
EE566 Solid State Devices

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Dept of Electrical Engineering
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Assignment 5

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Reading: Chapters 4 & 5 of the Textbook (MS).

Problem 1[*] (Designing the Voltage Blocking Capability of Diodes)
Solve Problem 4.34 from the TextBook (MS).

Problem 2 (p-n Junction Currents – Practice Problem)
Consider a GaAs p-n junction. The relevant parameters are $N_d=N_a=10^{18}/\text{cm}^3$, $\tau_n=\tau_p=10\text{ns}$, $D_n=100\text{cm}^2/\text{s}$, $D_p=20\text{ cm}^2/\text{s}$, and breakdown field $F_{BD}=400\text{kV/cm}$. Do the following –

a) Plot the charge-field-band diagram at zero bias. Compare with a 1D Poisson simulation.
b) Sketch the mobile charge (both majority and minority) density vs distance at a forward bias of 0.4 Volt.
c) Sketch the electric field and the band diagram (with quasi Fermi levels) at this forward bias.
d) Sketch the corresponding current densities (diffusion and drift components for both n- and p-type carriers) as a function of distance at 0.4 Volt forward bias. Find the total current density flowing across the junction.
e) Repeat the above sketches for a reverse bias of -5 Volts.
f) Find the reverse bias at which the p-n junction will break down.

Problem 3 (Current Flow in Heterojunction Diodes)
Instead of a homojunction diode, let us see what happens if a heterojunction is used as the emitter. The doping density in a GaAs based heterostructure p-n junction is $N_D=10^{17}/\text{cm}^3$ and $N_A=10^{16}/\text{cm}^3$. Design the emitter-base junction by introducing $\text{Al}_x\text{Ga}_{1-x}\text{As}$ in the emitter layer, such that the total current in the diode improves by a factor of $\eta=100$ than the normal GaAs p-n junction. Work out the following -

a) Solve the zero-bias p-n junction problem and determine the depletion thicknesses on both sides.
b) Design your emitter layer such that there are no spikes that impede the current flow. Make generous use of 1D Poisson.
c) Explain why the depletion-edge in the emitter should encompass the whole change in the bandgap, ΔE_G.
d) What are the advantages of the heterojunction over the homojunction? What are the disadvantages?

Problem 4 (Recombination Currents in The Space-Charge Region)
Consider a forward-biased p-n junction. Sketch the distribution of electron and hole current densities across the junction if there is significant recombination in the space-charge (depletion) region. Assume that the injected hole current is *twice* the injected electron current, and the recombination rate inside the space-charge layer is *half* the recombination rate of electrons in the p-type region.

Demonstrate that the total diode current is given by adding a term that describes the space-charge recombination current to the sum of diffusion currents at the edge of the (space-charge, or) depletion region.

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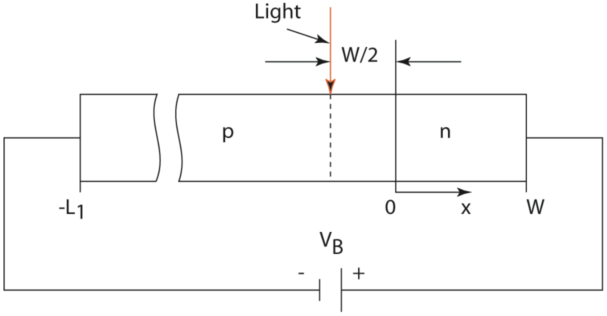
[*] Remember to use proper units and label every figure/plot. Turn in your answers worked out neatly. Please attach this question sheet to your solution when you turn it in.

Problem 5 (Generation/Recombination Currents)



A p-n junction has the configuration as shown in the figure above. Assume the following –

1) $N_a = N_d = N_0 >> n_i$,
2) $W << L$, the minority carrier diffusion length, and $L_1 >> L$.
3) All diffusion constants = D, all lifetimes = τ.
4) The space-charge (or depletion) region thickness << W.
5) The external reverse bias is V_B, which is much larger than the built-in voltage of the p-n junction.
6) The *excess* minority carrier density at $x = W$ is zero.

A beam of light is incident *on a plane of negligible width* on the p-side at a distance $W/2$ from the junction. It produces G_0 electron-hole pairs per unit area per unit time in the plane. Note the units carefully – G_0 is in $(\text{cm}^2.\text{s})^{-1}$.

a) Assuming low-level injection, find and sketch the minority-carrier concentrations in the neutral regions of the diode.
b) Calculate the current that flows in the illuminated diode in terms of G_0 and the diode properties.
c) In terms of the constants associated with the diode, what current flows when the light beam is removed (in steady-state conditions)?

Problem 6 (Storage delays in p-n junction rectifiers)

An ideal short-base Silicon n+-p diode has $N_d >> N_a$ and $N_a = 10^{17}/\text{cm}^3$. The width of the p-region from the edge of the depletion region to the p-contact is $W_B = 3\mu\text{m}$. The area of the diode is $A = 10^{-5}$ cm^2. Assume that the n-region is degenerately doped, and use reasonable values of any constants you need.

a) Calculate the charge stored in the neutral p-region if I= 0.5mA flows through the diode.
b) Determine the charge stored in the narrowed depletion region under forward bias.
c) How much time does it take a current source of 0.5mA to cause the diode to switch from an off condition (V_a=0) to the steady state with 0.5 mA of current?