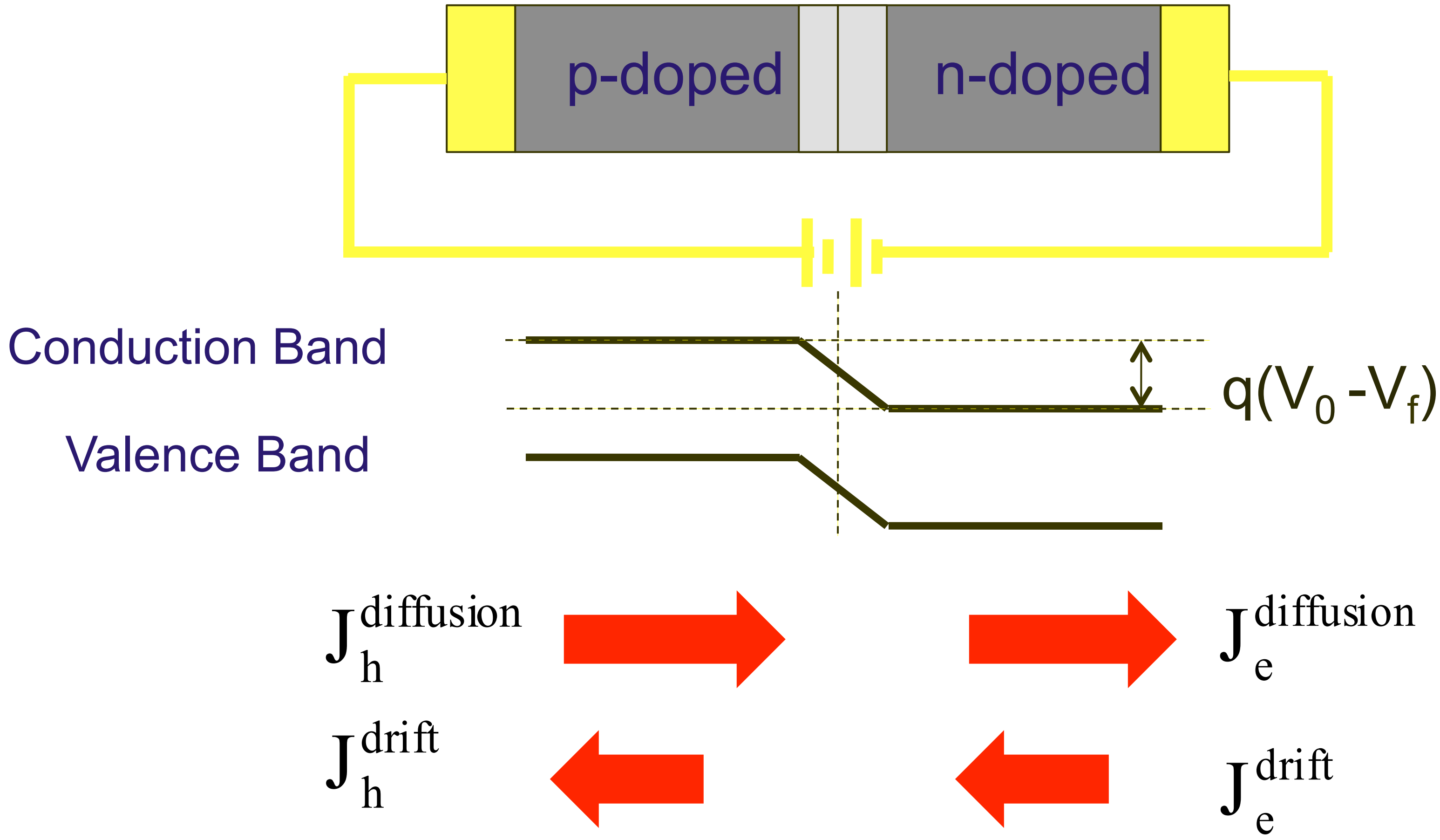
The University Of Sheffield.

Lecture 13

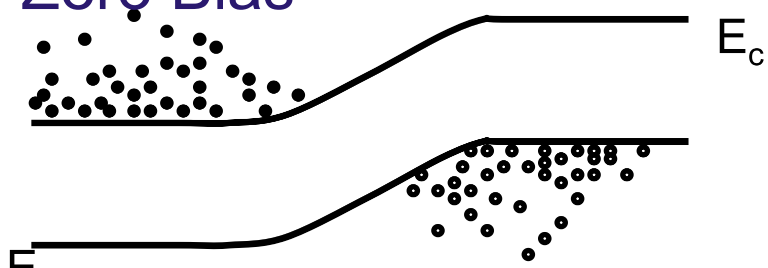
- Recap on p-n junctions
- Carrier distribution in the diode
- Light emitting diodes
- Lasers
- Detectors and solar cells

Forward Bias, V_f



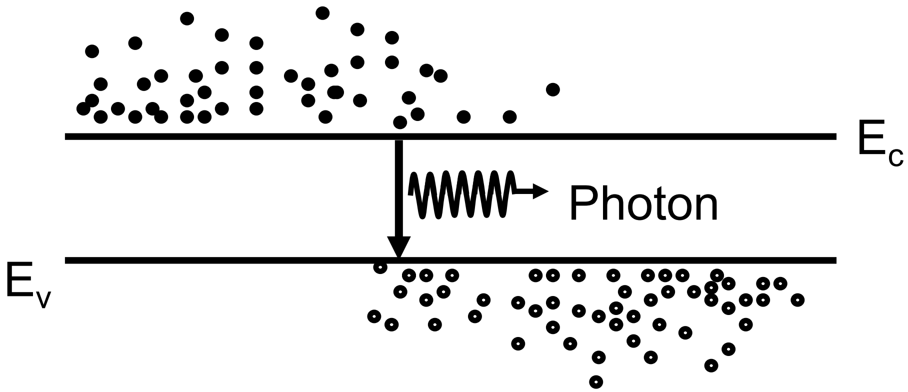
Electrons and holes in the diode

Zero Bias



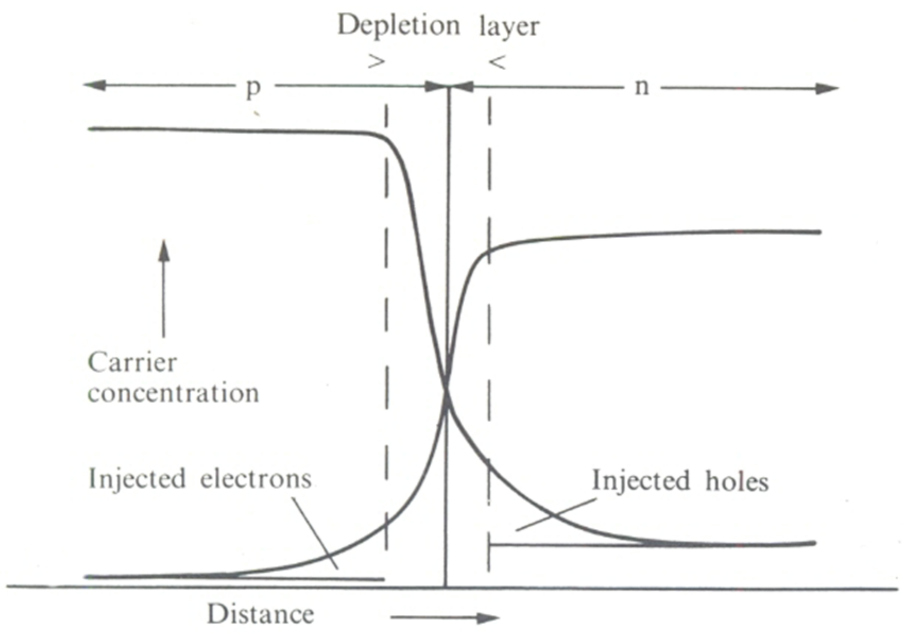
- At zero bias the electrons and holes are effectively separated from each other

Forward Bias



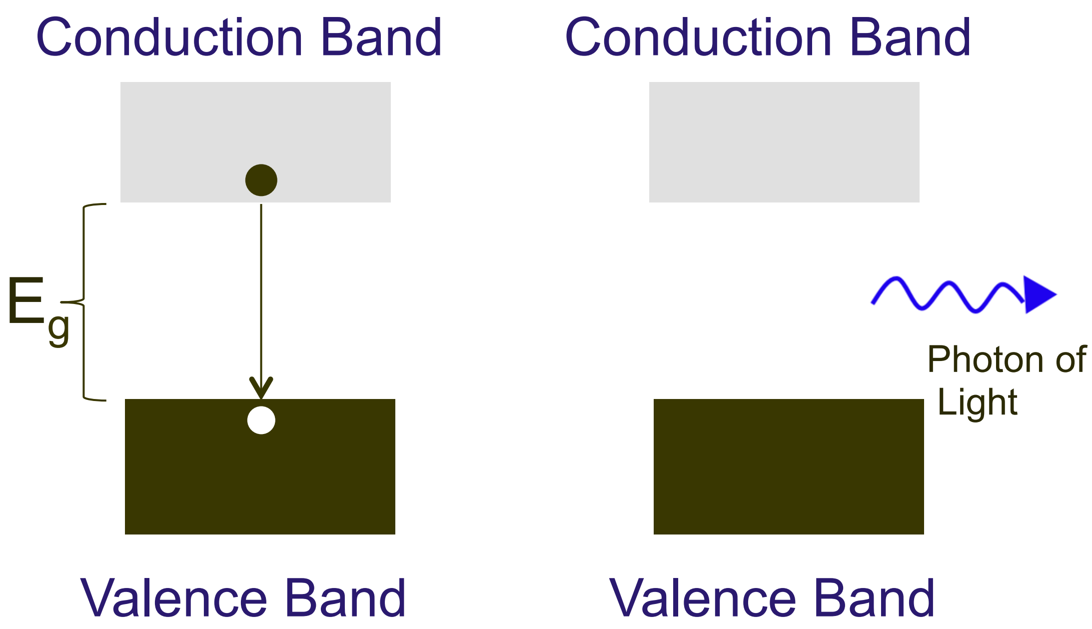
- With forward bias, electrons and holes both flow in the depletion region

Carrier Recombination in a diode



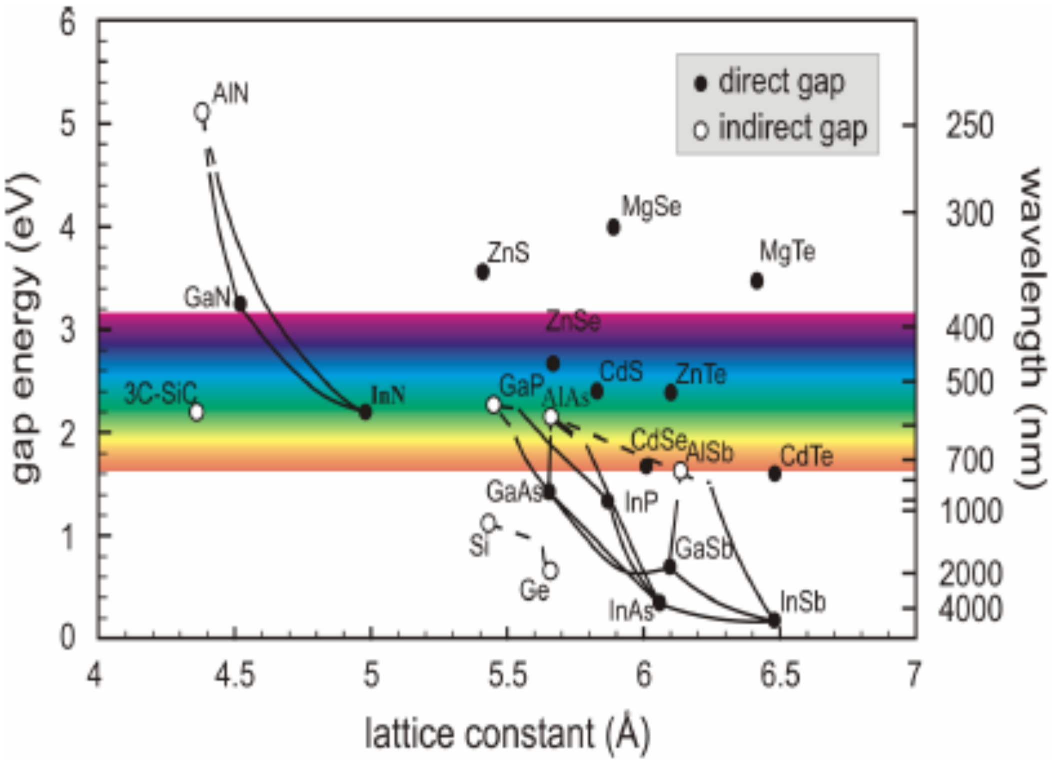
- In forward bias we can get a high concentration of electrons and holes in the same place controlled by the bias we apply
- In this region the electrons and holes can recombine liberating energy
- The most useful form of this energy is photons of light

Making coloured light - Energy and Wavelength



- Electrons recombine with holes across the band gap
- The electron ‘gives up’ its excess energy to return to the valence band
- This excess energy is equal to the band-gap of the semiconductor and is emitted as a photon
- Some semiconductors do this efficiently (e.g. GaAs, InP, GaN) others are innefficient and liberate their energy as heat rather than light (e.g. Si, Ge)

Making coloured light - Energy and Wavelength



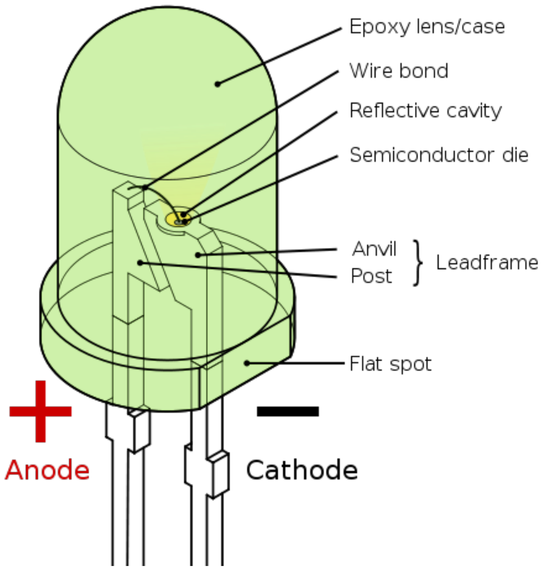
- The energy of a photon is given by

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

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

- The wavelength of the light is equated with the colour of that light
- Hence Semiconductors with different bandgaps can create light of different colours
- Visible light ranges from 400nm (blue) to 700nm (red)

Light Emitting Diode (LED)

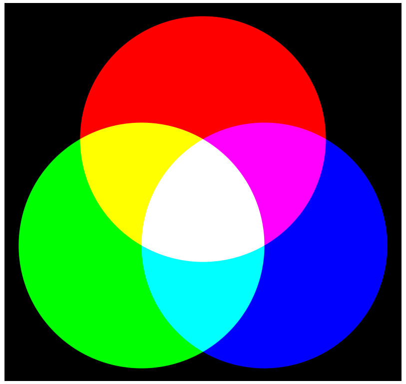


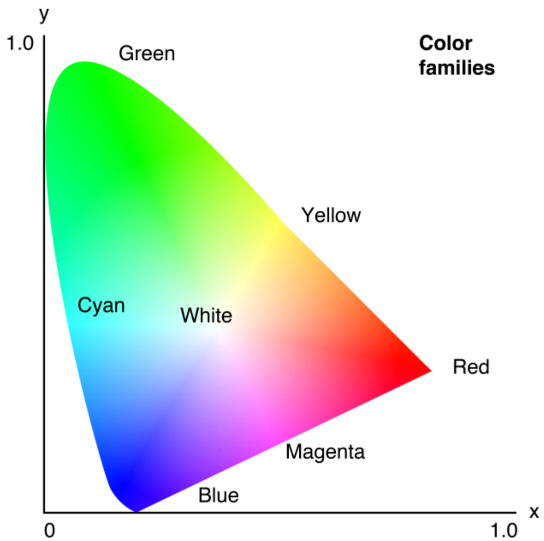
Direct and efficient method of generating light:

LEDs find widespread use e.g.;

- Indicators
- Motion sensors
- Communications
- Displays
- Lighting

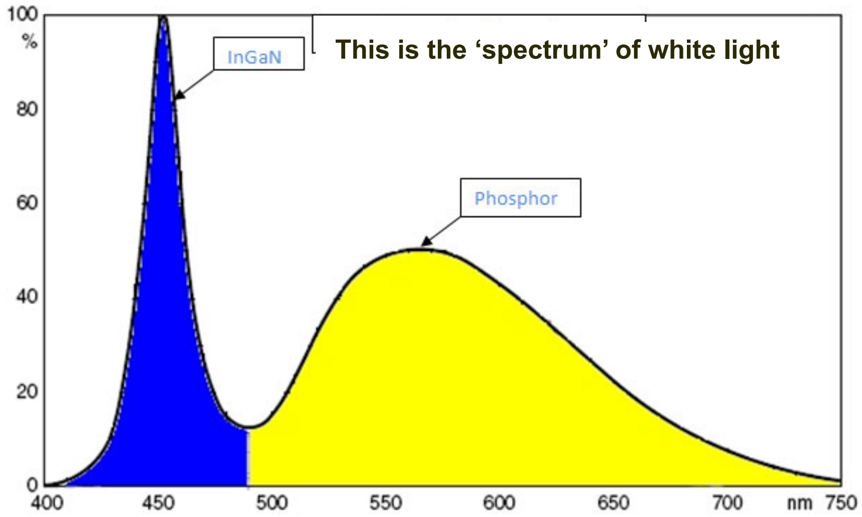
How do we make white light?





- White light is made by combining different colours
- e.g. red, green and blue mixed together in the right proportions gives white light
- In fact we can get it by combining two colours and this is typically how white LEDs are made
- We use a blue LED (using the semiconductor InGaN) and a yellow phosphor material

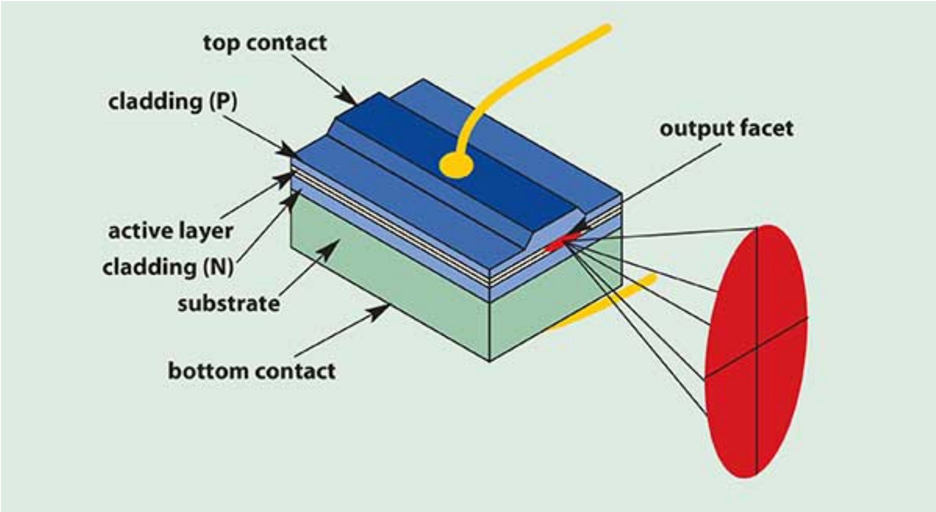
How do we make white light?

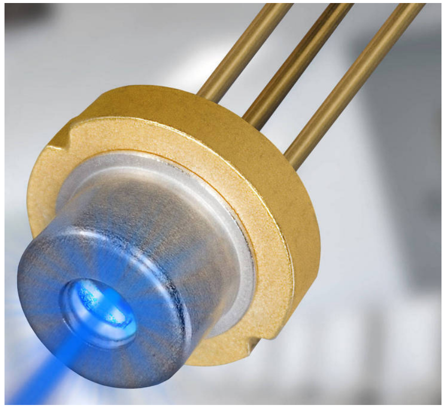


- Blue light from the LED 'excites' the phosphor which then emits yellow light

- When this is mixed with more blue light from the LED we get white light

Semiconductor Laser



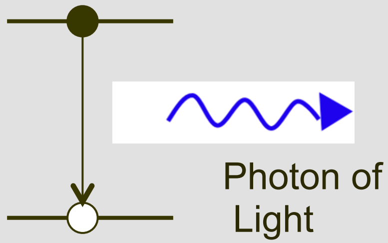


Similar concept to an LED but includes **Optical Amplification**

LASER = **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation

Spontaneous Emission and Stimulated emission

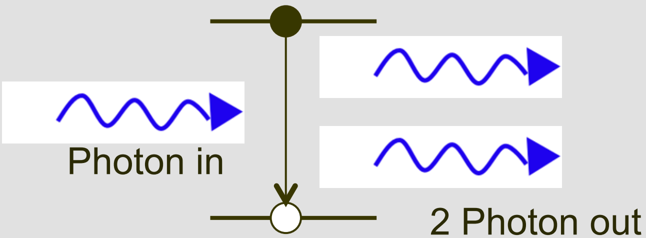
Spontaneous Emission



Random relaxation of an electron leads to emission of 1 photon

LED emits light through **Spontaneous Emission** process

Stimulated Emission

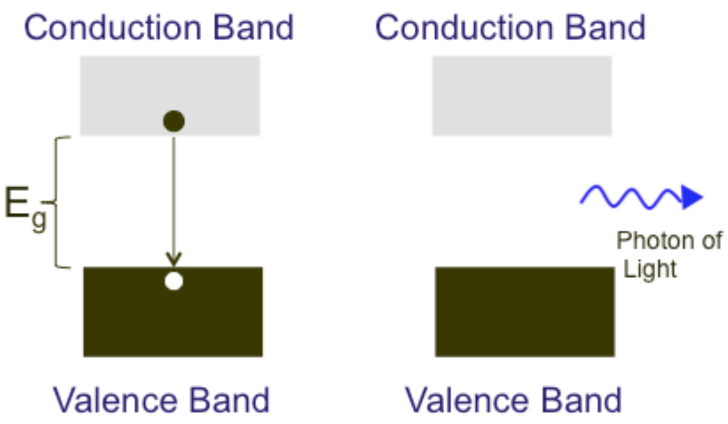


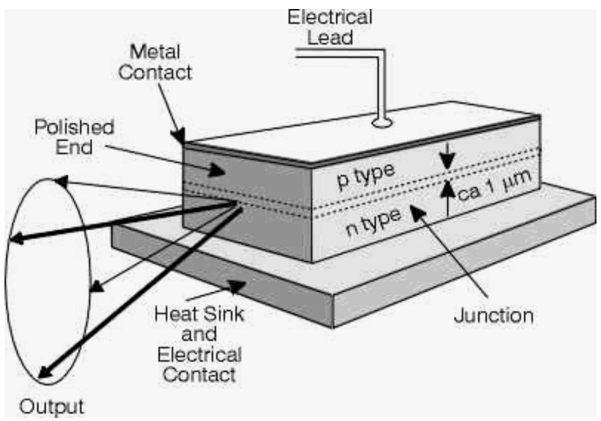
One photon interacting with electron stimulates relaxation and two photons emerge

Laser emits light through **Stimulated Emission** process

Each emitted photon can stimulate further emission:
1 -> 2 -> 4 ->8…
Hence a single photons is **amplified** in this process

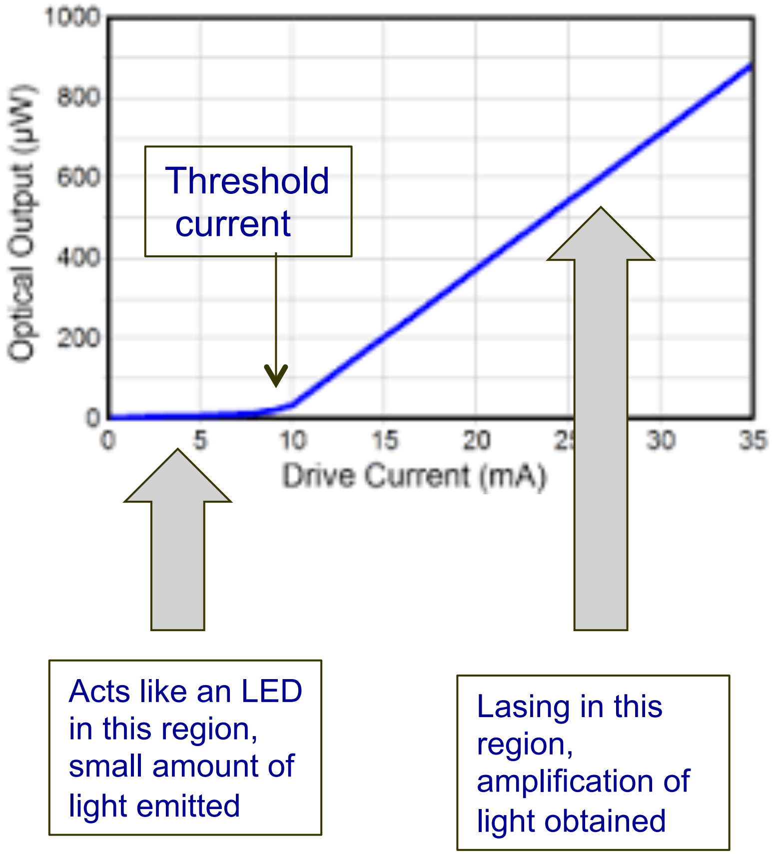
Spontaneous Emission and Stimulated emission





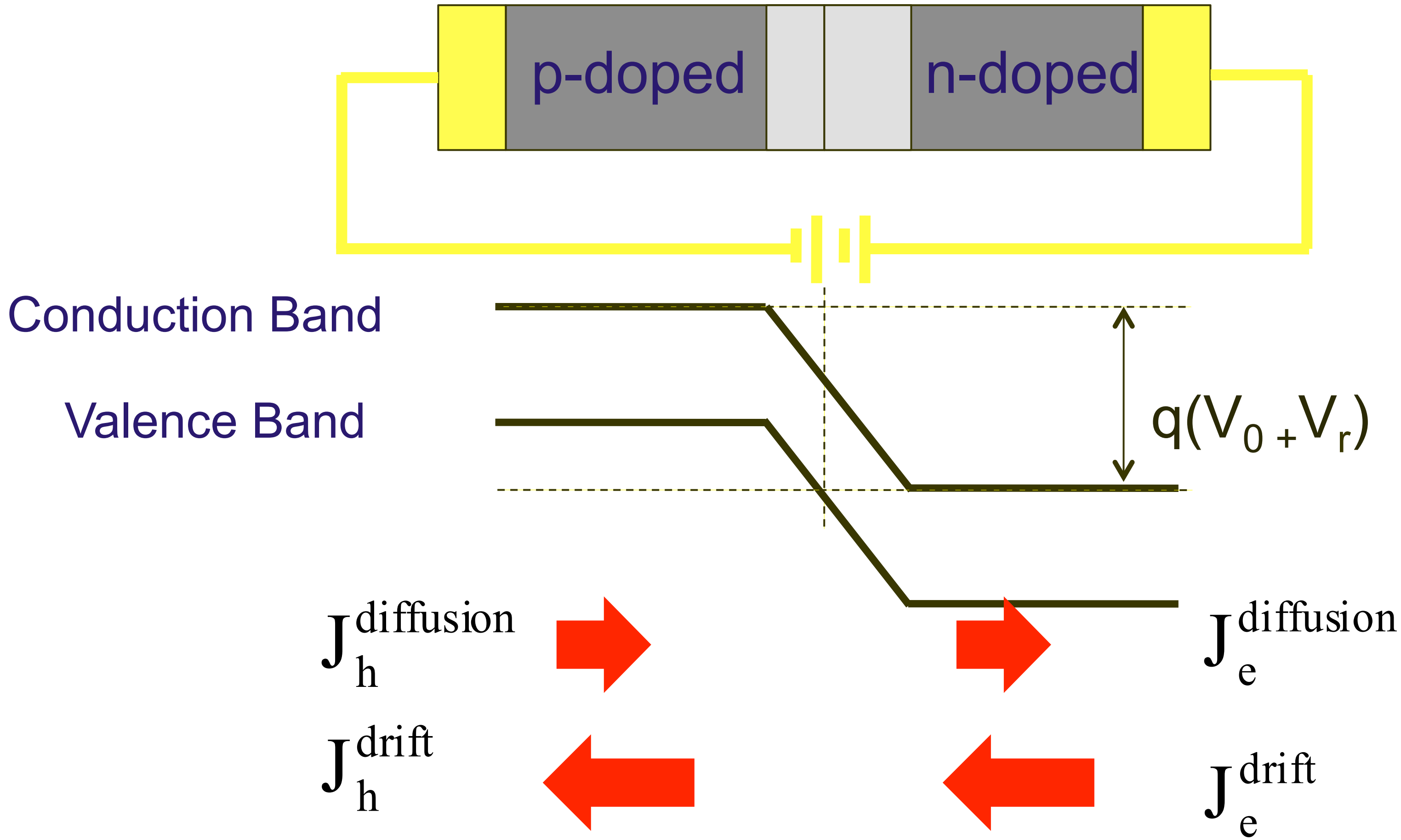
- In a semiconductor laser, the emission is between the bands
- In order to allow the photons to interact with as many atoms (electons) as possible a **feedback** mechanism is used. This consists of two mirrors surrounding the pn junction and reflecting light back in to the laser
- In a semiconductor the mirror is usually formed by the cleaved or polished edge of the laser chip
- Lasers emit a beam of light because only light travelling between the mirrors is amplified

Spontaneous Emission and Stimulated emission

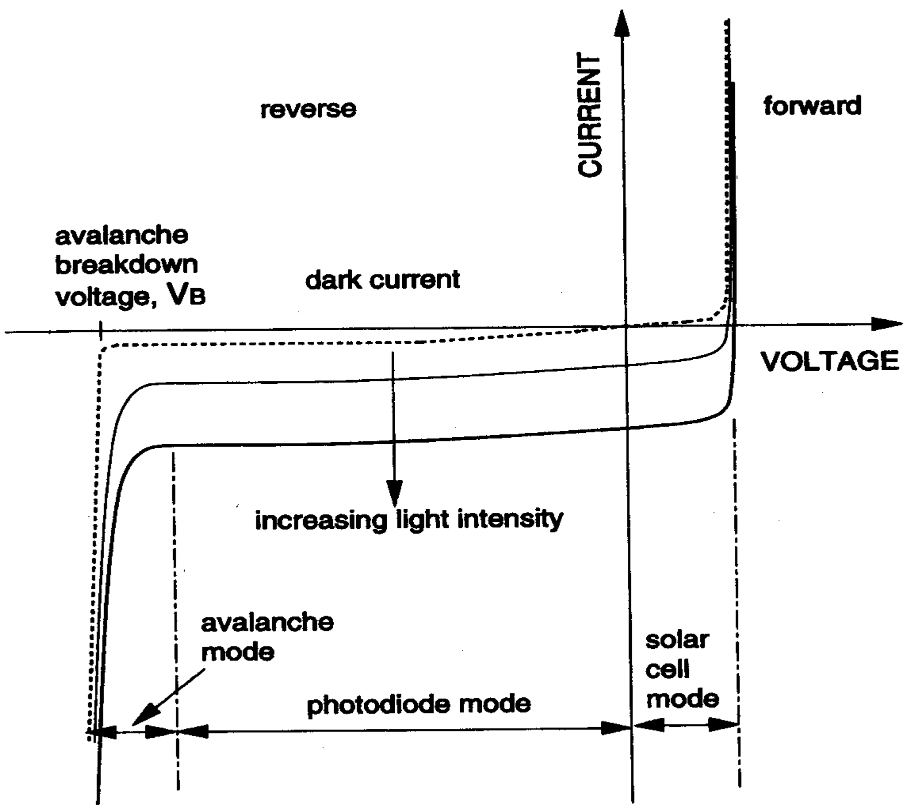


- There are special conditions under which the laser will ‘lase’ depending on how good the mirrors are and how much current is injected into the diode
- The ‘L-I’ curve shows the light output from the laser as a function of injected current
- Lasing action occurs at threshold current
- **Applications for semiconductor lasers Include:**
  - Data storage (CD, DVD, Blu-ray)
  - Communications
  - Printing
  - Projectors
  - Healthcare...

Reverse Bias, V_r



Absorption of Light



- In reverse bias, a PN junction can act as a detector for light.
- Minority carriers are generated in the depletion region if the energy of absorbed photons is larger than the band gap.
- The reverse bias field sweeps these carriers into the p and n- regions and this can be detected as a current in an external circuit
- In a Solar cell current and voltage (and hence power) are generated due to the effect of the internal electric field in the junction

Summary

- Semiconductor diode under forward bias allows electrons and holes in large concentrations to co-exist in the same spatial location
- This can result in light generation who's colour depends on the bandgap of the semiconductor
- White light is made by combining colours
- LED light is generated by Spontaneous emission, LASER light is generated by Stimulated emission
- Light is amplified in a laser by feedback from mirrors
- In reverse bias a diode acts as an efficient detector of light. Solar cells operate in similar fashion with the internal electric field acting on carriers