EE724: HW 5:

Q1: For a forward and reverse bias pn junction, (10)

a) Solve for IV
b) Find out the Efn and EFp profile. Does it match figure in books?
c) Draw the resistive network representation.

Q2. In a PN junction, we will discuss the derivation and features of recombination and generation current (20)

a) Draw the PN junction band diagram (for symmetric uniform PN junction) in forward and reverse bias along with E_{Fn} and E_{Fp} (assume that they are flat in depletion region- Is this accurate?)
b) Draw the electron and hole concentration for forward and reverse bias compared to equilibrium
c) Plot recombination current $J_R(x)$. Where is the max recombination in forward bias? Calculate the total current by integration as given in the slide 4 (PN Junction Lecture 4). What is x_c? Explain in 1-2 sentence the reason for ideality η=2 dependence? When will recombination current be equal to ideal current?
d) Where is the max generation in reverse bias?

Q3. In a PN junction, we will discuss the derivation and features of high level injection (30)

a) In a one sided junction n+ uniform doping of 10^{20}/cc and p uniform doping of 10^{15}/cc; draw equilibrium band diagram. Guess the positions of the Fermi levels on p and n sides by inspection and estimate the Fermi level.
b) small forward bias (0.1V - done before), large forward bias (0.7V- this is a guess assuming that band bending is only in depletion region) band diagram
c) in log scale draw n(x) and p(x) for both cases;
    a. In low forward bias, in the quasi-neutral p-region, there is excess $n(x)>n_{po}$, If an electric field is created, can it be maintained? What charges will respond quickly to the electric field – electrons, holes or dopants? Once these charges have responded, will any significant electric field remaining? What is the condition for charges that will produce zero electric field? Will there be any significant bending in the E_{Fp} or E_c?
    b. In high forward bias, in the quasi-neutral p-region, there is excess $n(x)>p_p>>n_{po}$, If an electric field is created, can it be maintained? What charges will respond quickly to the electric field – electrons, holes or dopants? Once these charges have responded, will any significant electric field remaining? What is the condition for charges that will produce zero electric field? Will there be any significant bending in the E_{Fp} or E_c? Assume that only E_c is bending, what is the extent of bending based on quasi neutrality? What is the

extent of reduction on n(x) due to this E_c bending? How does this affect the forward bias current- comment on the ideality η?

c. What is the condition for beginning of high-level injection?
   i. Will low doping cause earlier low level injection? What is the relation between doping and onset of high level injection?
   ii. Reducing doping increases mobility but affects high level injection. If the goal is to increase on-current at 1V, what will be the considerations and choice of doping?

Q4. (this is a difficult problem that makes you apply now familiar principles and strategies to the a new scenario)

In an n+/p/n+ diode device where electrodes are only connected to the n+ regions, p region is 10^{18}/cc doped. (20+20)

(a) if p region length is 1mm, draw the equilibrium band diagram and at 0.3V bias

- on which junction (f.b. or r.b.) will the voltage primarily drop? Why? There is a circuit picture- can you think of this as 2 diodes in series- in this case the same current must pass through both. Based on knowing the IV for the 2 diodes, what is the method of estimating current graphically?
- Now think of the microscopic picture- draw the quasi-Fermi levels. What are the relative differences in E_{Fn} (compared to equilibrium values) at the two edges of p-region? What determines these values? What is the shape of E_{Fn} if there on no RG? If there is RG?
- Estimate the current – comment on the dependence on p-region length and bias.
- Plot current Jn(x) across the device. Plot n(x). Verify the shape of E_{Fn} you have chosen.

(b) if p region length is 10nm, draw the equilibrium band diagram

- on which junction (f.b. or r.b.) will the voltage primarily drop? Why? There is the above circuit picture- can you think of this as 2 diodes in series- in this case the same current must pass through both. Is this valid here- comment on its extent of validity?
- Now think of the microscopic picture- draw the quasi-Fermi levels. What are the relative differences in E_{Fn} (compared to equilibrium values) at the two edges of p-region? What determines these values? What is the shape of E_{Fn} if there on no RG and If there is RG?
- Estimate the current – comment on the dependence on p-region length and bias. Remember, we always try to find a place where only diffusion occurs- will this strategy work here?
- Plot current Jn(x) across the device. Plot n(x). Verify the shape of E_{Fn} you have chosen.
- A simple estimation is that given a barrier, the Fermi function at the source causes an exponential current. Comment on how your detailed E_{Fn} based IV calculation differs from this.