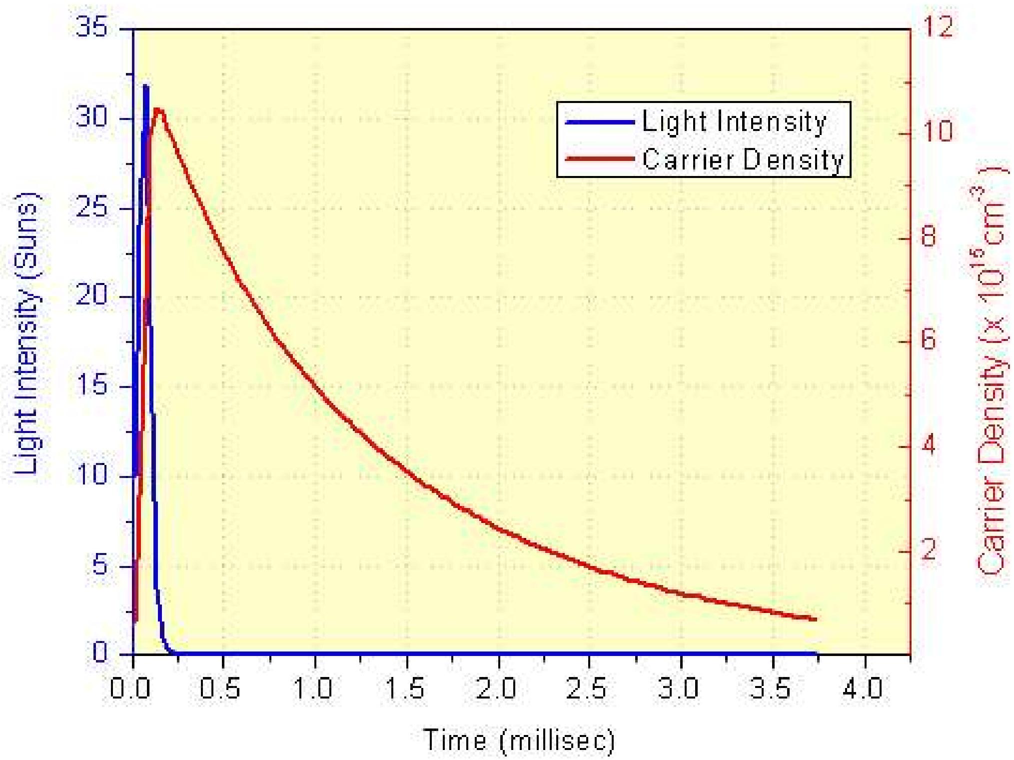
Non-equilibrium

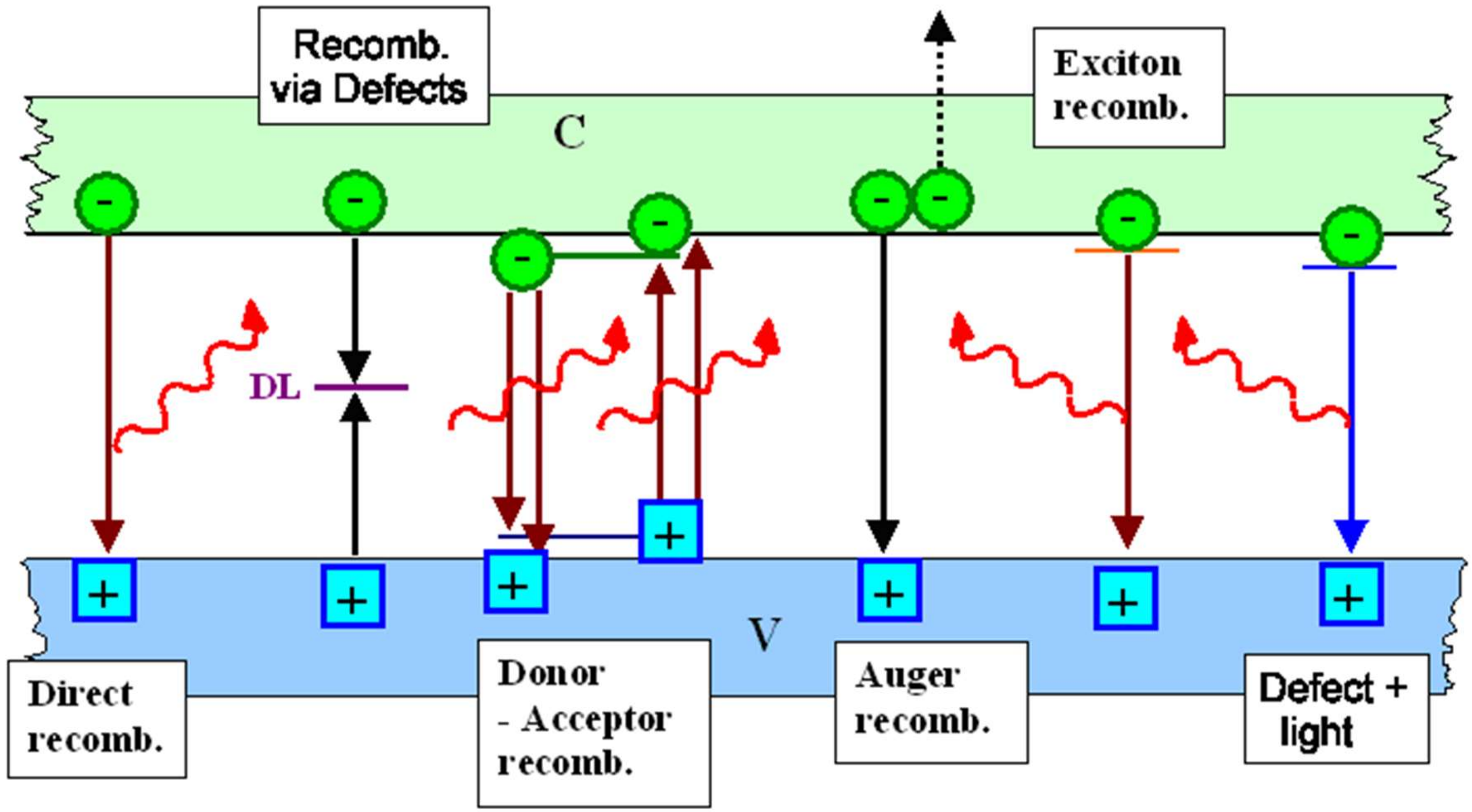


Example: Pulsed optical injection (single contact)

System returns to equilibrium after pulse ends

What relaxation processes equilibrate the system?

Electron-hole recombination

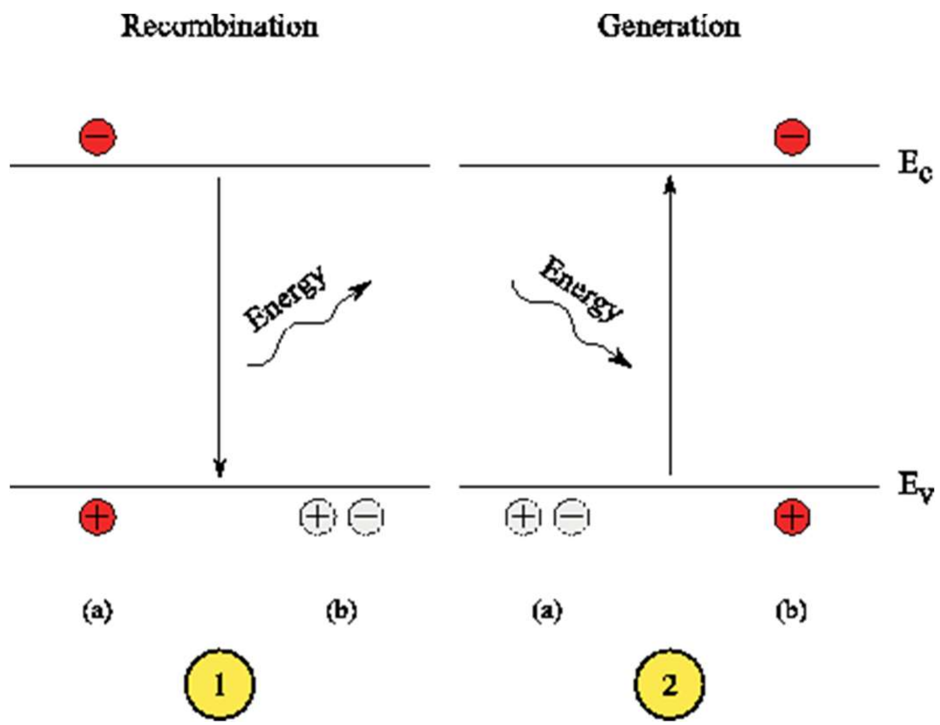


Energy conservation $\Delta E = E_f - E_i = \hbar\omega$

Momentum conservation $\Delta k = k_f - k_i = \hbar k$

Cannot be a photon for indirect material: why?

Direct (band-to-band) G-R



$$R = \alpha\left[(n_0+\delta n)(p_0+\delta p)-n_i^2\right]$$

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$$R = \alpha\left[n_0 p_0+\delta n(n_0+p_0)-n_i^2\right]$$

$$R = \alpha\cdot\delta n(n_0+p_0)=\delta n/\tau$$

Minority lifetime

$$\tau \cong \frac{1}{\alpha(n_0+p_0)} \simeq \frac{1}{\alpha p_0}$$

Law of Mass Action

$$R = \alpha np - ?$$

Net recombination

Equilibrium → $\alpha np = \alpha n_0 p_0 = \alpha n_i^2$

$$\boxed{R = \alpha\left(np - n_i^2\right)}$$

What happens if $np < n_i^2$?

$\delta n = \delta p$ **← Charge neutrality**

$p_0 \gg \delta n \gg n_0$ **Low-level injection**

$\delta n \gg p_0$ **High-level injection**

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Artwork Sources:

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6. Wang et al., J-KPS, 2003