Exam Device Physics NADP-12 30-3-2016 9:00-12:00

Write the answer to each of the 6 questions on a separate sheet. Please put your name and study number on each sheet. Total 100 points

Question 1 (20 pts)

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 and expression for the position of the Fermi energies in the (bulk) P and N doped regions. (3 pts)

b) Draw and explain the band structure of a PN junction. Describe why depletion regions are formed. Give the expression for the widths of the depletion regions in the P and N regions. (3 pts)

c) Give and expression for the built-in potential. (2 pts)

d) Describe how/if the band diagram changes for equilibrium, forward and reverse directions. Make drawings. (3 pts)

e) The width of the depletion region changes when a bias voltage is applied. Does that change the operation of the PN diode? Give arguments why/ or why not it changes the operation of the diode. (2 pts)

f) Give the expression for the I/V characteristics of a PN junction. (2 pts)

g) Describe a few mechanisms which can lead to non-ideal behavior of the PN junction. (2 pts)

h) Draw the band diagram for a Schottky junction for equilibrium, forward and reverse directions. (3 pts)

Question 2 (10 pts)

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 where the mobile carriers are, and what type they are (electrons/holes). (5 pts)

b) Give a schematic diagram of a metal-oxide-semiconductor field effect transistor. In which of the above regimes should the MOSFET be operated? (5 pts)

Question 3 (10 pts)

a) Describe the operation of a single electron transistor (SET). Give a schematic diagram of a single electron transistor. Show the distribution of the charges when the current through the transistor is off, and when it is on. (5 pts)

b) Discuss what is needed for a good operation of the transistor. Consider the role of capacitance, temperature, resistance and possible other effects which can influence the operation. (3 pts)

c) Do you think that single electron transistors can replace conventional field effect transistors? Give some reasons why, or why not. (2 pts)

Question 4 (total 20 pts)

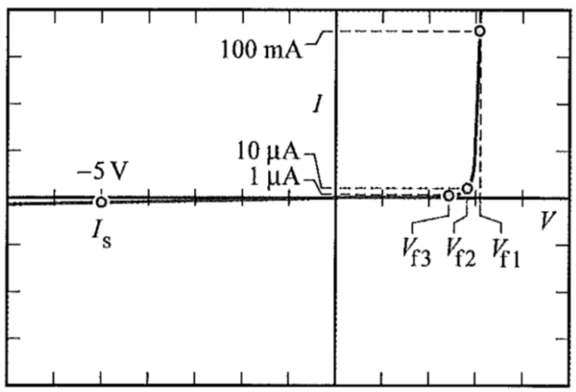
Consider a light-emitting diode based on an inorganic semiconductor. The LED emits light at a wavelength of 620 nm.

a) What is the relation between the band gap of the semiconductor and the energy of the emitted light? Explain your answer. (5 pts)

b) Calculate the luminous efficiency assuming that the LED has an external quantum efficiency of 50%. (5 pts)

c) Real (i.e. non-ideal) LEDs have finite series and shunt resistances. Usually, the current-voltage characteristic of an LED is characterised by four critical points (see graph):

- forward voltage 1: Vf1 (at operating current, 100 mA)
- forward voltage 2: Vf2 (small forward current, 10µA)
- forward voltage 3: Vf3 (very small forward current, 1µA)
- reverse saturation current Is (at -5V)



Explain the relevance of these critical points when comparing two LEDs made of the same semiconductor. (6 pts)

d) Two GaIN LEDs have the following data:

	device 1	device 2
Vf1	3.2 V	3.4 V
Vf2	2.5 V	2.0 V
Vf3	2.3 V	1.8 V
Is	0.8 µA	0.8 µA

Compare these 2 devices; which one has the more desirable properties?

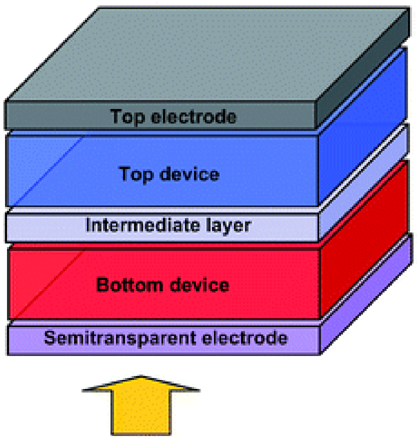
Explain your answer. (4 pts)

Question 5 (total 20 pts)

a) Explain why even an ideal solar cell cannot have an efficiency of 100% (5 pts).

b) What is the optimal band gap for a solar cell? (2 pts)

c) Two semiconductors with different band gaps can be combined to make a tandem solar cell (see image below). Light that is not absorbed by the bottom cell may then be absorbed by the top cell. The efficiency of such a tandem cell can exceed the Shockley-Queisser limit. Why? (6 pts)



d) What is the crucial difference between organic semiconductors and the classical inorganic semiconductors that are being used for PV, under illumination? (3 pts)

e) A typical silicon pn junction solar cell consists of a thick base (p-doped) and a thin emitter (n-doped). The open-circuit voltage of such a pn junction is limited by the diffusion voltage. How is the diffusion voltage related to the doping levels of the base and emitter? Why is it better to combine a highly doped emitter with a moderately doped base instead of vice versa? (4 pts)

Question 6 (20 pts)

Consider a GMR device (Ferromagnet/Spacer/Ferromagnet) where the thickness of two identical ferromagnets is given by t_F , the resistivity of spin-up and spin-down electrons is given by ρ_M and ρ_m respectively and t_s and ρ_s represent the thickness and resistivity of the spacer layer.

a) Using the parallel-resistor model write down the expression for the resistance of the device in both parallel and antiparallel configuration (NOT the GMR ratio).(6 pts)

b) What are the two common device configurations (device geometries) used for measuring a GMR device? (2 pts)

c) Give a key difference between electrical conduction in a ferromagnetic material (such as Co) and a metal (such a Cu). (2 pts)

d) Draw and describe a Magnetic Tunnel Junction device (MTJ). (2 pts)

e) Write down the expression for Spin polarization of typical ferromagnets at E_F. (1 pt)

f) Express Tunnel Magnetoresistance (TMR) in terms of spin-polarization (P_1, P_2) of the ferromagnets. (2 pts)

g) What are the most important (write down at least 2) requirements for spin-dependent tunnelling to occur in such MTJ's. (2 pts)

h) Write down the expression for tunnelling spin polarization (TSP)- how does TSP differ from spin polarization. (2 pts)