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

EE 105: Microelectronic Devices and Circuits Spring 2013

MIDTERM EXAMINATION #1

Time allotted: 45 minutes

NAME: ____________________ ____________________

STUDENT ID#: ________________

INSTRUCTIONS:

1. **Unless otherwise stated, assume**
    a. **temperature is 300 K**
    b. **material is Si**
2. **SHOW YOUR WORK. (Make your methods clear to the grader!)** Specially, while using chart, make sure that you indicate how you have got your numbers. For example, if reading off mobility, clearly write down what doping density that corresponds to.
3. **Clearly mark (underline or box) your answers.**
4. **Specify the units on answers whenever appropriate.**

SCORE: 1 ________ / 15

2 ________ / 15

Total ________ / 30

PHYSICAL CONSTANTS

Description	Symbol	Value
Electronic charge	q	1.6×10^{-19} C
Boltzmann's constant	k	8.62×10^{-5} eV/K
Thermal voltage at 300K	$V_T = kT/q$	0.026 V

$V_T\ln(10) = 0.060$ V at T=300K

PROPERTIES OF SILICON AT 300K

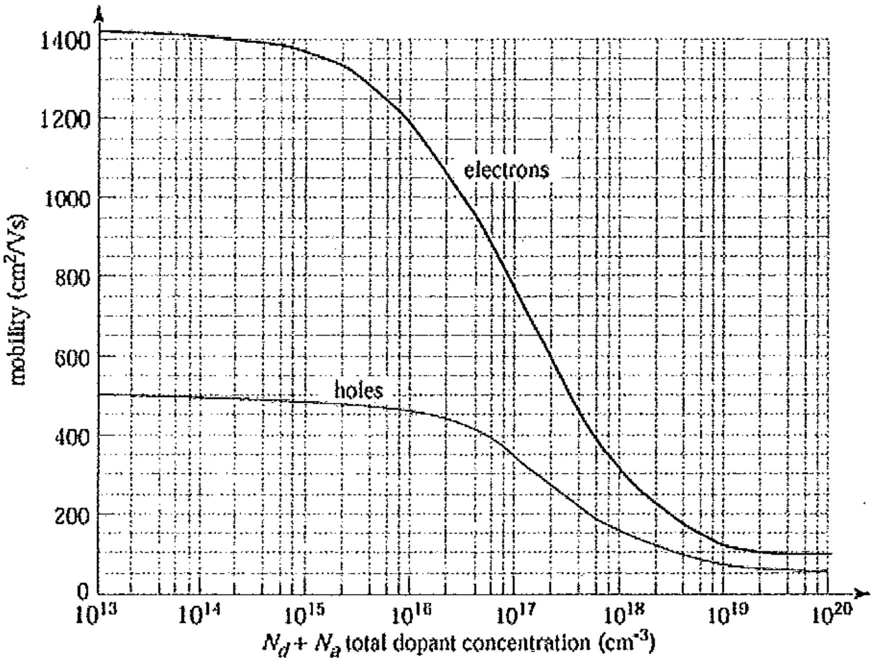
Description	Symbol	Value
Band gap energy	E_G	1.12 eV
Intrinsic carrier concentration	n_i	10^{10} cm^{-3}
Dielectric permittivity	ε_{Si}	1.0×10^{-12} F/cm

Electrostatics: $\frac{dE}{dx} = \frac{\rho}{\varepsilon}$ $\quad E = -\frac{dV}{dx}$

Depletion region Width: $W = \sqrt{\frac{2\varepsilon}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)\left(V_{bi}-V_{Applied}\right)}$

Reverse saturation current of a diode, $J_S = qn_i^2\left(\frac{D_n}{N_A L_n}+\frac{D_p}{N_D L_p}\right)$

Electron and Hole Mobilities in Silicon at 300K



Prob 1. [15]

(a) [12 pts] A Si sample is doped first with **B** to 10^{17} /cm^3.

(i) [2 pts] Find out the number of electrons and holes.

$$n = \frac{n_i^2}{N_A}$$

$$= \frac{10^{20}}{10^{17}}$$

$$\boxed{n = 10^3/cm^3}$$

$$\boxed{p = 10^{17}/cm^3}$$

Boron is an acceptor

(b) [10 pts] Now the Si sample is further doped with **As** to 2x 10^{17} /cm^3 and a voltage of 1 Volt is applied across the sample. Find out the amplitude of the current that will flow due to this voltage. Assume that the sample has the following dimensions: Length=10 µm, Width=1µm and thickness=1µm.

As is a donor.

$$N_A + N_D = (2+1)\times 10^{17} = 3\times 10^{17}/cm^3$$

$$n = (2-1)\times 10^{17} = 10^{17}/cm^3$$

$$\mu = 500\ cm^2/V\text{-}sec$$

$$\therefore \sigma = qn\mu_n = 1.6\times 10^{-19}\times 10^{17}\times 500$$

$$= 8\ \Omega^{-1}\,cm^{-1}$$

$$\rho = \frac{1}{\sigma} = \frac{1}{8}\ \Omega\text{-}cm$$

$$\therefore R = \rho\, L/A = \frac{1}{8}\times \underbrace{10\times 10^{-4}}_{L} \times \frac{1}{\underbrace{10^{-4}}_{W}\times \underbrace{10^{-4}}_{t}}$$

$$= \frac{10^5}{8}\ \Omega$$

$$\therefore I = \frac{V}{R}$$

$$= \frac{1}{10^5/8}$$

$$= 8\times 10^{-5}\ A$$

$$\boxed{I = 80\ \mu A}$$

(c) [3 pts] What is the mechanism of current flow in a p-n junction diode under (i) forward and (ii) reverse bias. Simply mention the mechanisms.

(i) forward bias → diffusion

(ii) reverse bias → drift

Prob 2: [15 pts]

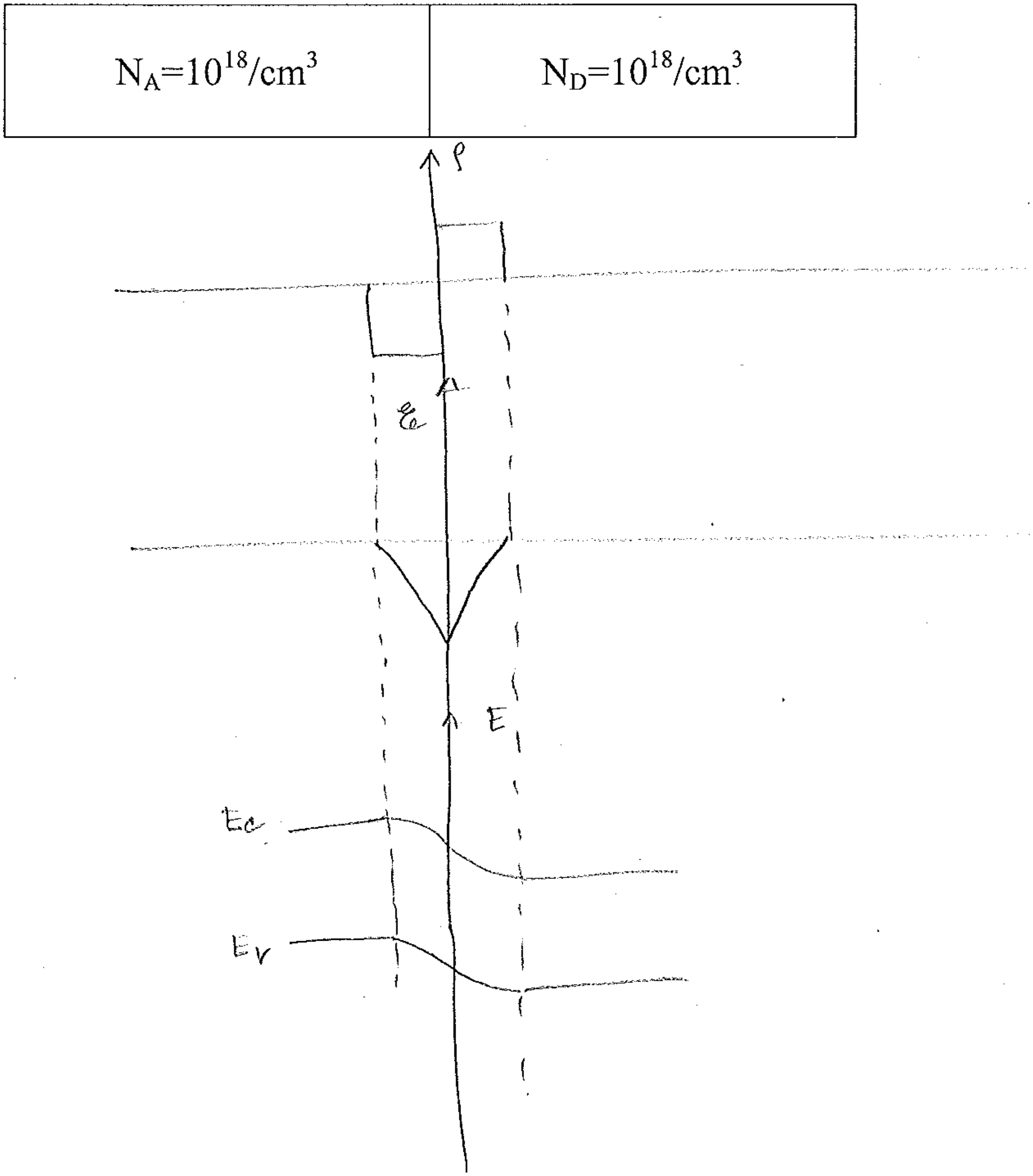
(a) [3 pts] For the following p-n junction diode, roughly sketch the

(i) charge density profile

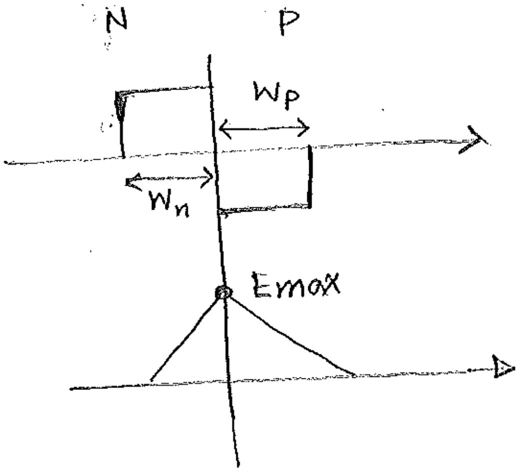
(ii) electric field profile

(iii) energy band diagram

across the junction.



(b)[8 pts] A p-n junction has to be designed such that the width of the depletion region on the N side is 0.212 μm, the built in potential is 0.72 V and the maximum electric field at the junction is 3.4x10⁴ V/cm. What doping density on the p and n side will have to be used to design such a diode? What is the capacitance of this diode?



$$\frac{\partial E}{\partial x} = \frac{\rho}{\varepsilon} \; ; \; E = -\frac{\partial V}{\partial x}$$

$$\varepsilon E_{max} = q N_D W_n$$ [area under the charge density profile]

$$\therefore N_D = \frac{\varepsilon E_{max}}{q W_n} = \frac{10^{-12} \times 3.4 \times 10^{4}}{1.6 \times 10^{-19} \times 0.212 \times 10^{-4}} = \frac{\overset{10}{\cancel{3.4}}}{0.339} \times \overset{10^{15}}{\cancel{\frac{10^{-8}}{10^{-23}}}} \cong 10^{16}/cm^3$$

$$V_0 = \frac{1}{2} E_{max} W_n + \frac{1}{2} E_{max} W_p$$ [from area under ε field plot]

$$= \frac{1}{2} E_{max} (W_n + W_p) = \frac{1}{2} E_{max} W$$

$$\therefore W = \frac{2V_0}{E_{max}} = \frac{2 \times 0.72}{3.4 \times 10^4} = 0.4235 \ \mu m$$

$$\therefore W_p = W - W_n = 0.4235 - 0.212 \cong 0.212 \ \mu m = W_n$$

$$\therefore \boxed{N_A = \frac{\varepsilon E_{max}}{W_p} \cong 10^{16}/cm^3 = N_D}$$

$$\boxed{C = \frac{\varepsilon}{W} = \frac{10^{-12}}{0.4235 \times 10^{-4}} = 2.36 \times 10^{-8} \ F/cm^2 = 23.6 \ nF/cm^2}$$

at and around $V_D = 0$ V!

(c) [4 pts] What are the different mechanisms of reverse bias breakdown in a p-n junction diode? What are the main physical mechanisms responsible for each of these breakdown mechanisms?

Two main mechanisms:

(i) zener: happens due to tunneling when the diode is heavily doped

(ii) avalanche: happens in a lowly doped junction at high reverse bias when the electrons can gain enough kinetic energy to generate additional electrons through avalanche.