Transport and non equilibrium behaviour in semiconductors.

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Carrier transport phenomena

Carrier drift

$$J_{\text{drf}} = \rho v_d$$

ρ is the charge density, v_d the drift current

$$J_{p|\text{drf}} = (ep)v_{dp}$$

v_p is the average drift velocity of holes, and $J_{p|\text{drf}}$ the drift current density due to holes.

$$F = m_{cp}^* a = m_{cp}^* \frac{d_v}{dt} = eE$$

is the equation of motion e is the magnitude of the electron charge E the electric field and m_{cp}^* the effective mass a the acceleration

$$v_{dp} = \mu_p$$

μ_p is the hole mobility

$$J_{p|\text{drf}} = e\mu_p pE$$

In total:

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

v is the velocity due to the electric field:

$$v = \frac{eEt}{m_{cp}^*}$$

Now let the time between collisions be τ_{cp}

$$\langle v_d \rangle = \frac{1}{2}\frac{eE\tau_{cp}}{m_{cp}^*}$$

$$\mu_p = \frac{v_{dp}}{E} = \frac{e\tau_{cp}}{m_{cp}^*}$$

There are two types of scattering, lattice and ionized:

$$\mu_L \propto T^{-3/2}$$

$$\mu_I \propto \frac{T^{3/2}}{N_I}$$

$$\frac{dt}{\tau} = \frac{dt}{\tau_I} + \frac{dt}{\tau_L}$$

$$\frac{1}{\mu} = \frac{1}{\mu_I} + \frac{1}{\mu_L}$$

$$J_{\text{drf}} = e(\mu_n n + \mu_p p)E = \sigma E = \frac{1}{\rho}E$$

$$J = \frac{I}{A} \quad E = \frac{V}{L}$$

$$\frac{I}{A} = \sigma \frac{V}{L}$$

$$V = \frac{L}{\sigma A} I = \frac{\rho L}{A} I = IR$$

ohms law. now think p-tpe such that $N_a \gg n_i$

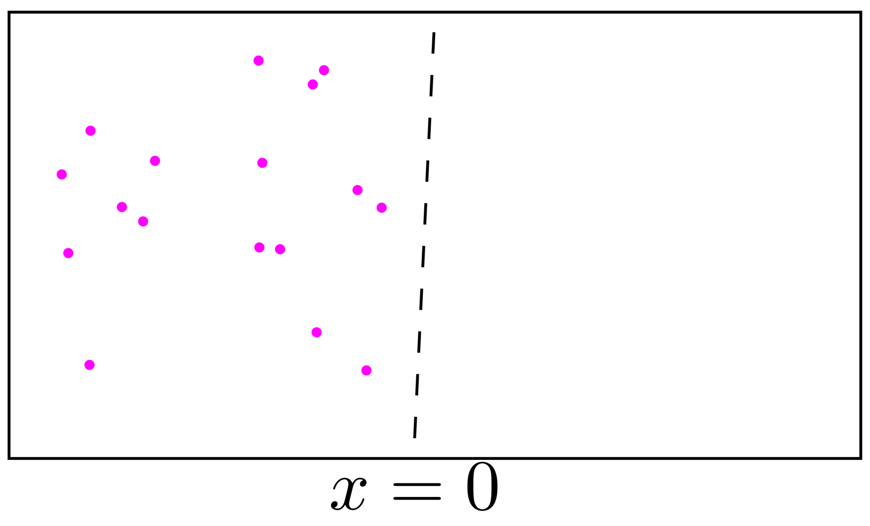
$$\sigma = e(\mu_n n + \mu_p p) \approx e\mu_p p \approx \frac{1}{\rho}$$

For an intrinsic material

$$\sigma = e(\mu_n + \mu_p)n_i$$

$$v_n = \frac{v_s}{\sqrt{1 + \left(\frac{E_{on}}{E}\right)^2}} \approx \left(\frac{E}{E_{on}}\right) v_s$$

Carrier diffusion



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

Taylor expansion

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

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

$$J = -eF_n = +ev_{th} l \frac{dn}{dx}$$

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

$$J_{px|\text{dif}} = -eD_p \frac{dp}{dx}$$

The total current is then

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

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

Graded impurity distribution

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

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

assuming quasi neutrality

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

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

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

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

no electrical connection and thermal equilibrium:

$$J_n = 0 = en\mu_n E_x + eD_n \frac{dn}{dx}$$

assume quasi-neutrality ($n \approx N_d(x)$)

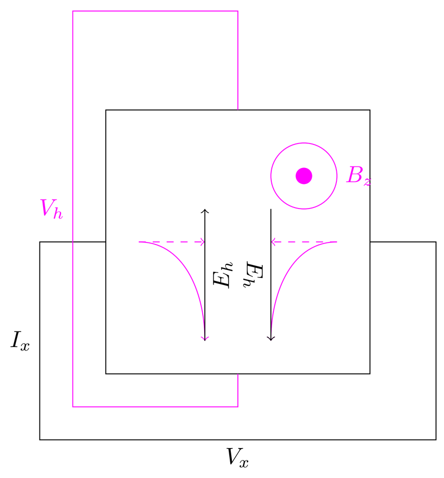
$$= eN_d(x)\mu_n E_x + eD_n \frac{dN_d(x)}{dx}$$

$$= -e\mu_n N_d(x) \frac{kT}{e}\frac{1}{N_d(x)}\frac{dN_d(x)}{dx} + eD_n \frac{dN_d(x)}{dx}$$

this needs the conditions (known as the Einstein relations

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

The Hall effect



$$F = qv \times B$$

As the holes and electrons move in the same direction the important thing is wheter or not there's an excess of one or the other. that's the case in an p or n type semiconducter. An electric field will then be made to compensate for this field:

$$F = q\left[E + v \times B\right] = 0$$

$$qE_y = qv_x B_z$$

$$v_H = v_x W B_z$$

$$v_{dx} = \frac{J_x}{ep} = \frac{I_x}{epWd}$$

$$v_H = \frac{I_x B_z}{epd}$$

$$p = \frac{I_x B_z}{edV_H}$$

$$v_H = \frac{I_x B_z}{end}$$

$$n = -\frac{I_x B_z}{edV_H}$$

$$J_x = ep\mu_p E_x$$

$$\frac{I_x}{Wd} = \frac{epp\mu_p V_x}{L}$$

$$\mu_p = \frac{I_x L}{epV_x Wd}$$

$$\mu_n = \frac{I_x L}{enV_x Wd}$$

In the above L is the length of the semiconductor in the direction of the current, W is the length of the semiconductor in the direction of neither the current nor the magnetic field, d is the length of the semiconductor in the direction of the magnetic field.

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