ECE615 - Semiconductor Devices I  
Winter 2019  
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Homework 4  
Due at the beginning of class Tuesday March 12th

Question 1 [9 marks]:

a) When we use the word “oxide” in the context of metal-oxide semiconductor (MOS) capacitors, what type of electronic properties do we mean?[1 mark]

b) Why is an extensive knowledge of MOS capacitors valuable to the microelectronics industry?[1 mark]

c) If we observe the surface potential in an MOS capacitor to be zero, what term do we use to describe this situation?[1 mark]

d) Draw a diagram of energy ($E$) vs position ($x$) for an MOS capacitor employing an n-type semiconductor, in accumulation. Label: the Fermi energy of the metal, the Fermi energy of the semiconductor, the width of the oxide, the conduction band, the valence band, intrinsic energy of the semiconductor, the bulk potential and the surface potential. [2 marks]

e) Draw a diagram of energy ($E$) vs position ($x$) for an MOS capacitor employing an n-type semiconductor, in depletion. Label: the Fermi energy of the metal, the Fermi energy of the semiconductor, the width of the oxide, the conduction band, the valence band, intrinsic energy of the semiconductor, the bulk potential and the surface potential. [2 marks]

f) How do we define strong inversion in terms of potential? How does this condition effect carrier density at the interface between the semiconductor?[2 marks]

Question 2 [8 marks]:

a) Under ideal conditions, state how we would expect the current in an MOS capacitor to behave as a function of applied voltage.[1 mark]

b) Figure 1 shows the space charge density as a function of surface potential for an MOS capacitor, over a limited range of surface potentials. This data is also available to download here. From this data determine what regime(s) are we most likely to be in.[2 marks]

![Figure 1](image-url) "Figure 1" space charge density as a function of surface potential for an MOS capacitor, over a limited range of surface potentials. This data is also available to download here.
c) A p-type silicon MOS capacitor has an acceptor dopant density of \( N_A = 10^{16} \text{ cm}^{-3} \). Approximate the capacitance of the depletion region of an MOS capacitor under flat band conditions, when measured at a temperature of \( T = 300K \). You can assume the majority carrier concentration is significantly higher than the minority carrier concentration in this semiconductor. You will need to use Equation 1 to approximate the exponential function as a truncated series. Hint: the capacitance is neither infinity, nor zero. Give your answer in F/cm\(^2\).[5 marks]

\[
e^x \approx 1 + x + \frac{x^2}{2}
\]  

(1)

You will need:
- Boltzmann constant: \( k_B = 1.38 \times 10^{-23} \text{ J/K} \).
- Vacuum permittivity: \( \epsilon_0 = 8.85 \times 10^{-12} \text{ F/m} \).
- Relative permittivity of silicon \( \epsilon_r = 11.7 \).
- Fundamental unit of charge: \( e = 1.60 \times 10^{-19} \text{ C} \).

**Question 3 [5 marks]:**

a) Figure 2 shows the capacitance per unit area of a MOS capacitor measured as a function of applied voltage (\( V \)) using a low frequency probe and a high frequency probe. From this data determine the capacitance of the depletion region of this capacitor. Give your answer in \( \mu \text{F/cm}^2 \).[2 marks]

![Figure 2](image)

**Figure 2** Capacitance per unit area of a MOS capacitor measured as a function of applied voltage (\( V \)) using a low frequency probe and a high frequency probe.

b) An MOS capacitor is made from a 200nm thick layer of silicon dioxide which contains oxide trapped charge with a concentration of \( Q_{OT} = 2.589 \times 10^{-9} \text{ C/cm}^2 \). Calculate the effect these trapped oxide charges have on the flatband voltage of the MOS capacitor, if the charge distribution in the oxide is described by Figure 3. You can ignore any other contributions to the flatband voltage such as work function offset and other insulator charges. Give your answer in volts.[3 marks]

You will need:
- Vacuum permittivity: \( \epsilon_0 = 8.85 \times 10^{-12} \text{ F/m} \).
- Relative permittivity of silicon dioxide \( \epsilon_r = 3.9 \).
Question 4 [3 marks]:

a) Draw the band diagram (energy vs position) of a Type I Heterojunction. Label the conduction band, valence band, and band gap of each semiconductor.[1 mark]

b) Draw the band diagram (energy vs position) of a Type II Heterojunction. Label the conduction band, valence band, and band gap of each semiconductor.[1 mark]

c) Draw the band diagram (energy vs position) of a Type III Heterojunction. Label the conduction band, valence band, and band gap of each semiconductor.[1 mark]