Microelectronics Technology S 2024 Crib Sheet Exam 1 Hayden Fuller

Basic:

n-type, donors, 5 electron, P, As, Sb, p-type, acceptors, 3 electron, B, Al, Ga, In

$1eV = 1.6 \times 10^{-19} J$

$k = 1.38 \times 10^{-23} J/K = 8.6 \times 10^{-5} eV/K$, $kT = 0.025eV$

$E_{G,Si} = 1.12eV$

$n_i = 10^{10}$, $n_i^2 = np$, $n = n_i e^{(E_F - E_i)/kT}$, $p = n_i e^{(E_i - E_F)/kT}$

$p - n + N_D - N_A = 0$, $n^2 - n(N_D - N_A) - n_i^2 = 0$

$N_D > N_A$ => $n = N_D - N_A$; $p = n_i^2/n$ $N_D \approx N_A$ => $n = p = n_i$

Band diagrams: n-type: E_C, E_F, E_i, E_v , p-type: E_C, E_i, E_F, E_v

Point defect: one atom missing. Electron generation: one electron missing

Electron moving: breaks off and moves. Hole moving: electron line rotates into hole.

effective mass:

Fermi function $f(E) = \frac{1}{1+e^{(E-E_F)/kT}}$, Steps from 1 to 0 at E_F at 0K, smoothe at temp.

$E_F = 1 - e^{\frac{E-E_F}{kT}} = \frac{E_C + E_V}{2}$ in intrinsic

Distribution of carriers = distribution of states * probability of occupancy = $g(E)f(E)$

Conduction band electrons: $n_0 = \int_{E_C}^{E_top} g_C(E) f(E) dE$, holes in VB: $p_0 = \int_{E_bottom}^{E_v} g_V(E)(1 - f(E)) dE$

total free electron concentration $3kT$ away from edges (non-degenerate): $n = N_c e^{-\frac{E_C - E_F}{kT}}$, hole: $p = N_v e^{-\frac{E_F - E_V}{kT}}$

where effective density of states $N_C = 2.8 \times 10^{19} cm^{-3}$ and $N_C = 1 \times 10^{19} cm^{-3}$, $3kT$ around $N_{AorD} = 2 \times 10^{17}$

Drift: caused by electric field, drift velocity $v_d = \mu_p E$ $cm/sec = cm^2/Vs * V/cm$

$I = Q/T$, $J_{P|drift} = I/A = qp\mu_p E = \frac{E}{\rho}$

resistivity: $\rho = 1/(1p\mu_p + qn\mu_n)$

resistivity measurement: 4 point probe, eddy current apparatus

Diffusion: random thermal mothion, high to low concentration, must be a concentration gradient

Flux $F = -D\frac{d\eta}{dx}$, $\eta =$ particle concentration, $D =$ diffusion coefficient

holes/electrons go high to low,that's flux, but diffusion current is negative for electrons

$J_{p|diff} = -qD_p \frac{dp}{dx}$, $J_{n|diff} = qD_n \frac{dn}{dx}$

$J_p = J_{p|drift} + J_{p|diff} = q\mu_p pE + -qD_p \frac{dp}{dx}$, $J_n = J_{n|drift} + J_{n|diff} = q\mu_n nE + qD_n \frac{dn}{dx}$, $J = J_n + J_p$

Band bending: electric field bends the band diagram

$KE = E - E_C$, $PE = E_C - E_{ref} = -qV$ (for electrons), $V = -(E_C - E_{ref})/q$, $E = -\frac{dV}{dx} = \frac{dE_{C,V,i}}{dx}/q$

Hot point measurement: Hot end makes particles move away.

p-type: holes move away, current goes out hot probe. n-type: electrons move away, current goes into hot probe

in thermal equilibrium: E_F is constant, net current $J_{p|drift} + J_{p|diff} = 0$, recombination and generation cancel

Einstein: $J_{n|drift} + J_{n|diff} = q\mu_n nE + qD_n \frac{dn}{dx} = 0$, $E = \frac{dE_i}{dx}/q$, $n = n_i e^{(E_F - E_i)/kT}$

electrons: $\frac{D_n}{\mu_n} = \frac{kT}{q}$, holes: $\frac{D_p}{\mu_p} = \frac{kT}{q}$

recombination:

band to band recombination gives off light, band to band generation through thermal and light absorption, RG center is indirect-middle step

auger recombination, electron drops, and gives another electron KE. Impact ionization, on a slope, electron moves and falls

SI is mostly RG recombination due to impurities

direct semiconductors: k is matched so with less energy there's a photon. With a difference in k, more energy, phonon.

RG statistics:

if photon energy hv is greater than band gap E_G , iti's absorbed and an electron is moved up.

absorption: $I = I_0 e^{-\alpha x}$, each photon creates an e-h pair. $\frac{dn}{dt}|_{light} = \frac{dp}{dt}|_{light} = G_L(x, \lambda) = G_{L0} e^{-\alpha x}$

α drops off with wavelength. Higher wavelength, lower frequency, lower energy, doesn't get absorbed

indirect thermal recombination-generation, n_0, p_0 under thermal equilibrium, n, p as functions of t.

$\Delta n = n - n_0$, $\Delta p = p - p_0$, Δ's are deviations from equilibrium. N_t is number of RG centers/cm^3

low level injection condition assumed, change in majority carrier concentration negligable, $\Delta p << n_0$, $n \approx n_0$

$\frac{dp}{dt} = \frac{dp}{dt}|_R + \frac{dp}{dt}|_G + G_L(x, \lambda)$, hole build up = recomb loss + gen gain + external light

$\frac{dp}{dt}|_R = -C_p N_t p$

thermal equilibrium: $\frac{dp}{dt}|_G = -\frac{dp}{dt}|R = C_pN_tp_0$
generally when $G_L = 0$, $\frac{dp}{dt} = -\frac{\Delta p}{\tau_p}$, minority carrier lifetime $\tau_p = \frac{1}{C_pN_t}$
$\frac{\delta \Delta p}{\delta p} = -\frac{\Delta p}{\tau_p}$
perturbation removed at $t = 0$: $\Delta p = \Delta p(0)e^{-t/\tau_p}$
$\frac{dp}{dt} = fracdpdt|_{drift} + \frac{dp}{dt}|_{diff} + \frac{dp}{dt}|_{thermalRG} + \frac{dp}{dt}|_{light/other}$
current input: holes: $\frac{dp}{dt} = \frac{1}{q}\frac{dJ_p}{dx} + \frac{dp}{dt}|_{thermalRG} + \frac{dp}{dt}|_{light/other}$, electrons: first term is positive
Minority carrier diffusion equiations: electrons for p type, simplifications
$J_n = q\mu_n nE + qD_n\frac{dn}{dx} \approx qD_n\frac{dn}{dx}$
$\frac{dn}{dx} = \frac{d}{dx}(n_0 + \Delta n) = \frac{d\Delta n}{dx}$
$\frac{dn}{dt}|_{thermalRG} = -\frac{\Delta n}{\tau_n}$, $\frac{dn}{dt}|_{light} = G_L$
$\frac{dn}{dt} = \frac{d}{dt}(n_0 + \Delta n) = \frac{d\Delta n}{dt}$
$\frac{d\Delta n_p}{dt} = D_n\frac{d^2\Delta n_p}{dx^2} - \frac{\Delta n_p}{\tau_n} + G_L$
$\frac{d\Delta p_n}{dt} = D_p\frac{d^2\Delta p_n}{dx^2} - \frac{\Delta p_n}{\tau_p} + G_L$
Minority carrier diffusion length: $L_p = (D_p\tau_p)^{1/2}$, average distance minority carriers can diffuse