Week 12 Semiconductor Conductivity Announcements

Intrinsic Carrier Concentration as a Function of Temperature

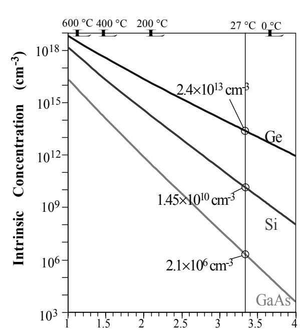

Fig. 5.16: The temperature dependence of the intrinsic concentration.

*Used with permission from Kasap

Ionization of Dopants

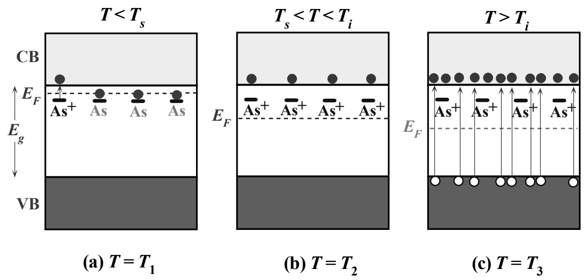

Fig. 5.14: (a) Below T_s, the electron concentration is controlled by the ionization of the donors. (b) Between T_s and T_i, the electron concentration is equal to the concentration of donors since they would all have ionized. (c) At high temperatures, thermally generated electrons from the VB exceed the number of electrons from ionized donors and the semiconductor behaves as if intrinsic.

*Used with permission from Kasap

Ionized Dopant Concentration

- If they aren't all ionized (low temperatures): need to calculate how many are ionized

$$n = \left(\frac{1}{2} N_C N_D\right)^{1/2} \exp\left(-\frac{\Delta E}{2kT}\right)$$

$$p = \left(\frac{1}{4} N_V N_A\right)^{1/2} \exp\left(-\frac{\Delta E}{2kT}\right)$$

- ΔE is the binding energy of the dopant

Temperature Dependence of Carrier Concentration

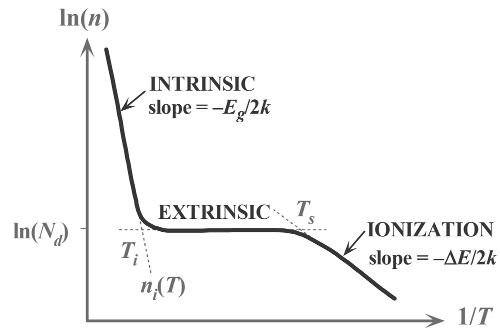

Fig. 5.15: The temperature dependence of the electron concentration in an n-type semiconductor.

*Used with permission from Kasap

Temperature Dependence of Dopant Concentration

- Low temperatures ($T<T_s$)
- Mid temperatures ($T_s<T<T_i$)
- High temperatures ($T>T_i$)

Temperature Dependence of Mobility

- Mobility also changes with temperature (which affects conductivity)
- Scattering as a function of temperature
  - Scattering increases due to increased thermal vibrations (same as metals)
- Scattering as a function of ionized impurities
  - How did impurities affect the conductivity of metals?
    - » Impurities (and other defects) acts as scattering sites for electrons because they disrupt the lattice
    - » Semiconductors have this affect: but the amount of impurity is minimal (in terms of lattice distortion and such)
  - Also have Coulombic scattering from ionized dopants

Scattering from Lattice Vibrations

$$\tau_L = \frac{1}{S v_{th} N_s} \propto \frac{1}{(T)T^{1/2}} \propto T^{-3/2}$$

Scattering from Ionized Dopants

- As electrons pass ionized dopants they are attracted by Coulomb's Force (if the KE energy of the electron is less than this Coulombic PE)
  – get a critical radius (distance from ion that the electrons will be scattered) r_c

Critical Radius of Ionized Scattering

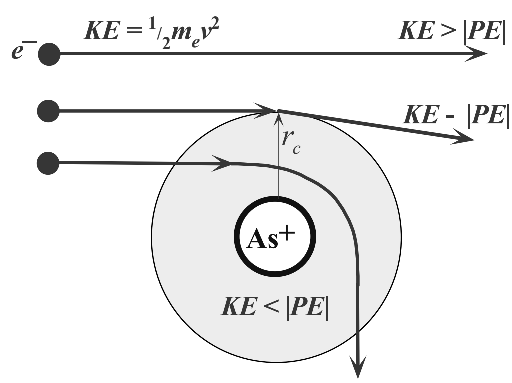

Fig. 5.17: Scattering of electrons by an ionized impurity

*Used with permission from Kasap

Scattering from Ionized Dopants

$$\frac{3}{2}kT = PE = \frac{e^2}{4\pi\varepsilon_o\varepsilon_r r_c}$$

$$r_c = \frac{e^2}{6\pi\varepsilon_o\varepsilon_r kT}$$

$$S = \pi r_c^2 = \frac{\pi e^4}{(6\pi\varepsilon_o\varepsilon_r kT)^2} \propto T^{-2}$$

Mathiessen's Rule

Temperature Dependence of Semiconductor Mobility

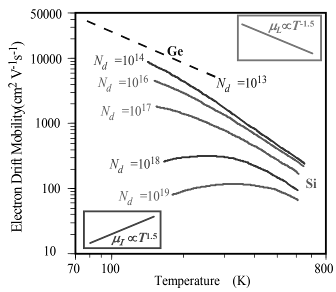

Fig. 5.18: Log-log plot of drift mobility vs temperature for *n*-type Ge and n-type Si samples. Various donor concentrations for Si are shown. N_d are in cm^{-3}. The upper right inset is the simple theory for lattice limited mobility whereas the lower left inset is the simple theory for impurity scattering limited mobility.

From *Principles of Electronic Materials and Devices, Second Edition*, S.O. Kasap (© McGraw-Hill, 2002)
http://Materials.Usask.Ca

*Used with permission from Kasap

Concentration Dependence of Semiconductor Mobility

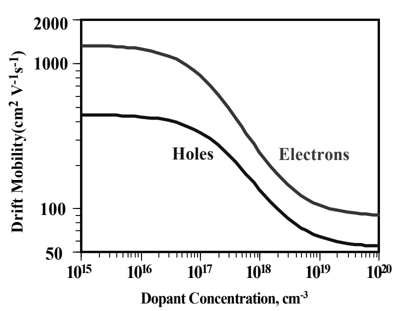

Fig. 5.19: The variation of the drift mobility with dopant concentration in Si for electrons and holes

From *Principles of Electronic Materials and Devices, Second Edition*, S.O. Kasap (© McGraw-Hill, 2002)
http://Materials.Usask.Ca

*Used with permission from Kasap

Temperature Dependence of Semiconductor Conductivity

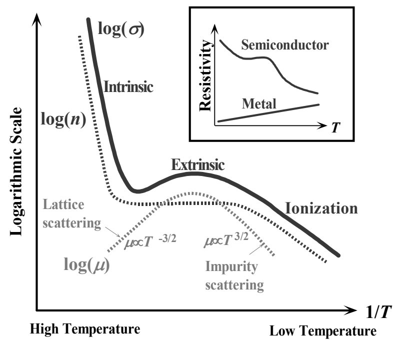

Fig. 5.20: Temperature dependence of electrical conductivity for a doped (*n*-type) semiconductor.

From *Principles of Electronic Materials and Devices, Second Edition*, S.O. Kasap (© McGraw-Hill, 2002) http://Materials.Usask.Ca

*Used with permission from Kasap

Temperature Dependence

- To understand temperature effect on semiconductor σ we need to combine the influence of free electron density (n) and mobility (μ)
- In the regions where n increases
- Where n is constant (mid temp region where dopants are saturated but intrinsic carriers are minimal)