Alexandria University
Faculty of Engineering
Electrical Engineering Department
Mid-term Exam, November 2014

جامعة الإسكندرية
كلية الهندسة
قسم الهندسة الكهربية
امتحان نصف الفصل الدراسي الثاني (نوفمبر ٢٠١٤)

Course Title and Code Number:
Semiconductor Devices (EE336)
Third Year (Communications and Electronics)
Time Allowed: 45 Mins

اسم المقرر والرقم الكودي له:
النبائط شبه الموصلة (EE336)
السنة الدراسية الثالثة (اتصالات و الكترونيات)
الزمن: ٤٥ دقيقة

Attempt All Questions: **(15 marks)**

Question 1: **(4 marks)**

For a non-degenerate semiconductor material:

a) Derive an expression of the energy levels at which the carrier distribution is maximum in both valence and conduction bands.

b) Expressed as a fraction of the electron population at the peak energy, what is the electron population in a non-degenerate semiconductor at $E = E_C + 5KT$.

c) Explain how changing the impurity concentration of n- and p-type extrinsic materials would change the energy levels at which the carrier distribution is maximum in both valence and conduction bands.

Question 2: **(4 marks)**

A non-degenerate n-type silicon semiconductor sample has $E_c - E_f = 4KT$ at room temperature.

a) Calculate the donor concentration N_D and the material resistivity.

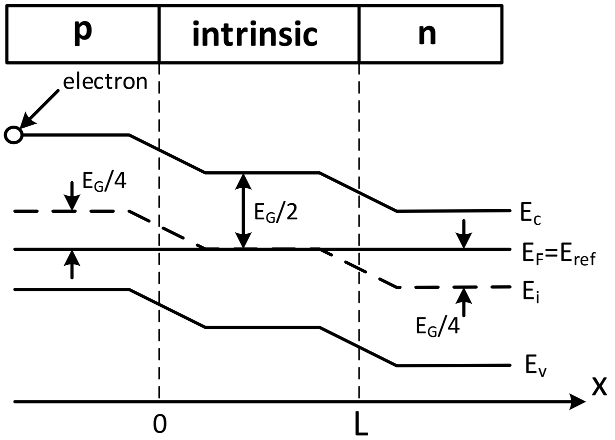
b) To make this sample become degenerate, the temperature or dopant concentration must be changed:

   i. Calculate the required donor concentration N_D at room temperature.

   ii. Calculate the required temperature assuming that N_D calculated in (a) is fixed.

Question 3: **(7 marks)**

For the Silicon sample with the band diagram shown in Figure, answer the following questions:



a) Sketch the electrostatic potential (V) inside the semiconductor as a function of x

b) Sketch the electric field (E) inside the semiconductor as a function of x.

c) Roughly sketch carrier concentrations n and p versus x inside the sample.

d) This structure is called pin diode. Using the depletion layer approximation, calculate the depletion region widths and the built-in potentials of the diode at room temperature.

Good Luck

*Examiner: **Dr. Mohammed Morsy***

Key Equations, Constants, and Curves

Table 2.4 Carrier Modeling Equation Summary.

Density of States and Fermi Function

$$g_c(E) = \frac{m_n^*\sqrt{2m_n^*(E - E_c)}}{\pi^2\hbar^3}, \quad E \geq E_c$$

$$g_v(E) = \frac{m_p^*\sqrt{2m_p^*(E_v - E)}}{\pi^2\hbar^3}, \quad E \leq E_v$$

$$f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$$

Carrier Concentration Relationships

$$n = N_C \frac{2}{\sqrt{\pi}} F_{1/2}(\eta_c) \qquad N_C = 2\left[\frac{m_n^* kT}{2\pi\hbar^2}\right]^{3/2}$$

$$p = N_V \frac{2}{\sqrt{\pi}} F_{1/2}(\eta_v) \qquad N_V = 2\left[\frac{m_p^* kT}{2\pi\hbar^2}\right]^{3/2}$$

$$n = N_C e^{(E_F - E_c)/kT}$$

$$p = N_V e^{(E_v - E_F)/kT}$$

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

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

n_i, np-Product, and Charge Neutrality

$$n_i = \sqrt{N_C N_V}\, e^{-E_G/2kT} \qquad np = n_i^2 \qquad p - n + N_D - N_A = 0$$

n, p, and Fermi Level Computational Relationships

$$n = \frac{N_D - N_A}{2} + \left[\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2\right]^{1/2} \qquad E_i = \frac{E_c + E_v}{2} + \frac{3}{4}kT\ln\left(\frac{m_p^*}{m_n^*}\right)$$

$$\left.\begin{array}{l} n \simeq N_D \\ p \simeq n_i^2/N_D \end{array}\right\} N_D \gg N_A,\ N_D \gg n_i \qquad E_F - E_i = kT\ln(n/n_i) = -kT\ln(p/n_i)$$

$$\left.\begin{array}{l} p \simeq N_A \\ n \simeq n_i^2/N_A \end{array}\right\} N_A \gg N_D,\ N_A \gg n_i$$

$$E_F - E_i = kT\ln(N_D/n_i) \quad N_D \gg N_A,\ N_D \gg n_i$$

$$E_i - E_F = kT\ln(N_A/n_i) \quad N_A \gg N_D,\ N_A \gg n_i$$

Table 3.3 Carrier Action Equation Summary.

Equations of State

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla \cdot \mathbf{J}_N + \left.\frac{\partial n}{\partial t}\right|_{\substack{\text{thermal}\\ \text{R–G}}} + \left.\frac{\partial n}{\partial t}\right|_{\substack{\text{other}\\ \text{processes}}} \qquad \frac{\partial \Delta n_p}{\partial t} = D_N\frac{\partial^2 \Delta n_p}{\partial x^2} - \frac{\Delta n_p}{\tau_n} + G_L$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla \cdot \mathbf{J}_P + \left.\frac{\partial p}{\partial t}\right|_{\substack{\text{thermal}\\ \text{R–G}}} + \left.\frac{\partial p}{\partial t}\right|_{\substack{\text{other}\\ \text{processes}}} \qquad \frac{\partial \Delta p_n}{\partial t} = D_P\frac{\partial^2 \Delta p_n}{\partial x^2} - \frac{\Delta p_n}{\tau_p} + G_L$$

Current and R–G Relationships

$$\mathbf{J}_N = \mathbf{J}_{N|\text{drift}} + \mathbf{J}_{N|\text{diff}} = q\mu_n n\mathscr{E} + qD_N\nabla n \qquad \left.\frac{\partial n}{\partial t}\right|_{\substack{\text{i-thermal}\\ \text{R–G}}} = -\frac{\Delta n}{\tau_n}$$

$$\Updownarrow \text{ drift} \qquad \Updownarrow \text{ diffusion}$$

$$\mathbf{J}_P = \mathbf{J}_{P|\text{drift}} + \mathbf{J}_{P|\text{diff}} = q\mu_p p\mathscr{E} - qD_P\nabla p \qquad \left.\frac{\partial p}{\partial t}\right|_{\substack{\text{i-thermal}\\ \text{R–G}}} = -\frac{\Delta p}{\tau_p}$$

$$\mathbf{J} = \mathbf{J}_N + \mathbf{J}_P$$

Key Parametric Relationships

$$L_N \equiv \sqrt{D_N\tau_n} \qquad \frac{D_N}{\mu_n} = \frac{kT}{q} \qquad \tau_n = \frac{1}{c_n N_T}$$

$$L_P \equiv \sqrt{D_P\tau_p} \qquad \frac{D_P}{\mu_p} = \frac{kT}{q} \qquad \tau_p = \frac{1}{c_p N_T}$$

Resistivity and Electrostatic Relationships

$$\rho = \frac{1}{q(\mu_n n + \mu_p p)}$$

$$\rho = \frac{1}{q\mu_n N_D} \quad \text{. . . } n\text{-type semiconductor}$$

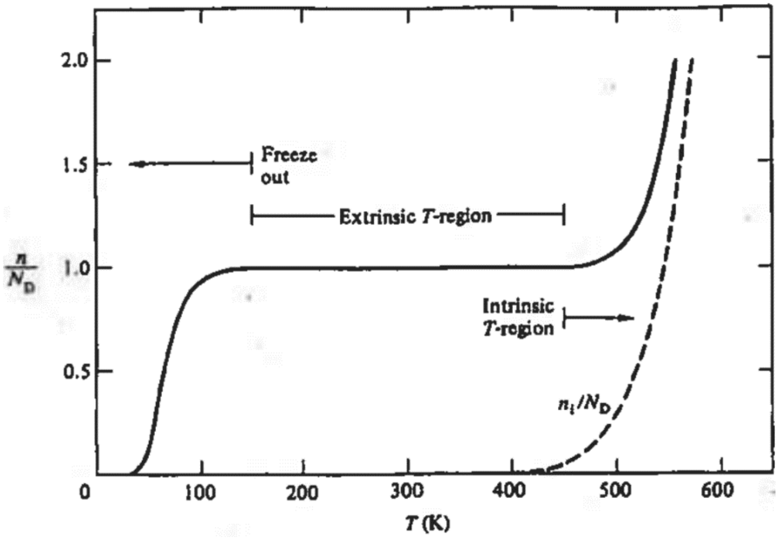
$$\rho = \frac{1}{q\mu_p N_A} \quad \text{. . . } p\text{-type semiconductor}$$

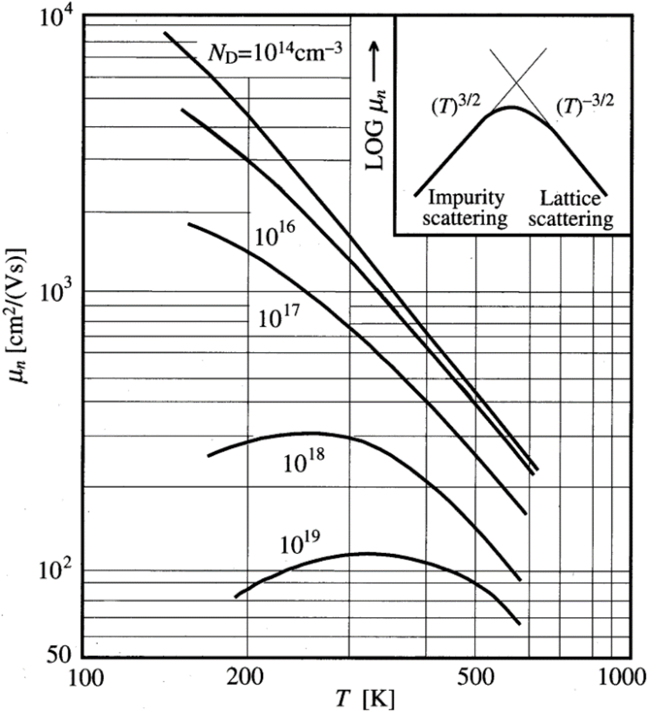
$$\mathscr{E} = \frac{1}{q}\frac{dE_c}{dx} = \frac{1}{q}\frac{dE_v}{dx} = \frac{1}{q}\frac{dE_i}{dx} \qquad V = -\frac{1}{q}(E_c - E_{\text{ref}})$$

Quasi-Fermi Level Relationships

$$F_N \equiv E_i + kT\ln\left(\frac{n}{n_i}\right) \qquad \mathbf{J}_N = \mu_n n\nabla F_N$$

$$F_P \equiv E_i - kT\ln\left(\frac{p}{n_i}\right) \qquad \mathbf{J}_P = \mu_p p\nabla F_P$$





- Electronic charge, $q = 1.6\times10^{-19}$ C
- Permittivity of free space, $\varepsilon_o = 8.854\times10^{-12}$ F/m
- Boltzmann constant, $k = 8.62\times10^{-5}$ eV/K
- Planck constant, $h = 4.14\times10^{-15}$ eV·s, $\hbar = h/2\pi$
- Free electron mass, $m_o = m_n^* = m_p^* = 9.1\times10^{-31}$ kg
- Thermal energy, $kT = 0.02586$ eV (at 300 K)
- Thermal voltage, $kT/q = 0.02586$ V (at 300 K)
- Silicon energy band gap, $E_G = 1.12eV$
- Intrinsic Si carrier concentration $n_i = 1\times10^{10}$ cm^{-3} (at 300 K)