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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2017/2018

COURSE NAME	:	ADVANCED SEMICONDUCTOR DEVICES
COURSE CODE	:	BED 41003
PROGRAMME	:	BEJ
EXAMINATION DATE	:	JUNE / JULY 2018
DURATION	:	3 HOURS
INSTRUCTION	:	1. ANSWER **ALL** QUESTIONS 2. THE QUESTION PAPER MUST BE SUBMITTED WITH THE ANSWER BOOKLET.

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

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Q1 (a) Given the parameters in the base region of an *npn* transistor are as follows:
$D_n = 20\ cm^s s^{-1}$, $n_{B0} = 10^4\ cm^{-3}$, $x_B = 1\ \mu m$, $A_{BE} = 10^{-4}\ cm^2$ and $v_{BE} = 0.6\ V$
Determine the collector current and supply current for this transistor.

(5 marks)

(b) There are three modes of operation for an *npn* transistor, namely cutoff, forward active and saturation. Analyse how the increment of V_{BE} will eventually changes operation mode from forward active to saturation.

(5 marks)

(c) Collector current, I_C, is known heavily dependent on the B-E junction voltage, V_{BE}, in bipolar transistor . Analyse the increment in I_C if the V_{BE} is quadrupled. Assume all other parameters are unchanged.

(5 marks)

Q2 (a) Suppose a square n-channel MOSFET at $T = 300\ K$ produces transconductance, g_m, of $4 \times 10^{-3}\ S$ during linear operation. Given the Si substrate is doped to $N_a = 10^{16}$ cm^{-3}, the oxide is SiO_2 with thickness of 100Å and the relative permittivity is 3.9. Calculate the drain voltage, V_D, and oxide capacitance, C_{ox}, of this device.

(5 marks)

(b) An inversion layer is created when a MOS capacitor is applied with large positive voltage. Analyse the factors that caused the inversion layer to reach its maximum size.

(5 marks)

(c) In MOSFET operation, both drain voltage, V_D, and gate voltage, V_G, have direct effect on drain current, I_D. Analyse how these two voltages control I_D during device operation. You may show the related electrical parameters to support your analysis.

(5 marks)

Q3 (a) Explain non-rectifying barrier in the perspective of carriers in metal-semiconductor junction.

(2 marks)

(b) Consider a non-rectifying barrier in Al-Ge junction at room temperature. If the temperature drops to 50% of room temperature, determine the ratio of change in contact resistance $\left(\frac{R_{C(new)}}{R_C}\right)$ in percentage. Given the doping concentration is 10^{16} cm^{-3}.

(10 marks)

(c) Analyse relative change both the depletion region width, W, and built-in potential, ψ_{bi}, if Al-Ge junction is being replace with Al-Si junction. You may use the appropriate diagram to support your analysis.

(6 marks)

(d) Analyse the effect on the electron-hole diffusion current ratio (J_n/J_p) if the energy bandgap is quadrupled. Assume other parameters are unchanged.

(6 marks)

Q4 (a) Explain how the conducting channel is created in MODFET device.

(2 marks)

(b) Determine the transconductance of a square *n*-type Si MESFET with Ti gate, given the doping concentration, $N_D = 10^{15}$ cm^{-3} and epitaxial layer width, $a = 100$ nm. Assume that the gate voltage, $V_G = 0$ V.

(10 marks)

(c) Analyse how the pinch-off point is achieved in a depletion mode JFET and the reason drain voltage unable to control drain current beyond the pinch-off point.

(6 marks)

(d) Analyse **ONE (1)** contributing factor that caused deterioration of transconductance in depletion mode JFET as the magnitude of gate voltage is increased.

(5 marks)

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

(2 marks)

(b) Determine the punchthrough voltage, V_{PT}, for Si thyristor given doping concentration, N_{n1} and width, W_{n1}, of n_1 region are 10^{14} cm^{-3} and 25 µm, respectively.
Assuming that there are three times larger N_{n1} in Ge thyristor, estimate W_{n1} required to produce similar V_{PT}.

(10 marks)

(c) To achieve forward conduction in thyristor operation, two conditions must be met: anode-cathode voltage is positive ($V_{AK} > 0$) and gate current is present $(I_g > 0)$. Analyse possibility of achieving forward conduction if I_g is missing.

(6 marks)

(d) Referring to DMOS structure in **Figure Q5(d)**, analyse the importance of having lightly doped region, n^-, in its structure.

(5 marks)

- END OF QUESTIONS -

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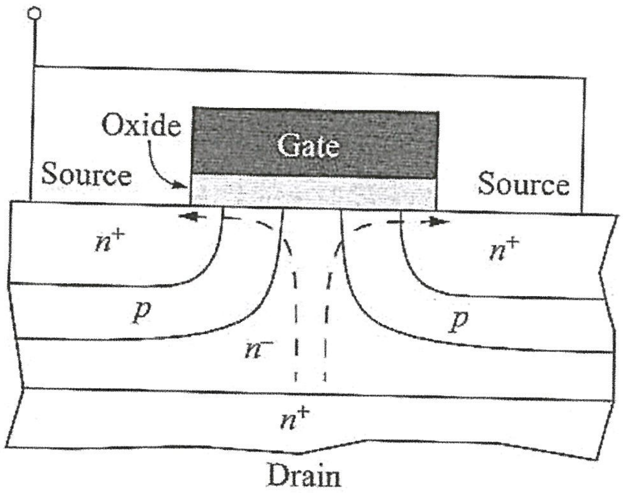

Figure Q5(d)

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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

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Table 4
List of formula

Bipolar Transistors

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

MOSFET

19. $x_{dT} = \sqrt{\dfrac{4\epsilon_s\phi_{fp}}{eN_a}}$

20. $x_d = \sqrt{\dfrac{2\epsilon_s\phi_s}{eN_a}}$

21. $C'(acc) = C_{ox} = \dfrac{\epsilon_{ox}}{t_{ox}}$

22. $\phi_{fp} = V_t ln\left(\dfrac{N_a}{n_i}\right)$

22. $C'(min) = \dfrac{\epsilon_{ox}}{t_{ox} + \left(\dfrac{\epsilon_{ox}}{\epsilon_s}\right)x_{dT}}$

24. $C'(depl) = \dfrac{C_{ox}}{1 + \dfrac{C_{ox}}{C'_{SD}}} = \dfrac{\epsilon_{ox}}{t_{ox} + \left(\dfrac{\epsilon_{ox}}{\epsilon_s}\right)x_d}$

25. $C'(inv) = C_{ox} = \dfrac{\epsilon_{ox}}{t_{ox}}$

26. $V_{DS(sat)} = V_G - V_T$

27. $I_D = \dfrac{W\mu_nC_{ox}}{2L}[2(V_G - V_T)V_{DS} - V_{DS}^2]$

28. $I_D = \dfrac{W\mu_nC_{ox}}{2L}(V_G - V_T)$

29. $g_{mL} = \dfrac{W\mu_nC_{ox}}{L}(V_{DS})$

30. $g_{ms} = \dfrac{W\mu_nC_{ox}}{L}(V_G - V_T)$

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

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Table 4
List of formula (Cont..)

JFET

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

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

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

60. $I_P=\dfrac{\mu_n\left(qN_d\right)^2Wa^3}{6\varepsilon_s L}$

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

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

MESFET

63. $R=\dfrac{L}{q\mu_nN_DA}$

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

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

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

67. $I_P=\dfrac{Z\mu_nq^2N_D^2a^3}{2\varepsilon_s L}$

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

69. $V_{Dsat}=\dfrac{qN_Da^2}{2\varepsilon_s}-V_{bi}-V_G$

70. $V_B=V_D+\left|V_G\right|$

71. $g_m=\dfrac{I_PV_D}{2V_{P0}^2}\sqrt{\dfrac{V_{P0}}{V_G+V_{bi}}},\ lin$

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

MODFET

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

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

75. $I=\dfrac{Z}{L}\mu_nC_i\left(V_G-V_T\right)V_D$

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

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

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Table 4
List of formula (Cont..)

Thyristors

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

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

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

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

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

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

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

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