Exam Device Physics 3/4/2019 9:00 12:00 Write the answers to the five questions on separate sheets. Please put your name and study number on each sheet. Explain your answers. Total 100 points. Good luck!

Question 1 (35 pts)

A semiconductor has a bandgap E_g and an effective density of states for electrons N_c and for holes N_v (assume $N_c=N_v$). The temperature is T. A pn junction is formed by doping the semiconductor with a donor density N_d and acceptor density N_a. The p and n doped semiconductor regions are in the extrinsic regime.

a) Calculate the positions of the Fermi energies in both p and n regions. (5 pts)
b) Draw the banddiagram of the pn junction. Describe why and how a depletion region is formed. Describe what determines the value for the built-in potential. (5pts)
c) The depletion region extends in both the n and p doped semiconductor regions. Is the width of the depletion region the same in p and n regions? Explain why or why not. (3pts)
d) Describe the basic operation of a pn junction. Describe how the current is carried (by electron/hole minority or majority carriers) in each of the three regions: (bulk) p region, (bulk) n region, and depletion region. (7pts)

For the operation of a pn junction the phenomenon of electron-hole recombination is very important.

e) Describe (and explain why) in what regions of the pn junction e-h recombination is bad for the operation. Give a schematic comparison between the I/V characteristics with and without recombination.(4pts)
f) In other regions e-h recombination is needed for a good operation of the pn diode. What regions are these, and describe why e-h recombination is required there. (4pts)

Consider a npn system. Here a thin p doped region is inserted between two n doped regions. This system can be considered as two pn junctions connected in series. However for both positive or negative voltage bias always one diode will be in reverse direction.

g) Give the banddiagram for this system. Consider two regimes: 1) The width of the p region is (much) larger than the depletion region width and 2) The width of the p region is (much) smaller than the depletion region width. (4pts)
h) Give the schematic I/V characteristics in both regimes (3pts). Explain the possible differences.

Question 2 (15pts)

Electrons with an effective mass m* are confined in a semiconductor sheet with thickness D. Assume a hard wall electrostatic confinement potential of the form V= 0 for $0<z<D$ and V= -infinity for $z<0$ and $z>D$. The motion in x and y direction is free.

a) First consider the motion in the z direction only. Calculate the quantized energy levels which are formed. (5 pts)

b) Derive the expression for the density of states (DOS) in (strictly) two-dimensions. Draw the total density of states for the system above as a function of energy. Indicate the range of Fermi energies for which the system is strictly two dimensional (assume T=0). (5 pts)

c) Now the electrons are also confined in the y direction with a hard wall potential. Indicate the energy range for which the electronic motion is strictly one-dimensional

Question 3 (25 points)

a) Describe the working mechanism and draw the energy/band diagrams of an heterostructure optimised for the fabrication of LEDs. Which type of heterostructure will give the best performance? How many layers will give the maximum performance and why? (5 points)

b) Which are the absolute and physiological figure-of-merits for the efficiency of a LED? Why it has been very hard to make an efficient blue light emitting diode? Is the response function of our eye responsible for this difficulty? (5 points)

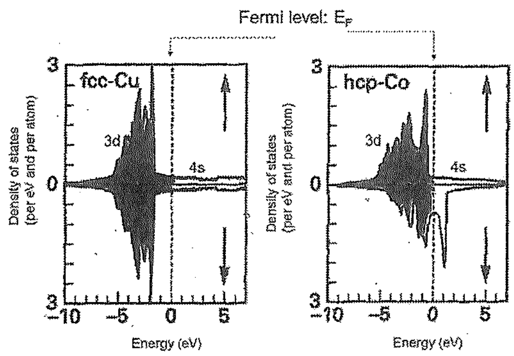
c) Describe the working mechanism and draw the energy/band diagrams of a solar cell. (5 points)

d) Write the figure of merit of a solar cell, in your opinion which is the most effective way to maximize the power conversion efficiency of one of these devices? Discuss it. (5 points)

e) Is there any difference between inorganic and organic semiconductor solar cells? Discuss similarities and differences between these 2 classes of solar cells in view of your knowledge on their active material properties. (5 points)

Question 4 (15 points)

Shown below are the density of states (DOS) as a function of energy for ferromagnetic Co and metallic Cu. Study the sketch carefully and answer the following:



a) How would you define the magnetization of Cu and that of Co? (2 points)
b) Would you expect a difference in electrical conduction between Co and Cu? Justify your answer. (2+2 points)
c) What is the basic device used to study giant magnetoresistance? (1 point)
d) I have made a spin valve of Co1/Cu/Co2. Draw the potential landscape picture of such a spin valve when the magnetization of Co1 is both parallel and antiparallel to the magnetization of Co2 and discuss why they are different . (4+2 points)
e) I have used similar ferromagnets (i.e Co) on either side of the Cu spacer (as in d)). Is it possible to realize an antiparallel state then? (2 points)

Question 5 (10 points)

a) Define tunnel spin polarization. How is it different from spin polarization? Is the spin polarization in Co negative or positive? [2+2+1 points]

b) What is the basic device used to study tunnel spin polarization –illustrate your answer with a diagram and explain the different components of the device. What are the three basic assumptions in spin dependent tunnelling? [2+3 points]