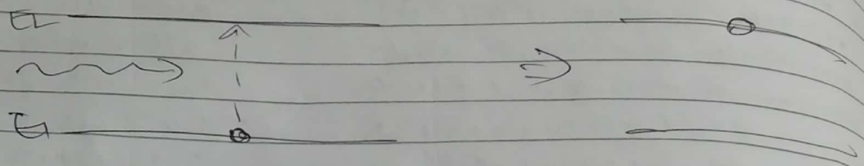
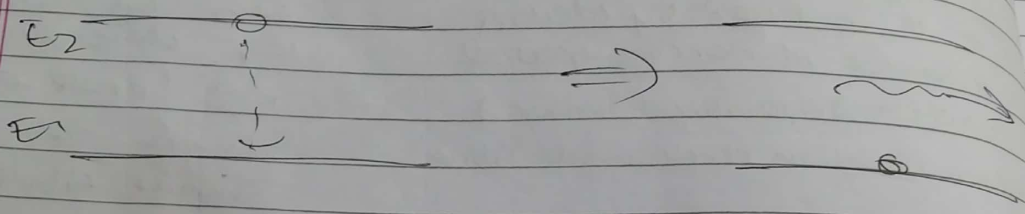
- Absorption



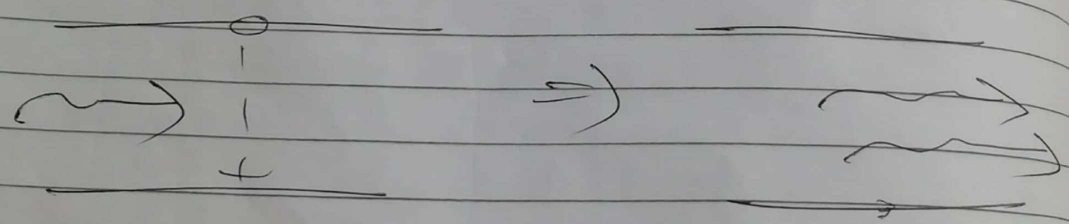
- Spontaneous emission:

LED



- Stimulated emission:

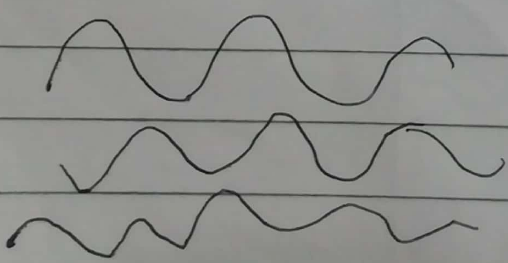
LASER



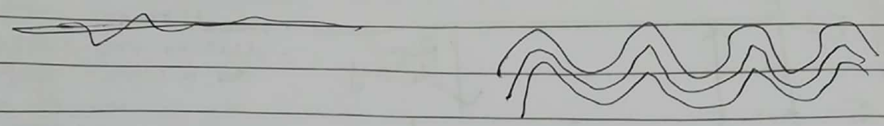
optical amplifier

→ $E_2 - E_1 = h\nu$

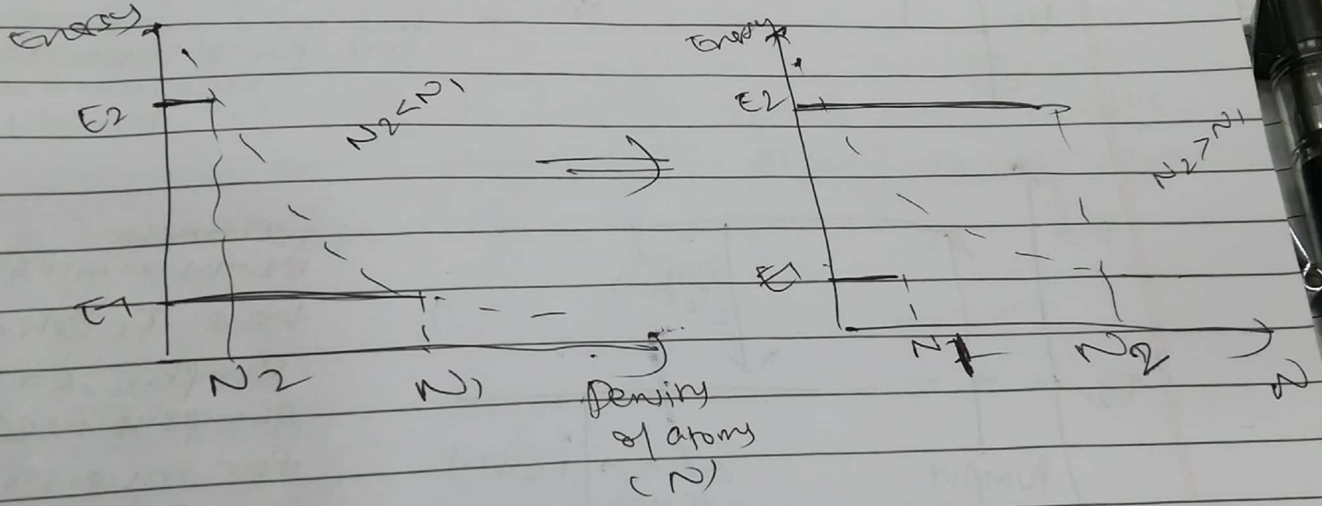
→ In spontaneous emission random phase changes so incoherent source



→ In stimulated emission coherent source as no abrupt phase change



→ Populn Inversion: working of laser



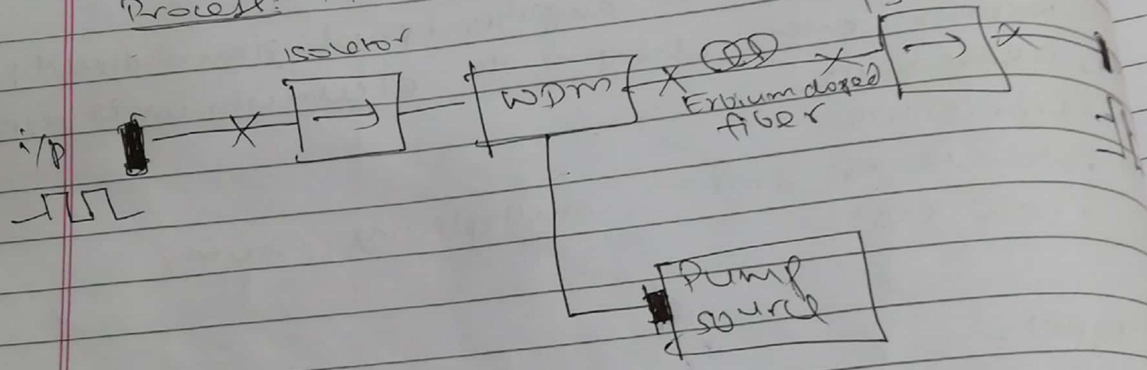
- To achieve optical amplification we need more no. of e's at higher energy state E_2 than E_1 but at thermal eqm no. of e's at lower energy state $(E_1) > E_2$.

- We an external energy source like optical flash tube or high-freq. radio fields & the process is called pumping pump signal used for popuⁿ inversion which is a necessity for amplifn

EDFA:

- Active medium 10 to 30m of optical fiber lightly doped with rare elements such as Er, Nd (neodynium).
- host fiber material will be silica, Flouride based glass or multi component glass.
- operation of EDFA limited to 1530 to 156
- i/p & pump signal used for stimulated emission

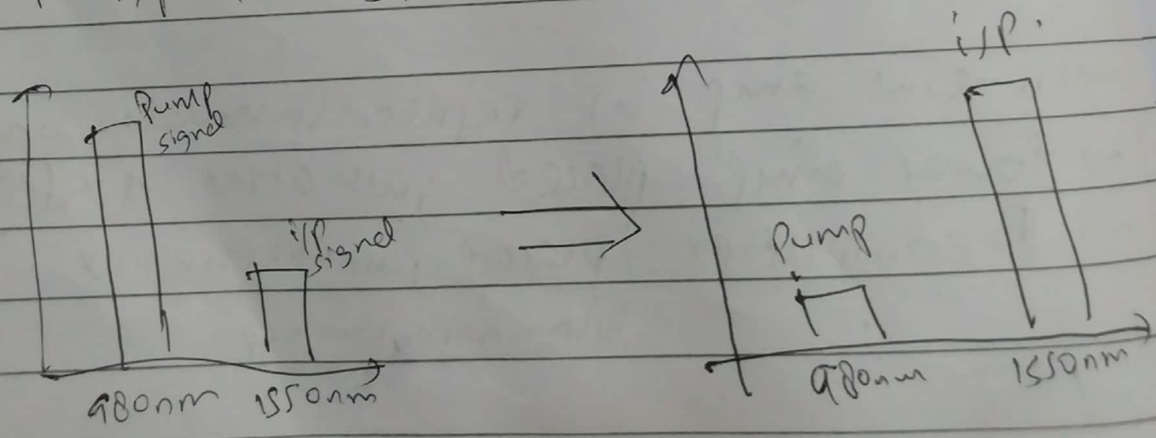
Process:



X → fusion splice

Isolator ensured amplifier not used as laser because if F/B occurs then lasing will happen.

- Pump optical signal added to i/p by WDM coupler
- with doped fibre part of pump energy transfer to i/p for stimulated emission.

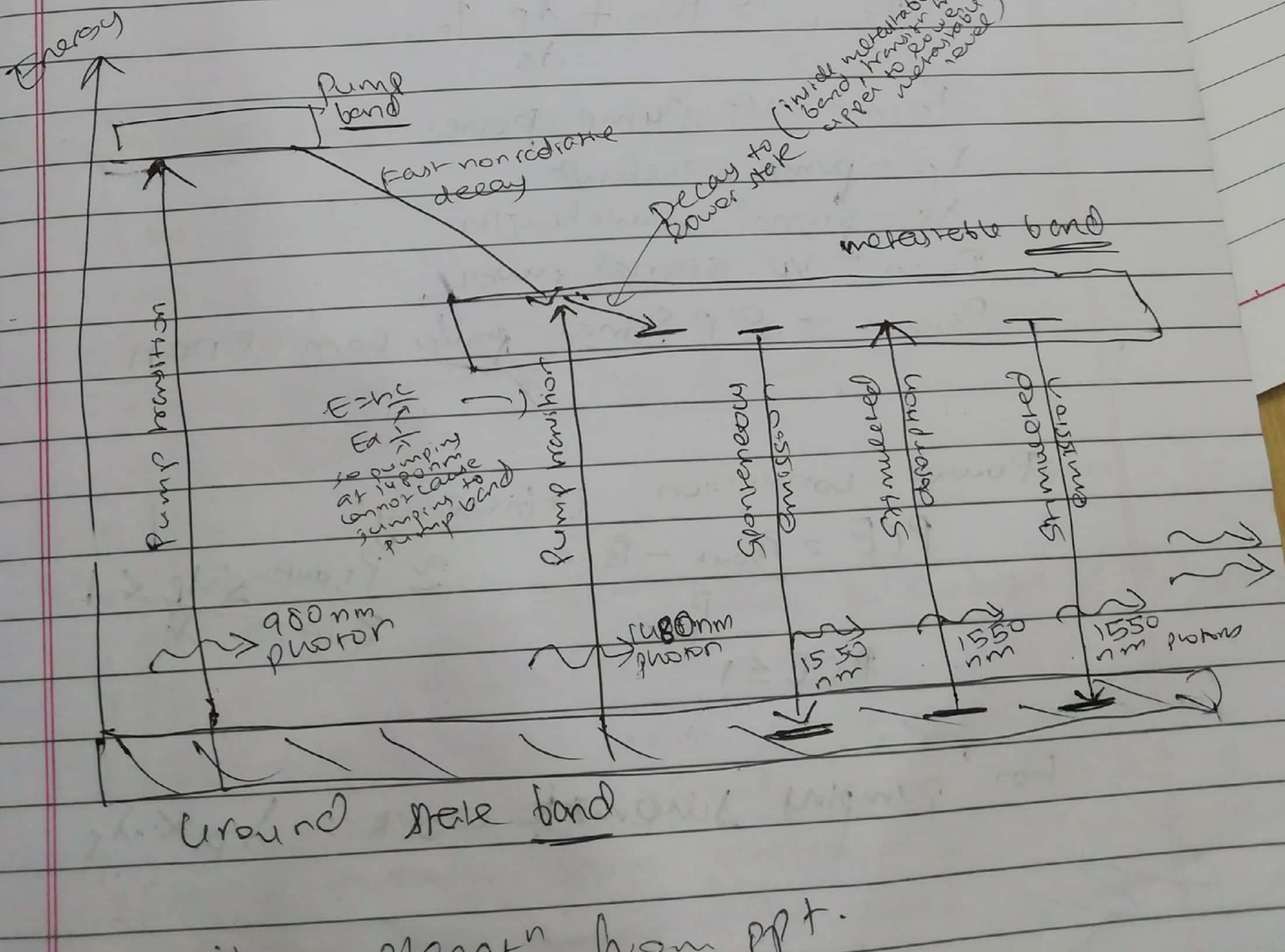


Oper:

- high powered beam
- mixed ligh with erbiu
- high pow to higher
- when ph erbium some energ
- erbi in
- isol rel a

Oper^n:

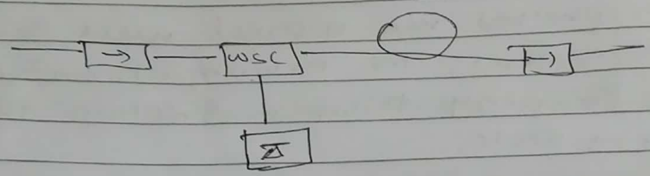
- high powered beam of light mixed with i/p signal using wavelength selective coupler
- mixed light is guided into section of fibre with erbium ions included in core.
- high powered light beam excites erbium ions to higher energy states.
- when photons ~~meet~~ of signal meet excited erbium atoms, the erbium atoms give up some energy to signal & return to lower energy state.
- erbium gives its energy in form of photons in same phase & dirn as signal being amplified.
- isolator used to prevent refl^ns as these refl^ns can disrupt amplifier oper^n & cause amplifier to behave as laser.



do this explanat^n from ppt.

- Pumping methods in EDFA

i) Co-directional (F/w) pumping:



- gives better noise performance.

<u>EDFA Power Conversion Efficiency:</u>

$$P_{s,out} \leq P_{s,in} + \frac{\lambda_p}{\lambda_s} P_{p,in}$$

$P_{p,in}$ – I/P pump power

λ_p – pump wavelength

λ_s – signal wavelength

$P_{s,in}$ – I/p signal power

$P_{s,out}$ – O/P signal power from EDFA.

Power conversion efficiency:

$$PCE = \frac{P_{s,out} - P_{s,in}}{P_{p,in}} \simeq \frac{P_{s,out}}{P_{p,in}} \leq \frac{\lambda_p}{\lambda_s} < 1$$

$PCE \leq 1$

For pumping scheme to work: $\lambda_p < \lambda_s$

· Quantum Conversion Efficiency:

$$QCE = \frac{\lambda_s}{\lambda_p} PCE$$

max value of $QCE = 1 \Rightarrow$ All pump photons converted to signal photons

· Gain:

$$G = \frac{P_{s,out}}{P_{s,in}} \leq 1 + \frac{\lambda_p P_{p,in}}{\lambda_s P_{s,in}}$$

~~when $P_{s,in} \gg$~~

To achieve max gain:

$$P_{s,in} \leq \frac{(\lambda_p / \lambda_s) P_{p,in}}{G - 1}$$

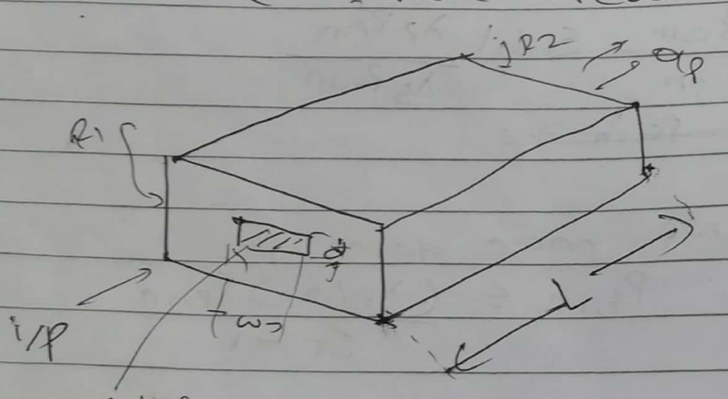
* Semiconductor optical Amplifier:

so that no f/b

· Laser diodes w/o end mirrors & has anti reflection coating coupled to both fiber ends.
· Fiber attached to both ends.
· Amplified version of signal produced.
· Adv: bidirectional
· Disadv: High coupling losses, High Noise figure
· It is an InGaAsP laser.
· Active medium consists of alloy semiconductor (P, Ga, In, As)
· Works in 1280 to 1650 nm. windows.
· Travelling wave amp. as in contrast to laser f/b mech. where optical signal makes many passes through lasing cavity, in SOA, optical signal travels through device only once.

Operⁿ:

DC current applied to device results in e^-s being pumped to condⁿ band and removed from valence band & creates popaln inversion which is pre-cursor to optical gain. When signal photons travel through device they cause stimulated emission to occurs when e^- & hole recombine.



Active region of width w, thickness d & length L

FIBER FABRICATION

- Direct melt method: made from molten state of purified components of silicate glasses.
- vapor phase oxidn: Highly pure vapors of metal helids $SiCl_4$, $GeCl_4$ react with oxygen to form white powder of SiO_2 particles. These are then collected on surface of a bulk glass by one of four methods and transformed to a homogenous glass by heating without melting by 1 method to form a clear glass rod or tube. This is called as preform

Steps:

→ Fabricn of preform
→ Drawing fiber from preform
→ Coating & jacketing process.
→ Preform will be 10-25mm in diameter & 60-120cm long.

Preform fabrication :- Chemical vapor Deopsition
→ modified CVD
→ Plasma activated CVD
→ outside vapor Deposition
(Portion) → vapor-phase Axial Deposition

CVD:
All methods based on thermal CVD that forms oxides.

$SiCl_4 + O_2 \rightarrow SiO_2 + 2Cl_2$

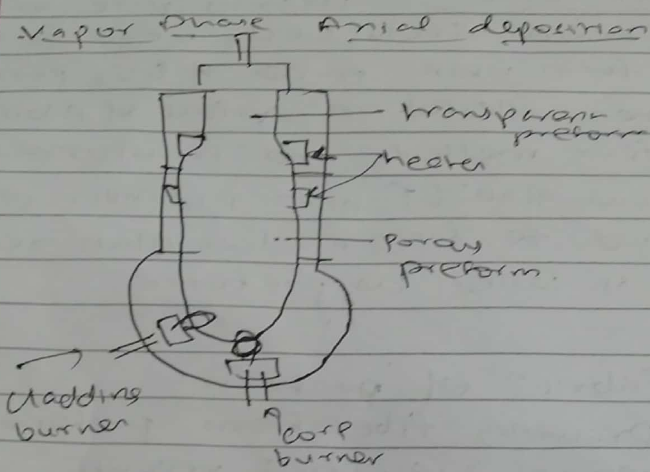
$GeCl_4 + O_2 \rightarrow GeO_2 + 2Cl_2$

$4POCl_3 + 3O_2 \rightarrow 2P_2O_5 + 6Cl_2$

$4BCl_3 + 3O_2 \rightarrow 2B_2O_3 + 6Cl_2$

To vary RI:
Germanium dioxide & phosphorous pentoxide inc.
RI of glass
Boron oxide decreases RI of glass.

Vapor Phase Axial deposition:



Adv:

- Both step & graded index fiber can be made
- No central hole in perform as occurs with OVD process
- Used in mass prodn

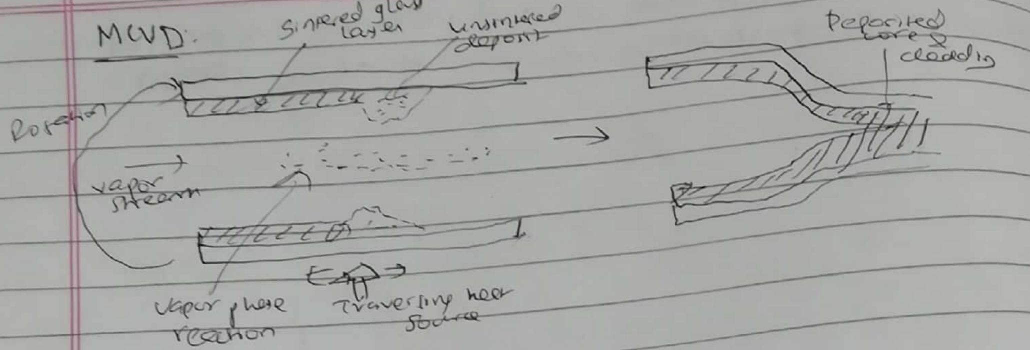
Process:
It uses an end on deposition onto a rotating fused silica target. The vaporized constituents are injected from burner & react to form silica soot by flame hydrolysis. This is deposited on end of starting target (rotating silica target) in axial dirn forming a solid porous glass preform. The preform which is growing in axial dirn is pulled up at a rate equal to growing rate in axial dirn. It is initially dehydrated by heating with $SOCl_2$:

$H_2O + SOCl_2 \rightarrow 2HCl + SO_2$

It is then sintered into a solid preform in a graphite resistance furnace at a temp. of about 1500°C.

cladding: pure silica SiO_2
core: silica SiO_2 doped with GeO_2

MCVD:



$SiCl_4 + O_2 \rightarrow SiO_2 + 2Cl_2$
$GeCl_4 + O_2 \rightarrow GeO_2 + 2Cl_2$

- Gaseous mixture of reactants is fed at one end of a rotating silica tube.
- For cladding we flow $SiCl_4$ gasses and heat it in an oxygen environment by using an oxyhydrogen flame at temp. of 1600°C
- The oxygen hydrogen burner traverses in horizontal dir^n & simultaneously silica tube is rotated so that entire surface area is covered & uniform deposition occurs
- By $SiCl_4 + O_2 \xrightarrow{\Delta} SiO_2 + 2Cl_2$, glass particles called soot are formed and deposited on internal walls of tube
- As the burner translates along tube at 1600°C the soot particles are vitrified & form a thin sintered glass layer
- we keep depositing cladding layer by layer.
- For core layer we start flowing required dopant amount $GeCl_4$ along with $SiCl_4$ into tube and similarly by heating in oxygen environment the core layer is formed by multiple back & forth motions of flame.
- When layers built up the temp. of burner increased to 2000°C & collapse the tube into a solid preform.

Adv:
- raw materials available in high purity form
- process takes place inside a tube so water bubbles not present in glass layer

Disadv: a starting tube needed so cost high.

No structural spec in portion
just basic working

* Types of LASERS:

• Tunable Laser:

⇓

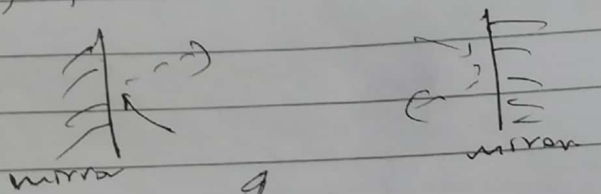
a laser which can give a range of wavelengths

(1) Dye laser - emits λ : 320 nm – 1200 nm

(2) Titanium Sapphire laser : 660 – 980 nm

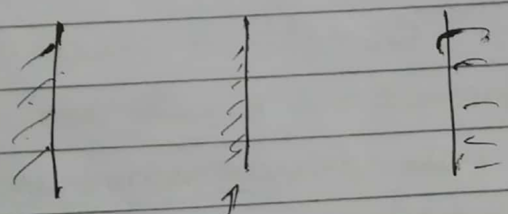
(3) Fiber laser : Near infrared region

Fabry perot laser structure



a photon reflected back to active medium so large no. of stimulated emission.

In Tunable laser:

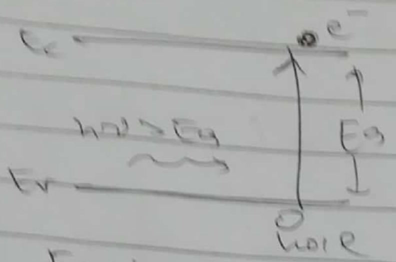


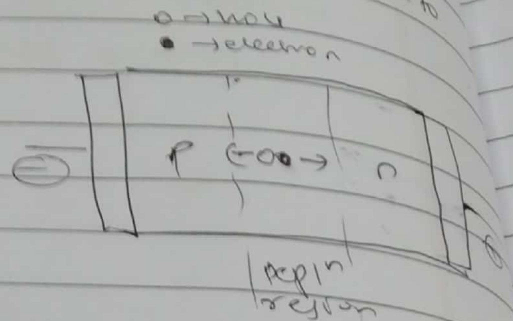
rotating intercavity mirror which is ~~used to tune~~ the laser to a particular wavelength

Using rotating intracavity mirror & gratings we can get TE_{00} mode.

Module 4: Optical Detectors

- Used to convert optical to electrical signal which is then amplified before processing.
- Principle: stimulated absorption
- detector is reverse biased as we dont want e^--hole recombination. I want to seperate them to obtain current





E_g: band gap energy

- ~~Photons having energy > bandgap are incident near depl^n region~~
  ↳ This process leaves an empty hole in valence band & is called photogeneration of e^--hole pair (as e^- jumps to E_c it leaves a hole in E_v)
- Carrier pairs near j^n are separated and swept under influence of electric field to produce displacement by current.

→ Imp parameters:

- Absorption coeff:
  The absorption of photons in photodiode to produce carrier pairs & a photocurrent is dependent on absorption coeff α_0 of light in semiconductor used to fabricate device.

$$I_p = \frac{P_0 e(1-r)}{hf}\left[1 - \exp(-\alpha_0 d)\right]$$

$e \rightarrow$ charge of e^-

$r \rightarrow$ Fresnel coeff. at semiconductor-air interface

$d \rightarrow$ width of absorption region

· **Quantum efficiency**: It is ratio of electrons generated by photodetector to the no. of photons incident on it

$$\eta = \frac{\text{no. of electrons collected}}{\text{no. of incident photons}}$$

$$\eta = \frac{r_e}{r_p}$$

$r_p \rightarrow$ incident photon rate (photons per sec)
$r_e \rightarrow$ electron rate (electrons per second)

· It is less than one as not all incident photons are absorbed to create electron-hole pairs as not all photons have energy > bandgap energy

· **Responsivity**: (do derivⁿ)
It is used to measure the performance of photodetector. It is ratio of o/p ~~photocurrent to~~ incident optical power

$$R = \frac{I_p}{P_o} \ (AW^{-1})$$

$$R = \frac{\eta e \lambda}{hc}$$

responsivity is directly prop. to quantum efficiency at a particular wavelength

· **Long wavelength cutoff**:
essential when considering intrinsic absorption process that energy of incident photons be greater or equal to bandgap energy E_g of material used to fabricate photodetector.

∴ photon energy: $\frac{hc}{\lambda} \geq E_g$

$$\lambda \leq \frac{hc}{E_g}$$

Thus, threshold for detⁿ, known as long-wavelength cutoff point

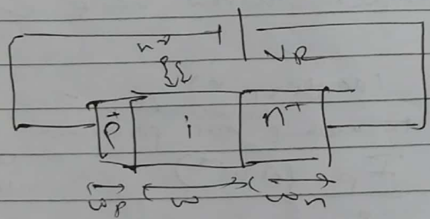
$$\boxed{\lambda_c = \frac{hc}{E_g}}$$

Scanned by CamScanner

* PIN photodiode:

- There are 3 region.
  p region, intrinsic & n region
- p & n heavily doped than a normal PN diode.
- width of intrinsic region should be larger than depl^n width of a normal PN junction.
- operates with ~~hea~~ applied reverse bias voltage and when reverse bias applied the depl^n region must cover entire intrinsic region.
- e^- hole pairs generated in space charge region by photon absorption

when light is incident on space charge region having energy > bandgap energy e⁻-hole pair gener^n occurs which are attracted by respective terminals producing a displacement photo current



Adv:

- very low reverse bias voltage
- high quantum efficiency
- large b.w. can be

Disadv:

- no amplific^n can be provided

* Avalanche photodiode:

- include an absorption region 'A' & multiplic^n region 'M'. The diode is R.B. When photon strikes then e^--hole gener^n occurs
- Across 'A' an electric field E serves to separate photo generated holes & electrons and sweeps one carrier towards multiplic^n region.
- multiplic^n region exhibits high electric field to provide internal photo-current gain by impact ionization
- gain of M at least 100 for silicon
  10-40 for germanium or InGaAs

Adv. • sensitivity high
• High gain & amplifier

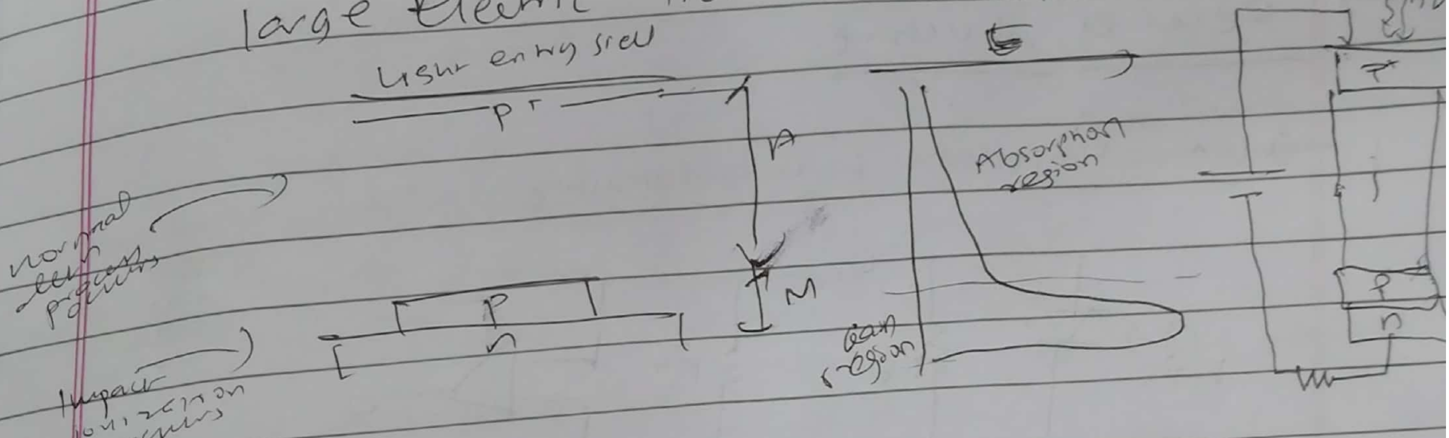
Disadv: • High reverse bias voltage
• High cost
• Balance b/w noise & gain difficult.

A region where e⁻-hole generation & one of the energetic particles i.e. e⁻ or holes further cause generation of e⁻-hole in M region.

Impact ionization: is process in which one energetic charge carrier can lose energy by creation of other charge carriers. → occurs in M region

eg. an e^- (or hole) with enough K.E. can knock a bound e^- out of its bound valence state and promote it to a state in condⁿ band creating e^--hole pair.

For carriers to have sufficient K.E. a sufficient large electric field is needed.



→ Noises in receiver:

• Thermal noise

spontaneous fluctuation due to thermal interaction b/w say free e^-'s & vibrating ions in conducting medium. It is prevalent in resistors at room temperature.

thermal noise current in a resistor R

$$\overline{i_t^2} = \frac{4KTB}{R}$$

K → boltzmann constant

T → absolute temp

B → b.w. of system.

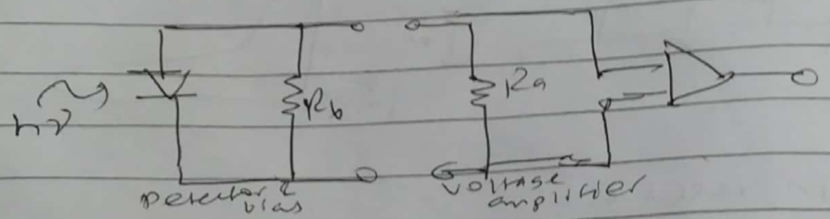
• Dark current noise.

When no optical power incident on photodetector a small reverse leakage current still flows from device terminals due to minority charge carriers. This dark current contributes to total noise as it gives random fluctuations in o/p current of diode.

$$\overline{i_d^2} = 2eBI_d$$

→ Receiver structure

→ Low impedance front end structure



• voltage amplifier with an effective i/p resistance R_a.

• The detector is loaded with a bias resistor R_b and an amplifier.

• ~~BW is given by:~~

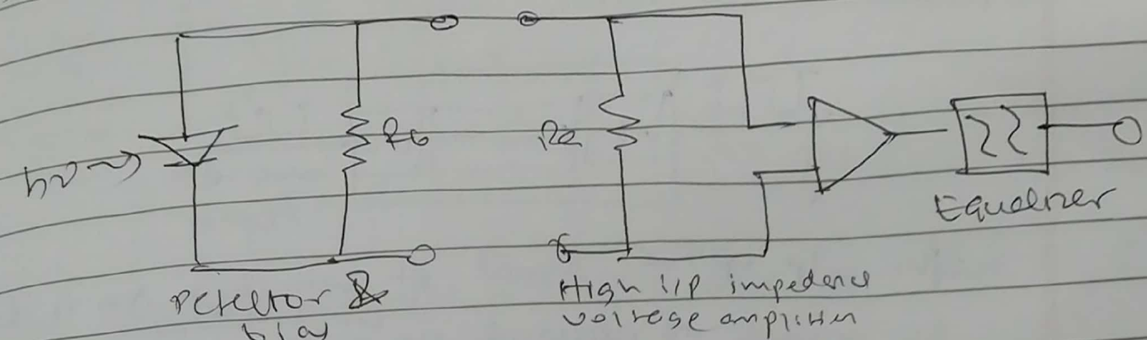
$$\frac{1}{2\pi R_L C_T} \geq B$$

$$R_{TL} = \frac{R_b R_a}{R_b + R_a}$$

• to achieve optimum bandwidth both R_b & R_a must be minimized.

• This design allows thermal noise to dominate which limits sensitivity.

→ High impedance front end.



• high i/p imp. amplifier together with large detector bias ~~resistor used to reduce effect of thermal noise~~ ~~high i/p im~~

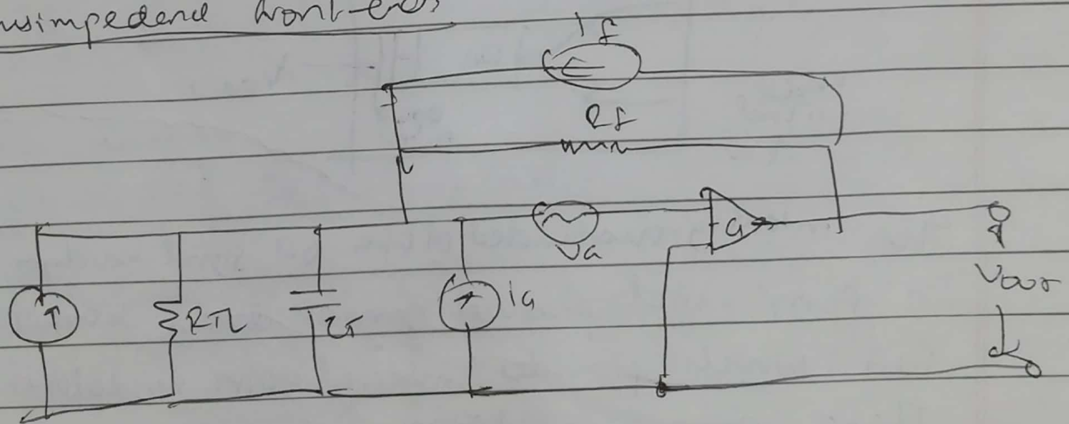
This structure, degraded frequency response & so detector o/p ~~obtained~~
integrated over a large time constant so must be restored directly by differentiation.
So ~~avoid~~ this equalizer is used

disadv: ~~need~~ for large equalization

disadv: corrects thermal noise problem but has large need for equalization

~~Transimp~~

→ Transimpedance front-end,

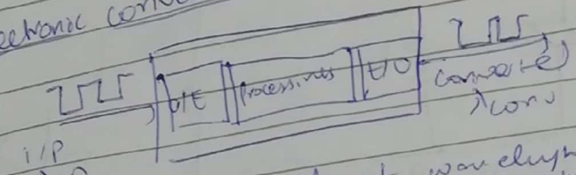


It overcomes drawback of above by using a low-noise, high o/p impedance amp. with -ve f/b. The device operates as a current mode amplifier where high i/p imp. reduced by -ve f/b

Provides a far greater bw without equalization than high impedence front end

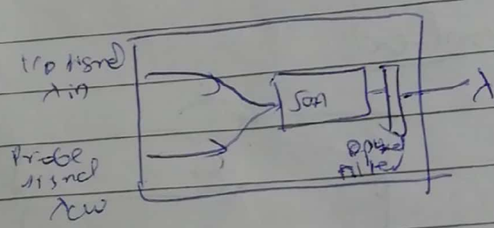
Wavelength Convertors:

• Optoelectronic convertor:



The i/p optical signal at wavelength λin is detected by optical to electrical block using a photodetector and the signal in electrical domain which is processed so as to regenerate signal by rectifying any errors that may occur during transmission. The electrical signal is converted back to optical signal by modulating with optical signal to produce o/p at converted λ $\lambda conv$.

• Cross gain modulation wavelength convertor:

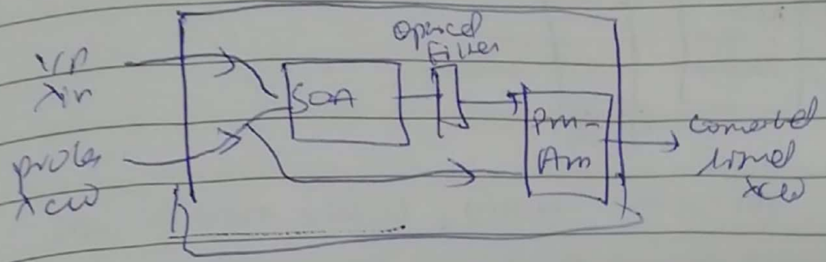


The intensity-modulated data on signal wavelength λin which is pump signal produces carrier density variations within SOA which provides inverted gain modulation in SOA medium. These gain modulations are imprinted on continuous wave λcw called probe signal. The probe signal acquires an inverse copy of data and wavelength conversion occurs as data has been shifted from pump signal wavelength to probe signal wavelength.

optical filter blocks the i/p signal λin.

Page

Cross phase modulation wavelength converter:

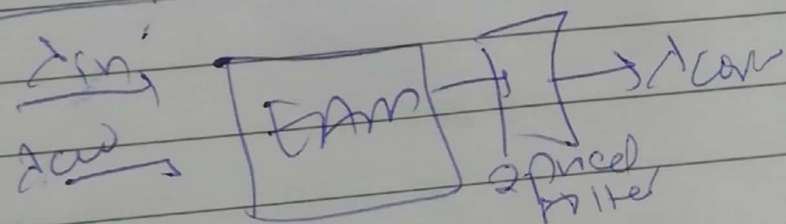


The carrier density variations give rise to ~~chge~~ change in R.I. of nonlinear medium ∝ amp. of I/P signal ∝ $\frac{1}{\text{carrier density variation}}$

These RI variations produces phase modulation when ~~to~~ probe signal coupled to SOA. When these phase modulations are converted to amplitude modulation using PM-AM element the resultant probe signal contains exact copy of intensity modulated pattern. The PM-AM element receives CW probe signal directly & phase modulated probe signal from SOA & combines them constructively so at O/P we get probe signal with exact copy of data of I/P signal but at a diff. λ.

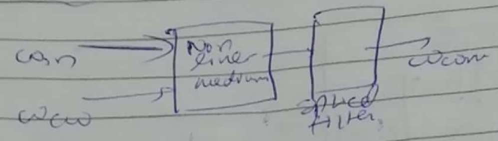
~~Coherent converter~~

Cross absorption modulation λ conv:



It uses non linear effects in an electroabsorption modulator (EAM) where absorption in active cavity of EAM due to intensity modulated I/P signal transferred to CW probe signal.

i) Coherent wavelength convertor):



It uses four wave mixing. When two or more optical signal interact in a non liner medium then generate new signal. The intensity of signals depends on intensity of original signal but phase & frequency of new signals are liner combination of the original wave. The info contained in any signal component is preserved and it resultant signal contain a signal with compliant frequency then λ conversion achieved when desired signal obtained by filtering through optical filter.