ECSE-2210 Microelectronics Technology
Class Activity 30 – Solution

1. a. Find the threshold voltage for a Si n-channel MOS transistor with $N_A = 10^{17}$ cm^{-3}, $\Phi_{ms} = -0.95$ eV, $Q_i = 10^{11}\ q/\text{cm}^2$, and a SiO_2 thickness $d = 200$ Å. ***Hint***: First calculate V_{FB}. Add this to V_T' (= threshold value for the ideal case) to get the actual V_T.

$C_{ox} = 0.33 \times 10^{-12}$ F/cm / $(200 \times 10^{-8}$ cm$) = 16.5 \times 10^{-8}$ F/cm^2

$$V_{FB} = \frac{1}{q}\Phi_{ms} + \left(-\frac{Q_i}{C_{ox}}\right)$$

$V_{FB} = -0.95$ V + [$(-10^{11} \times 1.6 \times 10^{-19}$ C/cm$^2) / C_{ox}$] $= -1.05$ V

This is the voltage to be applied to the gate to get flat band condition. All the ideal cases are assuming that the bands are under flat band condition before voltages to the gate are applied.

$$p = n_i \exp\left(\frac{E_i - E_F}{kT}\right)$$

$$\phi_F = E_i - E_F = 0.0259 \ln\frac{10^{17}}{10^{10}} = 0.417 \text{ V}$$

$$W_T = \sqrt{\frac{2K_s\varepsilon_0}{qN_A}\phi_s} = 0.102\ \mu\text{m}$$

This is the depletion layer width under inversion, i.e., for a surface potential $\phi_s = 2\,\phi_F$

$C_S = \varepsilon_{Si} / W_T = 9.8 \times 10^{-8}$ F / cm^2

This is the capacitance of the semiconductor part, assuming the depletion layer is W_T.

Therefore, $V_T' = 1.81$ V (assuming "ideal" conditions)

And $V_T = V_T' + V_{FB} = 1.81$ V + $(-1.05$ V$) = 0.76$ V (for the real MOSFET)

b. Repeat the above for a p-channel device ($N_D = 10^{17}$ cm^{-3}) with the same material parameters, except Φ_{ms}. Φ_{ms} for this case can be calculated from the change in E_F compared to that of part (a).

This is a p-channel device, so the ideal threshold voltage (V_T') magnitude is the same as above (since the doping concentration is the same as above), except the sign is reversed, i.e., V_T' (ideal) $= -1.81$ V.

Also, $\Phi_{ms} = \Phi_m - \Phi_s$, everything is the same, except that the position of the Fermi-level in the semiconductor is now shifted up by 2 ($E_i - E_F$) i.e., 2 × 0.417 eV. So, Φ_{ms} which is $\Phi_m - \Phi_s$ is reduced by an amount 0.834 eV.

Here $\Phi_{ms} = \Phi_{ms\,(NMOS)} + |2 \times q \times \phi_F| = -0.115$ eV

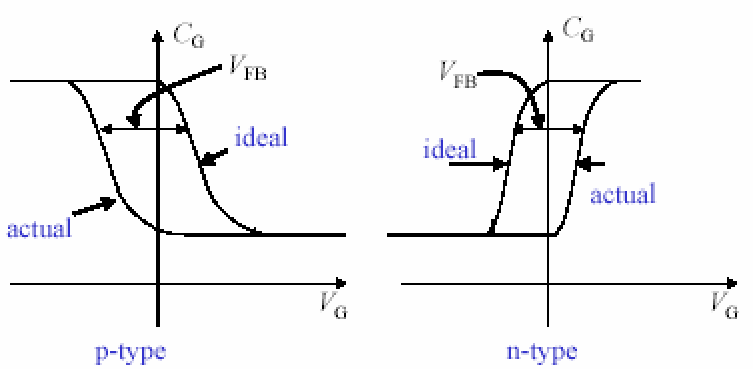
$$V_{FB} = \frac{1}{q}\Phi_{ms} + \left(-\frac{Q_i}{C_{ox}}\right)$$

$V_{FB} = -0.115\text{ V} + (-0.096\text{ V}) = -0.211\text{ V}$

$V_T' = -1.81\text{ V}$

$V_T = V_T' + V_{FB} = -2.02\text{ V}$

c. Plot qualitatively the C-V curves for the above two MOS capacitors at high frequency. Mark important points in the curves. Specifically, show the effect of V_{FB}. (Ignore the presence of source and drain for this problem).



See the solutions given in class. The C-V curve will shift by about V_{FB}.

d. Find the dose of boron (ions/cm^2) required to change the threshold voltage of the above n-channel device to + 1 V. Assume that the implanted boron resides just below the Si surface and all impurities are ionized. Is this an enhancement mode device or a depletion mode device?

Enhancement mode device since $V_T > 0$

$\Delta V_T = (1 - 0.76) = +0.24\text{ V} = -(-q \times B_{ions}) / C_{ox}$

➔ $B_{ions} = 2.5 \times 10^{11}/\text{cm}^2$.

e. Find the dose of (boron or phosphorus: choose one) required to change the threshold voltage of the above p-channel device to – 1 V. Assume that the implanted ions reside just below the Si surface. Is this an enhancement mode device or a depletion mode device?

This is an enhancement mode device, because V_T is negative in the p-channel device.

Here $\Delta V_T = -1\text{ V} - (-2.02\text{ V}) = +1\text{ V}$ and the dose is $10^{12}/\text{cm}^2$ of **boron**. Because the threshold voltage shift is along the positive side, we use boron implantation.