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

MIDTERM EXAMINATION 2
EE 130/230A: Spring 2016
Time allotted: 60 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.
   - 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:

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

Current in a PN junction:

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

Electron and Hole Mobilities in Silicon at 300K

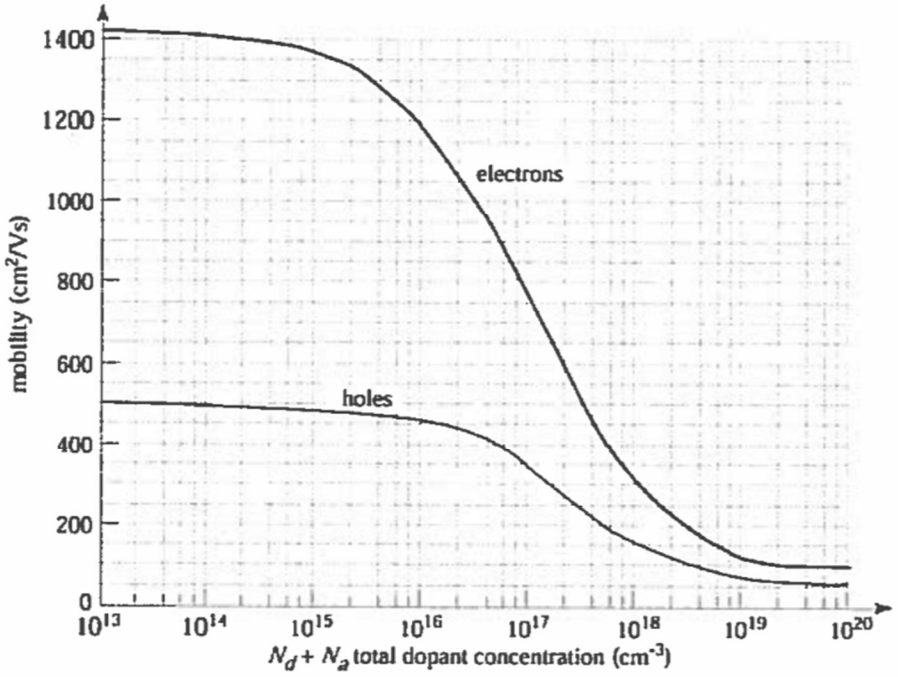


Table1: Barrier Heights of Different Metals to Si

Metal	Mg	Ti	Cr	Ni	W	Mo	Pd	Au	Pt
ϕ_{Bn} (V)	0.4	0.5	0.61	0.61	0.67	0.68	0.77	0.8	0.9
ϕ_{Bp} (V)		0.61	0.5	0.51		0.42		0.3	
Work Function ψ_m (V)	3.7	4.3	4.5	4.7	4.6	4.6	5.1	5.1	5.7

Table 2:Barriet Heights of Different Silicide Alloys to Si

Silicide	$ErSi_{1.7}$	HfSi	$MoSi_2$	$ZrSi_2$	$TiSi_2$	$CoSi_2$	WSi_2	$NiSi_2$	Pd_2Si	PtSi
ϕ_{Bn} (V)	0.28	0.45	0.55	0.55	0.61	0.65	0.67	0.67	0.75	0.87
ϕ_{Bp} (V)		0.45	0.55	0.49	0.45	0.45	0.43	0.43	0.35	0.23

Problem 1 [20 pts]

(a) [12 pts] Consider a metal-Si junction. It is known that ϕ_{Bn}=0.8 eV. It is also known that the built-in potential is 0.2eV and ϕ_{ms}<0.

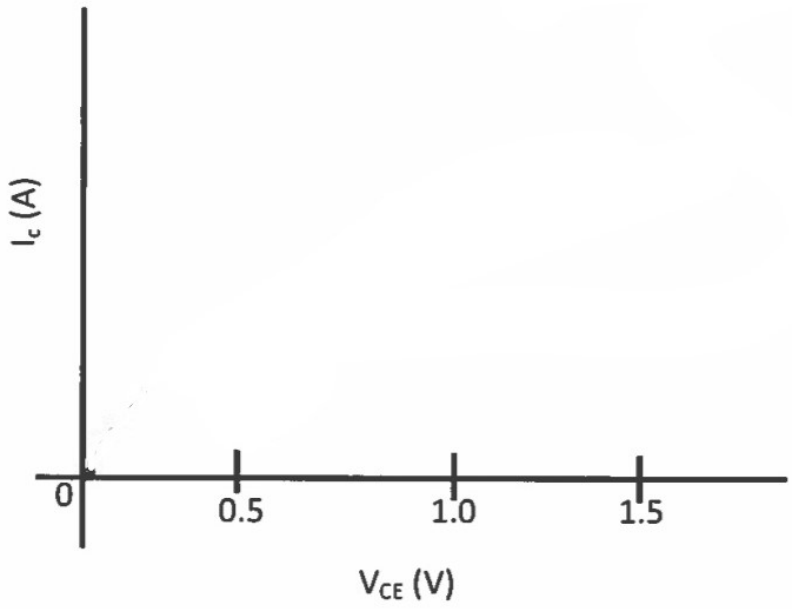
(i) [4 pts] Draw the energy-band diagram of the junction at equilibrium.

(ii) [4 pts] Find out the type and doping level of Si.

(iii) [6 pts] Draw the current voltage characteristics. Explain how current flows by clearly pointing out the mechanism and the directions that electrons and holes are flowing for each polarity of the voltage. For this, positive voltage means that the positive terminal of the battery is connected to the metal and positive current means the current is flowing from the metal to the semiconductor.

(b) [6 pts]

(i) [2 pts] A NPN transistor is biased such that V_{BE}=0.5 V. Draw the collector current as a function of V_{CE} for an ideal transistor in the following:



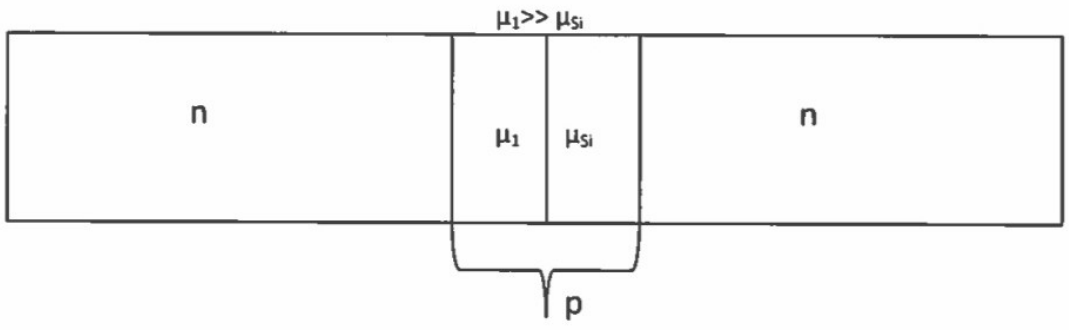
(ii) [4pts] How will the plot in (i) change for a realistic short base transistor? Show by drawing in the same plot in the previous page. What is reason behind this change? What measures are taken to minimize this effect?

Problem 2. [20 pts]

(a) [10 pts]Consider a NPN bipolar junction transistor as shown below. To increase the collector current, a thin layer of a very high mobility material is inserted into the short base. You can assume that there is no band bending at the interface of these two materials. You can assume that doping level is the same throughout the base.

(i) [6 pts] Draw the excess minority carrier distribution in the base by clearly showing the two boundaries. Justify your answer.

(ii) [4 pts] Will this appreciably increase the collector current? Why or why not?



(b) [6 pt]

(i) [2 pt] Draw the energy band diagram of a MOS capacitor at the flatband condition. Assume that the Si has been doped p-type and the gate is made of a metal with $\phi_{ms}<0$. Draw the charge density profile at the semiconductor for this bias condition.

(ii) [2 pt] Repeat problem (i) when V_{gs} is made more negative than the flatband voltage.

(iii) [2 pt] When V_{gs} is 3V more negative than the Flatband voltage, what is the voltage drop across the oxide?

(c) Please indicate 'TRUE' or 'FALSE'

Phenomenon	TRUE/FALSE
In the depletion mode, the semiconductor charge is primarily based on immobile ions	
For a MOS capacitor with p doped body, one must have Vgs>0 to reach the depletion mode	
After threshold voltage is reached any further increase in gate voltage almost completely drops across the semiconductor	
Beyond the threshold voltage free charges increases exponentially as a function of gate voltage	