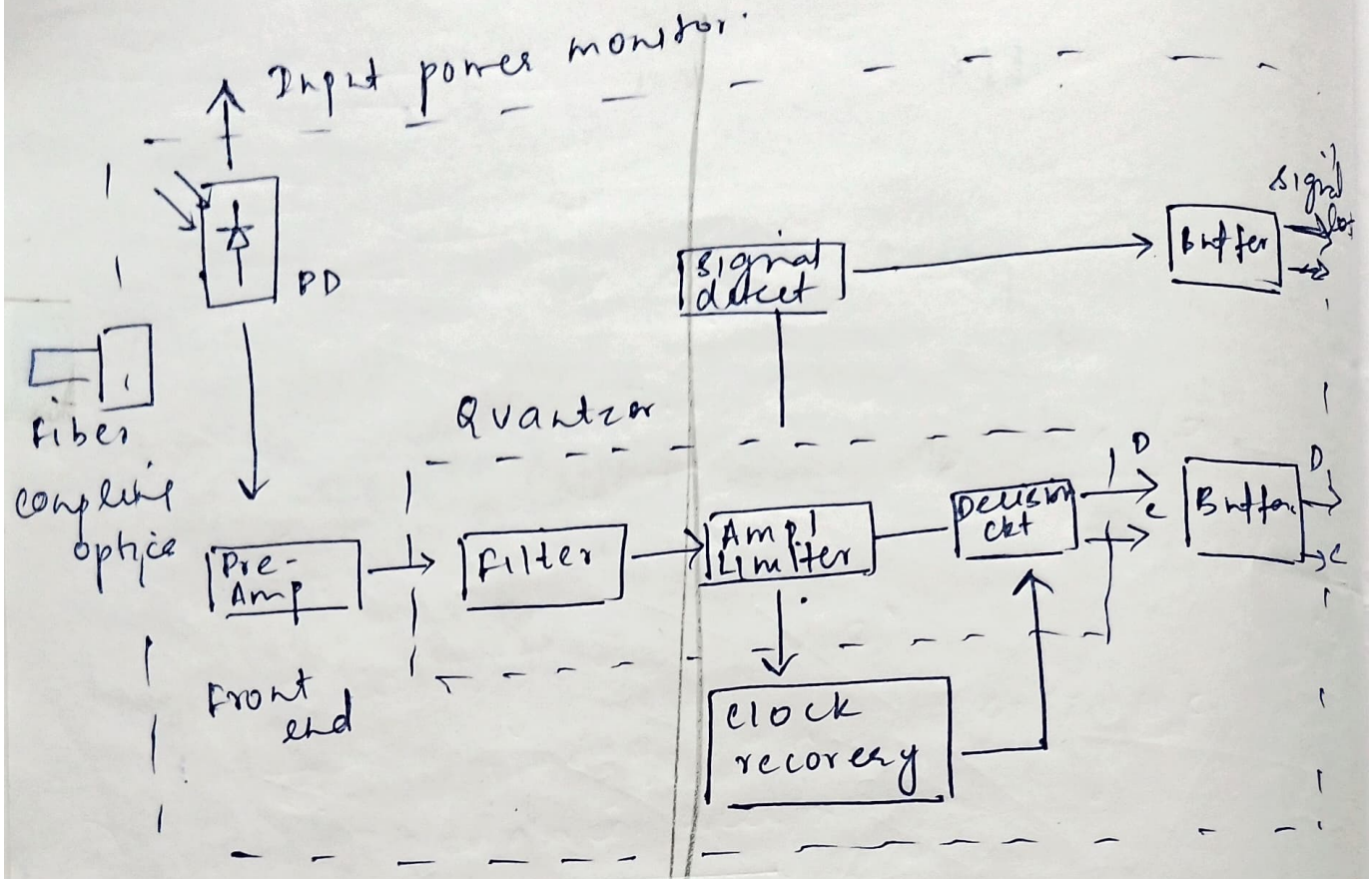


Non-resonant
Travelling wave amp

↓ non reflecting surface, anti reflection coated, or cleaved (no reflect)

* only once amplified.

Reciever Module



Working

* Photo diode converts light → photo current
* In pre amplifier photo current converted into voltage & amplified.

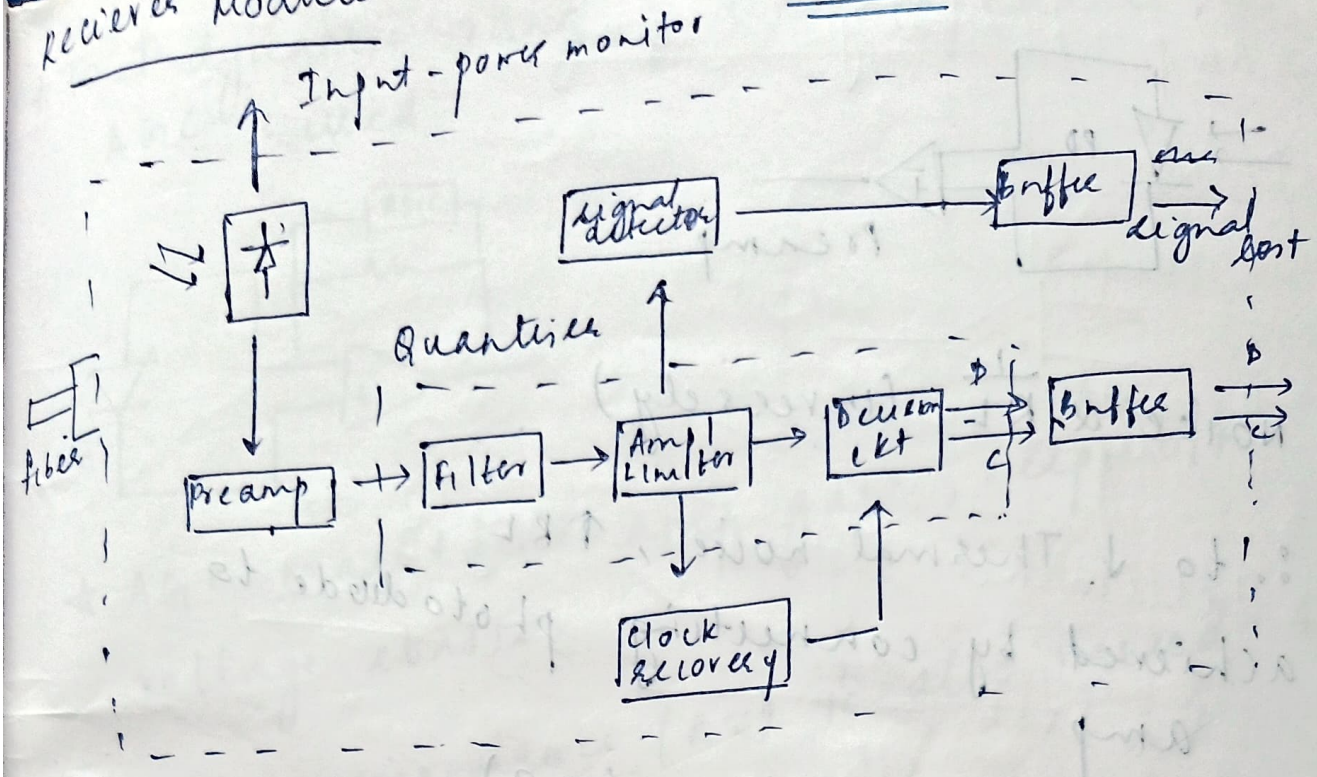
Reciever

* converts optical signal → electrical o/p.
* converts light pulses → electric pulses

Optical Front End

* A photo diode + preamplifier
*

Reciever Module



Reciever

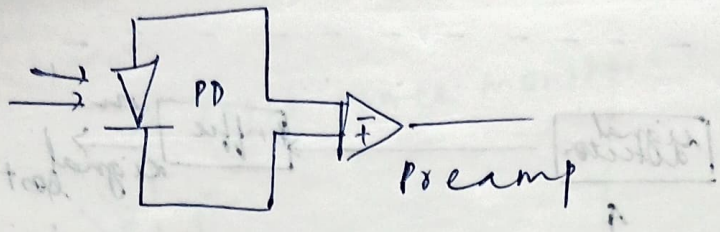
~~* converts light → photocurrent~~ ~~using photodiode~~

* converts optical signal → electrical O/P
  light pulses → electric pulse

Optical front end

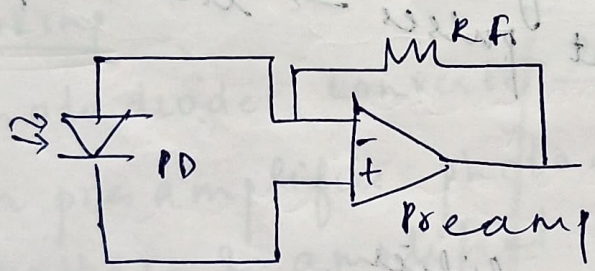
* photodiode + preamplifier.
* photodiode converts light → photocurrent
* preamplifier converts photocurrent into voltage and amplifies it.
* It is fed to the Quantizer.
* Types of optical front end

① High Impedance Amp



* Noise $\propto \frac{1}{R_L}$ (inversely)
* ∴ to ↓ Thermal noise, ↑ R_L
* achieved by connecting photodiode to amp
* circuit has high imp (MΩ)
* ↑ BW $\propto \frac{1}{R_L C_i}$ ∴ tradeoff b/w BW & noise

(b) Trans impedance design



$R = \frac{\eta q}{h\nu}$

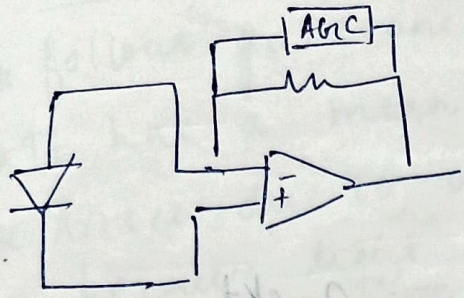
* ~~BW $\propto \frac{1}{R_L}$~~
* ~~∴ ↑ BW, ↓ R_L~~

$\eta = \frac{I_p \times (h\nu)}{q \times P_{in}}$

$I_p = \frac{\eta q \lambda}{hc} (P_{in})$

* consists of negative feedback
* Input imp + -ve feedback = trans imp (R_Z)
* photodiodes usually integrated with transimpedance amp called PINAMP.

* To ↑ dynamic range of transimpedance, AGC is used



* AGC maintains amp gain, keeps O/P voltage stable

* ∴ transimpedance (RZ) is also varied
  ↑ at low I/P signal
  ↓ at high I/P signal

Quantizer

consists of
- Noise filter
- Power amp / limiter
- Decision ckt

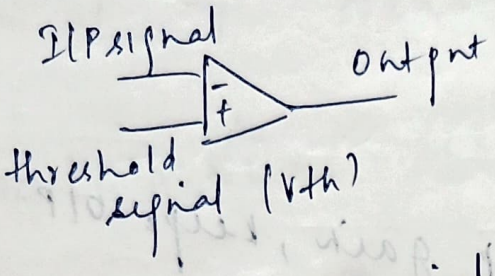
* Noise filter – Improves SNR, ~~Noise BW~~

* Power amp / limiter → provides power amp of signal obtained from pre-amp.

  Strong signal → ~~Amp~~ Limiter limits
  Weak signal → Amp.

* Amp necessary to drive decision ckt

Decision ckt → comparator



* determines logical meaning of ckt.

$V_{in} > V_{th} \xrightarrow{O/P} 1$

$V_{in} < V_{th} \xrightarrow{O/P} 0$.

* Vth is usually ½ the recieved signal value.

Buffer

* transfers signal from I/P → O/P unchanged but reshapes the electrical form.

Clock recovery

* extracts timing info from the data stream and helps decision ckt to generate clean output.

* Timing signal must be same at Tx & Rx to synchronize all operations

* If Rx has diff time, data sampling error occurs.

Noise sources in photodetectors

$i_{ph}(t) = (hq/h\nu)\, P(t)$

☆ Quantum noise or shot noise

☆ follows poissonic process.

☆ It has a mean square value

☆ Arises due to optical power fluctuation because light is made up of discrete number of photons.

$$\cancel{\langle i_Q^2 \rangle}$$

$$\langle i_Q \rangle^2 = \sigma_Q^2 = 2 q I_p B M^2 F(M)$$

where $F(M) = M^x$; $0 \le x \le 0.1$

$F(M) \rightarrow$ APD noise figure

$I_p \rightarrow$ mean detected current

$B \rightarrow$ BW

☆ Dark or leakage current noise

☆ Dark current $\rightarrow$ current generated without light incidence

☆ This generates 2 types
- Bulk dark current
- Surface dark current

Bulk Dark current $\rightarrow$ thermally generated e^-/h^+

$$\langle i_{DB}^2 \rangle = \sigma_{DB}^2 = 2 q I_{DB} B M^2 F(M)$$

I_D: primary detector bulk dark current

Surface leakage current noise.

* aka leakage current.

$$\langle i_{DS}^2 \rangle = \sigma_{DC}^2 = 2q I_L B$$

$I_L \rightarrow$ surface leakage current

* not affected by avalanche gain

Johnson noise current (thermal noise)

* PD load R contributes a mean square thermal noise current

$$\langle i_T^2 \rangle = \sigma_T^2 = 4 k_B T B / R_L$$

$T \rightarrow$ absolute Temp.

$k_B \rightarrow$ Boltzman const (1.38×10^{-23} J/K)

* reduced by using large load R.

mean sq PD noise current,

$$\langle i_N^2 \rangle = S_N^2 = \langle i_Q^2 \rangle + \langle i_{DB}^2 \rangle + \langle i_{DS}^2 \rangle$$

$$= S_Q^2 + S_{DB}^2 + S_{DC}^2$$

$$= 2q(I_p + I_d) M^2 F(M) B + 2q I_L B$$

Sums

noise in photodetector.

primary photocurrent $I_p = \frac{\eta P_{in} q \lambda}{hc}$

$\langle i_Q^2 \rangle = 2q I_p B$

↳ Take sq rt ✗

$\langle i_D \rangle^2 = 2q I_d B$

$h = 6.626 \times 10^{-34}$

$q = 1.6 \times 10^{-19}$

$\langle i_T^2 \rangle = 4 K_B T B / R_L = \frac{4 K_B T}{R_L} B$

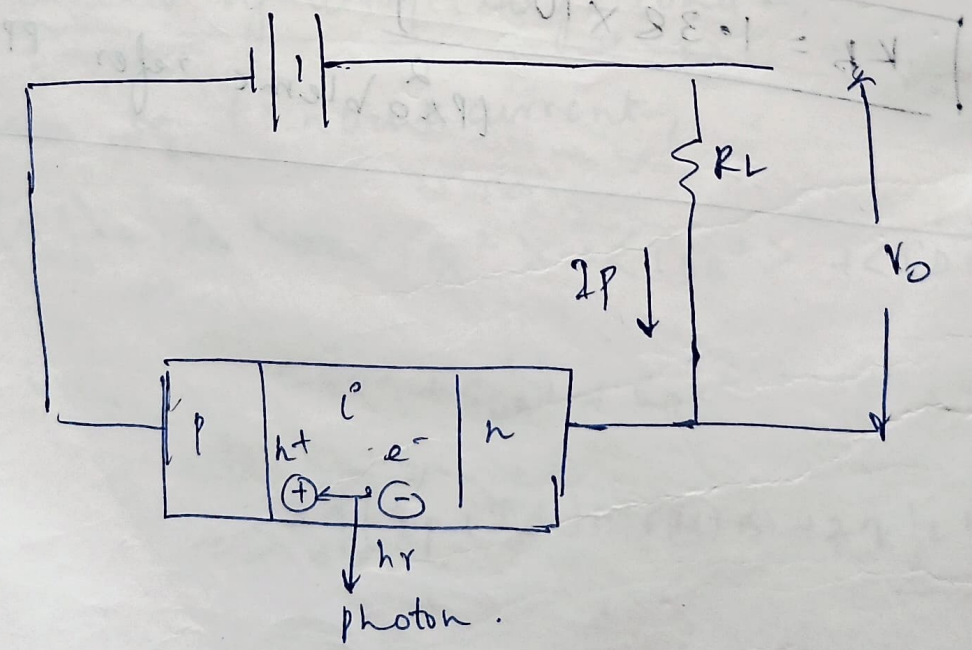
$T = 293$

$K_B = 1.38 \times 10^{-23}$

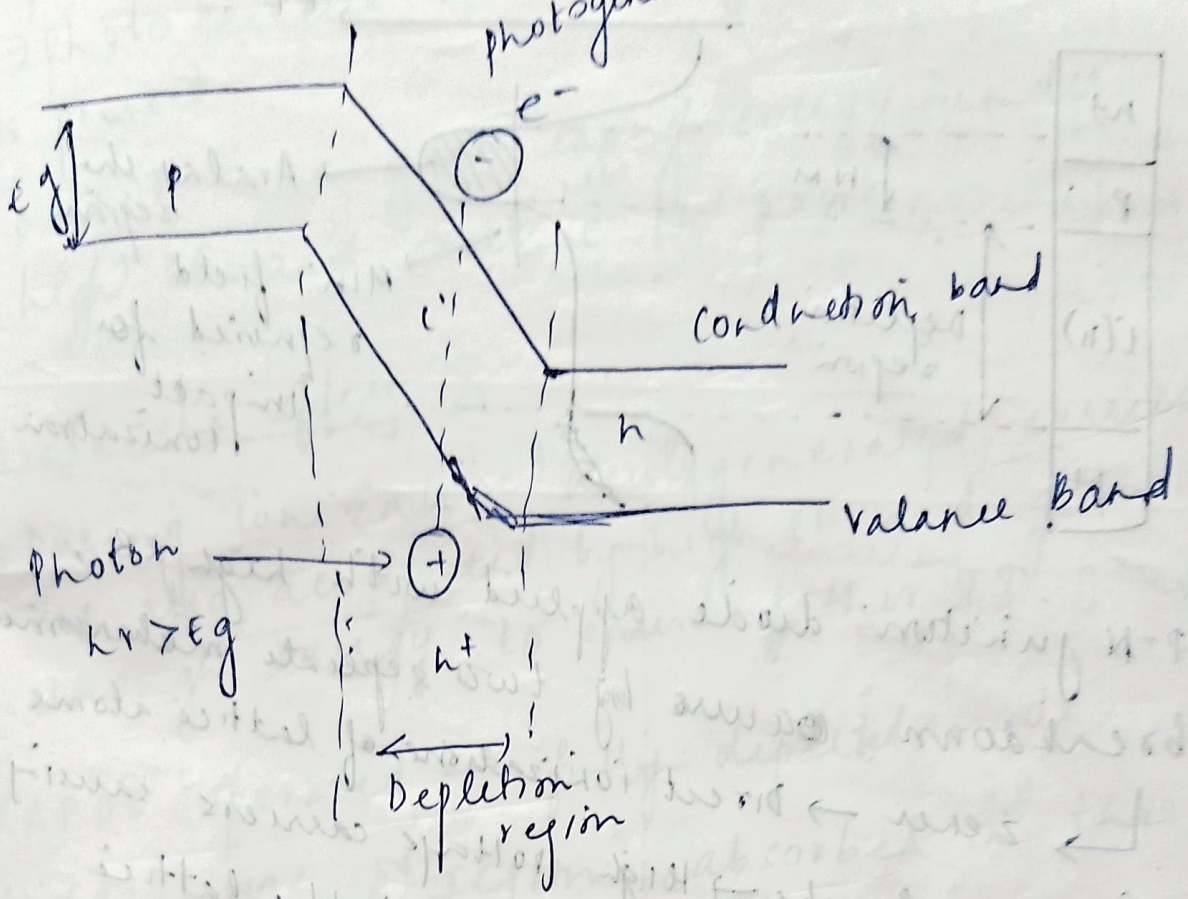
(Problems refer PPT)

PIN

* P & N regions seperated by lightly n doped intrinsic region.
* Incident photon with energy ≥ band gap energy (E_g) of PD will generate e^-, h^+ pairs → photocarriers.
* High EF present in depletion region causes carriers to seperate and be collected across reverse bias junction.
* raise to photocurrent flow → one e^- for every carrier pair.
* Absence of light, PIN → normal diode: If FB → conduct large current



energy band dia



Q operating modes — photoconductive / photovoltaic

Photovoltaic → no bias, very slow, not used for real world fiber optic reciever. (O/P current log I/P light)

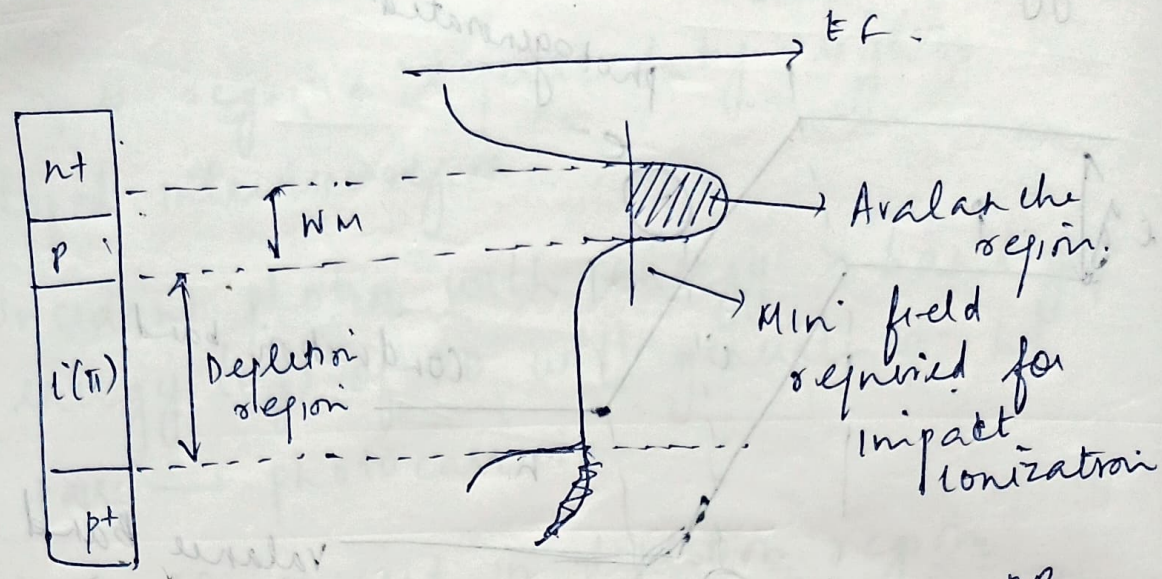
Photoconductive → R.B, O/P current linear with I/P light power region; intrinsic ~~light~~ improves sensitivity of device, no internal gain.

cut off

$$\lambda_c = \frac{1.24}{E_g(eV)} = \frac{1240}{E_g(eV)} \text{ (nm)}$$

(λ_c in μm; $1.24 \rightarrow hc$)

APD



when

* P-N junction diode applied with high RB, breakdown occurs by two seperate mechanisms
  - → zener → Direct ionization of lattice atoms
  - → Avalanche → High voltage carriers causing Impact ionization of the lattice atoms.

APD uses → Avalance breakdown phenomena.

APD has internal gain, ↑ responsivity.

* The doping conc and physical construction of n+ip+ junction enables EF high enough to cause II.

* Under normal op bias, I layer completely depleted.

* Known as Reach through condn (RAPD's).

- Impact ionization
↳ photo carrier travel in region where high EF is present
* carrier can gain enough energy under high EF and excite new e^- h^+ pair.

Avalanche effect
* During ionization newly generated carriers are also accelerated by high EF and gain enough energy to cause futher II.

* RAPDs operated → fully depleted mode.
* light entre p^+ region, absorbed in the p region.

* drift through p region in pn^+ region where high EF exits, multiplication takes place.

$k = \beta / \alpha$
β → h^+ ionization rate → avg no of e/h^+ created per unit dl.
α → e^-

↓ PD performance.

* APD biased closed to breakdown, results in leakage current, ∴ Biased just below breakdown.

* Avalanch Multiplication
$M = \frac{I_M}{I_P}$
I_M → total multiplied O/P I
I_P → primary unmultiplied photo current.

Adv

* Internal gain
* better SNR
* Better sensitivity.
* Wide range of gain variation.

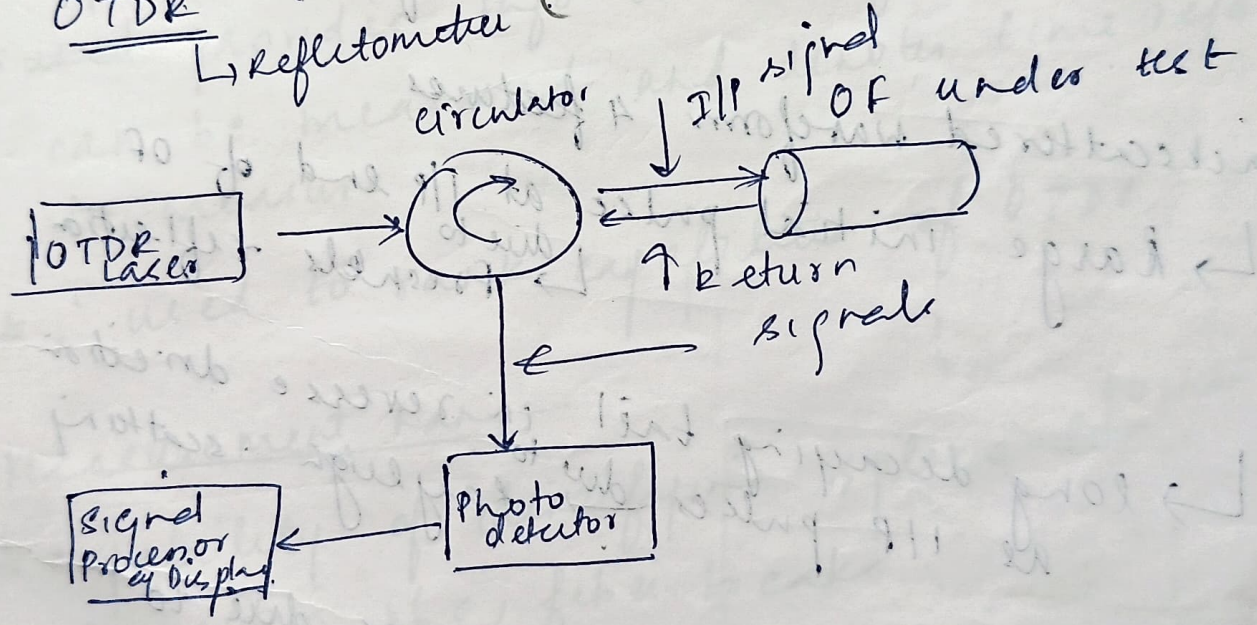
SLED	ELED (better)
* Easy to fabricate	* difficult
* lower coupling eff	* higher CE
* Low system performance	* high
* lower QE	
*	* more directional pattern.
* ↓ BW	* ↑ BW

LED	LASER
* spontaneous emission	* stimulated emission
* Wide emission spectrum	* Narrow emission spectrum.
* ~~co~~ non coherent	* coherent
* Low efficiency	
* Low response time	

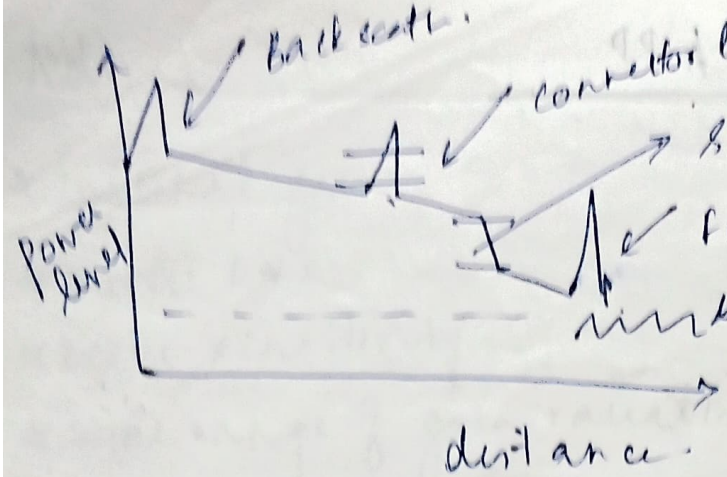
PIN	APD
* Less sensitive	*
* No internal gain	
* Poor SNR ratio	
* simple circuit	
* cheaper.	
* Low reverse bias voltage.	

OTDR

↳ Reflectometer (SM)



* optical radar.
* periodically launching narrow laser pulses into one end of the fiber under test by using directional couplers or beam splitters.
* properties of OF determined → analysing amp & characteristics of waveform of the backscattered light.



scale of vertical axis → logarithmic
measures back scattered

horizontal → dist b/w instrument and measurement pt on fiber.

Backscattered waveform 4 features

↳ large initial pulse at I/P end of OF
↳ due to Fresnels reflection.

↳ long decaying tail in reverse direction as I/P pulses due to Rayleigh scattering

↳ abrupt shift in curves due to bends, optical loss at joints.

↳ positive spikes arising from fresnels ~~scattering~~ reflection at far end of fiber, joints & imperfections.

~~Power~~ 2 imp parameters

Dynamic range

Measurement range.

Dynamic range.

* diff b/w initial backscattered power ~~lvl~~ level at front connector & noise lvl after 3 min of measurement time.

* expressed in dB.

* ~~used~~ provides info on max fiber loss that can be measured and denotes time reqd to measure.

* ∴ used to rank capabilities of OTDR.

Measurement range

* capability of identifying splice ~~lon~~ points, connection pts, fiber breaks.

* max allowable attenuation b/w OTDR and an event.

Photodetectors (Sums / Formulas)

Responsivity → Ratio of current O/P → ~~I/P~~ incident optical power

* varies with λ
* gives transfer char of diode

$$R = \frac{I_p}{P_{in}}$$

$$\eta = \frac{I_p/q}{P_{in}/h\nu}$$

$$= \frac{I_p h\nu}{q P_{in}}$$

$$= \frac{\eta q}{h\nu} = \frac{\eta q \lambda}{hc}$$

$$\boxed{R = \frac{\eta \lambda (nm)}{1240}}$$

QE : Ratio of e^-/h^+ generated by incident photons

$$\eta = \frac{\text{no of } e^- \text{ pairs}}{\text{no of } h^+ \text{ pairs}}$$

$$\boxed{\eta = \frac{n_e}{n_p}} = \boxed{\eta = \frac{I_p/q}{P_{in}/h\nu}}$$

→ avg photo current

QE<1 → no e/L^t generated

<u>cutoff λ</u> → highest λ over which semiconductor can absorb λ

$$\lambda_c = \frac{hc}{E_g} = \frac{1.24}{E_g}\,(\mu m) = \frac{1240}{E_g}\,(nm)$$

<u>Sums</u>

① $\lambda = 1550\,nm$

$$R = \frac{n\lambda}{1240} = \frac{1550}{1240} = 1.25\ A/W$$

② $\lambda = 800\,nm$

$$\eta = 10\% = \frac{10}{100} = 0.1$$

$$R = \frac{\eta\lambda}{1240} = \frac{0.1 \times 800}{1240} = 0.0645\ A/W$$

④ $\lambda = 800\,nm$

⑤ $I_p = \cancel{8000\,W}\ 80\,A$

$P_{in} = 800\,W$

$$QE = \frac{I_p/q}{P_{in}/h\nu} = \frac{80 \times 1.6 \times 10^{-19} \times 800}{6.63 \times 10^{-34} \times 3 \times 10^{8}}$$

$$I_p = \frac{\eta q \lambda}{hc}\,(P_{in})$$

$$\frac{I_p/q\lambda}{P_{in}\,hc} = \frac{1024 \times 10^{-19}}{19.89 \times 10^{-26}}$$

Quantum efficiency of LED [IT2 paper key]

* Rate eqn for carrier recombination in an LED can be written as:

$$\frac{dn(t)}{dt} = \frac{J}{qd} - \frac{n}{\tau}$$

$\tau \rightarrow$ carrier lifetime
$q \rightarrow$ charge of e^-
$d \rightarrow$ thickness of recombination region

Under equilibrium,

$$n = \frac{J\tau}{qd}$$

Internal q^E → fraction of h^+, e^- that recombine radiatively

$$\eta_{int} = \frac{R_r}{R_r + R_{nr}}$$

$R_r \rightarrow$ radiative recomb.
$R_{nr} \rightarrow$ non radiative

$$\therefore \eta_{int} = \frac{\tau}{\tau_r}$$

where Bulk recombination lifetime,

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

for homo LED : $\eta_{int} = 50\%$
hetro LED : $\eta_{int} > 60 - 80\%$

Total no of recombs per sec

$$R_r + R_{nr} = \frac{I}{q}$$

$$\therefore R_r = \eta_{int}\left(\frac{I}{q}\right)$$

$\therefore$ Optical power,

$$P_{int} = \eta_{int}\left(\frac{I}{q}\right)h\nu = \eta_{int}\left(\frac{hcI}{qd}\right)$$

Ext Q.E

ratio ~~no~~ of photons emitted from LED to no of internally generated photons.

$$\eta_{ext} = \frac{\text{no of photons emitted from LED}}{\text{no of internally generated photons}}$$

$$\eta_{ext} = \frac{1}{4\pi} \int_0^{\phi_c} T(\phi) \, (2\pi \sin\phi) \, d\phi$$

$T(\phi)$ → fresnels trans coff

$$\boxed{T(\phi) = \frac{4n_1 n_2}{(n_1+n_2)^2}}$$

∴ If $n_1 = n$

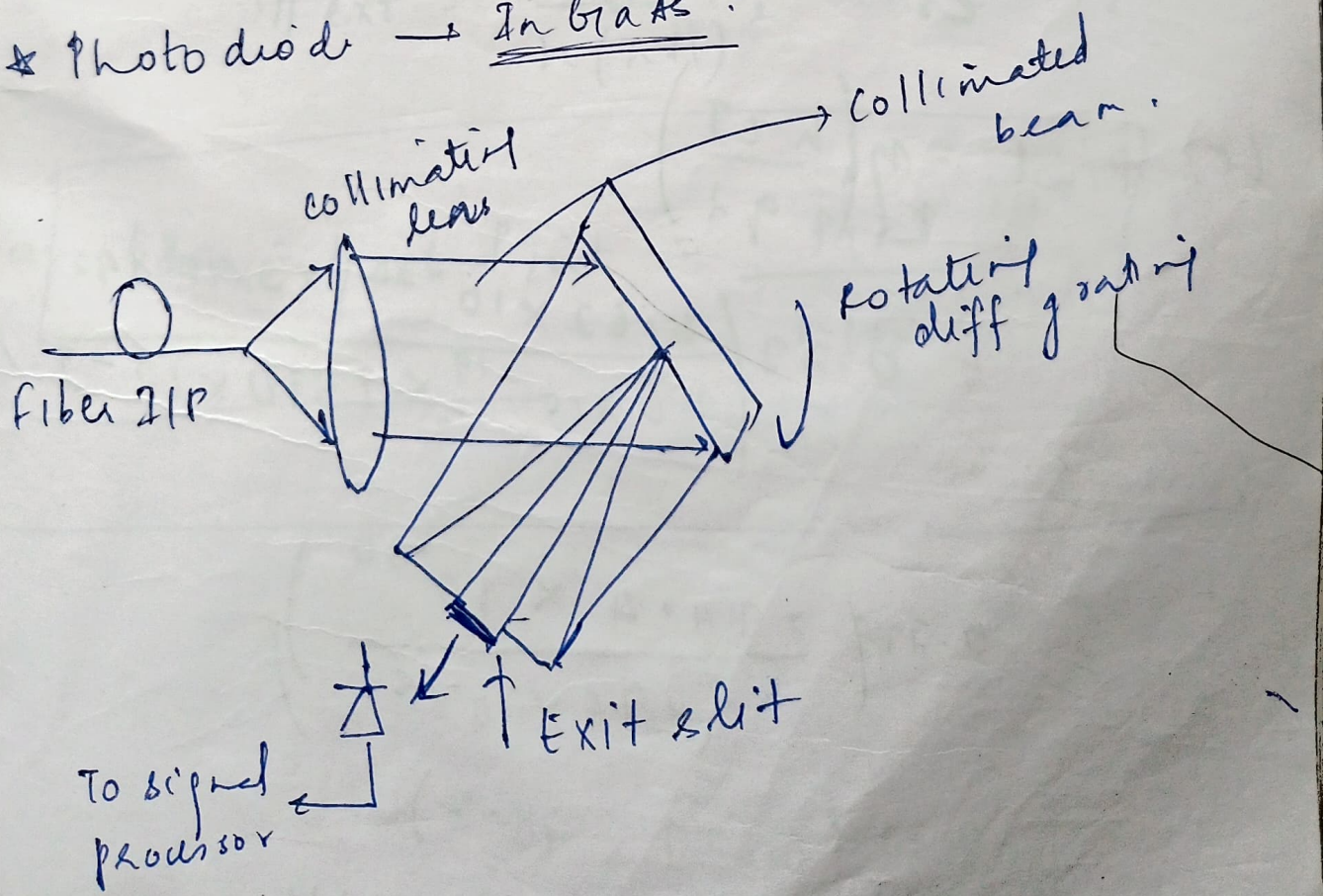
$$\boxed{\eta_{ext} = \frac{1}{n(n+1)^2}}$$

$$\boxed{P = \eta_{ext} P_{int} = \frac{P_{in}}{n(n+1)^2}}$$

P → OP emitted from LED

OSA → optical spectrum analyser. (m)

* measures power as function of λ.
* light from fiber is collimated ~~beam~~ by a lens and is directed to diffraction grating that can be rotated.
* Exit slit filters the spectrum of light from the grating
* ∴ determines spectral resolution of OSA.
* resolution describes width of optical filter.
* Determines dynamic range (ability to view large & small signals in same sweep)
* BW affects sensitivity by sweep time.
* Photodiode → InGaAs.



LED sum

$\lambda = 1310\ nm$

$\tau_r = 30$

$\tau_{nr} = 100$

$I = 40\ mA$

(a) Bulk recomb time : $\tau = \frac{\tau_r \tau_{nr}}{\tau_r + \tau_{nr}}$

$= \frac{30 \times \cancel{100}}{\cancel{130}}$

$= \frac{30}{13} = 23.1\ ns$

(b) QE:

$\eta = \frac{\tau}{\tau_r} = \frac{23.1}{30} = 0.77$

(c) $P_{int} = \eta \left(\frac{hcI}{q\lambda} \right)$

$= 0.77 \left(\frac{6.62 \times 10^{-34} \times 3 \times 10^{8} \times 40 \times 10^{-3}}{1.6 \times 10^{-19} \times 1310 \times 10^{-9}} \right)$

$= 0.77 \left(\frac{794.4 \times 10^{-30}}{209.6 \times 10^{-28}} \right)$

$= 0.77 \left(0.379 \times 10^{-2} \right)$

$= 0.292 \times 10^{-2} = 29.2\ mV$

Ext Quantum Eff (LED)

* Ratio of photons emitted from LED to no of internally generated photons.

$$\eta_{ext} = \frac{1}{4\pi} \int_0^{\phi_c} T(\phi)\, 2\pi \sin(\phi)\, d\phi$$

$T\phi \rightarrow$ Fresnels tx coeff.
↳ angle of incidence.

$$T(0) = \frac{4 n_1 n_2}{(n_1+n_2)^2}$$

$$n_1 = n, \quad T(0) = \frac{4n}{(n+1)^2}$$

$$\therefore \eta_{ext} = \frac{1}{n(n+1)^2}$$

$$\boxed{P_{out} = \eta_{ext} P_{int} = \frac{P_{int}}{n(n+1)^2}}$$

Formulas

$$\boxed{\lambda = \frac{1.24\ (\mu m)}{E_g}}$$

$$E = \frac{hc}{\lambda}$$

LED

$$\tau = \frac{\tau_r \tau_{nr}}{\tau_r + \tau_{nr}}$$

$$\eta_{int} = \frac{\tau}{\tau_r}$$

$$\eta_{ext} = \frac{1}{n(n+1)^2}$$

$$P_{int} = \eta\left(\frac{hcI}{q\lambda}\right)$$

$$P_{ext} = \frac{P_{int}}{n(n+1)^2}$$

Fabry Perrot

$$FSR = \frac{\lambda^2}{2nD}$$

D → dist

$$m = \frac{2nL}{\lambda}$$

m → no half wave

$$R_1 = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

Cathodo luminicence

$$R_c = k(E_b)^b$$

APD

$$R = \frac{\eta \lambda}{1240} = \frac{\eta q \lambda}{hc} \quad A/W$$

$$QE = \eta = \frac{I_p/q}{P_{in}/h\nu}$$

$$I_p = \frac{P \eta q \lambda}{hc}$$

MCQ's CT2

(4) Laser gain coeff for cavity

$$\boxed{g_{th} = \alpha + \frac{1}{2L} \ln\left(\frac{1}{R^2}\right)}$$

α 25 cm^{-1}

$L = 500\,\mu m$

$R = 30\% = \frac{30}{100} = 0.3$

$49.07\ cm^{-1}$

(7) $\frac{5.4}{6\times10^6} = 90\%$

(8) $BW = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 10\,pF \times 1}$

$= 15.9\ MHz$

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(14) APD

$\eta = 64\%$ $\quad \lambda = 900\,nm$

$P = 0.5\,\mu W$ $\quad M = ?$

~~$I_p = 10\mu A$~~ $\quad I_M = 10\,\mu A$

$$I_p = R P_{in} = \frac{\eta q}{h\nu} P_{in}$$

$$= \frac{\eta q \lambda}{hc} P_{in}$$

$$= \frac{0.65 \times 1.6\times10^{-19} \times 900\times10^{-9}}{6.626\times10^{-34} \times 3\times10^{8}}$$

$A = 0.235\,\mu A$

$$M = \frac{I_M}{I_P} = \frac{10 \times 10^{6}}{0.235 \times 10^{6}}$$

$$= \underline{\underline{43}}$$

$\alpha = 25\ cm^{-1}$

$R = 30\% = \frac{30}{100} = \underline{\underline{0.3}}$

$L = 500\ \mu m$

$$g_{th} = \bar{\alpha} + \frac{1}{2L} \ln\left(\frac{1}{R^2}\right)$$

$$g_{th} = \bar{\alpha} + \frac{1}{2L} \ln\left(\frac{1}{R^2}\right)$$

$$g_{th} = \bar{\alpha} + \frac{1}{2L} \ln\left(\frac{1}{R^2}\right)$$

$$= 25 + \frac{1}{2(500\ \mu m)} \ln\left(\frac{1}{0.09}\right)$$

$$\lambda_c = \frac{1240}{E_g} = 25 + \frac{11.1}{2(500)}$$

$$\frac{5.4 \times 10^{6}}{6 \times 10^{6}}$$

$$= 25 + \frac{1}{2(500 \times 10^{-6})} \ln\left(\frac{11.1}{1}\right)$$

$$= \cancel{25 \times} \quad 25 + \frac{11.1 \times 10^{6}}{1000}$$

$$= 25 + 11.1 \times 10^{3}$$