

NAME: _____

PUID: _____

ECE 305 – Fall 2017

Exam 2 – Thursday, October 5, 2017

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

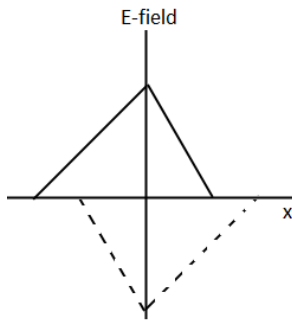
Course policy

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). The diagram to the left is drawn to scale. What is true about the the two E field profiles (solid and dashed)?

- A. The built-in potential V_{bi} is negative for one of these.
- B. Voltage is applied to transition from one to the other.
- C. They are from identical pn junctions, reversed along the x-axis.
- D. More negative charges exist in the depletion region than positive charges and vice versa for the separate profiles.
- E. None of the above.

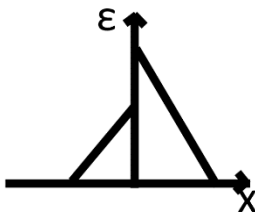
2 (8 points). What assumption(s) are made to derive the minority carrier diffusion equation (MCDE) given in the Formula Sheet?

- A. Flat conduction and valence bands
- B. Steady-state conditions
- C. Low carrier injection
- D. A and B
- E. A and C

3 (8 points). What is the correct ordering of processes before doping in silicon?

- A. Apply resist, expose, etch, develop, remove resist
- B. Expose, apply resist, develop, etch, remove resist
- C. Apply resist, expose, develop, remove resist, etch
- D. Apply resist, expose, develop, etch, remove resist
- E. Apply oxide, expose, develop, remove resist, etch

4 (8 points). What does the diagram below (E-field vs position x) represent?



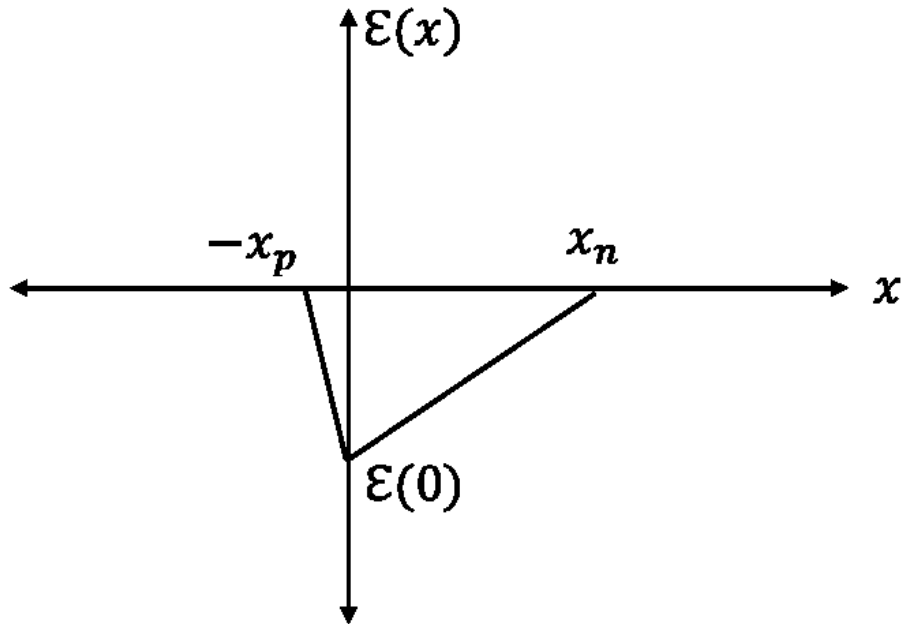
- A. Sheet charge embedded in a uniformly doped semiconductor
- B. Trapped charges at the interface of a pn junction
- C. E-field from voltage applied across pn junction
- D. E-field from voltage applied across uniformly-doped semiconductor
- E. Linear variation of dopant concentration across pn junction

5 (8 points). What assumption(s) are made in the equation pertaining to pn junctions: $N_D x_n = N_A x_p$?

- A. All mobile charge carriers recombine in the depletion region
- B. All acceptors and donors are fully ionized
- C. The p and n-type materials are the same, forming a homojunction
- D. A and B
- E. A, B and C

Part III (Free Response, 30 points)

The electric field versus position for a crystalline silicon ($K_s = 11.68$) pn homojunction at room temperature ($T = 300$ K) 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 (p-doped on the left, and n-doped on the right), $E(0) = -10$ kV/cm, n-type depletion length $x_n = 620$ nm, and the p-type depletion length $x_p = 100$ nm.

- a. What is the built-in voltage V_{bi} obtained using depletion approximation?

Continued on next page....

Part III (Continued)

- b. What is the value of N_A in the p-type region, and N_D in the n-type region, if the depletion approximation is used?
- c. Using the depletion approximation, calculate the np product just outside the right side of the junction (at $x = x_n^+$). How would this value change if you applied a forward bias of 0.28 V?

ECE 305 Exam 2 Formula Sheet (Fall 2017)

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 ⁻³
$m_0 = 9.109 \times 10^{-31}$ kg	$N_V = 1.83 \times 10^{19}$ cm ⁻³
$k_B = k = 1.38 \times 10^{-23}$ J/K	$n_i = 1.1 \times 10^{10}$ 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: $N_C = \frac{1}{4} \left(\frac{2m_n^* kT}{\pi \hbar^2} \right)^{3/2}$ $N_V = \frac{1}{4} \left(\frac{2m_p^* kT}{\pi \hbar^2} \right)^{3/2}$

$n = N_C e^{\frac{(E_F-E_C)}{kT}} = n_i e^{\frac{(E_F-E_i)}{kT}}$ $p = N_V e^{\frac{(E_V-E_F)}{kT}} = n_i e^{\frac{(E_i-E_F)}{kT}}$

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

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