Excess carriers in semiconductors

- Optical absorption
- Luminescense
- Carrier lifetime and photo-conductivity
- Diffusion of carriers

Optical absorption

- Photons with $hv > E_g$ will excite EHP and the excess energy ($hv - E_g$) will be absorbed as heat. EHPs increase conductivity.
- Photons with $hv < E_g$ will pass through unabsorbed.
- One can measure E_g in this fashion.
- CdSe will pass all IR while GaP will pass green light and all longer wavelengths.

Luminescense

- Light may be given off as EHPs recombine and shed the excess energy.
- You can create EHPs (that will recombine) in three ways
  - Photoluminescense
  - Cathodeluminescense
  - Electroeluminescense

Luminescense

- Photoluminescense
  - Shine monochromatic light larger than the bandgap of the material and measure frequency spectrum of emitted photons. Characterization tool.
- Cathodeluminescense
  - Excite material with accelerated electrons. The electrons beam can be pointed to various parts of the structure. Characterization tool. (Except for ZnS on light bulbs and TV screens.)

Luminescense

- Electroeluminescense
  - Excess electrons and holes that are supplied by a current or voltage source recombine to produce light.
  - LEDs, LASERS
  - While the other methods are characterization tools this method of creating luminescence is used in end use devices.

Carrier lifetime and photo-conductivity

- Direct recombination of Electrons and hole
  - Electron drops from conduction band to the valence band and recombines with a hole without any change in momentum (E vs K) .
  - The energy difference is used up in an emitted photon.
  - This process occurs at a certain rate in the form of how long does a free electron or hole remain free before it recombines (τ_n or τ_p)

Carrier lifetime and photo-conductivity

- Direct recombination of Electrons and hole
  - τ_n or τ_p are dependant on doping level, crystal quality and temperature.
- Indirect recombination; Trapping
  - The probability of a direct recombination is small in Si and Ge.
  - A trapping level is needed. No photons generated just phonons (lattice vibrations)
  - Minority carrier lifetime dominates recombination process.

Carrier lifetime and photo-conductivity

- The Fermi level (EF) is only meaningful at thermal equilibrium.
- Under excitation we use the quasi Fermi level to denote excess hole and electron concentrations.

$$n = n_i e^{(F_n - E_i)/kT}, n = n_0 + \delta n, \delta n = \tau_n g_{op}$$

$$p = n_i e^{(E_i - F_p)/KT}, p = p_0 + \delta p, \delta p = \tau_p g_{op}$$

Diffusion of carriers

- Diffusion process
  - The random motion of similar particles from a volume with high particle density to volumes with lower particle density
  - A gradient in the doping level will cause electron or hole flow, which causes an electric field to build up until the force from the gradient equals the force of the electric field.
    - no current will flow at equilibrium

Diffusion of carriers

- Diffusion process
  - t is the mean free time that 1/2 of the particle will enter the next dx segment.
  - l is the mean free path of a particle between collisions.

$$\phi_n(x) = \frac{-\bar{l}^2}{2\bar{t}} \frac{dn(x)}{dx} = -D_n \frac{dn(x)}{dx}, \; Jn(diff.) = -(-q)D_n \frac{dn(x)}{dx} = +qD_n \frac{dn(x)}{dx}$$

$$\phi_p(x) = \frac{-\bar{l}^2}{2\bar{t}} \frac{dp(x)}{dx} = -D_p \frac{dp(x)}{dx}, \; Jp(diff.) = -(+q)D_p \frac{dp(x)}{dx} = +qD_p \frac{dp(x)}{dx}$$

Diffusion and drift of carriers

- Drift diffusion equations
  - The hole drift and diffusion current densities are in the same direction.
  - The electron drift and diffusion current densities are in the opposite direction.

$$J(x) = J_n(x) + J_p(x)$$

Diffusion and drift of carriers

- Drift diffusion equations
  - – Minority current flow is primarily diffusion.
  - – Majority current flow is primarily drift.
- An applied electric field will cause a positive slope in E_i (Ev and Ec as well)
- This can be used to derive the ***Einstein relation.***

$$\frac{D}{\mu} = \frac{kT}{q}$$

Continuity equation

- Rate of hole build up = increase of hole concentration in the volume - the recombination rate

$$\frac{\partial \delta p}{\partial t} = -\frac{1}{q}\frac{\partial Jp}{\partial x} - \frac{\delta p}{\tau_p}$$

$$\frac{\partial \delta n}{\partial t} = \frac{1}{q}\frac{\partial Jn}{\partial x} - \frac{\delta n}{\tau_n}$$

Diffusion length

- L_p is the average distance a hole will move before recombining.
- L_n is the average distance an electron will move before recombining.

$$L_n \equiv \sqrt{D_n \tau_n}$$

$$L_p \equiv \sqrt{D_p \tau_p}$$