NAME:________________________________ **PUID: :**________________________________

SOLUTIONS: ECE 305 Exam 1: Spring 2015
January 30, 2015

Mark Lundstrom
Purdue University

This is a closed book exam. You may use a calculator and the formula sheet at the end of this exam.

There are three equally weighted questions. To receive full credit, you must **show your work** (scratch paper is attached).

The exam is designed to be taken in 50 minutes.

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.

75 points possible, 10 per question

1) 25 points (5 point per part)

2) 25 points (2a (10 points) 2b (10 points) 2c (5 points))

3) 25 points (3a (10 points) 3b (10 points) 3c (5 points))

------------------------ Course policy ------------------------

I understand that if I am caught cheating in this course, I will earn an F for the course and be reported to the Dean of Students.

Read and understood: ______________________________________
signature

Answer the **five multiple choice questions** below by **drawing a circle** around the **one, best answer**.

1a) In GaAs, how many of the nearest neighbors of an arsenic (As) atom are Ga atoms?

a) 1
b) 2
c) 3
d) 4
e) 5

1b) Which of the following is true about the unit cell of a crystal?

a) It can be used to reproduce the entire crystal.
b) It contains one atom.
c) It is unique.
d) Both a) and b).
e) Both b) and c).

1c) What is the probability that a state with energy $E = E_F$ is occupied?

a) 0.0
b) 0.5
c) 1.0
d) << 1
e) >> 1

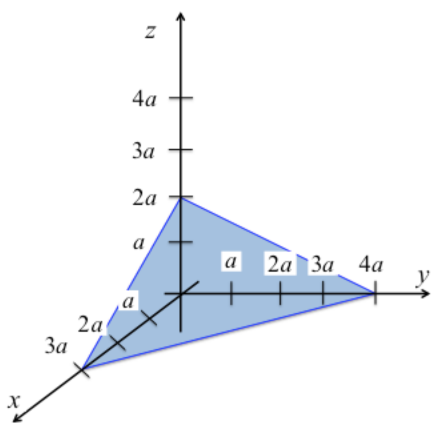
1d) Which plane is perpendicular to a $\left[1\bar{1}0\right]$ direction?

a) $\left(001\right)$
b) $\left(\bar{1}01\right)$
c) $\left(01\bar{1}\right)$
d) $\left(0\bar{1}1\right)$
e) $\left(1\bar{1}0\right)$

1e) As temperature increases from 0 K to high temperature, the carrier concentration goes through three regions. In what order does the transition occur?

a) intrinsic, extrinsic, freezeout
b) extrinsic, intrinsic, freezeout
c) freezeout, intrinsic, extrinsic
d) freezeout, extrinsic, intrinsic
e) intrinsic, freezeout, extrinsic

2a) Deduce the Miller indices for the plane shown below. **Show your work and draw a box around your answer.**

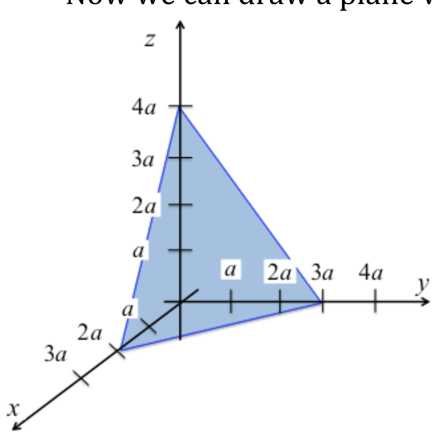


Solution:

Intercepts: 3a, 4a, 2a
Intercepts in units of a: 3, 4, 2
Invert the intercepts: 1/3, 1/4, 1/2
Multiply by 12: 4, 3, 6
Put in parentheses since this is a specific plane: (4 3 6)

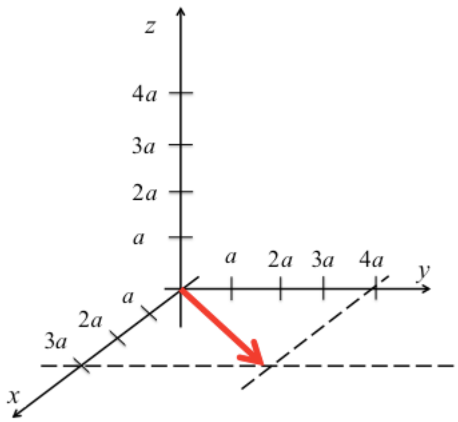
$\boxed{(436)}$

2b) Draw (6 4 3). **Show your work.**
Solution:
The notation refers to a plane because of the parentheses
Reverse the procedure above:
Invert the indices: 1/6, 1/4, 1/3
Mutiply by 12: 2, 3, 4
Multiple by a: 2a, 3a, 4a
Now we can draw a plane with x-intercept 2a, y-intercept 3a, and z-intercept 4a



2c) Draw [3 4 0]. **Show your work.**

Solution:
This is a vector with x-component, 3a, y-component 4a, and z-component, 0a.



3) An n-doped silicon sample is in equilibrium at T = 700 K. It has an electron concentration of $n = 7.148\times10^{16}\ \text{cm}^{-3}$ and an intrinsic carrier concentration of $n_i = 2.865\times10^{16}\ \text{cm}^{-3}$. Answer the following questions.

3a) What is the concentration of holes?

Solution:

In equilibrium: $np = n_i^2$, so

$$p = \frac{n_i^2}{n} = \frac{\left(2.865\times10^{16}\right)^2}{7.148\times10^{16}} = 1.148\times10^{16}\ \text{cm}^{-3}$$

$$\boxed{p = 1.148\times10^{16}\ \text{cm}^{-3}}$$

3b) What is the concentration of donors, N_D? (You may assume that $N_A = 0$ and that the donors are fully ionized.)

Solution:

The semiconductor must be charge neutral:

$$p - n + N_D = 0 \text{, so}$$
$$N_D = n - p = 7.148\times10^{16} - 1.148\times10^{16} = 6.000\times10^{16}\ \text{cm}^{-3}$$

$$\boxed{N_D = 6.000\times10^{16}\ \text{cm}^{-3}}$$

3c) Where is the Fermi level located with respect to the intrinsic level? (A numerical answer is required).

Solution:

Begin with the relation between the electron density and the Fermi level:

$$n = n_i e^{(E_F - E_i)/k_B T}$$
$$\left(E_F - E_i\right) = k_B T \ln\left(\frac{n}{n_i}\right) = 1.38\times10^{-23}\times700\times\ln\left(\frac{7.148}{2.865}\right) = 8.832\times10^{-21}\ \text{J}$$
$$E_F = E_i + 8.832\times10^{-21}\ \text{J}$$

or in electron volts:

$$\boxed{E_F = E_i + 0.0552\ \text{eV}}$$

As expected, the Fermi level is above the intrinsic level because *n* is greater than *p*.