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

MIDTERM EXAMINATION
EE 130/230A: Spring 2015
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:

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

Law of the Junction: $np = n_i^2\left(e^{qV_D/kT}\right)$

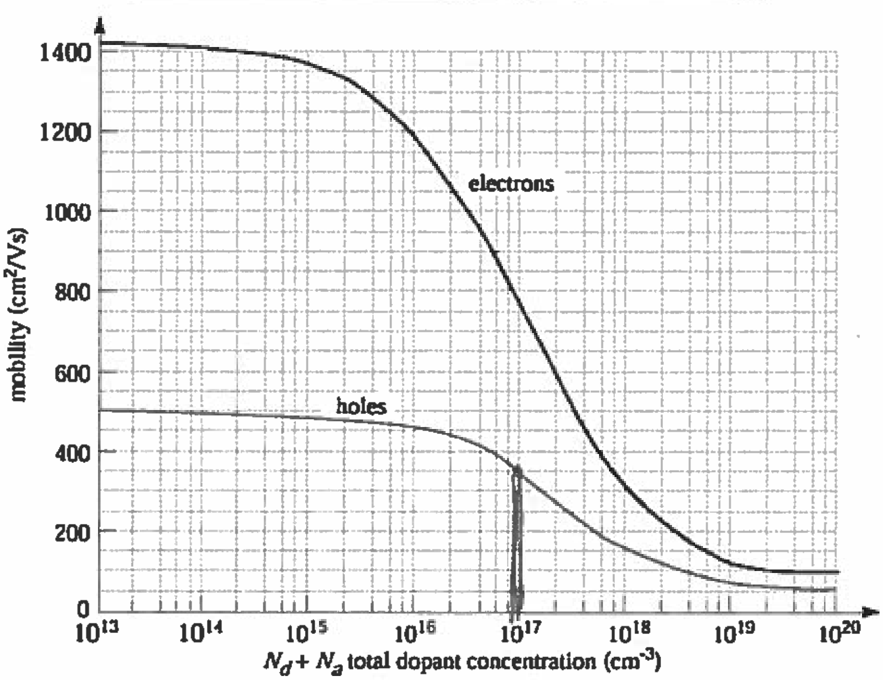
N_c=2.8x10^{19}/cm^3

N_V=1.04x10^{19}/cm^3

Current in a PN junction:

$$I = A\left(q\frac{D_p}{L_p}p_{n0} + q\frac{D_n}{L_n}n_{p0}\right)(e^{qV_D/kT} - 1)$$

Electron and Hole Mobilities in Silicon at 300K



Prob 1 [20 pts].

(a) [5 pt]

(i) What is effective mass [2pt]

(ii) Why can the effective mass be different for electrons and holes? [3pt]

(i) Due to atomic structure and how the atoms interact with each other, electrons moving through a solid experiences a specific potential energy which dictates the mass of a wave associated with the electron. This mass is different from what is experienced by the electron at free space where there is no potential. This mass is called the 'effective mass'.

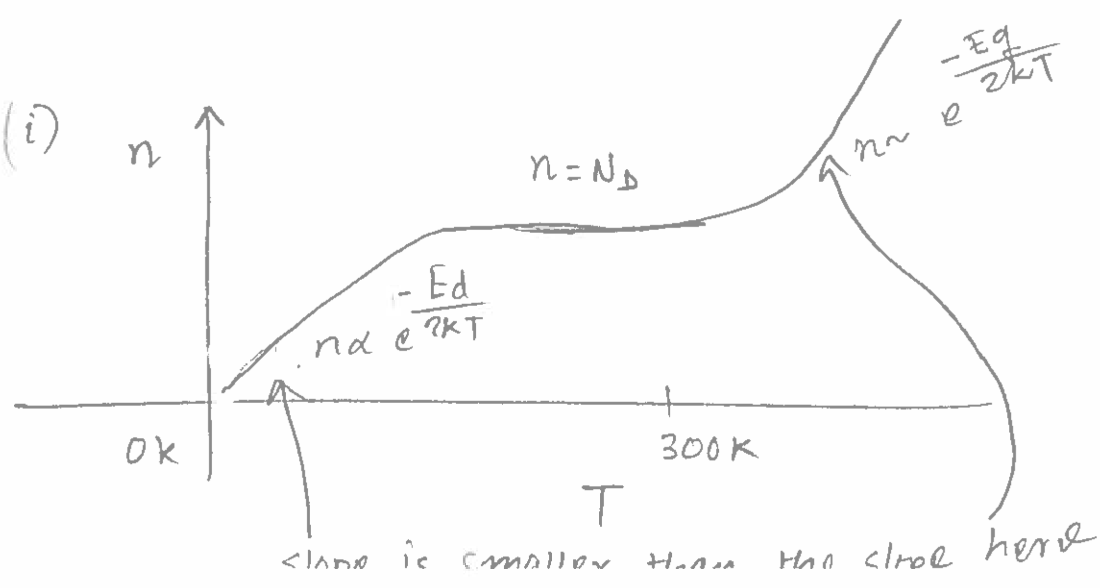
(ii) Since the potential energy felt by electrons is different in conduction and valence bands, the effective mass can be different for electrons and holes

(b) [10 pt]

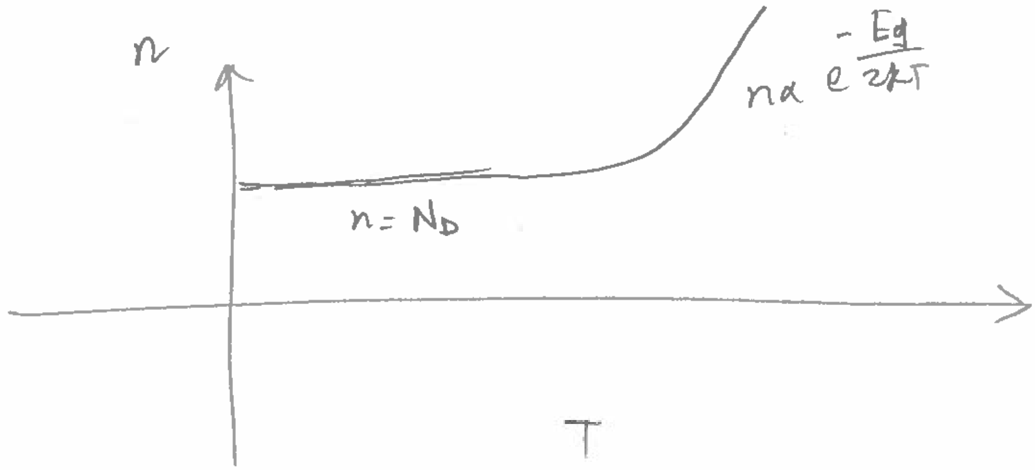
(i) [5pt] Draw carrier concentration vs. temperature in a n-type non-degenerately doped Si. Show the plot for a temperature range that starts from 0 K and goes up to much above the room temperature. In the plot clearly show the functional dependence of different regions.

(ii) [5 pt] Do the same as (i) but for a degenerately doped Si.

(i)



(ii)



(c) **[5 pt]** A doped Si film has a resistivity of 0.17 ohm-cm and a Diffusion constant of 9.75 cm^2/sec. Comment on the type of doping of this film (n or p type). Clearly justify your answer.

$$\rho = 0.17\ \Omega\text{-cm} = \frac{1}{en\mu}$$

$$D = 9.75\ cm^2/sec = \frac{kT}{q}\mu$$

$$\Rightarrow \mu = \frac{D}{kT/q} = \frac{9.75 \times 10^3}{26}$$

$$= 375\ cm^2/V\text{-sec}$$

$$\therefore n = \frac{1}{e\rho\mu} = \frac{1}{1.6\times10^{-19} \times 0.17 \times 375}$$

$$= 9.8\times10^{16}\ cm^{-3}$$

From the μ- Doping plot, $(375,\ 9.8\times10^{16})$ corresponds to holes.

So the doping was p-type

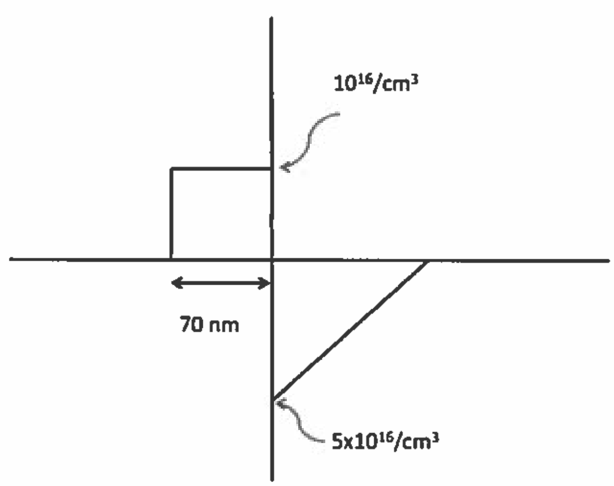
Prob 2.

(a) [4 pts] In a P^+N junction diode, what are the mechanisms of current flow in the forward and reverse bias?

(i) forward bias: Diffusion

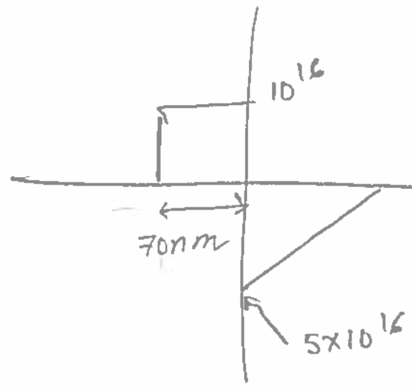
(ii) reverse bias: Drift

(b) [12 pts] Consider the following diode for which the charge profile of the depletion region is shown in the following figure.

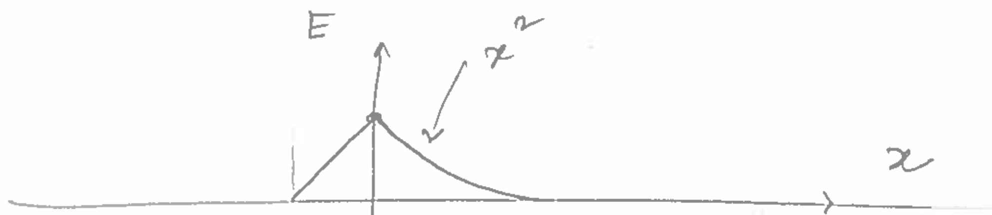


(not drawn to scale)

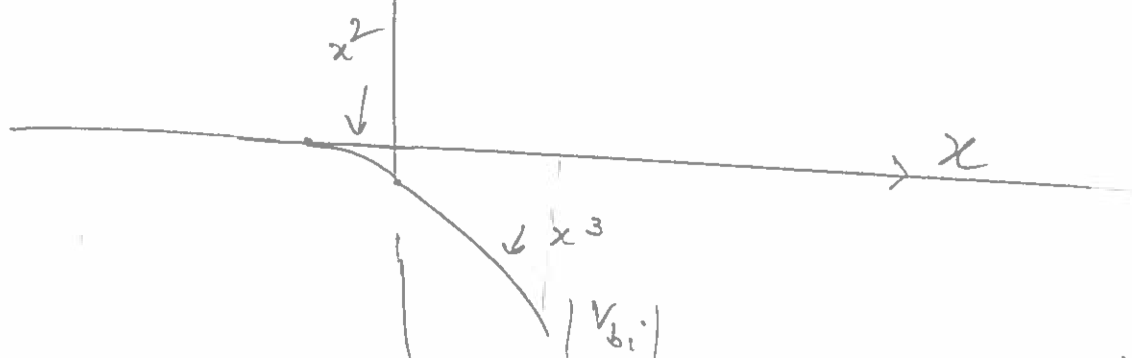
(i) [2 pt] Draw the electric field profile
(ii) [2 pt]Draw the potential profile
(iii) [2 pt]Draw the energy band diagram
(iv) [6 pt]Calculate the depletion region width



(i)



(ii)



(iii)

(iv) $\frac{1}{2}\times(5\times10^{16})\times w_p = 10^{16} \times N$

$\therefore w_p = \frac{10^{16}\times 2}{5\times10^{16}}\times(70nm$

$= 28$ nm

$\therefore W = 70+28 = 98$ nm

(c) [4 pts] Say two identical P^+N diodes are made of Si and Germanium (Eg=0.67 eV). The material properties are carefully controlled such that the Diffusion constants and recombination lifetimes for holes are also identical for both. Which diode will give more current in the forward bias? Which one will give more current in the reverse bias? Clearly justify your answer.

For the P^+N Diode:

$$I_D \propto qA \frac{n_i^2}{N_A} \frac{D_h}{L_h} \left(e^{\frac{eV_D}{kT}} - 1 \right)$$

$$\frac{D_h}{L_h} = \frac{D_h}{\sqrt{D_h \tau_h}} = \sqrt{\frac{D_h}{\tau_h}}$$

So, if both diodes have same doping profiles:

$$\frac{I_D^{Si}}{I_D^{Ge}} = \frac{n_{i\,Si}^2}{n_{i\,Ge}^2}$$

since $n_{i\,Ge}^2 >> n_{i\,Si}^2$ due to smaller band gap,

I_D^{Ge} will be larger for both forward and reverse bias.