Lecture 14

Reading Material

Reading:

Chapter 8 Solymar and Walsh

Scattering

- Recall that in the discussion of electrical conductivity we talked about the conductance, a measure of electrical conductivity

$$\sigma = \frac{q^2}{m}\tau N_e$$

- Where τ is the mean time between collisions (electrons in this case)

Semiconductor Conductivity-Ionized Impurities

- For ionized impurities, the positive charge of donors or negative chare of acceptors will impact the mean velocity of the carriers. If this electrostatic energy (given by some Zq^2) is of the same magnitude as the thermal vibration (thermal energy) we can write

$$\frac{Zq^2}{4\pi\varepsilon r_s} = \frac{3}{2}\kappa_B T$$

$$\xrightarrow{\text{Electrostatic Energy}} = \xleftarrow{\text{Thermal Energy}}$$

- Solving for the radius r_s

$$r_s = \frac{Zq^2}{6\pi\varepsilon\kappa_B T}$$

- The ion cross scattering section is related to the radius by

$$S_s = \pi r_S^2 = \frac{1}{\pi}\left(\frac{Zq^2}{6\varepsilon\kappa_B T}\right)^2$$

- Assuming that the mean free path is inversely proportional to the cross scattering section

$$\tau_{\text{ionizing impurity}} = \frac{l}{T^{1/2}} \approx \frac{1}{S_S}\frac{l}{T^{1/2}} \propto \frac{1}{T^{3/2}}$$

Scattering due to combined non-ionized and ionized impurities

- We can calculate and effective mean scattering time by considering both contributions as follows

$$\frac{1}{\tau_{\text{eff}}} = \frac{1}{\tau_{\text{thermal}}} + \frac{1}{\tau_{\text{ionizing impurity}}}$$

$$\tau_{thermal} = \frac{l}{\upsilon_g} \approx \frac{1}{T \bullet T^{1/2}} = \frac{1}{T^{3/2}}$$

$$\tau_{\text{ionizing impurity}} = \frac{l}{T^{1/2}} \approx \frac{1}{S_S} \frac{l}{T^{1/2}} \propto \frac{1}{T^{3/2}}$$

Dependence on impurity density

- At room temperature, when the material acts extrinsic, the combined scattering effect of holes and electrons can be empirically used to calculate the conductivity

$$\sigma = \frac{q^2}{m_e^*}\tau_e N_e + \frac{q^2}{m_h^*}\tau_h N_h$$

Relationship between electron and hole densities

- We discussed that the product of electron and hole densities in an intrinsic semiconductor is constant at any given temperature
- For an extrinsic semiconductor this is still true with

$$N_e N_h = 4\left(\frac{2\pi\kappa_B T}{h^2}\right)^3 \left(m_e^* m_h^*\right)^{3/2} e^{-E_g/\kappa_B T}$$

$$\text{Intrinsic Semicondutor}\begin{cases} r_{\text{int}\,rinsic} = aN_i^2, \text{ rate of recombination is proportional to intrinsic hole and electron desity} \\ g_{\text{int}\,rinsic} = aN_i^2, \text{ rate of generation is proportional to intrinsic hole and electron desity} \end{cases}$$

$$\text{Extrinsic Semicondutor}\begin{cases} r_{extrinsic} = aN_e N_h, \text{ rate of recombination is proportional to intrinsic hole and electron desity} \\ g_{extrinsic} = aN_i^2, \text{ rate of generation is proportional to intrinsic hole and electron desity} \end{cases}$$

$$r_{extrinsic} = aN_e N_h = g_{extrinsic} = aN_i^2, \text{ in thermal equilibrium, therefore}$$

$$N_e N_h = N_i^2$$

Semiconductor Property Measurements

- We can measure the following properties using various experimental techniques
  - Mobility
    - Measure the drift velocity using an applied DC field or an applied optical signal
    - Can also use the four-point probe method where current is supplied and voltage is measured to measure the conductivity directly.
    - Hall Effect – also uses a four point probe to measure the charge density and calculate mobility
  - Effective Mass
    - Cyclotron resonance absorption – an applied EM wave will be absorbed when the applied field is resonant with the motion of the carrier and this is directly related to the carrier mass using a spring-mass model. A microwave field may be used to spin the carrier around and measuring the microwave loss.

Semiconductor Property Measurements

- Energy Gap
  - Measure changes in conductivity with temperature

$$\sigma = \sigma_0 e^{-E_g / k_B T}$$

$$\sigma_0 = Aq(\mu_e + \mu_h)T^{3/2}$$

  - Changes in optical transmission
    - Measure absorption as a function of optical wavelength for low levels of light
- Carrier Lifetime
  - Light input – measure voltage or microwave reflectivity (see Blumenthal, APL 1981)