3.15
Carrier Drift, Diffusion and R&G
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Reference: Pierret, chapter 3.

Electron and holes can drift, diffuse, and undergo generation and recombination (R&G).

<u>Drift:</u>
thermal velocity $1/2\ mv^2_{thermal} = 3/2\ kT$
drift velocity, $v_d = \mu\mathbf{E}$ (μ = mobility, $\mathbf{E}$ = field)

Current density (electrons) $J = n\ e\ v_d$
Current density (electrons & holes) $J = e\ (n\ \mu_n + p\ \mu_h)\mathbf{E}$
Conductivity $\sigma = J/\mathbf{E} = e\ (n\ \mu_n + p\ \mu_h)$

Magnitude of mobility (cm^2/Vs)

	μ_n	μ_h	
Si	1500	450	
Ge	3900	1900	
Ag	50	-	
GaAs	8500	400	

Time between collisions is τ $\mu = e\tau/m^*$
Distance between collisions is l $l = \tau v_{thermal}$

<u>Diffusion</u>
$J = eD_n\ \nabla n + eD_p\ \nabla p$
Derivation of the Einstein relation: $D_n/\mu_n = kT/e$
typical D_n in Si is 40 cm^2/s

<u>Carrier R&G</u>
Mechanisms: band-to-band (direct)
RG centers or traps (indirect)

Thermal R and G at equilibrium: R = G
expect $R = G = rnp = r\ n_i^2$ r = rate constant

Shining light, etc. on the semiconductor causes additional R. These excess carriers n_l and p_l ($n_l = p_l$)decay once the light is turned off.

Illuminated: n-type material

$$n = N_D + n_l \qquad \sim N_D$$

$$p = n_i^2/N_D + p_l \qquad \sim p_l$$

net rate of change of carriers = $R - G = rnp - r\,n_i^2$

the rate of recombination of the minority carriers is

$$-dp/dt = r(N_D p - n_i^2) \qquad \text{but } n_i^2 = N_D(p - p_l)$$

$$-dp/dt = rN_D(p - p + p_l) = rN_D p_l$$

This has a solution $p_l = p_{l,\,t=0} \exp(-t/\tau_p)$, where $\tau_p = 1/rN_D$ = minority carrier lifetime.

<u>Example of Carrier Action – Formal solution</u>

A piece of p-type Si is illuminated at one end; how does the carrier concentration vary with depth x?

$$dn/dt = dn/dt_{drift} + dn/dt_{diffn} + dn/dt_{thermal\ RG} + dn/dt_{other\ RG}$$

$$= 0 \text{ at steady state}$$

$$n = n_p + n_l \quad \text{where } n_p = n_i^2/N_A$$

Inside the material there is only thermal R&G:

$$G_{thermal} = rn_i^2 = r\,n_p\,N_A$$

$$R_{thermal} = rnp \sim r\,n_l\,N_A$$

$$R - G = r\,N_A(n_l - n_p) \sim r\,N_A n_l = n_l/\tau_n$$

In the steady state,

$$dn/dt = dn/dt_{diffn} - (R - G) = 0$$

$$dn/dt = 1/e\ \nabla J_{diffn} - (R - G) = 0$$

$$d^2 n_l/dx^2 = n_l/\tau_n D_n$$

(since $dn/dt_{diffn} = 1/e\ \nabla J_{diffn} = D_n d^2 n/dx^2$ from Fick's law)

solution: $n_l = n_{l,\,x=0} \exp(-x/\sqrt{\tau_n D_n})$

Generally, if excess carrier concentrations are written as n_l or p_l, then

$$dn/dt_{thermal} = -\,n_l/\tau_n \quad \text{or} \quad dp/dt_{thermal} = -\,p_l/\tau_p$$

Minority carrier lifetimes are $\tau_n = 1/rN_A$, or $\tau_p = 1/rN_D$,

Minority carrier diffusion lengths are $\lambda_n = \sqrt{\tau_n D_n}$, or $\lambda_p = \sqrt{\tau_p D_p}$.

If traps dominate the recombination, then $\tau = 1/r_2 N_T$ where $r_2 >> r$