Session 8: Solid State Devices

Recombination-Generation
Outline

- A
  - B
  - C
  - D
  - E

- F
  - G

- H

- I

- J
Outline

- Ref: ?
Whenever the thermal-equilibrium condition of a semiconductor system is disturbed, $pn \neq n_i^2$, processes exist to restore the system to equilibrium.

Generation and recombination processes act to change the carrier concentrations, and thereby indirectly affect current flow.

Recombination mechanisms: $pn > n_i^2$

- Direct
- R-G Center
- Auger

Generation mechanisms: $pn < n_i^2$

- Band-to-band
- R-G Center

Recombination in Si is primarily via R-G centers.
Recombination Mechanisms

1. Direct or Band to Band:
   - Basis for light emission devices
   - Photon (single particle of light) or multiple phonons (single quantum of lattice vibration – equivalent to saying thermal energy)

2. R-G Center:
   - Also known as Schockley-Read-Hall (SRH) recombination
   - Photon (single particle of light) or multiple phonons (single quantum of lattice vibration – equivalent to saying thermal energy)
   - Note: Trap level, Two steps: 1st Carrier is trapped at a defect/impurity, 2nd Carrier (opposite type) is attracted to the RG center and annihilates the 1st carrier

3. Auger:
   - Requires 3 particles, Two steps:
     - 1st carrier and 2nd carrier of the same type collide instantly annihilating the electron hole pair (1st and 3rd carrier).
     - The energy lost in the annihilation process is given to the 2nd carrier.
     - 2nd carrier gives off a series of phonons until it’s energy returns to equilibrium energy ($E \sim E_c$)
**Generation Mechanisms**

1. **Direct or Band to Band:**
   - Does not have to be a direct bandgap material
   - Mechanism that results in $n_i$
   - Basis for light absorption devices such as semiconductor photodetectors, solar cells, etc.

2. **R-G Center:**
   - Two steps:
     - A bonding electron is trapped at an unintentional defect/impurity generating a hole in the valence band
     - This trapped electron is then promoted to the conduction band resulting in a new electron-hole pair
   - Almost always detrimental to electronic devices

3. **Impact Ionization:**
   - Requires 3 particles and typically high electric fields
   - 1st carrier is accelerated by high electric fields
   - Collides with a lattice atom
   - Knocks out a bonding electron
   - Creates an electron hole pair
   - What is it called when this process repeats and what device is it useful for?
Photon/Phonon Energy and Wavevector

Direct Materials
GaAs

Conservations of:
1. Energy
2. Momentum

Indirect Materials
Si, Ge

Applications: LEDs, Lasers

\[ E = h\nu = E_C - E_V \]
\[ \hbar k_{\text{photon}} \approx 0 \]
\[ E_{\text{phonon}} \approx 0 \]
Net Rate of Recombination-Generation

SRH recom-gen:

\[ R = \frac{np - n_i^2}{\tau_p(n + n_1) + \tau_n(p + p_1)} \]

\[ n_1 p_1 = n_i^2 \]

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

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

\[ \tau_n = \frac{1}{c_p N_T} \]

\[ \tau_p = \frac{1}{c_n N_T} \]
\[ E_G(Al_xGa_{1-x}As) = 1.24(GaAs) + 1.247x \]
\[ \Delta E_c = \Delta E_G \]