EE 121B Principles of Semiconductor Device Design
Winter 2011 Midterm Exam
February 15h, 2009, 2:10-3:50pm

LHS Neighbor First Initial and Last Name (e.g. K. Smith): ____________________	**Name :** Suggested Solutions **Student ID# :** ____________________ **Signature :** ____________________	**RHS Neighbor First Initial and Last Name (e.g. J. Smith):** ____________________

FORMAT:
- TOTAL: 100 POINTS
- TIME ALLOTTED: 100 MINUTES
- CLOSED BOOK
- ONE PAGE OF LETTER SIZE SHEET OF NOTES AND A SCIENTIFIC POCKET CALCULATOR ALLOWED

INSTRUCTIONS:
- USE THE FOLLOWING PHYSICAL CONSTANTS AND GENERAL ASSUMPTIONS IF NECESSARY
- SHOW ALL WORK AS CLEARLY AS POSSIBLE TO MAXIMIZE OPPORTUNITY FOR PARTIAL CERDIT
- USE COMMON SENSE TO INTERPRET THE QUESTIONS, OR ASK IF YOU ARE NOT SURE
- INSERT YOUR ONE PAGE NOTES INTO THE EXAM BOOKLET WHEN YOU TURN IN YOUR EXAM

Physical constants:

I. **Electronic charge = 1.60×10^{-19} C**
II. **Vacuum Permittivity = 8.85×10^{-14} F/cm**
III. **Boltzmann constant = 8.62×10^{-5} eV/K**
IV. **Planck constant = 6.63×10^{-34} J-s**
V. **Electron mass in vacuum = 9.10×10^{-31} kg**

General assumptions in all problems unless specifically stated otherwise:

I. **Temperature = 300 K**
   Semiconductor = Silicon
   a. **Intrinsic carrier concentration ≈ 1×10^{10} cm^{-3}**
   b. **Permittivity = 11.8**

Questions:

1) **{18 points}** Multiple choices with no partial credits. **Circle the correct answer.**

a) The electron velocity under random thermal motion in Si is closest to

i) 10^3 cm/s ii) 10^5 cm/s [✓ iii) 10^7 cm/s] iv) 10^9 cm/s

b) The saturated drift velocity in Si is closest to

i) 10^3 cm/s ii) 10^5 cm/s [✓ iii) 10^7 cm/s] iv) 10^9 cm/s

c) How does the PN junction built-in voltage change when we increase the ambient temperature from 300K to 1000K assuming the doping in both the P- and N-regions are not very heavy?

i) Increases ii) Does not change [✓ iii) Decreases]

d) Given a PN junction under steady-state forward bias at low-level injection, how will the current change if we double the P-region doping while keeping the N-region doping and external forward bias voltage the same?

i) Increases ii) Does not change [✓ iii) Decreases]

e) Given a long PN junction under steady-state forward bias at low-level injection, how does the current change if we illuminate the entire quasi-neutral P-region continuously and uniformly with a beam of light? Assume the light is absorbed, and that it is not intense enough to significantly change the majority carrier concentration.

i) Increases ii) Does not change [✓ iii) Decreases]

f) Given a p^+-n junction with a variable quasi-neutral N-region length (w_n). How does the steady-state forward bias current change when the w_n is reduced from 10 times of the minority carrier diffusion length to 0.1 times of that?

[✓ i) Increases] ii) Does not change iii) Decreases

2) {30 points} You have a very short base NPN BJT biased in the Forward Active Mode. **Fill in the table below on whether the quantities at the leftmost column will increase (↑), decrease (↓), or remain unchanged (Ø)** when the device parameters on the top row are changed. When considering each change, assume everything else, including quantities from other columns, remain constant. Further assume the terminal voltages are kept the same throughout. State your assumption(s) and explain your choice if necessary.

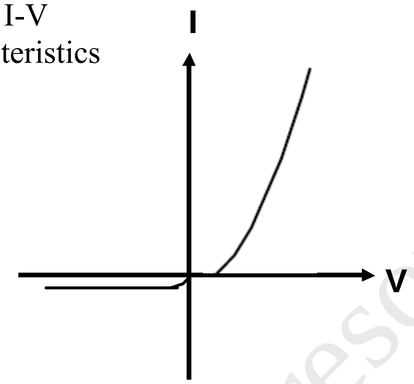
	Emitter Minority Carrier Lifetime ↑	**Base Doping ↑**	**Collector Doping ↑**	**Base width ↑**
I_{En}	Ans: Ø	Ans: ↓	Ans: Ø	Ans: ↓
	Exp: Slope of minority carrier profile in Base does not change	Exp: N_B↑, n_{p0}↓, carrier conc. at the E/B depletion edge ↓, slope ↓	Exp: Slope of minority carrier profile in Base does not change	Exp: Wbase↑, slope of minority carrier profile in Base ↓
I_{Ep}	Ans: ↓	Ans: Ø	Ans: Ø	Ans: Ø
	Exp: τ_p↑, L_p↑, slope of minority carrier profile in Emitter ↓, I_{EP} ↓	Exp: Slope of minority carrier profile in Emitter does not change	Exp: Slope of minority carrier profile in Emitter does not change	Exp: Slope of minority carrier profile in Emitter does not change
I_{Cn}	Ans: Ø	Ans: ↓	Ans: Ø	Ans: ↓
	Exp: Slope of minority carrier profile in Base does not change	Exp: N_B↑, n_{p0}↓, carrier conc. at the E/B depletion edge ↓, slope ↓	Exp: Slope of minority carrier profile in Base does not change	Exp: Wbase↑, slope of minority carrier profile in Base ↓

3) **{22 points}** You just bought a BJT from an electronics store in Westwood, CA. All electrical leads sticking out of the device are however not labeled. In your room, you only have a current-voltage meter that could measure either current (by applying voltage) or voltage (by applying current). **Suggest one way to find out what the three leads of the BJT are.**

Step1**: Determine which lead is Base**

Measure I-V between two different leads (3 different combinations: E/B, B/C, E/C). There will be a combination (E/C) that does not show diode I-V characteristics. So we know the rest lead out of this combination is Base.

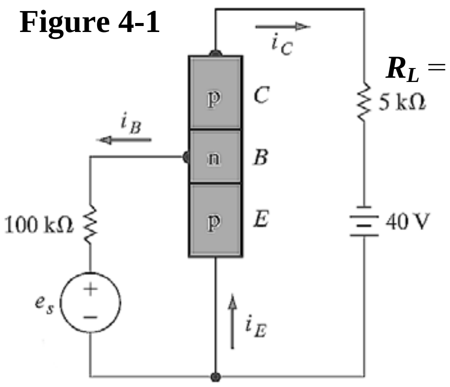
Diode I-V characteristics



Step2: **Determine Emitter and Collector**

In a normal BJT, emitter doping > base doping > collector doping. Therefore, the breakdown voltage at E/B junction is smaller than the breakdown voltage at B/C junction. So, after identifying Base lead, we measure breakdown voltage of 2 PN junctions (E/B & B/C). Lower breakdown voltage indicates it's a E/B junction, and higher breakdown voltage indicates it's a B/C junction.

Figure 4-1



I_{BF} = 80 μA and $|I_{BR}|$ = 40 μA
Base transit time = 1 ns
Hole lifetime in the base = 0.2 μs
Emitter injection efficiency = 1

4) **{30 points}** The switching PNP BJT in Figure 4-1 has the baseline transient characteristics shown in red dotted lines. Assume $Q_p(t)$ has reached a steady-state value prior to the $i_B(t)$ switching from I_{BF} to -$|I_{BR}|$ at $t = 0$.

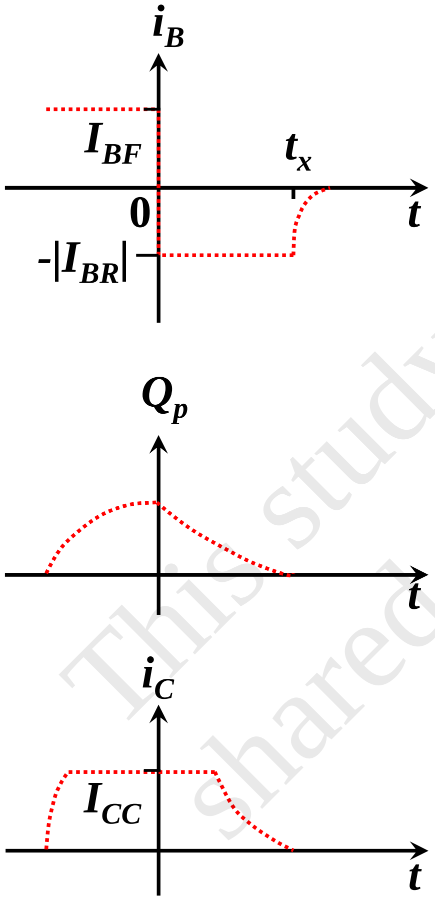
a) Start with the differential equation analyzed in the lecture and course reader

$$i_B(t) = \frac{Q_p(t)}{\tau_p} + \frac{dQ_p(t)}{dt} \quad \text{where} \quad Q_p(t) = i_B(t)\tau_p + Ae^{-t/\tau_p}$$

   i) **{5 points}** **Express $Q_p(t)$ in terms of I_{BF} and/or I_{BR} for $0 \le t \le t_x$**

   ii) **{6 points}** **Express the storage delay time in terms of I_{BF} and/or I_{BR}**

   iii) **{2 points}** **Compute the storage delay time using the numbers in Figure 4-1**



i)

$$Q_p(t) = -|I_{BR}|\tau_p + Ae^{-t/\tau_p}$$
$$Q_p(t=0) = I_{BF}\tau_p$$
$$\Rightarrow A = \tau_p(I_{BF} + |I_{BR}|)$$
$$\Rightarrow Q_p(t) = -|I_{BR}|\tau_p + \tau_p(I_{BF} + |I_{BR}|)e^{-t/\tau_p}$$

ii)

$$Q_p(t = t_{sd}) = I_{CC}\tau_t$$
$$\Rightarrow I_{CC}\tau_t = -|I_{BR}|\tau_p + \tau_p(I_{BF} + |I_{BR}|)e^{-t_{sd}/\tau_p}$$
$$\Rightarrow t_{sd} = \tau_p \, Ln\left(\frac{\tau_p(I_{BF} + |I_{BR}|)}{I_{CC}\tau_t + |I_{BR}|\tau_p}\right)$$

iii)

Plugging in,

$$I_{CC} = \frac{V}{R_L} = 8mA$$
$$t_{sd} = 8.1 \times 10^{-8} s$$

b) **Sketch, over the given graphs below, and briefly justify the new transient responses** when the following changes occur individually. Make sure the $i_B(t)$, $Q_p(t)$, and $i_C(t)$ in each figure are consistent with each other. Mark all the critical turning points in your sketches.

i) **{6 points}** $i_B(t)$ for $t \geq 0$ is reduced to zero (blue dashed trace in Figure 4-b-i)

ii) **{11 points}** $i_B(t)$ for $t \geq 0$ is slightly increased to above I_{BF} and then switched back to $-|I_{BR}|$ (blue dashed trace in Figure 4-b-ii)

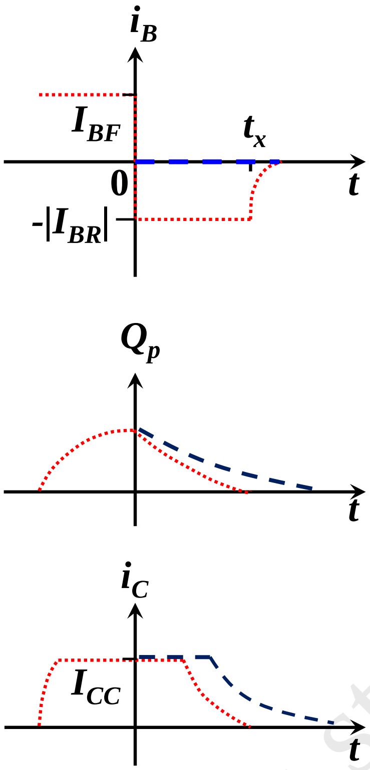


Figure 4-b-i

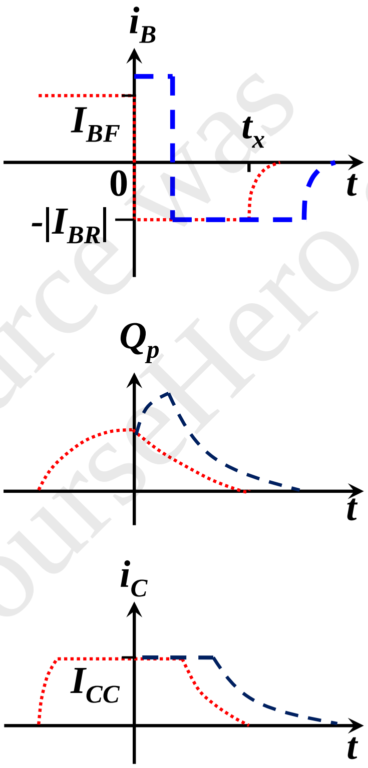


Figure 4-b-ii