UNIVERSITY OF SASKATCHEWAN
Department of Physics and Engineering Physics

EP 317.3 Final Examination

Instructor: Yansun Yao

April 11th, 2015 Time: 9:00 AM ~ 12:00 PM

ANSWER ALL FIVE QUESTIONS. MARKS PER EACH QUESTION ARE INDICATED.

Physical Constants:

Elementary charge:	$e = 1.602 \times 10^{-19}$ C	Avogadro's number:	$N_A = 6.022 \times 10^{23}$ mol^{-1}
Boltzmann constant:	$k = 1.381 \times 10^{-23}$ J·K^{-1}	Planck's constant:	$h = 6.626 \times 10^{-34}$ J ·s
Electron mass:	$m_e = 9.11 \times 10^{-31}$ kg		

Q1. The density of states (number of states per unit energy per unit volume) for free electrons in a metal is,

$$g(E) = (8\sqrt{2}\pi)\left(\frac{m_e}{h^2}\right)^{3/2} E^{1/2}.$$

The concentration of conduction electrons, n, is determinted by,

$$n = \int_0^{\text{Top of band}} g(E)f(E)dE\ ,\ f(E) : \text{Fermi-Dirac function,}$$

where the intergration is done over all energies in the band.

(1) Determine the relation between the Fermi energy (E_{FO}) and n at 0 K (show how you obtained your answer). (**8%**)

(2) Zinc (Zn) has two valence electrons per atom; that is, each Zn atom donates two electrons to the sea of conduction electrons. The atomic mass of Zn is 65.4 g/mol, and the density is 7140 kg/m^3. Calculate the Fermi energy of Zn at 0 K. (**8%**)

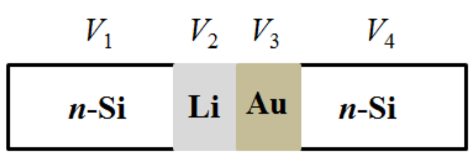
(3) Calculate the effective (rms) speed of the conduction electrons in Zn at 0 K. (**4%**)

Q2. Consider at $T = 300$ K, an n-type Si sample doped with 10^{16} donors cm^{-3}. The length L of the sample is 300 μm; the cross-sectional area A is 1.00 mm^2. The electron affinity (χ) and work function (Φ_n) for Si are 4.0 eV and 4.22 eV, respectively. Drift mobility of electrons (μ_e) in the sample is 1350 $cm^2\ V^{-1}\ s^{-1}$. For a metal to n-Si junction, effective Richardson constant B_e is 110 A $cm^{-2}\ K^{-2}$.

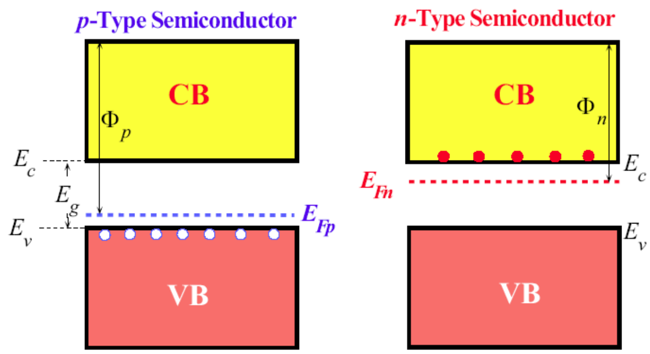
(1) Assume that this Si sample is in contact with Au and the work function (Φ_m) of Au is 5.0 eV. What is the current across the junction when there is a forward bias of 0.6 V? **(8%)**

(2) Assume that this Si sample is in contact with Li ($\Phi_m = 2.5$ eV). What is the current across the junction when there is an applied external voltage of 0.6 V? **(8%)**

(3) The two junctions described in (1) and (2) are now connected back to back under open circuit conditions as shown below. In equilibrium, the electric potential (voltage) V varies in four neutral regions. Assume that $V_1 = 0$ V, determine V_2, V_3 and V_4 (express your answers numerically in volts). **(8%)**



Q3. Consider the energy band diagram for a *p*-type and an *n*-type semiconductor of the same material before contact. The donor concentration in the *n*-type semiconductor is N_d. The acceptor concentration in the *p*-type semiconductor is N_a. The intrinsic concentration at the room temperature is n_i.



(1) At the room temperature, what are the majority **and** minority carrier concentrations in each semiconductor? **(8%)**

(2) Once these two semiconductors are in contact, a built-in voltage V_o will present across the junction, going from *p*-side to *n*-side. Use the expressions of electron concentration (n) in CB and hole concentration (p) in VB,

$$n = N_c \exp(-\frac{E_c - E_F}{kT}) \quad \text{and} \quad p = N_v \exp(-\frac{E_F - E_v}{kT}) \ ,$$

and the mass action law: $np = n_i^2 = N_c N_v \exp\left(-\frac{E_g}{kT}\right)$, prove that the built-in voltage V_o is,

$$V_o = \frac{kT}{e} \ln(\frac{N_a N_d}{n_i^2}) . \qquad \textbf{(8\%)}$$

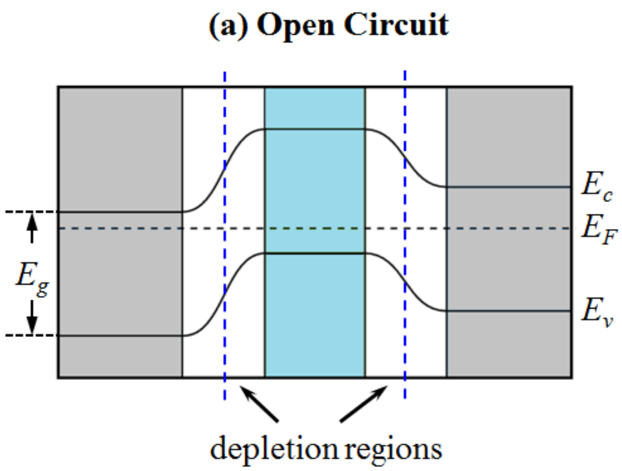
Q4. Consider at $T = 300$ K, a Si *pn* junction that has 2×10^{16} cm^{-3} acceptors on the *p*-side and 5×10^{15} cm^{-3} donors on the *n*-side. The permittivity (ε) of Si is 1.05×10^{-10} C V^{-1} m^{-1}, and the intrinsic carrier concentration (n_i) is 10^{10} cm^{-3}. The diffusion coefficients for electrons in the *p*-side and holes in the *n*-side are $D_e = 28.45$ cm^2 s^{-1} and $D_h = 11.65$ cm^2 s^{-1}, respectively. The diffusion lengths for electrons in the *p*-side and holes in the *n*-side are $L_e = 23.85 \times 10^{-4}$ cm and $L_h = 30.52 \times 10^{-4}$ cm^2 s^{-1}, respectively. The cross-sectional area is 1.00 mm^2.

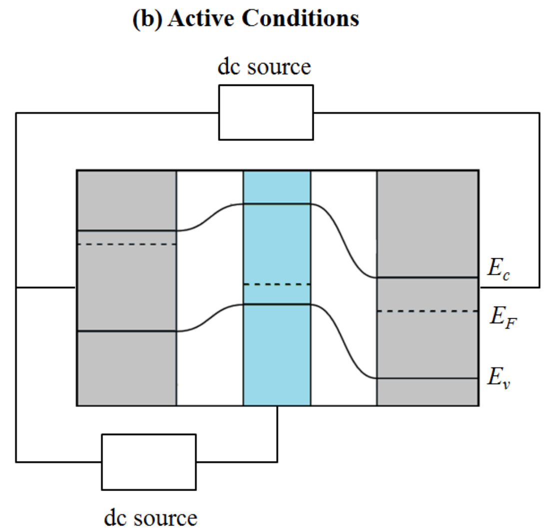
(1) Calculate the built-in potential V_o across the junction. **(6%)**

(2) Under a reverse bias of 1.5 V, determine the width of the depletion region on the *n*-side, W_n, and the width of the depletion region on the *p*-side, W_p. **(10%)**

(3) Under a forward bias of 0.6 V, determine the current across the junction. Assume that the current is by minority carrier diffusion (no recombination current). (**10%**)

Q5. Figures below show the energy band diagrams of a bipolar junction transistor (BJT) (a) in equilibrium, and (b) biased by two external dc voltages. The *n* and *p* regions are distinguished by different colors. Medians of the depletion regions are marked by vertical dashed lines.





<u>Assume that the two less doped regions have the same dopant concentration,</u>

(1) Examining the band diagram in (a), identify the type of this BJT and briefly explain your reasoning. Use a superscript plus sign for the heavier doped region. **(6%)**

(2) Under the normal active conditions, the Fermi energies in the three components of the BJT are not uniform. Examining the band diagram in (b), identify the positive and negative terminals of the two dc sources, and rank the magnitudes of the two voltages. **(8%)**

******************** END OF EXAM **********************