Lecture 30, Apr 11, 2022

Resistance and Resistivity

- Resistance is a property of a certain object, resistivity is a material property (resistance depends on length, area, etc)
- Resistivity is defined as $\rho = R\frac{A}{l}$ in units of $\Omega\mathrm{m}$
  - Resistance is proportional to length and inversely proportional to cross sectional area
- Conductivity is defined as $\sigma = \frac{1}{\rho}$ in units of Ω^{-1}/m
- For a metal, $\sigma = ne\mu_e$, where n is the density of free electrons (or holes in some rare cases) in m^{-3}, e is the electron charge, μ_e is the electron mobility (units of $\mathrm{m}^2/\mathrm{V\,s}$)

Semiconductors

- For an intrinsic semiconductor (i.e. no additives), charge is carried by both holes and free electrons in the valence band; $\sigma = n_i e(\mu_e + \mu_h)$ where μ_e and μ_h are the electron and hole mobilities
  - Increasing the temperature increases the charge density; $n_i \propto e^{-\frac{E_g}{2kT}}$ where E_g is the band gap, k the Boltzmann constant, and T the temperature in Kelvins
  - Optical absorption can also create charge carriers
  - Since charge carrier density changes with temperature, intrinsic semiconductor conductivity varies with temperature, so they're not often used
- Silicon semiconductors are tetrahedrally coordinated; if we put in a group 5 element, we get an extra electron; if we put in a group 3 element we get an extra hole
- In an extrinsic semiconductor, usually there are much more charge carriers introduced by doping, so we can approximate $\sigma = N_d e\mu_e$ for N-type (negative charge carrier) semiconductors, or $\sigma = Pe\mu_h$ for P-type (positive charge carrier) semiconductors
- Example: Doping silicon with 1 part per billion arsenic
  - As is a group 5 element, so this is a N-type semiconductor
  - 1 part per billion means the electron density is one one-billionth of the atomic density for silicon
  - For silicon $N = \frac{8}{a^3} = 4.997 \times 10^{22}\,\mathrm{cm}^{-3}$ where $a = 0.543\mathrm{nm}$ (8 because the diamond cubic structure has 8 atoms per unit cell)
  - So $N_d = 4.997 \times 10^{13}\,\mathrm{cm}^{-3}$
  - Using $\mu_e = 1350\mathrm{cm}^2/\mathrm{V\,s}$ and $\mu_h = 450\mathrm{cm}^2 V.s$, $\sigma = 1.08 \times 10^{-2}\,\Omega^{-1}\mathrm{cm}^{-1}$