MODULE 4B6: Solid State Devices and Chemical/Biological Sensors
Example Paper1
Unless otherwise stated the temperature T=300K is assumed.

1 A silicon MOS capacitor has an oxide thickness d=30 nm and is made on p-type silicon with $N_A = 10^{21}\ m^{-3}$.

Assuming the temperature T=300K:
a) Calculate the concentration of electrons and holes at the silicon/oxide interface when the surface potential ψ_S is equal to 0.25V and 0.7V

b) For each value of the surface potential, state whether the MOS is in depletion, weak inversion or strong inversion. (Assume E_i, the intrinsic Fermi Energy, equal to Eg/2.

2 For the MOS of question 1, calculate the width of the depletion region for $\psi_S =$ 0.25V.

Assuming that the MOS is ideal:

Calculate the potential drop in the oxide. (Hint: apply Gauss Law $V_i = Q_M / C_i$,, Q_M charge per unit surface on the metal, C_i oxide capacitance per unit surface).

Calculate the gate voltage required to produce the given surface potential.

3 Explain what is meant by deep depletion for an MOS capacitor.

A SiO_2/Si MOS ideal capacitor is made with p-type silicon ($N_A=10^{21}m^{-3}$) and the oxide thickness d=100 nm. Calculate the maximum field in the semiconductor and the field in the oxide, when a gate voltage V=5V is applied and assuming that the device is in deep depletion.

4 For the previous device calculate the maximum field in the semiconductor and the field in the oxide, under the same bias conditions, after the inversion layer is formed.

Assume strong inversion, that is the total space charge/unit surface Q_S is given by:

$$Q_S \approx \left(2q\varepsilon_S \frac{kT}{q}\frac{1}{N_A}\right)^{\frac{1}{2}} n_i \exp\left(\frac{q\psi_S}{2kT}\right)$$

and that $Q_S(d/\varepsilon_i) >> \psi_S$.

5 Repeat the calculations of question 2 for the case where a fixed charge, Q_f, equal to + or - 10^{-4} C m^{-2}, is present at the interface between the oxide and the semiconductor.

6* Repeat the calculation of Q.4, under the same bias conditions, in the case of a MOS with a fixed charge Q_f at the interface between the oxide and the semiconductor equal to + or -1.6 10^{-3}C m^{-2}.

7 Calculate the threshold voltage for a n-channel MOSFET with the same d and N_A as in Question 1: (i) in the ideal case; (ii) when a charge Q_f=+10^{-4}C m^{-2} is present at the semiconductor/oxide interface.

8 Explain what is the 'channel potential' in a MOSFET

Explain the meaning of 'linear' and 'saturation' regimes in a MOSFET. You may find useful to refer to a diagram of the channel potential versus distance from the source, as shown in the lecture notes

Draw a qualitative plot of the carrier concentration at the surface, as a function of position along the channel, for a MOSFET operating in the saturation regime.

What is the pinch off point?

*9 The drain current in a MOSFET is given by:

$$I_D = W\frac{dV_C}{dy}G(y)$$

Where :

$$G = \mu_n \frac{\varepsilon_i}{d}(V_{GS} - V_C - V_T)$$

G is the channel conductance. V_C is the channel potential which is a function of y, the distance from the source. V_{GS} and V_T are constant. For V_{GS}= 5V, V_T=0.5V, V_{DS}= 3V, find the channel potential at a distance y= 0.8L from the source, L being the channel length.

Formulas and constants

$\varepsilon_0 = 8.85\ 10^{-12}$ farad/m permittivity in vacuum

$k=1.38\ 10^{-23}$ Joules $^0K^{-1} = 8.625\ 10^{-5}$ eV $^0K^{-1}$ Boltzman constant

$kT/q = 0.025V$ at $T=300K$

$N_c=2.8\ 10^{25} m^{-3}$

$N_v=1.04\ 10^{25} m^{-3}$

Eg(silicon)=1.12eV

ε_i (silicon dioxide) = $3.9\varepsilon_0$

ε_s (silicon)= $11.9\varepsilon_0$

$n=N_C \exp((E_F-E_C)/kT))$

$p=N_V \exp((E_V-E_F)/kT))$

$(np)^{0.5} = n_i=6.6\ 10^{15} m^{-3}$