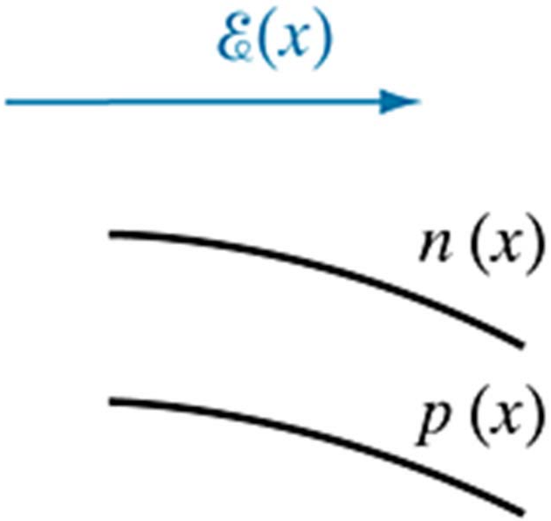
Tutorial - 3

Carrier Transport

(1) For the given carrier profile and E-field, determine the direction of fluxes and currents.



ϕ_p (diff.) and ϕ_p (drift)

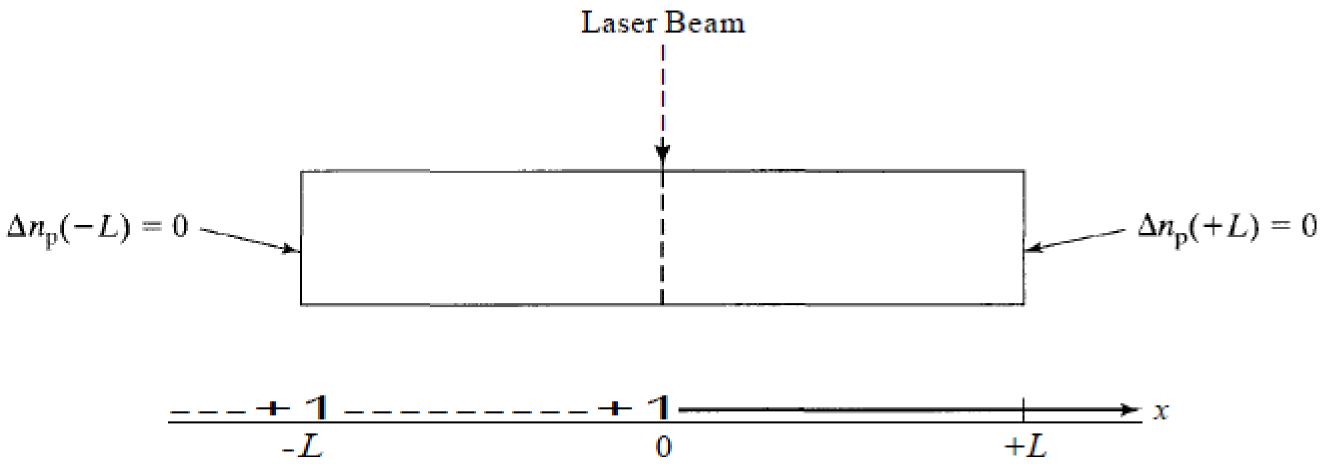
J_p (diff.) and J_p (drift)

ϕ_n (diff.)

ϕ_n (drift.)

J_n (diff.)

J_n (drift.)



6.7 A laser beam striking a uniformly doped p-type bar of silicon maintained at room temperature causes a steady state excess of Δn_p = 1011/cm^3 electrons at x = 0. Note that the laser-induced photogeneration only occurs at $x = 0$. As pictured in Fig. P6.7, the bar extends from $x = -L$ to $x = +L$ and $\Delta n_p(-L) = \Delta n_p(+L) = 0$. N_A = 1016/cm3 and $\mathscr{E} \cong 0$ inside the bar.

(a) What are the dominant physical processes that determine the steady-state excess electron concentration $[\Delta n_p(x)]$ in the regions of the bar removed from x = 0? Your choices are drift, diffusion, recombination, and generation.

(b) Sketch the expected general form of $\Delta n_p(x)$ inside the bar $(-L \leq x \leq L)$ under steady state conditions.

(c) Does low level injection exist under steady state conditions? Explain.

(d) Reduced to the simplest possible form, write down the equation that must be solved to determine $\Delta n_p(x)$ for $0 < x \leq L$.

(e) What is the general solution to the part (d) equation?

(f) What are the boundary conditions that must be applied in solving the part (d) equation to determine the solution constants?

(g) Complete the solution by applying the boundary conditions to obtain $\Delta n_p(x)$ for $0 < x \leq L$.

(h) What is the limit of the part (g) solution if $L \rightarrow$ oo ?

(i) What is the limit of the part (g) solution if $L \ll L_N$, where $L_N \equiv \sqrt{D_N \tau_N}$ is known as the minority carrier diffusion length?

6.8 A short n-type GaAs bar of length L (see Fig. P6.8) is subject to a perturbation such that, under steady-state conditions,

$$\Delta p_n(x) = \Delta p_{n0}(1 - x/L) \qquad \ldots 0 \leq x \leq L$$

The GaAs bar is uniformly doped with $N_D = 10^{16}/\text{cm}^3$ donors *and* $N_A = 5 \times 10^{15}/\text{cm}^3$ acceptors, $\Delta p_{n0} = 10^{10}/\text{cm}^3$, and $T = 300$ K.

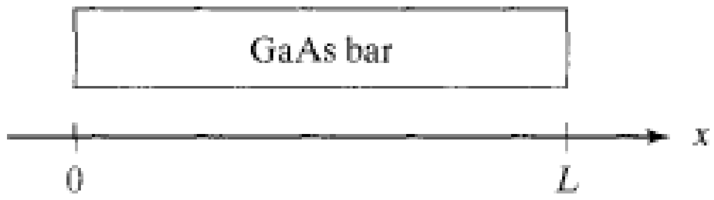


Figure P6.8

(a) Characterize the bar under *equilibrium* conditions by providing numerical values for (i) n_i, (ii) n_0, and (iii) p_0.

(b) Does the cited perturbed state correspond to a "low level injection" situation? Explain.

(c) For the given perturbation it is reasonable to assume $\mathscr{E} \simeq 0$ everywhere in the bar. Given $\mathscr{E} \simeq 0$, sketch the energy band diagram for $0 \leq x \leq L$ specifically including E_c, E_i, E_v, F_N, and F_P on your diagram. Only the rough positionings of F_N and F_P are required.

(d) (i) There must be a hole diffusion current in the bar. Explain why in words.
(ii) The hole drift current should be negligible compared to the hole diffusion current. Explain why.
(iii) Establish an expression for the hole current density.

(e) Show that the $\Delta p_n(x)$ quoted in the statement of the problem can be obtained by assuming R–G center recombination–generation and "other processes" are negligible inside the bar, solving the simplified minority carrier diffusion equation, and applying the boundary conditions $\Delta p_n(0) = \Delta p_{n0}$, $\Delta p_n(L) = 0$.

6.4 The energy band diagram pictured in Fig. P6.4 characterizes a Si sample maintained at room temperature. Note that $E_F - E_i = E_G/4$ at $x = \pm L$ and $E_i - E_F = E_G/4$ at $x = 0$.

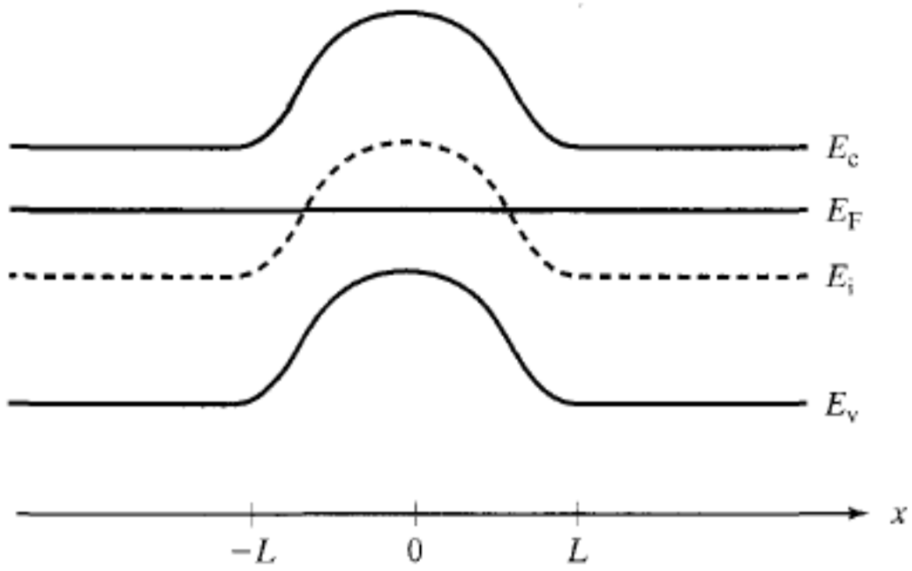


Figure P6.4

(a) The semiconductor is in equilibrium. How does one deduce this fact from the given energy band diagram?

(b) What is the electron current density (J_N) and hole current density (J_P) at $x = \pm L/2$?

(c) Roughly sketch n and p versus x inside the sample.

(d) Is there an electron diffusion current at $x = \pm L/2$? If there is a diffusion current at a given point, indicate the direction of *current* flow.

(e) Sketch the electric field ($\mathscr{E}$) inside the semiconductor as a function of x.

(f) Is there an electron drift current at $x = \pm L/2$? If there is a drift current at a given point, indicate the direction of current flow.

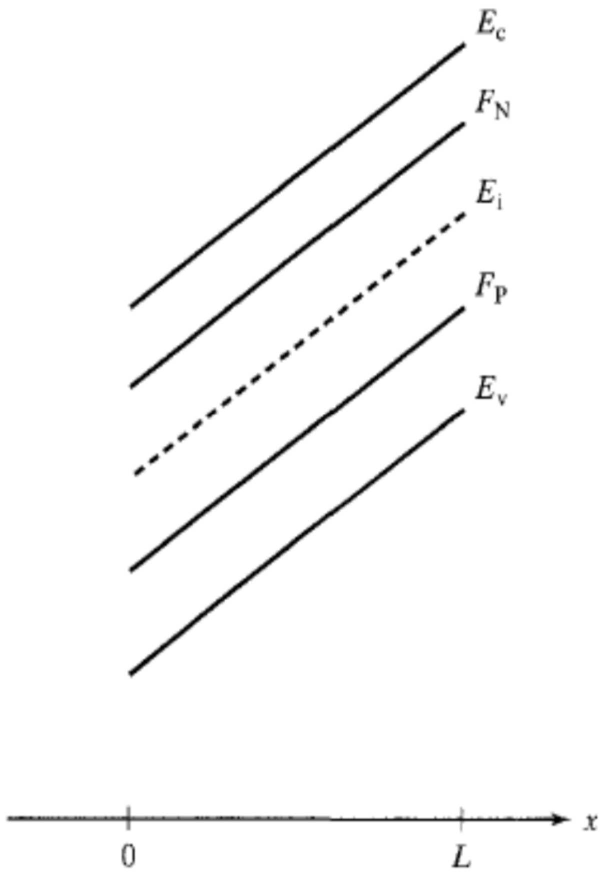
6.5 The energy band diagram characterizing a uniformly doped Si sample maintained at room temperature is pictured Fig. P6.5.

(a) Sketch the electron and hole concentrations (n and p) inside the sample as a function of position.

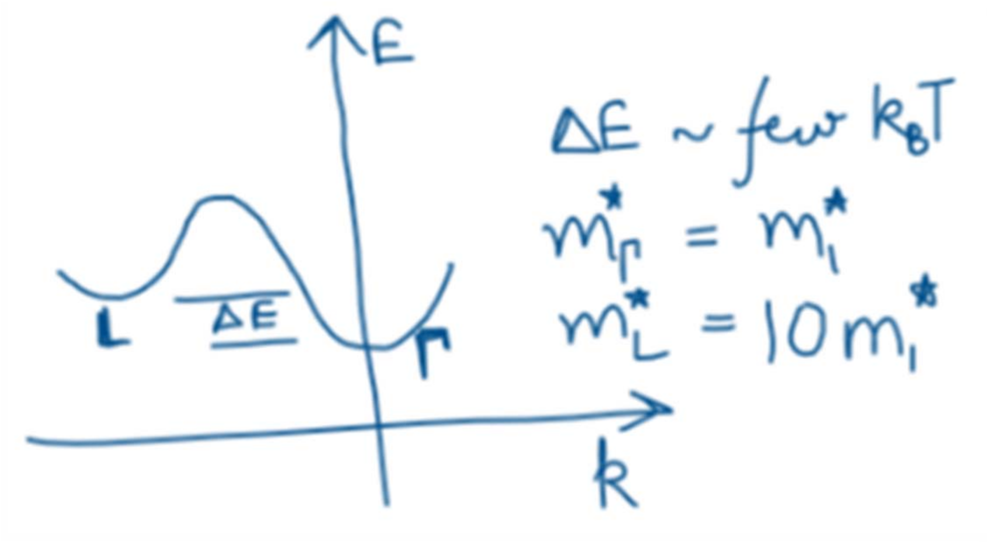
(b) Sketch the electron and hole diffusion current densities ($J_{N|diff}$ and $J_{P|diff}$) inside the sample as a function of position.

(c) Sketch the electric field ($\mathscr{E}$) inside the semiconductor as a function of position.

(d) Sketch the electron and hole drift current densities ($J_{N|drift}$ and $J_{P|drift}$) inside the sample as a function of position.



(5) For a semiconductor with the shown E-K, plot qualitatively the drift velocity as a function of electric field



Bonus part: Can you find the field at peak drift velocity.
What knowledge is necessary for that?

6.10 Consider a nondegenerate, uniformly doped, p-type semiconductor sample maintained at room temperature. At time $t = 0$ a pulse-like perturbation causes a *small* enhancement of the MAJORITY-carrier hole concentration at various points inside the sample. We wish to show that the perturbation in the hole concentration $[\Delta p(t)]$ will decay exponentially with time and that the decay is characterized by a time constant $\tau = \varepsilon/\sigma = K_S\varepsilon_0/q\mu_p N_A$. τ is referred to as the *dielectric relaxation time*—the time it takes for majority carriers to rearrange in response to a perturbation.

(a) Write down the continuity equation for holes. (Why not write down the minority carrier diffusion equation for holes?)

(b) Write down the properly simplified form of the hole continuity equation under the assumption that R–G center recombination–generation and all "other processes" inside the sample have a negligible effect on $\Delta p(t)$.

(c) Next, assuming that diffusion at all points inside the sample is negligible compared to drift, write down the appropriate expression for $\mathbf{J}_P$. After further simplifying $\mathbf{J}_P$ by noting $p = N_A + \Delta p \simeq N_A$, substitute your $\mathbf{J}_P$ result into the part (b) result.

(d) Write down Poisson's equation and explicitly express ρ (the charge density) in terms of the charged entities inside the semiconductor. Simplify your result, noting that $N_A \gg N_D$ and $p \gg n$ for the given sample and conditions.

(e) To complete the analysis:

(i) Combine the part (c) and (d) results to obtain a differential equation for p.

(ii) Let $p = N_A + \Delta p$.

(iii) Solve for $\Delta p(t)$. As stated earlier, $\Delta p(t)$ should be an exponential function of time characterized by a time constant $\tau = \varepsilon/\sigma$.

(f) Compute τ for $N_A = 10^{15}/\text{cm}^3$ doped silicon maintained at room temperature.