Spring Semester 2012 – Final Exam

Note:

- Show your work, underline results, and always show units.
- Official exam time: 2.0 hours; an extension of at least 1.0 hour will be granted to anyone.
- Materials' parameters may be looked up from the associated table entitled: "Room temperature properties of Si, Ge, GaAs, and GaN".

1. Indicate if the following statements are true or false:
   (a) Under low-injection conditions, the minority electron concentration injected into the neutral p-type region is much smaller than the majority hole concentration in the neutral p-type region.
   (b) Under high-injection conditions of a pn junction, the current-voltage (IV) characteristic of the pn junction is becoming linear.
   (c) Under low-injection conditions of a pn junction, the IV characteristic of the pn junction is exponential.
   (d) Minority carriers generally have a much shorter lifetime than majority carriers.
   (e) The lifetime of majority carriers can be approximated to be infinitely long.
   (f) In Si, the electron mobility is generally higher than the hole mobility.
   (g) Under normal operation of a bipolar transistor, the BE junction and the CE junction are both operated under forward bias.
   (h) In an n-channel metal-semiconductor field effect transistor (MESFET), the electron channel is pinched off at the drain end of the channel, if $V_{DS} - V_{GS} = V_{PO}$, where V_{GS} is negative quantity and V_{DS} is a positive quantity.
   (i) SiO_2 is a transparent material, because its bandgap energy is greater than the energy of visible light.
   (j) Si is a transparent material, because its bandgap energy is greater than the energy of visible light.

2. Consider an n-channel metal-semiconductor field-effect transistor (MESFET) that is made of n-type GaAs. The MESFET has a metal-semiconductor gate with a length of $L_{Gate} = 1$ μm and a barrier height of $e\Phi_B = 0.8$ eV (can be neglected). The electron channel has an n-type doping concentration of 2×10^{17} cm^{-3} and a channel height of 200 nm and a channel width of 100 μm. Assume that the electron mobility in the channel is 2000 cm^2/(V s).
   (a) Assume that the gate voltage is $V_{GS} = -1$ V and assume that $V_{DS} \approx 0$.
   Calculate the channel resistivity.
   Calculate the channel resistance.
   Draw a diagram of the the IV curve (I_D-versus-V_{DS} curve) to scale. In the diagram, the ordinate, I_D, should range from 0 to 750 mA and the abscissa, V_{DS}, should range from 0 to 7.5 V.

(b) Calculate the value of V_{DS} at which the drain current saturates, i.e. at which the channel is pinched off at the drain end.
Mark the calculated value of V_{DS} in the I_D-versus-V_{DS} curve.

(c) Calculate the drain current at the value of V_{DS} calculated under question (b).
Complete the trace of the I_D-versus-V_{DS} curve for $V_{GS} = -1$ V.

3. Consider an asymmetrically doped Si pn junction with the n-type doping concentration much greater than the p-type doping concentration, i.e. $n >> p$. Assume that $N_D = n = 5 \times 10^{18}$ cm^{-3} and $N_A = p = 1 \times 10^{17}$ cm^{-3}. Assume further that the area of the pn junction is $A = 1$ mm^2.
   (a) Calculate the diffusion voltage of the diode, i.e. V_D (note that the diffusion voltage is frequently called the built-in voltage, i.e. V_{bi})
   (b) Consider an applied voltage that is $0.8 \times V_D$. Calculate the concentration of injected electrons into the p-type neutral region and compare it to the concentration of the hole majority carriers. Is the junction operated under low-level injection or high-level injection?
   (c) For an applied voltage of $0.8 \times V_D$, calculate the electron injection current and the hole injection current. Which of the two currents is larger? Calculate the total current of the pn junction.
   (d) Consider that the pn junction would be used as the Base-Emitter (BE) junction of a bipolar transistor.
   Calculate the emitter efficiency if the n-type layer would be the emitter.
   Calculate the emitter efficiency if the p-type layer would be the emitter.
   If the pn junction would be used as the BE junction of a bipolar transistor, would this transistor advantageously be a pnp transistor or an npn transistor? Explain your choice.

4. Consider an n-type Si sample <u>under thermal equilibrium</u> at 300 K. The donor concentration varies from left to right as $N_D(x) = N_{D0} \exp(-ax)$ (where $N_{D0} = 10^{17}$ cm^{-3} and a = 1 μm^{-1}). Assume that donor concentration equals electron concentration (donors are fully ionized). The electron mobility in this sample is 1200 cm^2/ (V s).
   (a) What is the diffusion constant of electrons in this sample?
   (b) What is the diffusion current density of electrons at x = 0? Plot the diffusion current as a function of distance.
   (c) What is the total current density at any point x in the sample?
   (d) Plot the drift current density as a function of distance to scale.
   (e) Plot the band diagram from $x = 0$ to $x = 5$ μm.
   (f) What is the potential difference between $x = 0$ to $x = 5$ μm.
   (g) What is the direction of electric field? Briefly explain your answer.

5. Assume an npn bipolar junction transistor operating in forward active mode at 300 K has the following properties: μ_n = 1200 cm^2 / (V s) (electron mobility in base); μ_p = 425 cm^2/ (V s) (hole mobility in emitter). The base doping is $N_A = p = 10^{16}/cm^3$ and the base width is W_{Base} = 40 µm. While being fabricated, the device was contaminated, and, as a result, the minority carrier lifetimes are shortened. Assume the minority carrier lifetime is the only parameter of the device affected by this contamination, such that they are greatly reduced to τ_n = 50 ns (electron minority carrier lifetime in base) and τ_p = 100 ns (hole minority carrier lifetime in emitter).

   (a) What is the diffusion length of electrons in the base?

   (b) Assume a low level bias exists such that there is an injected minority carrier concentration in the base (at the emitter end) of 10^{10} /cm^3. Plot a rough sketch of the minority carrier concentration profile in the base and explain the slope of the line. The plot need not be to scale.

   (c) In one or two sentences, please explain qualitatively how the plot in part (b) would look differently if the sample had not been contaminated.