

NAME: \_\_\_\_\_

PUID: \_\_\_\_\_

**ECE 305 – Spring 2018**

**Exam 2 – Thursday, February 15, 2018**

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 60 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). To increase the resistivity of a semiconductor, we can:

- A. Decrease the carrier density.
- B. Increase the mobility.
- C. Decrease the electric field.
- D. Increase the cross-sectional area of the resistor
- E. Decrease the length of the resistor

2 (8 points). The discontinuity in the valence band alignment in a heterojunction is calculated from:

- A. Difference in bandgaps of the materials
- B. Difference in electron affinities of the materials
- C. Discontinuity of electric field at the junction
- D. A and B
- E. A and C

4 (8 points). If a device is in equilibrium, which of the following is/are true?

- A. Sum of all the drift currents is equal to sum of all the diffusion currents.
- B. Drift current due to electrons is equal to diffusion current due to electrons.
- C. Drift current due to holes is equal to diffusion current due to holes.
- D. B and C
- E. A, B and C

4 (8 points). For a high-quality crystalline silicon device operating at a very high voltage, what is the most important scattering mechanism?

- A. Lattice scattering
- B. Ionized impurity scattering
- C. Auger scattering
- D. Impact ionization scattering
- E. Polar optical phonon scattering

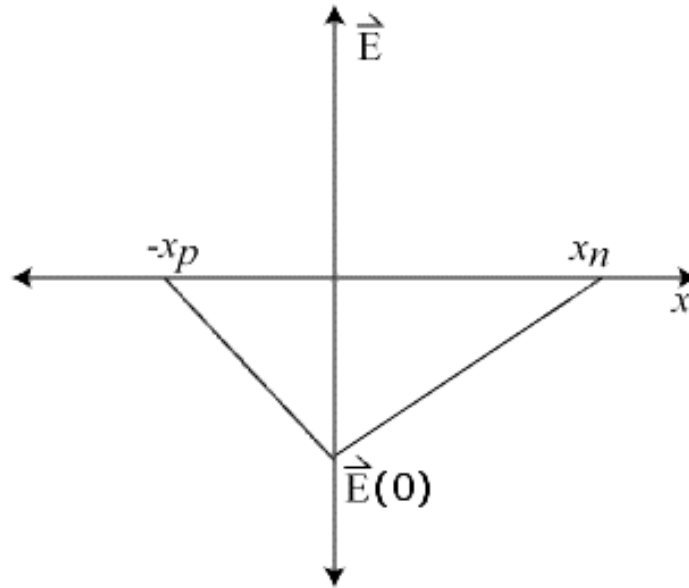
5 (8 points). As the doping density of a semiconductor decreases, the mobility generally:

- A. Stays the same
- B. Increases or stays the same
- C. Decreases
- D. First increases, then decreases
- E. First decreases, then increases



Part III (Free Response, 30 points)

The electric field versus position for a crystalline silicon ( $K_s = 11.68$ ) pn homojunction is given by the following graph (may not be precisely to scale):



For this problem, assume that the junction is abrupt at  $x = 0$  with a flat doping profile on each side,  $\mathcal{E}(0) = -12$  kV/cm, the n-type depletion length  $x_n = 520$  nm, and the p-type depletion length  $x_p = 120$  nm.

- Sketch the potential profile, clearly showing the numerical value of  $V_{bi}$ . Assume that the left-hand side is grounded (i.e.,  $\lim_{x \rightarrow -\infty} V(x) = 0$ ).

*Continued on the next page....*

b. Sketch the band diagram vs position, showing the values of  $E_C - E_F$  away from the junctions.

c. Sketch the electric field versus position if there is a region of intrinsic silicon of length 160 nm sandwiched between the p and n regions. Calculate and show the value of the peak electric field on the sketch, assuming that the intrinsic silicon is uncharged, and that  $V_{bi}$ ,  $x_n$ , and  $x_p$  remain the same.

## ECE 305 Exam 2 Formula Sheet (Spring 2018)

You may remove this page from the exam packet, and take it with you.

Physical Constants	Silicon parameters ( $T = 300$ K)
$\hbar = 1.055 \times 10^{-34}$ J·s	$N_C = 3.23 \times 10^{19}$ cm <sup>-3</sup>
$m_0 = 9.109 \times 10^{-31}$ kg	$N_V = 1.83 \times 10^{19}$ cm <sup>-3</sup>
$k_B = k = 1.38 \times 10^{-23}$ J/K	$n_i = 1.1 \times 10^{10}$ cm <sup>-3</sup>
$q = 1.602 \times 10^{-19}$ 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:**  $N_C = \frac{1}{4} \left( \frac{2m_n^* kT}{\pi \hbar^2} \right)^{3/2}$        $N_V = \frac{1}{4} \left( \frac{2m_p^* kT}{\pi \hbar^2} \right)^{3/2}$   
 $n_0 = N_C e^{(E_F-E_C)/kT} = n_i e^{(E_F-E_i)/kT}$        $p_0 = N_V e^{(E_V-E_F)/kT} = n_i e^{(E_i-E_F)/kT}$

**Space charge neutrality:**  $p - n + N_D^+ - N_A^- = 0$       **Law of Mass Action:**  $n_0 p_0 = n_i^2$

**Non-equilibrium carriers:**  $n = N_C e^{(F_N-E_C)/kT}$        $p = N_V e^{(E_V-F_P)/kT}$        $np = n_i^2 e^{(F_N-F_P)/kT}$

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

**Drift-diffusion current equations:**  $J_n = nq\mu_n \mathcal{E}_x + qD_n \frac{dn}{dx} = n\mu_n \frac{dF_n}{dx}$        $\frac{D_n}{\mu_n} = \frac{kT}{q}$   
 $J_p = pq\mu_p \mathcal{E}_x - qD_p \frac{dp}{dx} = p\mu_p \frac{dF_p}{dx}$        $\frac{D_p}{\mu_p} = \frac{kT}{q}$

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

**SRH carrier recombination:**  $R = \Delta n / \tau_n$       or       $R = \Delta p / \tau_p$

**Minority carrier diffusion equation:**  $\frac{\partial \Delta n}{\partial t} = D_n \frac{\partial^2 \Delta n}{\partial x^2} - \frac{\Delta n}{\tau_n} + G_L$        $L_{D,n} = \sqrt{D_n \tau_n}$

**PN homojunction electrostatics:**  $V_{bi} = \frac{kT}{q} \ln \left( \frac{N_D N_A}{n_i^2} \right)$        $\frac{d\mathcal{E}}{dx} = \frac{\rho(x)}{K_s \epsilon_0}$

$W = \sqrt{\frac{2K_s \epsilon_0 V_{bi}}{q} \left( \frac{N_A + N_D}{N_A N_D} \right)}$        $x_n = \left( \frac{N_A}{N_A + N_D} \right) W$        $x_p = \left( \frac{N_D}{N_A + N_D} \right) W$        $\mathcal{E}(0) = \sqrt{\frac{2qV_{bi}}{K_s \epsilon_0} \left( \frac{N_A N_D}{N_A + N_D} \right)}$