# EE566 Solid State Devices

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**Assignment 5**
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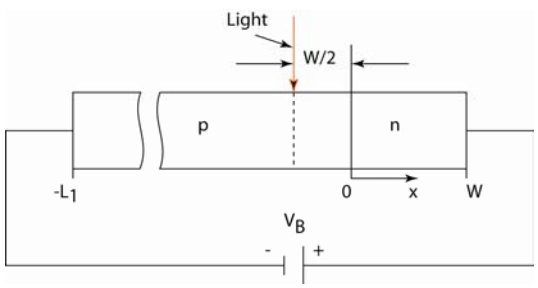
Due: 02/27/2006

**Reading**
Chapter 4 of textbook.
Note: This assignment has 3 problems in 2 pages.

**Problem 1 (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 = $\tau$.
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 $(cm^2.s)^{-1}$.

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 G0 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 2 (Long and Short base p-n junction currents)**
We will henceforth call the heavily doped side of an asymmetrical p-n junction as the *EMITTER*, and the lightly doped side the *BASE*, to prepare for the jargon used in bipolar transistors. Consider an ideal $n^+$-$p$ junction made of GaAs ($N_D=2.10^{17}/cm^3$, $N_A=10^{15}/cm^3$) at 300K. Assume that the minority carrier lifetime of electrons in the p-side and holes in the n-side is $\tau_n=\tau_p=0.2\mu s$. Look up data sheets for anything else you might need.

a) Calculate the saturation current density $J_0$ for the diode (current density is $J= J_0[\exp(V/V_{th})-1]$).
b) *Sketch* the minority and majority carrier profiles outside the depletion region at zero bias, and at a forward bias of $V$=0.5Volt. Label length scales (diffusion lengths, etc). (over…)

c) Calculate and *sketch* the electron and hole current components (both diffusion and recombination) outside the depletion region as a function of distance at this forward bias. Which carriers (minority or majority) dominate the current flow on each side of the junction?

d) Redo parts a) to c) for a *short-base* diode, with the *total* base width (thickness of the p-side) $W_B=2\mu m$. Verify that $W_B << L_n$, where $L_n$ is the minority carrier diffusion length in the base. Make reasonable approximations (linearize slow exponentials, etc) to simplify the problem.

e) Finally, what we are waiting for – when is the current larger – for long base or short base? Can you explain intuitively why this must be so?

**<u>Problem 3</u> (Heterojunction currents)**

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 $N_D=10^{17}/cm^3$ and $N_A=10^{16}/cm^3$. Design the emitter-base junction by introducing $Al_xGa_{1-x}As$ 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, $\Delta E_G$.

d) What are the advantages of the heterojunction over the homojunction? What are the disadvantages?