UNIVERSITY OF CALIFORNIA, BERKELEY
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE 130/230M — Spring 2013
Integrated Circuit Devices — Prof. Liu & Dr. Xu

QUIZ #3
Time allotted: 25 minutes

NAME: SOLUTIONS _____ _____ _____
(print) Last First Signature

STUDENT ID#: _____

1. **Use the values of physical constants provided below.**
2. **SHOW YOUR WORK, and write legibly!**
3. **Underline or box numerical answers, and specify units where appropriate.**

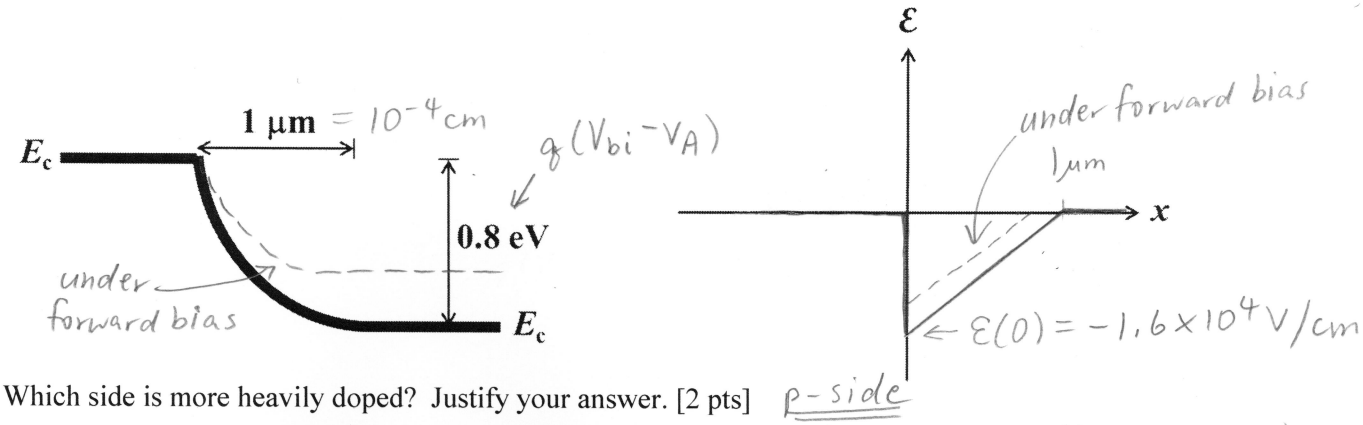
Physical Constants

Description	Symbol	Value
Electronic charge	q	1.6×10^{-19} C
Thermal voltage at 300K	kT/q	0.026 V

Properties of silicon (Si) at 300K

Description	Symbol	Value
Energy band gap	E_G	1.12 eV
Intrinsic carrier concentration	n_i	10^{10} cm^{-3}
Permittivity	ε_{Si}	1.0×10^{-12} F/cm

Problem 1 [13 points]
The conduction band edge (E_c) profile for a Si pn step junction in equilibrium at $T = 300$K is shown below.



a) Which side is more heavily doped? Justify your answer. [2 pts] p-side

All of the energy band bending occurs on the n-side (i.e. $x_n >> x_p$). Therefore, all of the voltage is dropped on the n-side, so it is more lightly doped.

b) What is the dopant concentration on the more lightly doped side of the pn junction? [4 pts]

$$W = \sqrt{\frac{2\varepsilon_s(V_{bi}-V_A)}{qN_D}}$$

$$\Rightarrow N_D = \frac{2\varepsilon_s(V_{bi}-V_A)}{qW^2} = \frac{2(10^{-12})(0.8)}{(1.6\times10^{-19})(10^{-4})^2} = \underline{10^{15}\ \text{cm}^{-3}}$$

c) Sketch the electric field ($\mathcal{E}$-field) distribution on the axes provided above. Indicate the peak value. [4 pts]

$$\frac{1}{2}|\mathcal{E}(0)|W = 0.8\text{ V} \Rightarrow |\mathcal{E}(0)| = \frac{2\times0.8}{10^{-4}} = \underline{1.6\times10^4\ \text{V/cm}}$$

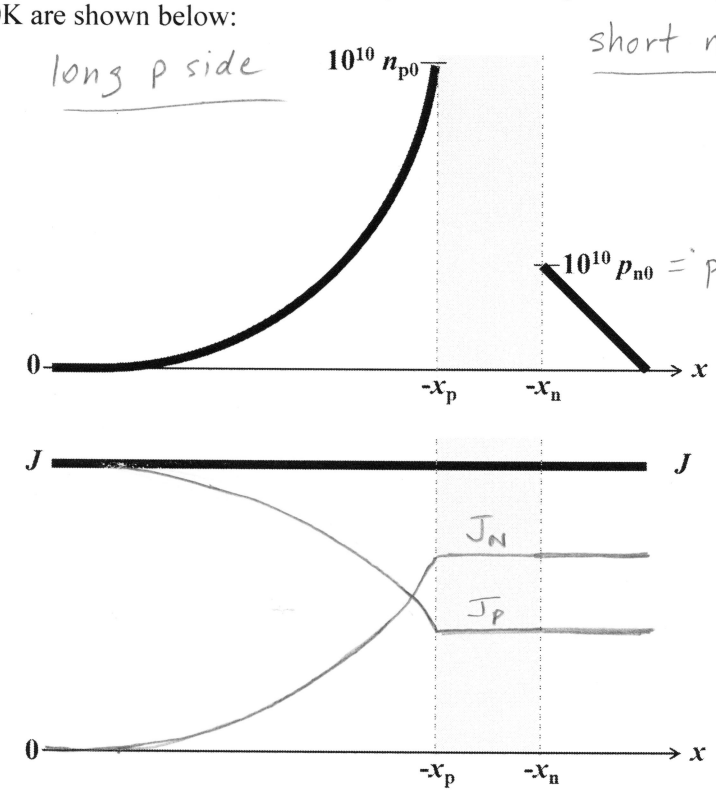
d) Qualitatively show how the band edge profile and $\mathcal{E}$-field distribution change under forward bias. [3 pts]

Problem 2 [7 points]
The excess minority carrier concentrations within the quasi-neutral regions of a Si pn step junction maintained at $T = 300$K are shown below:

$n_{p0} > p_{n0}$

$\frac{n_i^2}{N_A} > \frac{n_i^2}{N_D}$

$\Rightarrow N_A < N_D$



$10^{10}\, p_{n0} = p_{n0}(e^{qV_A/kT} - 1) \simeq p_{n0} e^{qV_A/kT}$

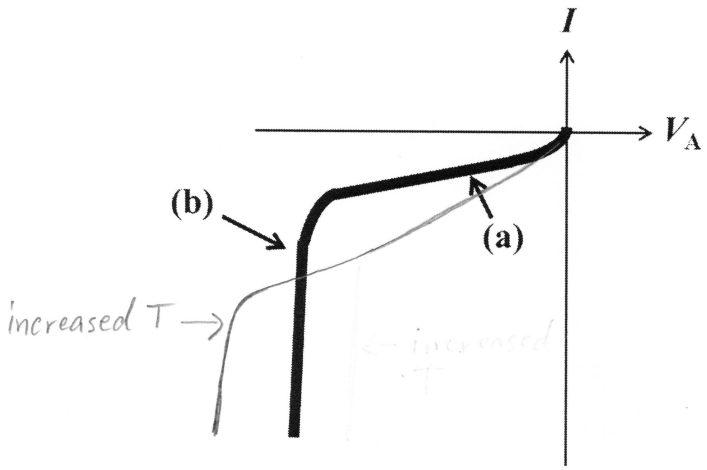
$\Rightarrow e^{qV_A/kT} = 10^{10}$

a) What is the magnitude of the applied bias voltage, V_A? [3 pts]
$(kT/q)\cdot ln(10) = 0.06$ V

$e^{qV_A/kT} = 10^{10} \Rightarrow V_A = \frac{kT}{q} \ln(10^{10}) = 10 \cdot \frac{kT}{q} \ln(10) = \underline{0.6\,V}$

b) Sketch the hole and electron current density components (J_P and J_N) on the plot provided above. [4 pts]
The n side is more heavily doped, so J_N will be larger than J_P within the depletion region.

Problem 3 [5 points]
The reverse-bias I-V characteristic of a non-degenerately doped pn junction diode maintained at $T = 300$K is shown below. Indicate the causes of the indicated non-ideal behaviors below:



(a) Net generation in and within one minority-carrier diffusion length of depletion region. [2 pts]

(b) Avalanche breakdown [1 pts]

(c) Show how the characteristic would change if the temperature were to be increased. [2 pts]