NAME:______________________________ **PUID:**____________________

ECE 305 – Fall 2015

Exam 1 – Friday, September 18, 2015

This is a closed book exam. You may use a calculator and the formula sheet at the end of this exam. Following the ECE policy, the calculator **must** be a Texas Instruments TI---30X IIS scientific calculator.

To receive full credit, you must **show your work** (scratch paper is attached).
The exam is designed to be taken in 50 minutes (or less). Be sure to fill in your name and Purdue student ID at the top of the page. DO NOT open the exam until told to do so, and stop working immediately when time is called. The last page is an equation sheet, which you may remove, if you want.

100 points possible,

I) 40 points (8 points per question)
II) 30 points
III) 30 points

Course policy

If I am caught cheating, I will earn an F in the course & be reported to the Dean of Students.

I repeat: ____

____

Signature: ____

Part I: Answer the 5 multiple choice questions below by entering them on your IDP-15 Scantron.

1 (8 points). For crystalline silicon with a lattice structure with a lattice constant $a = 5.43$ Å, what is the distance between next-nearest neighbor atoms (in Å)?

a. 1.36 Å
b. 2.35 Å
c. 2.72 Å
d. 3.85 Å
e. 5.43 Å

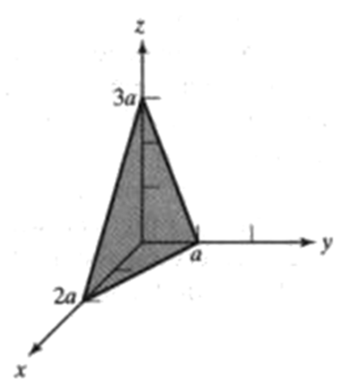
2 (8 points). What current is generated by electrons diffusing down a concentration gradient?

a. $+qE$
b. $-qE$
c. $+q\, D_p\, dp/dx$
d. $+q\, D_n\, dn/dx$
e. $-q\, D_n\, dn/dx$

3 (8 points). At what temperature would a typical semiconductor experience the highest mobility?

a. $T = 0$
b. arbitrarily large ($T \to \infty$)
c. $T < 0$
d. $T = 300$ K
e. finite temperature (material-dependent)

4 (8 points). What is the Miller index for the plane shown below?



a. (213)
b. (362)
c. (100)
d. (321)
e. (123)

5 (8 points). If crystalline silicon is n-type doped such that $N_D = 4.5 \times 10^{14}\ \text{cm}^{-3}$, what is its resistivity? Note that $\mu_n = 1400\ \text{cm}^2/\text{V·s}$ and $\mu_p = 450\ \text{cm}^2/\text{V·s}$.

a. $100\ \Omega \cdot \text{cm}$
b. $10\ \Omega \cdot \text{cm}$
c. $1\ \Omega \cdot \text{cm}$
d. $0.1\ \Omega \cdot \text{cm}$
e. $0.01\ \Omega \cdot \text{cm}$

Part II (Free Response, 30 points)

Assume that one has a p-type doped single-crystal wafer of gallium arsenide at an elevated temperature ($T = 700$ K) with intrinsic carrier concentration $n_i = 3 \times 10^{14}\ \mathrm{cm}^{-3}$. For low doping, the GaAs mobilities are approximately $\mu_n = 8000$ cm^2/V·s and $\mu_p = 400$ cm^2/V·s.

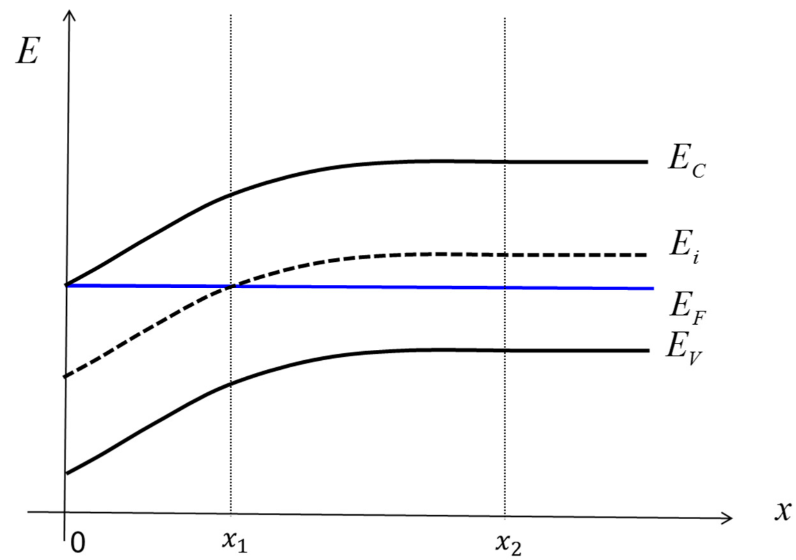
a. If one introduces fully-ionized acceptors, such that $N_A = 3 \times 10^{15}\ \mathrm{cm}^{-3}$, what is the hole density p?

b. Based on part (a), the temperature, and material, what is the electron density n?

c. If a 1 V potential difference is applied across a 250 μm wafer of GaAs, calculate the drift-induced electron current J_n, hole current J_p, and total current J.

Part III (Free Response, 30 points)

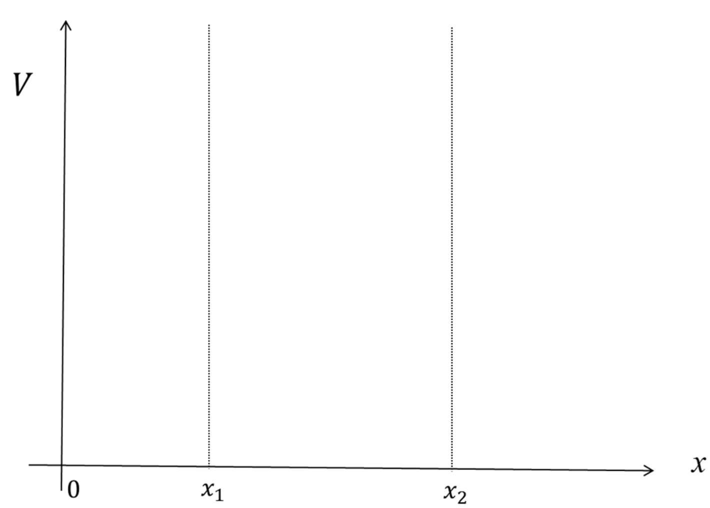
Assume that the band diagram below describes intrinsic crystalline silicon ($E_g = 1.12$ eV).



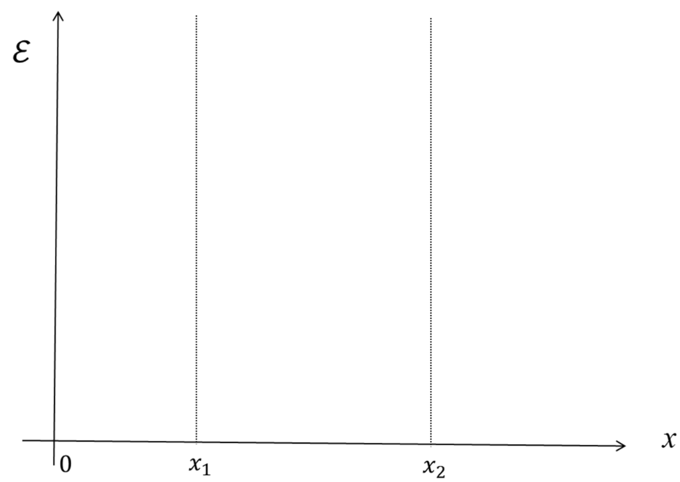
a. Calculate the hole density at $x = 0$. This must be a numerical answer.

b. Calculate the hole density at $x = x_1$. This must be a numerical answer.

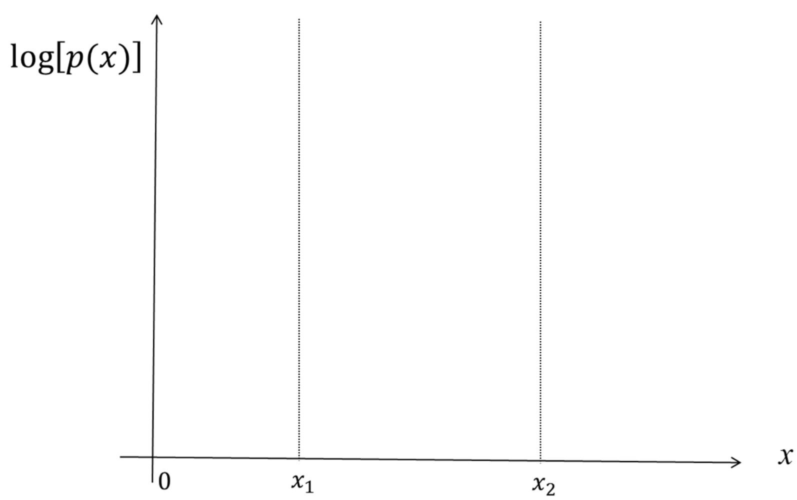
c. Assuming $V = 0$ for $x \gg x_2$, qualitatively plot the voltage as a function of position in this material on the graph below.



d. Qualitatively plot the electric field as a function of position in this material on the graph below.



e. Qualitatively plot the logarithm of the hole density as a function of position in this material on the graph below.



ECE 305 Exam 1 Formula Sheet (Fall 2015)

Physical Constants	Silicon parameters ($T = 300$ K)
$\hbar = 1.055 \times 10^{-34}$ J·s	$N_C = 3.23 \times 10^{19}\ \text{cm}^{-3}$
$m_0 = 9.109 \times 10^{-31}$ kg	$N_V = 1.83 \times 10^{19}\ \text{cm}^{-3}$
$k_B = 1.38 \times 10^{-23}$ J/K	$n_i = 1.1 \times 10^{10}\ \text{cm}^{-3}$
$q = 1.602 \times 10^{-19}$ C	$K_s = 11.8$
$\epsilon_0 = 8.854 \times 10^{-12}$ F/m	

Miller Indices: (hkl) {hkl} [hkl] <hkl>

Density of states $g_C(E) = \frac{(m_n^*)^{3/2}\sqrt{2(E-E_C)}}{\pi^2\hbar^3}$

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

Intrinsic carrier concentration $n_i = \sqrt{N_C N_V} e^{-E_g/2kT}$

Equilibrium carrier densities: $N_C = \frac{1}{4}\left(\frac{2m_n^* kT}{\pi\hbar^2}\right)^{3/2}$ $\quad N_V = \frac{1}{4}\left(\frac{2m_p^* kT}{\pi\hbar^2}\right)^{3/2}$

$n_0 = N_C e^{(E_F-E_C)/kT} = n_i e^{(E_F-E_i)/kT}$ $\quad p_0 = N_V e^{(E_V-E_F)/kT} = n_i e^{(E_F-E_i)/kT}$

Space charge neutrality: $p - n + N_D^+ - N_A^- = 0$

Law of Mass Action: $n_0 p_0 = n_i^2$

Conductivity/resistivity: $\sigma = \sigma_n + \sigma_n = q(n\mu_n + p\mu_p) = 1/\rho$

Drift-diffusion current equations:

$$J_n = nq\mu_n \mathcal{E}_x + qD_n \frac{dn}{dx} \qquad \frac{D_n}{\mu_n} = \frac{kT}{q}$$

$$J_p = pq\mu_p \mathcal{E}_x - qD_p \frac{dp}{dx} \qquad \frac{D_p}{\mu_p} = \frac{kT}{q}$$

Carrier conservation equations:

$$\frac{\partial n}{\partial t} = +\nabla \cdot \left(\frac{J_n}{q}\right) + G_n - R_n$$

$$\frac{\partial p}{\partial t} = -\nabla \cdot \left(\frac{J_p}{q}\right) + G_p - R_p$$

Poisson's equation:

$$\nabla \cdot (\epsilon \mathcal{E}) = \rho$$