Conductivity of Extrinsic Semiconductor.

$$\sigma = n_i e\mu_n + p_i e\mu_p$$

For n-type

$$\sigma_n = n_n e\mu_n + p_n e\mu_p$$ Since **(n_n)** >>**(p_n)**

$$\sigma_n = n_n e\mu_n$$

and if $n_n = N_D$ then $\sigma_n = N_D e\mu_n$

For p-type

$$\sigma_p = n_p e\mu_n + p_p e\mu_p$$

Since **(p_p)** >>**(n_p)**

$$\sigma_p = p_p e\mu_p$$

and if $p_p = N_A$ then

$$\sigma_p = N_A e\mu_p$$

Example

P-type sample with l=6mm, A=0.5mm^2, R=120Ω. Calculate majority and minority carriers if intrinsic carrier density is 2.5×10^{19}/ m^3. Given μ_n=0.38m^2/Vs, μ_p=0.18m^2/Vs .

Solution

$$R = \rho \frac{l}{A} = \frac{l}{\sigma A}$$

$$\sigma_p = p_p e\mu_p$$

$n_i^2 = n_p\, p_p$

$$p_p = \frac{\sigma_p}{e\mu_p} = \frac{100}{1.6\times10^{-19}\times0.18} = 3.46\times10^{21}/m^3$$

$$n_p = \frac{n_i^2}{p_p} = 1.9\times10^{17}/m^3$$

Drift Current Density

An electric field is applied to a semiconductor will produce force on electrons and holes so that they will experience a net acceleration and net movement. This net movement of charge due to an electric field is called ***drift***. The net drift of charge gives rise to a ***drift current***.

The current density due to electrons drift

$$J_n = ne\mu_n E$$ The current density due to electrons drift

$$J_p = pe\mu_p E$$

The total current density due to electrons and holes drift

$$J = J_n + J_p = ne\mu_n E + pe\mu_p E$$

Example

Calculate the drift current density in a gallium arsenide sample at T=300 K, with doping concentration $N_a=0$, $N_d=10^{22}/m^3$, $\mu_n=0.85 m^2/V.s$, $\mu_p=0.04 m^2/V.s$, E=10 V/cm, $n_i=2.2\times10^{17}/m^3$.

Solution

Since $N_D >> N_a$ then it is n-type

$$n_n \approx N_D - N_A$$

$$n \approx 10^{22} / m^3$$

The minority hole concentration is

$$p = \frac{n_i^2}{n} = 3.24 \times 10^2 / m^3$$

$$J = \left(1.6 \times 10^{-19}\right)\left(0.85\right)\left(10^{22}\right)\left(10^3\right) = 136 \times 10^4 A / m^2$$

Diffusion Current Density

It is gradual flow of charge from a region of high density to a region of low density. Current density due to electron diffusion is

$$J_n = eD_n \frac{dn}{dx}$$

Current density due to hole diffusion is

$$J_p = -eD_p \frac{dp}{dx}$$

Where D_n, D_p (cm^2/s) are electron and hole diffusion constants, respectively.

$\frac{dn}{dx}$	Density gradient of electrons
$\frac{dp}{dx}$	Density gradient of holes

Total Current Density

The total current density is the sum of these four components

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

Einstein Relation

This relation between the mobility and diffusion coefficient.

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

$$D = \frac{kT}{e}\mu = \frac{\mu}{39}$$

Example

Determine the diffusion coefficient, assume the mobility is 1000cm^2/V.s at T=300K.

Solution

$$D = \frac{kT}{e}\mu = 0.0259 \times 1000 = 25.9 cm^2 / s$$

Rcombination

Recombination that result from the collision of an electron with a hole. This process is the return of a free electrons in the conduction band to valence band, there is a net recombination rate by difference between the recombination and generation rates.

$$L_n = \sqrt{D_n \tau} \qquad L_p = \sqrt{D_p \tau}$$

Where L the distance traveled by charge carrier before, recombination τ life time.

Hall Effect:

As shown there is a current I_x resulting from an applied electric field E_x in x- direction an electrons will drift v_x. A magnetic field B_y (wb/m^2) is superposed on applied electric field E_x , whereby the current I_x and the magnetic flux B_y are perpendicular to each other. The electrons will experience a Lorentz force F_z perpendicular to I_x and B_y (in z direction)

$$F_z = ev_x B_y$$

Thus the electrons under the influence of this force will tend to crowds one face in the sample. This collection of electrons to one side establish an electric field in z-direction is known Hall effect E_H or E_z. Resulting a voltage V_H between the upper and the lower faces of the sample is observed:

On the other hand

$$eE_z = ev_x B_y$$

the current density J_x is given by:

$$E_z = v_x B_y \qquad J_x = \sigma E_x \qquad J_x = nev_x$$

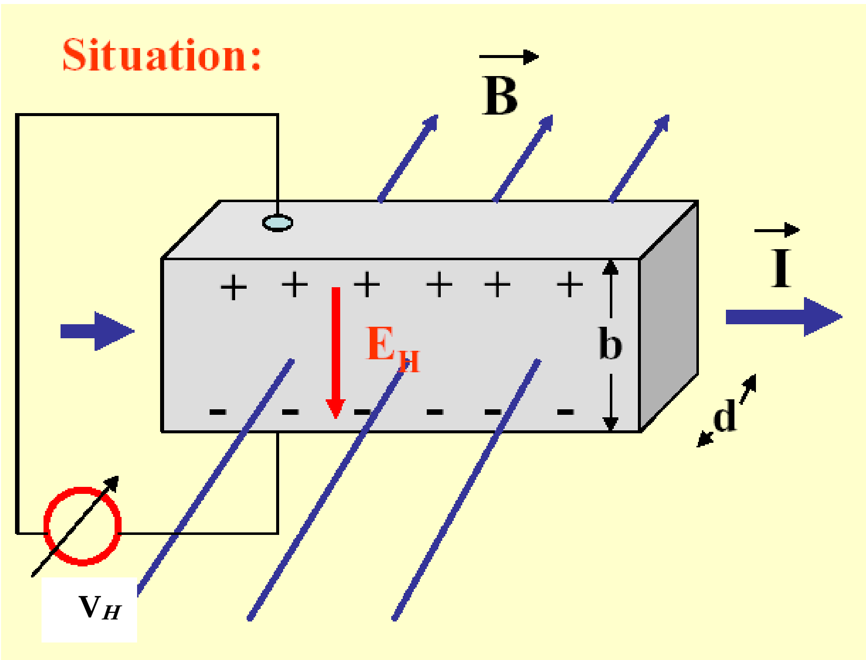

Fig. 5.7. Hall measurement situation

$$E_z = \frac{J_x}{ne} B_y$$

$$J_x = \frac{I_x}{A} = \frac{I_x}{bd}$$

Hall coefficient

$$R_H = \frac{1}{ne}$$ Where n is the total number of charge carrier per volum

$$E_z = R_H \frac{I_x}{bd} B_y$$

$$\frac{V_H}{b} = R_H \frac{I_x}{bd} B_y$$

$$V_H = R_H \frac{I_x}{d} B_y$$

$$n = \frac{I_x}{V_H ed} B_y$$

Where all the quantities in the right-hand side of the equation can *n* measured. Thus the carrier concentration and carrier type can e obtained directly from the Hall measurement.

$$J_x = \sigma E_x = ne\mu E_x$$

$$\frac{I_x}{A} = \frac{ne\mu V_x}{L}$$

$$\mu = \frac{I_x L}{neV_x A}$$

Example

Determine the majority carrier concentration and mobility, sample 10^{-1}cm length and $10^{-2}\times10^{-3}$cm^2 cross section area, given Hall effect parameters I_x=1mA, V_x=12.V, B=5×10^{-2}tesla, V_H=-6.25mV.

Solution

The negative Hall voltage indicate n-type semiconductor

$$n = \frac{I_x}{V_H ed} B_y$$

$$n = \frac{-(10^{-3})(5\times10^{-2})}{(1.6\times10^{-19})(10^{-5})(-6.25\times10^{-3})} = 5\times10^{21} m^{-3}$$

$$\mu = \frac{I_x L}{neV_x A}$$

$$\mu = \frac{(10^{-3})(10^{-3})}{(1.6\times10^{-19})(5\times10^{21})(12.5)(10^{-4})(10^{-5})} = 0.1 m^2 / V.s$$

Problems

Q1: Calculate the drift current density in silicon sample. If T=300 K, $N_d=10^{21}/m^3$, $N_a=10^{20}/m^3V$, $\mu_n=0.85m^2/V.s$, $\mu_p=0.04m^2/V.s$, E=35 V/cm..

(Ans: $6.8\times10^4 A/m^2$).

Q2: A cubic doped n-type silicon semiconductor sample at T=300 K, $\mu_n=0.85m^2/V.s$, R=10kΩ, $J=50A/cm^2$ when 5V is applied. Calculate $N_{D.}$.

Q3: Determine 10mm×1mm×1mm sample, a magnetic field $0.2wb/m^2$ is superposed on applied voltage 1mV. Calculate Hall voltage if electrons density $7\times10^{21}/m^3 \mu_n=0.4\ m^2/Vs$.