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: **PART II** **(15 marks)**

Question 1: **(8 marks)**

The Maxwell–Boltzmann distribution function $f(E) = e^{-(E-E_f)/kT}$ is often used as an approximation to the Fermi–Dirac function. Use this approximation and the densities of the states in the conduction band $D_c(E) = A(E - E_c)^{1/2}$ to find:

a) The energy at which one finds the most electrons (1/cm³ · eV).
b) The conduction-band electron concentration (explain any approximation made).
c) The ratio of the peak electron concentration at the energy of (a) to the electron concentration at $E = E_c + 40kT$ (about 1eV above E_c at 300 K). Does this result justify one of the approximations in part(b)?
d) The average kinetic energy, $E - E_c$ of the electrons. Hint: These relationships may be useful:

$$\int_0^\infty x^{n-1} e^{-x} dx = \Gamma(n) \qquad \text{(Gamma function)}$$

$$\Gamma(2) = \Gamma(1) = 1, \Gamma(3) = 2, \Gamma(4) = 6$$

$$\Gamma(1/2) = \sqrt{\pi},\ \Gamma(3/2) = 1/2\sqrt{\pi},\ \Gamma(5/2) = 3/4\sqrt{\pi}.$$

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 becomes degenerate (heavily doped), either 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: **(3 marks)**

A general relationship for the current density carried by electrons of density *n* is $J = qnv$, here *q* is the electron charge and *v* is the electron velocity.

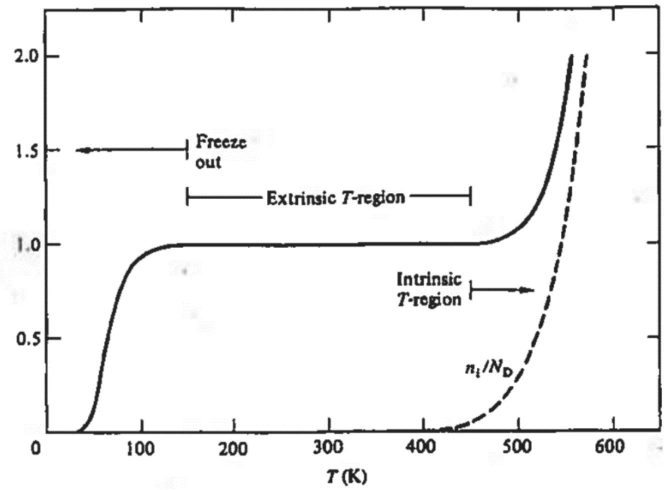
a) Find the velocity of electrons, *v(x)*, that are moving only by diffusion if they have a density distribution of $n(x) = n_0 e^{-x/\lambda}$. The electric field is zero.
b) What would be the electric field, $\mathcal{E}(x)$, that would lead to an electron drift velocity equal to that of the diffusion velocity in part (a)?
c) At 300 K, what value of λ would make the field in part (b) to be 1000 V/cm?

Good Luck

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

Key Equations, Constants, and Curves

- Electronic charge, q = 1.6×10^{-19} C
- Permittivity of free space, ε_o = 8.854×10^{-12} F/m
- Boltzmann constant, k = 8.62×10^{-5} eV/K
- Planck constant, h = 4.14×10^{-15} eV·s, $\hbar = h/2\pi$
- Free electron mass, $m_o = m_n^* = m_p^*$=9.1×10^{-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=1×10^{10} cm^{-3} (at 300 K)



Density of states and Fermi function:

$$D_c(E) \equiv \frac{8\pi m_n \sqrt{2m_n(E-E_c)}}{h^3}$$

$$D_v(E) \equiv \frac{8\pi m_p \sqrt{2m_p(E_v-E)}}{h^3}$$

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

Carrier Concentration Relationships:

$$n = N_c e^{-(E_c-E_f)/kT} \quad , \quad N_c \equiv 2\left[\frac{2\pi m_n kT}{h^2}\right]^{3/2}$$

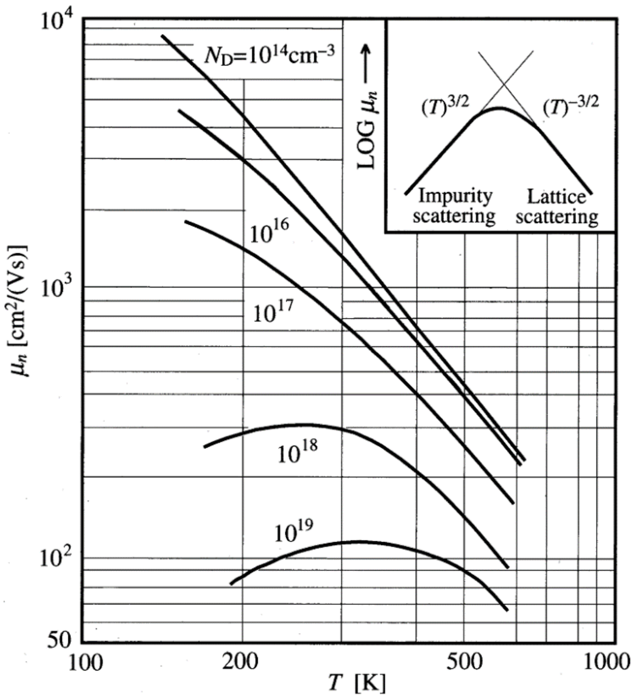
$$p = N_v e^{-(E_f-E_v)/kT} \quad , \quad N_v \equiv 2\left[\frac{2\pi m_p kT}{h^2}\right]^{3/2}$$

n_i, np product and carrier neutrality:

$$np = n_i^2 \qquad n_i = \sqrt{N_c N_v}\, e^{-E_g/2kT}$$

$$n + N_a = p + N_d$$

$$E_F = E_i + kT \ln\left(\frac{n}{n_i}\right) \quad , \quad E_F = E_i - kT \ln\left(\frac{p}{n_i}\right)$$



Mobility, Conductivity, and Diffusion:

$$v = \mu_p \varepsilon \qquad v = -\mu_n \varepsilon$$

$$\mu_p = \frac{q\tau_{mp}}{m_p} \qquad \mu_n = \frac{q\tau_{mn}}{m_n}$$

$$\sigma = qn\mu_n + qp\mu_p$$

$$D_n = \frac{kT}{q}\mu_n \qquad D_p = \frac{kT}{q}\mu_p$$

$$J_n = J_{n,drift} + J_{n,diffusion} = qn\mu_n\,\varepsilon + qD_n\frac{dn}{dx}$$

$$J_p = J_{p,drift} + J_{p,diffusion} = qp\mu_p\,\varepsilon - qD_p\frac{dp}{dx}$$