Fundamentals of Semiconductors

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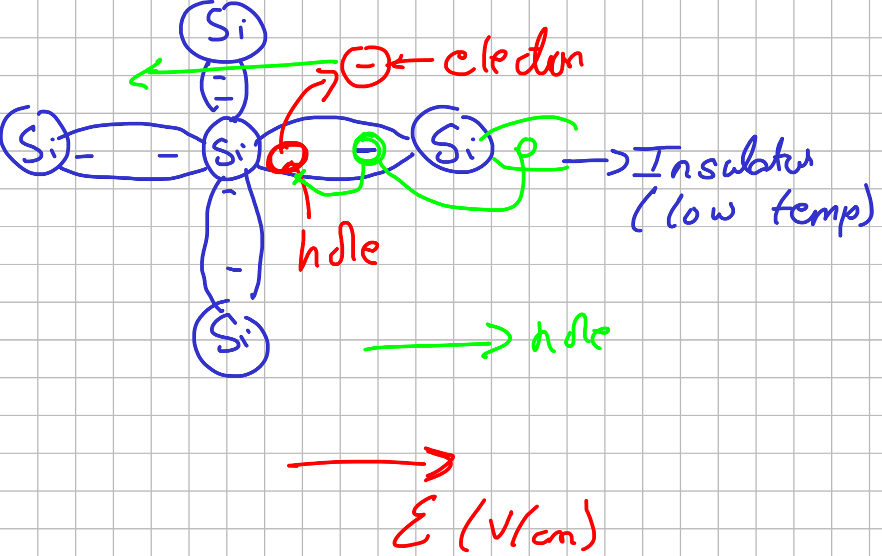
Report

1. Main Document
   - Title and your roll number
   - Aim
   - Procedure
     - How was the experiment performed
     - Figures
   - Results and Discussion
     - Quantitative results, tables and graphs
     - Understanding (a good writer not only knows where to start but also where to end)
   - Conclusion
2. Scripts

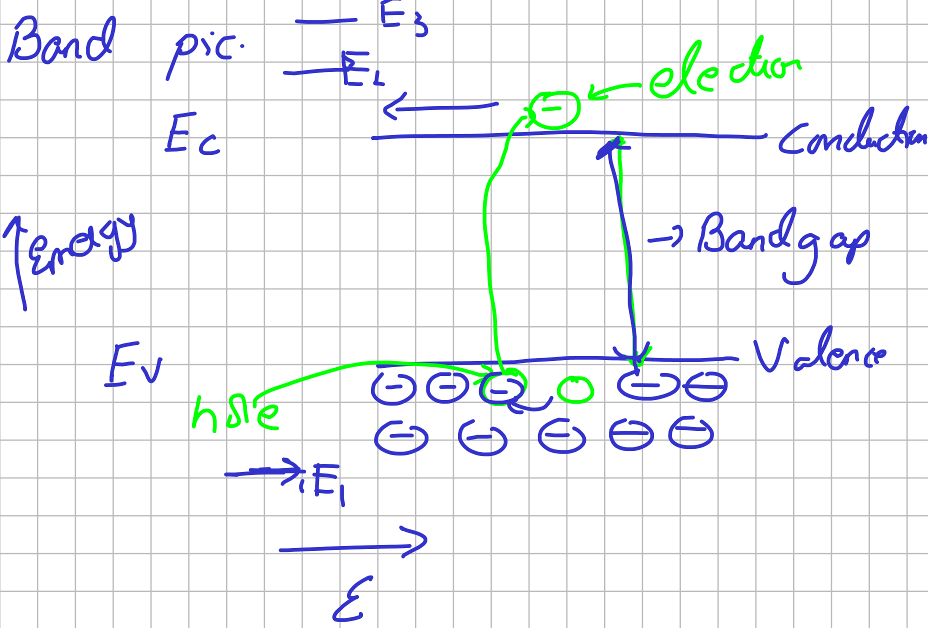
Material
- → Metals $\sigma > 10^4/\Omega cm$
- → Semiconductor
- → Insulators $\sigma < 10^{-10}/\Omega cm$

Semiconductors
- → Elemental
  - → Si, Ge, α-Sn
- → Compound, InAs, GaAs . . .



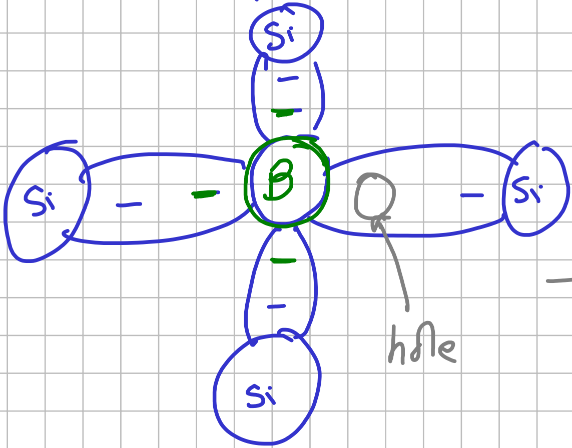
Bond Picture.

Band pic.



E3
E2
Ec
electron
Conduction
Energy
Bandgap
Ev
Valence
hole
E1
ℰ

Doping : Process of adding foreign atoms to the intrinsic crystal



— p-type

P-type - excess of hole.

n-type - excess of electrons

Classification based on doping

└→ intrinsic

→ p-type (eg Boron)

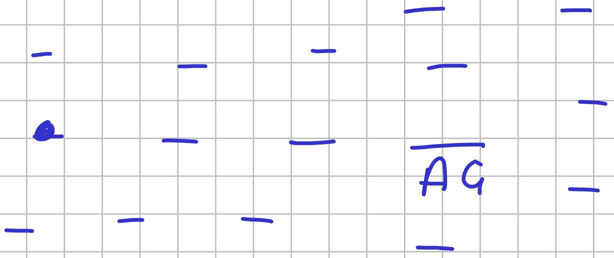
- n-type (eg P)

$$f(E) = \frac{1}{1+\exp\left[\frac{E-E_F}{k_B T}\right]}$$

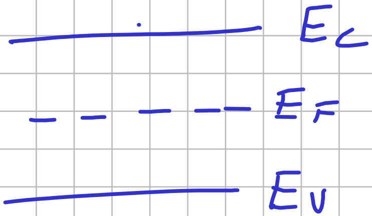
– Fermi-Dirac Statistics

$1 - f(E) \longrightarrow$ probability of occupation by a hole

$$n(E) = f(E)\,\underline{\underline{DoS}}(E)$$



$$f(E_F) = 1/2$$



$$\underbrace{n(E)}_{/cm^3 J} = DOS(E)\, f(E)$$

$$n = \int n(E)\, dE = \int D(E)\, f(E)\, dE$$

$$= N_c \exp\left[-\frac{E_c - E_F}{k_B T}\right]$$

$$p = \int p(E)\, dE = \int D(E)\,(1 - f(E))\, dE$$

$$p = N_V \exp\left[-\frac{E_F - E_V}{k_B T}\right]$$

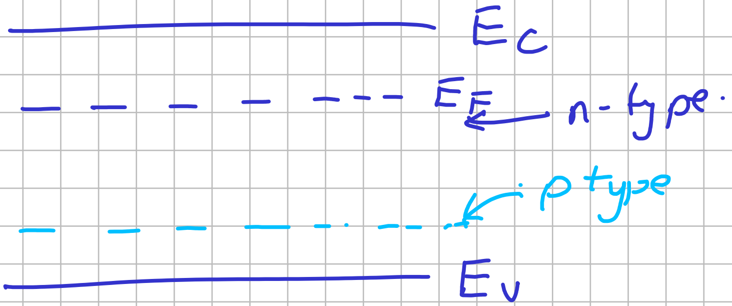
$$N_D = N_C \exp\left[-\frac{E_C - E_F}{k_B T}\right]$$

$$\frac{E_C - E_F}{k_B T} = -\ln\left[\frac{N_D}{N_C}\right]$$

$$E_C = 0$$

$$\frac{E_F - E_V}{k_B T} = -\ln\left[\frac{N_A}{N_V}\right]$$

$E_V = 0$



$$n_i^2 = np$$

$$n_i = 2\left(\frac{m^* k_B T}{2\pi\hbar^2}\right)^{3/2} \exp\left[\frac{-E_g}{2k_BT}\right]$$

$$Si = 1.1\,eV$$

$$m^* = m_0 = 9.1\times10^{-31}\,kg$$

$$\underbrace{n_i \geqslant N_D}_{\text{electron}} \quad ; \quad \underbrace{n_i \geqslant N_A}_{\text{holes}}$$

$N_D \quad 10^{18}\ cm^{-3}$

\# of electrons $= 10^{18}\ cm^{-3}$

$$n_i = C \exp\left[\frac{-E_G}{2k_BT}\right]$$

$n_i \geq N_D$

$n_i \geq N_A$

Semiconductors

- Types of semiconductors on the basis of doping
  - Intrinsic semiconductor
  - n-type – Group V elements
  - p-type – Group III elements
- The probability of an electron to occupy a particular energy level is given by Fermi-Dirac statistics

$$f(E) = \frac{1}{1 + exp\left(\frac{E - E_F}{k_B T}\right)}$$

- Thus the probability of absence of electron (hole) is given by $1 - f(E)$
- The Density of States (density of the allowed energy levels) is given by

$$D(E) = \frac{1}{2\pi^2}\left(\frac{2m^*}{\hbar^2}\right)^{1.5} E^{0.5}$$

- The intrinsic carrier density is given by

$$n_i = 2\left(\frac{m^* k_B T}{2\pi\hbar^2}\right)^{1.5} e^{-\frac{E_G}{2k_B T}}$$

- Electron/Hole density as a function of energy

$$n(E) = D(E)f(E)$$

- Assume that the effective mass is the same as free electron mass
- **Make sure that your units match**

Primer on Octave

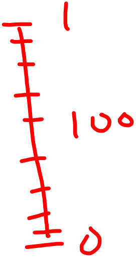
- Cleaning up
  - *clc*; *clear*; *close*;
- Assignment statement

$$a = 300;$$

- Mathematical operation § between 2 variables a, b

$$a\S b$$
$$a.\S b$$

- Plotting
  - $figure(1)\ plot(x, y, 'linewidth', 2); hold\ \ on$
  - $semilogx(x, y, 'linewidth', 2)$
  - $axis([xminxmaxyminymax])$
  - $xlabel(''Temperature(K)'')$
  - $ylabel(''Carrierconcentration(cm^{-3})'')$
  - $set(gca, ''linewidth'', 2, ''fontsize'', 24)$



$$f = \frac{1}{1+\exp\left[\frac{E-E_F}{k_BT}\right]}$$

$$\approx \exp\left[\frac{E_F-E}{k_BT}\right]$$

Problems

1. How does the occupation probability (Fermi-Dirac Statistics and Maxwell Boltzmann statistics) as a function of the energy and temperature ? Under what circumstances does the Fermi-Dirac statistics reduce to Maxwell-Boltzmann statistics
2. How the carrier density varies with respect to the energy ?
   - Group 1: p-type
   - Group 2: n-type
3. How does the intrinsic carrier concentration changes with respect to the temperature ? Assume effective density of states for conduction and valence band to be 2.8E19 cm^3 and 1.8E19cm^3. Assume doping to be 1E17 cm^3 and comment on the nature of semiconductor. Plot n_i on a semilog scale versus (1000/T)
   - Group 1: p-type
   - Group 2: n-type

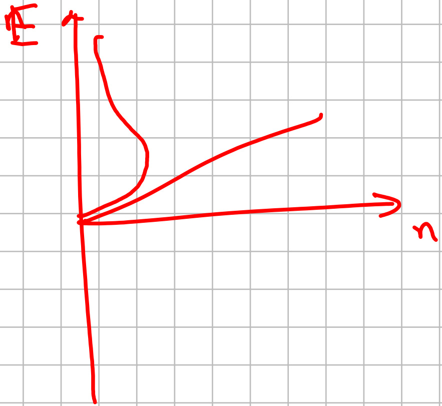
   Comment on the type of semiconducto
4. ~~Calculate and plot the position of the Fermi Level as a function of Temperature~~
   - ~~Group 1: p-type~~
   - ~~Group 2: n-type~~

→ 2 page of theory
↳ Understanding

→ 1 page graphs

→ Scripts

.zip



$$n_i = C \exp\left[\frac{-E_g}{2k_BT}\right]$$