EE724: HW 3: 2019

1. Here is an exercise in research problem definition and solution. Given the following [paper1](https://drive.google.com/open?id=0B6Vw29Er5yFHbTNKb3pxVTJiQTQ&authuser=0), and [paper2](https://ieeexplore.ieee.org/document/7946118), please review the paper1 in your HW teams and answer the following questions. Here is a brief [method](http://ccr.sigcomm.org/online/files/p83-keshavA.pdf) of reading technical papers. The goal is to efficiently read a technical paper on a topic that you understand and critically assess its strength and weakness.
   1. Write down the flow chart of the papers – essentially 1-2 line summary of each section from say background or challenge, problem statement, proposal, validation and impact of solution.
   2. Write down the assumptions of the analytical model proposed and comment on their validity
   3. Write down the proof of the solution presented. Comment on why it is credible and what is not?
   4. Comment on the “benefits” of the paper that is highlighted at the end – this is the “so what” question or what is the value of the analysis.
   5. Comment on YOUR extent of understanding of the paper based on concepts covered in class.
   6. Repeat (e) the same analysis for paper 2.

If there are any terms or ideas that are unclear, please post on moodle for TA / peer / faculty response.

1. **Carriers in Equilibrium:** Assume a parabolic conduction band with m\*=0.5mo with band edge at E=Eo at 300K;
   1. Please plot parabolic band E(k);
   2. If EO-EF=0.4eV, please use MATLAB to plot E vs f(E) i.e. probability function to compare Fermi Dirac vs Boltzmann distribution on the same plot in linear and log-linear scale;
   3. For same EO-EF=0.5eV, please plot E vs n(E) for numerical integration using FD statistics (remember analytical integration is not easy for FD statistics)
   4. Please repeat b-c for EO-EF=0.05eV,
   5. Please compare with MB approximation based analytical integration plots vs FD statistics based accurate numerical integration plots for E vs n(E) for the above case of EO-EF=0.5V and 0.05eV
   6. Can you tell at what EO-EF is there a 10% root mean square (RMS) difference in n(E) between FD and Boltzmann Distributions?
2. For a pn junction, linear doped at N(in /cm3)=1023 (cm4) \* (x in cm), where is x is distance from the metallurgical junction. Draw the band diagram in equilibrium using depletion approximation. Based on this, derive the free carrier charge profile as a correction to depletion approximation (plot it in Matlab semilogy scale). Calculate the potential profile correction to depletion approximation in the first *iteration*. Plot the percentage error vs x to indicate the sensitive regions.

1. For the following devices, write down the steps including assumptions to draw the band diagram. Draw charge (all components in linear and log scale), E field, V profiles and band diagram (including vacuum level) step-wise for (a) and (b) following the above methodology. For (a) calculate the doping to get 0.6V barrier height at zero bias. For (b) how can we engineer the barrier height to 0.5V without increasing the doping of any region. Can we device an analytical equation for the potential profile for (b) – this is a difficult problem- let us see how far you can proceed.

Comment on the critical similarities and difference between (a) and (b) band diagrams.

If the Si i-region in (b) is replaced with SiO2, how will the band diagram look? Use the above methodology to derive. State the physical properties of SiO2 used.



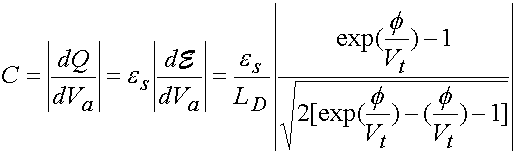
1. Take a pn junction with doping of 1017/cc on both sides.
   1. Using the depletion approximation, calculate the equilibrium band profile, electric field and charge (free carrier & ionic charge) analytically.
   2. For the exact solution, add the dominant free carrier term in the Poisson’s equation.
   3. Following MOSCAP derivation trick used in Ch 2.3.2.1 Taur and Ning, express the Poisson’s equation in terms of electric field related to φ where φ(x) = EC(x) –ECO, which is band bending. Integrate from x=0 (junction) to infinity (deep in the semiconductor) where we set φ to be zero. What is the value to E at infinity? Express electric field E in terms of *φ* and debye length, LD

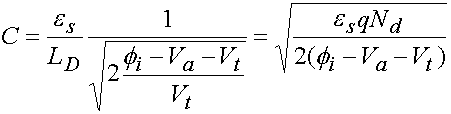
Show that for φ <0 and |φ/Vt|>>0; it tends to depletion approximation; Annotate φ in the band diagram.

Show that for φ <0 and |φ/Vt|~0; then φ has an exponential dependence on x.

Also note that getting φ(x) from this point looks analytically difficult. However, numerically this can be done. Please write down your strategy in maximum 10 sentences for a numerical solution.

* 1. Knowing electric field vs φ, show that the capacitance (on one side of the pn junction) is given by



* 1. If φsis the potential across the semiconductor depletion and equals -φ i+ Va. This expression can be approximated for φs< 0 and |φs| >> Vt ; show that 

Compare with full depletion approximation.

1. For numerical simulations of Poisson’s equation
2. Derive the linearization of the Poisson equation for a semiconductor with NA and ND doping (as done in class)
3. Derive the formulae for α, β in LU decomposition; find the recursive relations used to solve for V given the Poisson’s equation in matrix form
4. Review the Matlab code provided to do the following
   1. Find where the device structure is defined in the code. Ensure that the code is set for pn junction with NA=ND=1017/cm3. Run it. Plot analytical results on the same figure (using “hold on” command) and comment on the main locations of deviation from depletion approximation. Comment on the observed shape of the n and p profiles and the potential profile. Justify the observation.
   2. Modify for pn junction with NA=10\*ND=1017/cm3. Run it. Compare the V-profile compared to (1). Notice a notch in the charge profile- justify.
   3. Find the boundary conditions and justify
   4. Find the mesh definition terms and comment on the validity of the choice of uniform mesh size. Can the number of mesh-points be reduced without affecting the validity of the meshing?
   5. Comment on the error in the initial guess solution that must be corrected by the interactions
   6. Can you implement a different initial guess to see if the solution is initial condition dependent? E.g. we have used a step function. How about testing with another function – linear function of potential with the boundary conditions correct. Or Flat potential profile with steps at the edges.
   7. For the original code provided, modify it for part 4 (a) npn and (b) nin and plot the profile by commenting out certain sections of the code and uncommenting out others). For (a), compare the analytical plot with numerical plot of V-profile on the same plot. Comment on the difference. Also vary the doping of the p-region from 1015 to 1020/cc in factors of 10. Visually extract barrier height vs doping. Comment on the doping when carrier height starts increasing significantly. Provide a justification why this occurs at the specific doping.

For (b) plot the numerical plot. How close is this compared to your expectation? If you vary the n region doping from 1020 to 1015 /cc in factors of 10, plot the visually extracted barrier height vs. doping. Justify the observed trend. How is this related to the potential profile of SiO2 between n+ contacts as given in Q5 MOSCAP last part.