4. # $E(C_L) = \frac{1}{2} C_L V_{DD}^2$

$$i_{C_L} = C_L \frac{dV_o}{dt} = I_{DS,p}$$

$$E = \int_0^{\infty} V_{DD} C_L \left(\frac{dV_o}{dt}\right) dt = C_L V_{DD} \int_0^{V_{DD}} dV_o = V_{DD}^2 C_L$$

$E_{nmos} = 0$

$E_{pmos} = (1/2) C_L V_{DD}^2$

—— X —— X —— X ——

LED's & Lasers

Heterostructure

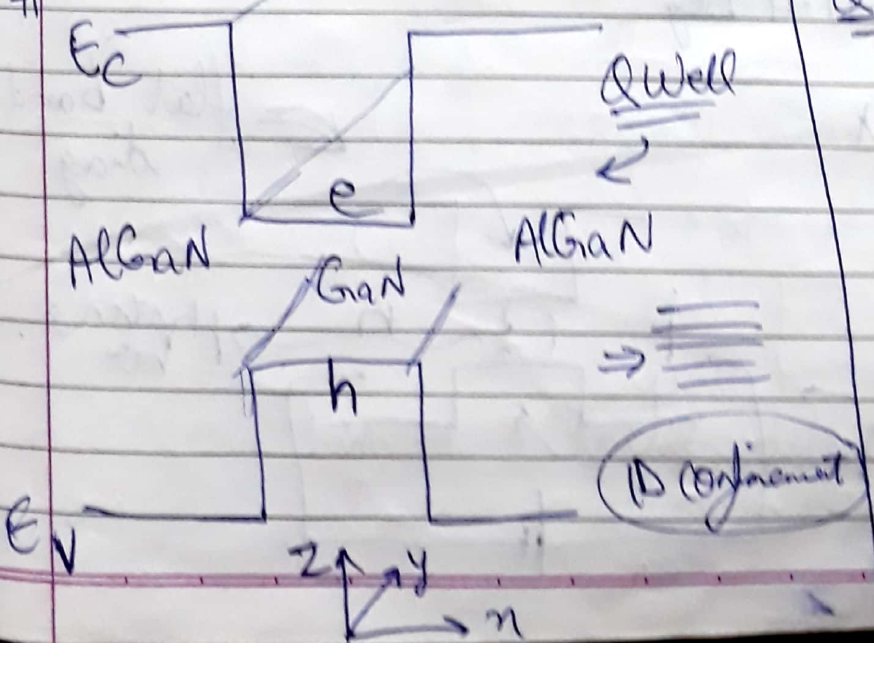
2 diff^n. materials grown on top of each other.

		E_g	
x	GaN	3.4eV	$In_{(1-x)}Ga_xN \rightarrow$ ternary
$(1-x)$	InN	0.7eV	$E_g = x \times 3.4 + (1-x)0.7$
			Vegards law.

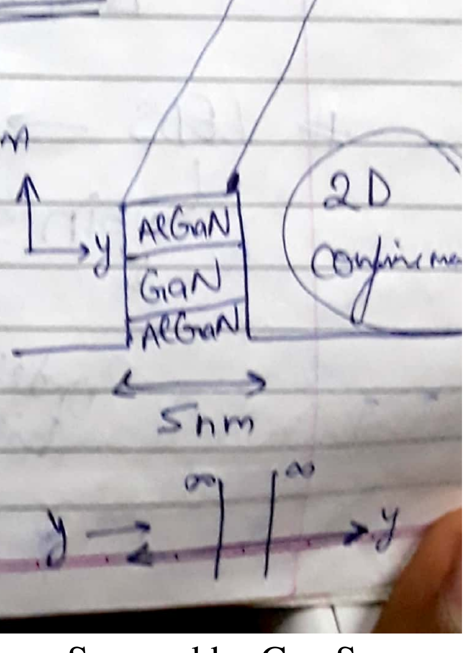
\# Impurities / Defects ⇒ Traps ⇒ ↓ in mobility ⇒ ↓ in I

\# Bulk material → No confinement.

\#

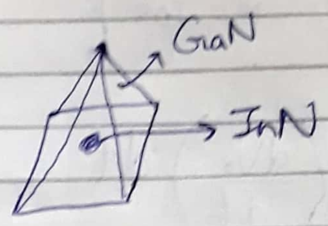


Q. wire



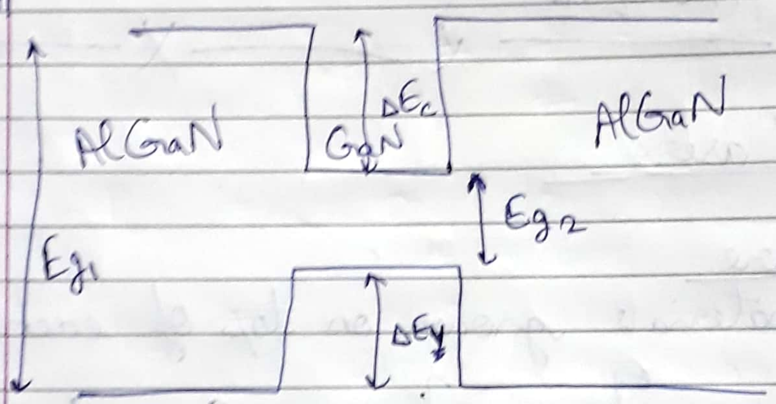
Quantum Dots
0D system

2D confinement



Heterostructural ⇒ surface energy is min.

#

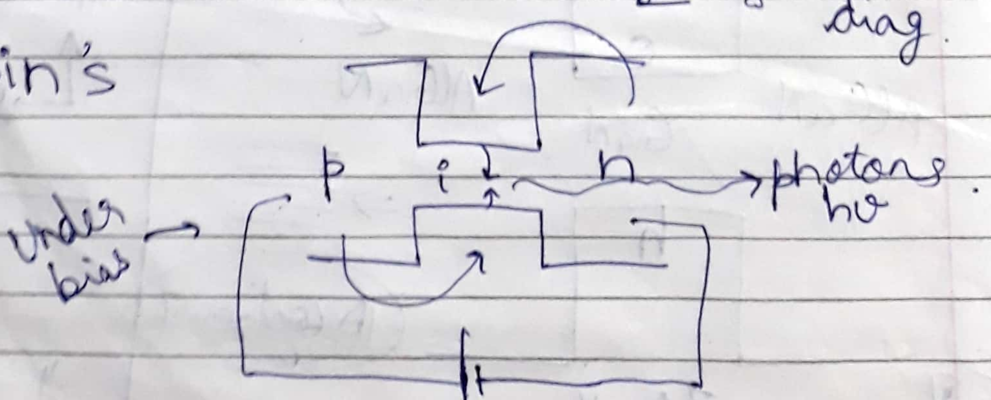


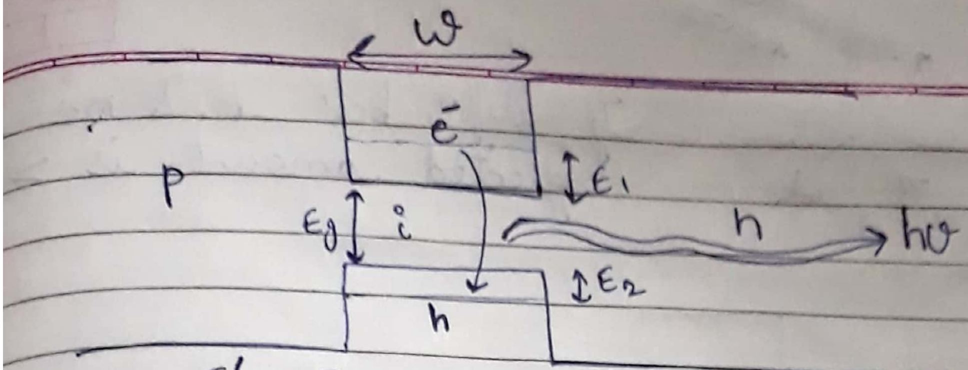
ΔE_c = condn. band offset
ΔE_v = Valence band offset
$\Delta E_g = E_{g_1} - E_{g_2}$

$\Delta E_c \approx 0.6\, \Delta E_g$
$\Delta E_v = 0.4\, \Delta E_g$

LEDS → λ
↳ pin's

flat band diag.





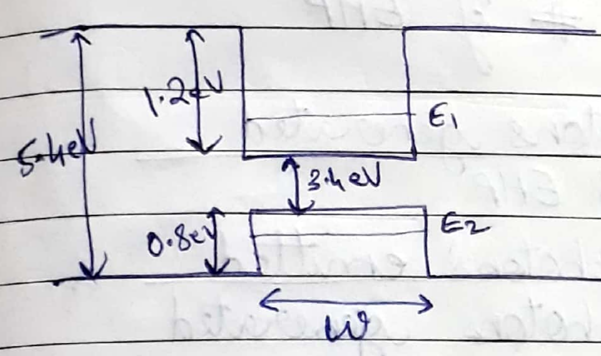
$$E_g' = E_g + E_1 + E_2 = \frac{hc}{\lambda}$$

$$E(eV) = \frac{1240}{\lambda(nm)}$$

★ for $\lambda = 300$ nm, $x = ?$, $w = ?$

AlN 6.1 eV
GaN 3.4 eV

∴ For $x = 0.7$
$Al_x Ga_{(1-x)} N \rightarrow 5.4$ eV



(As $\Delta E_c \uparrow$, $E_1 \uparrow$)

$$E_1 = \frac{n^2 h^2}{8mL^2}$$

Ad hoc basis

$$E_1 = \frac{n^2 h^2}{10mL^2} = \frac{h^2}{10m_e L^2}$$

$$E_2 = \frac{h^2}{10m_p L^2}$$

$$\therefore 3.4 + E_1 + E_2 = \frac{1240}{300}$$

Choosing x :- Not very large as to avoid defects
Not very small → lattice constant

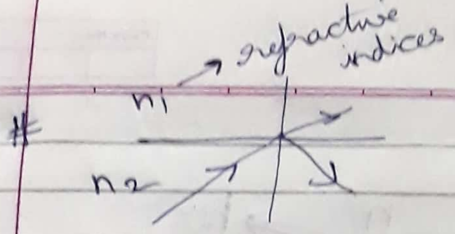
lattice constn.

GaN → a_1
AlN → a_2

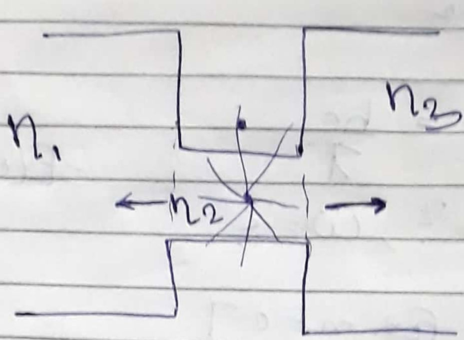
$x a_1 + (1-x) a_2$
↳ should be closer to a_1

but if x is very small there will be no confinement.

Very high x → lot of defects, poor material.



If diffn. betn. n_1 & n_2 is >, reflected amount is >,



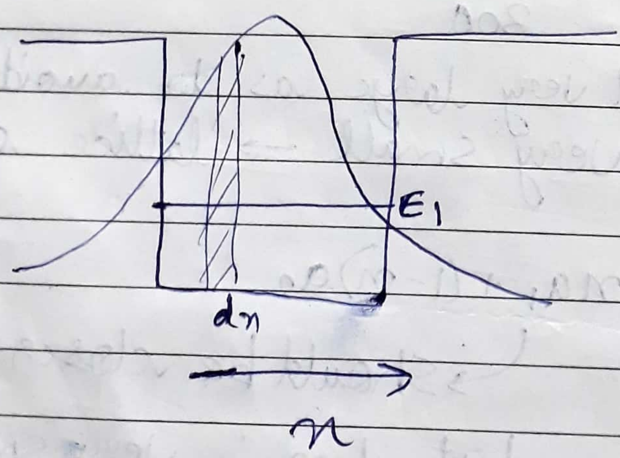
Quantum efficiency (QE) $= \dfrac{\#\text{ of photons}}{\#\text{ of EHP}}$

$\eta_i = \dfrac{\#\text{ of photons generated}}{\#\text{ of EHP}}$

$\eta_e = \dfrac{\#\text{ of photons emitted}}{\#\text{ of photons generated}}$

$\eta_i . \eta_e$ is what we want to maximise.

G. snider, schrodinger poisson, Book → Liboff, Schmidt

#


$E_x = E_1$

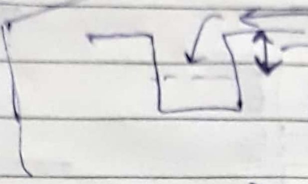
$E_{tot} = E_1 + \dfrac{\hbar^2}{2m}(k_y^2 + k_z^2)$ (Qwell)

$E_{tot} = E_1' + \hbar^2/2m \, k_z^2$ (Qwire)

Scanned by CamScanner

$$\therefore N = \int_{n=0}^{\infty}\int_{E_1}^{\infty} |\psi|^2 \, dn \, f(E) \, dE$$

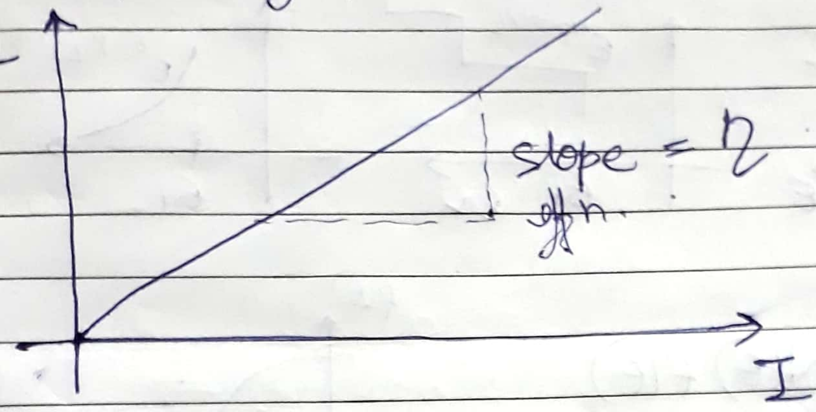
output p < input p for ideal LED also



LED

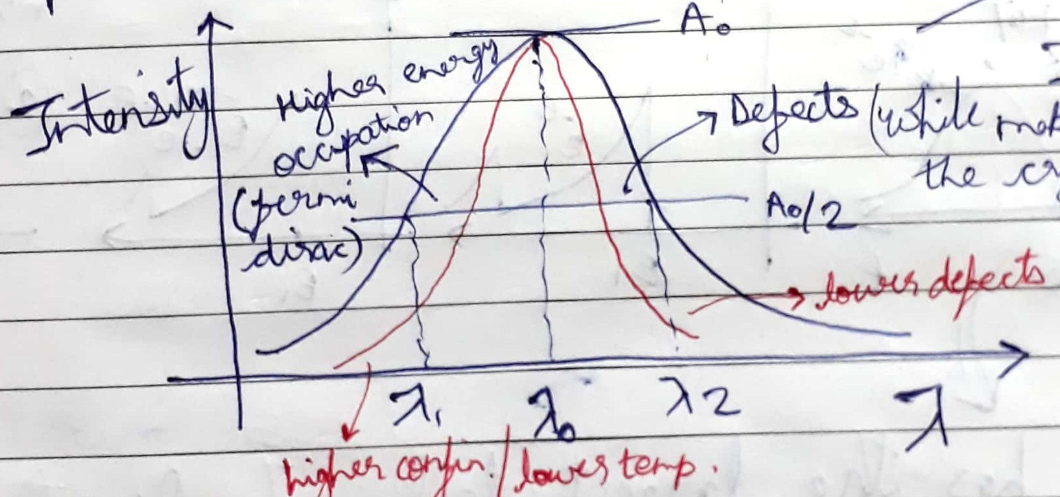
Find out for Q wire & Q well & compare which has > η.

1) Light-Input graph (LI)



slope = η = $\frac{\partial L}{\partial I}$ → In energy
effn.

2) Spectrum / Electroluminiscence



$I = I_0$ → PSD Power Spectral Density

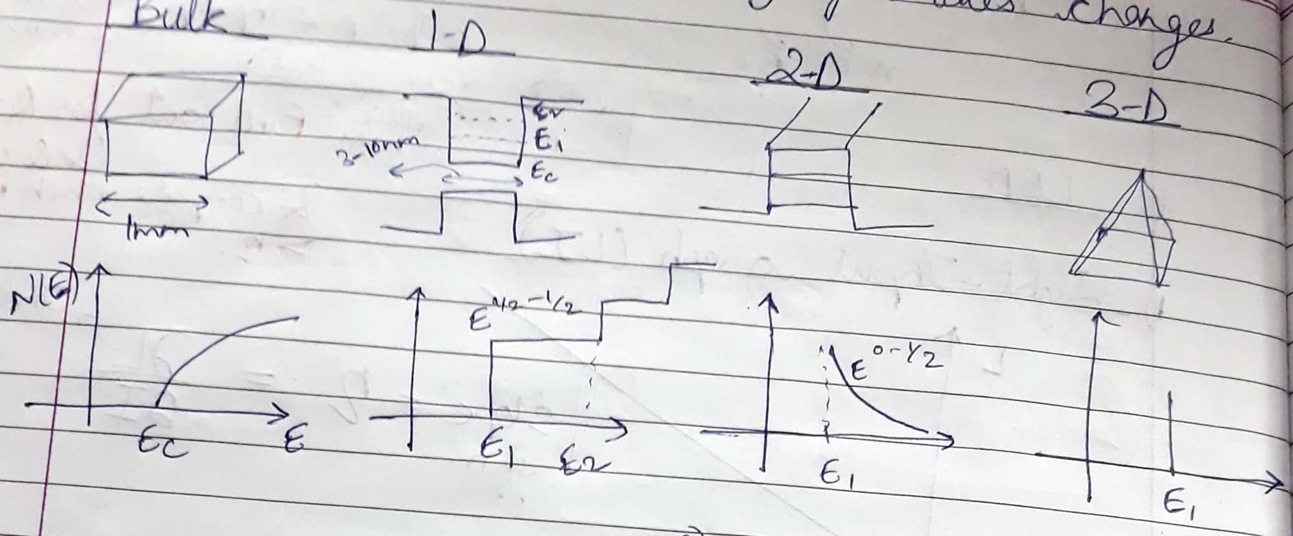
FWHM → Full width half maxima $= (\lambda_2 - \lambda_1)$

↳ Larger ⇒ Broad band emission

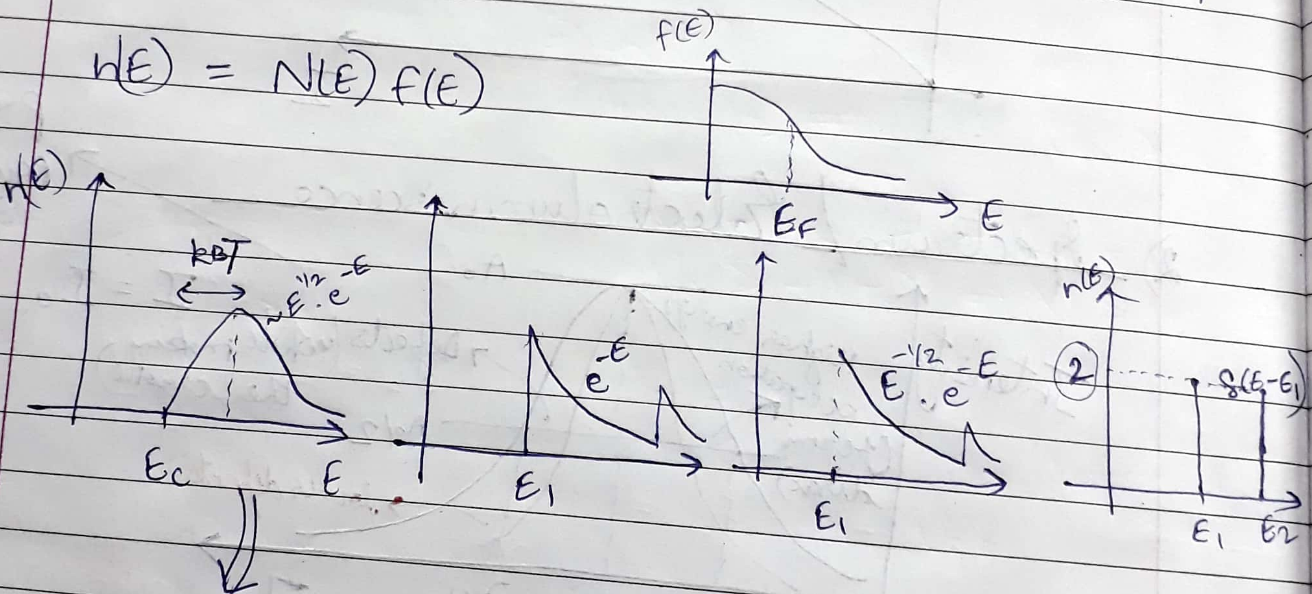
3) Photoluminiscence

↳ Optically generated carriers instead of electrically biasing.

Nanostructures → Density of states changes.



$n(E) = N(E) f(E)$



∴ Bulk has the largest tail. In Quantum structs. we are able to confine the e^- to a particular energy range.

For bulk & 1D, E_1 will always exist, in wire & dot, it may not.

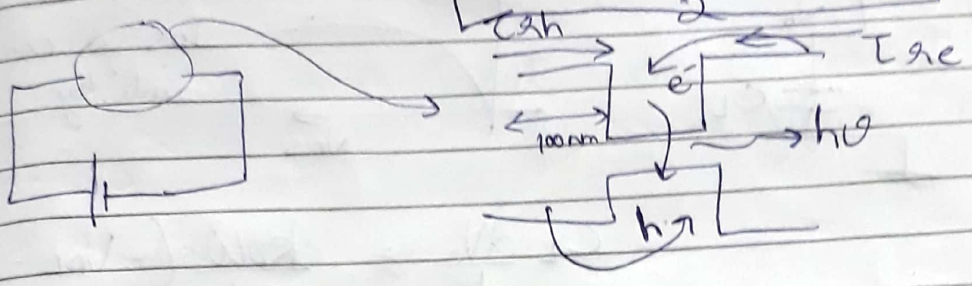
Molecular beam epitaxy

NH_3 ↙ Ga

↳ 10^{-11} – 10^{-12} torr

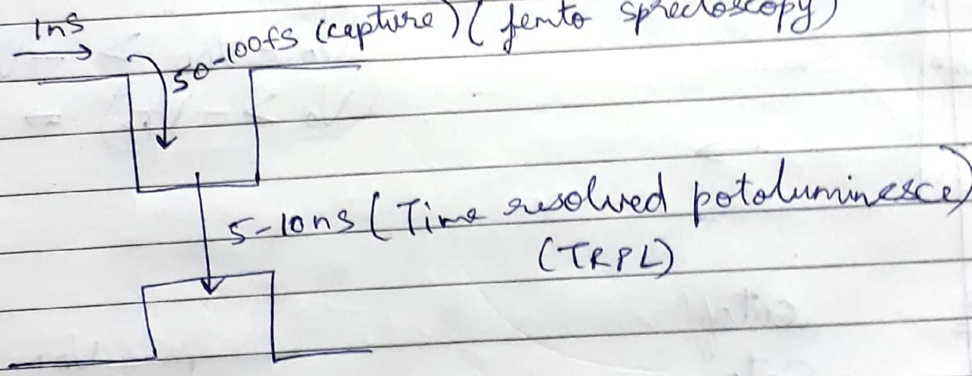
Intrinsic is defect free more → less traps.
Doping will add more traps.

Speed of diode → $\boxed{f = \dfrac{1}{\dfrac{\tau_{re}+\tau_{rh}}{2} + \tau_r}}$

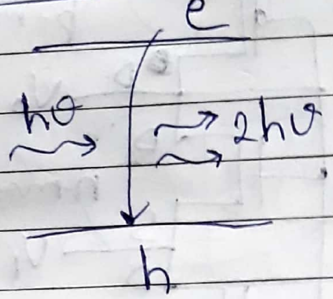


$\tau_{re} = \dfrac{100nm}{v_e} \approx 1ns$

While recombination process ≈ 5–10ns (RDS)



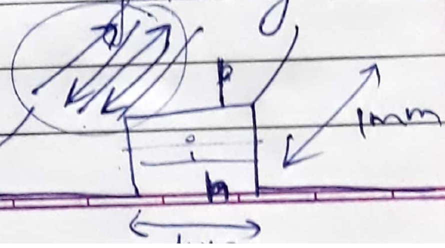
LASER



Phase coherence
Spectral purity (monochromatic light)
Spatial coherence

1.3 μm & 1.5μm lazer → for long distn. transm

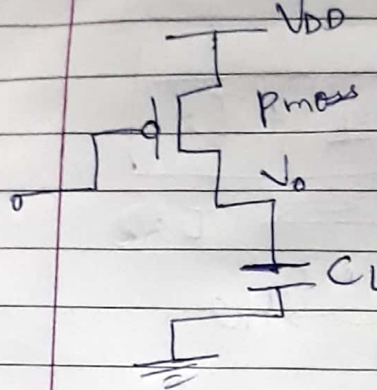
LED + oscillator = Laser



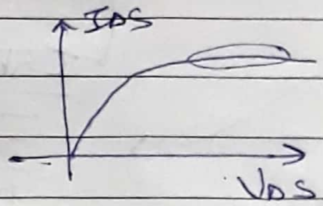
gain ← photon goes back & forth

MS

4# $V_{DS} > V_{GS} - V_T \Rightarrow$ Satn. of n-moss



Initially pmoss is in satn. as $|V_{DS}|$ is high. ($V_o = 0$ at $t=0$)

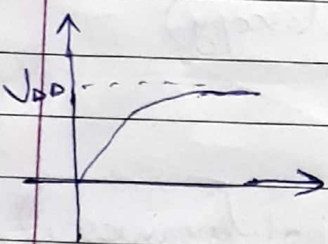


I_{DS} is constn. intially.

$$\therefore C_L \frac{dV_o}{dt} = \frac{k_p W}{2L}(-V_{DD} - V_{TP})^2$$

$$\therefore V_o = \alpha t$$

Till what time linear ? $\Rightarrow$ Till $V_{DS} > V_{GS} -$

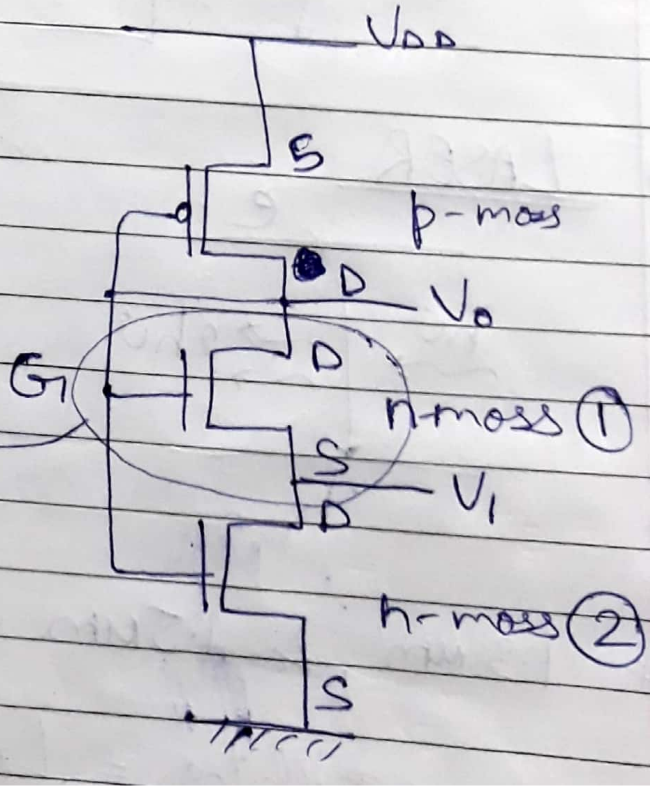


$$\therefore V_o - \cancel{V_{DD}} > \cancel{-V_{DD}} - V_{TP}$$

$$\therefore V_o > -V_{TP} \Rightarrow V_o > 1V$$

6# ~~cutoff~~
Satn.
lin.

V_{DS} $V_{GS} - V_T$
$\quad\quad\quad\quad \parallel$
$V_{DS} > V_{DS} - V_T$
$\Rightarrow$ Sat^n. always



Page No.:

Now if ② also in satn.

then $V_{GS2} = V_{GS1}$ (As $I_{DS1} = I_{DS2}$)

$$\left(\frac{kW}{2L}(V_{GS2}-V_{Tn})^2 = \frac{kW}{2L}(V_{GS1}-V_{Tn})^2\right)$$

$\therefore V_1 = 0$, But then ② is not in satn. as $V_{DS2} = 0$.

$\therefore$ ② is in linear.

Equating $I_{DS,p} = I_{DS,n_1}$

$$\therefore (\;)(V_{GSp} - V_{Tp})^2 = (\;)(V_{GS,n} - V_{Tn})^2$$

$$\therefore (V_0 - V_{DD} - V_{Tp}) = \ominus(V_0 - V_1 - V_{Tn})$$

↳ As for ⊕, V_0 disappears.

$$\therefore 2V_0 = V_{DD} + V_{Tn} + V_{Tp} + V_1$$

$$\therefore \boxed{V_0 = \left(\frac{5+V_1}{2}\right)} \text{ — ①}$$

Equating $I_{DS,p} = I_{DS,n_2}$

$$\frac{1}{2}(\;)(V_0 - V_{DD} - V_{TP})^2 = (\;)\left((V_0 - V_{Tn})V_1 - \frac{V_1^2}{2}\right)$$

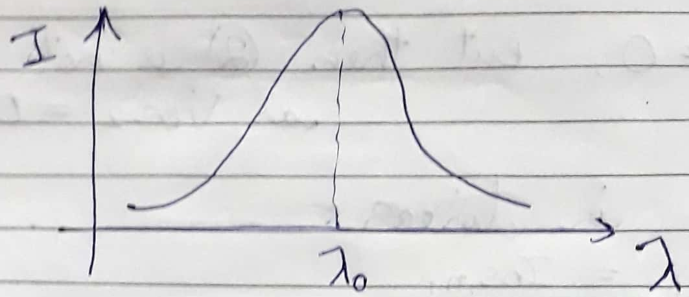
$$\therefore \boxed{\frac{1}{2}(V_0-4)^2 = \left((V_0-1)V_1 - \frac{V_1^2}{2}\right)} \text{ — ②}$$

From ① & ②, $V_0 = 2.757$

Optoelectronics by Pallab Bhatacharya

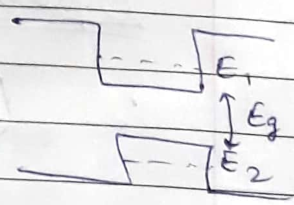
LED characteristics

i) Emission wavelength.

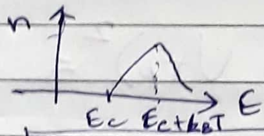


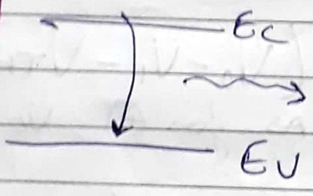
$$\boxed{\lambda_0 = \frac{hc}{E_1+E_2+E_g}}$$

→ Quantum Well



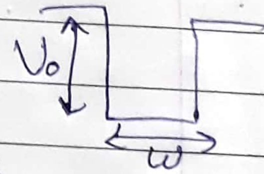
For Bulk →





$$\boxed{\lambda_0 = \frac{hc}{(E_g + k_BT)}}$$

Strength of confinement = wV_0



∴ ↑ V_0 & ↓ w will help ↑ confinement.

$$-\frac{\hbar^2}{2m}\frac{\partial^2 \psi_x}{\partial x^2} + V\psi_x = E_x \psi_x$$

Suppose confinement in x & y direction.

$$E_x = \frac{n_x^2 \pi^2 \hbar^2}{2mL_x^2}, \quad E_y = \frac{n_y^2 \pi^2 \hbar^2}{2mL_y^2}, \quad E_z = \frac{\hbar^2 k}{2m}$$

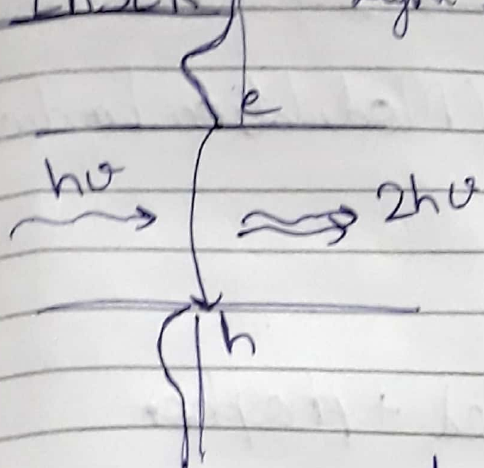
$$\therefore E = \frac{\pi^2 \hbar^2}{2m}\left(\frac{n_x^2}{L_x^2} + \cancel{\frac{n_y^2}{L_y^2}}\right) + \frac{\hbar^2}{2m}(k_z^2 + k_y^2)$$

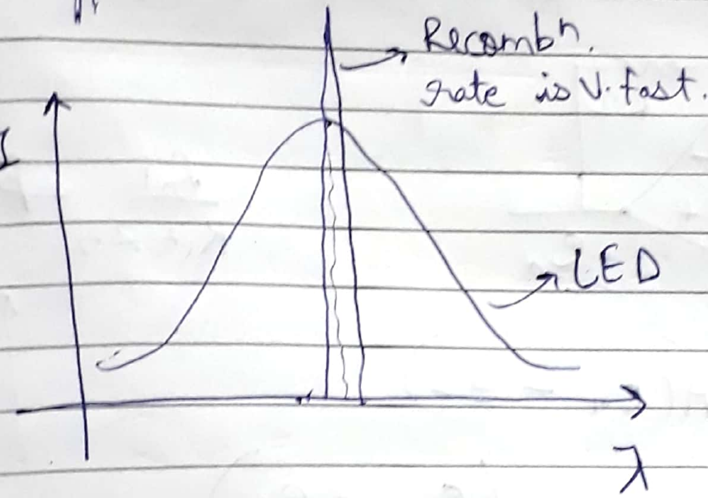
Quantum cascade

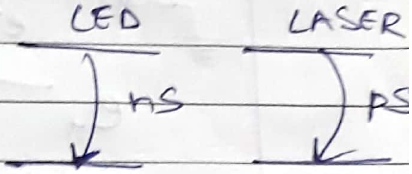
LASER → Light amplification by stimulated emiss^n of radn.

→ Fermi's golden rule

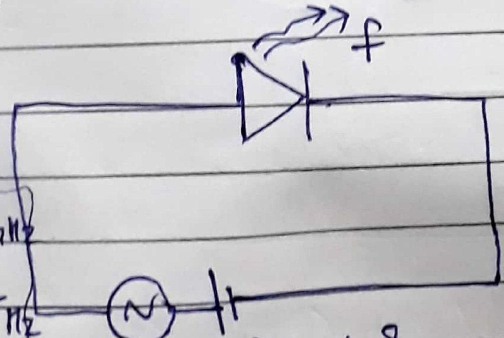
↘ Stimulated emission.



#




Directivity
Coherence (Same phase) (Same freq)
Light intensity (Higher power → fast recomb^n. rate)
Efficiency (High → fast recomb^n. rate)
Every device starts with an LED & becomes a laser

#


$v_o = A v_i, \omega$

LED ns GHz
LASER ps THz

Recomb^n. process is the limiting process

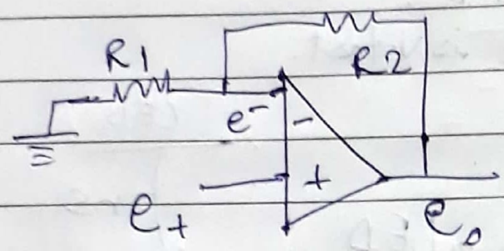
f ↑ → Modulation bandwidth.

On ↑ f too large, led can't keep up with the f cause of recomb^n.

$I_{threshold}$ → min. current reqd. for a laser to operate.
(Make spontaneous → stimulated emission)

normalised response (Modulation bandwidth)
→ $\dfrac{d(L/L_0)}{d(i_{ac}/i_0)}$

White led → blue led + phosphor

#


$\dfrac{R_1}{R_1+R_2} = \beta$ = Feedback factor

$$e_0 = A(e_+ - e_-)$$

$$\frac{0 - e_-}{R_1} = \left(\frac{e_- - e_0}{R_2}\right)$$

Solving

$$\boxed{\frac{e_0}{e_+} = \frac{A}{1+A\beta}}, \quad \beta = \frac{R_1}{R_1+R_2} \quad (-\text{ve feedback})$$

For +ve feedback

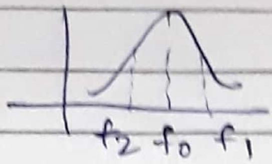
$$\boxed{\frac{e_0}{e_+} = \frac{A}{1-A\beta}}$$

If A & β depend on 'ω', $\dfrac{e_0}{e_+} = \dfrac{A(\omega)}{1-A(\omega)\beta(\omega)}$

∴ For 1 'ω' when $A\beta = 1$, gain = ∞ ⇒ oscillator

∴ An amplifier becomes an oscillator in +ve feedback.

Quality factor $= \dfrac{f_0}{f_1 - f_2}$



Laser

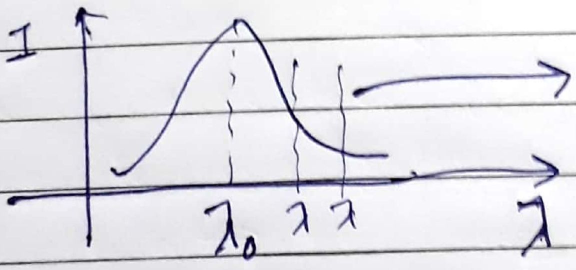
$\boxed{A\beta = 1}$, if β is small, A should be large

↓ for oscillation

β = fraction of output coming at input.

$= \dfrac{\text{reflected}}{\text{incident}}$

Distn. b/w 2 mirrors $= \boxed{L = \lambda_0/2}$



→ If λ is more, gain

→ ⇒ β must ↑.