Drift (contd.)

Next consider a p-type semiconductor with a large number of holes. An electric field E applied in one direction produces a force on the holes in the same direction, because of the positive charge on the holes. The holes aquire a drift velocity V_{dp} in (cm/s), which can be written as

$$V_{dp} = \mu_p E$$

where μ_p is a constant called the hole mobility and again has units of $cm^2/V-s$. For low doped Silicon the value of μ_p is typically 480 $cm^2/V-s$, which is less than half the value of electron mobility. The positive sign in the above equation indicates that the hole drift velocity is same as the applied electric field. The hole drift produces a drift current density J_p (A/cm^2) given by

$$J_p = qpV_{dp} = qp\mu_p E$$

where p is the hole concentration ($\#/cm^3$) and q is the magnitude of electronic charge.

The conventional drift current is in the same direction as ~~that~~ as the flow of positive charge, which means that the drift current ~~is~~ in a p-type material is also in the same direction as the applied electric field.

Since ~~the~~ a semiconductor contains both electrons and holes the drift current density is the sum of electron and hole components.

$$J = q n_{en} \mathcal{E} + q p \mu_p \mathcal{E} = \sigma \mathcal{E} = \frac{1}{\rho} \mathcal{E}$$

where

$$\sigma = q n_{en} + q p \mu_p$$

is the conductivity of the semiconductor in $(\Omega\,cm)^{-1}$ and ρ is the resistivity of the semiconductor in (Ωcm). The conductivity is related to the concentration of electrons and holes. If the electric field is the result of applying a voltage to the ~~semiconductor~~ semiconductor, then the above equation becomes a linear relationship between voltage and current — in the form of ~~of~~ Ohms law.

From the equation for σ, we see that the conductivity can be changed from strongly n-type $n >> p$ by donor impurity doping to strongly p-type $p >> n$, by acceptor impurity doping. Being able to control the conductivity of a semiconductor by selective doping is what enables us to fabricate a variety of electronic devices that are available.

* Consider silicon at $T = 300K$ doped with arsenic atoms at a concentration of $N_d = 8 \times 10^{15}\ cm^{-3}$. Assume mobility values of $\mu_n = 1350\ cm^2/V\text{-}s$ and $\mu_p = 480\ cm^2/V\text{-}s$. Let the applied electric field be $\mathcal{E} = 100\ V/cm$. Calculate the drift current density for the given semiconductor.

Solution: The electron and hole concentrations are

$$n_0 \simeq N_d = 8 \times 10^{15}\ cm^{-3}$$

and

$$p_0 = \frac{n_i^2}{N_d} = \frac{(1.5 \times 10^{10})^2}{8 \times 10^5} = 2.81 \times 10^4\ cm^{-3}$$

Because of the difference in magnitudes between the two concentrations, the conductivity is given by

$$\sigma = q n \mu_n + q p \mu_p \approx q n \mu_n$$

$$= (1.6 \times 10^{-19}) \times (8 \times 10^{15}) \times 1350$$

$$= 1.73 \ (\Omega\text{-cm})^{-1}$$

The drift current density is then

$$J = \sigma \mathcal{E} = 1.73 \times 100 = 173$$

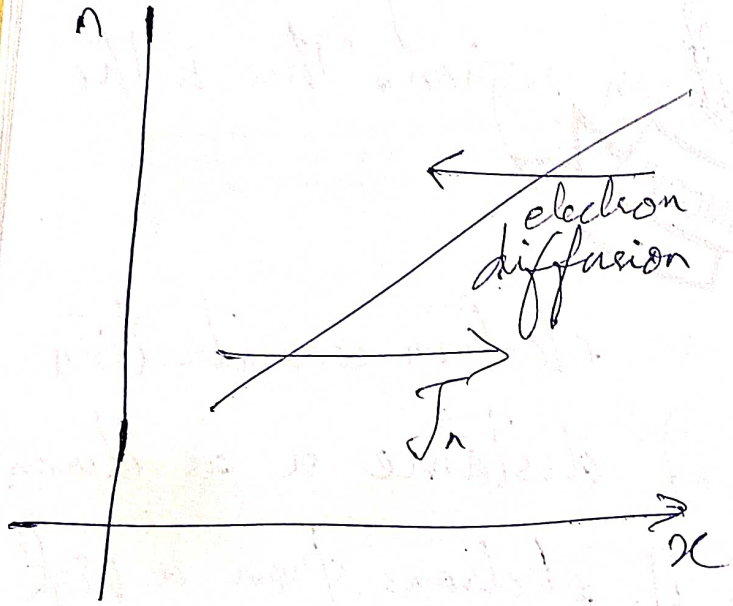
$$= 173 \ A/cm^2.$$

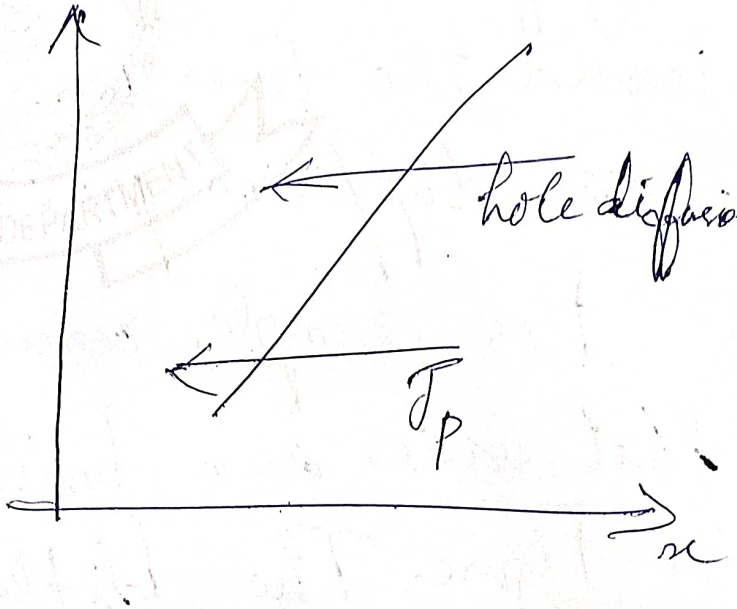
Diffusion Current Density

With diffusion, particles flow from a region of high concentration to a region of lower concentration. This is a statistical phenomenon related to kinetic theory. To explain, the electrons and holes in a semiconductor are in continuous motion, with an average speed determined by the temperature and with directions randomized with interactions with lattice atoms. Statistically, we can assume that, at any particular instant, approximately half of the particles in the high concentration region are moving away from the region

toward the lower concentration region. We can also assume that at the same time, approximately half of the ~~concentration~~ particles in the lower concentration region are moving toward the high concentration region. However, by definition there are fewer particles in the lower concentration region than there in the higher concentration region. Therefore the net result is a flow of particles away from the high concentration region and toward the lower concentration region. This is the basic diffusion process.

For example, consider an electron concentration that varies as a function of distance x as shown in Figure. The diffusion of electrons from a high concentration region to a low concentration region produces a flow of electrons in the negative x direction. Since electrons are negatively charged,


n
electron
diffusion
J_n
x


p
hole diffusion
J_p
x

the conventional current direction is in the positive x direction.

The diffusion current density due to diffusion of electrons can be written as (for one dimension)

$$J_n = q D_n \frac{dn}{dx}$$

where q is the electronic charge magnitude, $\frac{dn}{dx}$ is the gradient of electron concentration, and D_n is the electron diffusion coefficient.

In Fig (b) above the hole concentration is a function of distance. The diffusion of holes from a high concentration to low concentration region produces a flow of holes in the ~~neg~~ negative x direction. The diffusion current density due to flow of holes is

$$J_p = -q D_p \frac{dp}{dx}$$

where D_p is the hole diffusion coefficient.

Consider silicon at T=300K. Assume the electron concentration varies linearly from $n = 10^{12}\,cm^{-3}$ to $n = 10^{16}\,cm^{-3}$ over the distance from $x = 0$ to $x = 3\mu m$. Assume $D_n = 35\,cm^2/s$

$$J_n = qD_n\frac{dn}{dx} = (1.6\times10^{-19})(35)\times\frac{10^{12}-10^{16}}{0-3\times10^{-4}}$$

$$= 187\ A/cm^2$$

The mobility values in the drift current equations and diffusion coefficient values in diffusion current are not independent quantities. They are related by Einstein's equations.

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{kT}{q}$$