

CITY UNIVERSITY OF HONG KONG

Module code and title: EE3115 Semiconductor Materials and Devices

Session : Semester B 2004/2005

Time allowed : Two hours

This paper consists of NINE pages (including this one)

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Module code and title : EE3115 Semiconductor Materials and Devices

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

1. Approved electronic calculator
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Section A 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 ***n-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 extreme lightly doped semiconductors.

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

3. In a ***pnp transistor*** which of the following mechanisms dominates when the reverse-bias on the collector junction is increased far enough?

(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 inverted 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 saturation 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 electrical conductivity?

(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 width maximum of an ideal metal-insulator-semiconductor FET (MOS) ?

(a)

(b)

(c)

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

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

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

(d) None of the above.

8. Manufacturers' data sheets for transistors do not usually list the values of all parameters. Most often, only the common emitter parameters are stated. The parameter h_{fe} is called the common collector current gain of a bipolar junction transistor, which two terminal current ratios of a BJT does the h_{fe} come from?

(a) $I_C = qA(D_P/L_P)\Delta P_E(L_P/W_b)$, $I_B = qA(D_P/L_P)\Delta P_E(W_b/2L_P)$

(b) $I_B = qA(D_n/L_n)\Delta n_E(W_b/2L_n)$, $I_E = qA(D_n/L_n)\Delta n_E(L_n/W_b)$

(c) $I_C = qA(D_n/L_n)\Delta n_E(L_n/W_b)$, $I_E = qA(D_n/L_n)\Delta n_E(L_n/W_b)$

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

(a)

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

(b)

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

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

(c) $P = n + N_a - N_d$,

(d)

10. In the calculation for the diode current, we have simply calculated the excess minority carrier diffusion current. Which formula is used to calculate the excess minority carrier diffusion concentration?

(a)

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

(b)

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

(c)

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

(d)

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

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

Fill in the Blank

(Total 20 marks)

- a) The atom consists of a central nucleus surrounded by _____.
Electrons have a _____ charge, and the _____ in the nucleus have a _____ charge.
- b) The energy levels are measured in electron volts (ev). An electron volt is defined as the amount of energy required to move _____ through a _____ difference of one volt.
- c) 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 _____.
- d) If the two blocks of material have equal doping densities, the depletion layers on each side of the junction are equal in thickness. If the p-side is more heavily doped than that of the n-side, the depletion region _____ more _____ into the n-side in order to include an equal number of _____ atoms on each side of the junction.
- e) When a semiconductor is doped with both _____ and _____ (we say the semiconductor is compensated), the relation among the electron, hole, _____, and _____ concentration can be obtained by considering the requirements for _____.
- f) If a valence electron acquires sufficient energy, the electron will be excited to conduction band and leaving behind a hole in the valence band this process is called _____.
- g) A pn junction have a depletion region witch is called the transition region, and potential difference V_o is call the _____ potential (or _____ potential). This potential is necessary to the maintenance of _____ at the junction.
- h) A Voltage-variable capacitor diodes (VVC) device is simply a _____ diode, and its capacitance is that of the junction _____.
- i) In a metal-semiconductor junction, the absence of _____ carrier injection and the associated storage _____ is an important feature of Schottky barrier diodes. So their high-frequency properties and _____ are therefore generally better than typical *pn* junctions.
- j) Barrier potential and depletion regions exist at the two *pn*-junctions in a transistor, The barrier potentials are always _____ on the p-side and _____ on the n-side of each junction. The depletion regions penetrate deeply into the _____ doped base.
- k) Electrons in solid obey what is known as Fermi-Dirac statistics. The number of free electrons in the conduction band depends on 3 factors:
i) total number of _____ available, ii) number of _____ in conduction band, iii) probability of an _____ occupying an energy level at a particular _____.
- l) The critical reverse voltage for _____ breakdown occurred with _____ the band gap of the materials. Also, easy arrival the peak electric field within W increases with _____ doping on the more lightly doped side of the junction. Therefore, the breakdown voltage _____ as the doping _____.

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

Question B-1

(20 marks)

(a) The symmetrical *pnp* transistor of Fig.B-1, is connected as a diode in the four configurations shown. Assume that $V \gg KT/q$. Sketch $\delta P(X_n)$ in the base region for each case. Which connection seems most appropriate for use as a diode? Why? (10 marks)

(b) Suppose that V is negative in Fig.B-1-d, Find I from the equations; Find the expression for V_{CB} , and sketch $\delta P(X_n)$ in the base. (10 marks)

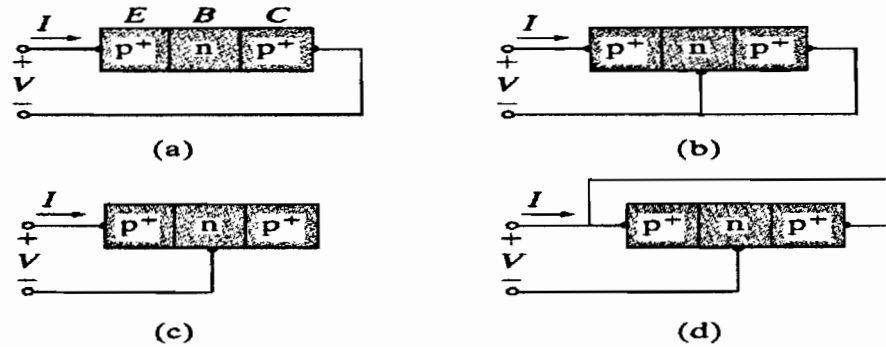


Fig.B-1

Question B-2

(20 marks)

Draw and complete Fig.B-2

- The device symbol of an enhancement-type n-channel MOSFET transistor;
- Draw in more detail and complete the cross section of the device;
- Schematic and explanation illustration of the induced n-channel and the depletion region near pinch-off
- Drain current-voltage characteristics as a function of gate voltage (I_D versus V_D) more detail finish the figure. (4 x 5 marks)

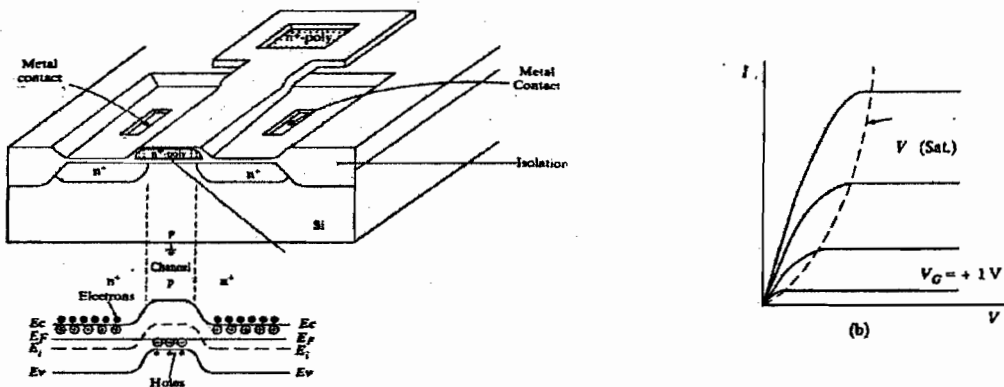


Fig.B-2

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
Dielectric constant of GaAs	ϵ_{GaAs}	13.1
Dielectric constant of Ge	ϵ_{Ge}	16.0
Intrinsic concentration in GaAs	n_i	$1.8 \times 10^6 \text{ cm}^{-3}$
Bandgap of GaAs	E_g	1.42 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 GaAs	μ_e	$8500 \text{ cm}^2/\text{V-s}$
Electron mobility of Si	μ_e	$1450 \text{ cm}^2/\text{V-s}$

Section C (40 %)

(Answer any Two questions out of three questions in this section)

Question C-1

(20 marks)

- (a) A Si bar 0.1 cm long and $100 \mu\text{m}^2$ in cross-sectional area is doped with 10^{17} cm^{-3} phosphorus. Find the current at 300 K with 10 V applied. Repeat for a Si bar 1 μm long.
- (b) How long does it take an average electron to drift 1 μm in pure Si at an electric field of 100 V/cm? Repeat for 10^5 V/cm .

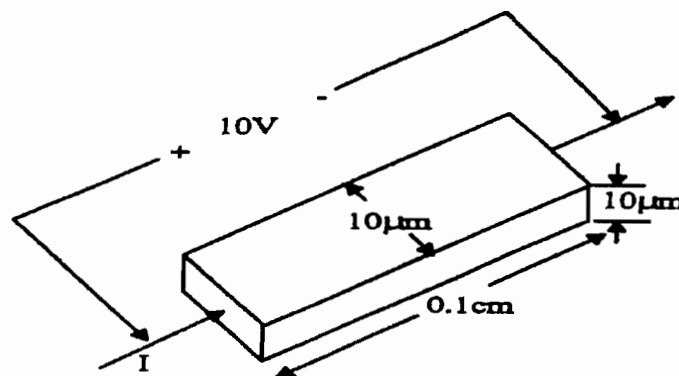


Fig.QC1-1

Question C-2

(20 marks)

An n-channel GaAs MESFET is shown in Fig. QC2-1, with $V_{GS} = -2V$, $\Phi_B = 0.9V$, $N_D = 10^{17} \text{ cm}^{-3}$, $a = 0.2 \mu\text{m}$, $L = 1 \mu\text{m}$ and $Z = 10 \mu\text{m}$. GaAs material electron affinity $\chi = 4.07$.

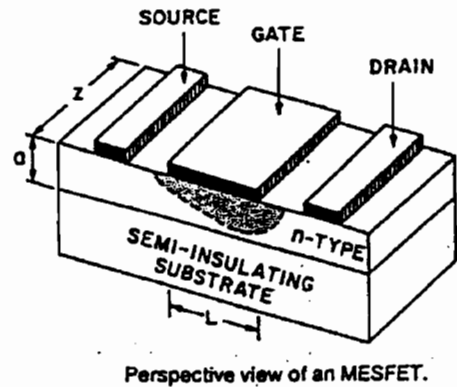
- Draw equilibrium energy band diagrams of the Schottky barrier.
- Calculate V_0 from the equation. Draw the reverse-bias diagrams for $V_r = -2V$.
- Calculate the depletion layer thickness at equilibrium and $V_r = -2V$.
- Determine the full channel resistance.
- What is the value of V_{DS} at pinch off? Determine the transconductance $g_{m(sat)}$.

$$G_0 = 2ZaqN_D\mu_e/L = 2aZ/\rho L, \quad V_p = -qa^2N_D/2\epsilon_0\epsilon_r$$

$$I_{DQ} = I_{DSS} \left(1 - \frac{V_{GSQ}}{V_P} \right)^2$$

$$g_{m(sat)} = \frac{\partial I_{D(sat)}}{\partial V_G} = G_0 \left[1 - \left(-\frac{V_G}{V_P} \right)^{\frac{1}{2}} \right]$$

Fig. QC2-1



(a, b, c, d, e, each part carries for 4 marks)

Question C-3

(20 marks)

A symmetrical npn bipolar transistor has a junction area of 10^{-3} cm^2 and a base width of $1 \mu\text{m}$. The parameters of base, emitter and collector are given below:

Emitter/Collector
 $N_d = 10^{18} \text{ cm}^{-3}$
 $\mu_h = 450 \text{ cm}^2/\text{V-s}$
 $\mu_e = 1300 \text{ cm}^2/\text{V-s}$
 $\tau_h = 0.1 \mu\text{s}$
 $\tau_e = 2 \mu\text{s}$

Base
 $N_a = 5 \times 10^{15} \text{ cm}^{-3}$
 $\mu_h = 200 \text{ cm}^2/\text{V-s}$
 $\mu_e = 700 \text{ cm}^2/\text{V-s}$
 $\tau_h = 1 \mu\text{s}$
 $\tau_e = 0.1 \mu\text{s}$

Assume that the transistor is operated at 300K.

(a) Assume a constant base width of $1 \mu\text{m}$, calculate the emitter current (I_E) and base current (I_B) when $V_{BE} = 0.6 \text{ V}$ and $V_{CB} = 2.0 \text{ V}$. (8 marks)

(b) Neglect the modulation of the base width by the emitter-base junction voltage (V_{EB}) and calculate the collector-base junction voltage (V_{CB}), at which the punch-through phenomenon occurs. (6 marks)

(c) Fig.QC3-1 shows the BJT output characteristics and an amplifier circuit. When the switch S is connected to different terminals : A, B, and C, determine the BJT operation of each mode. (6 marks)

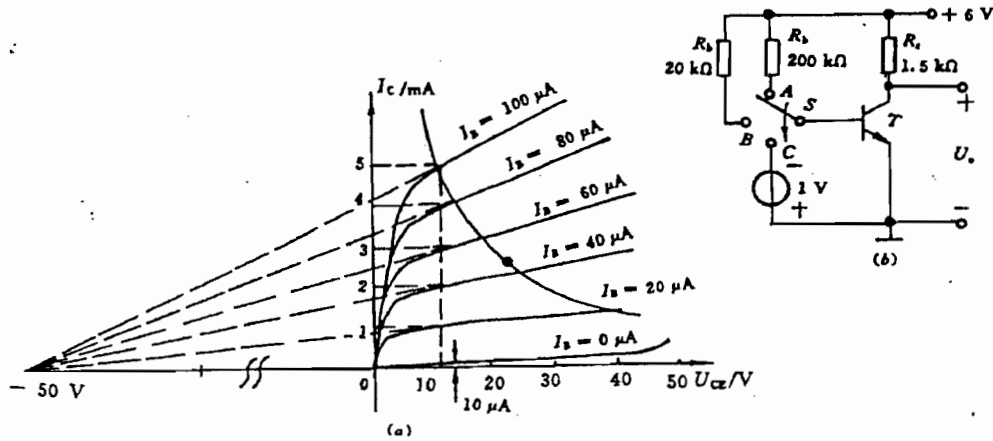


Fig.QC3-1

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

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