

## EXCESS-CARRIER LIFETIME

$$\underline{n = n_0 + n'} \quad E_c$$

$n', p'$ : EXCESS CARRIERS

$$\underline{p = p_0 + p'} \quad E_v$$

LOW LEVEL INJECTION:

$n' = p' \ll$  MAJORITY CARRIER  
CONCENTRATION

OR  $n' = p' \ll n_0 + p_0$

Ext  $J_n = J_p = 0$  BUT  $n' = p'$  EXCESS CARRIERS

$\Rightarrow$  CONTINUITY EQU.

$$\begin{aligned} \frac{dn'}{dt} &= \frac{1}{q} \frac{dJ_n}{dx} + G_n - R_n \\ &= -U = \frac{\overset{\text{ZERO}}{-(pn - n_i^2)}}{\left[ p + n + \epsilon n_i \cosh\left(\frac{E_c - E_i}{kT}\right) \right] \tau_0} \end{aligned}$$

WITH  $\tau_n = \tau_p = \tau_0$

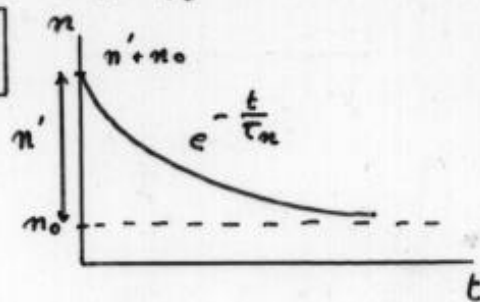
$$\text{BUT } \begin{cases} pn - n_i^2 = (p_0 + p')(n_0 + n') - n_0 p_0 = (p_0 + n_0) n' + \underbrace{p' n'}_{\text{NEGLECTABLE}} \\ p + n = p_0 + p' + n_0 + n' = p_0 + n_0 \end{cases}$$

$$\frac{dn'}{dt} = - \frac{(p_0 + n_0) n'}{\left[ p_0 + n_0 + \epsilon n_i \cosh\left(\frac{E_c - E_i}{kT}\right) \right] \tau_0} = - \frac{n'}{\tau_n}$$

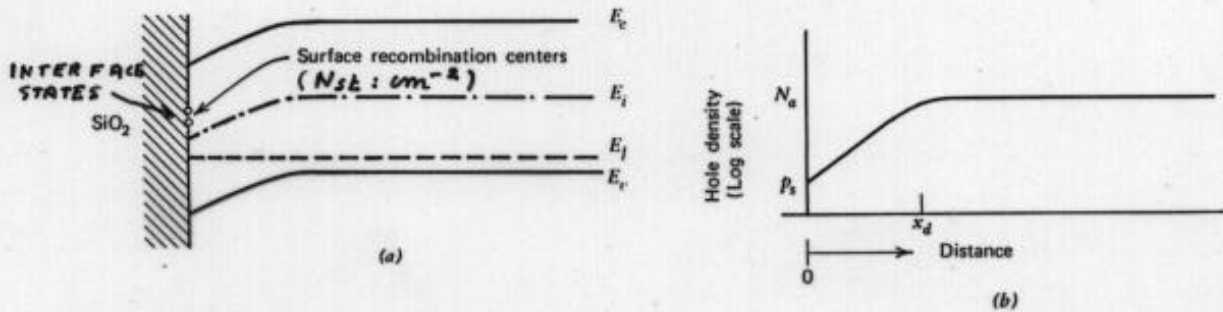
$$\text{WITH } \tau_n = \tau_0 \left[ 1 + \frac{\epsilon n_i}{n_0 + p_0} \cosh\left(\frac{E_c - E_i}{kT}\right) \right] = \tau_0 \quad \text{IF } E_c = E_i$$

SOLUTION:  $n'(t) = n'(0) e^{-\frac{t}{\tau_n}}$

MAJORITY CARRIER LIFETIME  $\rightarrow \tau_n = \tau_0 = \frac{1}{N_A \nu_{th} \sigma_0}$



# SURFACE RECOMBINATION



## SHR RECOMBINATION:

$$U_s = \frac{N_{st} v_{th} \sigma_n \sigma_p [p_s n_s - n_i^2]}{\sigma_p [p_s + n_i \exp(\frac{E_i - E_{st}}{kT})] + \sigma_n [n_s + n_i \exp(\frac{E_{st} - E_i}{kT})]} \quad \text{IN } cm^{-2} s^{-1}$$

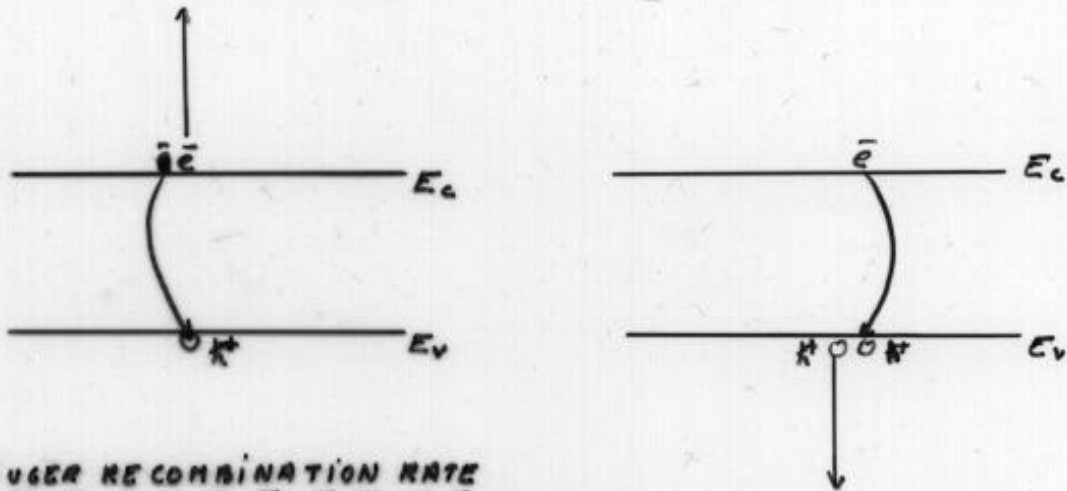
WITH  $\sigma_n = \sigma_p = \sigma_0$

$$U_s = N_{st} v_{th} \sigma_0 \frac{p_s n_s - n_i^2}{p_s + n_s + 2n_i \cosh(\frac{E_{st} - E_i}{kT})}$$

## SURFACE RECOMBINATION VELOCITY:

$$S = N_{st} v_{th} \sigma_0 \quad \text{IN } cm s^{-1}$$

## AUGER RECOMBINATION (INVERSE OF IMPACT IONIZATION)



### AUGER RECOMBINATION RATE

$$U_A = R_A - G_A = \Gamma_n n (pn - n_i^2) + \Gamma_p p (pn - n_i^2) \quad \text{cm}^{-3} \text{s}^{-1}$$

$\Gamma_n$ : AUGER COEFFICIENT FOR WHICH THE REMAINING CARRIER IS  $\bar{e}$

$\Gamma_p$ : \_\_\_\_\_  $\text{h}^+$

$$\Gamma_n, \Gamma_p \sim 2 \times 10^{-31} \text{ cm}^6 \text{ s}^{-1} \Rightarrow \text{HEAVY DOPING}$$

### AUGER LIFETIME OF MINORITY CARRIERS

$$\tau_A = \frac{c_{\text{min}}}{U_A} = \frac{1}{\Gamma_{\text{maj}} N_{\text{maj}}^2}$$

### OVERALL LIFETIME

$$\frac{1}{\tau_{\text{ov}}} = \frac{1}{\tau_{\text{SHR}}} + \frac{1}{\tau_A}$$