October 10, 2002 - Quiz #1

Name: ______________________________

General guidelines (please read carefully before starting):

- Make sure to write your name on the space designated above.
- **Open book**: you can use any material you wish.
- All answers should be given in the space provided. Please do not turn in any extra material.
- You have **120 minutes** to complete your quiz.
- Make reasonable approximations and *state them*, i.e. low-level injection, extrinsic semiconductor, quasi-neutrality, etc.
- Partial credit will be given for setting up problems without calculations. **NO** credit will be given for answers without reasons.
- Use the symbols utilized in class for the various physical parameters, i.e. N_c, τ, $\mathcal{E}$, etc.
- Pay attention to problems in which *numerical answers* are expected. An algebraic answer will not accrue full points. Every numerical answer must have the proper *units* next to it. Points will be subtracted for answers without units or with wrong units. In situations with a defined axis, the *sign* of the result is also part of the answer.
- If needed, use the doping-dependent Si parameters graphed throughout del Alamo's notes.
- If needed, use physical parameters for silicon at room temperature listed in Appendix B of del Alamo's notes.
- If needed, use the values of fundamental constants listed in Appendix A of del Alamo's notes.

1. *(10 points)* Describe a semiconductor in which Maxwell-Boltzmann statistics cannot be used in thermal equilibrium for *neither electrons nor holes* at room temperature. Explain.

2. *(10 points)* Does the threshold photon energy for carrier generation in a semiconductor depend on doping? Explain.

3. *(10 points)* Consider a Si sample at room temperature whith a dominant trap with a concentration $N_t = 10^{16}\ cm^{-3}$ located at E_i. The electron and hole capture rates for this trap are $c_e = c_h = 10^{-10}\ cm^3/s$.

This sample is placed under intense light illumination that causes the carrier concentrations to become $n = 2 \times 10^{17}\ cm^{-3}$ and $p = 10^{17}\ cm^{-3}$, uniformly in space. Calculate the net recombination rate by as many generation/recombination processes as you can.

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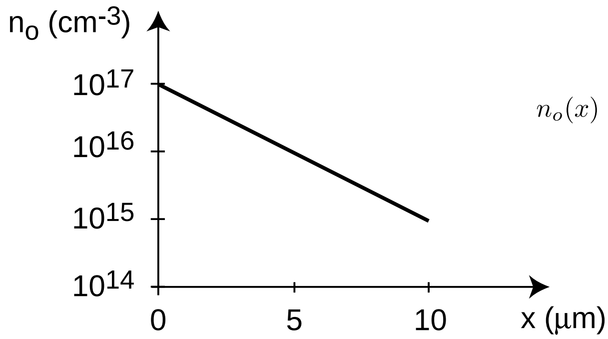
4. *(40 points)* Consider a piece of n-type Si in thermal equilibrium at room temperature. In a region defined by $0 \leq x$ $(\mu m) \leq 10$, there is a spatially varying electron concentration as sketched below.



$$n_o(x) = 10^{17} \times 10^{-2\times10^3 x}\ cm^{-3} \quad \text{with } x \text{ in } cm$$

a) *[10 points]* Derive an analytical equation for the minority carrier concentration in space. *Quantitatively* sketch the result in a suitable diagram.

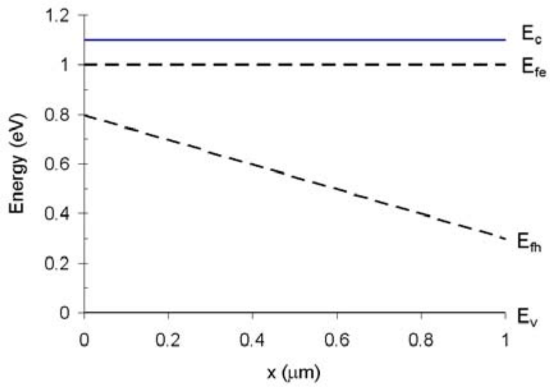
b) *[10 points]* Derive an analytical equation for the electrostatic potential in space. *Quantitatively* sketch the result in a suitable diagram.

c) *[10 points]* Derive an analytical equation for the electric field in space. *Quantitatively* sketch the result in a suitable diagram.

d) *[10 points]* Derive an analytical expression for the charge distribution that supports this electric field. *Quantitatively* sketch the result in a suitable diagram. Can this sample be considered quasi-neutral?

5. *(30 points)* The energy band diagram below corresponds to a region of a Si bar at room temperature next to a surface ($E_c - E_{fe} \simeq E_c - E_F$) under static conditions. The actual semiconductor surface is located at $x = 0$.

In answering the questions below, make whatever assumptions you need to make. State them and justify them clearly.



a) *(5 points)* Circle all the terms that apply to the situation:

- thermal equilibrium/out of equilibrium
- uniformly doped/non-uniformly doped
- n-type/p-type
- low-level injection/high-level injection/extraction
- intrinsic/extrinsic

b) *(5 points)* Estimate the hole current density at $x = 0$ (*numerical answer and appropriate sign expected*).

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c) *(5 points)* Estimate the net recombination rate at $x = 0$ (*numerical answer and appropriate sign expected*).

d) *(5 points)* Estimate the surface recombination velocity (*numerical answer and appropriate sign expected*).

e) *(5 points)* Estimate the electron diffusion current density at $x = 0$ (*numerical answer and appropriate sign expected*).

f) *(5 points)* Estimate the electron drift current density at $x = 0$ (*numerical answer and appropriate sign expected*).