ECSE-2210 MET – Midterm Exam – Fall Semester 2016

1. A semiconductor sample is illuminated with light having a wavelength $\lambda_1 = 400$ nm and an emission wavelength of λ_2 = 600 nm. Assume that the incident light power is 500 mW with all incident light being uniformly absorbed by the sample. Due to the illumination, the sample heats up with the heat power being 250 mW.
   (a) Sketch the experimental setup. Calculate the bandgap energy of the semiconductor sample.
   (b) Define and calculate the power efficiency of the experiment.
   (c) Define and calculate the incoming photon flux of the experiment.
   (d) Define and calculate the outgoing photon flux of the experiment.
   (e) Define and calculate the quantum efficiency of the experiment.

2. An abrupt pn-junction made of Si has a depletion layer thickness on the n-side (x_{n0}) that is 4 times wider than the depletion layer thickness on the p-side (x_{p0}). The depletion layer thickness (at zero bias) is W_D = 56.13 nm and the built-in voltage is V_{bi} = 0.958 V.[1]
   (a) Determine the doping concentrations N_A and N_D.
   (b) Determine at which applied voltage the injected hole concentration on the n-side (at the edge of the depletion region) is 1% of the free electron concentration on the n-side, n_{n0}.
   (c) Assume that the applied diode voltage significantly exceeds the voltage calculated under (b). What is the name of the regime in which the diode is operated?
   (d) If the applied voltage exceeds V_{bi}, across which regions does the applied voltage drop?

3. Assume a Si abrupt p-i junction, where "p" represents a p-type region and "i" represents an intrinsic region. On the p-side, the acceptor concentration is $N_A = 5 \times 10^{17}$ cm^{-3}.
   (a) Calculate the energetic distance of the Fermi level from the conduction band (CB) and valance band (VB) in the two neutral regions of the p-i junction. Sketch the band diagram and show the bandgap energy and the energies you just calculated.
   (b) Plot the charges in the p-i junction as a function of distance x. Identify the origin of these charges. Plot the net charges in the p-i junction as a function of x.
   (c) Plot the electric field and electrostatic potential caused by the charges as function of x.
   (d) Calculate the built-in voltage (V_{bi}) of the p-i junction.
   (e) Assume that we add donors to the i-region, thereby transitioning from a p-i junction to a pn junction. In this case, will V_{bi} increase or decrease? Explain your answer.

4. Determine if the following statements are true or false. Explain your answers with a few words.[2]
   (a) There are many electrons in the valence band (VB) of a semiconductor and they are mostly found at the bottom of the VB.
   (b) In a pn junction under forward bias, the hole diffusion electrical current and electron diffusion electrical current are directed in the same direction.
   (c) In a pn junction, the hole diffusion particle current and electron diffusion particle current are directed in opposite directions.
   (d) Shockley's drift-diffusion equation (which relates diode current to voltage) predicts that the reverse current of a pn junction has a constant value for applied voltages of $V < -1$ V.
   (e) Carriers are generated in n-type Si by means of optical excitation. Minority carriers in n-type Si, i.e. holes, have a lifetime of 1 μs. Then it is reasonable to assume that the semiconductor has reached equilibrium conditions 1 μs after the optical excitation has been turned off.

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[1] In this exam, one or more questions concern Si. Feel free to look up material parameters of Si.
[2] For a statement consisting of multiple sub-statements to be true, each sub-statement must be true.