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

Final

EE 130/230A: Spring 2016
Time allotted: 75 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**
3	_________	**/ 20**
Total	_________	**/ 60**

PHYSICAL CONSTANTS

Description	Symbol	Value
Electronic charge	q	$1.6 \cdot 10^{-19}$ C
Boltzmann's constant	k	$8.62 \cdot 10^{-5}$ 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}	$1.0 \cdot 10^{-12}$ F/cm

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

$N_c = 2.8\text{x}10^{19}/\text{cm}^3$

$N_V = 1.04\text{x}10^{19}/\text{cm}^3$

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:

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

MOSFET:

$V_g - V_{fb} = V_{ox} + V_{semiconductor}$;

at threshold: $V_{semiconductor} = 2(kT/q)\log(N/n_i)$

$$I_D = \frac{W}{L}\mu_n C_{ox}\left[(V_g - V_t)V_D - \frac{V_D^2}{2}\right]$$

$$I_{Dsat} = \frac{W}{2L}\mu_n C_{ox}(V_g - V_t)^2;$$

Electron and Hole Mobilities in Silicon at 300K

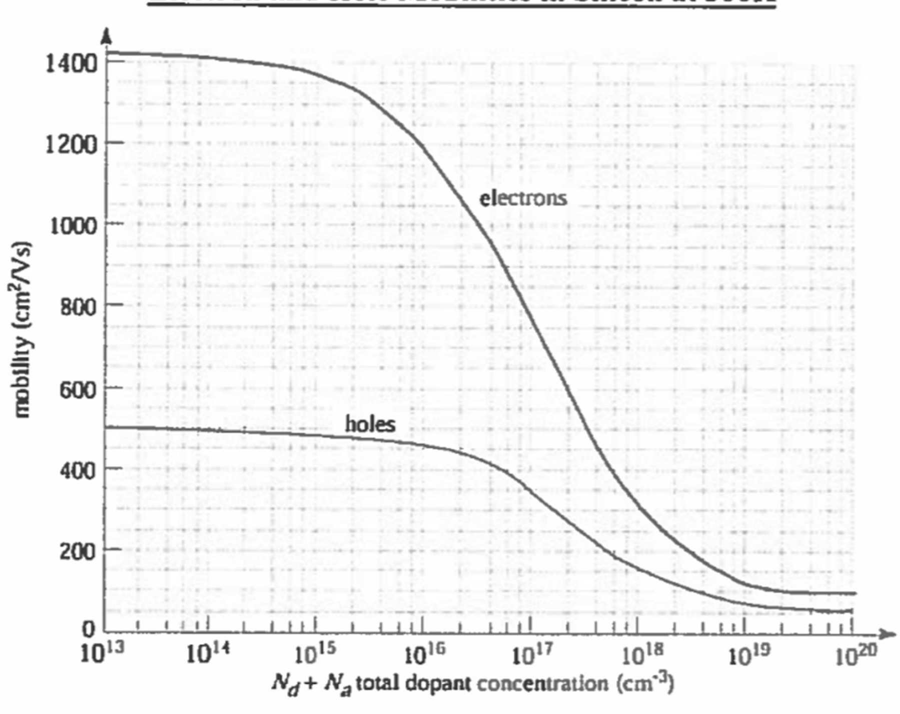


Table1: Barrier Heights of Different Metals to Si

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

Prob 1a.[10 pts] Consider a Si PN junction diode whose N-side is heavily doped such that the E_f aligns with the conduction band. From C-V measurement, the built in potential is found to be 0.8eV.

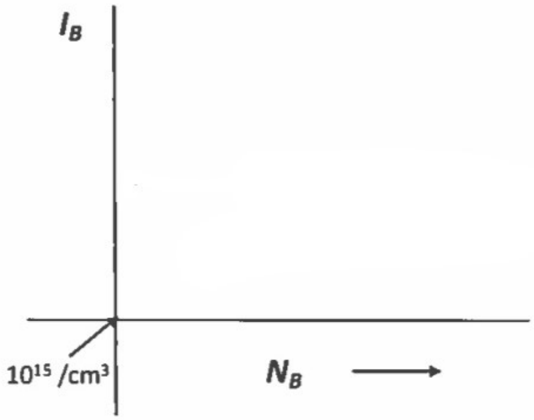
(i) What is the doping on the p-side?

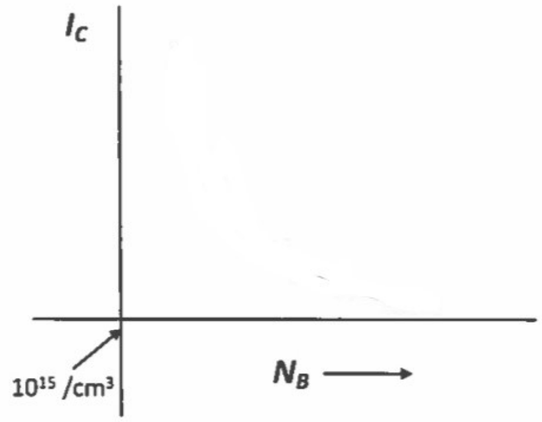
(ii) Draw the energy band diagram for the diode when a large reverse bias has been applied. Clearly show the Fermi levels on each side.

(iii) What is the mechanism of current flow under the condition specified in (ii)? Clearly show which direction the particles (electrons or holes or both) are flowing.

Prob 1b [10 pts] Consider a PN junction diode has been fabricated but rather than using crystalline Si, it is made of ***amorphous Si***. Draw the current-voltage characteristics of this device. In the same diagram also draw the current-voltage characteristics of a diode that has exactly the same doping levels for the N and P side but made of crystalline silicon. Clearly point out any differences and the rationale for those differences.

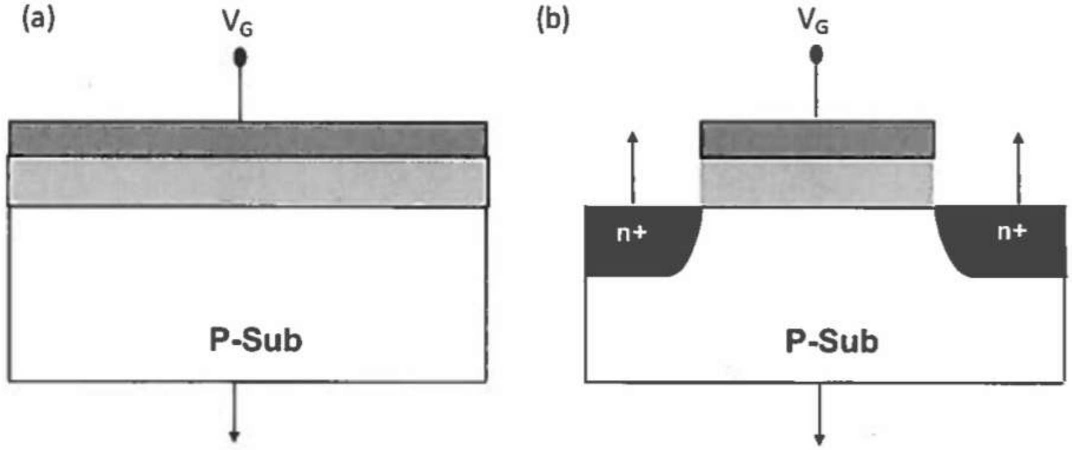
Prob 2a [5pts] Consider a few NPN transistors are made where the base doping is varied over a certain range. In the following, plot how I_C and I_B will vary as a function of base doping if all the transistors are biased in the forward active mode. Justify your answer.





Prob 2b [5 pts] Consider, for a NPN BJT, the emitter has been replaced by a material which has a larger bandgap compared to base and collector. Discuss how this will change (increase/decrease/no effect) I_C and I_B. If the collector is further replaced by a larger bandgap material than the base how would that affect I_C and I_B?

Prob 2c [10 pts] For each of the two structures shown in the following draw the (i) *free carriers* vs. V_G and (ii) Capacitance vs. V_G plots looking from the gate. Justify your answers.



Prob 3a [8 pts] Draw the log I_D-Vgs plot for (i) a long channel and a (ii) short channel transistor. In each case draw two curves, one for Vds=0.05 V and one for Vds=1 V. Clearly point out the differences and the reasons for those differences.

Prob 3b. [4 pts] Consider two MOSFETs one with a higher body doping than the other. For the same substrate bias, which one will have a larger shift in the threshold voltage? Why?

Prob 3c [4 pts] How does the body doping need to change (increase or decrease) as channel length is scaled down to account for the short channel effects? Does changing body doping affect any other parameter of the MOSFET?

Problem 2d [4 pts] Put an X mark in the 'True' of 'False' column for each question

	True	False
GIDL current is due to drift of electrons at high electric field at the drain end		
Using a metal gate increases the effective oxide capacitance		
V_T roll off affects the ON current more than the OFF current		
Once the velocity saturation is reached, the ON current no longer goes up with decreasing channel length.		