

ECE 3030: Physical Foundations of Computer Engineering

Fall 2021

Homework 5—Total points 100

Due on Thursday 10/29/2021 at 11.59am. In case of a late submission, you will be penalized by 50 points for each day after the submission deadline has passed. You will receive no score if you submit after the solution has been posted.

Q1 Band diagrams of a MOS capacitor for three different values of the gate voltage V_G are shown in figure 1. V_t is its threshold voltage. All the variables shown in figure 1 have their usual meanings. [30 pts]

[Q1.1] Based on the information provided in figure 1, find out whether V_G larger or smaller than V_t for each of the three cases. Briefly explain your answer. [10 pts]

[Q1.2] Find out the values of electron density and hole density at $x=0$ and $x=60$ nm for each of the three cases. Assume that $N_C=N_V=10^{25} \text{ /m}^3$, $kT=25 \text{ meV}$, $E_G= 1.1 \text{ eV}$ (all variables have their usual meaning). [20 pts]

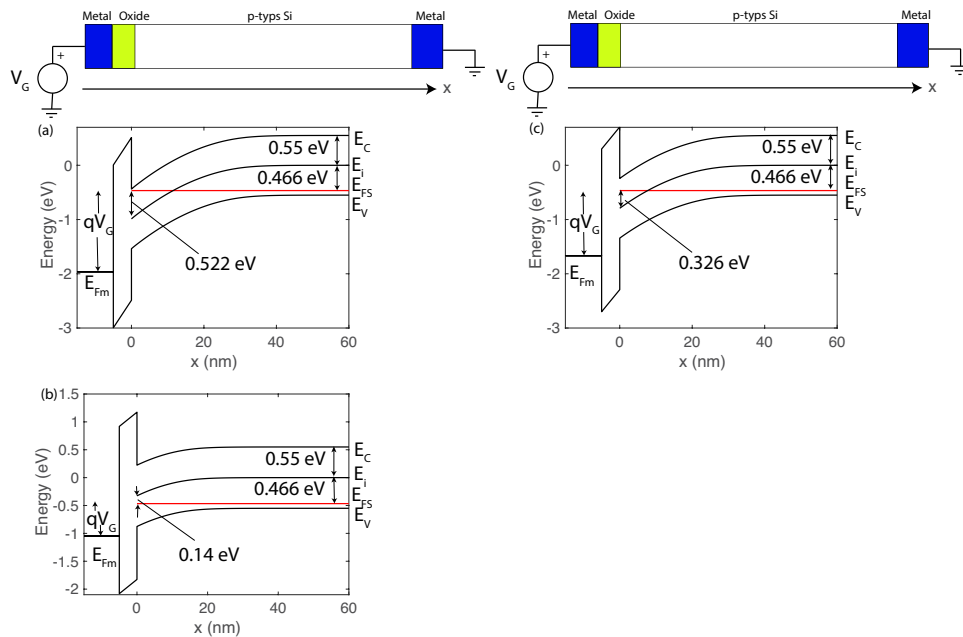


Figure 1: Band diagrams of a MOS capacitor at different gate voltages.

Q2 In class, we have derived an expression for the threshold voltage V_t in an n-type MOSFET. How does V_t change if the following parameters are increased. [25 pts]

Q2.1 Acceptor doping density, N_a .

Q2.2 Oxide thickness, t_{ox} .

Q2.1 Dielectric constant of oxide, ϵ_{ox} .

Q3 Consider an n-type MOSFET with $N_A=7 \times 10^{18} \text{ m}^{-3}$. The gate length of the MOSFET $L=2 \text{ } \mu\text{m}$, width $W=12 \text{ } \mu\text{m}$ and the oxide thickness $t_{ox}=8 \text{ nm}$. Take $N_C=N_V=10^{25} \text{ m}^{-3}$, $E_G=1.12 \text{ eV}$, $n_i=1.5 \times 10^{16} \text{ m}^{-3}$, $kT=0.026 \text{ eV}$, vacuum permittivity $\epsilon_o=8.854 \times 10^{-12} \text{ F/m}$, dielectric constant of oxide $\epsilon_{ox}=4$, dielectric constant of silicon $\epsilon_{Si}=12$, electron mobility $\mu_n=230 \times 10^{-4} \text{ m}^2/\text{Vs}$, hole mobility $\mu_p=83 \times 10^{-4} \text{ m}^2/\text{Vs}$.

Calculate $\phi_B = |E_F - E_i|/q$, the oxide capacitance C_{ox} , the maximum depletion width W_{max} and the threshold voltage V_t . [25 pts]

Q4 Draw the band diagram for n-type semiconductor (V_g is gate voltage and V_{th} is threshold voltage). [20 pts]

Q4.1 when $V_g = 0$

Q4.2 when $V_g > V_{th}$

Q4.3 when $V_g \leq V_{th}$