Exam Device Physics 2010. Please write the answers on each question on a separate sheet with name and studynumber.

Question 1

Consider a metal-insulator-semiconductor (MIS) diode. The semiconductor is n-doped with doping concentration N_D. The insulating oxide layer has a thickness d and a relative dielectric constant equal to 1. A voltage can be applied to the metal gate, a second (reference) contact is made to the semiconductor. Assume that when no gate voltage is applied a flatband condition exists, so that there is no band bending in the semiconductor. Also assume that at the interface between the semiconductor and the oxide there are no interface states.

A gate voltage V_g (positive or negative) is applied to the gate.

a) Describe the 3 (or 4) regimes in which the MIS diode can operate.
b) Give the names of these regimes.
c) Give the bandstructure for these regimes, and draw how the energy of the bands depends on the position.
d) Draw the charge distribution for these regimes. Indicate the regions where there is a density of charges (indicate if they are mobile or fixed)
e) Give (approximately) the relation between the gate voltage and the induced charge density.

In almost all cases the "flat-band" assumption for $V_g = 0$ does not hold, and there is already some degree of band bending at $V_g=0$.

f) Describe (qualitatively) how the band bending will depend on the workfunction of the metal of the gate.
g) Are there other parameters which can determine the band bending at $V_g=0$? If so, describe them.

Question 2:

A semiconductor quantum well is a thin semiconductor which is sandwiched in between two different semiconductors. Assume that the electronic states in the quantum well can be described by a free electron gas with effective mass m. The electrons can then be described as "particles in a box", where the box has a width d in the z-direction. There is no confinement in x and y directions.

a) Derive an expression for the density of states in two-dimensions.

The (two dimensional) electron density is N (N: number of electrons per unit area)

b) Calculate the Fermi energy (assuming that the electron system is two-dimensional)
c) When a certain electron density N is exceeded extra states become available for the electrons, and the system is no longer 2-dimensional Describe what states they are.
d) Calculate at which density N this happens.
e) Show (without detailed calculations) that when d is increased to infinity the density of states in the quantum well approaches the density of states in 3-dimensions.

Question 3.

The operation of a p-n diode has been explained in the lectures. The doping concentration of and p and n regions are the same $N_D = N_A = N$

a) Give an expression for the width W of the depletion region.

A p-i-n diode is a modification of a p-n diode. In between the p and n doped regions an undoped region is inserted, which has a thickness D.

b) Draw the band diagram for such a p-i-n diode in equilibrium.
c) In which regions is an electric field present? Give a schematic plot which shows the magnitude of the electric field as a function of position in p, undoped and n regions.
d) Two important length scales are W and D. Is there a difference in the band diagram between the case when W>>D or when W<<D? Why?
e) Compare the operation of a p-i-n diode with a p-n junction. First give the basic operation principle of a p-n diode and then describe if you expect a difference for a p-i-n junction.

Question 4

a) Describe briefly the difference in physical properties between organic and inorganic semiconductors.
b) Optical transitions are fundamental in determining the working mechanism of optoelectronic devices. Which are the main optical transitions and how is their efficiency defined?

Question 5

a) Describe the working mechanism and draw the energy/band diagrams of organic and inorganic LEDs. Discuss the similarities and differences.

b) Describe the working mechanism and draw the energy/band diagrams of organic and inorganic solar cells. Discuss the similarities and differences.

Question 6.

Using the simple Mott two-current model Giant Magnetoresistance (GMR) is defined as:

$$GMR = \frac{\Delta R}{R} = \frac{\rho_{AP} - \rho_P}{\rho_P}$$

Where ρ_{AP} and ρ_P are the resistivities in the parallel and antiparallel configuration of a GMR stack. If the resistivity of the spin down current with magnetization ↑ is ρ_{HI} and resistivity of the spin up current with magnetization ↓ is ρ_{LO} express GMR in terms of α where $\alpha = \frac{\rho_{HI}}{\rho_{LO}}$.

a) Does the GMR depend on the geometry of the GMR device?

b) Can you comment on the dependence of the GMR when one incorporates the thickness and resistivities of the Normal and Ferromagnetic layers?

You can refer to the Lecture1 notes on Spintronics (part on Giant Magnetoresistance).