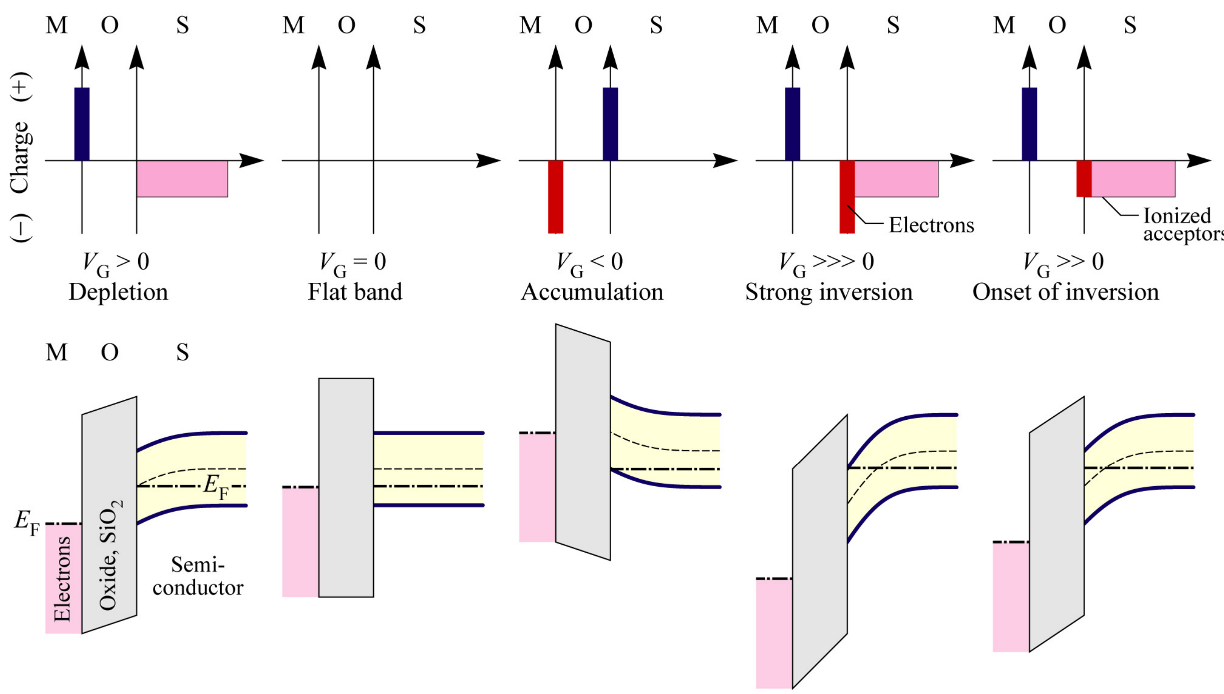
ECSE-2210 Microelectronics Technology
Class Activity 25 – Solution

1. Following are five figures showing charge density plots in ideal metal-oxide Si (p-type) structures. Identify whether the voltages applied to the metal gate are $V_G < 0$ or $V_G << 0$ or $V_G = 0$ or $V_G (= V_T) > 0$ or $V_G >> 0$ for each case. Identify which one is accumulation or depletion or flat-band or start of inversion or strong inversion. Qualitatively draw the band diagram for each case.



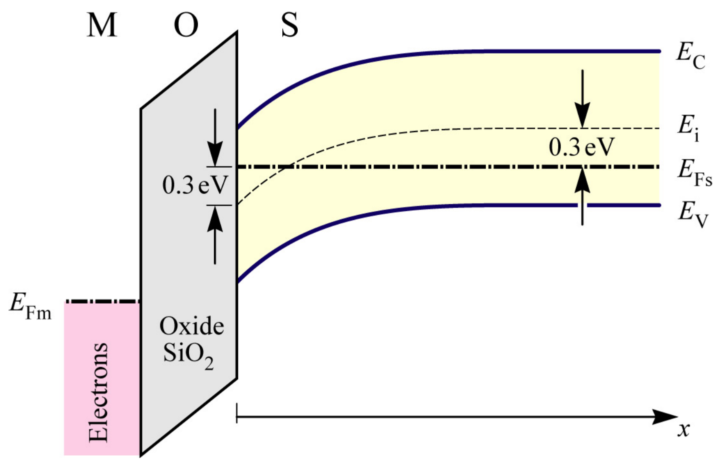
When the majority carrier concentration is greater near the oxide semiconductor interface than in the bulk of the semiconductor, it is known as **accumulation**.

When the electron and hole concentration at the oxide semiconductor interface is less than the background doping concentration, it is known as **depletion**.

The situation where the minority carrier concentration at the surface exceeds the bulk majority carrier concentration, it is known as **inversion**.

The situation where there is no band bending is known as **flat band condition** and is the dividing line between accumulation and depletion.

2. A MOS capacitor is made from Si. When V_G is applied to the gate of the capacitor, the band diagram looks as shown below. Answer the questions that follow.



a. Is the applied voltage V_G positive or negative? Explain.

Applied voltage is positive since the band bends upwards in positive *x*-direction, i.e., the electric field is positive.

b. Is the semiconductor p-type or n-type? What is the doping concentration?

Semiconductor is **p-type** since the E_i is above E_F in the bulk region.
Doping concentration:

$$p = n_i \exp\left(\frac{E_i - E_F}{kT}\right) \{E_i - E_F = 0.3 \text{ eV from the figure in the bulk region}\}$$

$$p = 10^{10}\,\text{cm}^{-3} \times \exp\left(\frac{0.3}{0.0259}\right)$$

$$p = N_A = 1 \times 10^{15}\,\text{cm}^{-3}$$

c. Calculate the number of electrons and holes in the bulk of the semiconductor.

Use $E_i - E_{FS}$ to calculate n and p!
The hole concentration is $p = 10^{15}$ cm^{-3};

Electron concentration is given by $n = \dfrac{n_i^2}{p} = \dfrac{10^{20}}{10^{15}} = 10^5\,\text{cm}^{-3}$

d. Calculate the number of electrons and holes near the surface of the semiconductor.

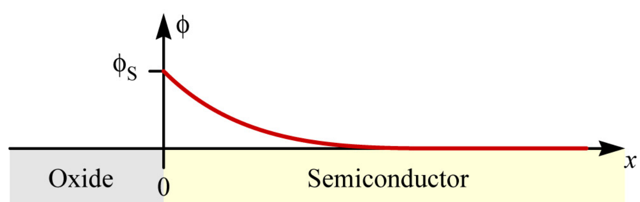
Near the surface, the conductivity type is changed, because this is just start of inversion, and the surface is changing from p to n type.
$n = 10^{15}\ \text{cm}^{-3}$ and $p = 10^{5}\ \text{cm}^{-3}$

e. Is the semiconductor under depletion, inversion or in flat-band condition?

See your result in Problem (d): It is in inversion (actually "start" or "onset" of inversion).

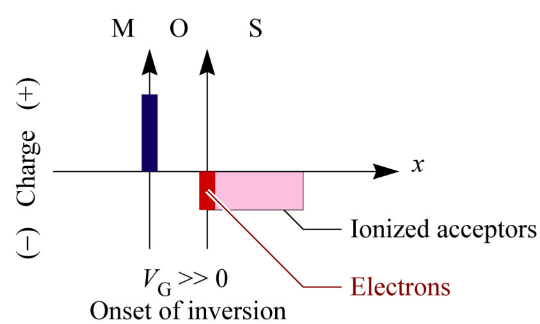
f. If we define the electrostatic potential, $\phi(x) = 1/q\ [E_i(\text{bulk}) - E_i(x)]$, plot $\phi(x)$ versus x. What is the potential difference between the surface and the bulk? ***Note***: This potential is similar to V_{bi}, from which we can calculate the depletion layer width.

The ϕ-versus-x curve will look like the band diagram "flipped upwards". Hence, the potential difference between the surface and the bulk should be 0.6 V



g. Plot the charge density as a function of x. Identify in your plot, which are mobile charges and which are ionized donors or acceptors.

The charge density plot will look like:



The inversion layer is made of mobile charges, which can move along the channel. The depletion region consists of the immobile ionized acceptors.