Semiconductors, Junctions, and MOSFET Overview

Semiconductors

Introduction

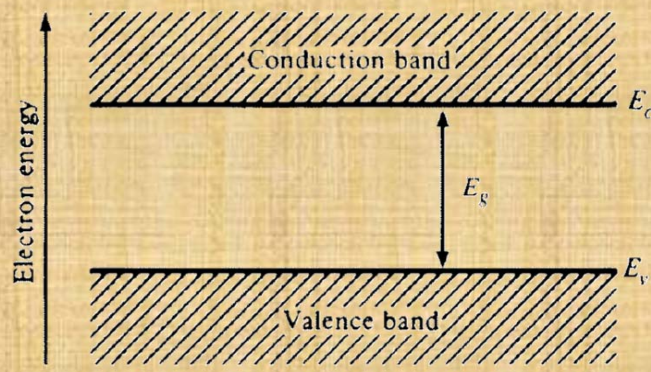
- Introducing semiconductors
- Evaluation of mobile carrier concentration
- Considering the mechanisms of current transport
- Contacts between different materials and the electrostatic potentials established in such contacts
- pn contact (junction)
- Overview of MOS transistor

Semiconductors

- Intrinsic Semiconductors, Free Electrons, and Holes
  - Equilibrium
  - Pure Silicon
    - Lattice constant: 0.5 nm
    - Crystal lattice and contains approximately 5 x 1022 atoms/cm3
    - Bohr Model, Free Electron and effect of Temperature
    - Hole concept – Valance electron movement
    - Carrying Charge mechanism
      - The motion of free electrons about the lattice
      - The motion of valance electrons from bond to bond corresponding to a motion of “ vacancies” or holes
    - Charge neutrality
    - Recombination

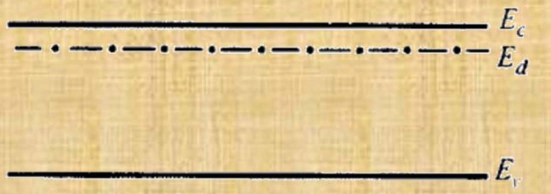
Semiconductors…

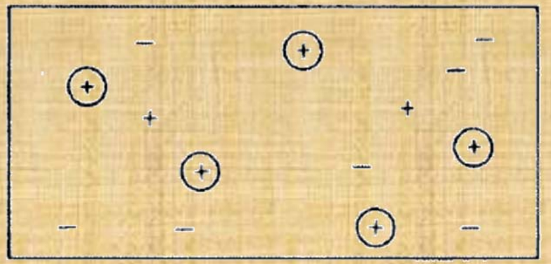
- Energy Bands
  - Band gap energy E_g
  - Conduction energy
  - Valance energy
  - Insulator and Conductor band gap energy
  - Charge neutrality $n_i = p_i$
  - Free carrier concentration temperature and material dependency



Semiconductors…

- Extrinsic Semiconductors
  - Impurities and doping
  - Donor and acceptor atoms
  - Introducing E_d and E_a
  - $N_o \times P_o = ni^2$
  - Donor Atoms (N_d): phosphorus, arsenic, and antimony
  - Acceptor Atoms (N_a): boron, gallium, and indium
  - Temperature effect on donor/Acceptor atoms
  - Carrier concentration
  - Majority and Minority Carriers
  - Degeneracy
  - N type and P type Semiconductors





Semiconductors

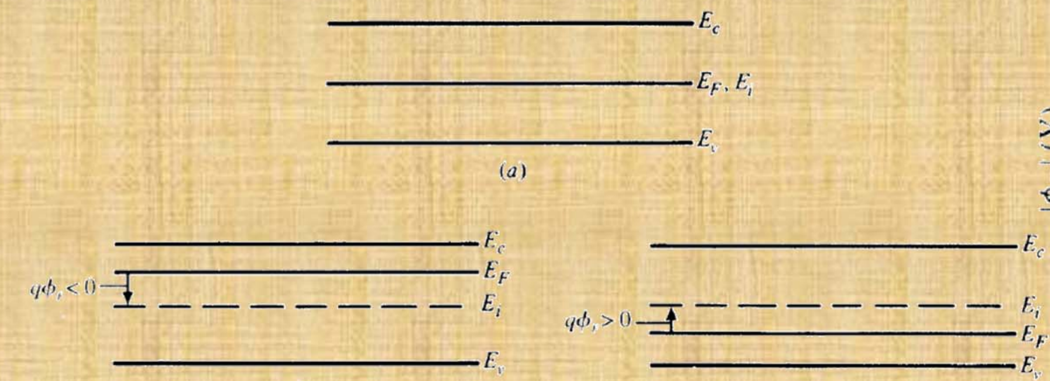
- Equilibrium in the Absence of Electric Field
  - General Carrier densities

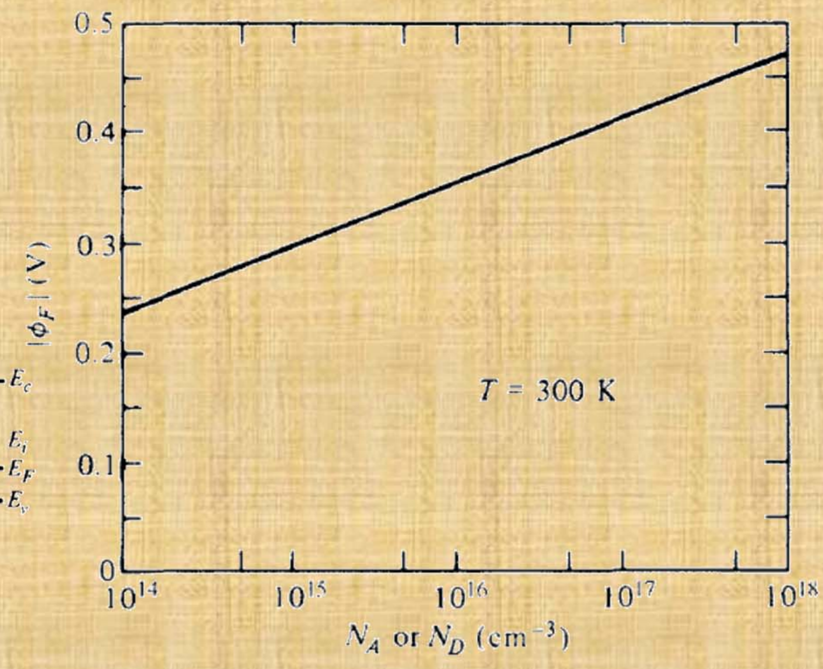
$$p_0 = n_i e^{(E_i - E_f)/kT}$$
$$n_0 = n_i e^{(E_f - E_i)/kT}$$

  - Fermi and Intrinsic Energies definitions
  - Φ_f and Φ_T definition

$$\phi_f = \frac{E_i - E_f}{q}$$
$$\phi_T = \frac{kT}{q}$$

Semiconductors…





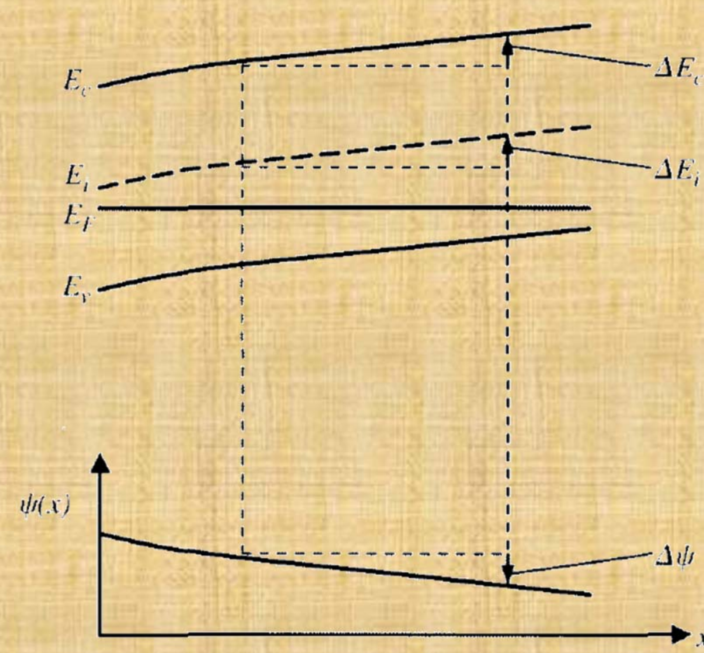
Semiconductors…

- Equilibrium in the Presence of Electric Field
  - Within electric field – 2 contact MOS
  - Charge neutrality – n, p product remain n_i^2

$$p = n_i e^{(E_i - E_f)/kT}$$
$$n = n_i e^{(E_f - E_i)/kT}$$

  - Zero current flow
  - Electrostatic potential

$$\psi(x) = E_i\,(x)/-q$$



Semiconductors…

- Electrostatic potential deference effects

$$\frac{n_1}{n_2} = \exp\left(\frac{\psi_{12}}{\phi_T}\right)$$

$$\frac{p_1}{p_2} = \exp(\frac{\psi_{12}}{\phi_T})$$

- Important result

$$n_1 p_1 = n_2 p_2$$

Semiconductors…

- Nonequilibrium; Quasi-Fermi Levels
  - Energy exchange between the semiconductor and the external world – Like using battery
  - Fermi level is not constant -- imref
  - Charge neutrality – space charge (Depletion region)

$$p = n_i e^{(E_i - E_{fp})/kT}$$
$$n = n_i e^{(E_{fn} - E_i)/kT}$$

  - In equilibrium $E_{fn}=E_{fp}=E_f$ and $np=ni^2$

Semiconductors…

- Relations between Charge Density, Electric Field, and Potential; Poisson's Equation
  - charge density (charge concentration per unit volume)
    1. holes, which contribute a charge density of $(+q)p$
    2. free electrons, with contribution $(-q)n$
    3. ionized donor atoms, with contribution $(+q)N_D$ (!)
    4. Ionized acceptor atoms, with contribution $(-q)N_A$ (!)
- *Total charge density* : $\rho = q(p - n + N_D - N_A)$

Semiconductors…

- Charge density…
  - Regularly N_A=0 or N_D=0
  - In fab. Process both present, why?
  - Charge neutrality
  - Locally natural region : $p_0 - n_0 = -(N_D - N_A), p_0 n_0 = {n_i}^2$
- Gauss Law

$$\frac{dE(x)}{dx} = \frac{\rho}{\varepsilon_S}$$

  - In the presence of electric fields, the charge density ρ can vary from point to point, why?

Semiconductors…

- Gauss law… .
  - By integrating both sides of Gauss Eq. from an arbitrary point y_0 to a point y, we obtain

$$E(y) = E(y_0) + \frac{1}{\varepsilon_s}\int_{y_0}^{y} \rho(y')dy'$$

  - We can do this for both the *pn* junction and the MOS structure

- Poisson equation
  - Electric Field and Potential relationship

$$E(x) = -\frac{d\psi}{dx}$$

$$\psi(y) = \psi(y_0) - \int_{y_0}^{y} E(y')dy'$$

$$\frac{d^2\psi(x)}{dx^2} = -\frac{\rho(y)}{\varepsilon_s}$$