EE 735 Assignment 4

Drain Current Models of MOSFETs

Non Extendible Deadline: 5 March 2025 11:59 pm(100% Penalty for Late Submission)

Implement all codes using Python

Hints, assumptions, and instructions:

1. Please define all input variables at the beginning of your code and use proper comments while developing the code. Your code must work for other input values too.
2. It is mandatory to submit your code along with the report (in pdf) in a single zip file. Name the file `EE735_A4_RollNo_Name` for this assignment.
3. Reference for the assignment:
   - Taur, Y., & Ning, T. H. (2009). Fundamentals of modern VLSI Devices. Chapter 2, Sections 3.1.1
   - Pao, H., & Sah, C. (1966). Effects of diffusion current on characteristics of metal-oxide (insulator)-semiconductor transistors. Solid-State Electronics, 9(10), 927–937. `https://doi.org/10.1016/0038-1101(66)90068-2`

Problems

Question1

Consider a NMOS transistor with a p doped Si substrate with doping $N_A = 1 \times 10^{17} cm^{-3}$ and thickness $t = 1\mu m$, SiO_2 as the dielectric material with oxide thickness $t_{ox} = 20nm$, and n+ doped poly-silicon gate (Consider the poly-silicon to be heavily doped such that $E_{f_m} = E_{c_m}$) and thickness $t_m = 10nm$. Dimensions of MOSFET $L = W = 1\mu m$. Vary the values of V_D and V_G from 0 to 5V. Assume $\mu_n = 200cm^2/Vs$.

A. Estimate the value of the surface potential ψ_s at source and drain ends of the MOSFET for $V_G = V_D = 5V$.

B. Numerically solve the Pao-Sah models for the given MOSFET. Plot transfer ($I_D - V_G$) characteristics for different V_D values (V_D = 0.2V and 2V) and output ($I_D - V_D$) characteristics for different V_G values (V_G = 1.5V and 3V).

C. Compare your results with the Piecewise Linear model of a MOSFET.

For the Pao-Sah model, the drain current can be determined using the equations:

$$I_D = \mu_{eff}\frac{W}{L}\int_0^{V_{DS}} [-Q_I(V)]\, dV$$

For an n type MOSFET,

$$[-Q_I(V)] = q\int_\delta^{\psi_s} \frac{\frac{n_i^2}{N_A}\exp\frac{q(\psi-V)}{kT}}{-\frac{d\psi}{dx}}\, d\psi$$

$$\text{where,}\ -\frac{d\psi}{dx} = \sqrt{\frac{2kTN_A}{\epsilon_{Si}}}\left[\frac{q\psi}{kT} + \frac{n_i^2}{N_A^2}\exp\frac{q(\psi - V)}{kT}\right]^{0.5}$$

ψ_s is calculated using the equation:

$$V_{GS} = V_{FB} + \psi_s + \frac{\sqrt{2kTN_A\epsilon_{Si}}}{C_{ox}}\left[\frac{q\psi_s}{kT} + \frac{n_i^2}{N_A^2}\exp\frac{q(\psi_s - V)}{kT}\right]^{0.5}$$

The current equation using the Piecewise Linear Model of a MOSFET are given by:

$$I_D = \begin{cases} 0, & \text{if } V_{GS} > V_{th} \\ \mu_{eff}C_{ox}\frac{W}{L}V_{DS}\left(V_{GS} - V_{th} - 0.5V_{DS}\right), & \text{if } V_{DS} > V_{GS} - V_{th} \\ \mu_{eff}C_{ox}\frac{W}{L}\frac{(V_{GS}-V_{th})^2}{2}, & \text{if } V_{DS} < V_{GS} - V_{th} \end{cases}$$