ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

SCHOOL OF ENGINEERING (STI)
Institute of Electrical Engineering (IEL)

EE 557 - Semiconductor devices I

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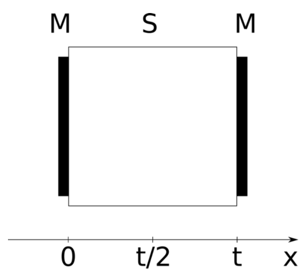
Exercises - list 4

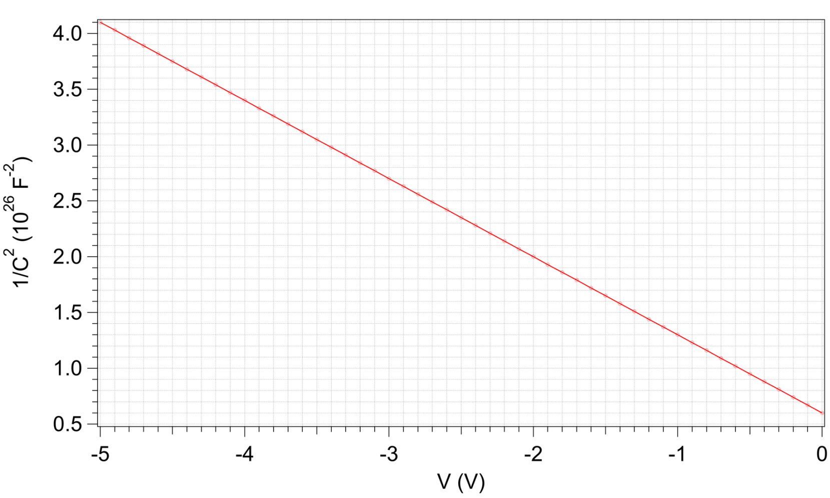
1. Consider a thin Si sample with two metallic contacts on each side, as shown in the figure below. The structure is at room temperature in thermal equilibrium and the doping is $N_D = 10^{15}$ cm^{-3} everywhere. The Schottky barrier height of both metal-semiconductor junctions is $q\varphi_{Bn} = 0.7$ eV.



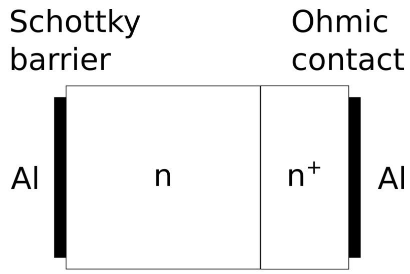
Consider three scenarios t = 5 µm, 1 µm and t→0:

a) Calculate the electron and hole concentration and the electric field at the centre of the sample x = t/2.
b) Sketch the corresponding energy band diagram throughout the structure.
c) Compute the built-in potential of each metal-semiconductor junction.

2. You have received a Si Schottky diode with its C-V plot and know that the junction's area is 20 × 20 µm^2. Extract the Schottky barrier height from the available information (V in the plot represents the voltage of the metal with respect to the semiconductor).



3. Consider a Schottky diode built on n-type Silicon, as sketched in the figure below. The Schottky metal is Al which has a Schottky barrier height on n-type Si of $q\varphi_{Bn} = 0.68$ eV. The doping level in the n region is $N_D = 10^{16}$ cm^{-3}. In order to provide good ohmic contact to this diode, there is an n^+ region with a doping level of $N_{D+} = 10^{19}$ cm^{-3}. Al is also used as an ohmic metal.



3a) Consider this structure in thermal equilibrium at room temperature. Use Boltzmann statistics to treat the n^+ region. Sketch a complete energy band diagram across the entire structure (from metal to metal). Calculate and indicate the location of the Fermi level in the different regions. Assume that both semiconductor regions are wide enough to accommodate the depletion regions associated with the metal-semiconductor junctions fully. Be neat in your sketch.

3b) Compute the depletion region extension at the two MS junctions. What is the phenomenon that takes place at the right junction?

4. The diagram illustrates the relationship between the electric field and position within an MS junction. The semiconductor used is silicon doped at 1×10^{16} cm^{-3} and is at room temperature. This system is in equilibrium, and we're operating under the assumption of the depletion approximation. Additionally, we can consider the electron affinity to be 4.0 eV. Please address the following questions based on this context.

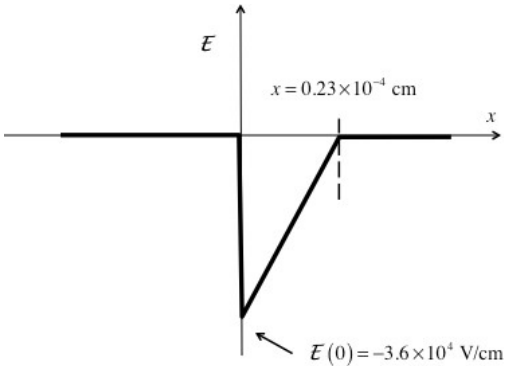
4a) Determine whether the semiconductor is N-type or P-type and provide the reasoning behind your choice.

4b) Calculate the Schottky barrier height.

4c) Given an electron affinity of $\chi = 4.03$ eV, determine the work function.

4d) Compare the electrostatic potential of the bulk semiconductor with that of the metal. Which one is greater?

4e) Illustrate the energy band diagram of the isolated metal and semiconductor before their combination into the MS diode. Include the vacuum level, the semiconductor's work function, and any other pertinent quantities.



5. Consider a metal contact made with tungsten, whose workfunction is 4.6 eV; a junction with Si is made, whose electron affinity is 4.03 eV. This MS junction behaves differently depending on the Si doping.

   5a) Assume that Si is N-type with $N_D = 10^{17}$ cm^{-3}. Draw the energy band diagram, indicating the Schottky barrier height.

   5b) Assume now that the doping is P-type with $N_A = 10^{17}$ cm^{-3}. Draw energy band diagram and Schottky barrier height.

   5c) Calculate numerically the Schottky barrier height in the two situations.

   5d) What happens if instead of tungsten, the metal is replaced with platinum (W = 5.3 eV) ?

6. Consider a Schottky diode at room temperature that is formed with Mg on n-type silicon. Use Figure 9.5 (Neamen, Donald. Semiconductor physics and devices. McGraw-Hill, Inc., 2002.) to determine the barrier height. Assume a doping concentration of $N_d = 10^{16}$ cm^{-3} and assume a cross-sectional area $A = 10^{-4}$ cm^2.

   6a) Compute I_S and built-in potential, Φ_{bi}, for this diode.

   6b) What happens if T increases up to 350K?

   6c) As expected, barrier height increases linearly with the metal work function for Si. According to your knowledge, what can be the reason behind the different behavior of the presented GaAs?
   Hint: think about issues that are present in the real world

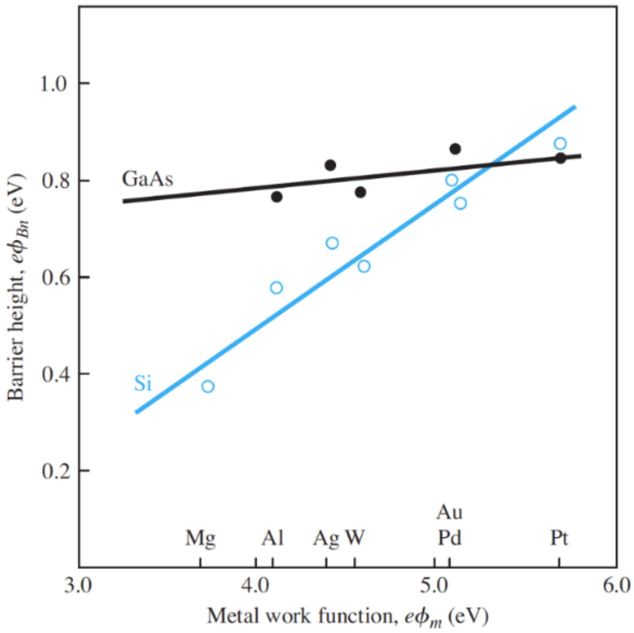


Figure 9.5 | Experimental barrier heights as a function of metal work functions for GaAs and Si.
(From Crowley and Sze [2].)