EE 735 Assignment 3

Simulating Diffusion and Turn-Off Transient of PN Junction Diode

Non Extendible Deadline: 22 Feb 2025 11:59 pm(100% Penalty for Late Submission)

Implement all codes using Python

Hints, assumptions, and instructions:

1. Please define all input variables at the beginning of your code and use proper comments while developing the code. Your code must work for other input values too.
2. It is mandatory to submit your code along with the report (in pdf) in a single zip file. Name the file `EE735_A3_RollNo_Name` for this assignment.
3. Reference for the assignment:
    - Vasileska, D., Goodnick, S. M., & Klimeck, G. (2017). Computational Electronics: Semiclassical and Quantum Device Modeling and Simulation. Chapter 4, Sections 4.1.1 to 4.1.7.
    - Plummer, J. D., Deal, M., & Griffin, P. B. (2000). Silicon VLSI Technology: Fundamentals, practice and Modeling. Chapter 7.
    - Pierret, R. F. (1996). Semiconductor device fundamentals. Chapter 8.
    - Muhammad A. Alam (2009), "ECE 606 Lecture 24: Large Signal Response," `https://nanohub.org/resources/6498`.

Problems

Question1

Simulating a P-N junction diode.
Consider a P-N junction diode in equilibrium with thickness of the P and N regions is L = 1 μm each. For an abrupt junction with dopant concentrations $N_A = 1 \times 10^{16} cm^{-3}$ and $N_D = 1 \times 10^{16} cm^{-3}$. Use $n_i = 1.5 \times 10^{10} cm^{-3}$. Plot the following considering no depletion approximation:

A. Potential (V)

B. Electric Field(E)

C. Charge concentration (ρ)

D. Electron (n) and hole (p) concentrations

E. Energy band diagram

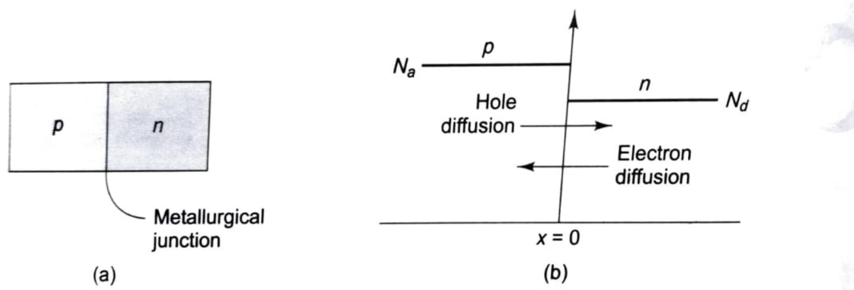

Fig. 6.1 *(a) Simplified geometry of a pn junction (b) Doping profile of an ideal uniformly doped pn junction*

Figure 1: An Abrupt PN Junction Diode

Question2

Steady state diffusion.

In this question, we will model the steady state diffusion equation which is also known as time independent diffusion equation. This is defined by the equation.

$$D \cdot \frac{\partial^2 n}{\partial x^2} = \frac{n}{\tau}$$

Consider a region of length $10\mu m$ from point A (x= $0\mu m$) to point B (x= $10\mu m$). Assume $\tau = 10^{-7}s$ and $D = 0.1cm^2/s$. Carry out the following simulations:

A. For diffusive transport of particles from point A to point B. The concentration of particles at A is $n = 10^{12}cm^{-3}$, and at B is $n = 0cm^{-3}$. Plot the particle profile and flux from A to B.

B. Now, we introduce continuous particle flux at $x = 5\mu m$ at the rate of $10^{13}cm^{-2}/s$. Assume that the particle densities at points A and B are held constant at n=0. Plot the particle profile and flux from A to B. Also, compare the obtained profiles with the analytical solution.

Question3

Transient diffusion.

In this question, we will model the transient diffusion equation which is also known as time dependent diffusion equation. This is defined by the equation.

$$\frac{\partial n}{\partial t} = D \cdot \frac{\partial^2 n}{\partial x^2}$$

Consider a region of length $10\mu m$ from point A (x= $0\mu m$) to point B (x= $10\mu m$). Assume that the region is devoid of any particles at time t=0. Take $D = 2 \times 10^{-5}cm^2/s$. Carry out the following simulations:

A. Consider that particles are injected midway at $x = 5\mu m$ such that the density is $10^{10} cm^{-3}$ at the location. The injection is a delta function in both space and time. Consider perfectly absorbing boundary conditions at A and B, at time t = 0. What value of Δt should we take? Plot the evolution of the particle density profile. Plot the evolution of particle density with time in the material. Compare with analytical solution. How does the evolution of particle density change as we change the value of Δt? What is the significance of the quantity $\sqrt{Dt}$?

B. At point A, particles are injected in such a manner that particle density at A is a constant $500 cm^{-3}$ in time. At point B, we have a perfectly absorbing boundary condition. Solve for the diffusion of particles from the side x=0 as a function of time. Compare the numerical solution with the analytical solution.

Question4

Turn-off Transient of PN Junction Diode

Consider the same p-n junction diode defined in Question1 of the assignment. Consider that a voltage of 1V is applied in forward bias for a long period of time and then a voltage of 1V is applied in reverse bias at time, t=0. Plot the decay profile of stored hole charge in the PN junction diode as a function of time from the edge of depletion region (of N-side) to the end of diode. Also, estimate an approximate value of storage time (t_s).

Use the following constants: $n_i = 1.5 \times 10^{10} cm^{-3}$, $\mu_p = 450 cm^2/s$, $\tau_p = 20\mu s$, $J_R = 2KA/cm^2$.

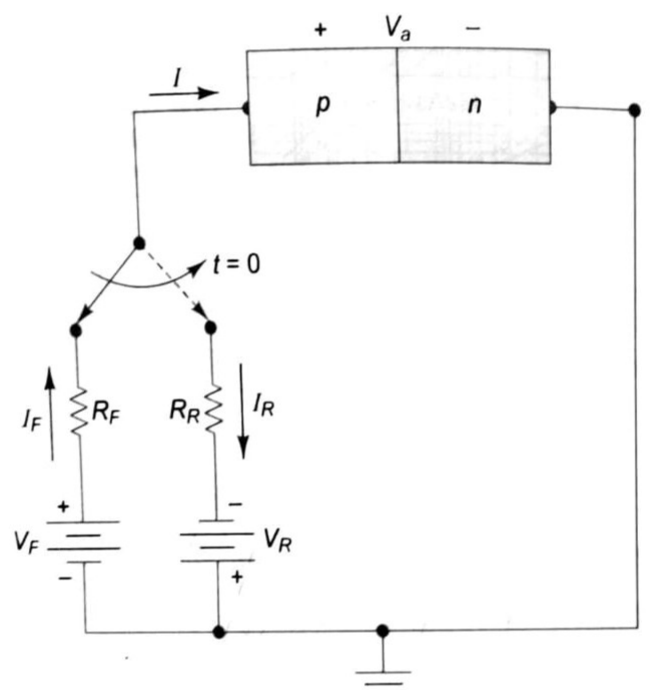

Figure 2: A simple circuit for switching a diode from FB to RB

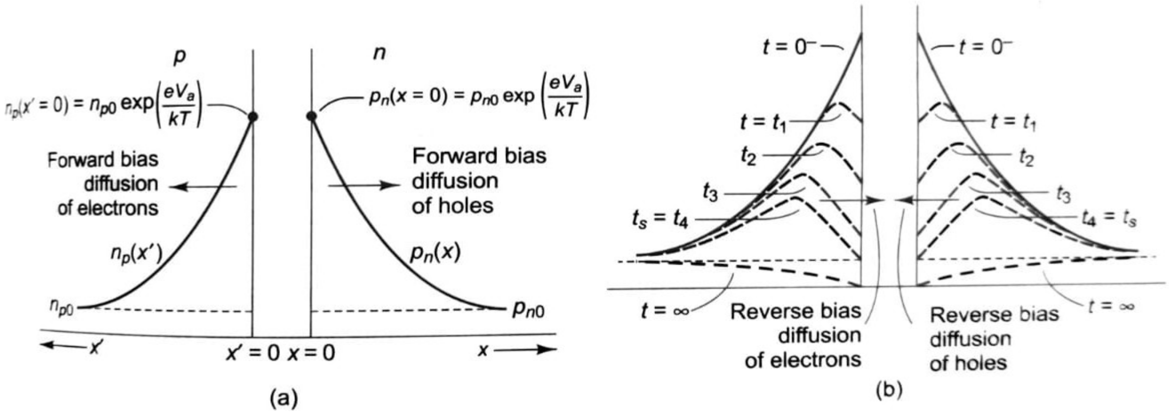

Figure 3: (a)Steady state forward bias minority carrier concentration and (b) minority carrier concentration at various times during switching

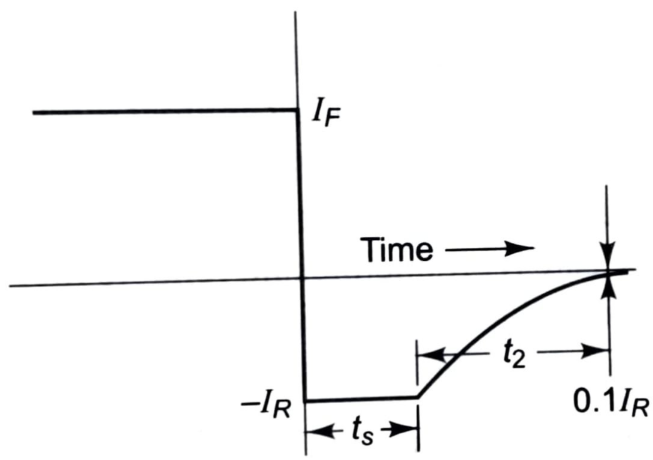

Figure 4: Current transient during switching

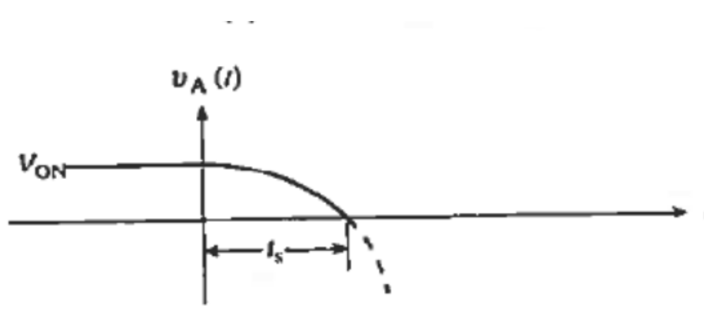

Figure 5: Voltage transient during switching