LECTURE 17

GENERATION/RECOMBINATION

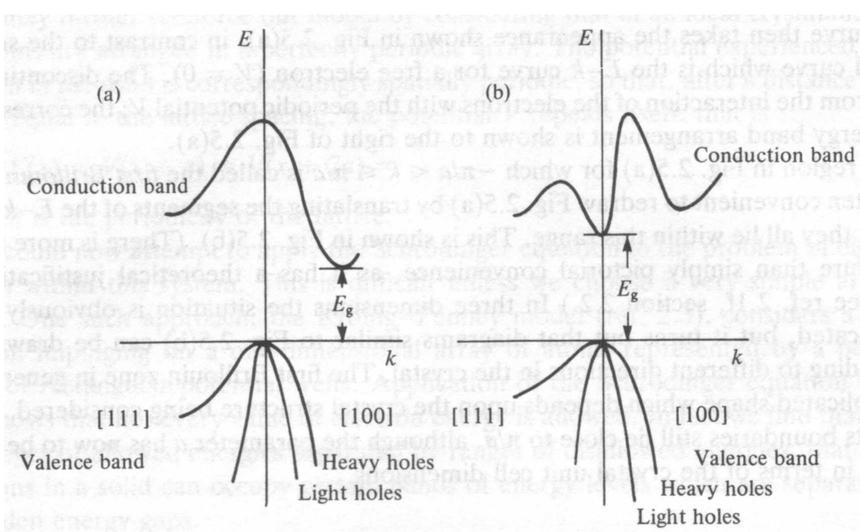
Generation of Electrons and Holes

Generation: The movement of an electron from the valence band to the conduction band. This results in the creation of an electron-hole pair.

We have talked about the thermal generation of holes and electrons but they can also be generated by light (Photogeneration).

Photogeneration

Remember that E-k diagrams of real crystals (whose structure is still periodic but more complex than a simple chain of atoms) are not simple parabolas.

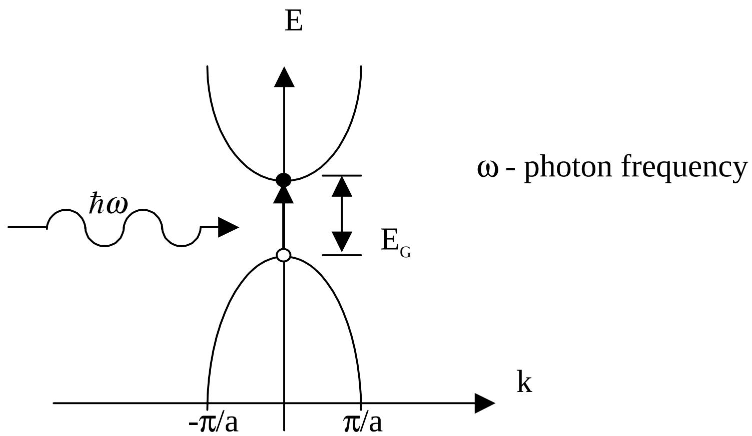


The previous figure shows the E-k relationship for real solids (a) Silicon (which has an indirect bandgap) and (b) gallium arsenide (which has a direct bandgap).

One point that arises is that the maximum of the valence band does not always occur at the same *k* value as the minimum of the conduction band. We speak of a *direct* bandgap semiconductor when they do and an *indirect* bandgap semiconductor when they do not.

Analyzing the two cases:

a) Direct gap material (e.g. GaAs) –(min of conduction band at same *k* as max of valence band)



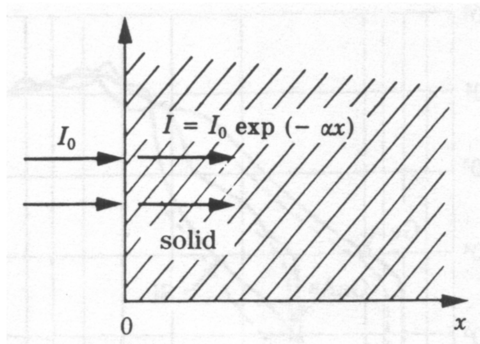
(Δk = 0) Change of electron momentum is zero

A photon (a "particle of light") with energy $E = \hbar\omega$ can be absorbed by promoting a valence band electron to the conduction band, creating an electron-hole pair. This is a two body collision (electron, photon).

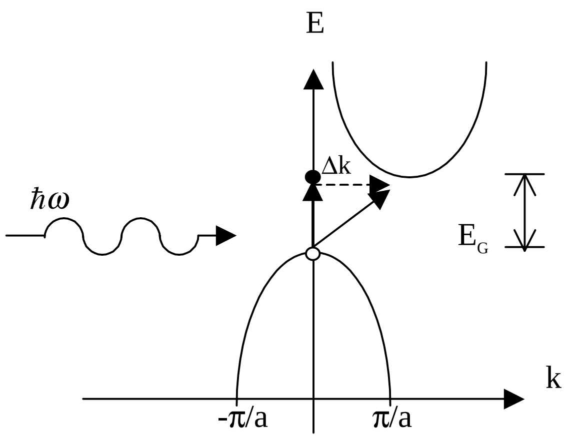
Direct bandgap materials have strong light absorption and are modeled by an absorption parameter.

Model for light absorption: $I(x) = I_o e^{-\alpha x}$

Where α - absorption coefficient [cm^{-1}], I_o – incident intensity



b) Indirect gap material (e.g. Si) –(min of conduction band not! at same *k* as max of valence band)



(Δk != 0) Change of electron momentum is non zero.

A photon carries little momentum, for a transition we need Δk (a momentum change) and this can not be provided by the photon itself.

Promotion of valence band electron to conduction band requires momentum transfer from crystal lattice (interaction with a "phonon"); this is a relatively unlikely event as it is a three body collision (electron, photon, phonon).

"phonon" = quantized lattice vibration ("particle" of heat)

∴ light absorption is relatively weak.

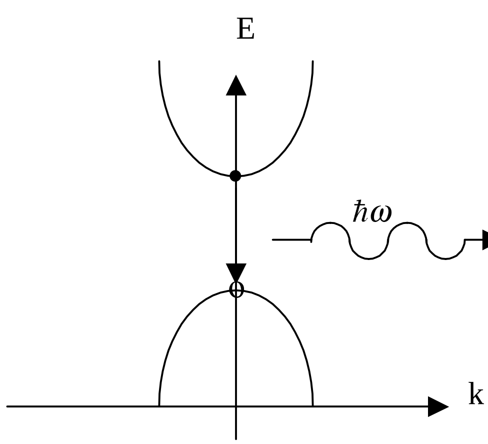
Note: all semiconductors are effectively - transparent for light with $hv < E_G$ (no possible transition).

- absorb for $hv > E_G$ (transitions allowed)

Recombination of Electrons and Holes

Recombination: The movement of an electron from the conduction band to the valence band. This results in the destruction of and electron-hole pair.

Once created holes and electrons can recombine and be eliminated, in doing so, the energy released in the recombination is given up as light (radiative recombination) or heat (non-radiative recombination).



a) Direct radiative recombination (e.g. GaAs)

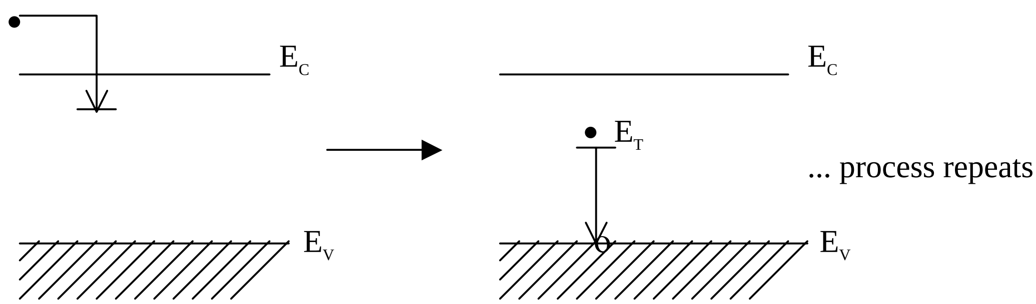
The conduction band electron fills valence band hole, releasing a photon with the energy $E_{photon \sim EG.}$

This is the basis of semiconductor LEDs and lasers, and is a very unlikely process in indirect gap materials (need a phonon for momentum).

Therefore can not make Si LEDs or lasers easily, without modifying material properties.

b) Recombination through Midgap Energy levels (traps) (two stage process).

Defect centers or traps are energy levels (E_T) in the forbidden gap which are associated with defect states caused by the presence of impurities or lattice imperfections.



1) trap captures conduction band electron

2) trap transfers electron to valence band (capture hole)

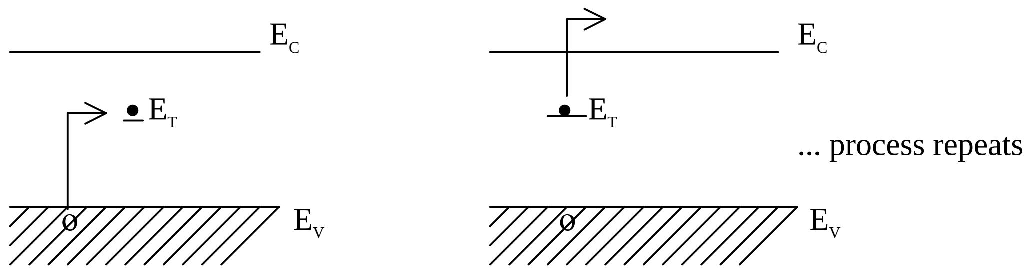
- In silicon, midgap defect centers generally associated with transition metal contamination: Cu, Fe, etc like dopant.

- Traps are generally undesirable as we want long carrier lifetimes (elapsed time before recombination) in most devices.

- Traps shorten lifetime, produce multiple frequencies and energy pathways (contribute to non-radiative recombination).

Thermal Generation (trap aided)

- heat (phonon) gives energy to electron.
- usually enabled by midgap energy levels (smaller energy).



1) trap captures valence band electron (create hole)

2) trap emits electron to conduction band