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

MIDTERM EXAMINATION 2
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:

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

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

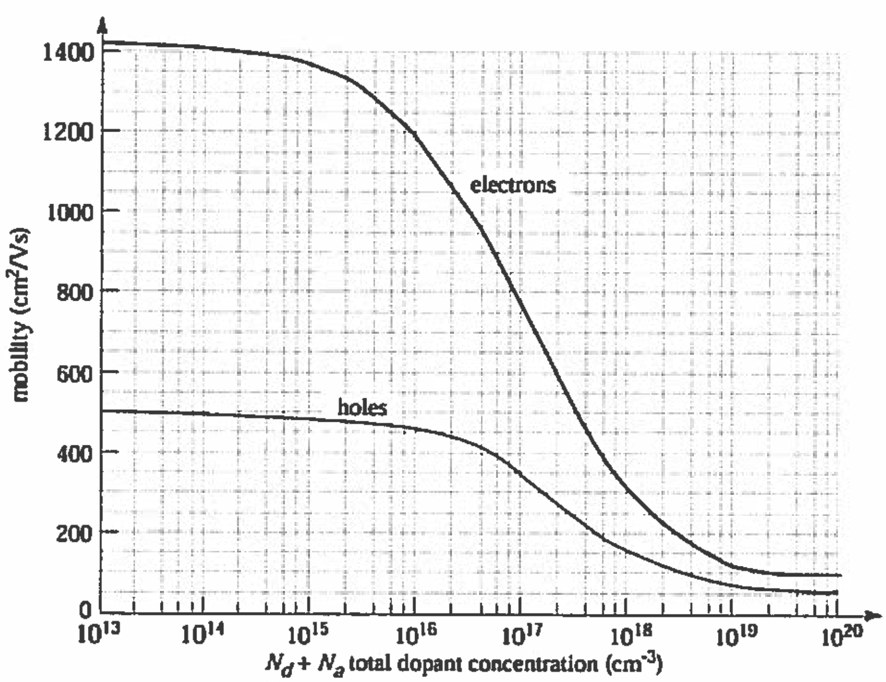


Table1: Barrier Heights of Different Metals to Si

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. Consider that a M-S junction is fabricated by putting Pt on Si. The Si is doped to $10^{16}/cm^3$ by **As.** It is known that Fermi-level pinning dominates the metal-semiconductor interface. Answer the following questions. For current voltage characteristics, positive voltage should mean that the positive terminal of the battery is connected to the metal side.

(i) [3 pts] Draw the energy-band diagram of the junction.

(ii) [4 pts] Draw the current voltage characteristics. On the same plot, draw current voltage characteristic at an elevated temperature.

(iii) [3 pts] Now the semiconductor is doped by **Boron** to $2\times10^{16}/cm^3$. Draw the energy band diagram.

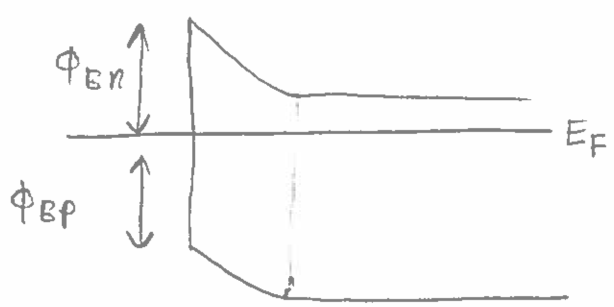
(iv) [4 pts] For the problem in (iii) draw the current voltage characteristic. On the same plot, draw current voltage characteristic at an elevated temperature.

(v) [3 pts] Now consider that the semiconductor is re-doped with As but to a much higher level than before so that it becomes degenerate. Draw the energy band diagram.

(vi) [3 pts] For the problem in (v) draw the current voltage characteristic. On the same plot, draw current voltage characteristic at an elevated temperature.

Fermi level pinning → $\phi_{Bn} = \phi_{Bp} = \frac{1}{2} E_g$ → independent of the metal being used

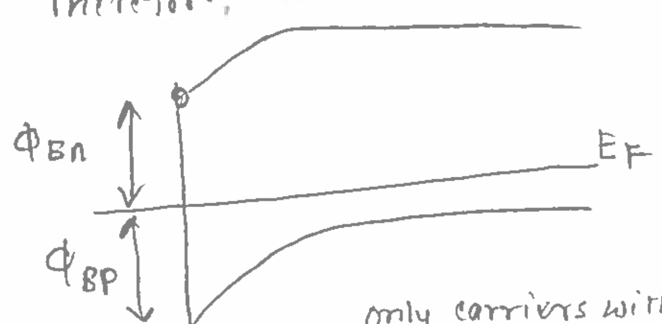
(i) As is a donor



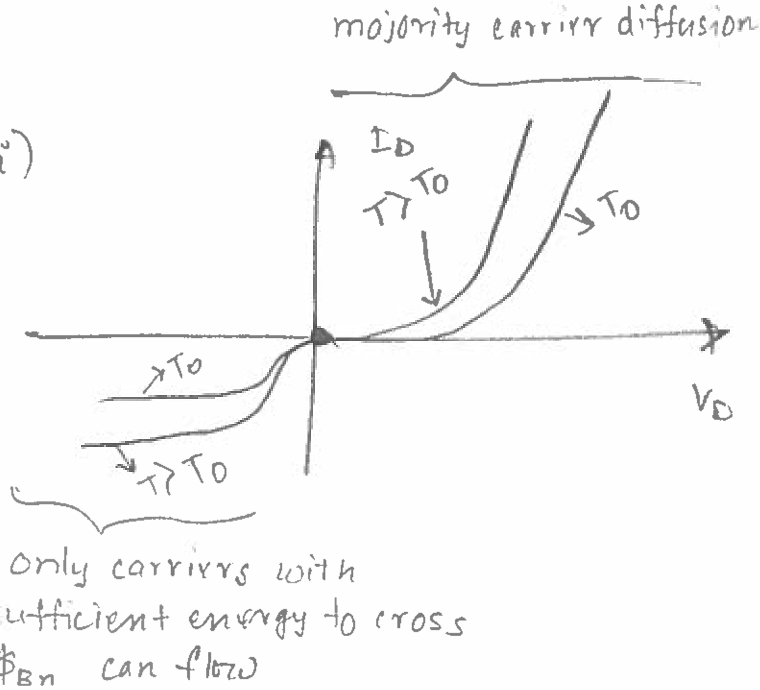
(iii) Boron is an acceptor

∴ $N_A - N_D = 2\times10^{16} - 10^{16} = 10^{16}$

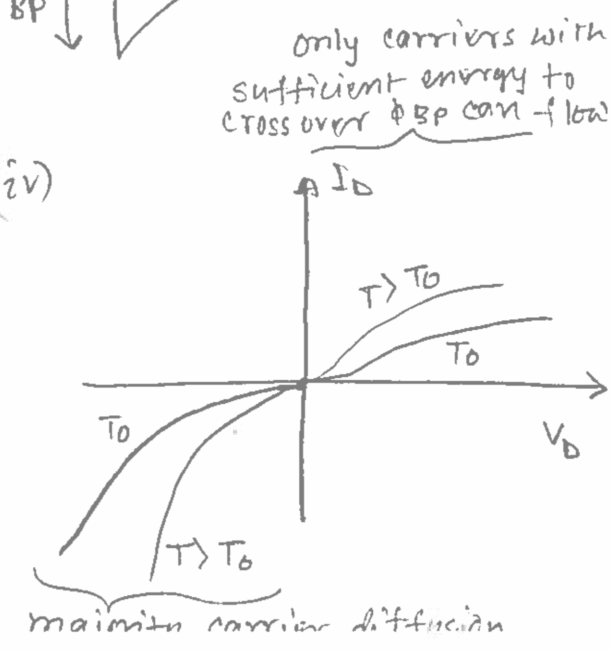
Therefore, Si is now p-type



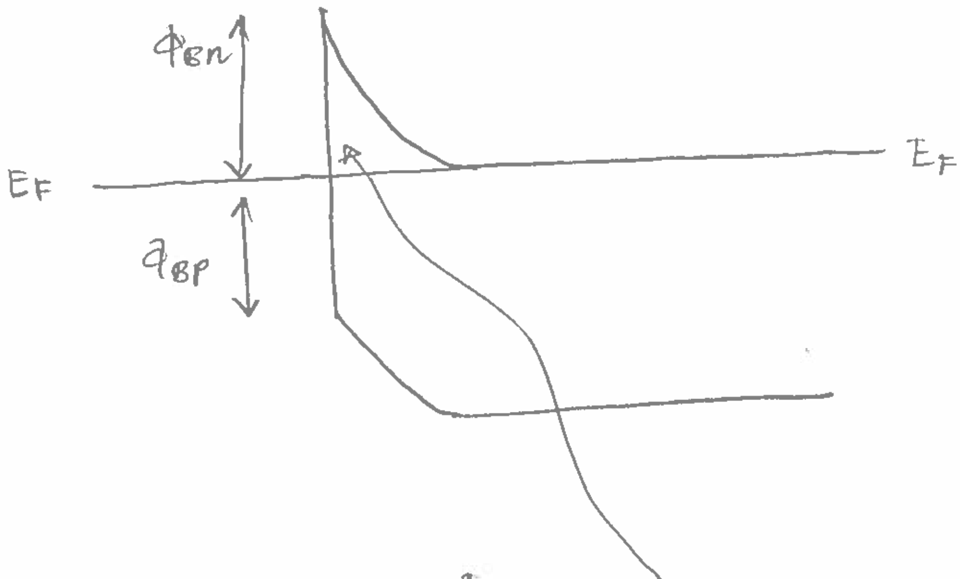
(ii)



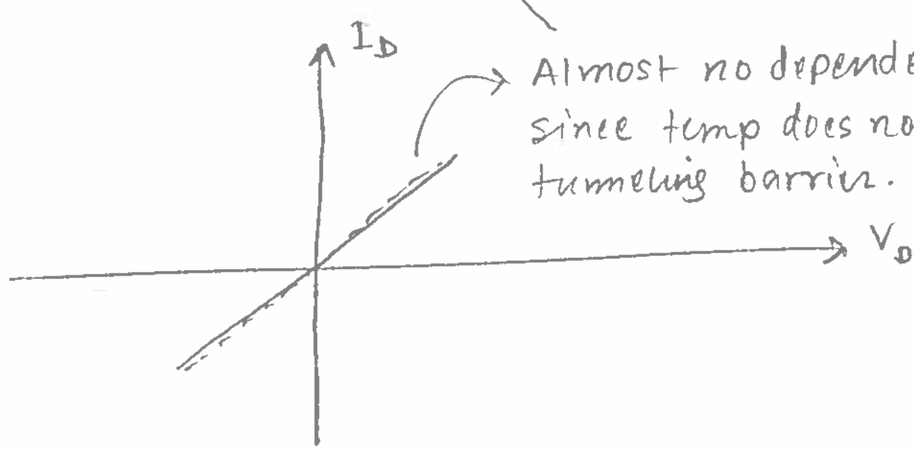
(iv)



(V) semiconductor again becomes n-type



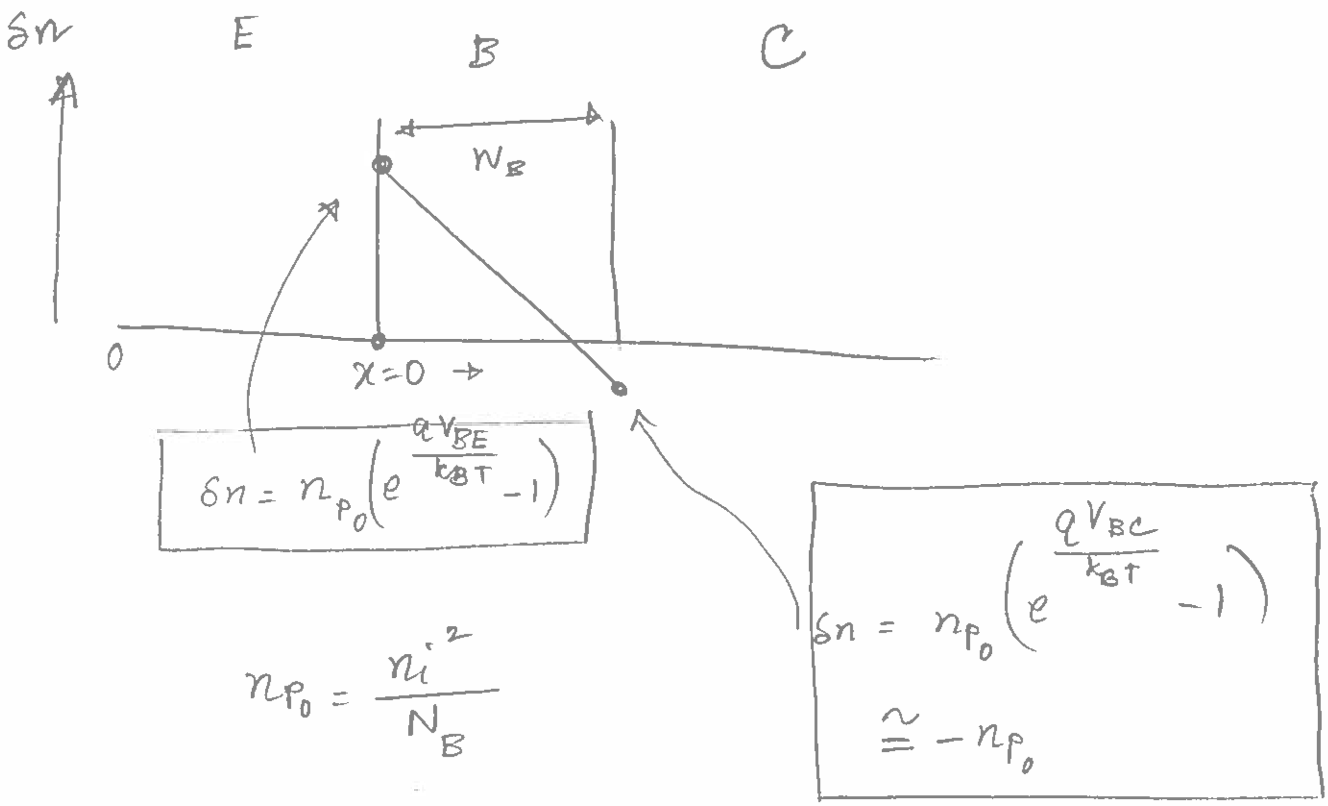
(vi)

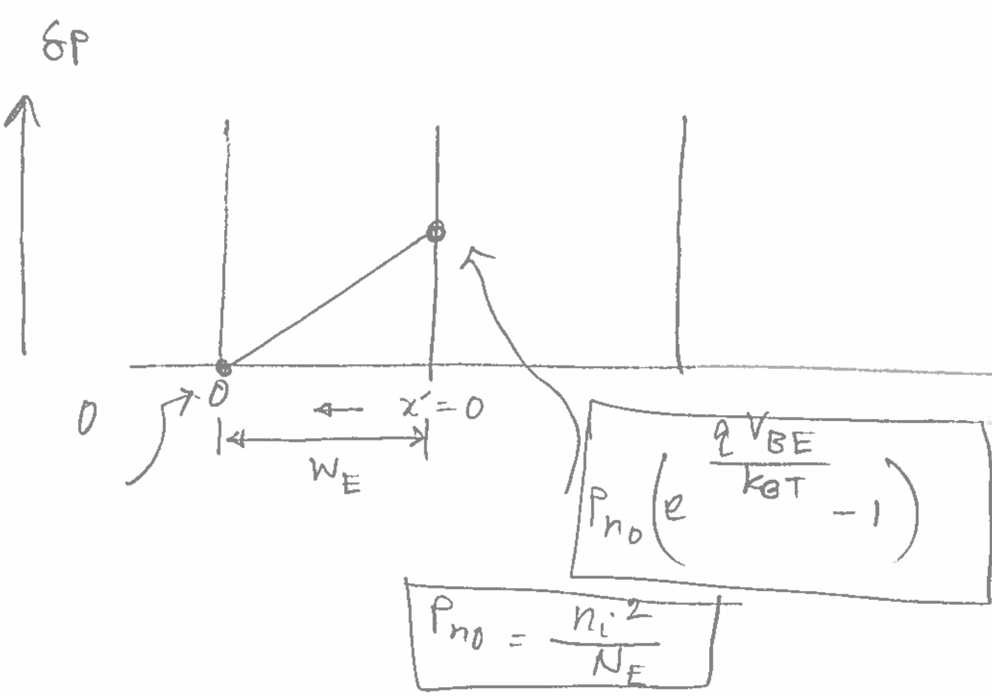


current mostly flows through tunneling giving an ohmic behavior

Problem 2. Consider a NPN bipolar junction transistor. The base width is much shorter than the minority carrier diffusion length. Also the emitter has the same length as the base and also much shorter than the relevant minority carrier diffusion length in the emitter. A metal contact at the end of the emitter makes sure that the excess carrier density at that point is zero. The transistor is biased in the forward active mode.

(i) [5 pts] Draw the distribution of minority carrier concentration in the emitter and base. Clearly mention the values of the excess carrier concentration at the edges of the depletion regions in terms of V_{BE} and V_{CE}.





(ii) [5 pts] From the diagrams of problem (i), derive expressions for the collector current. Clearly mention any assumptions that you are making.

$$I_c = -qAD_n \frac{dn}{dx} = -qAD_n \frac{n(x=0) - n(x=W_B)}{W_B}$$

$$= -qA\left(\frac{k_BT}{q}\right)\frac{\mu_n}{W_B} \cdot \left[\delta n(x=0) - \delta n(x=W_B)\right]$$

since, $n = n_{p_0} + \delta n$

$$= -A(k_BT)\frac{\mu_n}{W_B}\left[n_{p_0}\left(e^{\frac{qV_{BE}}{k_BT}} - 1\right) - (-n_{p_0})\right]$$

$$\boxed{I_c = -A(k_BT)\frac{\mu_n}{W_B} \cdot \frac{n_{iB}^2}{N_B} e^{\frac{qV_{BE}}{k_BT}}}$$

(iii) [7 pts]Find an expression for b (=I_c/I_B). If you had all the freedom of choosing system for the emitter and base, which material combination will you chose from the following table and why?

Material	Bandgap	m_n^*	m_p^*
Ge	0.67	0.12	0.3
GaAs	1.43	0.068	0.5
InAs	0.35	0.023	0.3

Following the same procedure as in (ii)

$$I_B = A(k_BT)\frac{\mu_p}{W_E} \cdot \left[p_{no} e^{\frac{qV_{BE}}{k_BT}} - 1\right]$$

$$\boxed{I_B \simeq A(k_BT)\frac{\mu_p}{W_E} \cdot \frac{n_{iE}^2}{N_E} e^{\frac{qV_{BE}}{k_BT}}}$$

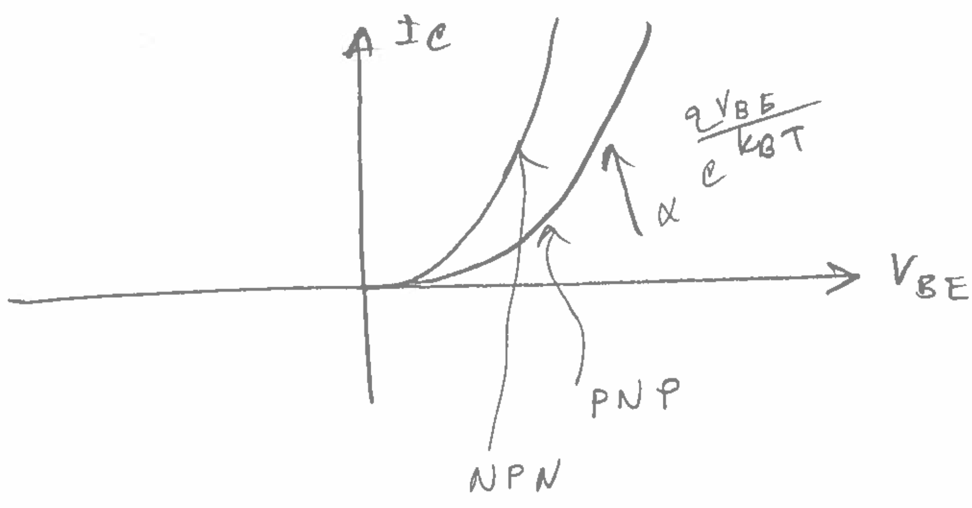
$$\therefore \beta = \frac{I_c}{I_B} = \frac{\mu_n}{\mu_p} \cdot \frac{W_E}{W_B} \cdot \frac{n_{iB}^2}{n_{iE}^2} \cdot \frac{N_E}{N_B}$$

These two factors are dependent on materials.

So, we want larger μ and lower bandgap at the base. Hence

InAs for base, GaAs for emitter.

(iV) [3 pts] From the expression for collector current found in (ii), draw I_C vs. V_{BE} for NPN and a PNP transistor in the same plot, if the material is Si and dimensions and doping level remain the same for both transistors.



Since $I_C \propto \mu$, NPN transistor gives more current as for all practical doping levels, $\mu_n > \mu_p$.