Semiconductor: Diffusion current

day06

1. Review

The reading of Razavi section 2.2.1 was assigned and expected to have been completed by the start of this class session. Also §2.2.2, but your reading assignments are intentionally ahead of class time topics.

Tourbook table: Four currents in a semiconductor

Symbol	Name	Units
V		
n		
p		
μ_n		
μ_p		
k_B		
n_i		
N_D		
N~A		
W, h, d		

Charge carriers of interest

- e^-
- h^+

Charges move by

- Electric field → $\mathrm{V(olts)_{ab}} = -\int_a^b \vec{E}\,dl$

2. Diffusion

Motion from high to low regions of concentration

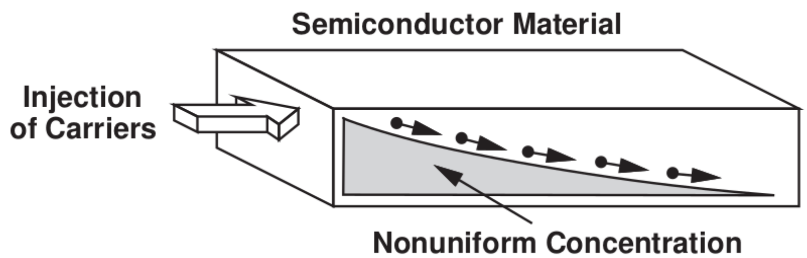

Figure 1. From Razavi Fundamentals of Microelectronics

$$J_n = -q\ D_n \left(-\frac{\delta n}{\delta x}\right)$$

density gradient ($\#/cm^4$)

motion *opposite* gradient

diffusion constant (cm^2/s)

electrons are negatively charged! (C)

$$\frac{C}{s \cdot cm^2} \rightarrow A/cm^2$$

$$J_n = +q\ D_n \frac{\delta n}{\delta x}$$

Figure 2. Electron diffusion current density

$$J_p = +q\ D_p \left(-\frac{\delta p}{\delta x}\right)$$

density gradient ($\#/cm^4$)

motion *opposite* gradient

diffusion constant (cm^2/s)

holes are positively charged! (C)

$$\frac{C}{s \cdot cm^2} \rightarrow A/cm^2$$

$$J_p = -q\ D_p \frac{\delta p}{\delta x}$$

Figure 3. Hole diffusion current density

The total **diffusion current density** is then

$$J_{total}(\text{diff}) = J_n + J_p \tag{1}$$
$$= q\left(D_n\frac{\delta n}{\delta x} - D_p\frac{\delta p}{\delta x}\right)\ \text{A/cm}^2 \tag{2}$$

> Look back at our four currents in a semiconductor and match the terms we've just worked through. **Only** one term has a negative sign, hole diffusion, *be careful* to not make sign errors!

2.1. Einstein relation

Surely there is some relationship between how easily a free charge carrier moves in a semiconductor (**μ, mobility**) and the quickness that a dose of charge disperses within a volume (**$D_{n,p}$, diffusivity**). Why would this make sense? What is happening internally when charges diffuse?

Indeed, this is the *Einstein relation*:

$$\frac{D_n}{\mu_n} = \frac{k_B T}{q} \tag{3}$$

$$\frac{k_B T}{q} = V_T \ \text{ thermal voltage} \tag{4}$$

$$D_n = \mu_n \frac{k_B T}{q} \tag{5}$$

I like this last presentation of the relationship best for the intuition on how the diffusion constant changes with temperature. Consider a drop of dye in a class of cold versus hot water—the dye in the hot water will diffuse faster because the thermal motion that creates the movement is greater.