Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2019/2020

COURSE NAME : ADVANCED SEMICONDUCTOR DEVICES

COURSE CODE : BED 41003

PROGRAMME CODE : BEJ

EXAMINATION DATE : DECEMBER 2019 / JANUARY 2020

DURATION : 3 HOURS

INSTRUCTION : ANSWER **ALL** QUESTIONS

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THIS QUESTION PAPER CONSISTS OF **EIGHT (8)** PAGES

Q1 (a) Explain the effect of base voltage towards the output current formation in BJT.
(3 marks)

(b) An npn BJT has the parameters of $D_n = 25\ cm^2/s$, $n_{B0} = 3.2 \times 10^4\ cm^{-3}$, and $v_{BE} = 0.6\ V$. Determine the ratio $\frac{A_{BE}}{x_B}$ to ensure the BJT produces $I_C = 34\ mA$.
(5 marks)

(c) Analyse the appropriate method to minimise current crowding effect in BJT. Use a related diagram to support your analysis.
(6 marks)

Q2 (a) Explain the purpose of semi-insulating substrate in a MODFET.
(3 marks)

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

$N_a = 10^{17}\ cm^{-3}$, $N_d = 10^{14}\ cm^{-3}$, $V_{p0} = 0.10\ V$, $V_G = 0.2\ V$, $I_p = 4.5 \times 10^{-6}\ A$.

Determine the I_{Dsat} for this JFET.
(5 marks)

(c) Using the appropriate formula, analyse the effect on the saturation drain current in MODFET if the substrate is changed from gallium arsenide to germanium.
(6 marks)

Q3 (a) Explain **ONE (1)** advantage of planar double gate MOSFET to improve the transistor performance.
(3 marks)

(b) Consider a silicon DG MOSFET with the following parameters:

$$N_d = 3 \times 10^{15}\ cm^{-3},\ N_a = 4 \times 10^{13}\ cm^{-3},\ C_{ox} = 2.5\ \mu F,\ t_{Si} = 16\ \mu m,\ T = 300\ K.$$

(i) Calculate the potential coefficients ϕ_s and m_1.
(6 marks)

(ii) Estimate maximum and minimum values of m_1 given $12\ \mu m \leq t_{Si} \leq 20\ \mu m$.
(4 marks)

(c) Analyse the effect of oxide layer thickness towards the strength of electric field in DG MOSFET.
(5 marks)

(d) Analyse the reason symmetric gate FinFET produces higher on-current compared to independent-gate FinFET. Use the appropriate diagram to support your analysis.
(6 marks)

Q4 (a) Explain the importance of depletion region during the operation of a varactor.
(3 marks)

(b) A silicon p-i-n diode has the following parameters:

$$\Delta n = 4 \times 10^{16}\ cm^{-3},\ W = 6\ \mu m,\ A = 2.4 \times 10^{-6}\ cm^{2},\ v_s = 10\ cm/s.$$

(i) Calculate the R_{RF} and J_F of this diode.
(6 marks)

(ii) Estimate the required Δn in a germanium p-i-n diode to produce R_{RF} 10% higher than the silicon p-i-n diode, assuming other parameters are similar.
(4 marks)

(c) Analyse the reason carrier ionisation normally reaches its maximum value near p-n junction in IMPATT diode.
(6 marks)

(d) Using the appropriate formula, analyse the reason a germanium Read diode has much higher breakdown voltage than a silicon Read diode.
(5 marks)

Q5 (a) Explain **ONE (1)** feature of a thyristor that makes it suitable for high power applications.
(3 marks)

(b) Consider a germanium thyristor in reverse blocking mode with these parameters:

$$W_{n1} = 25\ \mu m,\ L_{n1} = 14\ \mu m,\ V_{AK} = 10\ V,\ N_{n1} = 4 \times 10^{14}\ cm^{-3}.$$

(i) Calculate the V_{PT}, W, and α_1.
(7 marks)

(ii) Estimate W_{n1} needed in silicon thyristor to obtain similar V_{PT} as in the germanium thyristor. Assume all other parameters are unchanged.
(3 marks)

(c) Using the two-transistor model, analyse the importance of gate voltage in enabling the thyristor to conduct current.
(6 marks)

(d) Using the related formula, analyse the appropriate method to turn thyristors into forward conduction mode without applying the gate voltage.
(5 marks)

- END OF QUESTIONS -

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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.	$i_C = \frac{eD_nA_{BE}}{x_B} \cdot n_{B0} exp\left(\frac{v_{BE}}{V_t}\right)$	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.	$\alpha_0 = \frac{J_C}{J_E} = \frac{J_{nC} + J_G + J_{pc0}}{J_{nE} + J_R + J_{pE}}$	8.	$\alpha = \frac{\partial J_C}{\partial J_E} = \frac{J_{nC}}{J_{nE} + J_R + J_{pE}}$
9.	$\alpha = \gamma \alpha_T \delta$	10.	$\gamma \approx \frac{1}{1 + \frac{N_B}{N_E} \cdot \frac{D_E}{D_B} \cdot \frac{x_B}{x_E}}$
11.	$\alpha_T \approx \frac{1}{1 + \frac{1}{2}\left(\frac{x_B}{L_B}\right)^2}$	12.	$\delta = \frac{1}{1 + \frac{J_{r0}}{J_{s0}} exp\left(-\frac{eV_{BE}}{2kT}\right)}$
13.	$x_{dB} = \sqrt{\left(\frac{2\varepsilon_s(V_{bi} + V_{CB})}{q}\right)\left(\frac{N_C}{N_B}\right)\left(\frac{1}{N_B + N_C}\right)}$	14.	$V_{bi} = \frac{kT}{q} ln\left(\frac{N_C N_B}{{n_i}^2}\right)$
15.	$n_p(0) = n_{p0} exp\left(\frac{eV_{BE}}{kT}\right)$	16.	$p_p(0) = p_{p0} = N_A$

JFET

17.	$h = \sqrt{\frac{2\varepsilon_s(V_{bi} + V_{DS} - V_{GS})}{qN_D}}$	18.	$I_D = I_P\left[3\left(\frac{V_D}{V_{p0}}\right) - 2\left(\frac{V_D + V_{bi} + V_G}{V_{p0}}\right)^{3/2} + 2\left(\frac{V_{bi} - V_G}{V_{p0}}\right)^{3/2}\right]$
19.	$V_{p0} = \frac{qa^2N_d}{2\varepsilon_s}$	20.	$I_p = \frac{\mu_n(qN_d)^2Wa^3}{6\varepsilon_s L}$
21.	$V_{Dsat} = V_{p0} - (V_{bi} - V_G)$	22.	$I_{Dsat} = I_P\left[1 - 3\left(\frac{V_{bi} - V_G}{V_{p0}}\right)\left(1 - \frac{2}{3}\sqrt{\frac{V_{bi} - V_G}{V_{p0}}}\right)\right]$

MESFET

23.	$R = \frac{L}{q\mu_n N_D A}$	24.	$V_{Dsat} = \frac{qN_Da^2}{2\varepsilon_s} - V_{bi}, V_G = 0$
25.	$V_{Dsat} = \frac{qN_Da^2}{2\varepsilon_s} - V_{bi} - V_G$	26.	$I_D = I_P\left[\frac{V_D}{V_P} - \frac{2}{3}\left(\frac{V_D + V_G + V_{bi}}{V_P}\right)^{3/2} + \frac{2}{3}\left(\frac{V_G + V_{bi}}{V_P}\right)^{3/2}\right]$
27.	$I_P = \frac{Z\mu_n q^2 N_D^2 a^3}{2\varepsilon_s L}$	28.	$V_P = \frac{qN_Da^2}{2\varepsilon_s}$
29.	$I_{Dsat} = I_P\left[\frac{1}{3} - \left(\frac{V_G + V_{bi}}{V_P}\right) + \frac{2}{3}\left(\frac{V_G + V_{bi}}{V_P}\right)^{3/2}\right]$	30.	$V_{Dsat} = V_P - V_G - V_{bi}$
31.	$g_m = \frac{\partial I_D}{\partial V_G}\bigg\rvert_{V_D} = \frac{I_PV_D}{2V_P^2}\sqrt{\frac{V_P}{V_G + V_{bi}}} \quad (lin)$	32.	$g_m = \frac{I_P}{V_P}\left(1 - \sqrt{\frac{V_G + V_{bi}}{V_P}}\right) \quad (sat)$

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Table 4
List of formula (Cont..)

MODFET

33.	$V_P = \frac{qN_D d_1^2}{2\varepsilon_s}$	34.	$V_T = \phi_{Bn} - \frac{\Delta E_C}{q} - V_P$
35.	$I = \frac{Z}{L}\mu_n C_i V_D (V_G - V_T)$	36.	$V_{Dsat} = V_G - V_T$
37.	$I_{Dsat} = \frac{Z\mu_n \varepsilon_s}{2L(d_1 + d_0 + \Delta d)}(V_G - V_T)^2$	38.	

DG MOSFET

39.	$\Psi(x,y) = \Psi_{S1}(x) + \alpha(x)y + \beta(x)y^2$	40.	$E_1 = \frac{\varepsilon_{ox}}{\varepsilon_{Si}} \frac{V_{G1} - V_{FB1} - \Psi_{S1}}{t_{ox1}}$
41.	$E_2 = \frac{\varepsilon_{ox}}{\varepsilon_{Si}} \frac{V_{G2} - V_{FB2} - \Psi_{S2}}{t_{ox2}}$	42.	$\alpha = -\frac{V_{G1} - V_{FB1} - \Psi_{S1}}{\gamma t_{ox}}$
43.	$\beta = -\frac{V_{G2} - V_{FB2} - \Psi_{S1}}{(2\gamma t_{ox} + t_{Si})t_{Si}} - \alpha \frac{(\gamma t_{ox} + t_{Si})}{(2\gamma t_{ox} + t_{Si})t_{Si}}$	44.	$\gamma = \frac{\varepsilon_{ox}}{\varepsilon_{Si}}$
45.	$\Psi_{S1}(x) = C_1 exp(m_1 x) + C_2 exp(-m_1 x) - \frac{R(x)}{{m_1}^2}$	46.	$I_D = \mu \frac{W}{L}\frac{kT}{q}\left[1 - exp\left(-\frac{qV_D}{kT}\right)\right]$
47.	$\phi_S = \left(\frac{kT}{q}\right) ln\left(\frac{N_A N_{SD}}{{n_i}^2}\right)$	48.	$m_1 = \sqrt{\frac{2C_{ox}}{\varepsilon_{Si} t_{Si}}}$

Varactor

49.	$N = Bx^m$	50.	$s = \frac{1}{m+2}$
51.	$W_D = \left[\frac{\varepsilon_s(m+2)(V_R + \psi_{bi})}{qB}\right]^{\frac{1}{m+2}}$	52.	$C_D = \frac{\varepsilon_s}{W_D} = \left[\frac{qB\varepsilon_s^{m+1}}{(m+2)(V_R + \psi_{bi})}\right]^{\frac{1}{m+2}}$

p-i-n Diode

53.	$\tau = \frac{W}{v_s}$	54.	$C = \frac{\varepsilon_s}{W}$
55.	$V_{BD} = \mathrm{E}_m W$	56.	$J_{re} = \frac{qWn_i}{2\tau} exp\left(\frac{qV_F}{2kT}\right)$
57.	$R_{RF} = \rho\frac{W}{A} = \frac{W}{q\Delta n(\mu_n + \mu_p)A}$	58.	$J_F = \frac{qW\Delta n}{\tau}$

Table 4
List of formula (Cont..)

	IMPATT Diode		
59.	$\langle\alpha\rangle = \alpha_n exp\left[-\int_x^{W_D}(\alpha_n-\alpha_p)dx\right]$	60.	$\int_x^{W_D}\langle\alpha\rangle\,dx = 1$
61.	$V_B = \frac{1}{2}\mathbf{E}_m W_D = \frac{\varepsilon_s \mathbf{E}_m^2}{2qN}\quad(1-sided)$	62.	$V_B = \frac{1}{2}\mathbf{E}_m W_D = \frac{\varepsilon_s \mathbf{E}_m^2}{qN}\quad(2-sided)$
63.	$V_B = \mathbf{E}_m W_D = -\frac{qN_1 b}{\varepsilon_s}\left(W_D - \frac{b}{2}\right)\quad(Read)$	64.	$V_B = \frac{\mathbf{E}_m b}{2} + \frac{qN_2 W_D(W_D-b)}{2\varepsilon_s}\quad(Hi-Lo)$
65.	$V_B = \mathbf{E}_m b + \left(\mathbf{E}_m - \frac{qQ}{\varepsilon_s}\right)(W_D-b)\quad(Lo-Hi-Lo)$	66.	$\int_0^{x_A}\langle\alpha\rangle\,dx = 0.95$
67.	$\mathbf{E}_{min} = \mathbf{E}_m - \frac{q[N_1 b + N_2(W_D-b)]}{\varepsilon_s}$	68.	$V_m = \mathbf{E}_m W_D$
69.	$J_m = \frac{\mathbf{E}_m\varepsilon_s v_s}{W_D}$	70.	$P_m = \mathbf{E}_m^2 \varepsilon_s v_s$
	Thyristors		
71.	$V_B \approx 6\times 10^{13}(N_{n1})^{-0.75}$	72.	$V_{PT} = \frac{qN_{n1}W_{n1}^2}{2\varepsilon_s}$
73.	$V_{BR} = V_B\,(1-\alpha_1)^{\frac{1}{n}}$	74.	$\alpha_1 = sech\left(\frac{W}{L_{n1}}\right)$
75.	$W = W_{n1}\left(1-\sqrt{\frac{V_{AK}}{V_{PT}}}\right)$	76.	$I_{C1} = \alpha I_E + I_{CO1}$
77.	$I_{B1} = (1-\alpha_1)I_A - I_{CO1}$	78.	$I_{C2} = \alpha_2 I_K + I_{CO2}$
79.	$I_A = \frac{\alpha_2 I_g + I_{CO1} + I_{CO2}}{1-(\alpha_1+\alpha_2)}$	80.	$V_{BF} = V_B(1-\alpha_1-\alpha_2)^{1/n}$
81.	$V_{AK} = V_1 - \lvert V_2\rvert + V_3$	82.	$J = \frac{qnW_i}{\tau_{eff}}$
83.	$\tau_{eff} = \frac{1}{\left(2A_r n^2 + \frac{1}{\tau_{p0}+\tau_{n0}}\right)}$	84.	