

CITY UNIVERSITY OF HONG KONG

Module code and title: EE3115 Semiconductor Materials and Devices

Session : Semester B 2003/2004

Time allowed : Two hours

This paper consists of EIGHT pages (including this one)

-

Module code and title : EE3115 Semiconductor Materials and Devices

-
1. This paper consists of **three** sections
 2. Answer **all** questions in **Section A**
 3. Answer any **one** question in **Section B**
 4. Answer any **two** questions in **Section C**
 5. Remember to start a **new page** for **each question** in **Section B and C**
 6. Remember that a complete answer to questions in Section B and C ought to include all your steps
-

-

Materials, aids and instruments permitted to be used during the examination:

1. Approved electronic calculator
-

Section A (20% + 20%)

PART A (Students are required to answer ALL questions in this part)

Attempt **all** questions in this part by choosing the most suitable (**ONLY ONE**) answer to each question. (each chosen answer carries 2 marks, Total 20 marks)

1. In an *p-channel enhancement MOSFET* transistor, both boron and phosphorus are usually present as the dopants in the channel region, which one of the dopants has a higher concentration in the channel region?

(a) boron (b) phosphorus (c) boron and phosphorus have the same concentration

2. The carrier mobilities in intrinsic semiconductors are (chosen answer) those in heavily doped semiconductors.

(a) higher than (b) lower than (c) the same as

3. In a lightly doped *pn junction diode* which of the following mechanisms dominates when the reverse-bias breakdown?

(a) Avalanche breakdown (b) Zener breakdown (c) Punch-through breakdown
(d) None of the above

4. When a practical bipolar transistor is operating in the saturation mode, the collector current keeps increasing as a function of increasing collector bias. This is due to

(a) the saturation current at the collector-base junction
(b) the diffusion of minority carriers in the base region
(c) the electron-hole recombination in the base region
(d) the modulation of base width by the collector bias

5. If an *npn* transistor is operated in the inverted mode, which one of the following biasing combination is possible?

(a) $V_E > V_B > V_C$ (b) $V_E < V_B < V_C$ (c) $V_E > V_B < V_C$ (d) $V_E < V_B > V_C$

6. Drift current is the type of current flow that normally occurs in conductors and semiconductors, which one of the following formula is used to get the carrier drift velocity?

(a) $D/\mu = kT/q$ (b) $J = qDdp/dx$ (c) $\mu = q\tau/m^*$ (d) $J = nq\mu E$

7. Which one of the following formulas is used for calculating the depletion layer thickness of a Schottky barrier? (a) $X_{p0} = \sqrt{WN_d / (N_a + N_d)}$

(b)

(c)

(d)

$$W = \left(\frac{2\epsilon V_0}{qN_d} \right)^{\frac{1}{2}}$$

$$W = \left[\frac{2\epsilon V_0}{q} \left(\frac{1}{N_a} + \frac{1}{N_d} \right) \right]^{\frac{1}{2}}$$

$$W = \left[\frac{2\epsilon_s \phi_s}{qN_a} \right]^{\frac{1}{2}}$$

8. Manufacturers' data sheets for transistors do not usually list the values of all parameters. The parameter h_{fb} is called the common base current gain of a bipolar junction transistor, which two terminal current ratios of a **npn** BJT does the h_{fb} value come from?

$$\begin{array}{ll} \text{(a)} I_C = qA(D_P/L_P)\Delta P_E \operatorname{csch}(W_B/L_P), & I_B = qA(D_P/L_P)\Delta P_E \tanh(W_B/2L_P) \\ \text{(b)} I_B = qA(D_N/L_N)\Delta n_E \tanh(W_B/2L_N), & I_E = qA(D_N/L_N)\Delta n_E \operatorname{ctnh}(W_B/L_N) \\ \text{(c)} I_C = qA(D_N/L_N)\Delta n_E \operatorname{csch}(W_B/L_N), & I_B = qA(D_N/L_N)\Delta n_E \tanh(W_B/2L_N), \end{array}$$

9. A piece of silicon is doped with phosphorus atoms, which equation is used to calculate the electron concentration at 300 K ?

(a)

(b)

$$n = n_i \exp \frac{(E_F - E_i)}{kT}$$

$$n = \frac{n_i^2}{P}$$

$$\text{(c)} n = P + N_d - N_a$$

(d)

$$L_P = \sqrt{D_P \tau_P}$$

10. When a **pn** junction is in reverse bias, the potential barrier increase and more electrons and holes move away from the depletion region. The junction current remains constant and can be approximated as I_0 , which formula can be used to calculate the reverse saturation current I_0 ?

(a)

$$P(X_n) = P_n + P_n \left(e^{\frac{qV}{kT}} - 1 \right) e^{\frac{-X_n}{L_P}}$$

(b)

$$I_p(X_n) = qA \frac{D_p}{L_p} P_n e^{\frac{-X_n}{L_p}} \left(e^{\frac{qV}{kT}} - 1 \right)$$

(c)

$$I_n(X_n) = I - I_p(x_n) = qA \left[\frac{D_p}{L_p} \left(1 - e^{\frac{-X_n}{L_p}} \right) P_n + \frac{D_n}{L_n} n_p \right] \left(e^{\frac{qV}{kT}} - 1 \right)$$

(d)

$$I = qA \left(\frac{D_p}{L_p} P_n + \frac{D_n}{L_n} n_p \right) \left(e^{\frac{qV}{kT}} - 1 \right)$$

PART B 20% (students are required to answer ALL questions in this part)

Fill in the Blank

(20 marks)

1. Electrons normally cannot exit at an energy level represented by the _____ between the conduction and _____.
2. Bonding between atoms in a solid _____ bonding occurs in conductors. _____ bonding is found in semiconductors and in some types of insulating material. In glass and similar solids, the bonding force is _____.
3. When donors and acceptors are non-ionized, they are electrically _____ (zero charge). When a donor is ionized (lose the extra electron), it becomes _____ charged. When an acceptor is ionized (accept an electron), It becomes _____ charged.
4. Some free electrons from the n-side are attracted across the junction to fill holes on the p-side. They are said to _____ across the junction, i.e., flow from a region of _____ carrier _____ to one of _____.
5. The movement of charge carriers across the junction leaves a layer on each side which is _____ of charge carriers. On the n-side, the depletion region consists of _____ atoms which have lost the free electron associated with them.
6. A region depleted of charge carriers spreads across both sides of a pn-junction and _____ deepest in the more _____ doped side.
7. If the applied bias voltage is increased from zero, the barrier potential gets progressively _____ until it effectively _____, and charge carriers can _____ flow across the junction. Thus, a _____ carrier current flows, and the junction is said to _____ biased.
8. Two commonly used techniques for manufacturing diodes are the _____ method and _____ method.
9. The region W is called the _____ region and potential difference V_0 is call the _____ potential (or _____ potential). This potential is necessary to the maintenance of _____ at the junction.
10. Zener breakdown, when a _____ doped junction is _____ biased, the energy bands become crossed at relatively _____ voltages (i.e., the n-side conduction band goes below the p-side valence band). The _____ in the p-side valence band and can go to the n-side valence band by _____ and generates a reverse current from n to p; that is _____ effect.
11. Metal-semiconductor Junctions, the absence of _____ carrier injection and the associated storage _____ is an important feature of Schottky barrier diodes. So their _____ properties and _____ are therefore generally better than typical p-n junctions.
12. In order to have the majority of the injected holes to reach the collector, we must have a n-type base region _____ compared with a hole _____.
13. The _____ may be large, small, or nonexistent. The distinction between conductors, insulators, and semiconductors is largely concerned with the relative widths of the _____.

Section B (20%) (select only one out of two questions in this part)

Question B-1

(4marks x 5 = 20 marks)

Three n-p-n transistors are identical except that transistor #2 has a base region twice as long as transistor #1, and transistor #3 has a base region doped twice as heavily as transistor #1. All other dopings and lengths are identical for the three transistors.

Which transistors have the largest value of each parameter listed below?

- Emitter injection efficiency.
- Base transport factor.
- Punch through voltage.
- Collector junction capacitance with V_{CB} reverse biased at 10 V.
- Common emitter current gain.

Give clear mathematical reasons for each of your answers.

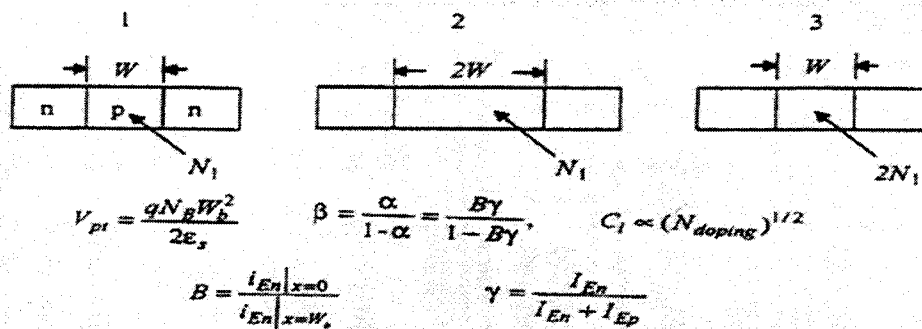


Fig.B-1

Question B-2

(20 marks)

- (a) Finish the Table:

(4 marks)

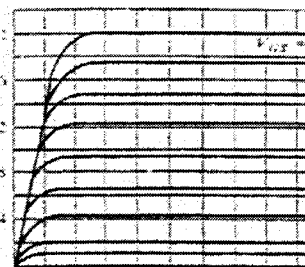
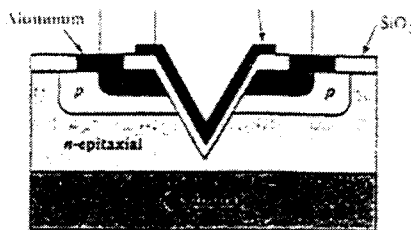
Electrical Nature of Ideal Metal-Semiconductor Junction Contacts

$\Phi_m < \Phi_s$ or $\Phi_m > \Phi_s$	p-type Semiconductor	n-type Semiconductor
	Rectifying	Ohmic-like contact
	Ohmic-like contact	Rectifying

- (b) Draw and write down the name of every part of a cross section of a vertical FET (VMOS Power Field-Effect Transistor) and list some advantageous properties compared with the low-power n-channel enhancement MOSFET. (10 marks)

- (c) Draw the device symbol of an enhancement-type n-channel MOSFET transistor;

- (d) Drain Current-voltage characteristics as a function of gate voltage (I_D versus V_D) label the scale of I_D , V_D , V_{GS} and V_P curve. (c: 2marks, d: 4marks)



Physical Constants and Parameters at 300 K

Boltzman constant	k	$1.38 \times 10^{-23} \text{ J/K}$
Electronic charge (eV)	q	$1.6 \times 10^{-19} \text{ C}$
Permittivity of free space	ϵ_0	$8.85 \times 10^{-14} \text{ F/cm}$
Thermal energy at 300 K	kT	0.0258 eV
Intrinsic carrier concentration in Si	n_i	$1.5 \times 10^{10} \text{ cm}^{-3}$
Bandgap of Si	E_g	1.12 eV
Dielectric constant of Si	ϵ_{Si}	11.8
Hole mobility of Si	μ_h	$450 \text{ cm}^2/\text{V-s}$
Dielectric constant of Ge	ϵ_{Ge}	16.0
Intrinsic carrier concentration in Ge	n_i	$2.5 \times 10^{13} \text{ cm}^{-3}$
Bandgap of Ge	E_g	0.66 eV
Electron rest mass	m_0	$9.1 \times 10^{-31} \text{ kg}$
Permittivity in vacuum	ϵ_0	$8.85 \times 10^{-12} \text{ F/m}$
Electron mobility of Si	μ_e	$1450 \text{ cm}^2/\text{V-s}$

Section C (40%) (select only two out of three questions in this part)

Question C1

(20 marks)

Aluminum is alloyed in an n-type Si sample ($N_d = 10^{16} \text{ cm}^{-3}$), forming an abrupt junction of circular cross section, with a diameter of 0.02 in. Assume that the acceptor concentration in the alloyed region is $N_a = 4 \times 10^{18} \text{ cm}^{-3}$.

Calculate V_0 , x_{n0} , x_{p0} , Q_+ , and ϵ_0 for this junction at equilibrium (300 K).

(5x3 marks)

Sketch $\epsilon(x)$ and charge density to scale, as in Fig. C-1.

(5 marks)

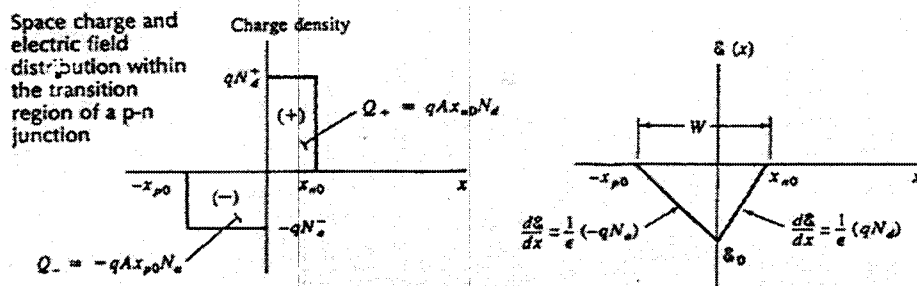


Fig. C-1

Question C2**(20 marks)**

An abrupt Si *p-n* junction has the following properties at 300 K and $A = 10^{-4} \text{ cm}^2$;

n side

$$\begin{aligned} N_d &= 10^{15} \text{ cm}^{-3} \\ \tau_p &= 10 \text{ } \mu\text{S} \\ \tau_n &= 2 \text{ } \mu\text{S} \\ \mu_p &= 450 \text{ cm}^2/\text{V-s} \\ \mu_n &= 1450 \text{ cm}^2/\text{V-s} \end{aligned}$$

p side

$$\begin{aligned} N_a &= 10^{17} \text{ cm}^{-3} \\ \tau_n &= 0.1 \text{ } \mu\text{S} \\ \tau_p &= 1 \text{ } \mu\text{S} \\ \mu_p &= 200 \text{ cm}^2/\text{V-s} \\ \mu_n &= 700 \text{ cm}^2/\text{V-s} \end{aligned}$$

(a) Draw an equilibrium band diagram for this junction, including numerical values for the Fermi level position relative to the intrinsic level on each side. Find the built-in potential from the diagram and check your answer with the analytical expression for V_0 . **(5 marks)**

(b) Draw the band diagram qualitatively under forward and reverse bias showing the quasi-Fermi levels. **(2 marks)**

(c) This *p-n* junction is forward biased by 0.5 V. What is the forward current? What is the current at a reverse bias of -0.5 V ? **(9 marks)**

(d) If a *p-n* junction, the n-doping N_d is doubled. How do the following change if everything else remains unchanged? Indicate only increase or decrease. **(4 marks)**

- i) Junction capacitance
- ii) Built-in potential
- iii) Breakdown voltage
- iv) Ohmic losses

$$V_0 = \frac{KT}{q} \ln \frac{N_d N_a}{n_i^2} = \frac{E_0 W}{2}$$

Question C3**(20 marks)**

A symmetrical Si *pnp* BJT with area 10^{-4} cm^2 and base width of one micron has an emitter with $N_a = 10^{17} \text{ cm}^{-3}$, $\tau_n = 0.1 \text{ } \mu\text{s}$, and $\mu_n = 700 \text{ cm}^2/\text{V-s}$.

In the base $N_d = 10^{15} \text{ cm}^{-3}$, $\tau_p = 10 \text{ } \mu\text{s}$ and $\mu_p = 450 \text{ cm}^2/\text{V-s}$.

(a) Find I_{ES} , (the collector, emitter saturation current with the emitter collector shorted) and I_B with $V_{EB} = 0.3 \text{ V}$ and large reverse bias on the collector junction. **(10 marks)**

(b) Find the Emitter injection efficiency γ , Base transport factor B , and current gain β for the BJT. **(10 marks)**

— END —