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ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electronics & Telecommunication Engineering

Test-5: Analog Circuits + Materials Science
Electronic Devices & Circuits-1 + Advanced Electronics Topics-1
Analog and Digital Communication Systems-2

Name : Sakshi Singh

Roll No : E C 1 9 M T D L A 0 0 3

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Student's Signature

Sakshi

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

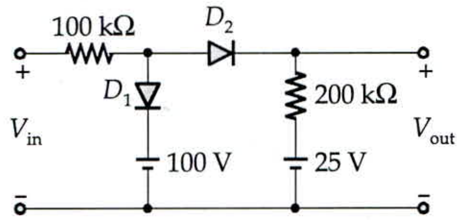
Question No.	Marks Obtained
Section-A	
Q.1	38
Q.2	35
Q.3	38
Q.4	–
Section-B	
Q.5	34
Q.6	–
Q.7	41
Q.8	–
Total Marks Obtained	186

Signature of Evaluator: Neha

Cross Checked by: [signature]

Section A : Analog Circuits + Materials Science

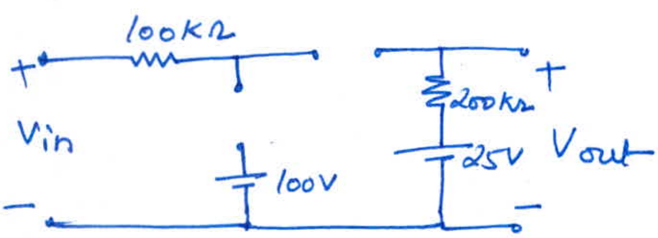
a) Consider the circuit shown in the figure below:



By assuming that the diodes are ideal, develop the transfer characteristic curve of the above circuit.

[12 marks]

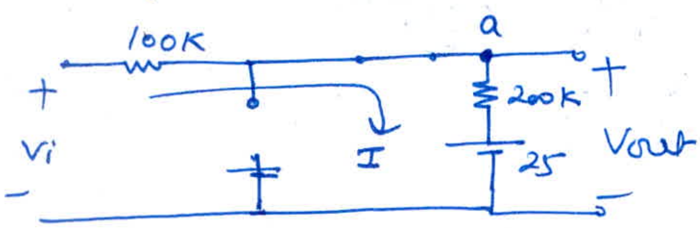
When Both diodes are open (D_1 and D_2 off)



For $0 < V_i < 25$

$V_{out} = 25\ V$

Considering D_2 on and D_1 off when $V_i > 25$



$-V_i + I(300) + 25 = 0$ $\quad I = \frac{V_i - 25}{300}$ $\quad V_{out} = \frac{2}{3}V_i - \frac{50}{3} + 25$

$= \frac{2}{3}V_i + \frac{25}{3}$

$V_a = \frac{25 \times 100 + 200 V_i}{300} = \frac{25 + 2V_i}{3}$

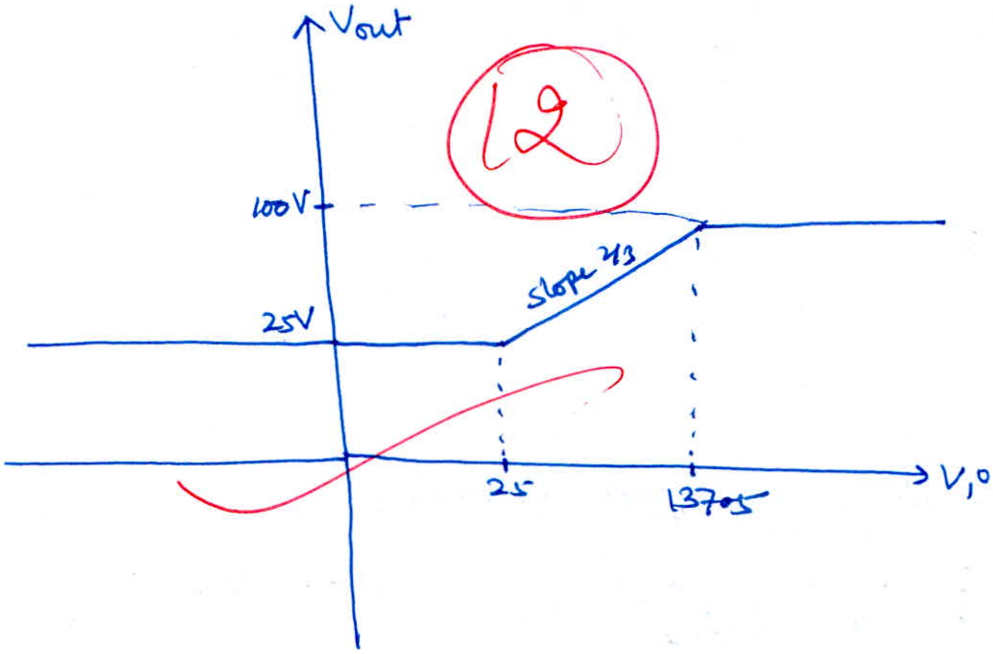
Diode D_1 on when $\frac{25 + 2V_i}{3} > 100$

$2V_i > 275$

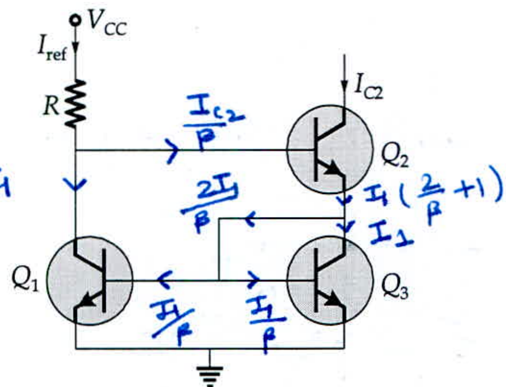
$V_i \geq 137.5$ Volts.

For $25 < V_i < 137.5$ Diode D_1 off and D_2 on

* $V_i > 137.5$ both diodes are On $V_{out} = 100\ V$



Q.1 (b) Consider the Wilson current mirror circuit as shown in the figure below:



Assume that the three transistors to be matched with $V_{BE1} = V_{BE3}$ and $\beta_1 = \beta_2 = \beta_3 = \beta$. Derive an expression for I_{C2} in terms of I_{ref}.

[12 marks]

$$I_{ref} = \frac{V_{CC} - 2V_{BE}}{R}$$

$$I_{ref} = I_1 + \frac{I_{C2}}{\beta}$$

$$\frac{I_{C2}}{\beta} + I_{C2} = I_1\left(\frac{2}{\beta}+1\right)$$

$$I_1 = \frac{I_{C2}\left(\frac{1}{\beta}+1\right)}{\frac{2}{\beta}+1}$$

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$$I_{ref} = \frac{I_{C_2}\left(\frac{1}{\beta}+1\right)}{\frac{2}{\beta}+1} + \frac{I_{C_2}}{\beta}$$

$$= \frac{I_{C_2}(1+\beta)}{2+\beta} + \frac{I_{C_2}}{\beta}$$

$$= I_{C_2}\left\{\frac{1+\beta}{2+\beta} + \frac{1}{\beta}\right\}$$

$$= I_{C_2}\left\{\frac{\beta^2+\beta+2+\beta}{2(\beta+2)}\right\}$$

$$I_{ref} = I_{C_2}\left\{\frac{\beta^2+2\beta+2}{2(\beta+2)}\right\}$$

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$$I_{ref} = I_{C_2}\left\{\frac{(\beta+1)^2+1}{2(\beta+2)}\right\}$$

Q.1 (c) A long narrow rod (having cubic structure) has an atomic density of 5×10^{28} atoms/m^3. Each atom has a polarizability of 10^{-40} F-m^2. Calculate the internal electric field in the rod when an external axial field of 1 V/m is applied.

[12 marks]

$$E_i = E + \frac{\gamma \vec{P}}{\epsilon_0}$$

For Cubic structure $\gamma = \frac{1}{3}$

ρ = density = 5×10^{28} atoms/m^3

$P_{\text{each atom}} = 10^{-40}$ F-m^2 $\quad \vec{P} = 10^{-40} \times 5 \times 10^{28}$

$E = 1$ V/m $\quad = 5 \times 10^{-12} \frac{F}{m}$

$$E_i = 1 + \frac{10^{-40} \times 5 \times 10^{28}}{3 \times 8.85 \times 10^{-12}}$$

$$= 1 + \frac{10^{-40+12} \times 5 \times 10^{28}}{26.55}$$

$$= 1 + 0.03766 \times 10^{-28} \times 5 \times 10^{28}$$

$$= 1 + 0.1883$$

$$E_i = 1.1833 \text{ V/m}$$

2

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d) Explain Silsbee's rule for superconductors. Also give some applications of superconductors.

[12 marks]

Superconductor

It is a state of Material in which it has Zero resistivity and have perfect diamagnetism Below critical Temperature (T_c) and Certain Magnetic field called as critical field (H_c)

Superconductivity is shown by Material at low or DC freq. on increasing Magnetic field above H_c and/or temperature and current above I_c it loses its superconductivity and behave as Normal Conductor.

Silsbee's Rule → To make superconductor behave as Normal Conduct it is Not necessary that direct Magnet field above critical field (H_c) is applied it can be in form of critical Current I_c ($I > I_c$) such that superconductivity destroy.

Ampere circuital law,

$$\oint H \cdot dl = I$$

$$H_c \cdot 2\pi r = I_c$$

$$H_c = \frac{I_c}{2\pi r} \quad ; \; r = \text{radius of cond}^r$$

$$H_c = H_0\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

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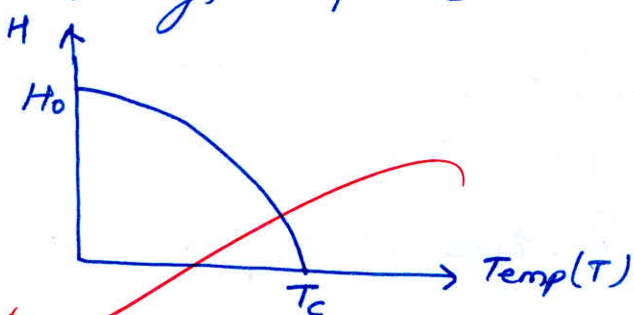
H_0 = Critical field at 0° Kelvin

On increasing temp H_c can be reduced.



application

- → Used in Maginetically Leviated Trains (Maglev)
- → MRI
- → Used in storage devices
- → Used in Computers

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e) Write short notes on the following nanomaterials:
(i) Quantum dots
(ii) Carbon nanotubes

[6 + 6 marks]

(ii) Carbon Nanotubes

Nanomaterial, designing and engineering of a material of dimension in 1–100 nm are called Nanomaterial.

Nanomaterials acquires less space, faster and much more efficient that conventional devices.

In the era of Miniturization, we are developing lot many Materials in nano size. Carbon nanotube is one of them, it is 1-D Nanomaterial in which one dimension is large and other two are in range of nm.

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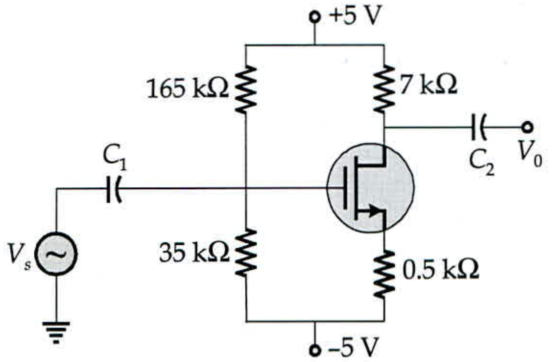
(a) **(i)** Consider the common source transistor circuit shown in the figure below:



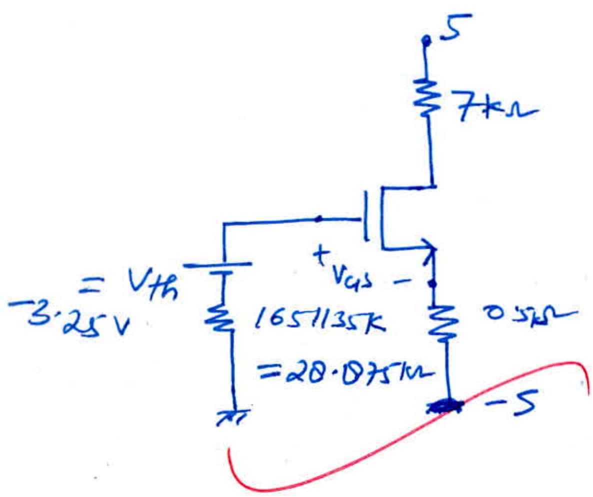
The transistor parameters are $V_{TN} = 0.8$ V, $K_n = \dfrac{\mu_n C_{ox} W}{2L} = 1\ \text{mA/V}^2$ and $\lambda = 0$.

Calculate the value of small signal voltage gain V_0/V_s of the circuit.

(ii) A differential amplifier has input voltages $V_1 = 1$ mV and $V_2 = 3$ mV. The amplifier has differential gain $A_d = 5 \times 10^3$ and CMRR = 1000. Calculate the output voltage of the amplifier.

[15 + 5 marks]

i) DC analysis



$V_{th} = \dfrac{165 \times -5 + 35 \times 5}{200}$

$= \dfrac{-825 + 175}{200}$

$= \dfrac{-650}{200}$

$= -3.25$ V

$R_{th} = \dfrac{165 \times 35}{200}$

$= 28.875$ kΩ

Considering in saturation

$I_D = 1(V_{gs} - 0.8)^2$

$-V_{th} + V_{gs} + I_D\, 0.5 - 5 = 0$

$0.5 I_D + V_{gs} = -3.25 + 5$

~~$I_D = (-3.25 - V_{gs})2 = (-6.5 - 2V_{gs})$~~

$I_D = 2(1.75 - V_{gs}) = 3.5 - 2V_{gs}$

0.64
6.5
7.14

$-6.5 - 2V_{gs} = (V_{gs} - 0.8)^2$

$-6.5 - 2V_{gs} = V_{gs}^2 + 0.64 - 1.6V_{gs}$

$V_{gs}^2 + 0.4V_{gs} + 7.14 = 0$

$\Rightarrow 3.5 - 2V_{gs} = (V_{gs} - 0.8)^2$

$\Rightarrow 3.5 - 2V_{gs} = V_{gs}^2 + 0.64 - 1.6V_{gs}$

$V_{gs}^2 + 0.4V_{gs} - 2.86 = 0$

$V_{gs} = 1.502$

$I_D = 1(1.502 - 0.8)^2$

$I_D = 0.4928$ mAmp

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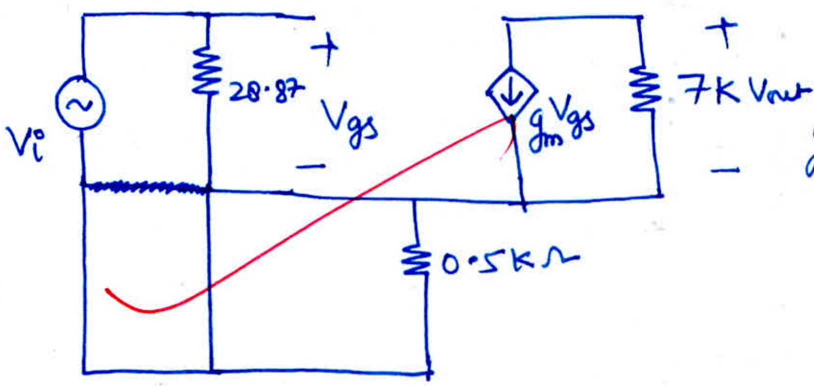


$g_m = \frac{I_D}{V_T}$

$g_m = 0.0189$

$V_i = V_{gs} + g_m V_{gs} 0.5$

$V_{out} = -g_m V_{gs} 7$

$\frac{V_{out}}{V_i} = \frac{-g_m 7}{1 + g_m 0.5} = \frac{-7g_m}{1 + g_m 0.5} = \frac{-0.1326 \times 1000}{10.45}$

$= -12.66$

(ii) $V_1 = 1 mV$ $V_2 = 3 mV$

$A_d = 5 \times 10^3$ $CMRR = 1000$

$$V_o = A_d (V_1 - V_2) + A_{cm} \left(\frac{V_1 + V_2}{2} \right)$$

$$CMRR = \frac{A_d}{A_{cm}} = \frac{5 \times 10^3}{A_{cm}} = 1000$$

3

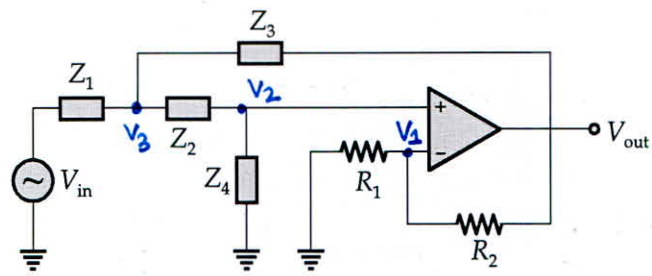
$A_{cm} = 5$

$$V_o = 5 \times 10^3 (3 - 1) \times 10^{-3} + 5 \times \left(\frac{1+3}{2} \right) \times 10^{-3}$$

$= 10 + 10 \times 10^{-3}$

$V_o = 10.01$ volts

Q.2 (b) Consider the circuit shown in the figure below:



The figure represents a second order active filter system.

(i) Derive an expression for V_{out}/V_{in}.

(ii) If each of the impedance elements Z_1 through Z_4 are replaced by a resistor of value R, then find the value of V_{out}/V_{in}.

[20 marks]

(i) $V_1 = \dfrac{V_{out} R_1}{R_1 + R_2}$

$V_1 = V_2$

$$\frac{V_3 - V_{in}}{Z_1} + \frac{V_3 - V_2}{Z_2} + \frac{V_3 - V_{out}}{Z_3} = 0 \quad \text{--- (1)}$$

$$\frac{V_2 - V_3}{Z_2} + \frac{V_2}{Z_4} = 0$$

$$V_2\left(\frac{1}{Z_2} + \frac{1}{Z_4}\right) = \frac{V_3}{Z_2}$$

$$V_3 = V_2\left(1 + \frac{Z_2}{Z_4}\right)$$

$$V_3 = V_1\left(1 + \frac{Z_2}{Z_4}\right)$$

$$V_3 = V_{out}\left(\frac{R_1}{R_1 + R_2}\right)\left(1 + \frac{Z_2}{Z_4}\right)$$

$$\frac{V_{out}\left(\frac{R_1}{R_1+R_2}\right)\left(1+\frac{Z_2}{Z_4}\right)-V_{in}}{Z_1}+\frac{V_3-V_2}{Z_2}+\frac{V_3-V_{out}}{Z_3}=0$$

From eqn. (1)

$$V_3\left(\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_3}\right)=\frac{V_{in}}{Z_1}+\frac{V_2}{Z_2}+\frac{V_{out}}{Z_3}$$

$$=\frac{V_{in}}{Z_1}+\frac{V_1}{Z_2}+\frac{V_{out}}{Z_3}$$

$$=\frac{V_{in}}{Z_1}+\frac{V_{out}R_1}{R_1+R_2}+\frac{V_{out}}{Z_3}$$

$$V_{out}\left(\frac{R_1}{R_1+R_2}\right)\left(1+\frac{Z_2}{Z_4}\right)=\frac{V_{in}}{Z_1}+V_{out}\left(\frac{R_1}{R_1+R_2}+\frac{1}{Z_3}\right)$$

$$V_{out}\left\{\frac{R_1}{R_1+R_2}+\frac{Z_2R_1}{Z_4(R_1+R_2)}-\frac{R_1}{R_1+R_2}-\frac{1}{Z_3}\right\}=\frac{V_{in}}{Z_1}$$

$$V_{out}\left\{\frac{Z_2Z_3R_1-Z_4R_1-Z_4R_2}{Z_3Z_4(R_1+R_2)}\right\}=\frac{V_{in}}{Z_1}$$

$$\frac{V_{out}}{V_{in}}=\frac{Z_3Z_4(R_1+R_2)}{Z_1Z_2Z_3R_1-Z_1Z_4R_1-Z_1Z_4R_2}$$

ii) $$\frac{V_{out}}{V_{in}}=\frac{R^2(R_1+R_2)}{R^3R_1-R^2R_1-R^2R_2}=\frac{R_1+R_2}{RR_1-R_1-R_2}$$

$$V = \frac{R_1 + R_2}{RR_1 - (R_1 + R_2)}$$

$$V = \frac{R_1 + R_2}{R_1(R-1) - R_2}$$

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Q.2 (c) **(i)** For a dielectric, establish an expression for the relationship between the polarizability and permittivity. How does this relation lead to Clausius-Mossotti equation?

(ii) When an NaCl crystal is subjected to an electric field of 1000 V/m, the resulting polarization is 4.3×10^{-8} C/m^2. Calculate the relative permittivity of NaCl.

[15 + 5 marks]

$$P = N \alpha E_i$$

$$D = \epsilon E = \epsilon_0 E + P = \epsilon_0 \epsilon_r E$$

$$P = \epsilon_0 (\epsilon_r - 1) E$$

$$P = \epsilon_0 \chi_e E$$

$$E_i = E + \frac{\gamma P}{\epsilon_0}$$; E_i = internal electrical field

E = applied external field

γ = For cubic lattice $= \frac{1}{3}$

$$E_i = E + \frac{\gamma \epsilon_0 (\epsilon_r - 1) E}{\epsilon_0}$$

$$E_i = E + \frac{(\epsilon_r - 1)E}{3} = E\left\{1 + \frac{\epsilon_r - 1}{3}\right\} = E\left\{\frac{2 + \epsilon_r}{3}\right\}$$

$$P \Rightarrow N\alpha E\left(\frac{2+\epsilon_r}{3}\right) = \epsilon_0(\epsilon_r - 1)E$$

$$= N\alpha\left(\frac{2+\epsilon_r}{3}\right) = \epsilon_0(\epsilon_r - 1)$$

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$$\Rightarrow \boxed{\frac{\alpha N}{3\epsilon_0} = \frac{\epsilon_r - 1}{\epsilon_r + 2}}$$ Clausius Mossotti eqn.

$E = 1000\ V/m$

$P = 4.3\times10^{-8}\ C/m^2$

$\epsilon_r = ?$

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$P = \epsilon_0(\epsilon_r - 1)E$

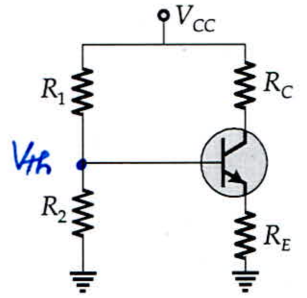
$$4.3\times10^{-8} = 8.85\times10^{-12}(\epsilon_r - 1)1000$$

$$(\epsilon_r - 1) = \frac{4.3\times10^{-8}}{8.85\times10^{-9}} = 0.4858\times10$$

$$\epsilon_r - 1 = 4.858$$

$$\epsilon_r = 5.858$$

a) Consider the voltage divider biasing circuit shown in the figure below:



For this circuit,

(i) Derive an expression for stability factor S [i.e., the variation of I_C w.r.t. I_{CO}].

(ii) Derive an expression for stability factor S' [i.e., the variation of I_C w.r.t. V_{BE}].

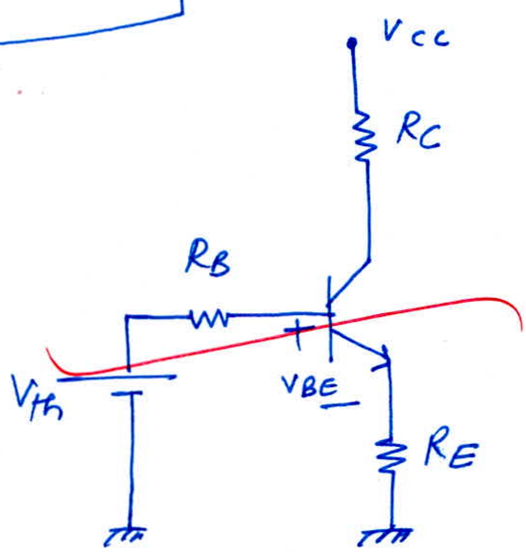
(iii) Derive a relation between S and S'.

[20 marks]

)

$$V_{th} = \frac{R_2}{R_1 + R_2} V_{cc}$$

$$R_B = \frac{R_1 R_2}{R_1 + R_2}$$



$$I_C = \beta I_B + (1+\beta) I_{CO}$$

$$I_E = (1+\beta) I_B$$

$$-V_{th} + I_B(R_B) + V_{BE} + I_E R_E = 0$$

$$\frac{I_C - (1+\beta) I_{CO}}{\beta} R_B + V_{BE} + (1+\beta)\left(\frac{I_C - (1+\beta) I_{CO}}{\beta}\right) R_E = V_{th}$$

$$\frac{I_C R_B}{\beta} - \frac{(1+\beta) I_{CO} R_B}{\beta} + V_{BE} + \frac{R_E(1+\beta)}{\beta} I_C - \frac{(1+\beta)^2 I_{CO} R_E}{\beta} = V_{th} \quad \text{—(1)}$$

Differentiating above eqn. wrt I_{CO}

$$\frac{\partial I_C}{\partial I_{CO}}\frac{R_B}{\beta} - \frac{(1+\beta)R_B}{\beta} + \frac{R_E(1+\beta)}{\beta}\frac{\partial I_C}{\partial I_{CO}} - \frac{(1+\beta)^2}{\beta}R_E = 0$$

$$\frac{\partial I_C}{\partial I_{CO}}\left(\frac{R_B}{\beta} + \frac{R_E(1+\beta)}{\beta}\right) = \frac{(1+\beta)R_B}{\beta} + \frac{(1+\beta)^2}{\beta}R_E$$

$$\frac{\partial I_C}{\partial I_{CO}} = \frac{(1+\beta)(R_B+R_E)}{R_B + R_E(1+\beta)}$$

$$S = \frac{\partial I_C}{\partial I_{CO}} = \frac{(1+\beta)(R_B+R_E)}{(R_B+R_E)+R_E\beta} = \frac{(1+\beta)}{1+\frac{R_E\beta}{R_E+R_B}}$$

(ii) $S' = \frac{\partial I_C}{\partial V_{BE}}$

2

Diff. eqn. (i) wrt V_{BE}

$$\frac{\partial I_C}{\partial V_{BE}}\frac{R_B}{\beta} + 1 + \frac{(1+\beta)}{\beta}R_E\frac{\partial I_C}{\partial V_{BE}} = 0$$

$$\frac{\partial I_C}{\partial V_{BE}}\left(\frac{R_B}{\beta} + \frac{(1+\beta)R_E}{\beta}\right) + 1 = 0$$

$$\frac{\partial I_C}{\partial V_{BE}} = \frac{-\beta}{R_B+R_E+\beta R_E} = \frac{-\beta/R_E+R_B}{1+\beta\frac{R_E}{R_E+R_B}}$$

$$S = \frac{(1+\beta)(R_E+R_B)}{(R_E+R_B)+\beta R_E} \qquad S' = \frac{-\beta}{(R_E+R_B)+\beta R_E}$$

For much larger β, $1+\beta \simeq \beta$

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$$\frac{S}{S'} \approx -(R_E+R_B)$$

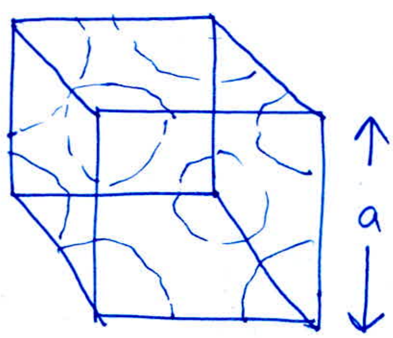
(b) What are the types of cubic crystal structure? Derive the atomic packing factor of all the cubic crystal structures.

[20 marks]

There are 3 types of Cubic Crystal Structure.

i) Simple cubic

In this at each corner of cube $\frac{1}{8}^{th}$ part of atom is accupied.



r = radius of atom

$2r = a$

$r = a/2$

Total No. of atoms $= \frac{1}{8} \times 8 = 1$ atom

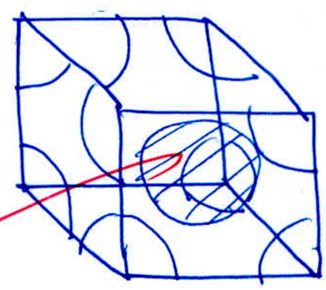
$$\text{Packing factor} = \frac{1 \times \frac{4}{3}\pi r^3}{a^3} = \frac{\frac{4}{3}\pi (a/2)^3}{a^3}$$

packing fraction = $\dfrac{\dfrac{\frac{4}{3}\pi a^3}{8}}{a^3} \times 100\%$

$= 0.52$ or 52%.

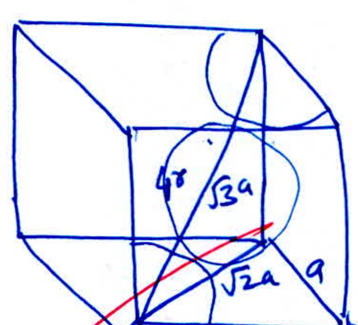
(ii) <u>Body centered Cube</u>

In this along with corner atoms (contribution is $\frac{1}{8}$ of whole atom) an atom at center of cube is present.



· effective atoms $= \frac{1}{8} \times 8 + 1$

$= 2$ atoms.



$\sqrt{3}a = 4r$

$r = \frac{\sqrt{3}}{4}a$

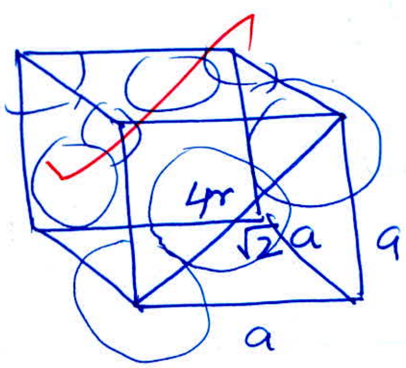
packing fraction = $\dfrac{\text{Vol. of atoms occupied}}{\text{cube volume.}}$

$$= \frac{\frac{4}{3}\pi r^3 \times 2}{a^3} = \frac{\frac{4}{3}\pi\left(\frac{\sqrt{3}}{4}a\right)^3 \times 2}{a^3}$$

$= 0.68$ or 68%.

(iii) Face centered Cube

In this crystal atom is present at all faces of cube with contribution of $\frac{1}{2}$ of whole atom along with $\frac{1}{8}$ th of atom at each corner.



$4r = \sqrt{2}a$

effective atoms $= \frac{1}{2} \times 6 + \frac{1}{8} \times 8$

$= 3 + 1 = 4$ atoms.

packing fraction $= \frac{4 \times \frac{4}{3}\pi\left(\frac{a}{2\sqrt{2}}\right)^3}{a^3}$

$= 0.74$ or 74%.

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Q.3 (c) Electron drift mobility in indium (In) has been measured to be 6 $cm^2 V^{-1} s^{-1}$. At room temperature (27°C), the resistivity of In is 8.37×10^{-8} Ω m and its atomic mass and density are 114.82 $g mol^{-1}$ and 7.31 $g cm^{-3}$ respectively.

(i) Based on the resistivity value, determine the effective number of free electrons donated by each In atom in the crystal.

(ii) If the mean speed of conduction electrons in In is 1.74×10^8 $cm s^{-1}$, what is the mean free path?

(iii) Calculate the thermal conductivity of In at room temperature.

[20 marks]

$\mu = 6 \ cm^2 V^{-1} s^{-1}$

$\rho = 8.37 \times 10^{-8} \ \Omega m = \frac{1}{q n \mu}$

$m = 114.82 \ g/mol$

density $= 7.31 \ g/cm^3$

i) $8.37 \times 10^{-8} \times 10^2 = \frac{1}{1.6 \times 10^{-19} \times n \times 6}$

1

$n = \frac{1}{1.6 \times 10^{-19} \times 8.37 \times 10^{-6} \times 6}$

$= \frac{1}{80.352 \times 10^{-25}}$

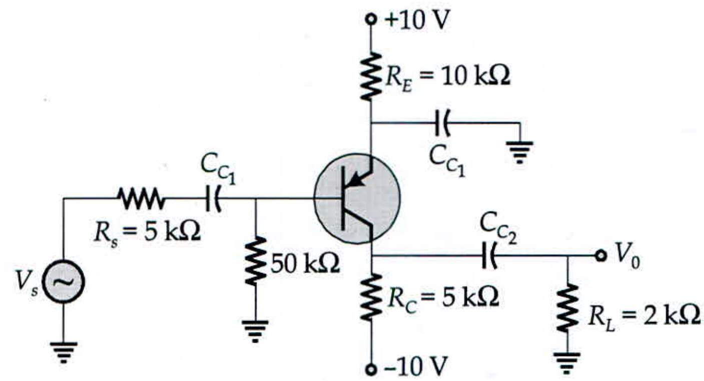
$= 124.4 \times 10^{+21}$

$n = 1.244 \times 10^{23}$

ii) $\mu = \frac{q\tau}{m}$

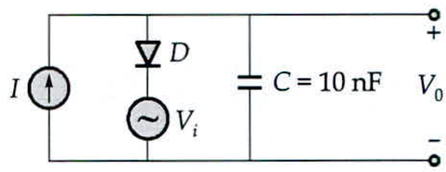
$\tau = \frac{\mu m}{q} = \frac{6 \times 114.82}{1.6 \times 10^{-19}} = 4.3 \times 10^{19}$

Q.4 (a) Consider a *p-n-p* transistor shown in the figure below. The transistor has $V_{EB(on)} = 0.7$ V, $\beta = 150$ and $V_A = \infty$. Draw a neat and labelled graph for DC and AC load line. Mark the *Q*-point on the graph.



[20 marks]

Q.4 (b) Consider the circuit shown in the figure below:



I is DC current and V_i is a sinusoidal signal with small amplitude and frequency of 100 kHz. Thus for small signal input and output voltages V_i and V_0, calculate:

(i) Phase angle difference between V_i and V_0.

(ii) The value of DC current I for which the phase shift between V_i and V_0 is –45°. (Assume V_T = 25 mV)

(iii) The range of phase shift that is achieved as I is varied over the range of 0.1 to 10 times of the value obtained in part (ii).

[20 marks]

Do not write in this margin

c) **(i)** What do you understand by magnetic hysteresis? Differentiate between hard and soft magnetic materials?

(ii) In a magnetic material, the field strength is found to be 10^6 A/m. If the magnetic susceptibility of the material is 0.5×10^{-5}, calculate the intensity of the magnetization and the magnetic flux density in the material.

[12 + 8 marks]

Do not write in this margin

Section B : Electronic Devices & Circuits-1 + Advanced Electronics Topics-1 + Analog and Digital Communication Systems-2

(a) With neat diagrams, explain the Local Oxidation of Silicon (LOCOS) isolation technique used in IC fabrication.

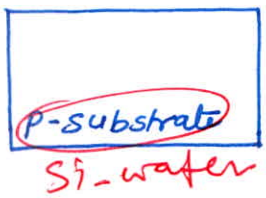
[12 marks]

LOCOS

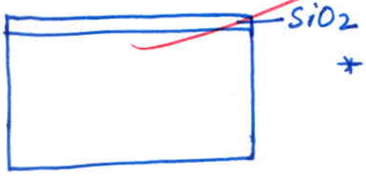
* It is a isolation technique used in fabrication to separate the devices so as to avoid malfunctioning of the devices.

Steps involved

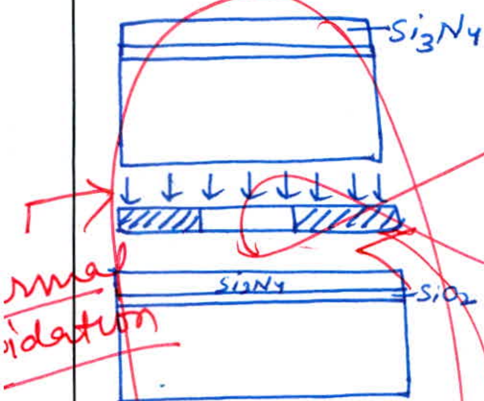
2



* Take substrate (p or N according to requirement)



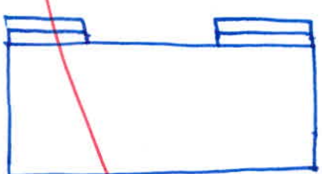
* grow pad oxide (thin oxide) using dry oxidation or Wet

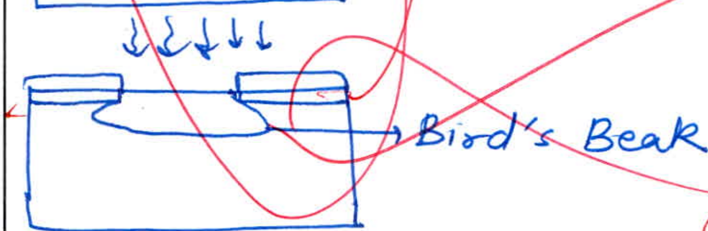


* grow layer of Si_3N_4 for better protection.

* using Mask and UV ray perform photolithography to etch the unwanted layers using HF or H_2SO_4 (dilute acid)

2





* Then perform oxidation process using suitable reactants. ?

In this ~~typ~~ process of oxide formation their is formation of Bird's beak like structure which is unwanted and leads to Malfunction in the device in (case of small devices) Therefore Now a day shallow trench isolation is preffered.

label the diagrams properly with sequences.

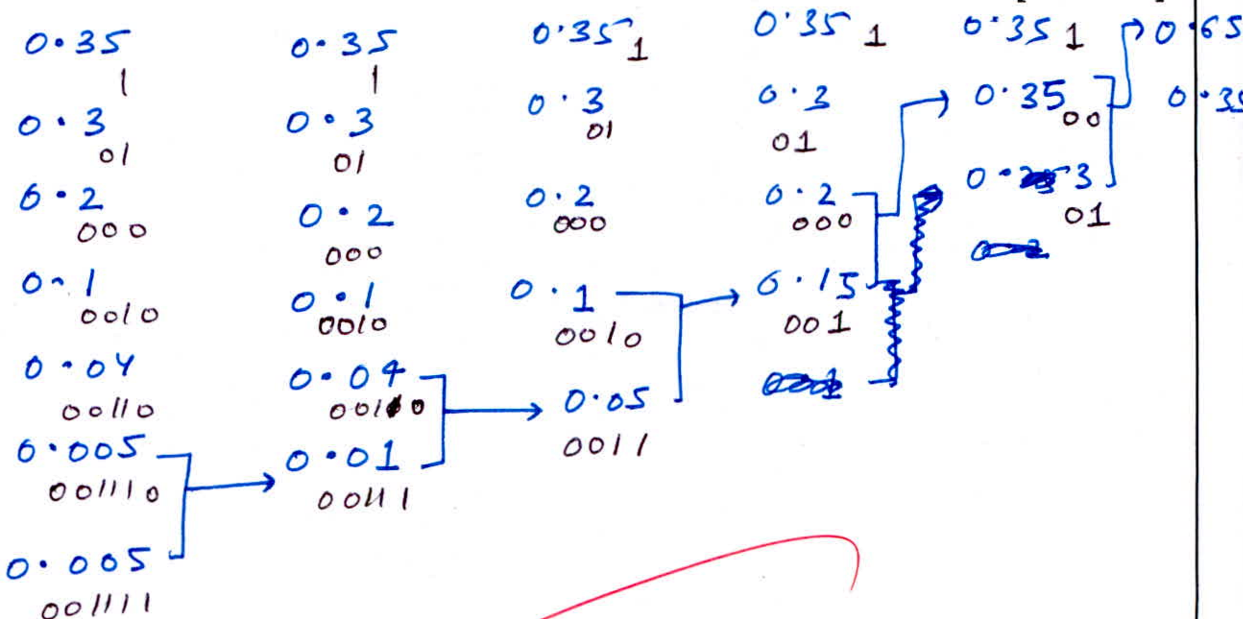
Q.5 (b) **(i)** The oxide removal rate and the removal rate of a layer underneath the oxide (called a stop layer) are r and $0.1r$ respectively. To remove 1 μm of oxide and a 0.01 μm stop layer, the total removal time is 5.5 minutes. Find the oxide removal rate (r).

(ii) Calculate the Al average etch rate and etch rate uniformity on a 200 mm diameter silicon wafer, assuming the etch rates at the center, left, right, top and bottom of the wafer are 750, 812, 765, 743 and 798 nm/min respectively.

[6 + 6 marks]

Q.5 (c) A source emits seven symbols with probabilities 0.35, 0.3, 0.2, 0.1, 0.04, 0.005, 0.005. Give Huffman coding for these symbols and calculate average bits of information and average binary digits of information per symbol.

[12 marks]



$$H(x) = -\Big(0.35\log_2 0.35 + 0.3\log_2 0.3 + 0.2\log_2 0.2$$

$$+ 0.1\log_2 0.1 + 0.04\log_2 0.04 + 0.005\log_2 0.005 + 0.005\log_2 0.005\Big)$$

$$= 0.53 + 0.521 + 0.4643 + 0.332$$

$$+ 0.1857 + 0.03821 + 0.03821$$

$H(x) = 2.1094$ bits/symbol

$$L = 0.35\times1 + 0.3\times2 + 0.2\times3 + 0.1\times4$$

$$+ 0.04\times5 + 0.005\times6 + 0.005\times6$$

$$= 0.35 + 0.6 + 0.6 + 0.4 + 0.20$$

$$+ 0.03 + 0.03$$

$L = 2.21$ bits/symbol.

$$\eta = \frac{H(x)}{L} = \frac{2.1094}{2.21}$$

$$= 0.9544$$

11

95.44 % efficiency

(d) The distribution (with respect to energy) of electron concentration in the conduction band is given by density of allowed quantum states times the probability that state being occupied by an electron. i.e., $n(E) = g_C(E)\, f(E)$

where, $g_C(E)$ = Density of allowed states, $f(E)$ = probability of state being occupied.

Assuming that Boltzmann approximation in a semiconductor is valid, calculate the ratio of $n(E)$ at $E = E_C + 4kT$ to that at $E = E_C + (kT/2)$. Here, k = Boltzmann constant, E_C = edge of the conduction band and T = temperature in °K.

[12 marks]

$$f_E = \frac{1}{1+e^{(E-E_c)/KT}}$$

$$f_{E_1} = \frac{1}{1+e^{4KT/KT}}$$

$$= \frac{1}{1+e^4} = \frac{1}{27.55} = 0.03629$$

Probability of e^- at $E = E_c + 4KT$ is 0.03629

$$f_{E_2} = \frac{1}{1 + e^{(kT/2)/kT}}$$

$$= \frac{1}{1 + e^{1/2}}$$

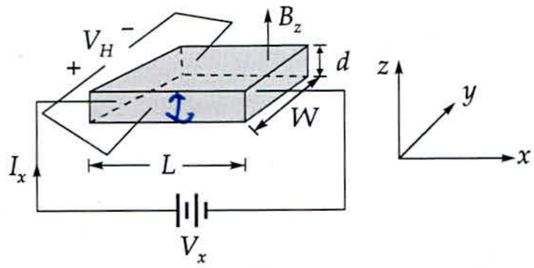
7

$$f_{E_2} = \frac{1}{2.5066} = 0.3989$$

0.0854

$$\frac{f_{E_1}}{f_{E_2}} = \frac{0.03629}{0.3989} = 0.0909$$

(e) Consider a silicon Hall effect device which is used for the experiment as shown below:



The device has dimensions $d = 5 \times 10^{-3}$ cm, $W = 5 \times 10^{-2}$ cm and $L = 0.5$ cm. The electrical parameters measured as the result of the experiment are $I_x = 0.5$ mA, $V_x = 1.25$ V and $B_z = 6.5 \times 10^{-2}$ T. If the induced Hall electric field is $E_{Hy} = -16.5$ mV/cm, then determine:

(i) Hall voltage (V_H)

(ii) The type of semiconductor

(iii) The majority carrier concentration

[12 marks]

$$V_H = \frac{I_x R_H B_z}{d}$$

$$\frac{V_x}{I_x} = R = \frac{1.25}{0.5 \times 10^{-3}}$$

$$R = 2.5\ k\Omega$$

$$E_{Hy} = -16.5 \times 10^{-3}\ \frac{V}{cm}$$

i) $V_H = E_{Hy} \times W$

$= -16.5 \times 10^{-3} \times 5 \times 10^{-2}$

$= -82.5 \times 10^{-5}$ volts.

$= -0.825$ mV volts.

10

ii) Since V_H is negative therefore it is N type semiconductor.

$n = \frac{1}{qR_H} = 4.96 \times 10^{21}$

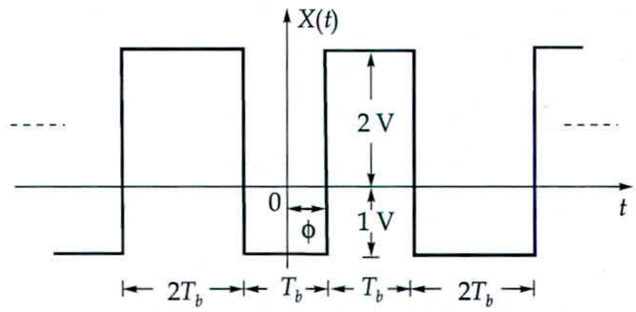
unit?

iii) $R_H = \frac{V_H\, d}{I_x B_z} = \frac{-0.825 \times 10^{-3} \times 5 \times 10^{-5}}{0.5 \times 10^{-3} \times 6.5 \times 10^{-2}}$

$R_H = 1.2692 \times 10^{-3} = \frac{1}{nq}$

Do not write in this

Q.6 (a) Consider the random binary wave shown below:



In this binary wave, logic-1 is represented with positive rectangular pulse and logic-0 is represented with negative rectangular pulse, both with different amplitudes. ϕ is an independent random variable uniformly distributed in the range $[0, T_b]$, where T_b is the bit duration. Determine and sketch the auto-correlation function of $X(t)$. Assume that logic-1 and logic-0 are occurring with equal probability.

[20 marks]

Q.6 (b) A 1 cm long bar of n-type Ge has a cross section of 1 mm × 1 mm. The resistivity of material is 20 Ω-cm and the lifetime of the carriers is 100 microseconds.
(Assume μ_n = 3800 cm²/V-s, μ_p = 1800 cm²/V-s and intrinsic carrier concentration $n_i = 2.5 \times 10^{13}/\text{cm}^3$).

(i) Calculate the resistance of the bar.

(ii) Calculate the donor concentration.

(iii) Calculate the resistance of the bar when it is illuminated such that excess electron-hole pairs are generated at a rate of 10^{15} cm^{-3} s^{-1}, uniformly all over the bar.

[20 marks]

Do not write in this margin

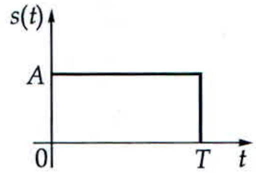
c) (i) Binary data (equiprobable bits) with a rate of 1 Mbps is transmitted through an AWGN channel using different modulation schemes. The two sided power spectral density of the channel noise is 0.5×10^{-11} W/Hz and the carrier signal used in the transmitters is $5\cos(2\pi f_c t)$ mV. In each case of different modulation schemes, the signals are received by their respective correlator receivers with exact phase synchronisation and with optimum threshold detection. Find the average symbol error probability for modulation schemes BASK, BFSK and BPSK.

(ii) Suppose that two signals $s_1(t)$ and $s_2(t)$ are orthogonal over the interval $(0, T)$. A sample function $n(t)$ of a zero-mean white noise process is correlated with $s_1(t)$ and $s_2(t)$ separately, to yield the following variables:

$$n_1 = \int_0^T s_1(t)n(t)\,dt \text{ and } n_2 = \int_0^T s_2(t)n(t)\,dt$$

Prove that n_1 and n_2 are orthogonal. **[15 + 5 marks]**

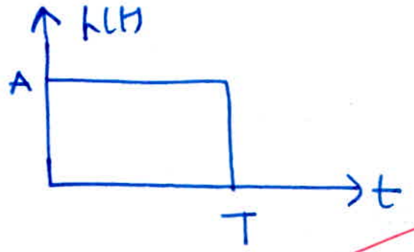
Q.7 (a) Consider the signal shown in the figure below:

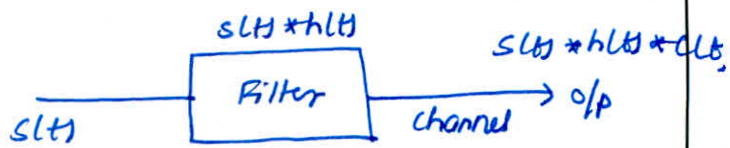


This signal is passed through a channel and applied to a filter matched to the signal $s(t)$ at the receiving end. If the channel is not ideal, but has an impulse response $c(t) = \delta(t) + \frac{1}{2}\delta\left(t - \frac{T}{2}\right)$, then determine and sketch the output of the matched filter.

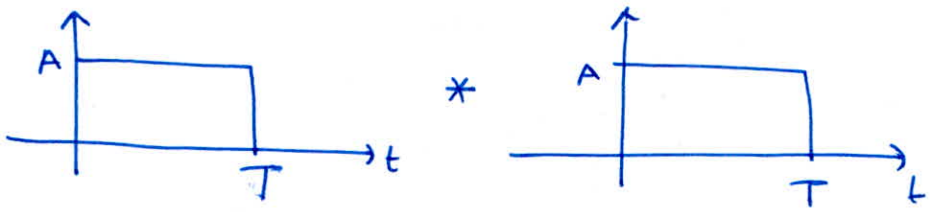
[20 marks]

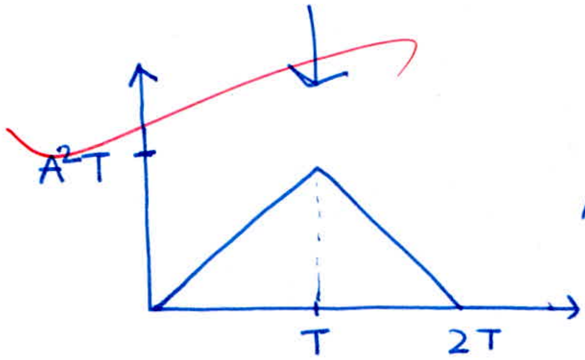
$h(t) = s(T-t)$





$s(t) * h(t)$

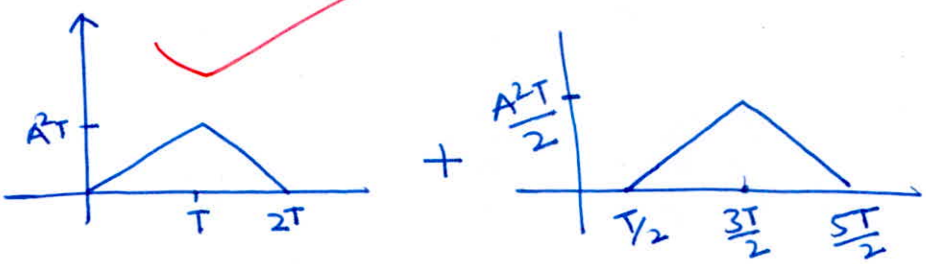


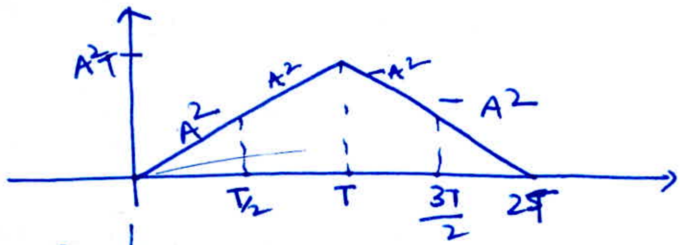


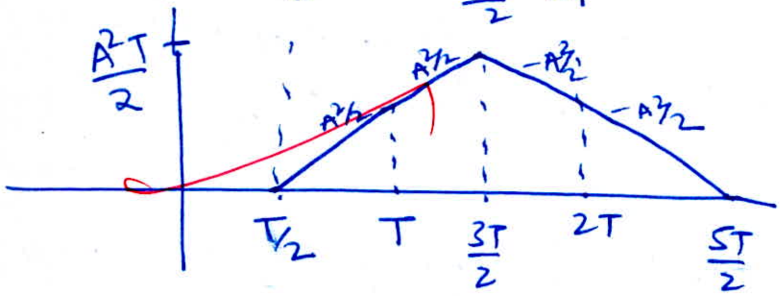
$A^2 \text{Sinc}^2 T \, e^{-j\omega T}$

passed through channel $c(t)$

$\delta(t) + \frac{1}{2}\delta(t - T/2)$







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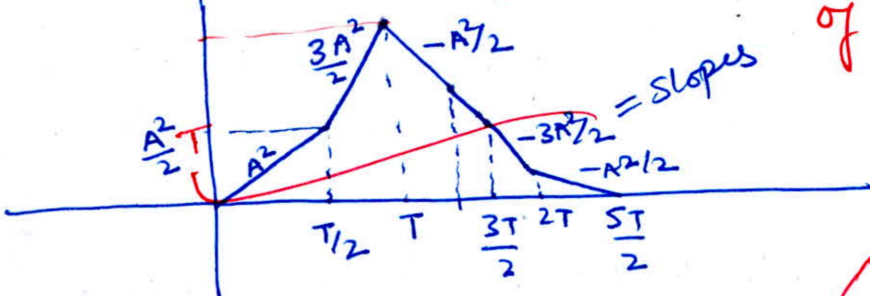
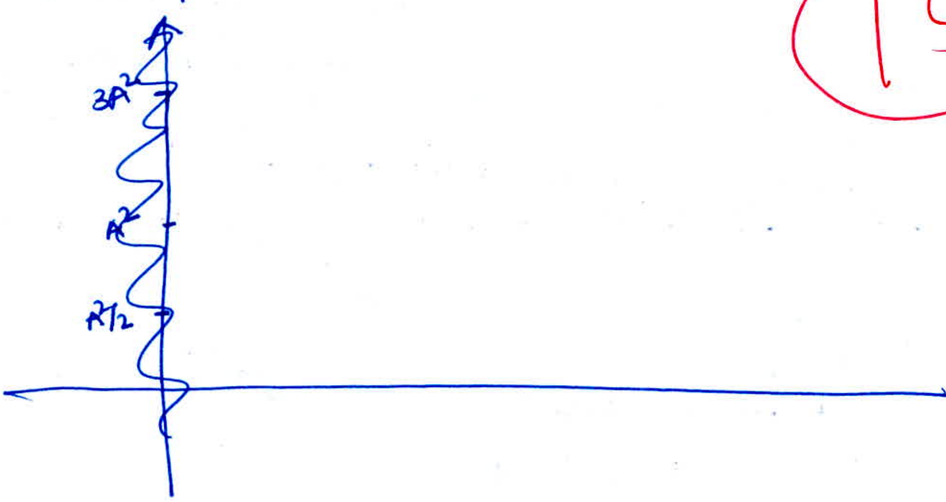


→ Write it in the form of equation also.

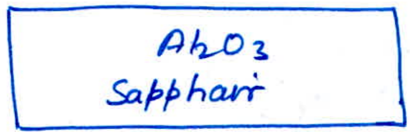
15



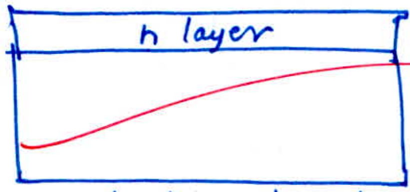
Q.7 (b) Explain the basic steps involved in the fabrication of a CMOS transistor using silicon on sapphire (SOS) process.

[20 marks]

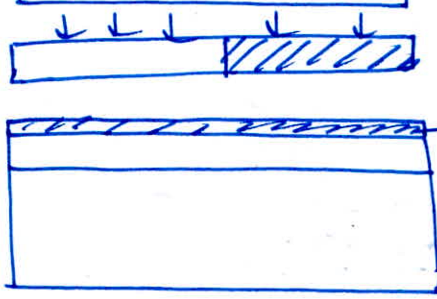
Steps



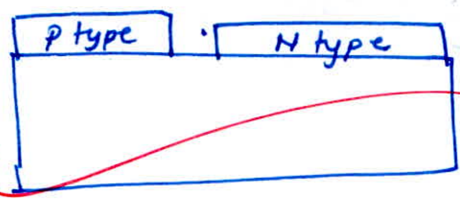
Take sapphair substrate (Al_2O_3)



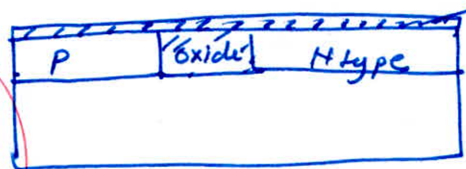
deposite (grow) n type layer



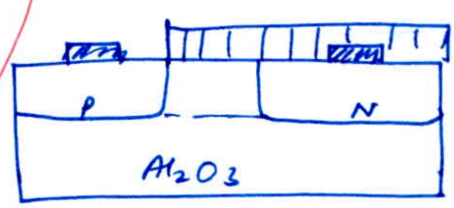
perform lithography to etch out undesired layer

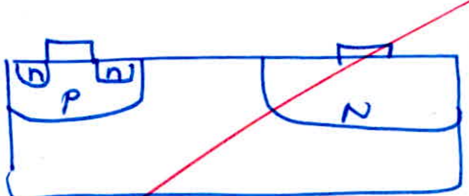


grow n and p well using oxidation

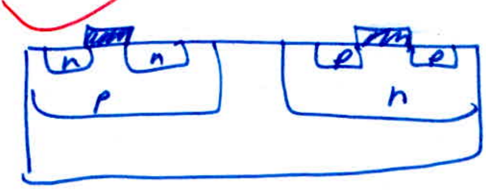


grow polysilicon layer for self alignment of gate





Make (grow) source and drain using doping of n/p required accordingly



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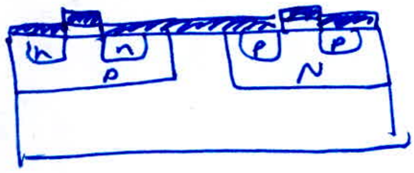
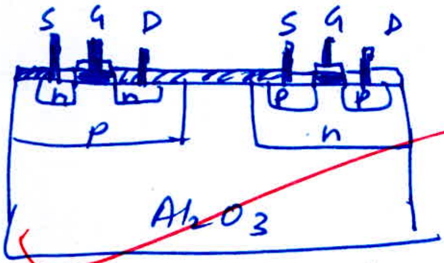




41

Q.7 (c) A p-type lightly doped semiconductor has electron mobility μ_n, hole mobility μ_p, intrinsic carrier concentration n_i and the acceptor impurity concentration N_A.

(i) Derive an expression for the hole concentration 'p' in terms of n_i, μ_n and μ_p, such that the conductivity of the semiconductor is minimum.

(ii) Derive an expression for the minimum conductivity of the semiconductor.

(iii) If $n_i = 1.5 \times 10^{10}$ cm^{-3}, $\mu_n = 1300$ cm^2/V-sec and $\mu_p = 500$ cm^2/V-sec, then calculate the value of minimum conductivity.

(iv) If there is 100% ionization of doping atoms, then calculate the value of acceptor impurity concentration (N_A).

[20 marks]

$$np = n_i^2$$

$$n + N_d = p + N_A$$

$$\sigma = qn\mu_n + qp\mu_p$$

$$\sigma = q\frac{n_i^2}{p}\mu_n + qp\mu_p$$

For min conductivity,

$$\frac{\partial \sigma}{\partial p} = 0$$

$$\frac{\partial \sigma}{\partial p} = \frac{-q n_i^2 \mu_n}{p^2} + q\mu_p = 0$$

$$\boxed{p = n_i\sqrt{\frac{\mu_n}{\mu_p}}}$$

Similarly,

$$\boxed{n = n_i\sqrt{\frac{\mu_p}{\mu_n}}}$$

ii) $\sigma = qn\mu_n + qp\mu_p$

Using previous result for min conductivity,

$$\sigma = qn_i\sqrt{\frac{\mu_p}{\mu_n}}\mu_n + qn_i\sqrt{\frac{\mu_n}{\mu_p}}\mu_p$$

$$= qn_i\sqrt{\mu_n\mu_p} + qn_i\sqrt{\mu_n\mu_p}$$

$$= 2qn_i\sqrt{\mu_n\mu_p}$$

13

iii) $\sigma_{min} = 2 \times 1.6 \times 10^{-19} \times 1.5 \times 10^{10} \sqrt{1300 \times 500}$

$$= 4.8 \times 10^{-9} \sqrt{650000}$$

$$= 3869.88 \times 10^{-9}$$

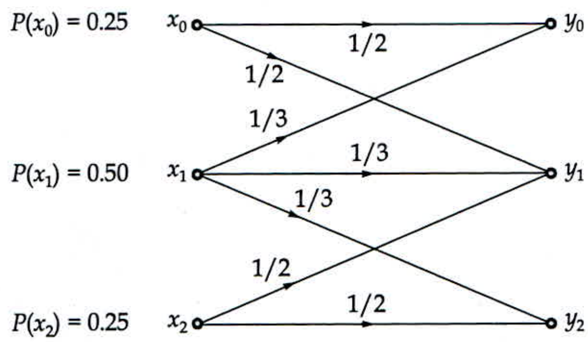
$$= 3.869 \times 10^{-6} \text{ cm}^{-1} V^{-1} \text{sec}^{-1}$$

iv) $3.869 \times 10^{-6} = \dfrac{1}{1.6\times10^{-19} \times N_A \times 500 + 1.6\times10^{-19}\dfrac{(1.5\times10^{10})}{N_A}1300}$

$N_A = \dfrac{?}{\quad}$

Write formula then put the values!

Consider the discrete memoryless channel shown below:



Determine the mutual information $I(X\,;\,Y)$.

[20 marks]

Q.8 (b) For a boron diffusion in silicon at 1000°C, the surface concentration is maintained at 10^{19} cm^{-3} and the diffusion time is 1 hour. Assume that the diffusivity (D) of Boron in Silicon at 1000°C is 2×10^{-14} cm^2/s. Determine:

(i) The total number of dopant atoms per unit area of semiconductor.

(ii) The distance of the location from the surface where the dopant concentration reaches 10^{15} cm^{-3}. Assume that $\text{erfc}^{-1}(10^{-4}) = 2.75$.

(iii) The gradient of the diffusion profile at the surface.

(iv) The gradient of the diffusion profile at the distance from the surface obtained in part (ii).

[20 marks]

Q.8 (c) **(i)** Find the expression for reverse saturation current I_0 in a *p-n* junction diode in terms of intrinsic carrier concentration n_i.

(ii) Find an expression for the reverse saturation current in terms of the conductivity of the device and prove that, $I_0 = AV_T \frac{b\sigma_i^2}{(1+b)^2}\left[\frac{1}{L_p\sigma_n}+\frac{1}{L_n\sigma_p}\right]$ where, $b = \frac{\mu_n}{\mu_p}$

[20 marks]

OOOO

Space for Rough Work

Space for Rough Work