EECS 2077
Semiconductor Devices

2 Carrier Dynamics **Name:_____________________________**

Note, today has lots of problems, and unlike most days, they will likely take you more than the allotted time. Today the Prof. will also need to likely help you get through at least problem 6 during the class period by bringing several groups together if they get stuck.

In-Class Problems

(1) Assume GaAs is doped p-type to p_0=10^{15}/cc, and from a data table you find the e and h lifetimes to be 10^{-8} s.

(a) using $\tau_n = \tau_p = \dfrac{1}{\alpha_r(n_0 + p_0)}$ calculate the lifetime if we increase the doping to p_0=10^{17}/cc. This is easy, you don't need to calculate, solve, or look up any other values since recombination coefficient does not change with doping. You should be able to do this in your head…

(b) next, you shine $2\text{x}10^{20}$ photons/s of light onto 2 cubic centimeters of GaAs. Assume for simplicity, the light is 100% absorbed by the GaAs and it is absorbed uniformly. For the case p_0=10^{15}/cc, calculate the excess hole concentration that is created by the light only.

$$\delta_n(1/cc) = \delta_p = g_{op}\tau_n = g_{op}\tau_p$$

(c) why does the optically generated carriers NOT go to infinite concentration over time? One word answer please!

(d) does this really change the total hole concentration?

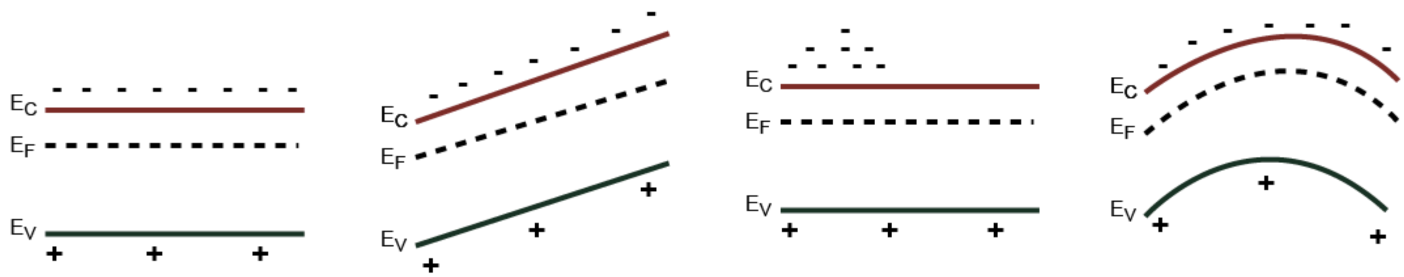
(2) Get comfortable w/ units! Using only the equations below, derive the units for mobility and for diffusion coefficient.

$$J_n(drift) = q\mu_n n(x)\ \mathrm{E}(x) = A/cm^2 \qquad J_n(diffusion) = qD_n \frac{dn(x)}{dx} = A/cm^2$$

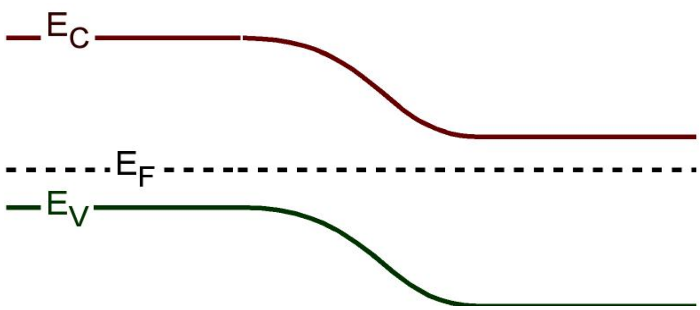
(3) Draw a chunk of n-type semiconductor, for simplicity, just draw a rectangle with maybe a dozen electrons in it. Next, apply positive voltage on the left side and ground on the right side, and redraw it again. Here is the key question: will the electrons move all the way to one edge as an infinitesimally thin layer, or not, and why?

(4) Draw each band-diagram below and diagram/label the: (a) direction of flow of carriers; (b) the current type (drift or diffusion, majority or minority current); (c) voltages applied with +/- signs to show polarity. In some cases you may not have to label some, or any, of these. Remember, the soda-pop analogy, the electrons are like water and a hole is the absence of an electron (a bubble), and the bands are like 'tarps' that guide both of these as they try to flow down or float up. ★

Hint – flat bands means NO E-field effectively, sloped bands means E-field is present. You cannot have drift current without E-field!



(5) Next…. Do you ALREADY know enough to understand when a diode is forward or reverse biased? I think so! Remember, forward biased, lots of current, reverse biased almost no current. You can figure it out already! Below is a band-diagram for a diode made of p-type and n-type material that has been joined together. We will talk more about how band forms later. However, for now…



(a) draw the band-diagram above, which is for ZERO voltage on the diode.

(b) next, draw where you expect to see lots of electrons and holes, and where you expect to see very few electrons or holes. For example, for lots, maybe draw 12 carriers, and for very little, draw 3 (knowing of course, that the real difference is orders of magnitudes!).

(c) now, apply POSTIVE voltage on the left (assume right side is grounded), it should push the bands on the left side of the diode downwards and therefore reduce the amount of band bending in the middle... As you keep applying more and more positive voltage assume you can make the bands all flat, and then remember all the carriers that you drew before… will a very small or a large current start to flow, and is the current DRIFT or DIFFUSION?

(d) now, apply NEGATIVE voltage on the left (assume right side is grounded). As you keep applying more and more negative voltage, will a very small or a large current start to flow, and is the current DRIFT or DIFFUSION?

(6) In this course, you will learn possibly more than ever to TRUST units to guide you through a problem. Here is a simple example. Drift current density or diffusion current density (J) both have units of A/cm^2.

(a) First, lets turn current density into a particle flux F (flux of electrons or holes)… I will describe here how to do it: Flux is has units of simply particles (or number of anything) per unit area per second (1/cm^2-s) you can simply divide J by q which gets rid of the coulomb (C) in amps (C/s), and will give you flux (F).

(b) Now, you figure out the next part. Lets say you want to know how fast (velocity), in cm/s, an electron or hole is moving due to drift or diffusion. What ONE term would you multiply or divide flux by to achieve velocity? It is a term we are already using a lot in this course… Trust units! It will also make sense once you figure it out (think of a highway, with a density of cars, for a constant 'flux' of cars if the density of cars increases then their velocity has to increase to maintain the same flux of cars…).

(7) A Si bar 0.1 cm long and 100 μm^2 in cross-sectional area is doped with 10^{17} boron, resulting a mobility for holes of 500 (cm/s)/(V/cm).

(a) What is the DRIFT current (current I_p, not current density J_p) with 1V applied?

(b) The calculation you did above, was this a steady state calculation or thermal equilibrium calculation?

(8) [5 pts] As you increase p-type doping in a Si wafer….

(a) does the lifetime for electrons (τ_n) increase or decrease? One sentence max.

(b) as you increase doping, the diffusion length for electrons (L_n) decreases, one reason is because mobility (μ_n) decreases as there are more carriers to 'bump into' which decreases diffusion co-efficient ($D_n = \mu_n kT / q$), just like a crowded hallway, you can't walk as fast down it! What is the other reason why diffusion length decreases? Hint – look at the equation for diffusion length.