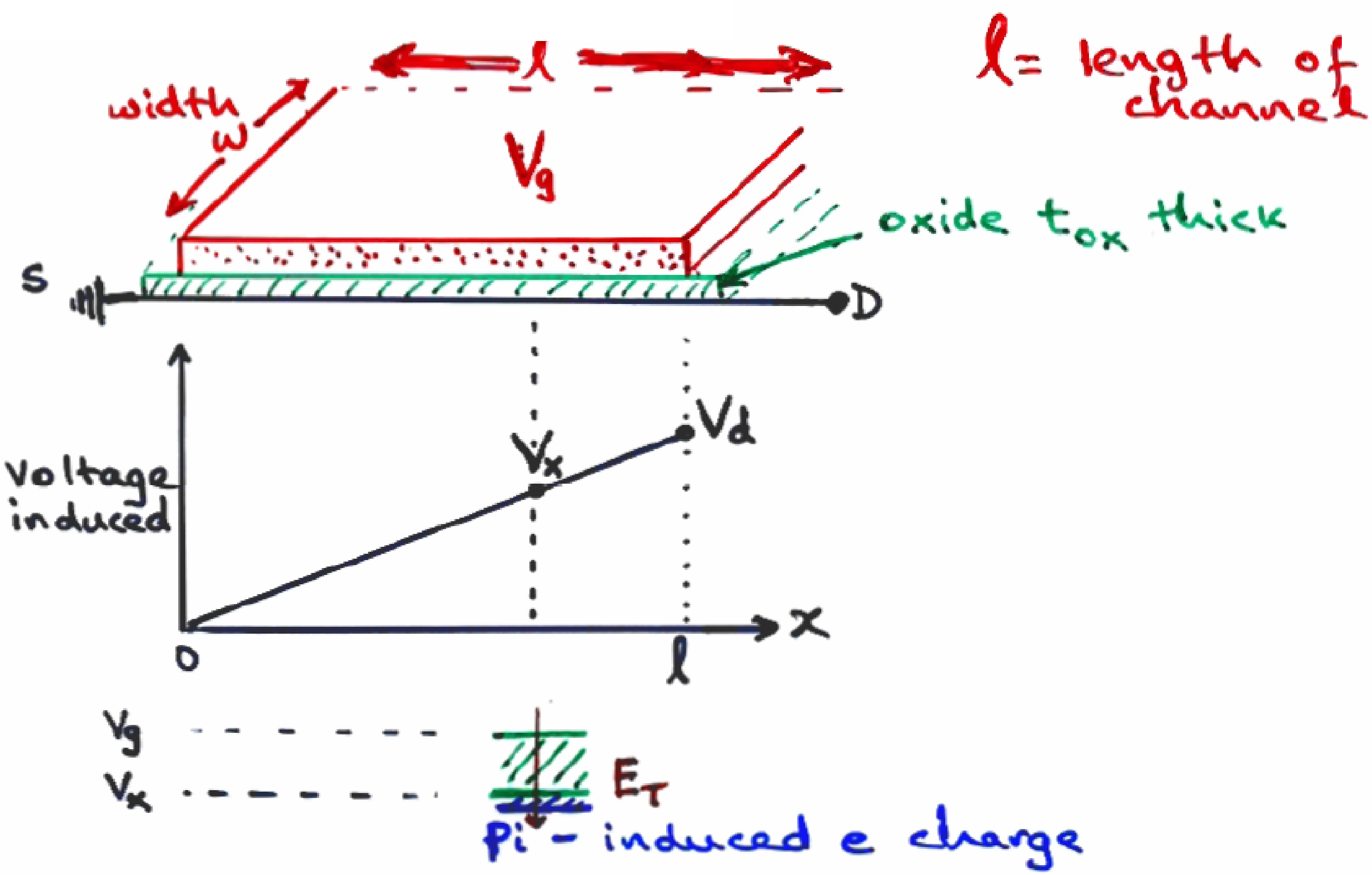
Metal oxide Semiconductor Transistor

I_d versus drain (V_d) characteristics

Related to the conducting inversion layer.



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Voltage across oxide at x = $V_g - V_x$

Oxide is t_{ox} thick, so transverse electric field is $E_T = (V_g - V_x)\ t_{ox}$

By Gauss Law, surface charge density in channel (Q/A)

$(\rho_i) = \varepsilon_r E \qquad = \varepsilon_r \varepsilon_o (V_g - V_x)/\ t_{ox}$ (1)

Not all of this is available for conduction. At low V_g only a depletion layer is formed. Requires a minimum $V = V_t$

effective voltage= $(V_g - V_x) - V_t$

$\rho_{ieff} = \varepsilon_r\ \varepsilon_o (V_g - V_x - V_t)/t_{ox} = e.\ \Delta n(x)$ (the surface electron density in the channel) (2)

This surface charge will behave like a capacitance (C) =Q/V $\quad C_g = \dfrac{\varepsilon_r \varepsilon_o lw}{t_{ox}}$

$\rho_{ieff} = e.\ \Delta n(x) = C_g\ (V_g - V_x - V_t)\ /lw$, $\quad V_g - V_x > V_t$ (3)

$\rho_{ieff} = 0 \quad V_g - V_x < V_t$

We know about charge, now what about the resistance?

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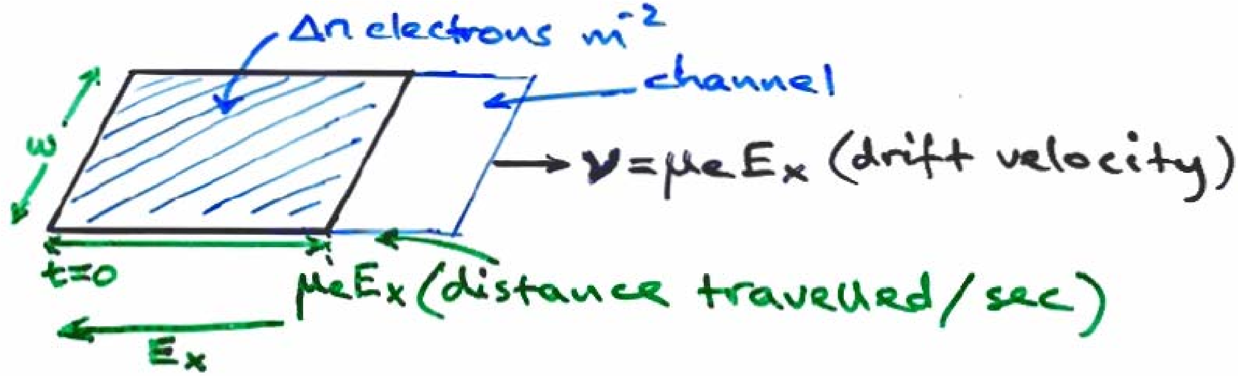
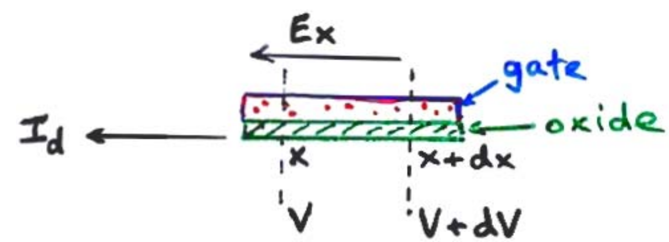


No of electrons passing through plane is $(\mu_e E_x . W)\ \Delta n$

Charge/sec is $\mu_e E_x . W)\ e.\ \Delta n = I_d$ (4)



Consider d_x of channel

$E_x = dV/dx$ substitute in (4)

$I_d = \mu_e (dV/dx)\ W\ e\ \Delta n$ or $I_d\ dx = \mu_e dV\ W\ e\ \Delta n$

Know $e\Delta n$, its given in equation (3)

$$I_d\ dx = \mu e (C_g/l)\ (V_g - V_t - V_x).\ dV$$

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Integrate over channel length,

$$I_d \int_0^l dx = \frac{\mu_e C_g}{l} \int_0^{Vd} (V_g - V_0 - V_x) dV$$

$$I_d = \mu_e (C_g/l^2)\ [V_g - V_T - V_d/2], V_d$$

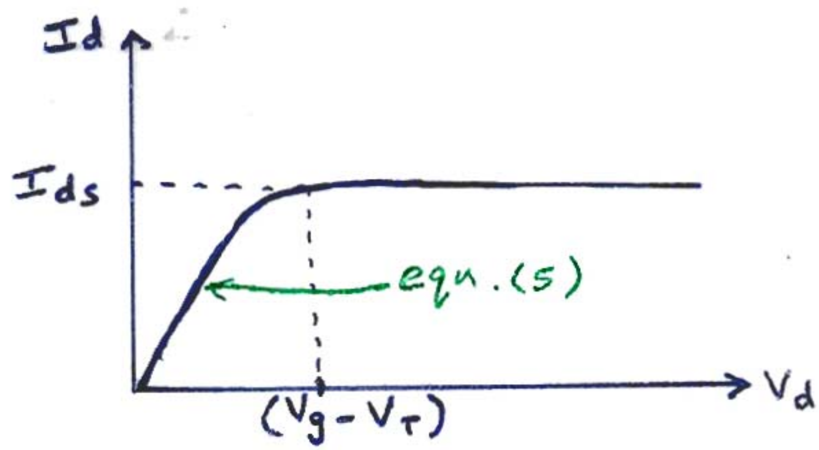
V_d can be increased until V_g-V_t= V_d

this is called the saturation condition

As V_d increases further, I_d saturates and excess voltage is dropped across the high resitance depletion layer. Saturation current is I_{ds}.

I_{ds}= $\mu_e(C_g/l^2)\ [V_g-V_t]^{2/}2$ or we can say,

$$I_{ds} = \frac{C_G \mu_e V_{ds}^{\ 2}}{2l^2}$$



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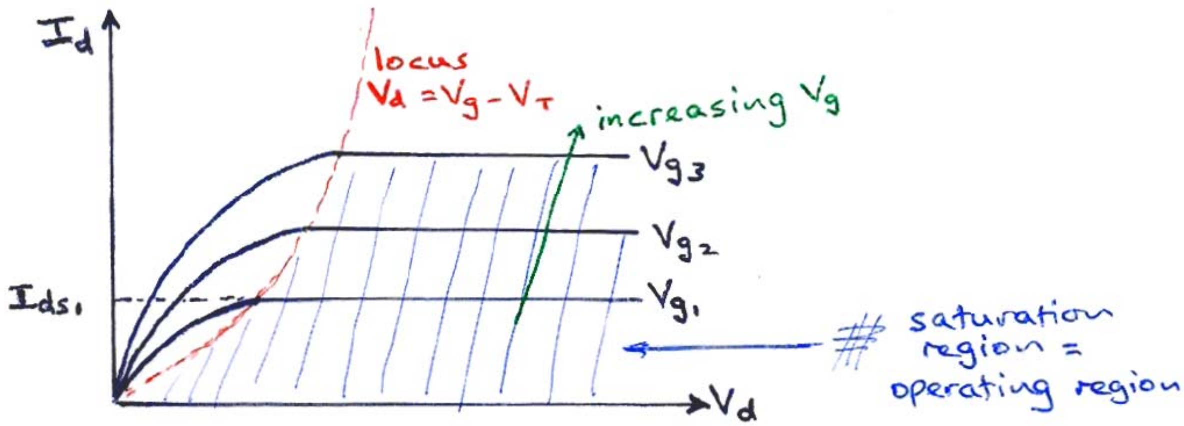


Another useful parameter is the Transconductance (i.e. gain)

$$g_m = \frac{dI_d}{dV_{gs}} \vdots = \frac{C_G \mu_e V_{ds}}{l^2}$$

In practice the g_m is less than this value, for a number of reasons:

We have ignored parasitic source and drain resistances (cant assume contacts are completely ohmic)

There is scattering of electrons due to the oxide, causing a reduced channel mobility for thin channel widths

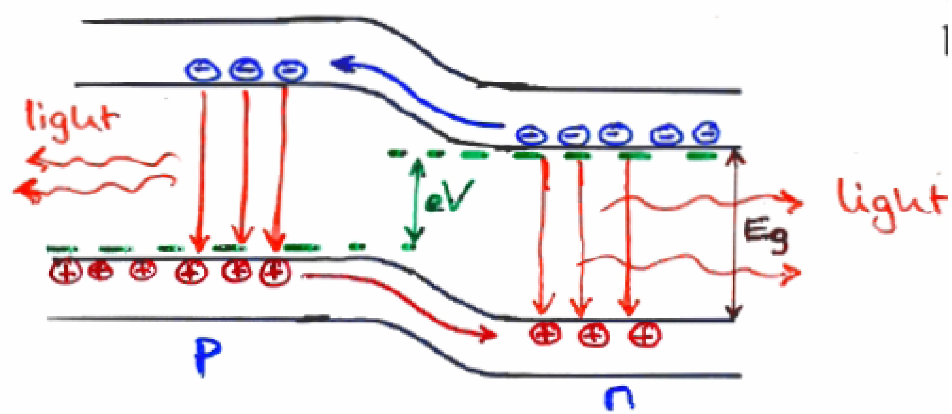
Light emitting diodes

Under forward bias

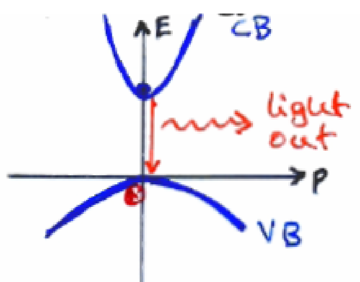
Energy of Photons $$E_g = \frac{hc}{\lambda}$$

eg: for GaAs E_g=1.44eV – λ=860nm

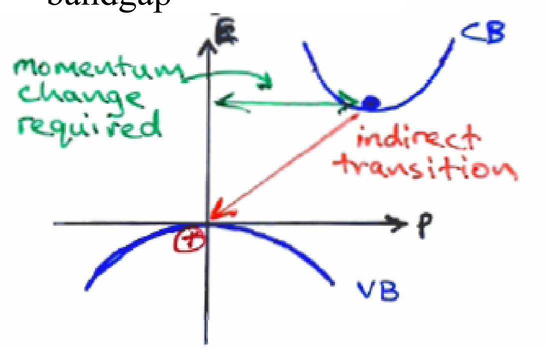
Simple rule E_g (eV) = 1240/λ(nm)



Electrons and holes injected across the junction recombine with majority carriers and emit a photon of energy = bandgap



Direct band-structure
- efficient, recombination.
e.g. GaAs, InP, InGaAs



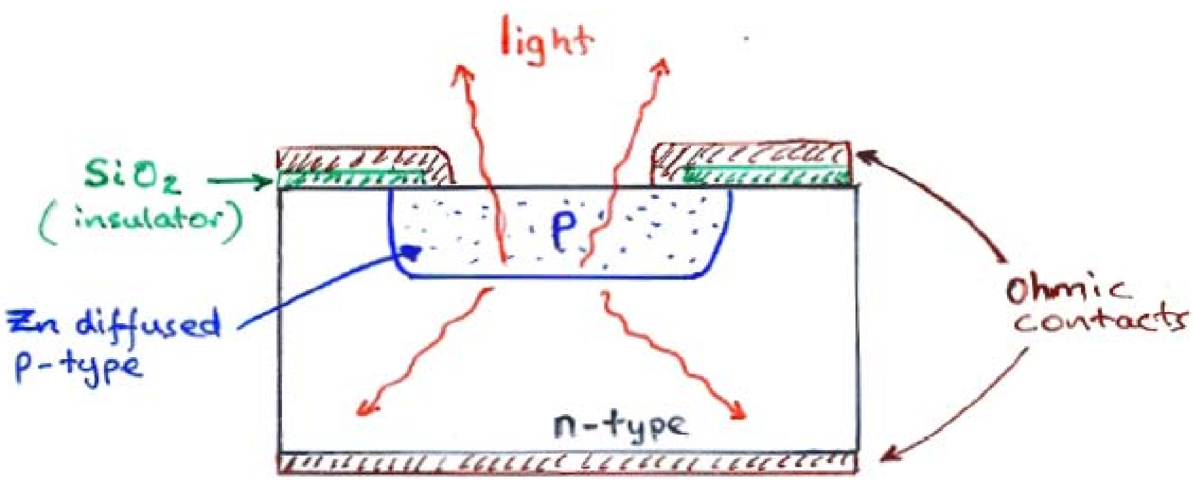
Indirect band structure
- poor recombination - need momentum change - phonon, interaction with lattice
e.g. Si, Ge

Semiconductor Optoelectronics

Emitted wavelength depends on the choice of material

InAs	3800nm	Mid IR (sensing)
InGaAs	1300-1550nm	Near IR (optical fibre telecommunications)
AlGaAs	750-800nm	Deep red (CD player)
GaP	690nm	Green (basic green LED)
GaInP	550-580nm	Orange/Yellow LED
InGaN	340-690nm	Blue/green LE,Laser (eg:Blu-ray)

Typcal LED structure



An important property is the internal quantum efficiency = $\dfrac{number.of.photons}{number.of.injected.e-h.pairs}$

Some electron-hole pairs will be lost through

non-radiative recombination. Better crystal quality gives

Better IQE. IQE is typically 20-50%. At> 30% LEDs become viable for lighting applications. However have other advantages such as longer lifetime, which means they are taking over in high maintenance applications (eg: traffic lights)

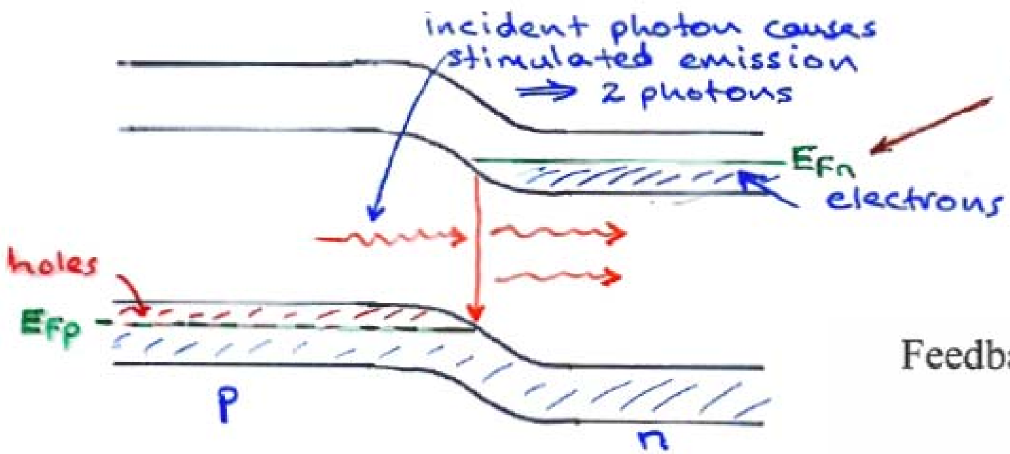
Power efficiency = $\dfrac{\phi}{IV}$ where ϕ is the optical power

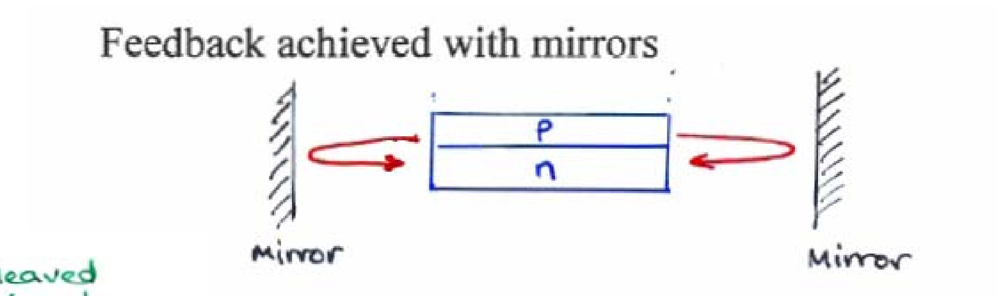
However ϕ is often quite difficult to measure. It involves the external quantum efficiency, which is a measure of how many photons escape. Many photons are lost through absorption and reflection. ExQE is often 10-20%.

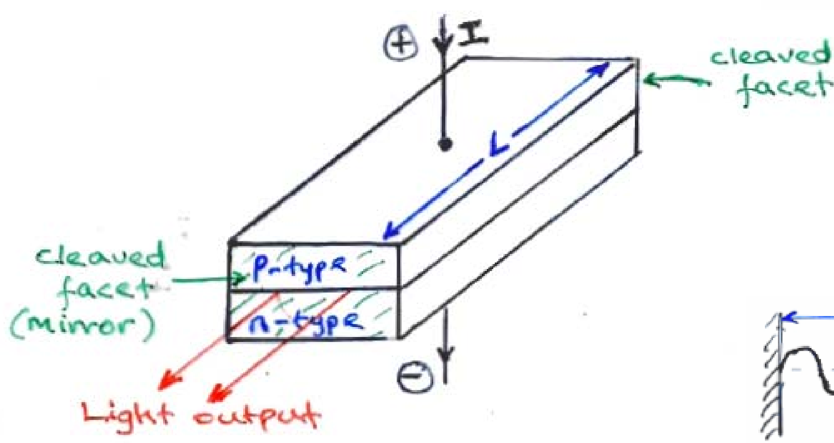
Semiconductor laser

The semiconductor laser is very similar to an LED in construction. The difference here is that light is fed back using reflective mirrors (often just the facets of the semiconductor which have 30% reflectivity)

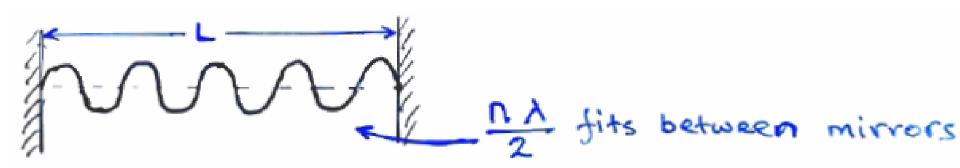
Semiconductor Optoelectronics





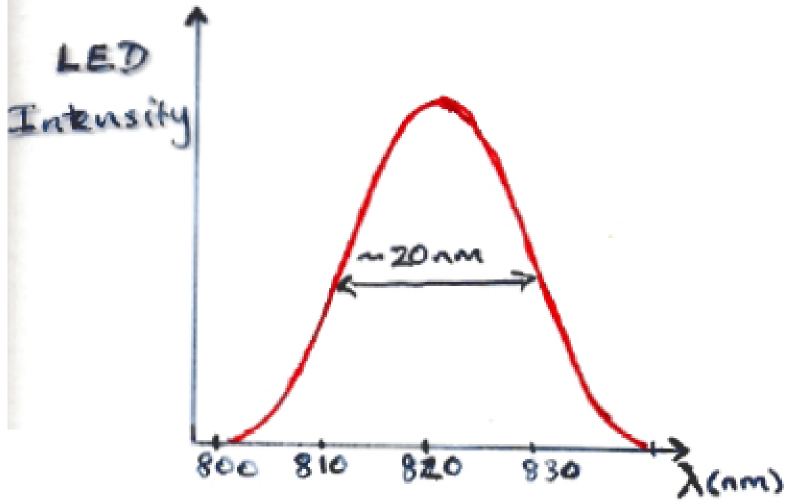


Get constructive interference when nλ/2=l
or λ=2l/n, where n is an integer



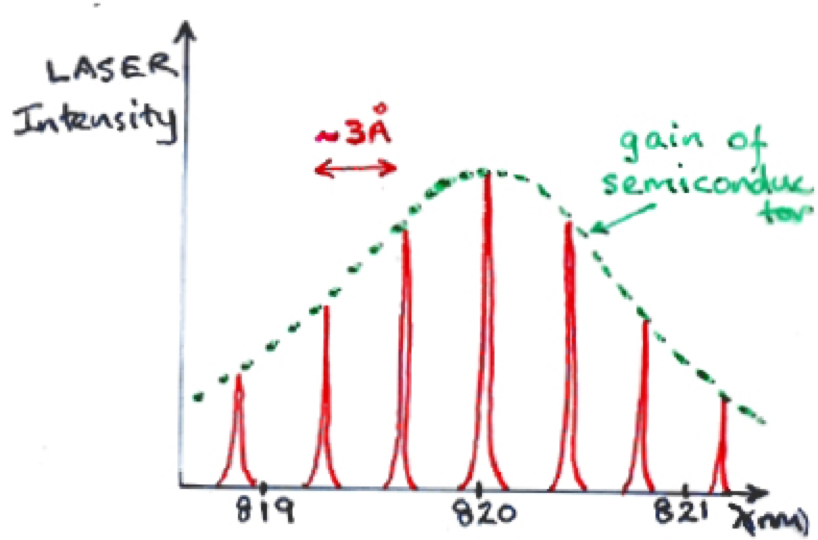
Semiconductor Optoelectronics

Spectral Output



Broad linewidth centered ~ on material band-gap.

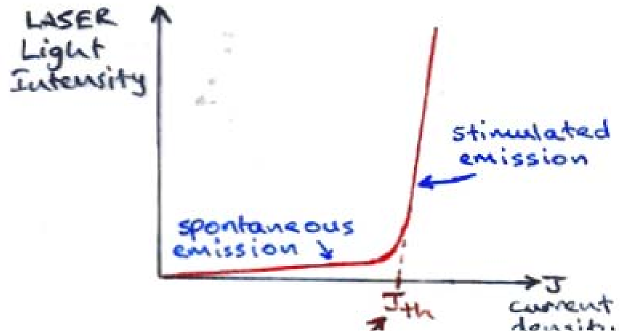
- Photons have a spread in energy
- Photons have no phase relationship with each other – i.e. random
- Spontaneous emission



Linewidth of each mode is very narrow compared to LED. ~ 6 longitudinal modes covering 2nm.

- Photons have almost identical energies
- Photons have the same phase relationship with each other – coherent
- Stimulated emission

L-I characteristics



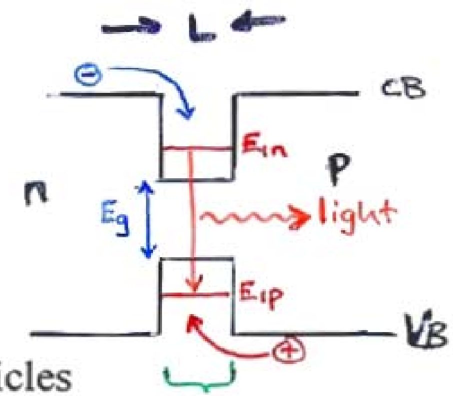
At J_{th}, device gain = loss

Quantum Well Laser

Fully forward biased

Electrons and holes form quantum confined states

From section on Bound particles



Narrower band gap semiconductor between wider band gap materials

$$E_{1n} = \frac{n^2h^2}{8mL^2}$$

m different for e, h

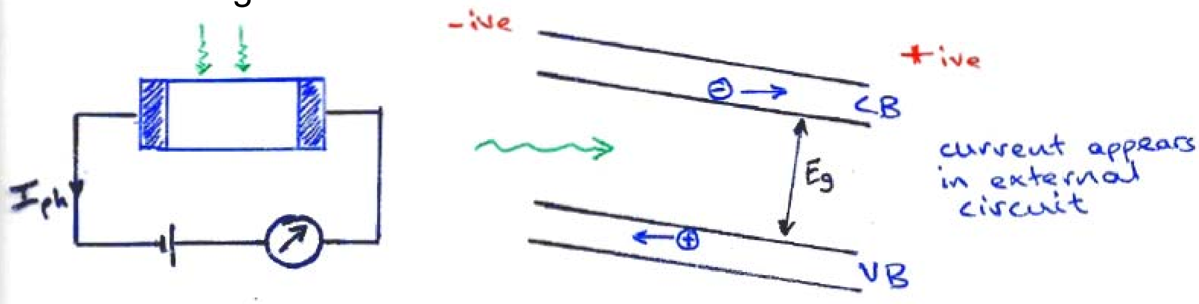
Hence wavelength determined by $\underline{E_g + E_{1n} + E_{1p}}$

Also quantum well lasers are much more efficient than 3-dimensional structures.

Detectors

Two types

(a) Photoconductive. Conductivity increases as the light increases



Needs photons of energy > E_g to work. Also the conductivity of the semiconductor needs to be high in the dark (σ-> 0).

Under illumination **$\sigma = e(n_e\mu_e + n_p\mu_p)$.**
But 1 photon makes 1 electron and 1 hole so **$\sigma = en(\mu_e + \mu_p)$.**

Assume light of frequency ω (energy $h\omega$) and input optical power P(J/s).

Average number of e-h pairs/sec = $= \dfrac{P}{h\omega} x\eta$

Where η is the efficiency

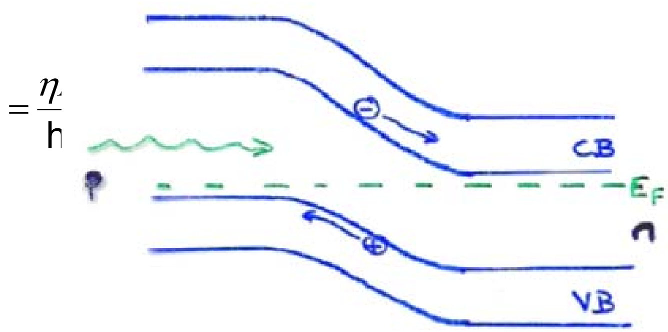
= no.pairs/ no..photons

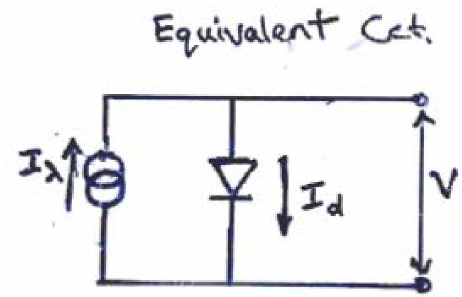
However some of these pairs will recombine before they reach the contacts.

Hence the equilibrium number of pairs $= \dfrac{\eta P \tau}{h\omega}$

Since $\sigma = en(\mu_e + \mu_p)$. Conductuvtivity (s) is proportional to Input optical power (P)

(b) Photodiode





Built in field (can also be reversed baised) causes e-h pairs to separate, generating a current or voltage (open circuit).

Consider the equivalent circuit.
Remember diode equation

$$I_d = I_0 \exp(\frac{eV}{KT} - 1)$$

The University Of Sheffield.

Semiconductor Optoelectronics

For an open circuit $I_d = I_\lambda$ (input current due to arriving photons)

I_λ= charge arriving per second $= \dfrac{\eta e P}{h\omega}$

$$I_\lambda = \frac{\eta e P}{h\omega} = I_0[\exp(\frac{eV}{kT}) - 1)]$$

$$V = \frac{kT}{e} In[\frac{\eta e P}{h\omega I_0}]$$

In photoconductive mode $$I_{ext} = I_d - I_\lambda = I_0[\exp(\frac{eV}{kT}) = 1] - \frac{\eta e P}{h\omega}$$

First term is insignificant if reverse biased $$I_{ext} = \frac{\eta e P}{h\omega}$$

In a **Solar cell** the photodiode is optimised

for maximum power output