Carrier Equations

Dielectric constant ε

- The Coulomb interaction becomes $\frac{q_1 q_2}{4\pi\varepsilon\epsilon_0 r}$.
- The symbol K_s is also used in place of ε.
- **Question**. Inside a very good metal, which of the following is true?

  A. $\varepsilon \to \infty$ B. $\varepsilon \to 0$ C. $\varepsilon \to 1$
- Please do <u>not</u> associate ε with "resistivity" or "resistance."

Recombination, Generation

- The recombination and generation occurs via the interaction of the electron with photon (Figs. T3.15a,d), phonon (Figs. T3.15b,e), or other electron (Figs. T3.15c,f).
- Of these, the process involving **R-G centers** (Figure T3.165) and phonons (Figs. T3.15b,e) are the most important for Si.

Why is the RG process important? ("Let us put all together")

- Drift and Diffusion: how carriers **move**.

$$J_p = pev_{d,p} - eD_P\nabla p = pe\mu_p E - eD_P\nabla p$$

For electron (n), change e to –e in the 2nd term only. First term does not change since E and J should point the same direction.

- Recombination and Generation: how carriers **(dis-)appear**.

$$\frac{\partial p}{\partial t}\Big|_{RG} = G - R$$

$$\frac{\partial}{\partial t} = \frac{\partial}{\partial t}\Big|_{RG} + \frac{\partial}{\partial t}\Big|_{DD}$$

- Another important relation: the equation of **continuity**.

$$e\frac{\partial p}{\partial t}\Big|_{DD} + \nabla \cdot \vec{J}_p = 0$$

For electron (n), change e to –e in the 1st term.

The Carrier Equations

$$\frac{\partial p}{\partial t} = -\cancel{e}\mu_p \nabla \cdot \left(p\vec{E}\right) + \cancel{e}D_P \nabla^2 p + G_p - R_p$$

Consider the variation in a specific direction (x) only.

$$\frac{\partial p}{\partial t} = -\cancel{e}\mu_p \frac{\partial(pE)}{\partial x} + \cancel{e}D_P \frac{\partial^2 p}{\partial x^2} + G_p - R_p$$

$$\frac{\partial n}{\partial t} = \cancel{e}\mu_n \frac{\partial(nE)}{\partial x} + \cancel{e}D_N \frac{\partial^2 n}{\partial x^2} + G_n - R_n$$

Partials $(\partial t, \partial x)$ are to be understood in terms of the multi-variable calculus in the (t, x) space.

The Carrier Equations

- It was nice to write those down …
- But they are too general to be useful …

  "too true to be good"

- Let us look at these equations in the important case of near equilibrium ("perturbation" or "low level injection").
- Assume that the carrier density is perturbed slightly w.r.t. the equilibrium density (n_0, p_0), which we assume is spatially uniform (and so $\partial_x n_0 = \partial_t n_0 = \partial_x p_0 = \partial_t p_0 = 0$).

Time derivative is zero because of an equilibrium quantity should not depend on time.

Minority Lifetime

- $n = n_0 + \Delta n \qquad\qquad p = p_0 + \Delta p$
- $\partial_x n_0 = \partial_t n_0 = \partial_x p_0 = \partial_t p_0 = 0$
- $\Delta n, \Delta p, \min(n_0, p_0) \ll \max(n_0, p_0)$

$$G_p - R_p = -\frac{\Delta p}{\tau_p}$$

n type semiconductor
$p_0 + \delta p$ is the minority carrier density

$$G_n - R_n = -\frac{\Delta n}{\tau_n}$$

p type semiconductor
$n_0 + \delta n$ is the minority carrier density