Drift carrier : An electric field : The net movement of charge due to an electric field is called drift. The net drift of charge gives rise to a drift current.

Drift current Density :

If we have a positive volume density of p moving at an average drift velocity v_d

$$J_{drf} = (\rho v_d) \quad \text{amps/cm}^2 \quad \text{(1)}$$

If the volume charge density is due to positively charged holes, then

$$J_{p\,drf} = (e p) v_{dp}$$

v_{dp} = Average drift velocity of holes

The equation of motion of a positively charged hole in the presence of an electric field is

$$F = m_p^* a = eE$$

m_p^* = effective mass

e = magnitude of electronic charge

Average drift velocity is $\propto$ to electric field

$u_{dp} = \mu_p E$; μ_p = hole mobility factor

$$J_{p|drf} = (ep)u_{dp} = e\mu_p p E \quad -①$$

The same discussion of drift applies to electrons

$$J_{n|drf} = \rho v_{dn} = (-en) v_{dn}$$
$$= (-en)(-\mu_n E)$$
$$= e\mu_n n E \quad -②$$

$v_{dn} = -\mu_n E$

$$J_{drf} = e(\mu_n n + \mu_p p) E$$

Carrier diffusion

Diffusion is the process whereby particles flow from a region of high concentration toward a region of low concentration

If the gas molecules were electrically charged, the net flow of charge would result in a diffusion current.

Diffusion current Density :

The net rate of electron frone F_n,

$$F_n = \frac{1}{2} n(-l)\, v_{th} - \frac{1}{2} n(+l)\, v_{th} = \frac{1}{2} v_{th} [n(-l) - n(l)] \quad -①$$

If we expond equation ① into tylor series.

$$F_n = \frac{1}{2} v_{th} \left\{ \left[n(0) - l \frac{dn}{dx} \right] - \left[n(0) + l \frac{dn}{dx} \right] \right\}$$

$$= - v_{th}\, l \frac{dn}{dx}$$

each electron has a charge $(-e)$. So the current is

$$J = -eF_n = + e v_{th}\, l \frac{dn}{dx}$$

$$J_{n\,drif} = e D_n \frac{dn}{dx}$$

, D_n is called electron diffusion coefficient

$$J_{p\,drif} = -e D_p \frac{dp}{dx}$$

D_p, hole diffusion coefficient

***

$\boxed{5.4}$ $T = 300\,K$, electron concentration varies linearly from 1×10^{18} to 7×10^{17} cm^{-3} over a distance of 0.10 cm

$D_n = 225$ cm^2/s

Sol^n:

The diffusion current density is given by

$$J_{n|dif} = eD_n \frac{dn}{dx}$$

$$\simeq eD_n \frac{\Delta n}{\Delta x}$$

$$= 1.6\times10^{-19} \times 225 \frac{(1\times10^{18} - 7\times10^{17})}{0.10}$$

$$= 108 \ A/cm^2$$

29/11/2019

→ Total current density
→ Induced electric field
→ example 5.5

Total current density :

we now have four possible independent current mechanisms in a semiconductor. These components are electrons are electron drift and diffusion currents and hole drift and diffusion currents. The total current density is the sum of these four components, or, for the one-dimensional case.

$$J = en\mu_n E_x + ep\mu_p E_x + eD_n \frac{dn}{dx} - eD_p \frac{dp}{dx}$$

This equation may be generalized to three dimensions.

$$J = en\mu_n E + ep\mu_p E + eD_n \nabla n - eD_p \nabla p$$

The electron mobility gives an indication of how well an electron moves in a semiconductors as a result of the force of an electric field.

Induced electric field

The separation of positive and negative charge induces an electric field that is in a direction to opposite the diffusion process.

The electric potential ϕ is related to electron potential energy by the charge $(-e)$. so we can write

$$\phi = +\frac{1}{e}(E_F - E_{Fi})$$

The electric field for the one-dimension situation is defined as

$$E_x = -\frac{d\phi}{dx} = \frac{1}{e}\frac{dE_{Fi}}{dx}$$

$$n_0 = n_i \exp\left[\frac{E_F - E_{Fi}}{KT}\right] \simeq N_d(x)$$

$$E_F - E_{Fi} = KT \ln \frac{N_d(x)}{n_i}$$

$$\Rightarrow -\frac{dE_{Fi}}{dx} = \frac{KT}{N_d(x)} \frac{dN_d(x)}{dx}$$

$$E_x = -\left(\frac{KT}{e}\right)\frac{1}{N_d(x)}\frac{dN_d(x)}{dx}$$

Scanned by CamScanner

Since we have an electric field, there will be a potential difference through the semiconductor due to the nonuniform doping.

Scanned by CamScanner

5.5

Electric field $E_x = ?$

$T = 300\ K$

$N_d(x) = 10^{16} - 10^{19}x$

$x = 0 \le x \le 1\ cm$

Sol: Taking the derivative of the donor concentration, we have

$$\frac{dN_d(x)}{dx} = -10^{19}$$

$$E_x = -\left(\frac{KT}{e}\right)\frac{1}{N_d(x)}\frac{dN_d(x)}{dx}$$

$$= \frac{-(0.0259)(-10^{19})}{10^{16} - 10^{19}x}$$

at $x = 0$

$E_x = 25.9\ V/cm$

02/11/2019

* The Einstein Relation
* Math
* carrier generation and Recombination
* The semiconductor in equilibrium
* Excess carrier generation and Recombination
* Math

The Einstien Relation

we assume there are no electrical connections that the semiconductor is in thermal equilibrium, then the individual electron and hole currents must be zero.

$$J_n = 0 = e n \mu_n E_x + e D_n \frac{dn}{dx}$$

If we assume quasi-neutrality so that $n \neq N_d(x)$

$$J_n = 0 = e \mu_n N_d(x) E_x + e D_n \frac{dN_d(x)}{dx}$$

putting the value of E_x

$$0 = -e \mu_n N_d(x) \frac{KT}{e} \cdot \frac{1}{N_d(x)} \cdot \frac{dN_d(x)}{dx} + e D_n \frac{dN_d(x)}{dx}$$

— (1)

Equation ① valid for $\frac{D_n}{\mu_n} = \frac{KT}{e}$ — ⓐ

The hole current must also be zero in the semiconductor

$$\frac{D_p}{\mu_p} = \frac{KT}{e} \quad \text{— ⓑ}$$

combining ⓐ and ⓑ

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{KT}{e}$$

this is the Einstein relation

5.6

mobility of carrier is $1000 \ cm^2/V\text{-}s$

at $T = 300 \ K$

Determine diffusion coefficient

Sol^n:

$$D = \frac{KT}{e} \mu$$

$$= 0.0259 \times 1000$$

$$= 25.9 \ cm^2/s$$

Chapter six (6)

* Carrier generation and Recombination

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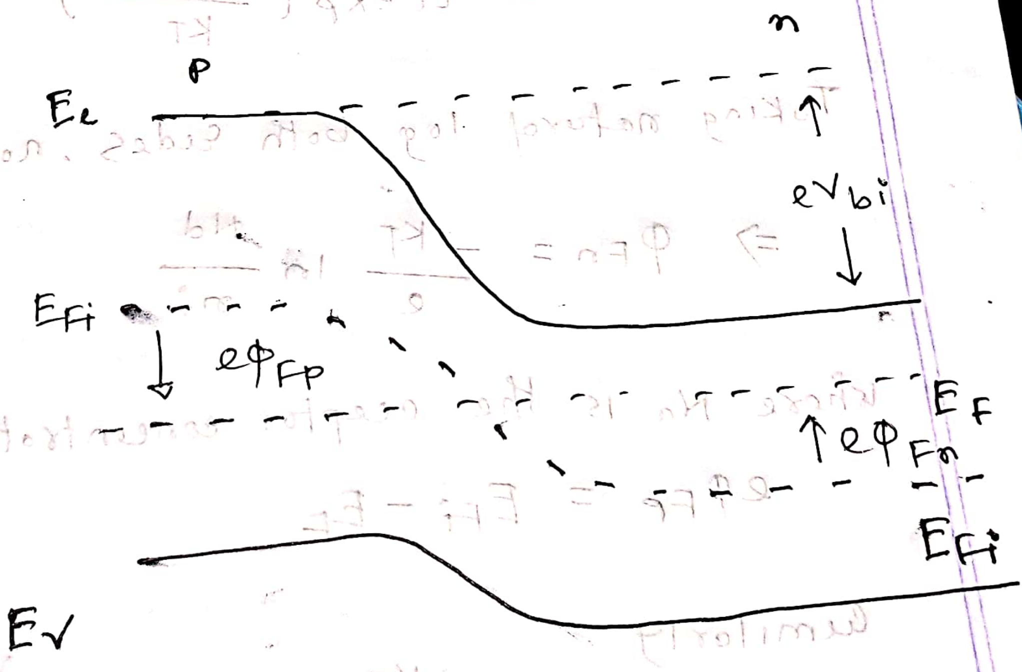
chapter – 7

→ Basic structure of the p-n Junction
→ Built in potential Barrier
→ Math 7.1

Electrons in the conduction band of the n region ~~This potential~~ see a potential barrier in trying to move into the conduction band of the p region. This potential barrier is reffered to as the built-in potential barrier and is denoted by V_{bi}.



Now we can write, $V_{bi} = |\phi_{Fn}| + |\phi_{Fn}|$ — ①

in the n region, the electron concentration in the conduction band is given by

$$n_0 = N_c \exp\left[\frac{-(E_c - E_F)}{KT}\right]$$

which can also be written in the form

$$n_0 = n_i \exp\left[\frac{E_F - E_{Fi}}{KT}\right]$$

the potential ϕ_{Fn} in the n region as

$$e\phi_{Fn} = E_{Fi} - E_F$$

$$n_0 = n_i \exp\left(\frac{-(e\phi_{Fn})}{KT}\right)$$

Taking natural log both sides, $n_0 = N_d$

$$\Rightarrow \phi_{Fn} = -\frac{KT}{e} \ln \frac{N_d}{n_i}$$

where N_a is the aceptor concentration

$$e\phi_{Fp} = E_{Fi} - E_F$$

similarly

$$\phi_{Fp} = +\frac{KT}{e} \ln \frac{N_a}{n_i}$$

$V_{bi} = \frac{KT}{e} \ln \frac{N_a N_d}{n_i^2} = V_T \ln \frac{N_a N_d}{n_i^2}$

25/11/2019

* Reverse bias
* Space charge width
* Math 7.1

$\boxed{7.1}$ To calculate the built-in potential in a pn Junction

$T = 300K$, $N_a = 1\times10^{18}\ cm^{-3}$, $N_d = 1\times10^{15}\ cm^{-3}$

$n_i = 1.5\times10^{10}\ cm^{-3}$

Soln: $V_{bi} = V_T \ln \dfrac{N_a N_d}{n_i^2}$

$= 0.0259 \ln \dfrac{10^{18}\times10^{15}}{(1.5\times10^{10})^2}$

$= .754\ V$

* Space charge width: