Serie 07

Preamble

1.1 Work function

The **work function** W of a material is defined as the energy required to extract an electron from the Fermi level to the vacuum level. Essentially, if enough energy is supplied to an electron, it can be extracted from the material. A direct manifestation of this phenomenon can be seen in the photoelectric effect. When light is shone onto a metal, electrons are emitted if the photons have sufficient energy.

Conventionally, the vacuum level energy E_0 is defined as zero. Therefore, any particle that is gravitationally or electrically bound has negative potential energy, meaning it requires a positive energy to free it. Consequently, the work function is always positive.

$$W = \phi \cdot q = E_0 - E_f \tag{1}$$

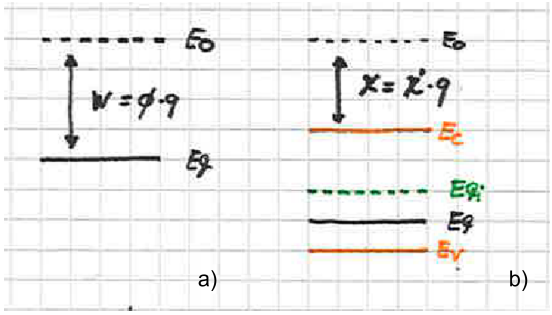

Figure 1: a) Working function. b) Electron affinity.

1.2 Electron affinity

As can be easily understood, the work function can be annoying to use in the case of a semiconductor. In a doped semiconductor, the Fermi level will change depending on the doping level, and hence the work function will also change. Therefore, in this case, we prefer to use the electron affinity instead.

The **electron affinity** χ is defined as the energy required to extract an electron from the conduction band level to the vacuum. Like the work function, the electron affinity is positive due to the convention of defining the vacuum level energy as zero.

$$\chi = \chi' \cdot q = E_0 - E_c \tag{2}$$

An illustration of the electron affinity can be found at Fig. 2.

1.3 Connecting Materials with Different Work Functions

In the same structure, the vacuum level and the Fermi level should always be continuous. Therefore, when we put two materials with different work functions in contact, we will see the creation of an electric field and the movement of charge. This will locally change the work function and "bend" the energy level to match the preceding conditions. The amplitude of this bending is necessarily equal to the difference in the work functions of the two materials. In the case of MOS structures, this will create the depletion region in the base and the accumulation of charges on the gate.

The most important parameter is the difference between the Fermi level and the other energy levels. Therefore, graphical representations can have multiple references. In this course, we prefer to keep the vacuum level constant. However, in other courses, especially ones which include band diagram drawing, they prefer to keep the Fermi level constant at 0 bias.

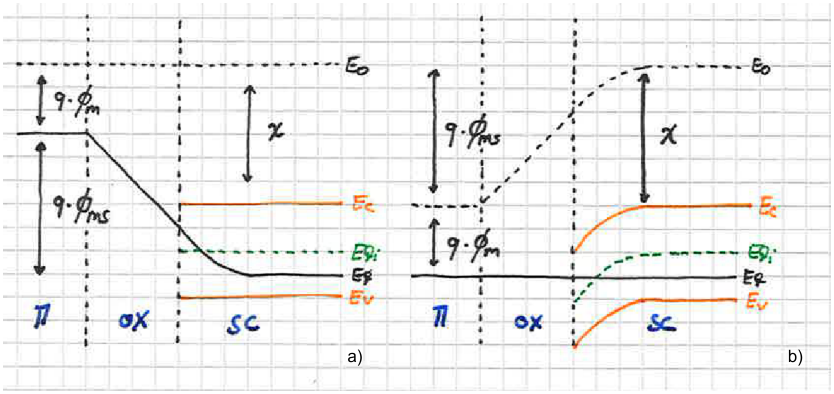

Figure 2: a) Constant E_0 convention used in the MOS structure in this course. b) Constant E_f convention used in the MOS structure.

1.4 Interfacial charges

During the course, you learned about the charge distribution in an ideal MOS structure. However, in reality, charges can get trapped in the oxide layer or at the junction between the base and the oxide. There are many factors that can lead to the appearance of these charges, such as wafer or oxide contamination during the fabrication process. These parasitic charges are known as interfacial

charges (Q_{ss}), and they can significantly impact the characteristics of the MOS structure. Even if some of the charges are trapped in the oxide, we model them by adding them at the junction between the oxide and the channel.

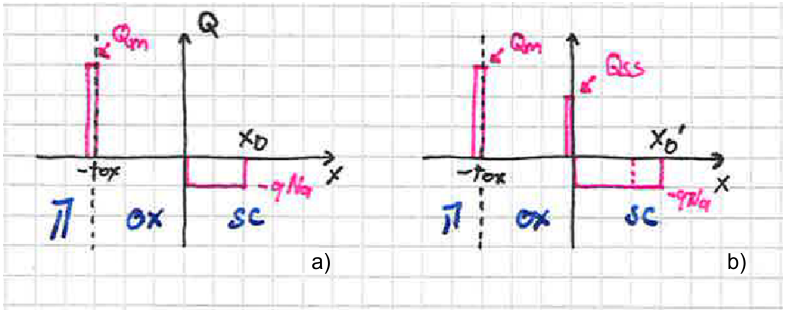

Figure 3: a) Ideal MOS structure without interfacial charges. b) Non-Ideal MOS structure with interfacial charges.

In Fig. 3, Q_{ss} and Q_m are shown as rectangles, but in reality, the interfacial charges Q_{ss} and the charge accumulated on the gate Q_m are closer to a Dirac function. These small rectangles are a graphical representation of these charges.

Given constants

$kT/q = 25.9\,[mV] \quad @ \quad T = 300\,[K]$
$n_i(Si) = 1.5 \cdot 10^{10}\,[cm^{-3}] \quad @ \quad T = 300\,[K]$
$q = 1.60 \cdot 10^{-19}\,[C]$
$\epsilon_0 = 8.85 \cdot 10^{-14}\,[F/cm]$
$\epsilon_{Si} = 11.7 \cdot \epsilon_0$
$\epsilon_{SiO} = 3.9 \cdot \epsilon_0$

Exercise 01

Calculate the work function difference between the metal and the semiconductor ϕ_{ms} in a MOS structure. The MOS structure is composed of an aluminum gate with a work function $\phi_m = 3.2\,[V]$ and a silicon channel with an electron affinity $\chi' = 3.25\,[V]$. We assume that the silicon has a band gap $E_g = 1.11\,[eV]$ and a doping concentration of $N_a = 10^{14}\,\left[cm^{-3}\right]$ and $n_i = 1.5 \cdot 10^{10}$.

Exercise 02

Calculate the maximum width of the Space Charge Region (SCR) in a MOS structure. The doping concentration of the semiconductor is $N_a = 10^{16}\left[cm^{-3}\right]$, the temperature is $T = 300\,[K]$, and we assume $n_i = 1.5 \cdot 10^{10}\left[cm^{-3}\right]$.

Exercise 03

Calculate the flat-band voltage V_{FB} of a MOS structure based on p-type silicon doped with $N_a = 10^{16}\left[cm^{-3}\right]$. The structure has a silicon oxide layer with a thickness of $t_{ox} = 50\,[nm]$, and a gate made of n+ doped polysilicon. We assume a work function difference between the metal and the semiconductor of $\phi_{ms} = -1.1\,[V]$ and an interfacial charge density of $Q_{ss} = 10^{11}\left[cm^{-2}\right]$.