Exam Device Physics 3-4-2023 8:30-10:30

Write the answer to each of 4 questions on a separate sheet. Please put your name and study number on each. Total 100 points

Question 1 (30 pts total)

A semiconductor has a bandgap E_g, and an effective density of states for electrons N_C and for holes N_V. The temperature is T. A pn junction is formed by doping the semiconductor with a donor density N_D and an acceptor density N_A. The semiconductor is in the extrinsic regime.

a) Give an expression for the position of the Fermi energies in the (bulk) p and n doped regions. (6 pts)

b) Draw and explain the band structure of a pn junction in equilibrium. Describe why depletion regions are formed. Give the expression for the widths of the depletion regions in the p and n regions. (6 pts)

c) Describe how/if the band diagram changes for equilibrium, forward and reverse directions. Make drawings. (6pts)

d) Give the expression for the I/V characteristics of a pn junction. Describe in a few lines why the I/V characteristic has this form. Explain which properties of the semiconductor influence the I/V characteristic. (6 pts)

e) Describe the role of electron-hole recombination in a pn junction. In what regions of the pn junction can it occur, and why? Is there a difference in recombination when the pn junction is in equilibrium, or in forward or reverse bias? (6 pts)

Question 2 (20 pts total)

Consider a metal-insulator-semiconductor (MIS) junction. The semiconductor is n-doped.

a) Give the band diagram for the following regimes: 1) flatband condition, 2) depletion regime, 3) inversion regime, 4) accumulation regime. Describe for these regimes where the mobile carriers are, and what type they are (electrons/holes). (6 pts)

b) Derive the expression for the density of states in 2 dimensions. (6pts)

c) Describe how you can make a 2 dimensional electron gas using a MIS junction. What are the requirements (for example: for the properties of the semiconductor, the insulating barrier, temperature and gate voltage) to realize such a system? (8 pts)

Question 3 (20 pts total)

a) With the help of a simple drawing discuss the differences between the density of states in ferromagnetic Cobalt from that of metallic Copper close to the Fermi level. (4 pts)

b. Using a parallel resistor model for a simple spin valve structure such as Co/Cu/Co derive the parallel and antiparallel state resistance of such a structure, when the thickness of both the Co layers are t_f and that of non-magnetic Cu t_{nm} The resistivity of the majority spins is $\rho_{f(M)}$ and the resistivity of the minority spins is $\rho_{f(m)}$ The resistivity of the non-magnetic metal is ρ_{nm}. (12 pts)

c.) Does the Giant magnetoresistance ratio depend on the spin dependent scattering in the bulk and/or at the interface? (4 pts)

Question 4 (30pts total)

a) Describe the working mechanism and draw the energy/band diagrams of a heterostructure optimized for the fabrication of inorganic LEDs. Sketch the JV characteristics of the device. Which type of heterostructure will give the best performance? How many layers will give the maximum performances, what is the function of this layers? (10 pts)

b) Describe the working mechanism and draw the energy/band diagrams of an inorganic solar cell. Draw the JV characteristics in dark and under illumination and write down how the efficiency of a solar cell can be calculated. Which type of illumination should be used to measure solar cells? In case of organic semiconductors, what are the main differences with what you wrote above? (10 pts)

c) Is the band-gap of the semiconductor an important parameter for the functioning of a solar cell? In what way? Which will be the difference between the JV characteristics of a device made with a semiconductor of 3.2 eV band gap and of 1.2 eV band-gap. (10 pts).