Concordia University
Department of Electrical and Computer Engineering

Introduction to Semiconductor Materials and Devices
ELEC 321/H, Winter 2013-14

Final Test April 22, 2014

Instructor: M. Z. Kabir
Test Duration: 3 hours
Materials allowed: **Calculator (SHARP EL-531 or CASIO FX-300 MS with "ENCS" Sticker on it).**

Last Name: ______________________________ First Name: ______________________________

Student ID: __________________

Typical Parameters:
Physical constants

Permittivity of free space	$\varepsilon_0 = 8.85\times10^{-14} F/cm$
Electronic charge	$e = 1.6\times10^{-19} C$
Boltzmann's constant	$k = 1.38\times10^{-23} J/K = 8.62\times10^{-5} eV/K$
Thermal voltage	$V_t = \frac{kT}{e} = 0.0259 V \quad at \quad T = 300K$
Plank's constant	$h = 6.625\times10^{-34} J-s = 4.135\times10^{-15} eV-s$
Free electron rest mass	$m_0 = 9.11\times10^{-31} kg$

Properties at T = 300 K	**Si**	**GaAs**	**Ge**
Lattice constant, Å	5.43	5.65	5.65
Dielectric constant, ε_r	11.7	13.1	16.0
Bandgap energy, E_g, (eV)	1.1	1.42	0.66
Density of states effective mass Electron hole	 1.08 m_0 0.56 m_0	 0.067 m_0 0.48 m_0	 0.55 m_0 0.37 m_0
Intrinsic carrier concentration, n_i, (cm^{-3})	1.0×10^{10}	1.8×10^{6}	2.4×10^{13}
Effective density of states in conduction band, N_c, (cm^{-3}) Effective density of states in valence band, N_v, (cm^{-3})	2.8×10^{19} 1.04×10^{19}	4.7×10^{17} 7×10^{18}	1.04×10^{19} 6.0×10^{18}

Marks obtained:

Q1/10	Q2/15	Q3/15	Q4/15	Q5/10	Q6/20	Q7/15	Total/100

Problem #1 (10%)
A cubic unit-cell is defined in terms of the following placement of atoms on a cube of edge-length a:

- 4 atoms positioned a/2 up each of the vertical edges of the cube
- 2 atoms in the middle of the top and bottom surfaces.

(a) This unit cell explains one of the standard cubic unit cell which were named in class. Which one is it? **(5 points)**
(b) How many atoms are there per unit cell? **(5 points)**

Problem #2 (15%)
For the step potential function shown in Fig. P2, assume that particle energy $E > V_0$ and that the particle is incident from the +x direction traveling in the -x direction.

(a) Write the wave solutions for each region **(5 points)**
(b) Derive expressions for the transmission and reflection coefficients. **(10 points)**

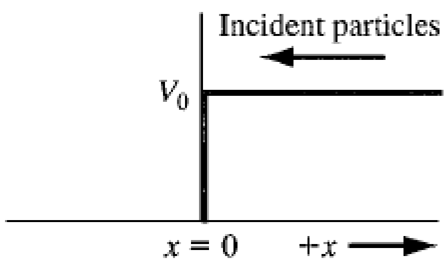

Fig. P2

Problem #3 (15%)
The Fermi energy level for copper at T = 300 K is 7.0 eV. The electrons in copper follow the Fermi-Dirac distribution function.

(a) Find the probability of an energy level at 7.15 eV being occupied by an electron. **(5 points)**
(b) Find the probability of an energy level at 6.85 eV being occupied by an electron. **(5 points)**
(c) Determine the probability of an energy level at $E = E_F$ being occupied at T = 300 K and at 1000 K. **(5 points)**

Problem #4 (15%)
Consider Si sample at T = 300 K with a donor concentration three times the acceptor concentration.

(a) If the probability of finding an electron at the bottom of conduction band is 10^{-5} calculate the electron and hole concentration. **(5 points)**
(b) Calculate the acceptor and donor concentration assuming complete ionization. **(5 points)**
(c) Calculate the electron and hole concentration at T = 500 K. **(5 points)**

Problem #5 (10%)

At 300°K, in an n-type silicon slab of 1μm thickness, the donor concentration is changing exponentially from the surface down according to

$$N_d(x,y) = 10^{17} exp\left[-\frac{(x-0.25)^2}{0.1}\right] \quad cm^{-3}$$; x is in micrometers.

x is the coordinate normal to the surface (x=0 marks the surface) and y is coordinate parallel to the surface.

(a) What is the maximum value of internally-induced electric-field perpendicular to the surface? Please pay very careful attention to the units!

(b) What is the maximum value of internally-induced electric field in the horizontal direction? Please pay very careful attention to the units!

Problem #6 (20%)

The semiconductor is a homogeneous, p-type material in thermal equilibrium for $t \leq 0$. The excess minority carrier lifetime is $\tau_{n0} = 10^{-6} s$. At $t = 0$, an external source is turned on which produces excess carriers uniformly at rate of $g' = 10^{20} cm^{-3} s^{-1}$. At $t = 2 \times 10^{-6} s$, the external source is turned off.

(a) Derive the expression for the excess-electron concentration as a function of time for $0 \leq t \leq \infty$. **(7 points)**
(b) Determine the value of excess electron concentration at (i) $t = 0$, (ii) $t = 2 \times 10^{-6} s$, (iii) $t = 3 \times 10^{-6} s$ and (iv) $t = \infty$. **(8 points)**
(c) Plot the excess electron concentration as a function of time. **(5 points)**

Problem #7 (15%)

Consider a GaAs p-n junction uniformly doped on either side of the metallurgical junction. T is 300 K. At zero bias, only 20 percent of the total space charge region is to be in the “p” region. The built-in potential is V_{bi}=1.2 V. For zero bias determine N_a, N_d, x_n, x_p, W, and E_{max}. Relative permittivity of GaAs is 13.1.