UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2018/2019

COURSE NAME : ADVANCED SEMICONDUCTOR DEVICES

COURSE CODE : BED 41003

PROGRAMME : BEJ

EXAMINATION DATE : JUNE / JULY 2019

DURATION : 3 HOURS

INSTRUCTION : ANSWER **ALL** QUESTIONS

THIS QUESTION PAPER CONSISTS OF **TEN (10)** PAGES

Q1 (a) Explain the importance of electron diffusion process during BJT operation.

(3 marks)

(b) Determine the emitter injection efficiency, γ, given emitter concentration, N_E, is 1000 times higher than base concentration, N_B, emitter diffusion, D_E, is quadruple compared to base diffusion, D_B, and emitter width, x_E, is double than base width, x_B.

(5 marks)

(c) Analyse how the recombination process affect the output current of BJT.

(3 marks)

(d) Analyse the change in collector current, i_C, if the base width, x_B, is halved and base-emitter junction area, A_{BE}, is increased by 20%. Express the change in percentage and assume all other parameters are unchanged.

(4 marks)

Q2 (a) Explain the main factor that causes space-charge effect in an IMPATT diode.

(3 marks)

(b) Referring to **Figure Q2(b)**, calculate the maximum electric field, E_m, and breakdown voltage, V_B, for a Si 2-sided IMPATT diode for concentration $N = 2 \times 10^{15} cm^{-3}$.

(5 marks)

(c) Analyse the reason carrier ionisation occurs close to p-n junction in IMPATT diode

(4 marks)

(d) Analyse main factors that cause the depletion region covers the whole middle layers in an IMPATT diode.

(4 marks)

Q3 (a) Explain the change in energy band diagram of semiconductor material forming Schottky barrier when being applied with reverse bias.

(3 marks)

(b) Suppose a Schottky barrier is formed between Ge and Ti. Calculate the depletion region width, x_n, created in the Ge layer doped to $N_d = 10^{16}\ cm^{-3}$ at $T = 300\ K$. Next, determine the maximum electric field in the Ge layer. Assume $\chi_{Ge} = 4.13\ V$.

(10 marks)

(c) Suppose a Schottky barrier is formed between a metal and a semiconductor with the condition of $\phi_m > \phi_s$. Analyse a solution to change this Schottky barrier to become an ohmic contact without changing the semiconductor material.

(5 marks)

(d) Analyse the appropriate expression of relative change in the contact resistance, R_C, if the semiconductor layer in an ohmic contact is changed from Ge to Si. Assume the doping concentration is similar for both semiconductor materials.

(5 marks)

Q4 (a) Explain the usefulness of forming ohmic contact at gate terminal in a MESFET.

(3 marks)

(b) Suppose a Si JFET at $T = 300\ K$ has the following parameters:

$$N_a = 10^{17}\ cm^{-3},\ N_d = 10^{14}\ cm^{-3},\ a = 1.25\ \mu m,\ L = 15\ \mu m,\ W = 60\ \mu m, \text{ and}$$
$$\mu_n = 1000\ \frac{cm^2}{V-s}$$

Determine the internal pinch off voltage, V_{p0}, built-in potential, V_{bi}, and pinch off current, I_p, for this transistor.

(10 marks)

(c) Analyse the importance of n$^+$ contact layer coincides with the undoped GaAs layer in MODFET structure as shown in **Figure Q4(c)**.

(5 marks)

(d) Using the appropriate formula, analyse the effect of metal work function, ϕ_m, to the saturation drain voltage, V_{Dsat}, in MESFET.

(5 marks)

Q5 (a) Explain **ONE (1)** purpose of having low doping concentration of n_1 layer in a thyristor.

(3 marks)

(b) Calculate the anode current, I_A, cathode current, I_K, and internal base current, I_{B1}, when a thyristor is in forward blocking mode given the following parameters:

$$\alpha_1 = 0.455,\ \alpha_1 = 0.403,\ I_{CO1} = 54\ \mu A,\ I_{CO2} = 90\ \mu A, \text{ and } I_g = 1\ mA$$

Next, determine gate current, I_g, and I_{B1} needed to maintain I_A if I_{CO1} and I_{CO2} increases 20% and 30% respectively. Assume both current gains are unchanged.

(10 marks)

(c) Analyse the essential parameter that determines which breakdown mechanism that occur in the thyristor.

(4 marks)

(d) Analyse the required condition to prevent the thyristor entering forward conduction mode using the two-transistor model.

(6 marks)

- END OF QUESTIONS -

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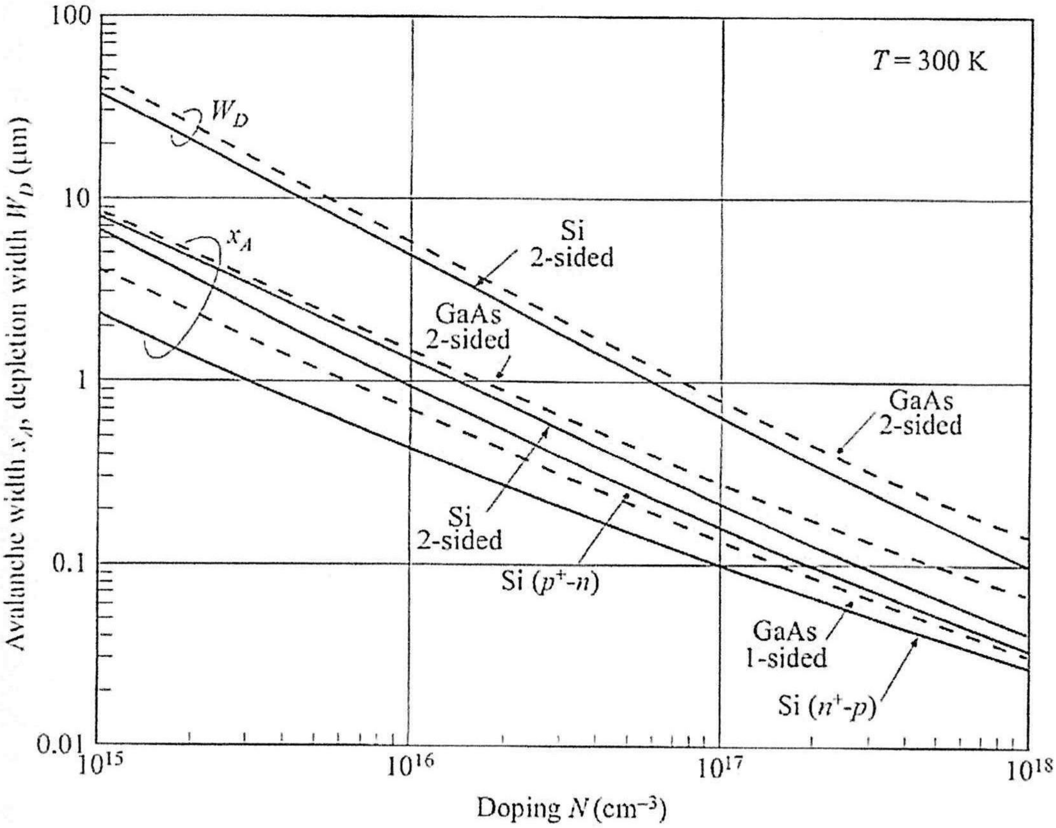

Figure Q2(b)

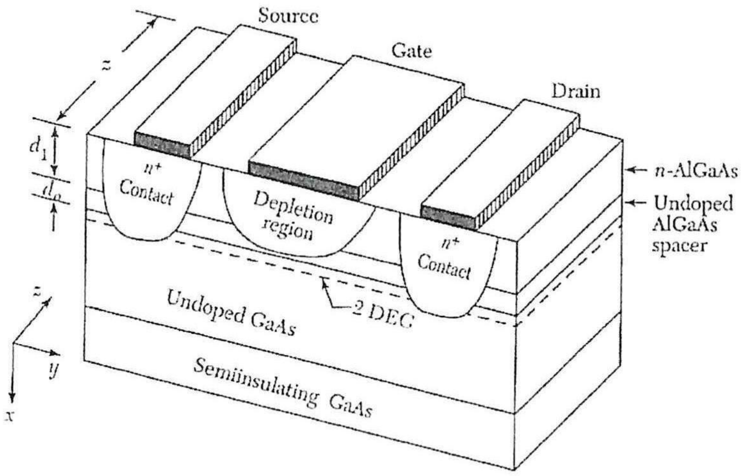

Figure Q4(c)

Table 1
Physical constants

Boltzmann's constant	$k = 1.38 \times 10^{-23}$ J/K $= 8.62 \times 10^{-5}$ eV/K
Electronic charge (magnitude)	$q = 1.6 \times 10^{-19}$ C
Free electron rest mass	$m_0 = 9.11 \times 10^{-31}$ kg
Permeability of free space	$\mu_0 = 4\pi \times 10^{-7}$ H/m
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-14}$ F/cm $= 8.85 \times 10^{-12}$ F/m
Planck's constant	$h = 6.625 \times 10^{-34}$ J-s $= 4.135 \times 10^{-15}$ eV-s
Modified Planck's constant	$\hbar = 1.054 \times 10^{-34}$ J-s
Proton rest mass	$M = 1.67 \times 10^{-27}$ kg
Speed of light in vacuum	$c = 2.98 \times 10^{10}$ cm/s
Thermal voltage ($T = 300$ K)	$V_t = kT/q = 0.0259$ V

Table 2
Work function of selected metals

Metal	Work function (V)
Silver (Ag)	4.26
Aluminum (Al)	4.28
Gold (Au)	5.10
Titanium (Ti)	4.33
Tungsten (W)	4.55

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Table 3
Silicon, Gallium Arsenide and Germanium properties ($T = 300$ K)

Property	**Si**	**GaAs**	**Ge**
Atoms (cm^{-3})	5.0×10^{22}	4.42×10^{22}	4.42×10^{22}
Atomic weight	28.09	144.63	72.60
Density (g/cm^{-3})	2.33	5.32	5.33
Lattice constant (Å)	5.43	5.65	5.65
Melting point (°C)	1415	1238	937
Dielectric constant	11.7	13.1	16.0
Bandgap energy (eV)	1.12	1.42	0.66
Electron affinity, χ (volts)	4.01	4.07	4.13
Effective density of states in conduction band, N_c (cm^{-3})	$2.8\ 10^{19}$	4.7×10^{17}	1.04×10^{19}
Effective density of states in valence band. N_v (cm^{-3})	1.04×10^{19}	7.0×10^{18}	6.0×10^{18}
Intrinsic carrier concentration (cm^{-3})	1.5×10^{10}	1.8×10^{6}	2.4×10^{13}
Mobility (cm^2/V-s)			
Electron, μ_n	1350	8500	3900
Hole, μ_p	480	400	1900
Effective mass (density of states)			
Electrons $\left(\frac{m_n^*}{m_0}\right)$	1.08	0.067	0.55
Holes $\left(\frac{m_p^*}{m_0}\right)$	0.56	0.48	0.37

Table 4
List of formula

Bipolar Transistors

1. $i_C = eD_nA_{BE}\frac{dn_x}{dx} = -\frac{eD_nA_{BE}}{x_B}\cdot n_{B0}exp\left(\frac{v_{BE}}{V_t}\right)$

2. $i_C = I_S exp\left(\frac{V_{BE}}{V_t}\right)$

3. $i_{E2} = I_{S2}exp\left(\frac{v_{BE}}{V_t}\right)$

4. $i_E = i_{E1} + i_{E2} = I_{SE}exp\left(\frac{v_{BE}}{V_t}\right)$

5. $\frac{i_C}{i_E} = \alpha$

6. $\frac{i_C}{i_B} = \beta$

7. $V_{CC} = I_CR_C + V_{CB} + V_{BE} = V_R + V_{CE}$

8. $V_{CE} = V_{CC} - I_CR_C$

9. $\alpha_0 = \frac{J_C}{J_E} = \frac{J_{nC} + J_G + J_{pc0}}{J_{nE} + J_R + J_{pE}}$

10. $\alpha = \frac{\partial J_C}{\partial J_E} = \frac{J_{nC}}{J_{nE} + J_R + J_{pE}}$

11. $\alpha = \gamma\alpha_T\delta$

12. $\gamma \approx \frac{1}{1 + \frac{N_B}{N_E}\cdot\frac{D_E}{D_B}\cdot\frac{x_B}{x_E}}$

13. $\alpha_T \approx \frac{1}{1 + \frac{1}{2}\left(\frac{x_B}{L_B}\right)^2}$

14. $\delta = \frac{1}{1 + \frac{J_{r0}}{J_{s0}}exp\left(-\frac{eV_{BE}}{2kT}\right)}$

15. $I_C = g_0(V_{CE} + V_A)$

16. $p_p(0) = p_{p0} = N_A$

17. $n_p(0) = n_{p0}exp\left(\frac{eV_{BE}}{kT}\right)$

18. $p_p(0)n_p(0) = p_{p0}n_{p0}exp\left(\frac{eV_{BE}}{kT}\right)$

Microwave Diodes

19. $V_B = \frac{1}{2}\mathrm{E}_mW_D = \frac{\varepsilon_s\mathrm{E}_m^2}{2qN}\cdots(1 - sided)$

20. $V_B = \frac{1}{2}\mathrm{E}_mW_D = \frac{\varepsilon_s\mathrm{E}_m^2}{qN}\cdots(2 - sided)$

21. $V_B = \mathrm{E}_mW_D - \frac{qN_1b}{\varepsilon_s}\left(W_D - \frac{b}{2}\right)\cdots(read)$

22. $V_B = \frac{\mathrm{E}_mb}{2} + \frac{qN_2W_D(W_D - b)}{2\varepsilon_s}\cdots(hi - lo)$

22. $V_B = \mathrm{E}_mb + \left(\mathrm{E}_m - \frac{qQ}{\varepsilon_s}\right)(W_D - b)\cdots(lhil)$

24. $\int_0^{x_A}\langle\alpha\rangle dx = 0.95$

25. $\mathrm{E}_{\min} = \mathrm{E}_m - \frac{q[N_1b + N_2(W_D - b)]}{\varepsilon_s}$

26. $I = Aq\Delta nv_s$

27. $R_{SC} = \frac{(W_D - x_A)^2}{2A\varepsilon_sv_s}$

28. $J_m = \frac{\mathrm{E}_m\varepsilon_sv_s}{W_D}$

29. $V_m = \mathrm{E}_mW_D$

30. $P_m = V_mJ_m = \mathrm{E}_m^2\varepsilon_sv_s$

Table 4
List of formula (Cont..)

Schottky barrier

31. $q\phi_{Bn0} = q(\phi_m - \chi)$

32. $q\phi_{Bp0} = E_g - q(\phi_m - \chi)$

33. $q\psi_{bi} = q(\phi_{Bn0} - \phi_n)$

34. $Q_{sc} = qN_D W_D = \sqrt{2q\varepsilon_s N_D \psi_{bi}}$

35. $|E_{\max}| = \dfrac{qN_D x_n}{\varepsilon_s}$

36. $x_n = \sqrt{\dfrac{2\varepsilon_s \psi_{bi}}{qN_D}}$

37. $J = \left[A^* T^2 \exp\left(-\dfrac{e\phi_{Bn0}}{kT}\right)\right]\left[\exp\left(\dfrac{eV_F}{kT}\right) - 1\right]$

38. $J = J_{sT}\left[\exp\left(\dfrac{eV_F}{kT}\right) - 1\right]$

39. $Q_{ss} = -qD_{it}(E_g - q\phi_0 - q\phi_{Bn0})$

40. $Q_M = -(Q_{ss} + Q_{sc})$

41. $Q_{sc} = \sqrt{2q\varepsilon_s N_D\left(\phi_{Bn0} - \phi_n - \dfrac{kT}{q}\right)}$

42. $\Delta = \phi_m - (\chi + \phi_{Bn0}) = -\dfrac{\delta Q_M}{\varepsilon_i}$

Ohmic contact

43. $\phi_{Bn} = \phi_n$

44. $J_t \propto \exp\left(-\dfrac{q\phi_{Bn}}{E_{00}}\right)$

45. $E_{00} = \dfrac{e\hbar}{2}\sqrt{\dfrac{N_d}{\varepsilon_s m_n^*}}$

46. $R_C = \dfrac{k}{A^{**}Tq}\exp\left(\dfrac{q\phi_{Bn}}{kT}\right)$

47. $R_C = \dfrac{\left(\dfrac{kT}{q}\right)\exp\left(\dfrac{q\phi_{Bn}}{kT}\right)}{A^* T^2}$

48. $R = \dfrac{R_C}{A}$

Heterojunction

49. $\psi_{bi} = |\phi_{m1} - \phi_{m2}|$

50. $W_{D1} = \sqrt{\dfrac{2N_2\varepsilon_{s1}\varepsilon_{s2}(\psi_{bi} - V)}{qN_1(\varepsilon_{s1}N_1 + \varepsilon_{s2}N_2)}}$

51. $W_{D2} = \sqrt{\dfrac{2N_1\varepsilon_{s1}\varepsilon_{s2}(\psi_{bi} - V)}{qN_2(\varepsilon_{s1}N_1 + \varepsilon_{s2}N_2)}}$

52. $C_D = \sqrt{\dfrac{qN_1N_2\varepsilon_{s1}\varepsilon_{s2}}{2(\varepsilon_{s1}N_1 + \varepsilon_{s2}N_2)(\psi_{bi} - V)}}$

52. $J_n = \dfrac{qD_{n2}n_{i2}^2}{L_{n2}N_2}\left[\exp\left(\dfrac{qV}{kT}\right) - 1\right]$

54. $J_p = \dfrac{qD_{p1}n_{i1}^2}{L_{p1}N_1}\left[\exp\left(\dfrac{qV}{kT}\right) - 1\right]$

55. $\dfrac{J_n}{J_p} \approx \dfrac{N_1}{N_2}\exp\left(-\dfrac{\Delta E_g}{kT}\right)$

56. $J = qN_{D2}\sqrt{\dfrac{kT}{2\pi m_2^*}}\exp\left(\dfrac{q\psi_{b2}}{kT}\right)\left[\exp\left(\dfrac{qV_2}{kT}\right) - \exp\left(\dfrac{-qV_1}{kT}\right)\right]$

Table 4
List of formula (Cont..)

JFET

57. $h = \sqrt{\frac{2\varepsilon_s (V_{bi} + V_{DS} - V_{GS})}{qN_D}}$

58. $I_D = I_P\left[3\left(\frac{V_{DS}}{V_{p0}}\right) - 2\left(\frac{V_{DS} + V_{bi} - V_{GS}}{V_{p0}}\right)^{3/2} + 2\left(\frac{V_{bi} - V_{GS}}{V_{p0}}\right)^{3/2}\right]$

59. $V_{p0} = \frac{qa^2 N_d}{2\varepsilon_s}$

60. $I_P = \frac{\mu_n (qN_d)^2 W a^3}{6\varepsilon_s L}$

61. $V_{Dsat} = V_{p0} - (V_{bi} - V_{GS})$

62. $I_{Dsat} = I_P\left[1 - 3\left(\frac{V_{bi} - V_{GS}}{V_{p0}}\right)\left(1 - \frac{2}{3}\sqrt{\frac{V_{bi} - V_{GS}}{V_{p0}}}\right)\right]$

MESFET

63. $R = \frac{L}{q\mu_n N_D A}$

64. $I_D = \frac{V_D}{R}$

65. $I_D = I_P\left[\frac{V_D}{V_P} - \frac{2}{3}\left(\frac{V_D + V_G + V_{bi}}{V_P}\right)^{3/2} + \frac{2}{3}\left(\frac{V_G + V_{bi}}{V_P}\right)^{3/2}\right]$

66. $V_{p0} = \frac{qa^2 N_d}{2\varepsilon_s}$

67. $I_P = \frac{Z\mu_n q^2 N_D^2 a^3}{2\varepsilon_s L}$

68. $I_{Dsat} = I_P\left[\frac{1}{3} - \left(\frac{V_G + V_{bi}}{V_{P0}}\right) + \frac{2}{3}\left(\frac{V_G + V_{bi}}{V_{P0}}\right)^{3/2}\right]$

69. $V_{Dsat} = \frac{qN_D a^2}{2\varepsilon_s} - V_{bi} - V_G$

70. $V_B = V_D + |V_G|$

71. $g_m = \frac{I_P V_D}{2V_{P0}^2}\sqrt{\frac{V_{P0}}{V_G + V_{bi}}}$, *lin*

72. $g_m = \frac{I_P}{V_{P0}}\left(1 - \sqrt{\frac{V_G + V_{bi}}{V_{P0}}}\right)$, *sat*

MODFET

73. $V_{p0} = \frac{qa^2 N_d}{2\varepsilon_s}$

74. $V_T = \phi_{Bn} - \frac{\Delta E_C}{q} - V_{P0}$

75. $I = \frac{Z}{L}\mu_n C_i (V_G - V_T) V_D$

76. $V_{Dsat} = V_G - V_T$

77. $I_{sat} = \frac{Z\mu_n \varepsilon_s}{2L(d_1 + d_0 + \Delta d)}(V_G - V_T)^2$

Table 4
List of formula (Cont..)

Thyristors

79. $V_B \approx 6.0 \times 10^{13} \left(N_{n1}\right)^{-0.75}$

80. $V_{PT} = \dfrac{qN_{n1}W_{n1}^2}{2\varepsilon_s}$

81. $V_{BR} = V_B \left(1 - \alpha_1\right)^{\frac{1}{n}}$

82. $\alpha_1 = \text{sech}\left(\dfrac{W}{L_{n1}}\right)$

83. $W = W_{n1}\left(1 - \sqrt{\dfrac{V_{AK}}{V_{PT}}}\right)$

84. $I_{C1} = \alpha I_E + I_{CO1}$

85. $I_{B1} = (1 - \alpha_1)I_A - I_{CO1}$

86. $I_{C2} = \alpha_2 I_K + I_{CO2}$

87. $I_A = \dfrac{\alpha_2 I_g + I_{CO1} + I_{CO2}}{1 - \left(\alpha_1 + \alpha_2\right)}$

88. $V_{BF} = V_B \left(1 - \alpha_1 - \alpha_2\right)^{1/n}$

89. $V_{AK} = V_1 - V_2 + V_3$

90. $J = \dfrac{qnW_i}{\tau_{eff}}$

91. $\tau_{eff} = \dfrac{1}{\left(2A_r n^2 + \dfrac{1}{\tau_{p0} + \tau_{n0}}\right)}$