Semiconductor Devices

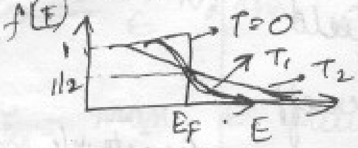
$$m^* = \frac{\hbar^2}{d^2E/dk^2}$$

m^* = effective mass
d^2E/dk^2 = curvature of E-k rel^n

$$f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$$

$f(E)$ = prob. of E being filled — indistinguishable

E_F = fermi level



$T_2 > T_1$

$$n_0 p_0 = n_i^2$$

$$n_0 = n_i e^{(E_F - E_i)/kT}$$

$$p_0 = n_i \cdot e^{(E_i - E_F)/kT}$$

n_i = intrinsic conc.
E_i = mid-energy level b/w CB & VB. — when no excess carriers are present

$$E_C - E_i = E_g/2$$

$$n_i = \sqrt{N_C N_V} \cdot e^{-E_g/2kT}$$

$$N_V = 2\left(\frac{2\pi m_p^* kT}{h^2}\right)^{3/2}$$

$$\frac{dE_f}{dx} = 0$$

no gradient exists in fermi level — at equilibrium

Recombination

$$\text{Rate of decay} = \alpha_r n(t) p(t)$$

α_r = proportionality const. for recombination — Direct Recombination.

$$\frac{d\delta n(t)}{dt} = -\alpha_r (n_0 + p_0)\, \delta n(t)$$

$\delta n(t)$ = excess carrier conc. — "

$$\delta n(t) = \Delta n \cdot e^{-t/\tau_n}$$

τ_n = recombination lifetime
Δn = initial excess carrier conc.

where $\tau_n = 1/\alpha_r(n_0 + p_0)$

$$\delta n = \delta p = g_{op} \tau_n$$

g_{op} = optical generation rate] for steady optical excitation

$$n = n_i e^{(F_n - E_i)/kT}$$

$$p = n_i \cdot e^{(E_i - F_p)/kT}$$

F_n, F_p = quasi-Fermi levels for e^- & holes — in presence of excess carriers. (but steady state)

$$g = p_0 / \tau_p$$

g: thermal gen. — p type.

Diffusion Eq

$J_n(x) = q\mu_n n(x) \mathcal{E}(x) + q D_n \frac{dn(x)}{dx}$

$J_p(x) = q\mu_p p(x) \mathcal{E}(x) - q D_p \frac{dp(x)}{dx}$

$J_n(x), J_p(x)$ = current densities of e^- & holes

μ_n, μ_p = mobilities of e^- & hole

$\mathcal{E}(x)$ = electric field

D_n, D_p = diffusion coeff.

$\frac{D}{\mu} = \frac{kT}{q}$ — Einstein's rel. (at equilibrium)

$\frac{kT}{q} \approx 0.026V$ — at room temp

Diffusion eq^n

$\frac{\partial \delta n}{\partial t} = D_n \frac{\partial^2 \delta n}{\partial x^2} - \frac{\delta n}{\tau_n}$ — general

(similarly for holes)

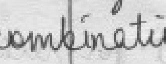
$\frac{d^2 \delta n}{dx^2} = \frac{\delta n}{D_n \tau_n} = \frac{\delta n}{L_n^2}$ — steady state (time der. are zero)

L_n, L_p = diffusion lengths for e^- & hole (avg.)

$L_n = \sqrt{D_n \tau_n}$

* L_n, L_p = average length charge carrier travels before recombination.

$\delta p(x) = \Delta p \cdot e^{-x/L_p}$

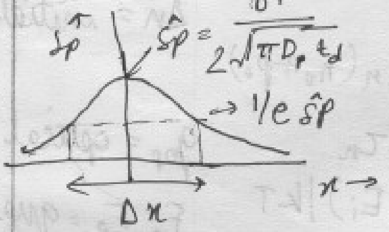


Haynes-Shockley expt.

$\delta p(x,t) = \left[\frac{\Delta p}{2\sqrt{\pi D_p t}}\right] e^{-x^2/4D_p t}$ — negligible recombination

Gaussian dist^n

$D_p = \frac{(\Delta x)^2}{16 t_d}$



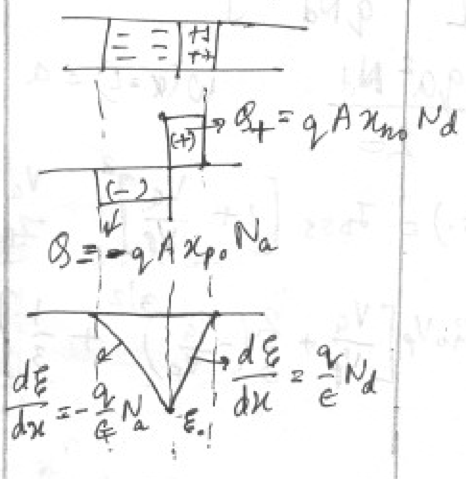
$g_{th} = p_n/\tau_n$ g_{th} = eq^m thermal gen.-recombination rate

p-n Junctions

$$V_0 = \frac{kT}{q} \ln \frac{N_a N_d}{n_i^2}$$

V_0 = contact potential

$$\frac{p_p}{p_n} = \frac{n_n}{n_p} = e^{qV_0/kT}$$

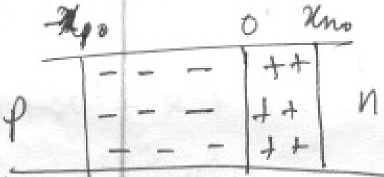


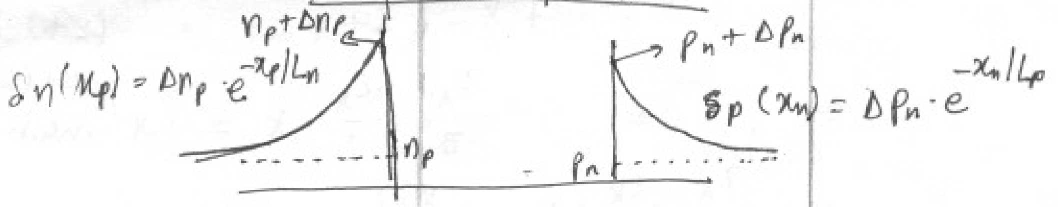
$$\mathcal{E}_0 = -\frac{q}{\epsilon} N_d x_{no} = -\frac{q}{\epsilon} N_a x_{po}$$

$\mathcal{E}_0$ = max. E-field

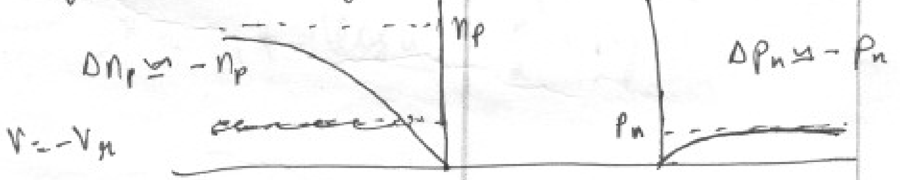
$$V_0 = -\frac{1}{2}\frac{q}{\epsilon}\frac{N_a N_d}{N_a + N_d} W^2$$

$$x_{po} = \frac{W N_d}{N_a + N_d}$$





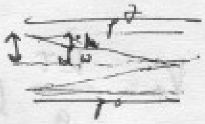
Effective voltage $= V_0 - V_f$ (fwd bias voltage)



FET & MOSFET

$$W(x=L) = \left[\frac{2\epsilon(-V_{GD})}{qN_d}\right]^{1/2}$$

p^+ n-channel FET



$$V_p = \frac{qa^2N_d}{2\epsilon}$$

$W(x=L) = a$ and $V_G - V_D = V_{GD} = -V_p$

$$I_D(sat.) = I_{DSS}\left[1+\frac{V_G}{V_p}\right]^2$$

V_G (-ve)

$I_{DSS} = I_D(sat.)$ at no gate voltage

$$I_D(sat.) = G_0V_p\left[\frac{V_G}{V_p} + \frac{2}{3}\left(-\frac{V_G}{V_p}\right)^{3/2} + \frac{1}{3}\right]$$

$G_0 = 2aZ/\rho L$ (only upto pinch-off)