Section 16
Recombination & Generation
16.2 Derivation of SRH formula (Shockley, Reed, Hall)
16.2.4 Recombination-Generation Rate

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School of Electrical and Computer Engineering

Recombination-Generation Rate

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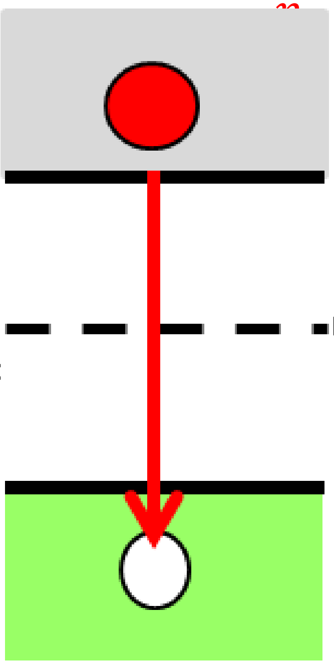
N_T



n_T electron-filled traps

p_T hole-filled (empty) traps

$= n_i g_D e^{\beta(E_T - E_i)}$

$p_1 = n_i g_D{}^{-1} e^{\beta(E_i - E_T)}$

$p_1 n_1 = n_i^2$

electron capture coef.

electron emission coef.

hole capture coef.

e_p hole emission coef.

$$R = -\frac{dp}{dt}$$

Rate of hole destruction
Net Recombination

$$e_p = c_p\, p_1$$

$$e_n = c_n\, n_1$$

$$\left.\frac{\partial p}{\partial t}\right| = -c_p(p n_T - p_T p_1)$$

$$n_T = \frac{c_n N_T n + c_p N_T p_1}{c_n\left(n + n_1\right) + c_p\left(p + p_1\right)}$$

n_T trap occupation for a given n,p

$$n_T = \frac{c_n N_T n + c_p N_T p_1}{A}$$

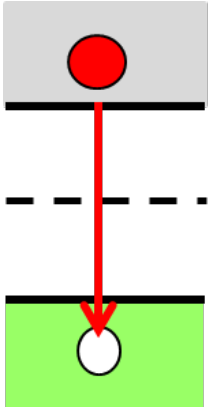
$$A = c_n(n + n_1) + c_p(p + p_1)$$

Net Rate of Recombination-Generation

$$R = -\frac{dp}{dt}$$

Rate of hole destruction

Net Recombination



n_T electron-filled traps

p_T hole-filled (empty) traps

$n_1 = n_i g_D e^{\beta(E_T - E_i)}$

$p_1 = n_i g_D^{-1} e^{\beta(E_i - E_T)}$

$p_1 n_1 = n_i^2$

$$R = -\frac{dp}{dt} = c_p\left(p\, n_T - p_T p_1\right)$$

$$= c_p\left(p\, n_T - N_T p_1 + n_T p_1\right)$$

$$= c_p n_T\left(p + p_1\right) - c_p N_T p_1$$

$$= c_p(p + p_1)\frac{c_n N_T n + c_p N_T p_1}{A} - c_p N_T p_1$$

Seek expression in terms of occupied traps

$$\left.\frac{\partial p}{\partial t}\right| = -c_p(p n_T - p_T p_1)$$

$$N_T = p_T + n_T$$

$$p_T = N_T - n_T$$

$$n_T = \frac{c_n N_T n + c_p N_T p_1}{A}$$

c_n electron capture coef.

e_n electron emission coef.

c_p hole capture coef.

e_p hole emission coef.

$e_p = c_p\, p_1$

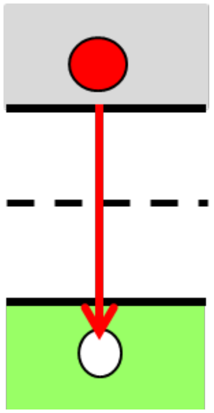
$e_n = c_n\, n_1$

$A = c_n(n + n_1) + c_p(p + p_1)$

Net Rate of Recombination-Generation

$$R = -\frac{dp}{dt}$$

Rate of hole destruction
Net Recombination



n_T electron-filled traps

p_T hole-filled (empty) traps

$n_1 = n_i g_D e^{\beta(E_T - E_i)}$

$p_1 = n_i g_D^{-1} e^{\beta(E_i - E_T}$

$p_1 n_1 = n_i^2 \qquad N_T = p_T + n_T$

$p_T = N_T - n_T$

$$= c_p(p + p_1)\frac{c_n N_T n + c_p N_T p_1}{A} - c_p N_T p_1$$

$$= c_p(p + p_1)\frac{c_n N_T n + c_p N_T p_1}{A} - c_p N_T p_1 \frac{A}{A}$$

$$A = c_n(n + n_1) + c_p(p + p_1)$$

$$= \frac{c_p N_T}{A}\left(p c_n n + p_1 c_n n + p c_p p_1 + p_1 c_p p_1 - p_1 c_n n - p_1 c_n n_1 - p_1 c_p p - p_1 c_p p_1\right)$$

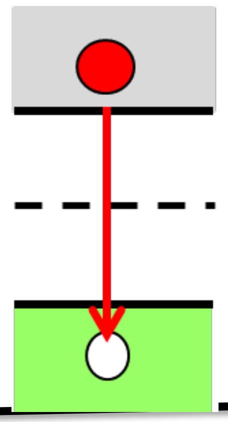
$$R = \frac{c_p N_T c_n}{A}(pn - p_1 n_1)$$

$$n_T = \frac{c_n N_T n + c_p N_T p_1}{A}$$

Net Rate of Recombination-Generation

$$R = -\frac{dp}{dt}$$

Rate of hole destruction
Net Recombination



n_T electron-filled traps

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$$p_1 = n_i g_D{}^{-1} e^{\beta(E_i - E_T}$$

$$R = \frac{c_p N_T c_n}{A}(pn - p_1 n_1)$$

$$p_1 n_1 = n_i^2$$

$$N_T = p_T + n_T$$

$$R = \frac{c_p N_T c_n}{A}(pn - n_i^2)$$

$$p_T = N_T - n_T$$

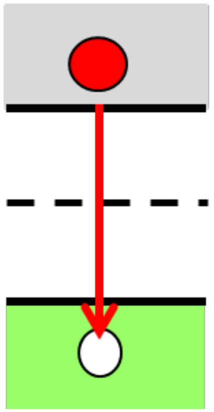
$$A = c_n(n + n_1) + c_p(p + p_1)$$

$$n_T = \frac{c_n N_T n + c_p N_T p_1}{A}$$

Net Rate of Recombination-Generation

$$R = -\frac{dp}{dt}$$

Rate of hole destruction
Net Recombination



n_T electron-filled traps

p_T hole-filled (empty) traps

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$$p_1 n_1 = n_i^2 \qquad N_T = p_T + n_T$$

$$p_T = N_T - n_T$$

$$R = \frac{c_p N_T c_n}{A}(pn - p_1 n_1)$$

$$R = \frac{c_p N_T c_n}{A}(pn - n_i^2)$$

$$R = \frac{pn - n_i^2}{A/(c_p N_T c_n)}$$

$$A = c_n(n + n_1) + c_p(p + p_1)$$

$$\frac{A}{c_p N_T c_n} = \frac{c_n(n + n_1) + c_p(p + p_1)}{c_p N_T c_n}$$

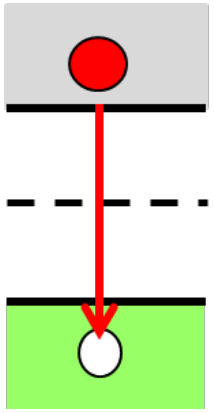
$$= \frac{c_n(n+n_1)}{c_p N_T c_n} + \frac{c_p(p+p_1)}{c_p N_T c_n}$$

$$\frac{A}{c_p N_T c_n} = \frac{1}{c_p N_T}(n + n_1) + \frac{1}{N_T c_n}(p + p_1)$$

Net Rate of Recombination-Generation

$$R = -\frac{dp}{dt}$$

Rate of hole destruction
Net Recombination



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$$p_1 = n_i g_D{}^{-1} e^{\beta(E_i - E_T)}$$

$$p_1 n_1 = n_i^2 \qquad N_T = p_T + n_T$$

$$p_T = N_T - n_T$$

$$= \frac{c_p N_T c_n}{A}\left(pn - n_i^2\right)$$

$$A = c_n(n + n_1) + c_p(p + p_1)$$

$$= \frac{pn - n_i^2}{A/(c_p N_T c_n)}$$

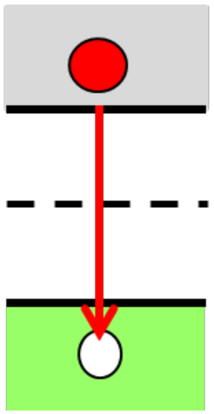
$$\frac{A}{c_p N_T c_n} = \frac{1}{c_p N_T}(n + n_1) + \frac{1}{N_T c_n}(p + p_1)$$

$$R = \frac{pn - n_i^2}{\frac{1}{c_p N_T}(n + n_1) + \frac{1}{N_T c_n}(p + p_1)}$$

Shockley-Read-Hall Recombination & Generation

$$R = -\frac{dp}{dt}$$

Rate of hole destruction
Net Recombination



n_T electron-filled traps

p_T hole-filled (empty) traps

$$R = \frac{pn - n_i^2}{\frac{1}{c_p N_T}(n + n_1) + \frac{1}{N_T c_n}(p + p_1)}$$

$$p_1 n_1 = n_i^2$$

$$N_T = p_T + n_T$$

c_n electron capture rate (volume/s) for one tra

$c_n N_T$ total electron capture rate (1/s)

$$R = \frac{pn - n_i^2}{\tau_p(n + n_1) + \tau_n(p + p_1)}$$

$$\tau_n = \frac{1}{c_n N_T}$$

Average time for an electron to be captured by a trap

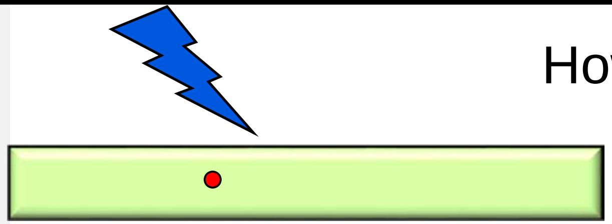
Electron minority carrier lifetime

$$n_1 = n_i g_D e^{\beta(E_T - E_i)}$$

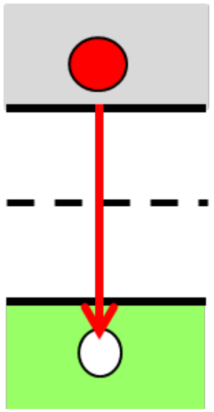
$$p_1 = n_i g_D{}^{-1} e^{\beta(E_i - E_T)}$$

$$\tau_p = \frac{1}{c_p N_T}$$

Hole minority carrier lifetime



How does the system go BACK to equilibrium?



$$\tau_n = \frac{1}{c_n N_T} \qquad \tau_p = \frac{1}{c_p N_T}$$

$$n_1 = n_i g_D e^{\beta(E_T - E_i)}$$

$$p_1 = n_i {g_D}^{-1} e^{\beta(E_i - E_T)}$$

- 16.1 Capture coefficient & Capture Cross Section
- 16.2 Derivation of SRH formula (Shockley, Reed, Hall)
  - » 16.2.1 Trap Assisted Recombination Rates
  - » 16.2.2 Capture and emission relationship (n_1 and p_1)
  - » 16.2.3 Steady State Trap Population
  - » 16.2.4 Recombination-Generation Rate

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$$R = \frac{pn - n_i^2}{\tau_p(n + n_1) + \tau_n(p + p_1)}$$

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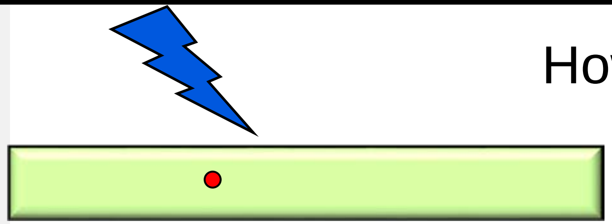

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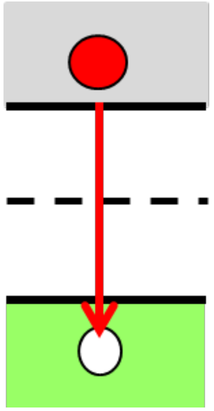

$$\tau_n = \frac{1}{c_n N_T} \qquad \tau_p = \frac{1}{c_p N_T}$$

$$n_1 = n_i g_D e^{\beta(E_T - E_i)}$$

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- 16.3 Application of SRH formula for special cases
  - Low level, high-level injection, depletion region

$$R = \frac{pn - n_i^2}{\tau_p(n + n_1) + \tau_n(p + p_1)}$$

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Section 16
Recombination & Generation

16.3 Application of SRH formula for special cases

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