ELEG 340 - Fall 08  
Solid-State Electronics  
Quiz 1  

25 September 2008  

NAME  

Solution  

Time Limit: 30 minutes  
Closed Books and Notes. You may use your own calculator, but you may not loan or borrow calculators (ask proctor if you have questions). Put expression in a final form as best you can, and indicate final units (dimensions).

Guidelines:  
I. Full credit requires giving the final dimensions/units for all numerical quantities that you calculate.  
II. Show all work and calculations for full credit.  
III. Accuracy to 2 significant figures is sufficient.  
IV. Assume that the material is silicon at room temperature (300 K or 296 K), unless otherwise stated.  
V. At room temperature (300K), assume that the thermal energy $k_B T = 0.0258 \text{ eV}$ (or $0.026 \text{ eV}$), and that silicon has intrinsic concentration $n_i = 1 \text{ (or 1.5)} \times 10^{10} \text{ cm}^{-3}$.  

Note permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-14} \text{ F/cm}$; magnitude of electron charge $q = 1.6 \times 10^{-19} \text{ Coul}$  

VI. Equations:  
$$\rho_p = i_h d/dx$$  
$$f_{FD}(E) = 1/[1 + \exp(E-E_f)/k_B T]$$  
$$n = n_i \exp[(E_F-E_i)/k_B T].$$  
$$p = n_i \exp[(E_F-E_f)/k_B T]$$  
$$J_n = q \mu_n n \varepsilon + q D_n d n/dx$$  
$$J_p = q \mu_p p \varepsilon - q D_p d p/dx$$  
$$U_n = (n_p - n_{po})/\tau_n$$  
$$U_p = (p_n - p_{po})/\tau_p$$  
$$C = \varepsilon_0 /W$$  
$$E = Q /V$$  

One-sided step junction:  
$$W = [2\kappa_\varepsilon \varepsilon_0 (\phi_{bi} - V_B)/q N_A]^{1/2} \ \text{ or; } \ \ W = [2\kappa_\varepsilon \varepsilon_0 (\phi_{bi} - V_B)/q N_D]^{1/2}$$  

pnp transistors: $I_E = I_C + I_B$  

$I_{PE} = A_B q^2 n_i^2 D_p/Q_{B0} \exp((q V_B E)/k_B T)$  

$Q_{B0} = q \int_0^{WB} N_D(x) dx$
1. On the x-y-z axes below, draw and indicate the following crystal directions for a cubic crystal with unit vectors \( \mathbf{a}, \mathbf{b}, \mathbf{c} \) that are equal in length:

(a) \([111]\)

(b) \([011]\)

2. Multiple choice (circle your answers): Silicon has the following crystal properties: (a) hexagonal structure; (b) face-centered cubic structure with a 2 atom basis; (c) amorphous, non-crystalline structure.

3. Consider the following drawing of a 1-dimensional quantum well, of width, 2\(a\), on the order of an electron wavelength. (a) Indicate qualitatively the energy of the ground state for an electron that is confined to the well; (b) sketch the magnitude and shape of the electron wave function in the ground state.

\[ E = 1 \text{ eV} \]

\[ E = 0 \text{ eV} \]

\[ x = -a \quad x = a \]
4. An electron plane wave has functional dependence: \( \exp(ikx) \) in 1-dimension. What is the momentum of this wave in the \( x \) direction?

\[ p = h \frac{\hbar}{k} \]

5. An electron has a kinetic energy of 1 eV (electron volt). What is its energy in Joules?

\[ \omega = e\nu = 1.6 \times 10^{-19} \text{ Joules} \]

6. Energy bands can be either direct or indirect in \( k \)-space. On a graph of energy versus \( k \), draw a direct band configuration, and label both the valence and conduction bands.

\[ \text{CB} \quad E \quad \text{VB} \quad k_x \]
7. A piece of silicon at room temperature (300K) is doped with a concentration of $10^{17}$ cm$^{-3}$ of donor impurities. Assume that all of the donors are ionized at this temperature. (a) What is the concentration of electrons in the conduction band?

$$-n = N_0 = 10^{17} \text{ cm}^{-3}$$

8. Using the Fermi-Dirac distribution function, calculate the probability that a state at the conduction band edge $E_C$ is occupied by an electron if the energy separation is given by: $E_C - E_F = 10 \text{ k}_B T$. Hint: you may use the approximations: $e^x = 10^{0.3}$; and $10^{0.3} = 2$. Assume that $T = 300$ K if you think that you need the temperature.

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

$$= \frac{1}{1 + e^{10/2.3}} = \frac{1}{1 + e^{10}}$$

$$= \frac{1}{1 + 10^{0.23}} = 10^{-10/2.3}$$

$$= 10^{-4.3} = 10^{-5} = 5 \times 10^{-5}$$

9. Consider the following energy band diagram. Based on where the Fermi level $E_F$ is located with respect to the band edges and the intrinsic level $E_i$ which charge carrier has a greater concentration; electrons in the conduction band, or holes in the valence band?