EEE105
"Electronic Devices"

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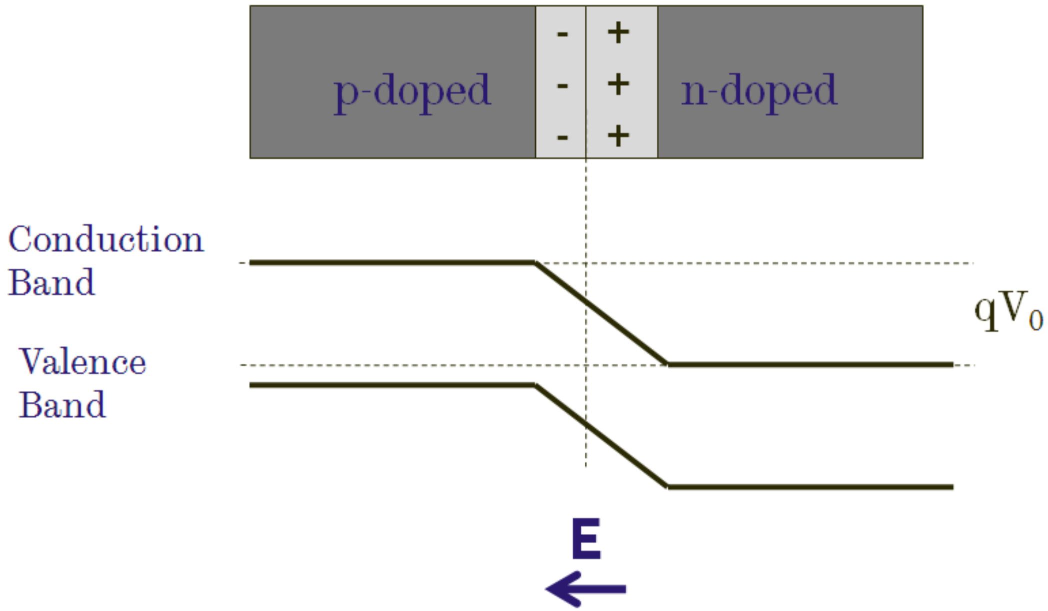
Lecture 15

- Recap on p-n junctions
- Carrier distribution in the diode
- Application – Light emitting diodes
- Application - Lasers

p-n Junction



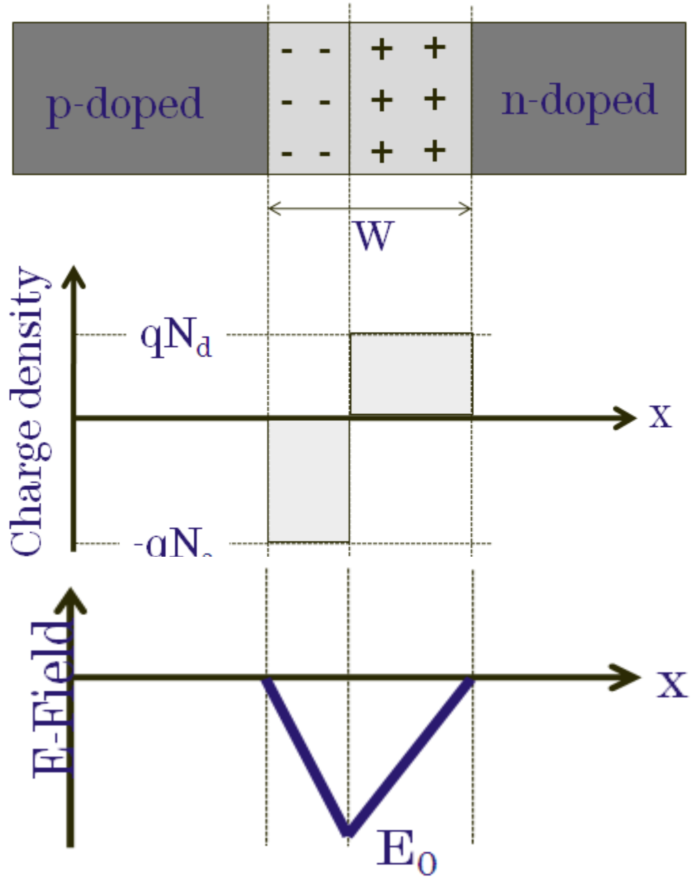
In a p-n junction the free carriers recombine in the region of the junction revealing charged dopant atoms

By assuming no net current, we can deduce the built in voltage V_0

$$V_0 = \frac{k_B T}{q} \ln\left(\frac{n_{(n)}}{n_p}\right)$$

This is a little smaller than the band-gap

Space Charge at a Junction



Poisson's equations relate the charge density to E-field and potential

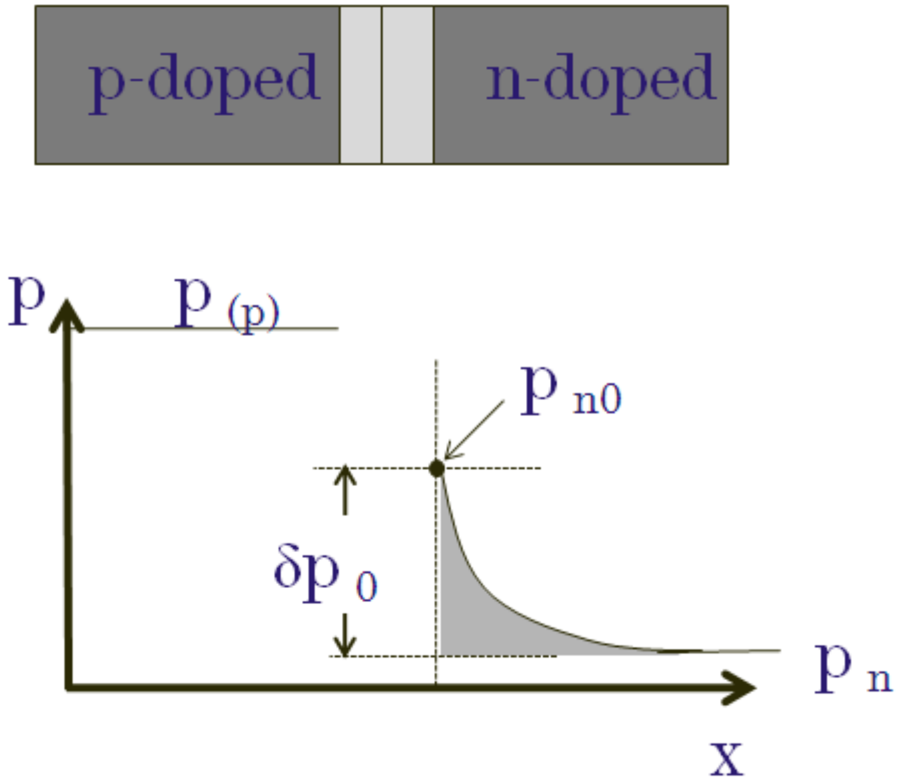
Using this we can calculate the E-field in the junction and relate V_0 to the doping densities and the width of the depletion region

$$x_{p0} N_a = x_{n0} N_d$$

$$E_0 = -\frac{q}{\varepsilon} N_d x_{n0} = -\frac{q}{\varepsilon} N_a x_{p0}$$

$$W = \left[\frac{2\varepsilon (V_0 - V_f)}{q} \left(\frac{N_a + N_d}{N_a N_d} \right) \right]^{1/2}$$

Diode Equation – $I(V_f)$



The total current in the diode is dominated by diffusion current

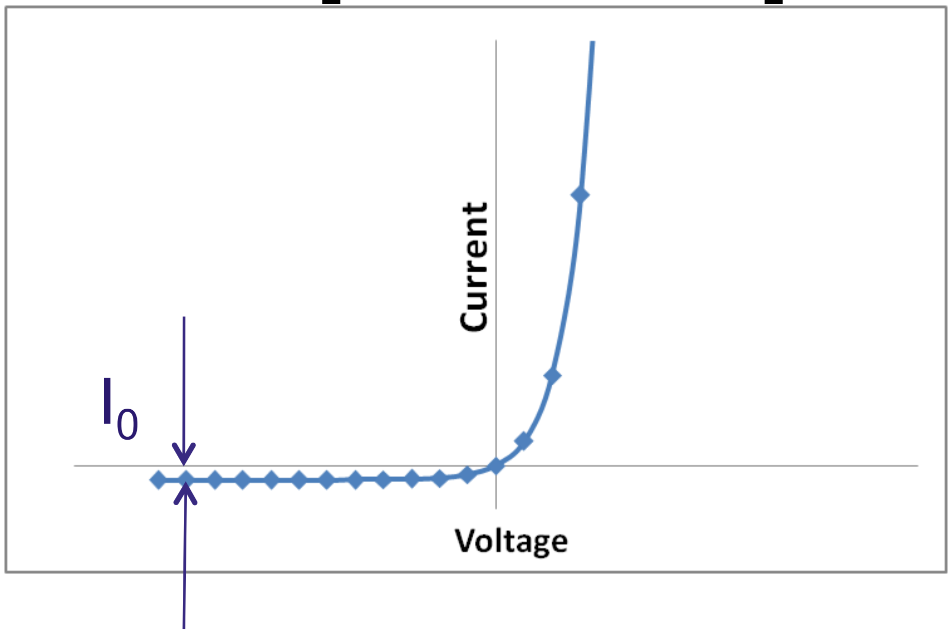
This is due to the diffusion of carriers over a potential barrier where they become minority carriers

These carriers diffuse into the majority carriers, where they recombine causing a current

I(Vf) is derived by calculating the amount of charge per unit time injected into the n and p-type regions

Diode Equation

$$I = I_0\left[\exp\left(\frac{qV_f}{k_B T}\right) - 1\right]$$



The current is exponential in forward voltage

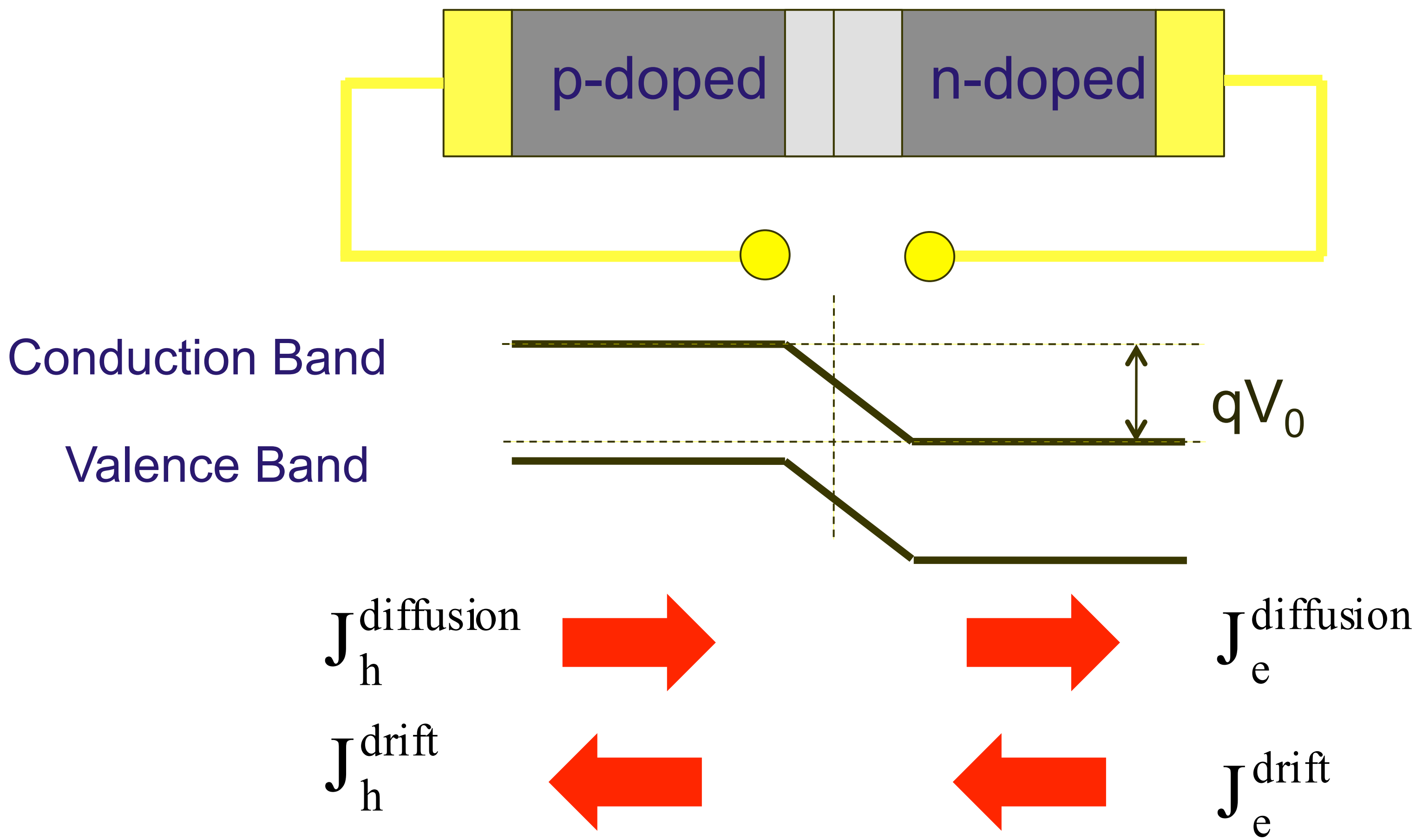
In reverse bias a "saturation current" is observed

$$I_0 = I_{e0} + I_{h0} = qA\left[\frac{L_e n_p}{\tau_e} + \frac{L_h p_n}{\tau_h}\right]$$

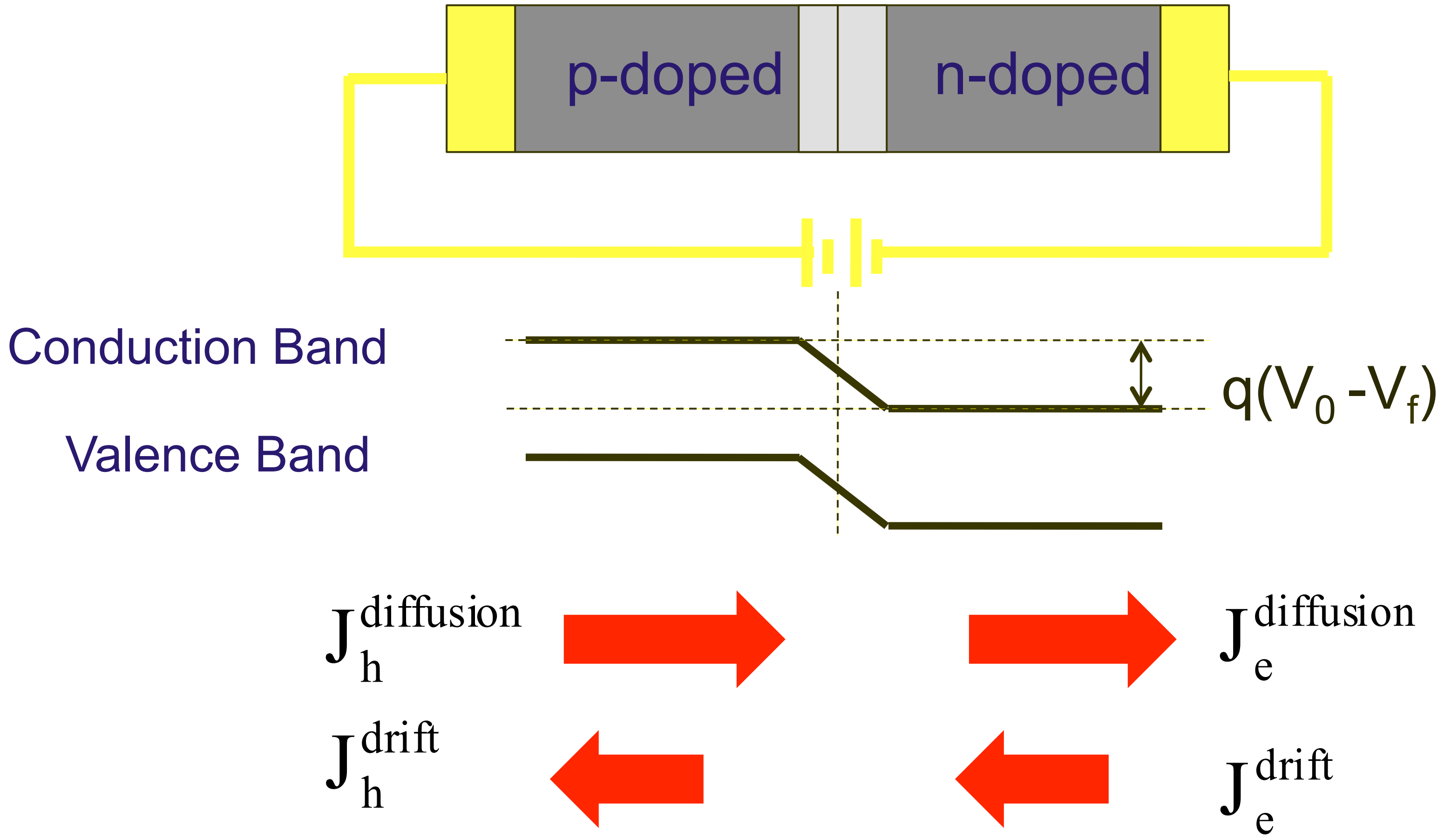
(Can substitute these)

This directional behaviour is very useful – e.g. rectification

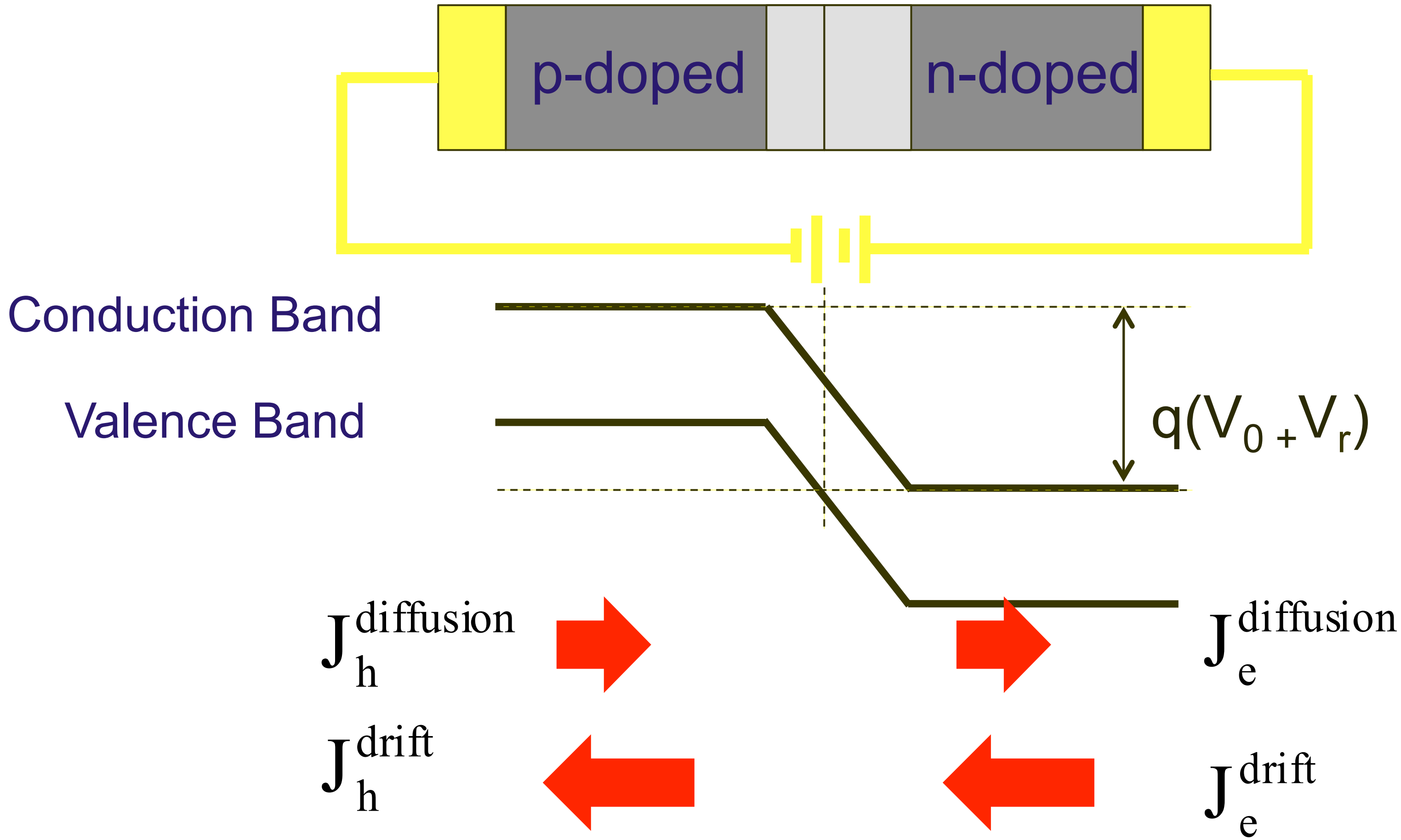
Zero Applied Voltage



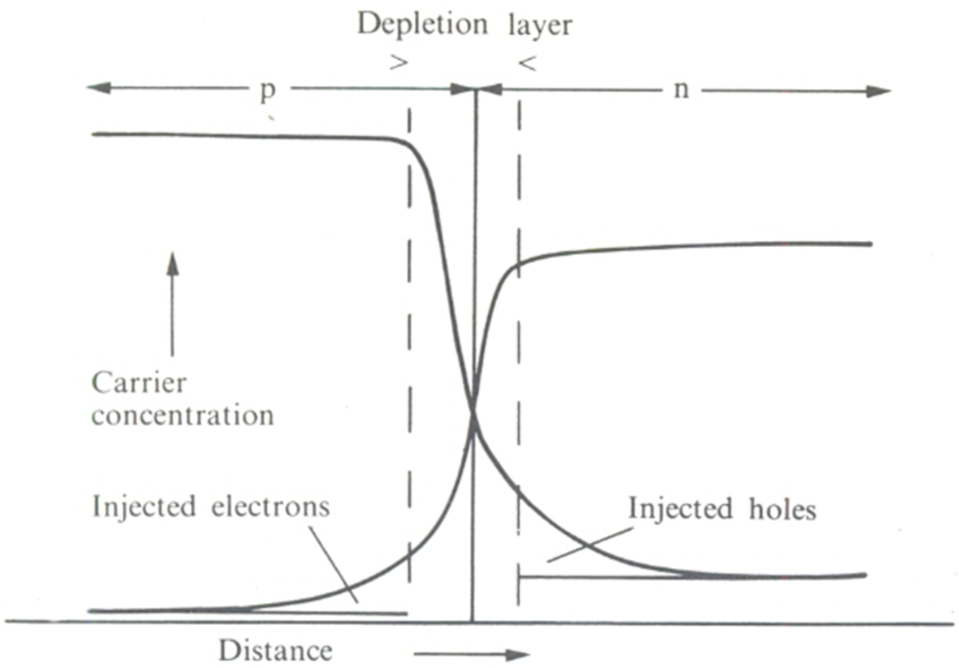
Forward Bias, V_f



Reverse Bias, V_r



Carrier Densities



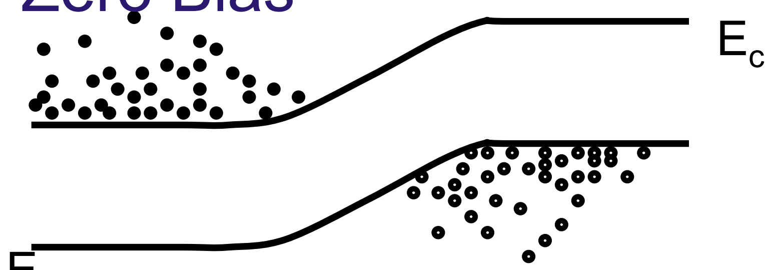
In a diode we can get a high concentration of electrons and holes in the same place

We can get strong light emission ....

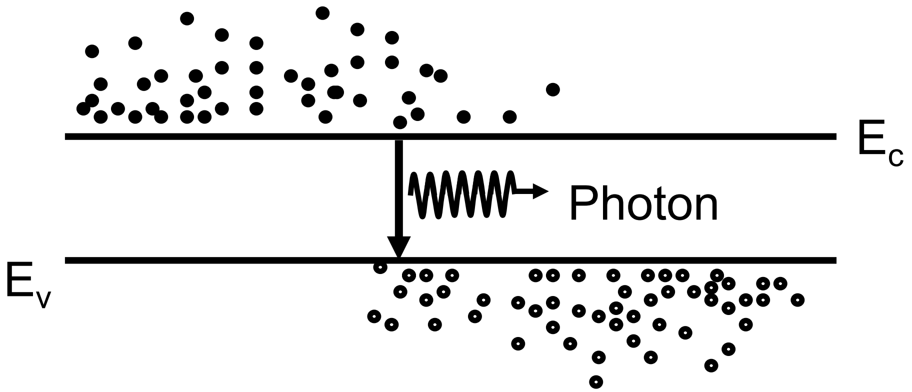
Light emitting diode (LED)

Light Emission

Zero Bias



Forward Bias



Forward bias brings electrons and holes together in large concentrations in the depletion region

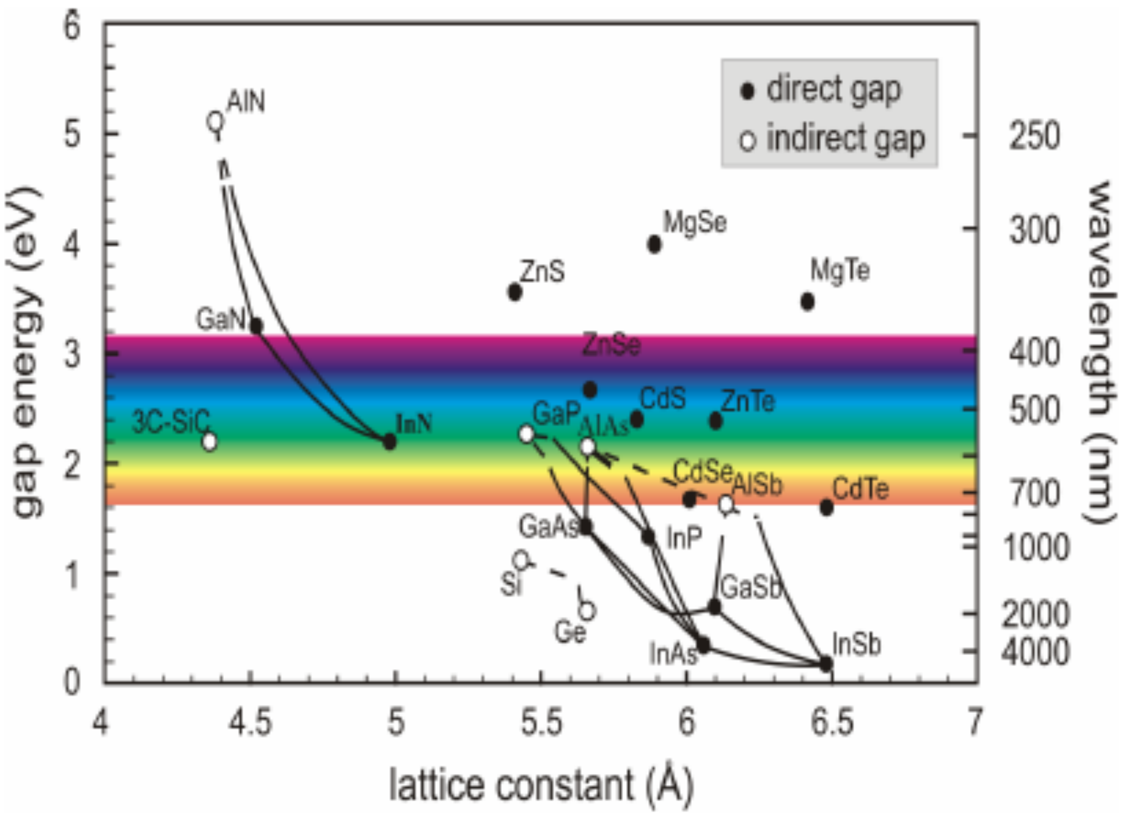
Non-equilibrium case

Electrons and holes can readily recombine to give up their energy – this may create a photon

Si is very bad at this

Other semiconductors e.g. GaAs and InP are very good at this

Energy and Wavelength



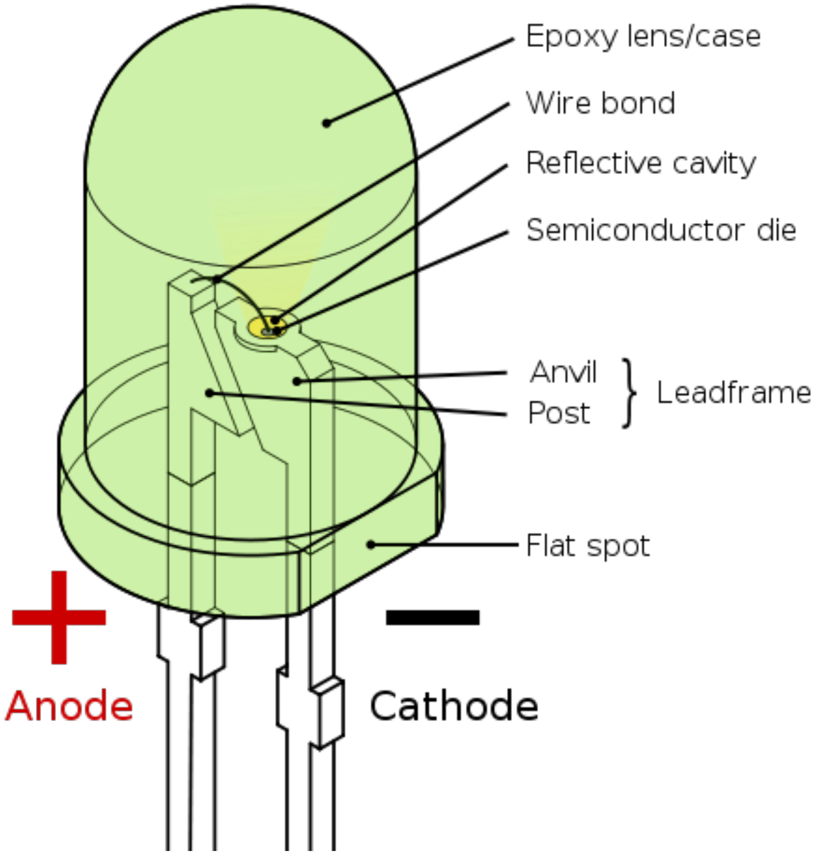
Light is emitted with the band-gap energy

The energy of a photon is given by

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

Where
c = speed of light,
h = Planck's constant
λ= wavelength

LED

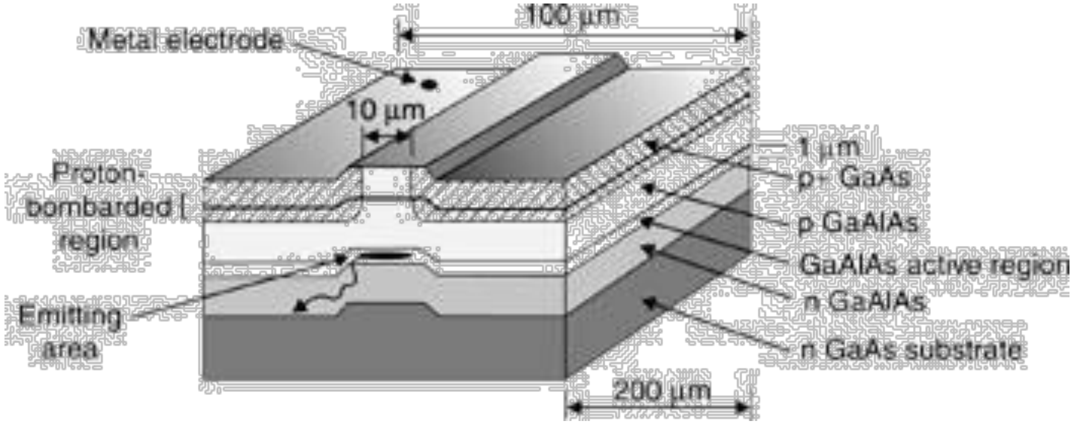


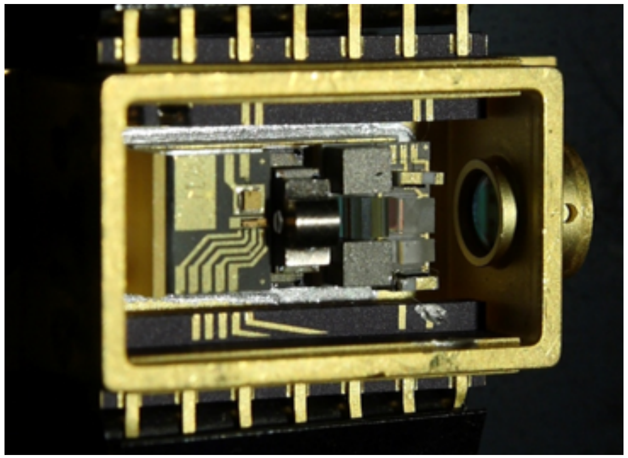
Direct and efficient method of generating light

LEDs find widespread use e.g.;
•Motion sensors
•Communications
•Displays
•Lighting

However
Total efficiency is poor – very efficient generation inside the semiconductor - but it is difficult to get the light out of the semiconductor, and focussing / direct / use it

Semiconductor Laser



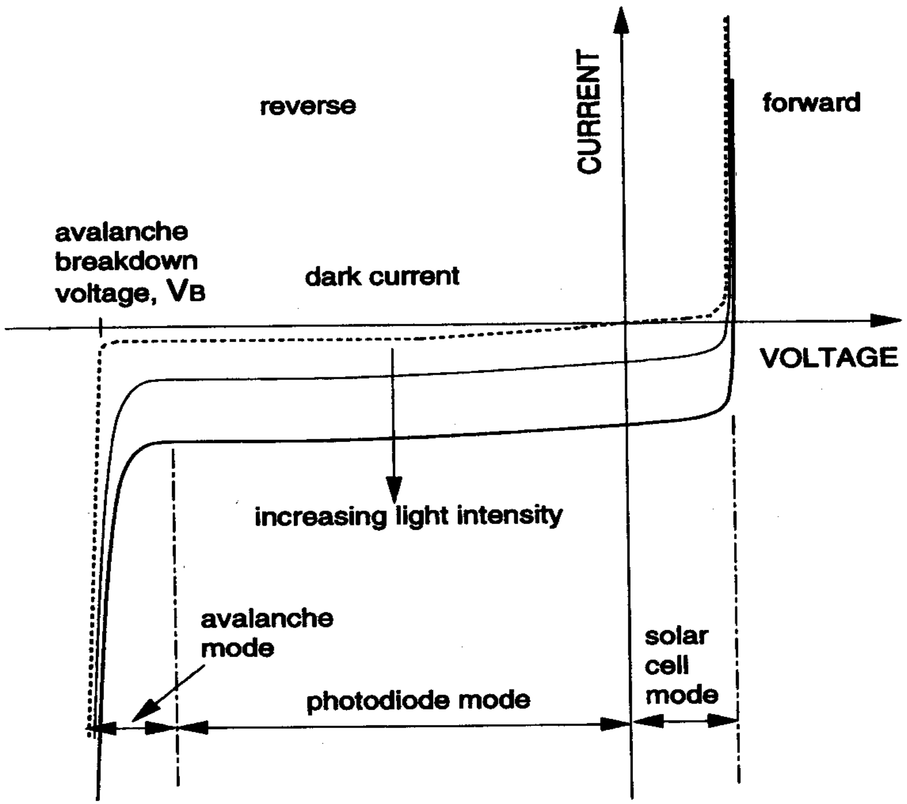


Comprising;
•p-n junction
•Optical confinement
•Optical feedback

External Efficiencies ~ >50%

Applications Include
Data storage
Communications
Printing
Displays
Healthcare...

Absorption of Light



When we shine light of energy > band-gap

Applications Include;

Signals (reverse bias)-
Optical communications
Data storage
Imaging
Sensors

Power (forward bias)-
Solar Cells

Summary

- Reviewed p-n junction
- Semiconductor diode under forward bias allows electrons and holes in large concentrations to co-exist in the same spatial location
- This can result in efficient light generation (depends on material)
- LEDs are vital components for a number of applications but their overall efficiency is poor, and the light is highly divergent
- Laser diodes have high external efficiency, directional beams and are also widely used for a huge number of applications

