NAME:________________________________ **PUID: :**________________________________

ECE 305 Exam 4 SOLUTIONS: Spring 2015

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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. Following the ECE policy, the calculator **must** be a Texas Instruments TI-30X IIS scientific calculator.

There are three equally weighted questions. To receive full credit, you must **show your work**.

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 (5 points per part)

3) 25 points (5 points per part)

------------------------ 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) To make an ohmic contact to an p-type semiconductor, one could:

a) Select a metal with a workfunction smaller than that of the semiconductor.
b) Select a metal with a workfunction larger that that of the semiconductor.
c) Use a lightly doped semiconductor.
d) Insert a thin insulating layer under the metal.
e) Reduce the minority carrier lifetime in the semiconductor.

1b) For an ideal <u>metal-N-type</u> GaAs diode, which type of carrier transport dominates under <u>reverse bias</u>?

a) Electron injection from the metal to semiconductor.
b) Electron injection from the semiconductor to metal.
c) Hole injection from the metal to semiconductor.
d) Hole injection from the semiconductor to metal.
e) Electron-hole recombination in the semiconductor.

1c) The electrostatics of an ideal <u>metal-P-type</u> GaAs diode are similar to which of the following?

a) A p+/n junction.
b) A p/n junction.
c) An n+/p junction.
d) An n/p junction
e) None of the above.

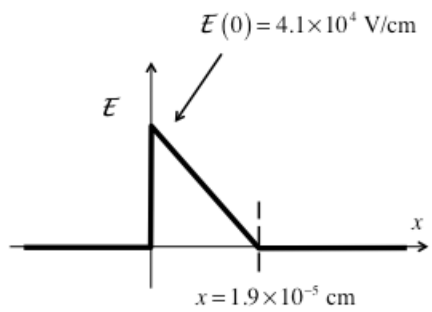
1d) The bandbending in the semiconductor is proportional to what?

a) The Schottky barrier height .
b) The semiconductor electron affinity.
c) The semiconductor workfunction.
d) The metal workfunction.
e) The built-in potential of the MS diode.

1e) What is the consequence of the fact that MS diodes are majority carrier devices, not minority carrier devices like NP diodes?

a) The barrier height is smaller than the bandgap.
b) The small signal model does not have a diffusion capacitance.
c) The small signal model does not have a junction capacitance.
d) The diode turn on voltage is smaller.
e) The series resistance is smaller.

2) The electric field vs. position for an MS junction in equilibrium is sketched below. (The depletion approximation is assumed, and you may assume that $K_S = 12$). Given the information provided, answer the following questions.



2a) Is the semiconductor N-type or P-type? Explain how you know.

Solution:

We are told that the depletion approximation is assumed. The Poisson equation tells us that

$$\frac{d\mathcal{E}}{dx} = \frac{\rho}{K_S\varepsilon_0} < 0$$

because the slope is negative in the figure. The negative charge in the semiconductor must be ionized acceptors, so the Poisson equation is

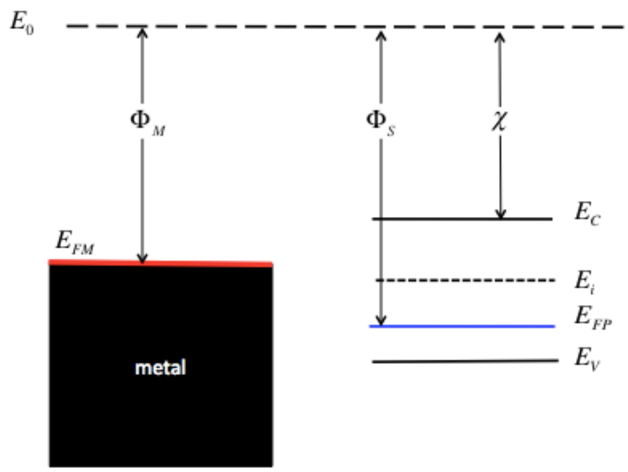
$$\frac{d\mathcal{E}}{dx} = -\frac{qN_A}{K_S\varepsilon_0}$$

The semiconductor is P-type.

2b) Draw and label the energy band diagram for the metal and semiconductor before they are joined together.

Solution:

The p-type semiconductor must be depleted. This occurs when $\Phi_M < \Phi_S$
The energy band diagram before connecting the metal and semiconductor is shown below.



2c) What is the built-in voltage for this junction?

Solution:
Voltage is the integral of the electric field, so the built-in voltage is the area under the curve above (by definition, V_{bi} is positive).

$$V_{bi} = \frac{1}{2}\mathcal{E}(0)W = 0.5\times 4.1\times 10^4 \times \left(1.9\times 10^{-5}\right) = 0.39 \quad \boxed{V_{bi} = 0.39 \text{ V}}$$

2d) Determine the numerical value of the doping density.

Solution:

Begin with the Poisson equation: $\frac{d\mathcal{E}}{dx} = -\frac{qN_A}{K_S\varepsilon_0}$

The electric field is linear, so the derivtive is easy to write:

$$\frac{d\mathcal{E}}{dx} = \frac{\mathcal{E}(W) - \mathcal{E}(0)}{W} = \frac{0 - \mathcal{E}(0)}{W} = -\frac{qN_A}{K_S\varepsilon_0}$$

$$-\frac{\mathcal{E}(0)}{W} = -\frac{qN_A}{K_S\varepsilon_0}$$

Now solve for the doping density:

$$N_A = \frac{K_S\varepsilon_0\mathcal{E}(0)}{qW} = \frac{12\left(8.854\times 10^{-14}\right)\left(4.1\times 10^4\right)}{\left(1.6\times 10^{-19}\right)\left(1.9\times 10^{-5}\right)} = 1.43\times 10^{16}$$

$$\boxed{N_A = 1.43\times 10^{16} \text{ cm}^{-3}}$$

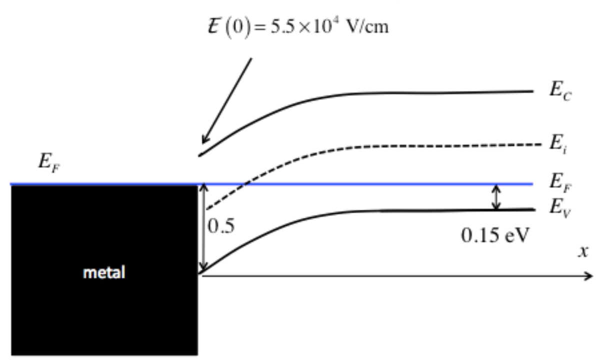
2e) If the voltage on the metal is $V = 0$, then is the voltage on the semiconductor positive or negative? You must explain your answer to receive credit.

Solution:

From the energy band diagram in 2b), we see that **the semiconductor must acquire a negative potential** so that the Fermi level in the semiconductor lines up with the Fermi level in the metal.

Alternatively, from the first figure, we see that the electric field is positive. We have to "push" a positive test charge against the force of the electric field as we move it from the semiconductor to the metal. This means that the potential in the metal is higher than in the semiconductor, so **the semiconductor must have a negative potential** with respect to the metal.

3) Consider an ideal metal-semiconductor junction with the band diagram shown below. The semiconductor has a relative dielectric constant of 12 and an electron affinity of 4.0 eV. Answer the following questions.



3a) What is the built-in potential of this junction?

Solution:

The built-in potential is related to the bandbending in the semiconductor. From the figure, we see:

$$V_{bi} = 0.5 - 0.15 = 0.35 \text{ V}$$

$$\boxed{V_{bi} = 0.35 \text{ V}}$$

3b) What is the numerical value of the depletion layer width, *W*?

Solution:

$$V_{bi} = \frac{1}{2}\mathcal{E}(0)W$$

$$W = \frac{2V_{bi}}{\mathcal{E}(0)} = \frac{2(0.35)}{5.5\times10^{4}} = 0.13\times10^{-4}\text{ cm}$$

$$\boxed{W = 0.13\times10^{-4}\text{ cm}}$$

3c) What is the doping density of the semiconductor?

Solution:

$$\frac{d\mathcal{E}}{dx} = \frac{\mathcal{E}(W)-\mathcal{E}(0)}{W} = -\frac{qN_A}{K_S\varepsilon_0}$$

$$-\frac{\mathcal{E}(0)}{W} = -\frac{qN_A}{K_S\varepsilon_0}$$

$$N_A = \frac{K_S\varepsilon_0\mathcal{E}(0)}{qW} = \frac{12(8.854\times10^{-14})(5.5\times10^{4})}{(1.6\times10^{-19})(1.3\times10^{-5})} = 2.81\times10^{16}$$

$$\boxed{N_A = 2.81\times10^{16}\text{ cm}^{-3}}$$

3d) What is the numerical value of the small signal capacitance measured under zero d.c. bias? You may assume that the area of the diode is $200\ \mu\text{m}\times200\ \mu\text{m}$.

Solution:

$$C_j = \frac{K_S\varepsilon_0 A}{W} = \frac{12(8.854\times10^{-14})(2\times10^{-2})^2}{0.13\times10^{-4}} = 32.7\times10^{-12}\text{ F}$$

$$\boxed{C_j = 33\text{ pF}}$$

3e) The metal is grounded ($V = 0$), and a voltage of $V = -0.35$ is applied to the right side of the P-type semiconductor. Draw the energy band diagram and label the important quantities such as Fermi levels, bandbending, etc.

Solution:

A negative voltage reverse biases the diode. The energies on the semiconductor side increase – the band bending increases. The Fermi levels on the two sides must split by 0.35 V.