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

MIDTERM EXAMINATION

EE 130/230A: Spring 2016
Time allotted: 60 minutes

NAME: Solution ______________________

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.
    - Clearly write down any assumption that you have made.
- **Clearly mark (underline or box) your answers.**
3. **Specify the units on answers whenever appropriate.**

SCORE: 1 __________ **/ 20**

2 __________ **/ 20**

Total __________ **/ 40**

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

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

USEFUL NUMBERS

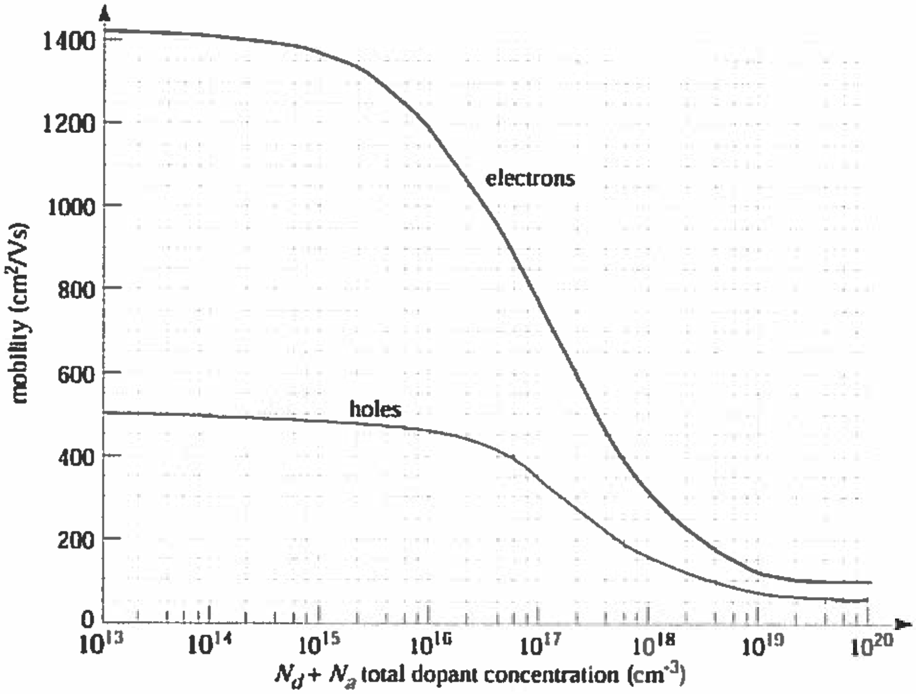
$V_T \ln(10) = 0.060$ V at T=300K

Depletion region Width:

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

$$n_i = \sqrt{N_c N_v}\exp(-E_G/2k_B T)$$

Electron and Hole Mobilities in Silicon at 300K



Prob 1 [20 pts].

(a) **[8 pt]**

(i) **What kind of dopant would one use to dope an III-V semiconductor like GaAs. What determines whether or not it is a donor or acceptor? [4 pt]**

(ii) **After doping a Si by donors it is found that the carrier concentration does not change appreciably from 0K-400K. How can this happen? Explain by drawing Ec, Ev and the energy level for the dopants, Ed. [4pt]**

(i) group IV elements such as Si.

The relative size of the dopant atom compared to the constituent atoms determine which of the two species will be replaced by the dopant and hence whether the dopant will act as a donor or acceptor.

(ii) This can happen if the doping level is so that the energy levels for dopants, Ed is inside the conduction band. This will mean the donors can ionize without needing help from temprature.

The doping level N_D must also be much higher than n_i at room temperature.

(b) **[6 pt]** A compensated Si sample was measured and it was found that the conductivity is σ=16 (ohm-cm)$^{-1}$ and mobility of 375 cm^2/V-sec. Find out the doping concentration of the sample.

$\sigma = e\,|N_D - N_A|\,\mu$ → it is not known if the Si was n-type or p-type after compensation.

$|N_D - N_A| = \dfrac{\sigma}{e\mu}$

$$\therefore \cancel{\mu =} \; = \frac{16}{1{\cdot}6 \times 10^{-19} \times 375} = \frac{10^{20}}{375} = \frac{1}{3{\cdot}75} \times 10^{18}/cm^3$$

$$= 2{\cdot}67 \times 10^{17}/cm^3$$

From the μ vs. $N_D + N_A$, $\mu = 375\ cm^2/V\text{-}sec$ can occur

for holes at $N_D + N_A = 10^{17}/cm^3$

for electrons at $N_D + N_A = 8 \times 10^{17}/cm^3$

This means the Si has to be n-type.

$N_D + N_A = 8 \times 10^{17}$

$N_D - N_A = 2{\cdot}67 \times 10^{17}$

$$\therefore \boxed{\begin{aligned} N_D &= 5{\cdot}335 \times 10^{17}/cm^3 \\ N_A &= 2{\cdot}67 \times 10^{17}/cm^3 \end{aligned}}$$

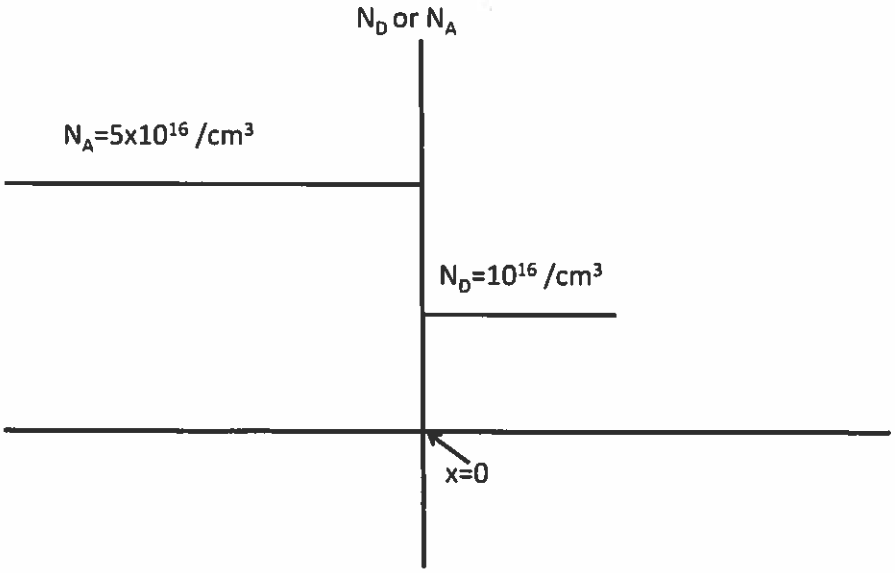
(c)[**6 pts**] Please indicate 'True' or 'False'

Phenomenon	True/False
Impurity scattering goes up at higher temperature	F
In a solid electrons and holes see same electrostatic potential	F
At equilibrium flows of electrons and holes balance each other to give zero current	F
In Si electron velocity saturates at high electric field due to impurities	F
When low level injection holds, $np=n_i^2$ also holds	F
Diffusion depends on the total number of carriers and not only on the excess carriers	F

Prob 2: [20 pts] For the P-N junction diode shown below, answer the following questions. Note that the picture shown below only shows the amplitude (and not '**sign**') of the doping concentrations.

While drawing the diagrams,

- please be careful to indicate ***relative quantities*** (such as the amplitude of charge densities, the curvature of potential profiles, the width of the depletion region etc)
- For each diagram you need to draw quantities at both the P and N sides
- If you are using the same diagram to answer multiple questions, please mark the answers clearly.



(i) [2 pt] Draw energy band profile at zero bias

(ii) [3 pt] Calculate the built in potential

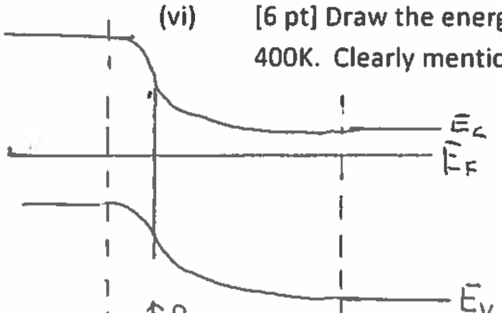
(iii) [3 pt] Draw the electric field and potential profile

(iv) [3 pt] Calculate the depletion region width

(v) [3 pt] Draw the energy band profile if a reverse bias of |Vd| is applied.

(vi) [6 pt] Draw the energy band profile at zero bias if the temperature is increased from 300K to 400K. Clearly mention all the approximations.

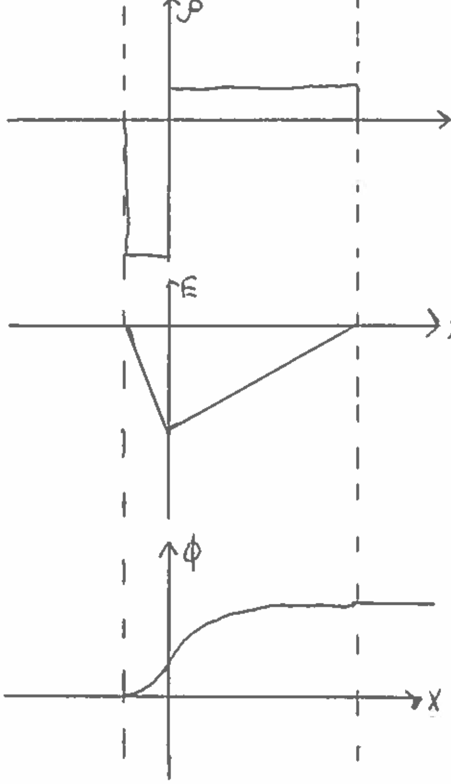
(i)



(ii) $V_{bi} = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2} = 0.259 \ \ln \frac{5\times10^{32}}{10^{20}}$

$$\boxed{V_{bi} = 0.76V}$$

(iii)



(iv) $W_{dep} \simeq \sqrt{\frac{2\varepsilon_{si}}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)V_{bi}}$

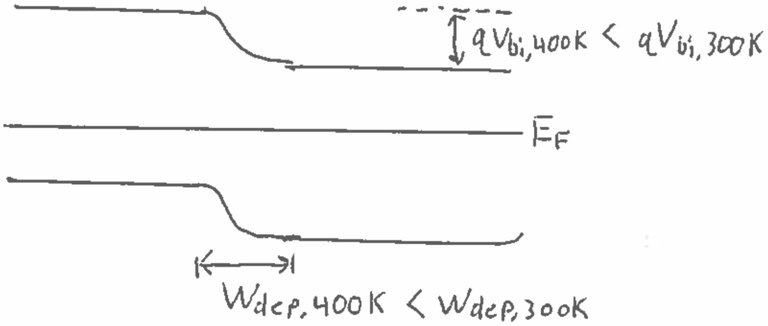
$$\cong \sqrt{\frac{2\times10^{-12}}{1.6\times10^{-19}} \times \frac{1.2}{10^{16}} \times 0.76} = \sqrt{\frac{1.8}{1.6}\times10^{-9}} = 3.16\times10^{-5} \text{cm}$$

$$\boxed{W_{dep} \cong 316\text{nm}}$$

(vi) $V_{bi} = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2}$

n_i^2 goes up with temperature, therefore V_{bi} decreases. (See Pierret Fig. 2.20)

With smaller V_{bi}, W_{dep} decreases.



(v)