NAME:________________________________ **PUID:** ________________________________

SOLUTIONS: ECE 305 Exam 2: Fall 2014

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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, 25 per question

1) 5 points per part – 25 points total

2) 5 points per part – 25 points total

3) 25 points – 3a) 15 pts 3b) 10 pts

------------------------ Exam Integrity Statement ------------------------

I certify that I have neither given nor received unauthorized aid on this exam.

Write out the above statement:

Signature: ____

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

1) If the temperature of a phosphorous-doped Si wafer ($N_D = 10^{16}$ cm^{-3}) increases from 300 K to 600 K, what happen?
   a) The percentage of ionized donors increases substantially
   b) The percentage of ionized donors decreases substantially
   c) The Fermi level drops to a lower energy
   d) The Fermi level increases to a high energy
   e) The number of holes in the valence decreases.

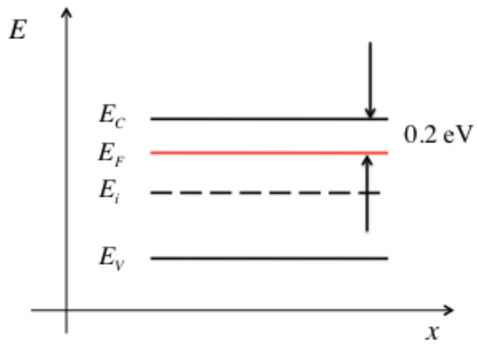
2) What is the **electron concentration** in Si at 300 K with a boron doping of $N_A = 10^{15}$ cm^{-3}?
   a) $n = 10^{10}$ cm^{-3}
   b) $n = 10^{15}$ cm^{-3}
   c) $n = 10^{3}$ cm^{-3}
   d) $n = 10^{5}$ cm^{-3}
   e) $n = 10^{7}$ cm^{-3}

3) What is the **electron concentration** in Si at 300 K with a boron doping of $N_A = 10^{15}$ cm^{-3} **and** an arsenic doping of $N_D = 10^{15}$ cm^{-3}
   a) $n = 10^{10}$ cm^{-3}
   b) $n = 10^{15}$ cm^{-3}
   c) $n = 10^{3}$ cm^{-3}
   d) $n = 10^{5}$ cm^{-3}
   e) $n = 10^{7}$ cm^{-3}

4) 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

5) Which of the following atoms would be an n-type dopant in GaAs?
   a) O (a column VI) element) on a Ga (column III) lattice site.
   b) Si (a column IV element) on a Ga (column III) site
   c) Si (a column IV element) on an As (column V) site
   d) F (a column VII element) on a Ga (column III) site.
   e) F (a column VII element) on an As (column V) site

2) Consider a hypothetical semiconductor with $E_G = 1.2\text{ eV}$ and $N_C = N_V = 3\times10^{19}\text{ cm}^{-3}$ at room temperature (300 K). Answer the following questions about the energy band diagram shown below. **Numerical answers are required; be sure to show your work and draw a box around your answer.**



2a) What is the electron concentration in the conduction band?

Solution:

$$n = N_C e^{(E_F - E_C)/k_BT} = 3\times10^{19} e^{-0.2/0.026} = 1.4\times10^{16}$$

$$\boxed{n = 1.4\times10^{16}\text{ cm}^{-3}}$$

2b) What is the hole concentration in the valence band?

Solution:

$$p = N_V e^{(E_V - E_F)/k_BT} = 3\times10^{19} e^{-1.0/0.026} = 5.9\times10^{2}$$

$$\boxed{p = 5.9\times10^{2}\text{ cm}^{-3}}$$

2c) What is the intrinsic carrier concentration?

Solution:

$$np = n_i^2 = 1.4\times10^{16}\times5.9\times10^{2} = 8.3\times10^{18} \qquad n_i = \sqrt{8.3\times10^{18}} = 2.9\times10^{9}$$

$$\boxed{n_i = 2.9\times10^{9}\text{ cm}^{-3}}$$

2d) What is the probability that a state at energy $E = E_C + k_BT$ is occupied?

Solution:

$$f = \frac{1}{1+e^{(E-E_F)/k_BT}} = \frac{1}{1+e^{(E_c+k_BT-E_F)/k_BT}} = \frac{1}{1+e^{(E_c-E_F)/k_BT}\times e^{1}} = \frac{1}{1+e^{0.2/0.026}\times e^{1}}$$

$$f = \frac{1}{1+e^{0.2/0.026} \times e^{1}} = \frac{1}{1+5957} = 1.68\times10^{-4}$$ $$\boxed{f = 1.68\times10^{-4}}$$

2e) How far below the conduction band is the intrinsic level?

Solution:

$$E_i = \frac{E_V + E_C}{2} + k_B T \ln\left(\frac{N_V}{N_C}\right) = \frac{E_V + E_C}{2} + 0$$

Exactly in the middle of the bandgap. $\boxed{E_i = E_C - 0.6 \text{ eV}}$

3) Consider a hypothetical semiconductor with $n_i = 10^{17}\text{ cm}^{-3}$. Assume that $N_A = 0$ and $N_D = 1\times10^{17}\text{ cm}^{-3}$, but assume that the donor is "deep" (i.e. $E_C - E_D >> k_B T$) such that $N_D^+ = 0.5 N_D$. Answer the following questions. **Numerical answers are required; be sure to show your work and draw a box around your answer.**

3a) Set up an equation and solve for the density of electrons in the conduction band.

Solution:

Space-charge neutrality: $p - n + N_D^+ = 0 \rightarrow \frac{n_i^2}{n} - n + \frac{N_D}{2} = 0$

$$n_i^2 - n^2 + \frac{N_D}{2} n = 0 \rightarrow n^2 - \frac{N_D}{2} n - n_i^2$$

physically meaningful root: $n = \frac{N_D}{4} + \sqrt{\left(\frac{N_D}{4}\right)^2 + n_i^2}$

$$n = 0.25\times10^{17} + \sqrt{\left(0.25\times10^{17}\right)^2 + 10^{34}} = 0.25\times10^{17} + \sqrt{6.25\times10^{32} + 10^{34}} = 1.28\times10^{17}$$

$\boxed{n = 1.28\times10^{17}\text{ cm}^{-3}}$

3c) Find the density of holes in the valence band.

Solution:

$$np = n_i^2$$

$$p = \frac{n_i^2}{n} = \frac{10^{34}}{\left(1.28 \times 10^{17}\right)} = 0.78 \times 10^{17}$$

$$\boxed{p = 0.78 \times 10^{17} \text{ cm}^{-3}}$$