Final Exam: ENEE 313

Part I (30pts):

A BJT has the emitter doped with N\textsubscript{DE} donors, the base with N\textsubscript{AB} acceptors, and the collector doped N\textsubscript{DC} donors.

1. Is this an NPN or PNP transistor, why?
2. Describe qualitatively how a BJT works in forward active mode.
3. If the Base-Emitter voltage is zero, what will be the value of the collector current for any collector voltage greater than zero, why?
4. By solving the current and continuity equations together, derive the expression for the base current component that flows through the base-emitter junction and then diffuses into the emitter. Assume the emitter is long enough so that its length can be approximated as infinite, and the device is in forward active.
5. Derive the expression for the current gain, $\beta$ of a BJT, starting with the expressions for the individual current components as given in the formula sheet.
6. What will happen to the collector current in the NPN BJT if the Base and Emitter voltages are both zero, and the Collector voltage is negative 0.7V? Don’t derive, but provide an educated guess for the analytical expression that describes the collector current will be under these circumstances, and explain your reasoning.

Part II (30pts):

1. Sketch and label the cross-section of an N-MOSFET and a P-MOSFET
2. Qualitatively describe how an N-MOSFET works for three regions of operation
   a. Cutoff
   b. Linear
   c. Saturation
Describe the relative values of the gate, source and drain voltages in these regions of operation. Assume the body voltage is zero. Use words like channel, threshold voltage, inversion, etc.

3. Derive the expression for the threshold voltage of an N-MOSFET. Use the following expression for the electric field in the semiconductor at the semiconductor-SiO\textsubscript{2} interface
   \[ E_{Si} = \frac{q}{\varepsilon_{Si}} N_A \left[ \frac{2\varepsilon_{Si}}{qN_A} \left( \varphi_s - \varphi_p \right) \right]^{1/2} \]
(Recall, deriving this expression for the field was probably the most detailed part of the derivation, so this should make it much easier.).

4. What do we mean when we say that the surface is inverted. Provide an expression for the surface potential in terms of known quantities when inversion is reached. Why do we use this expression?
5. Write down the expression for drain current
   a. in the linear region,
   b. in the saturation region
Under what conditions do you use the different expressions?
Part III (25pts):
A hypothetical intrinsic semiconductor has the following conduction and valence band structure:

Conduction band: \( E = Ak^2 + B \) (\( B \) is the bandgap)
Valence band: \( E = -Ck^2 \)

The electrons and holes in the semiconductor have an average time between collisions of \( \tau \), which of course affects their mobility. A bar of length \( L \) and cross-sectional area \( \Delta \) is composed of this material.

1. If a voltage \( V \) if applied across the length of the bar, obtain an expression for the current in the intrinsic semiconductor bar.
2. If the bar is now doped with \( N_D \) donors and \( N_A \) acceptors, so that it is now extrinsic with \( N_A \gg N_D \), obtain an expression for the ratio of the electron current to the hole current.

The expressions you obtain should be in terms physical constants like \( h \) and \( K \), temperature \( T \), and the band structure parameters given in this problem.

Part IV (15): Answer the following questions in a short sentences

1. What fundamental equation that we discussed in class is used for quantum mechanics, and what is its solution called? Typically, what do the eigenvalues of this fundamental equation give you? What does the square of the solution of this equation give you?
2. What is the structural difference between a solid that is a crystal and a solid that is not a crystal? Give an example of a crystalline solid. Give an example of a non-crystalline solid.