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

Final
EE 130/230A: Spring 2014
Time allotted: 90 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**

3 _________ **/ 20**

Total _________ **/ 60**

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

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

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

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

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:

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

MOSFET:

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

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

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

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

Electron and Hole Mobilities in Silicon at 300K

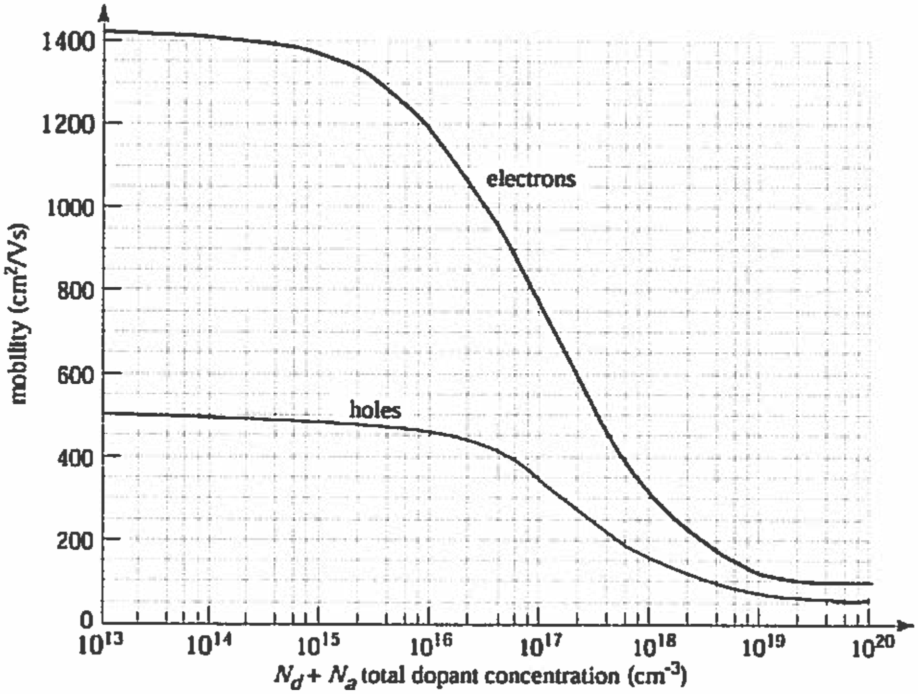


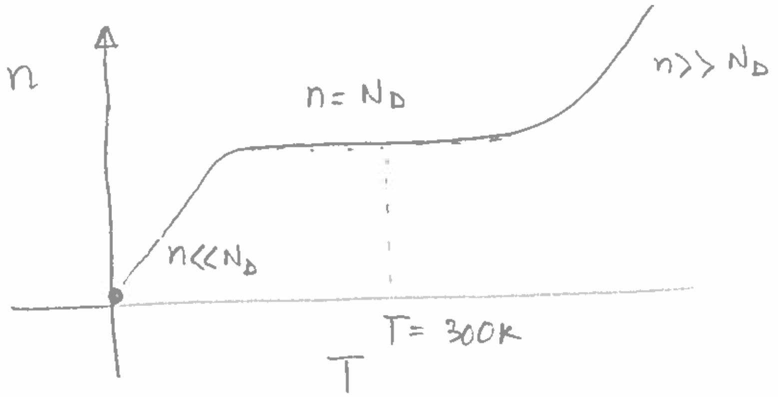
Table1: Barrier Heights of Different Metals to Si

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.[5 pts] Consider a Si sample that has been homogeneously doped with Donors to a concentration of N_D /cm^3. Plot the electron density as a function of temperature (starting from much below the room temperature to much above). Briefly explain the different regions of your plot.



$n \ll N_D$: at low T dopants cannot ionize and $n \cong n_i$ which increases exponentially with T.

$n = N_D$: at moderate T including room temperature

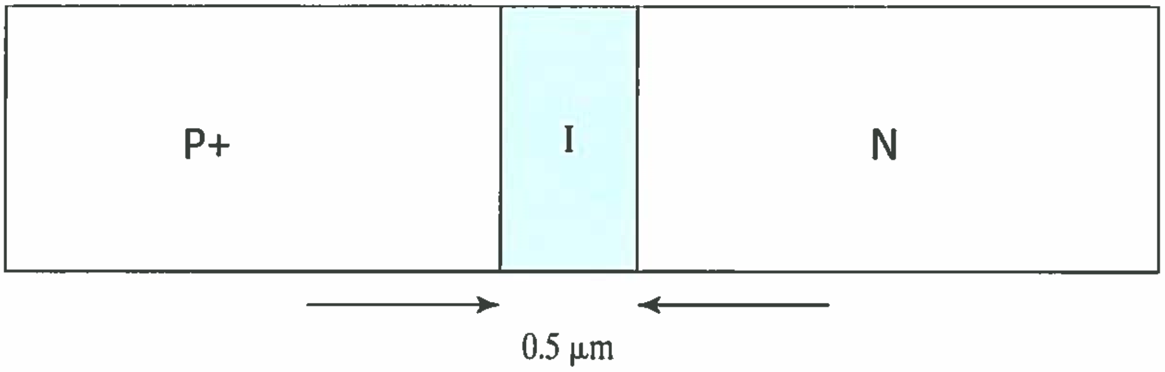
$$n = n_i + N_D \cong N_D$$

$n \gg N_D$: at very high T, ni again dominates $n = N_D + n_i$ and hence n increases exponentially with T.

Prob 1b[5 pts] Put an X mark in the 'True' of 'False' column for each question

	True	False
Current flow mechanism in a forward biased p-n junction is diffusion	X	
The maximum electric field in a p-n junction occurs on the p-side		X
Built in voltage for junction with larger area is also larger		X
Reverse bias current in a p-n junction increases with increasing temperature	X	
Both depletion and diffusion capacitance can be present in a forward biased p-n junction	X	

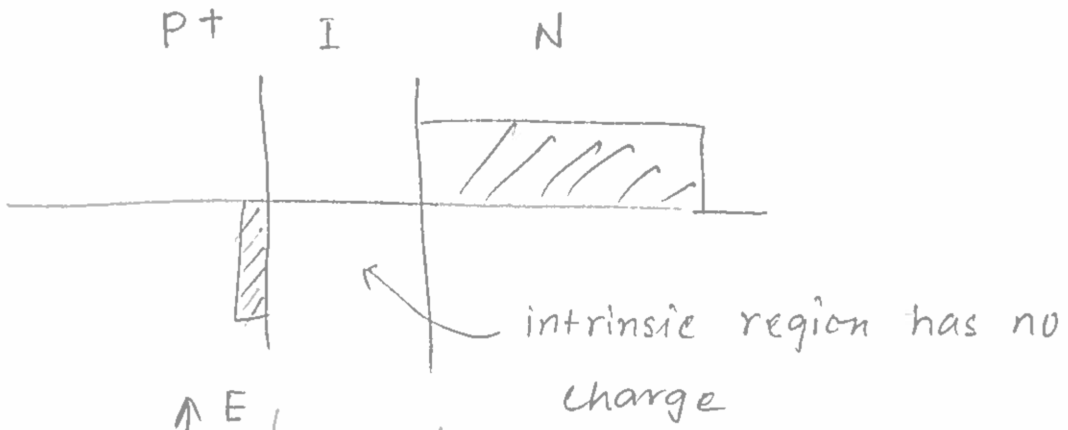
Prob 1c [10 pts].



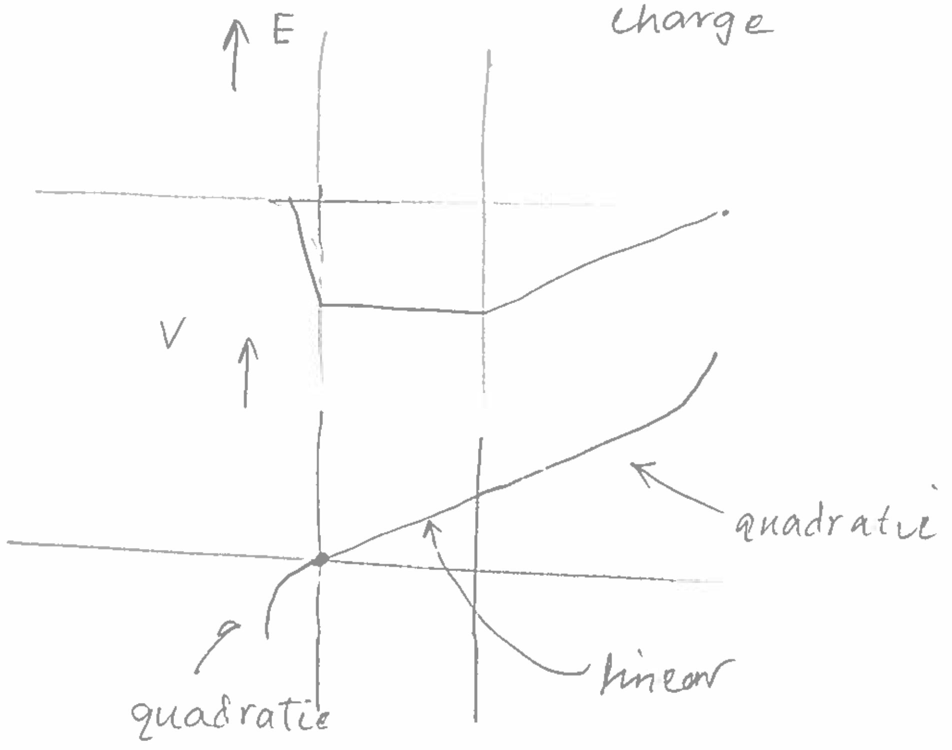
For the P$^+$IN diode shown above:

- (i) [2 pts] Draw the charge density profile along the position in the device
- (ii) [2 pts] Draw the potential profile along the position of the device
- (iii) [6 pts]Qualitatively draw the current voltage characteristic for reverse bias. You should change the reverse bias from small to very large values (**i.e.,strongly reverse biased conditions**). In the same plot draw the current-voltage characteristic (for reverse bias) for an identically doped P+N diode. Clearly justify your answer.

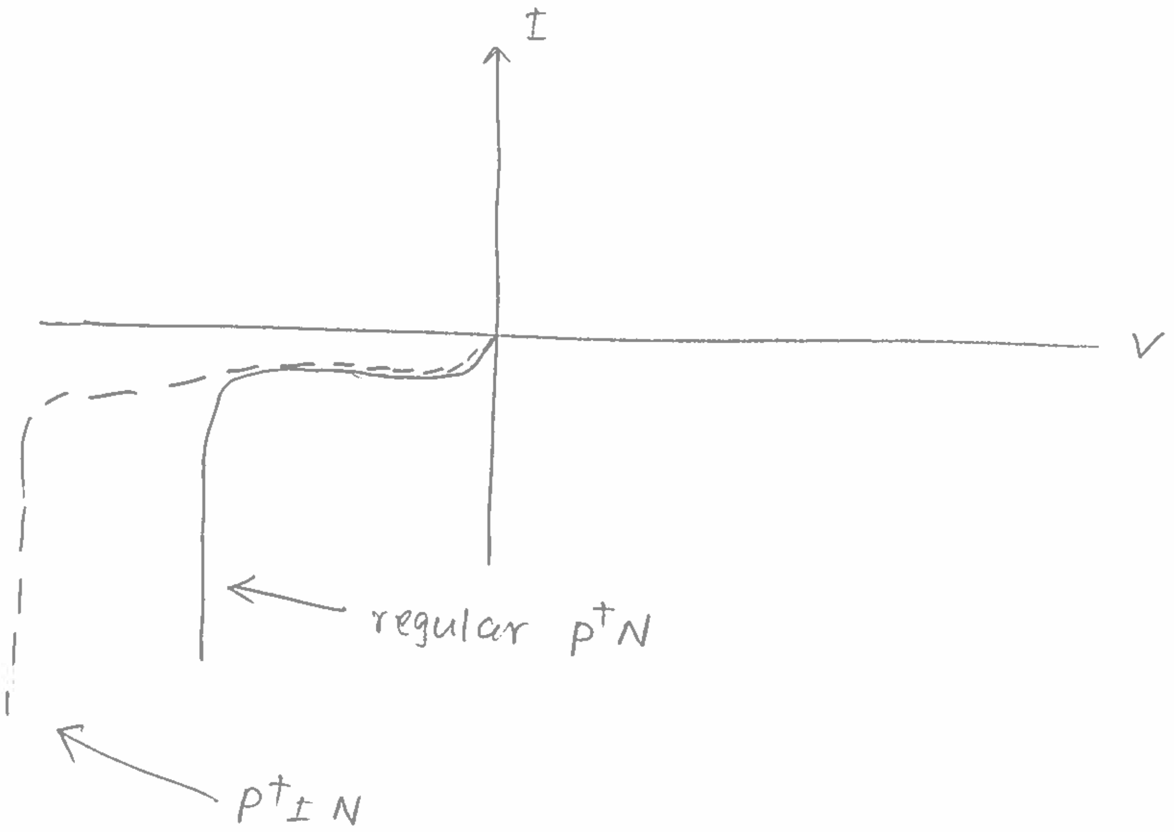
(i)



(ii)



(iii)



Note: I region is fully depleted

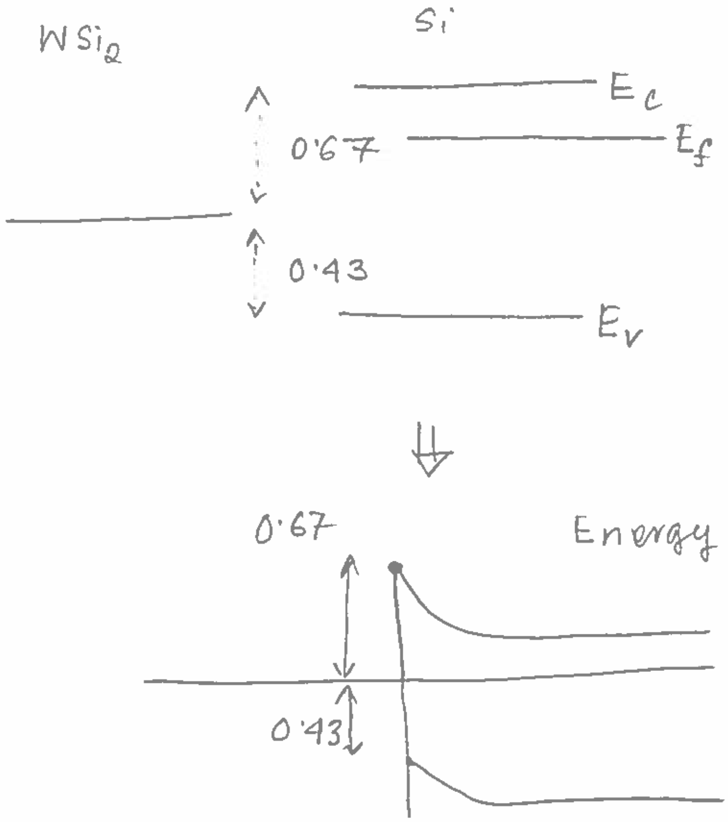
Due to added depletion region from I, it is harder for a tunnel current to flow. Therefore, the main breakdown mechanism for p^+IN is avalanch which requires larger voltage.

Prob 2a. [10 pts] Consider a Metal Semiconductor Schottky diode is fabricated with WSi_2 contact and a N-doped Si (N_D=$10^{19}$$cm^{-3}$).

(a) [5 pts] Draw the energy band diagram

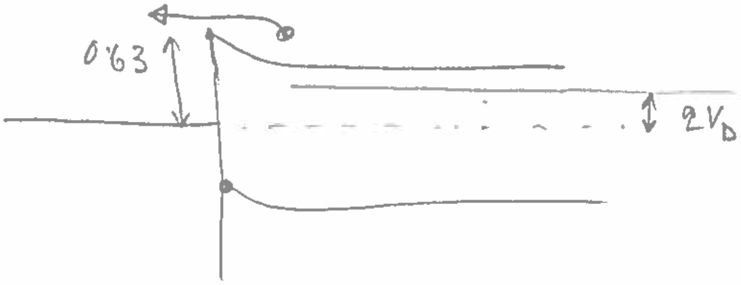
(b) [5 pts] Qualitatively explain how current flows when (i) a positive and (ii) a negative voltage is applied between the metal and the semiconductor.

(a)



Energy band diagram.

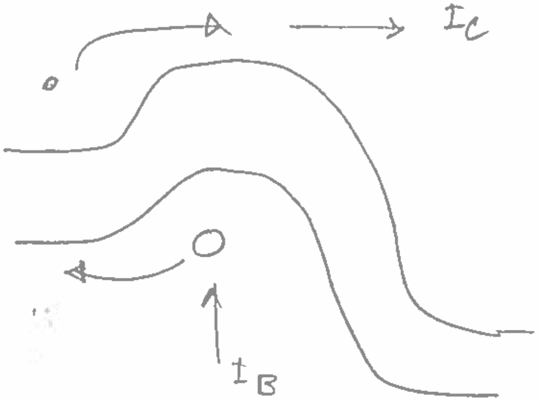
ⓑ (i) metal positive; semiconductor negative



$\bar{e}$ flow from semiconductor to metal. Current increases exponentially with voltage.

(ii) current flows from metal to semiconductor. Only electrons having energy larger than the barrier height can flow. As a result current is weakly dependent on voltage.

Problem 2b. [6 pts] Consider two NPN transistors A & B. A is made of a semiconductor material that has the same effective mass for electrons and holes. By contrast, B is made of a semiconductor where electrons have larger effective mass compared to holes. Which transistor will give larger current gain? Justify your answer.



In a NPN transistor,

I_C: carried by electrons

I_B : carried by holes

$\therefore I_C \propto \frac{1}{m_e}$

$I_B \propto \frac{1}{m_h}$

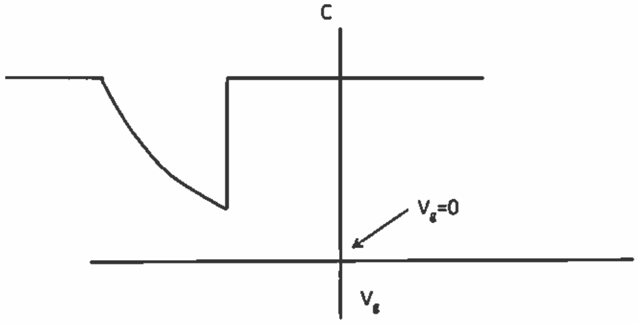
Therefore, if everything else is the same, Transistor A will give larger current.

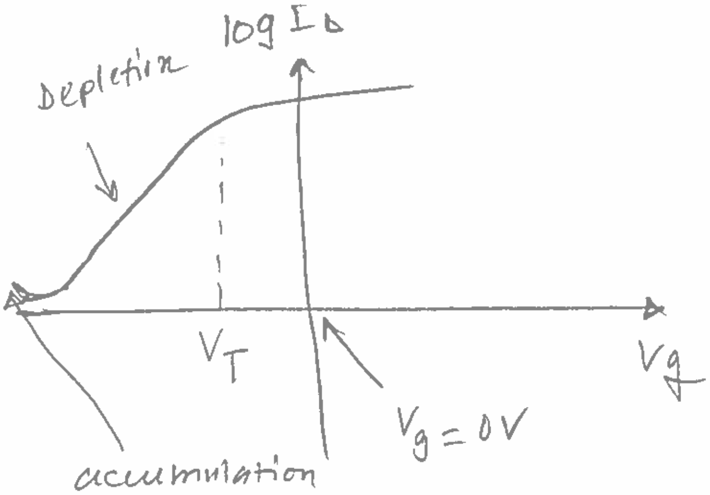
Problem 2c [4 pts] Put an X mark in the 'True' of 'False' column for each question

	True	False
GIDL happens only in short channel MOSFETs		X
DIBL happens only in short channel MOSFETs	X	
Body doping should go down as the channel length decreases		X
PN Junction leakage currents contribute to the OFF current of a MOSFET	X	

Problem 3a [5 pts]

Ideal C-Vg characteristic for a MOSFET is shown below. Draw the corresponding log(Id)-Vg characteristic for this MOSFET. Briefly explain all regions.





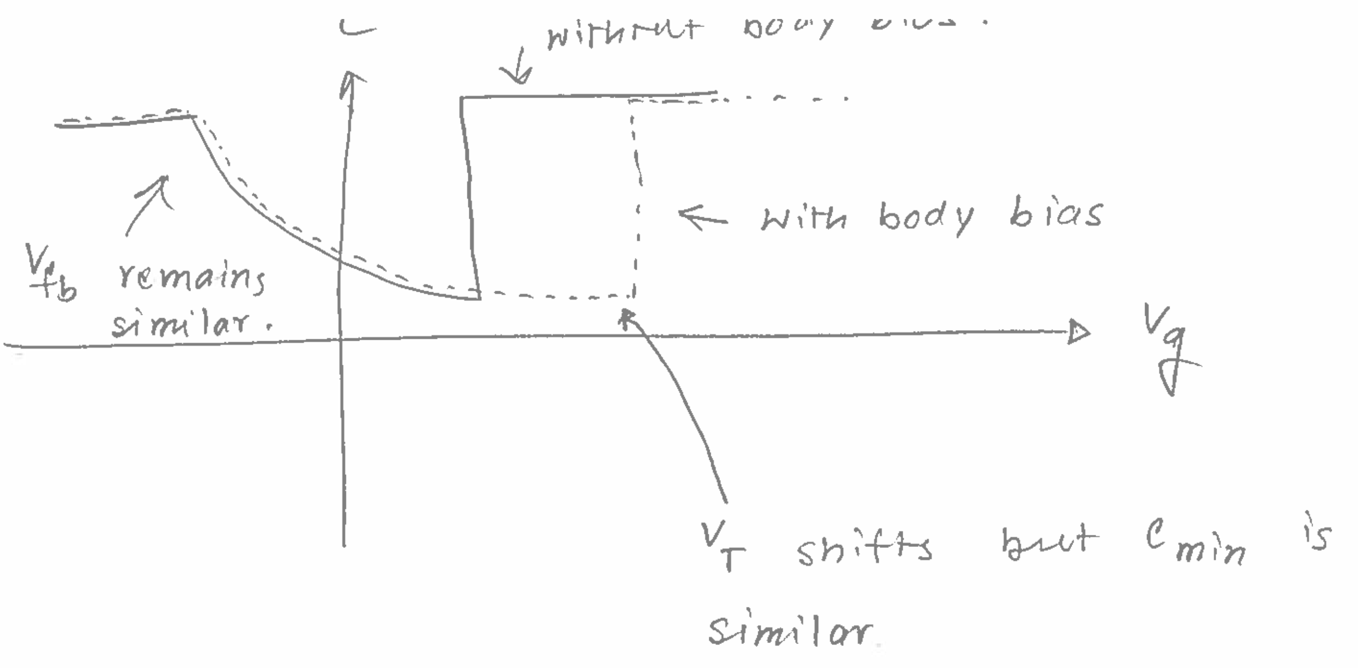
1. The transistor is already ON at $V_g = 0$ V.

2. It takes large negative voltage to turn it off

3. Once in accumulation, the current is determined by reverse saturation current and PN junction leakage

Problem 3b [5 pts] In a long channel MOSFET with p-body, it was found that the threshold voltage shifts linearly with Body Bias voltage. Draw the Ideal C-V_g characteristic of this MOSFET (i)without and (ii) with body bias on the same plot. For (ii) just plot the behavior for one single value of body bias. Clearly justify your answer.

The linear relationship indicates that the W_d^{max} does not change appreciably with body bias. Therefore, C_{min} in both cases are roughly the same.

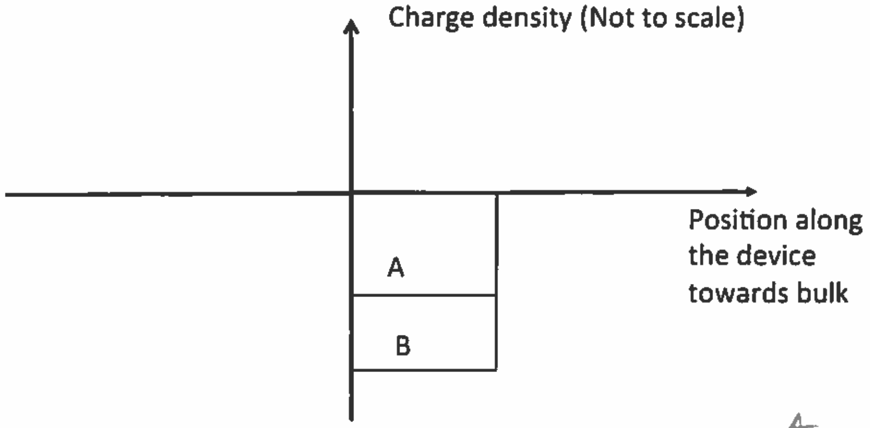


Prob 3c [10 pts] For two p-body MOSFETS A & B, the charge density profile on the semiconductor side is shown in the following figure at respective gate voltages V_{GA} and V_{GB} for which the depletion width for both is the same.

(i) [5 pts] Find the ratio of the doping concentration between A and B if $V_{GA}/V_{GB}=1/2$.

(ii) [5 pts] Draw the energy band diagram for the MOSFETS looking from the gate towards the bulk for these biasing conditions in two separate plots. Briefly state what the main differences are between the two.

For each MOSFET, a metal gate is chosen such that the flatband voltage is zero.



$$(i)\quad V_{g_A} = \cancelto{0}{V_{fb}} + V_{ox_A} + V_{s_A} = \frac{qN_A^A W}{C_{ox}} + \frac{qN_A^A}{2\varepsilon_{si}} W^2 \checkmark$$

$$V_{g_B} = \cancelto{0}{V_{fb}} + V_{ox_B} + V_{s_B} = \frac{qN_A^B W}{C_{ox}} + \frac{qN_A^B W^2}{2\varepsilon_{si}}$$

$$\therefore \frac{V_{g_A}}{V_{g_B}} = \cancel{\frac{\cancel{q}N_A^A\left(\cancel{\frac{W}{C_{ox}} + \frac{W^2}{2\varepsilon_{si}}}\right)}{\cancel{q}N_A^B\left(\cancel{\frac{W}{C_{ox}} + W^2/2\varepsilon_{si}}\right)}} = \frac{N_A^A}{N_A^B}$$

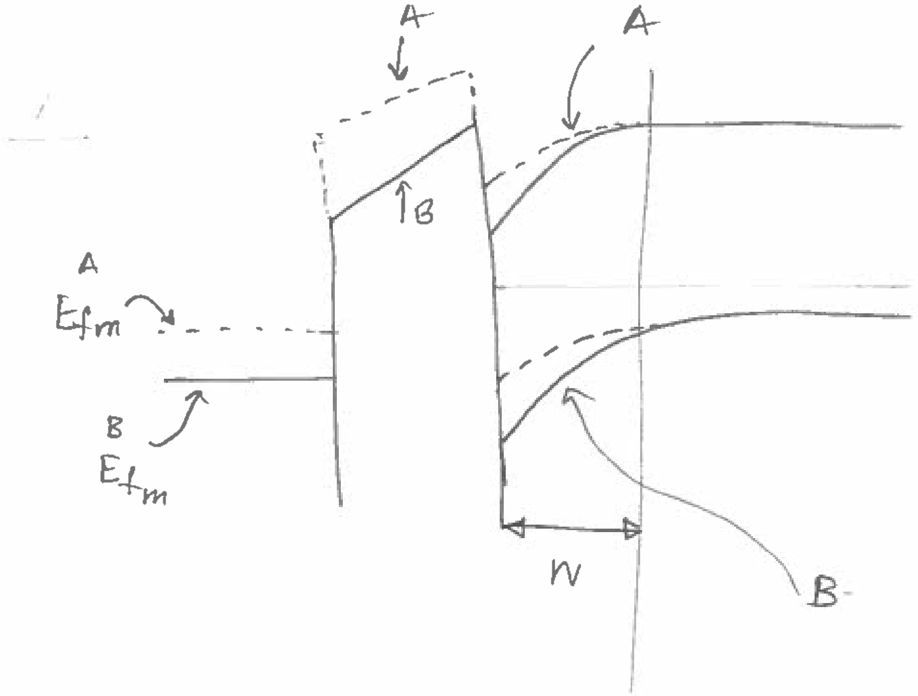
$$\therefore \boxed{\frac{N_A^A}{N_A^B} = \frac{1}{2}}$$

(ii) Main differences:

(i) V_{ox} is larger for B

(ii) V_s is larger for B

Both are proportional to doping.


A
A
B
A
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B
Efm
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B