Reg No.:_______________ Name:__________________________

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

Third Semester B.Tech Degree Examination December 2020 (2019 Scheme)

## Course Code: ECT201
## Course Name: SOLID STATE DEVICES

Max. Marks: 100 Duration: 3 Hours

**PART A**

***Answer all questions. Each question carries 3 marks*** Marks

| | | |
|---|---|---|
| 1 | With suitable examples, distinguish between elemental and compound semiconductors. Give their applications. | (3) |
| 2 | Draw the energy band diagrams under equilibrium for the following semiconductors. i) intrinsic ii) n type iii) p type | (3) |
| 3 | Write down the current equations in a semiconductor. | (3) |
| 4 | What is the significance of quasi fermi level? If there is gradient in quasi fermi level, what does it indicates? | (3) |
| 5 | Draw the V-I characteristics of a P N junction diode & mark the regions of operation. Write down the ideal diode equation. | (3) |
| 6 | Draw the structure of a PNP transistor. Clearly Indicate the current components on the figure. | (3) |
| 7 | Plot the transfer characteristics of an n-channel MOSFET. Give the current equation. | (3) |
| 8 | An nMOS transistor has W/L= 4/2, gate oxide thickness 40 $A^o$, Mobility of electrons 180 $cm^2$/Vsec. The threshold voltage is 0.4 V, relative permittivity of gate oxide $\epsilon_{ox}$ =3.9. Calculate the drain current when Vgs = 1.5 V, Vds = 1.8 V. | (3) |
| 9 | What is channel length modulation in MOSFETs? How does it affect the output characteristics of the MOSFET? | (3) |
| 10 | Explain the principle of operation and advantage of FinFET. | (3) |

**PART B**

***Answer any one full question from each module. Each question carries 14 marks***

**Module 1**

| | | | |
|---|---|---|---|
| 11 | a) | Derive the equation for hole concentration in a semiconductor under thermal equilibrium in terms of $n_i$, $E_f$ and $E_i$. | (8) |

b) A silicon sample doped with $2x10^{16} cm^{-3}$ of Boron atoms. ( $n_i = 1.5x10^{10} cm^{-3}$ for Silicon at 300 K) Determine,

i. The equilibrium electron and hole concentrations

ii. Position of fermi energy level in the band gap (6)

iii. Plot the energy band diagram

12 a) Plot and explain the temperature dependence of intrinsic carrier concentration in semiconductors (4)

b) With suitable sketches explain the indirect recombination mechanism via traps. (5)

c) An n-type Si sample with Nd = $10^{15}$ $cm^{-3}$ is steadily illuminated such that $g_{op} = 10^{21}$ EHP/$cm^3$s. If $\tau_n = \tau_p$ = l μs for this excitation, calculate the separation in the quasi-Fermi levels, ($F_n$ - $F_p$). ( $n_i = 1.5x10^{10} cm^{-3}$ for Silicon at 300 K) (5)

**Module 2**

13 a) Explain the term mobility with respect to semiconductors. What are the factors on which the mobility depends on? Explain the variation of mobility with temperature and doping. (8)

b) A potential of 100 mV is applied across a semiconductor bar, and the resulting current is 1 mA. A magnetic field of $10^{-4}$ Wb/$cm^2$ is applied perpendicular to this semiconductor bar. The hall voltage measured is -2 mV. The dimensions of the bar are width = 0.1 mm, length = 5 mm and thickness = 10 µm. Find (6)

i. the type of the semiconductor bar

ii. the concentration and the mobility of majority carriers

14 a) Derive continuity equation for holes. (4)

b) Solve the continuity equation, under steady state conditions assuming the semiconductor is long and no drift current is present. Plot the solution. (6)

c) A p type semiconductor injected at one end with minority carrier electrons, under steady state conditions. Na = $10^{15}$ $cm^{-3}$ , $\tau_n$ = 0.l µs, $\mu_n$ = 700 $cm^2$/V Sec. Calculate the electron diffusion length. (4)

**Module 3**

15 a) With the help of energy band diagrams, explain the behaviour of the contact between a metal and an n -type semiconductor. Clearly distinguish between Schottky and ohmic contacts. (10)

b) What is base width modulation? How does it affect the input and output characteristics of a BJT? (4)

16 a) Derive the equation for the built in potential of a PN junction under thermal equilibrium. (7)

b) A PN junction, doped on one side with $10^{18}$ $cm^{-3}$ Boron atoms and the other side with $10^{16}$ $cm^{-3}$ of Arsenic atoms at 300 K. ($n_i$ = 1.5x$10^{10}$$cm^{-3}$ at 300 K and $\epsilon_r$ =11.9 for Silicon). Calculate, the built in potential. (3)

c) The following parameters are given for a PNP transistor. $I_{EP}$= 2 mA, $I_{En}$= 0.01 mA, $I_{cP}$= 1.98 mA and $I_{cn}$= 0.001mA. Determine

i. The base transport factor

ii. The emitter injection efficiency (4)

iii. $\alpha$ and $\beta$

**Module 4**

17 a) Draw and explain the C-V Characteristics of an Ideal MOS capacitor. Derive the expression for threshold voltage. (8)

b) Draw the energy band diagrams, of an ideal MOS capacitor under equilibrium, and strong inversion conditions. (6)

18 a) Draw the structure of n channel MOSFET. Derive the expression for drain current of a MOSFET in the two regions of operation. What are the assumptions made in deriving the expression? (10)

b) What is meant by body effect in MOSFET? How does it affect the threshold voltage of the MOSFET? (4)

**Module 5**

19 a) What is meant by scaling in MOSFETs? Explain the challenges in device scaling? (7)

b) Explain the concept of constant voltage scaling and its limitations. (7)

20 a) What is meant by DIBL in MOSFETs? How does it affect the threshold voltage of a MOSFET? (7)

b) Explain the concepts of velocity saturation and hot carrier effects in a MOSFET. (7)

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**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

Third Semester B.Tech Degree Examination December 2021 (2019 scheme)

## Course Code: ECT201
## Course Name: SOLID STATE DEVICES

Max. Marks: 100 Duration: 3 Hours

## PART A

*Answer **all** questions. Each question carries **3 marks*** Marks

| | | |
|---|---|---|
| 1 | State and explain law of mass action. | (3) |
| 2 | Explain the concept of quasi Fermi level | (3) |
| 3 | State and explain the terms in Einstein's relation. | (3) |
| 4 | Distinguish between drift and diffusion mechanisms. Write the expression for the corresponding currents | (3) |
| 5 | Explain Early effect and its impact on collector and base currents. | (3) |
| 6 | Derive the expression for built in potential of a PN junction diode | (3) |
| 7 | Draw the energy band diagram of a MOS capacitor at equilibrium, accumulation and strong inversion condition. | (3) |
| 8 | Explain the transfer characteristics of a MOSFET. | (3) |
| 9 | Explain Drain induced barrier lowering? | (3) |
| 10 | Draw and label the structure of a FINFET | (3) |

## PART B

*Answer **any one full question** from each module. Each question carries **14 marks***

### Module 1

| | | | |
|---|---|---|---|
| 11 | (a) | Define Fermi Dirac distribution function. Explain with relevant figures Fermi Dirac distribution of carriers in intrinsic and extrinsic materials. | (10) |
| | (b) | The Fermi level in a Si sample at 300K is located at 0.3eV below the bottom of the conduction band. The effective density of states $N_C$=3.22x$10^{19}$cm$^{-3}$ and $N_V$=1.83x$10^{19}$cm$^{-3}$. Determine (i) the electron and hole concentration at 300K (ii) the intrinsic carrier concentration at 300K | (4) |
| 12 | (a) | An n-type Si sample with $N_d$ = $10^{15}$ cm$^{-3}$ is steadily illuminated such that | (7) |

gop = $10^{21}$ EHP/$cm^3$s. If $\tau_n = \tau_p$ = lμs for this excitation, calculate the separation in the quasi-Fermi levels, $(E_{Fn} - E_{Fp})$.

(b) Illustrate the direct and indirect recombination process of excess carriers in semiconductors (7)

## Module 2

13 (a) Explain Hall effect? Derive the expression for determining carrier concentration in a semiconductor bar using Hall effect. . (7)

(b) (i) Show that the minimum conductivity of a semiconductor sample occurs when $n_0 = n_i\sqrt{\frac{\mu_p}{\mu_n}}$ (ii) What is the expression for the minimum conductivity $\sigma_{min}$? (iii) Calculate $\sigma_{min}$ for Si at 300 K and compare with the intrinsic conductivity. (7)

14 (a) Derive the expression for drift current density, mobility of carriers and conductivity of a semiconductor. (8)

(b) A Si sample with $10^{15}$/$cm^3$ donors is uniformly optically excited at room temperature such that $10^{19}$/$cm^3$ electron-hole pairs are generated per second. Find the separation of the quasi-Fermi levels and the change of conductivity upon shining the light. Electron and hole lifetimes are both 10 μs. $D_p$ = 12 $cm^2$/s. (6)

## Module 3

15 (a) Draw the energy band diagram of a metal N type semiconductor with $\phi_m > \phi_s$ under equilibrium condition and on biasing. Is the contact rectifying or ohmic. Justify your answer. (9)

(b) Assume that a p-n-p transistor is doped such that the emitter doping is 20 times that in the base, the minority carrier mobility in the emitter is one-fourth that in the base, and the base width is one-tenth the minority carrier diffusion length. The carrier lifetimes are equal. Calculate α and β for this transistor. (5)

16 (a) Derive ideal diode equation. (8)

(b) A Schottky barrier diode is formed from n type Si of a doping $10^{16}cm^{-3}$ and area $10^{-3}cm^2$. A Si PN junction has the same area and $N_A=10^{19}cm^{-3}$, $N_D=10^{16}cm^{-3}$, $\tau_n=\tau_p=1\mu s$. (i)Calculate the Schottky barrier diode current at 0.4V and 300K. (ii) Calculate the value of forward bias to obtain same (6) current for a PN junction.[R*=110A/$K^2$, Electron affinity of Si=4.15eV, metal work function=4.9eV,Diffusion constant=12$cm^2$/s]

## Module 4

17 (a) Draw and explain the CV characteristics of a MOS capacitor (8)

(b) For a long channel n-MOSFET with W = 1V, calculate the $V_G$ required for an $I_{D(sat.)}$ of 0.1 mA and $V_{D(sat.)}$ of 5V. Calculate the small-signal output conductance g and the transconductance $g_{m(sat.)}$ at $V_D$ = 10V. Recalculate the new $I_D$ for $V_G$ - $V_T$ = 3V and $V_D$ = 4V. (6)

18 (a) Draw and explain the drain characteristics and transfer characteristics of a MOSFET. (8)

(b) An Al-gate p-channel MOS transistor is made on an n-type Si substrate with $N_d$ = 5x$10^{17}$ $cm^{-3}$. The $SiO_2$ thickness is 100 Å in the gate region, and the effective interface charge $Q_i$ is 5 x $10^{10}$ q C/$cm^2$ and the work function difference between metal and semiconductor is -0.15V. Find $W_{max}$ , $V_{FB}$ , and $V_T$ of the device. (6)

## Module 5

19 (a) Distinguish between constant voltage scaling and constant field scaling (8)

(b) Illustrate the operation of FinFET (6)

20 Explain any four short channel effects in MOSFET (14)

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**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

Third Semester B.Tech Degree Regular and Supplementary Examination December 2022 (2019 scheme)

**Course Code: ECT201**

**Course Name: SOLID STATE DEVICES**

Max. Marks: 100 Duration: 3 Hours

**PART A**

***Answer all questions. Each question carries 3 marks*** Marks

| | | |
|---|---|---|
| 1 | Define Fermi-Dirac distribution function of semiconductor. | (3) |
| 2 | Draw the energy band diagrams under equilibrium for i) Intrinsic ii) n-type iii) p-type semiconductors. | (3) |
| 3 | Differentiate drift and diffusion movement of carriers in semiconductors. | (3) |
| 4 | Derive continuity equation. | (3) |
| 5 | Explain the terms emitter injection efficiency and base transport factor of a BJT. | (3) |
| 6 | Differentiate Ohmic and rectifying contacts metal-Semiconductor contacts. | (3) |
| 7 | What is meant by body effect in MOSFET? | (3) |
| 8 | Draw and explain the transfer characteristics of an enhancement type MOSFET. | (3) |
| 9 | Define Sub threshold conduction in MOSFET | (3) |
| 10 | Define threshold Voltage of MOSFET. How it can be varied? | (3) |

**PART B**

***Answer any one full question from each module. Each question carries 14 marks***

**Module 1**

| | | | |
|---|---|---|---|
| 11 | (a) | Derive the expression for electron concentration ($n_0$) and hole concentration ($p_0$) at equilibrium. | (8) |
| | (b) | For a silicon sample at 300K, the equilibrium hole concentration is $4x10^{12}$ $cm^{-3}$. Determine (i) equilibrium electron concentration (ii) the acceptor concentration if the donor concentration is $10^{12}$ $cm^{-3}$. (Assume ni for silicon is $1.5x10^{10}$ $cm^{-3}$). | (6) |
| 12 | (a) | Explain different types of recombination mechanisms. | (7) |
| | (b) | A silicon sample doped with $10^{16}cm^{-3}$ donors at 300K is optically excited such that the optical generation rate is $10^{20}$ EHP/($cm^{-3}$ $s^{-1}$). Find the separation between Quasi Fermi levels and show the positions of equilibrium and quasi Fermi levels if $\tau_p = \tau_n = 2$ µs. | (7) |

## Module 2

13 (a) State and prove Einstein's relation. (9)

(b) An n type silicon bar 0.1 cm long and 100 μ$m^2$ in cross sectional area has a majority carrier concentration of $5x10^{15}$ $cm^{-3}$ and electron mobility $\mu_n$=1300 $cm^2$/Vs at 300K. What is the resistance of the bar? (5)

14 (a) Explain Hall Effect? Derive the expression for carrier concentration and mobility in terms of Hall voltage. (7)

(b) Derive the expression for diffusion current density in a semiconductor. (7)

## Module 3

15 (a) Derive ideal diode equation. State any two assumptions used. (8)

(b) Draw the energy band diagram of a metal-n type semiconductor with φm > φs when it is i) under equilibrium and ii) when it is biased. Is the contact rectifying or ohmic? (6)

16 (a) Derive the expression for Built in potential of an abrupt PN junction at equilibrium. (7)

(b) An abrupt silicon PN junction has $N_A=10^{17}$ $cm^{-3}$ on the p-side and $N_D=10^{15}$ $cm^{-3}$ on the n-side. The area of cross section of the diode is $10^{-4}$ $cm^2$. The relative permittivity of Si is 11.8. Calculate the built in voltage ($V_0$) and depletion layer width ($W_0$) at 300K. (7)

## Module 4

17 (a) Derive the expression for drain current at linear region and saturation region for a MOSFET. (7)

(b) An Al-gate p-channel MOS transistor is made on an n-type Si substrate with $N_D$ = $5x10^{17}$ $cm^{-3}$. The $SiO_2$ thickness is 100 Å in the gate region, and the effective interface charge Qi is 5 x $10^{10}$ q C/$cm^2$ . Find $W_m$ , $V_{FB}$ , and $V_T$, if the gate to substrate work function difference Φms = -0.15V. (7)

18 (a) With the help of necessary band diagrams, explain the working and CV characteristics of a MOS capacitor. (8)

(b) Derive the equation for threshold voltage of MOSFET. (6)

## Module 5

| | | | |
|---|---|---|---|
| 19 | (a) | What is drain induced barrier lowering. Discuss its effect on MOSFET performance. | (6) |
| | (b) | What is MOSFET scaling? Explain different types of scaling. Discuss the advantage and disadvantage of scaling. | (8) |
| 20 | (a) | Explain different types of short channel effects in MOSFET. | (8) |
| | (b) | Draw and explain the structure and working of Fin FET. | (6) |

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