Exam Physics of Electronic Devices **13-04-2007**
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Use separate paper for each of the 4 questions

1) **Ge has a bandgap of 0.66 eV at roomtemperature. The effective densities of states N_C and N_V are $10^{25}/m^3$ at room temperature.**

a) Calculate the intrinsic electron and hole concentrations at room temperature.

b) Calculate the position of the Fermi energy

Ge is n-doped with a concentration $N_D = 10^{22} / m^3$

c) Calculate the position of the Fermi energy. For this you can assume that the donor energy levels are very close to the conduction band edge. Also you can neglect the intrinsic electron and hole concentrations.

A Schottky diode (junction) is formed by connecting the n-doped Ge to a metal. The metal has a workfunction W. The electron affinity of the Ge is X. The doping concentration in the Ge is $N_D = 10^{22}/ m^3$.

d) Give a schematic drawing of the energy bands of the metal and the Ge in the junction. Assume that an "ideal" Schottky barrier is formed (no interface states).

e) Give an expression for the Schottky barrier height.

f) Assume that the Schottky barrier height is 0.3 eV. Calculate the width of the depletion region.

g) Draw the energy bands for "forward" voltage bias and "reverse" voltage bias.

h) Give an expression for the current/voltage characteristics of an ideal Schottky junction. And a non-ideal Schottky junction?

i) In the depletion region an electric field is present, even for the case when no external voltage is applied. Explain why there is no current, although there is an electric field.

2) **A metal-oxide-semiconductor field effect transistor (MOSFET) is fabricated by fabricating two heavily doped n++ doped regions in a silicon substrate, separated by a spacing L. The substrate is lightly p-doped. The silicon substrate is oxidized to form a thin SiO2 layer at the surface. After this, two metal source and drain contacts are made to the n++ regions. Finally a metal gate electrode is made.**

a) Make a schematic drawing of the device.

b) Will the device operate as an n-channel or a p-channel MOSFET?
Why?

c) The electrical resistance between the metal contacts and the n++ regions must be as small as possible. How can this be achieved? What doping concentration is required?

d) Draw a picture of the energy bands in the metal, oxide and semiconductor. Do this for three cases: 1) flatband 2) inversion 3) accumulation.

e) The mobility of the carriers is μ, the width of the device is W, and the capacitance between the gate electrode and the semiconductor is C.

f) Calculate how the conductance depends on the gate voltage.

g) Draw the current/voltage characteristics of the device, for a few gate voltages.

3) In organic field-effect transistors the field-effect mobility is often strongly dependent on the gate voltage that is applied.

a) Explain why the field-effect mobility is measured in the linear regime

b) Explain why the field-effect mobility depends on the gate voltage.

c) What determines the temperature dependence of the mobility?

d) How can the mobility of organic transistors be further enhanced?

4) The efficiency of polymer based solar cells has been increased from 0.5% to about 4% in the last 5-6 years.

a) Explain why it is important that the hole and electron transport are equally efficient for extraction of the photogenerated charges.

b) Give the conditions for which the photocurrent is space-charge limited.

c) Explain why in poly(p-phenylene vinylene) based solar cells a large fraction of the non-absorbing fullerenes is required to reach a high efficiency.

d) The current state-of-the-art solar cells based on poly(3-hexyl thiophene) have an efficiency of about 4%. Give suggestions how the efficiency of polymer based solar cells can be further improved.