



جامعة مولاي إسماعيل  
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UNIVERSITÉ MOULAY ISMAÏL



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ⵜⴰⵎⴻⵔⴰⵏⵜ ⵏ ⵙⴰⵎⴰⵢⵉⵍ  
FACULTÉ DES SCIENCES

# Course Optoelectronic

## Parcours électronique S6 2025-2026

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# Chapitre 2: Optical processes in semiconductors

- Understand different optical processes in semiconductors
- Explain absorption in semiconductors and indirect intrinsic transitions
- Explain exciton absorption, donor-acceptor and impurity-band absorption
- Discuss effect of electric field on absorption
- Understand radiation in semiconductors
- Explain relation between absorption and emission spectra
- Discuss near band gap radioactive transitions

# Optical Processes in Semiconductors

## Energy of band structure

Total energy of the electron in the conduction

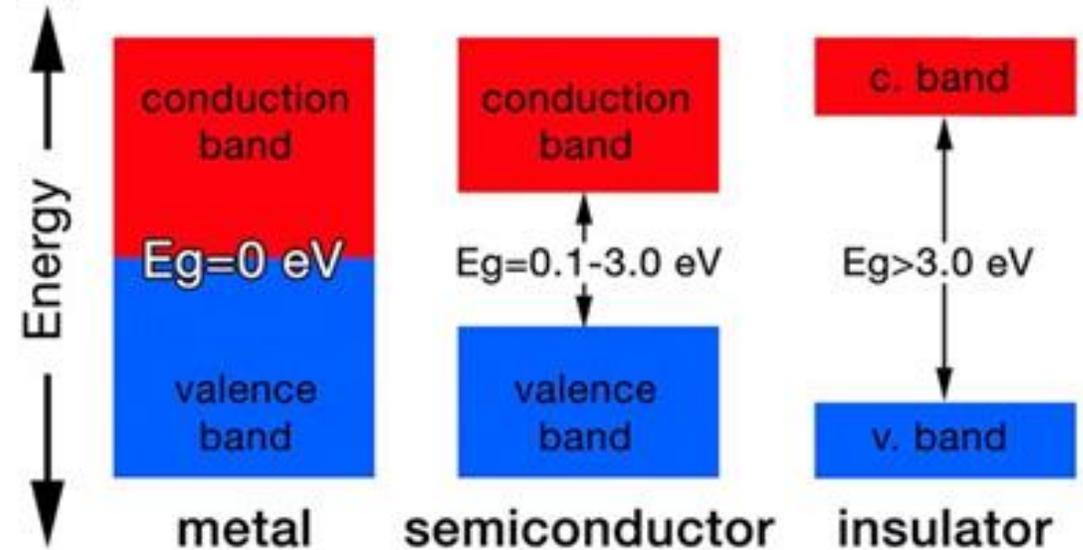
band at a specific wave vector  $K = \frac{2\pi}{\lambda}$

$$E_c = E_g + \frac{\hbar^2 k^2}{2m_e}$$

$E_g$ : band gap energy (forbidden energy gap).

$\hbar^2 k^2$ : kinetic energy of the electron.

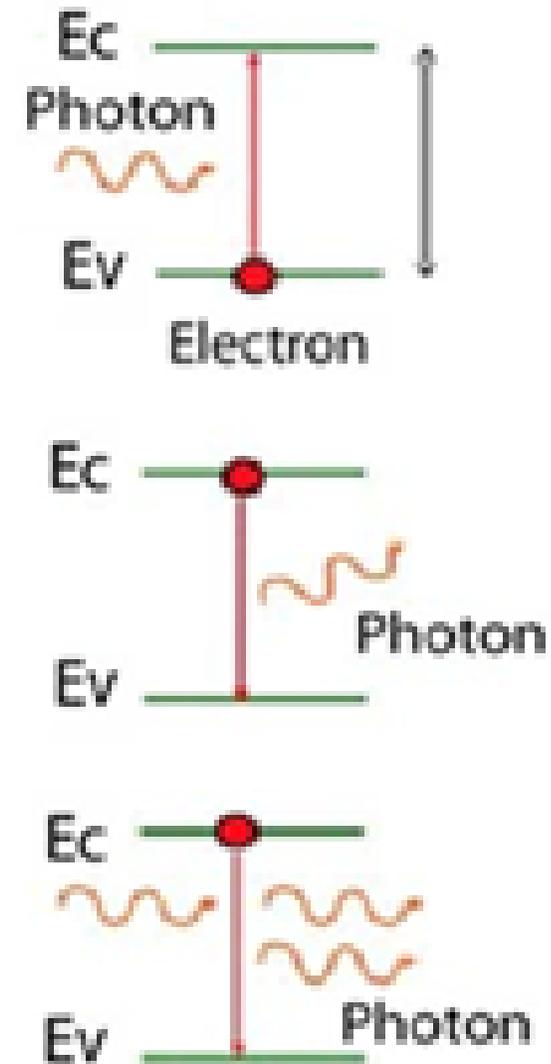
$m_e$ : effective mass of the electron.



# Optical Processes

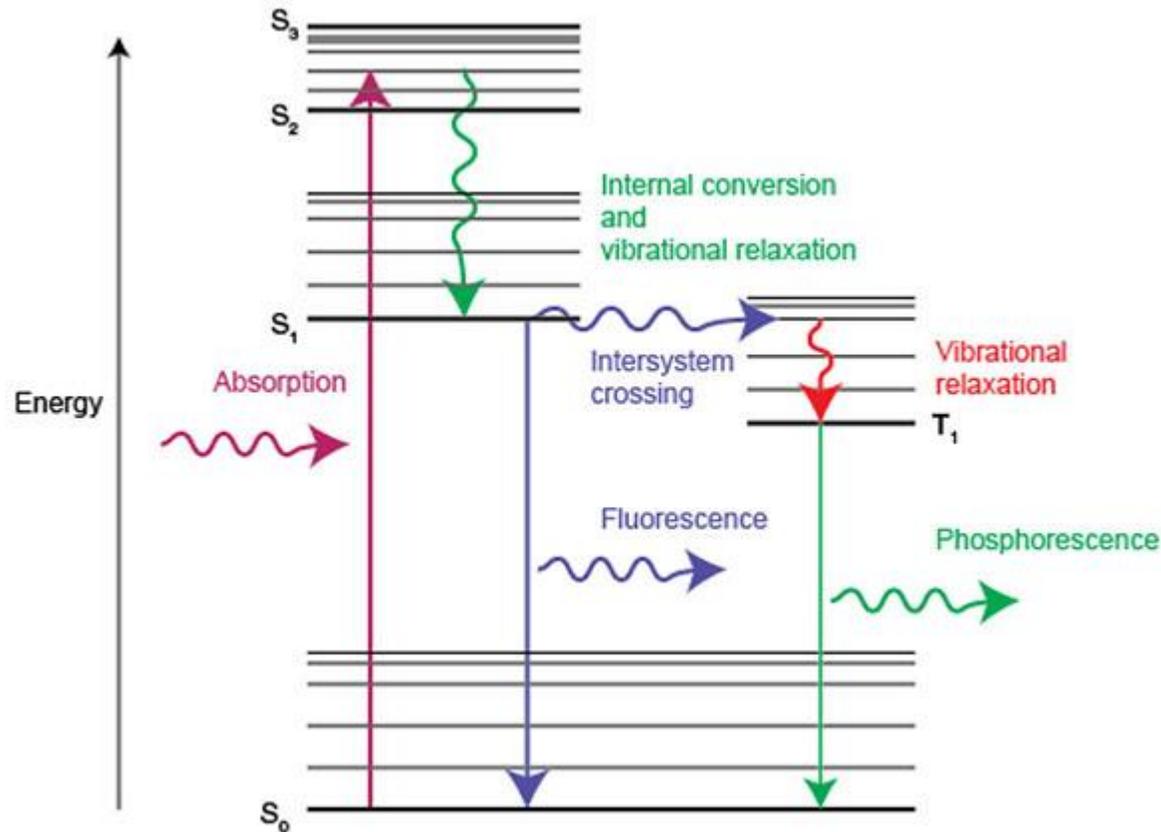
## ➤ Key Phenomena:

- **Absorption:** Photon energy creates electron-hole (e-h) pairs.
- **Spontaneous Emission:** Random recombination releasing light (LEDs).
- **Stimulated Emission:** Coherent light release (Lasers)

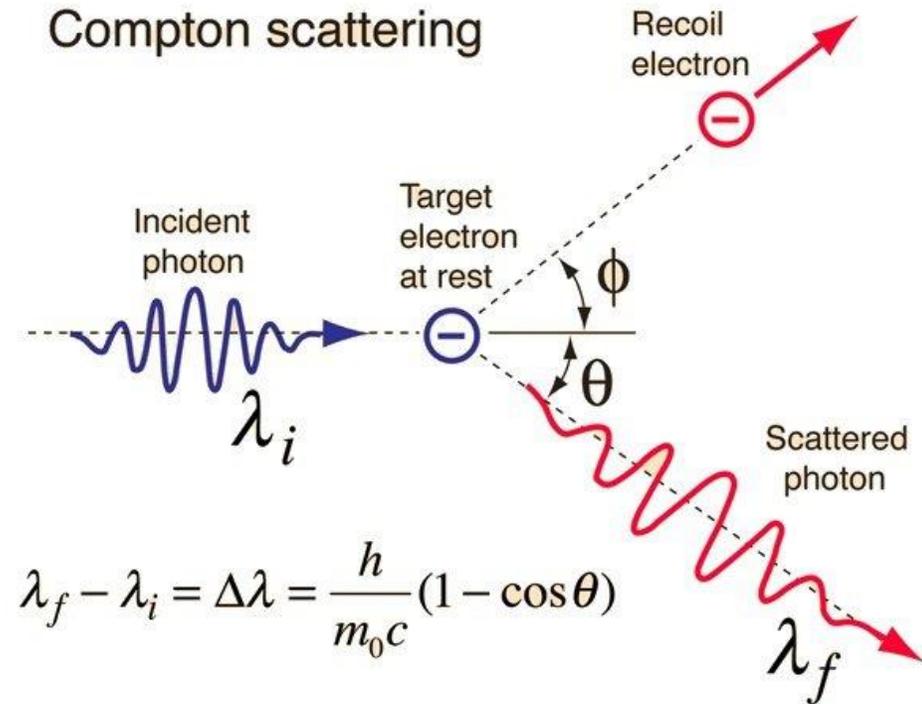


# Optical Processes

## ■ Photoluminescence

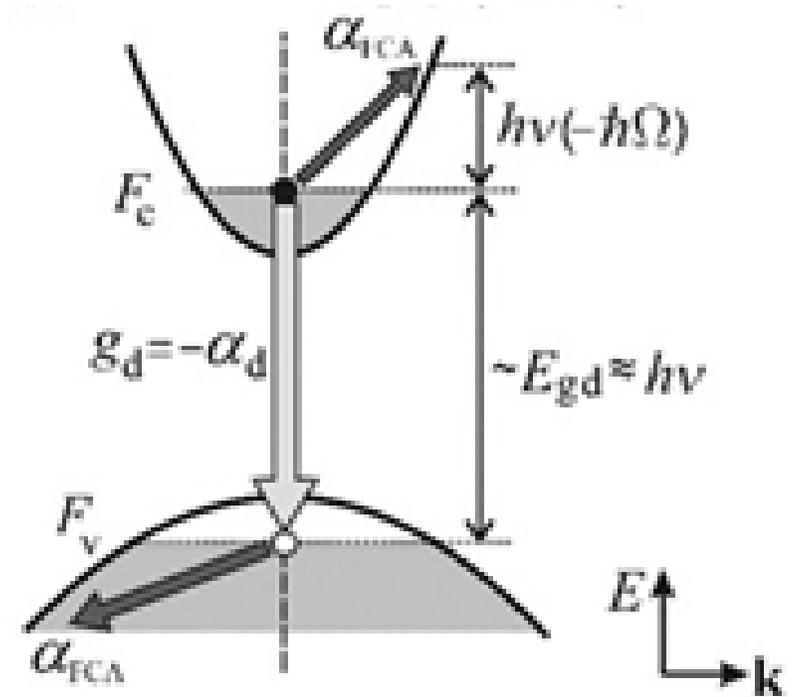


- **Scattering:** Change in photon direction or energy (Raman/Rayleigh).



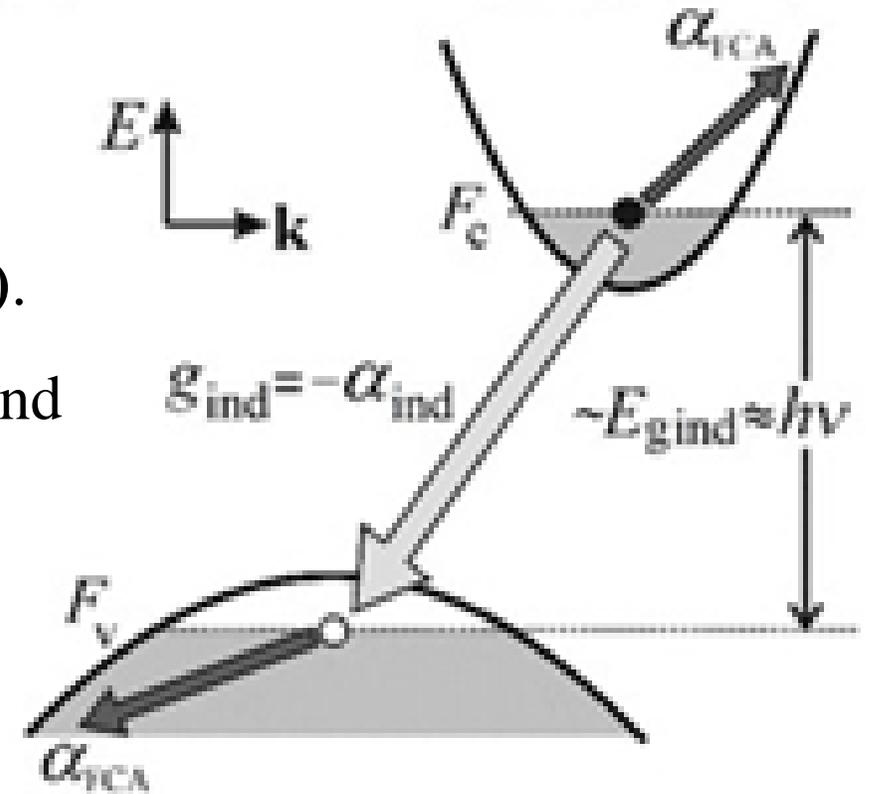
## Absorption & Indirect Intrinsic Transitions

- **Fundamental Absorption:** Occurs when  $h\nu \geq E_g$
- **Direct Transitions:** Electron moves vertically in  $k$ -space (momentum conserved by photon). (GaAs)



## Absorption & Indirect Intrinsic Transitions

- **Fundamental Absorption:** Occurs when  $h\nu \geq E_g$
- **Indirect Intrinsic Transitions:**
  - Common in **Silicon (Si)** and **Germanium (Ge)**.
  - The conduction band minimum and valence band maximum are offset in momentum.
  - **Mechanism:** Requires a **Phonon** (lattice vibration) to conserve momentum.
  - **Result:** Lower absorption coefficient compared to direct materials.



# Absorption & Indirect Intrinsic Transitions

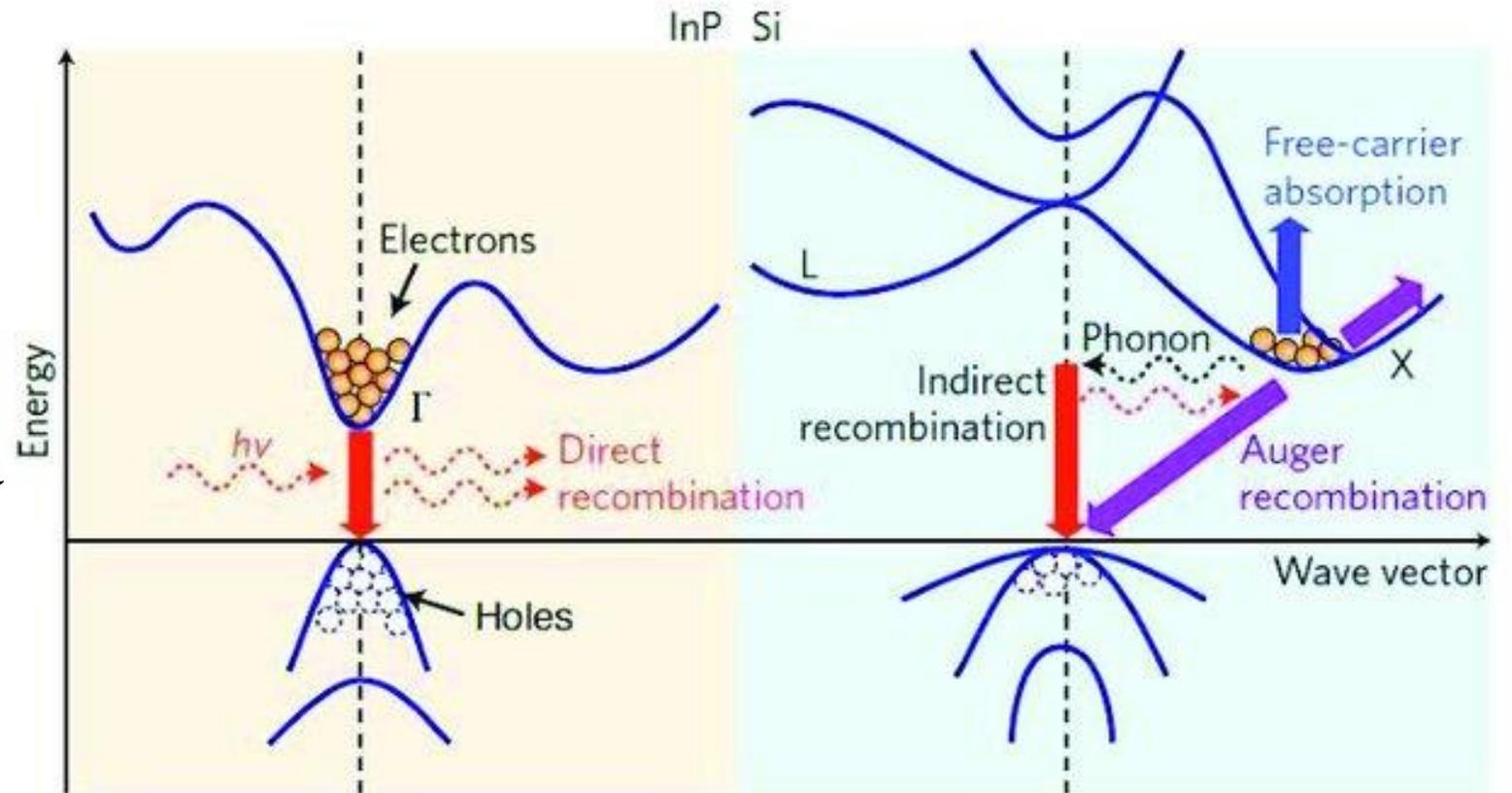
## ➤ Fundamental Absorption:

Occurs when  $h\nu \geq E_g$

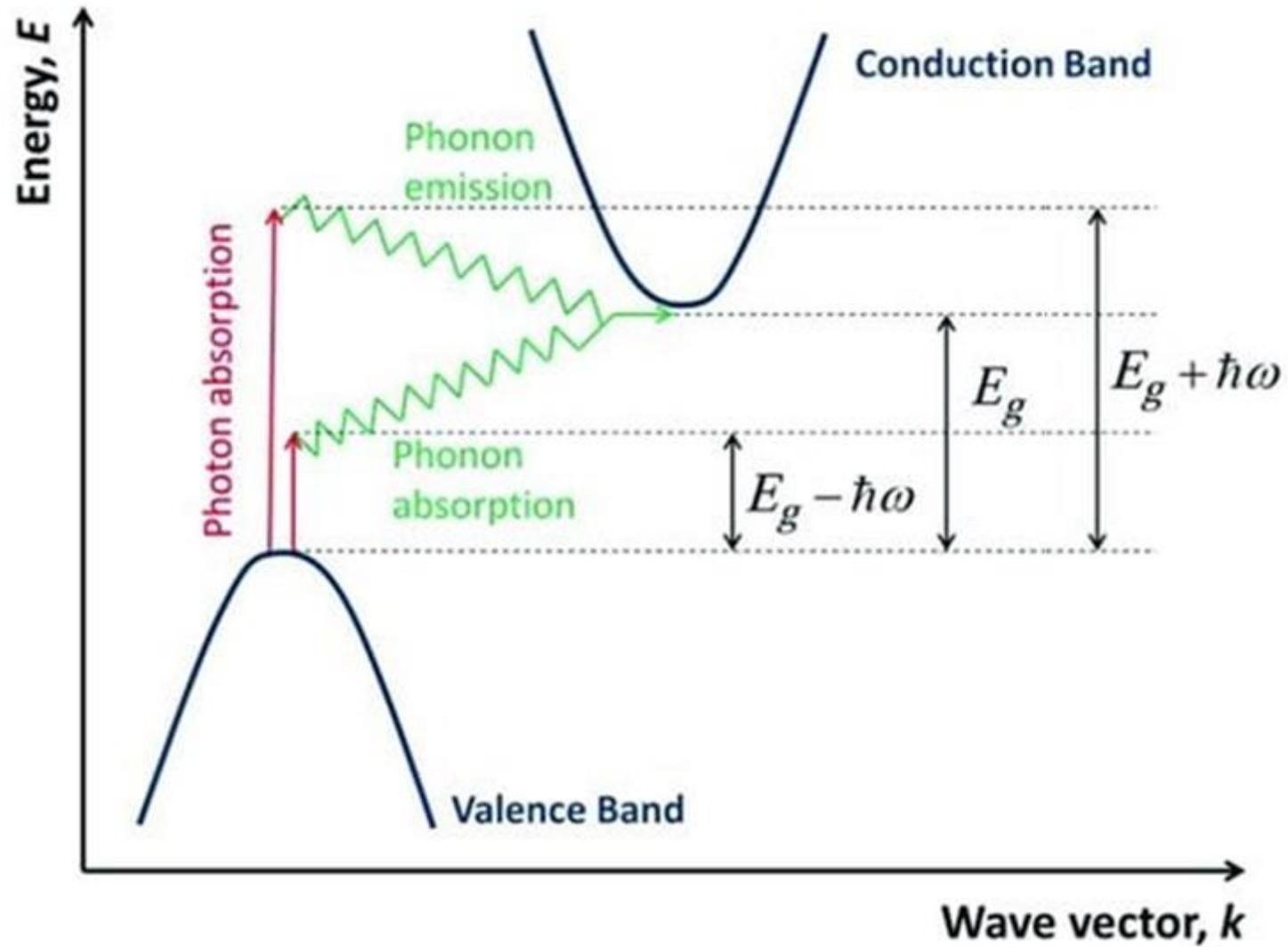
## ➤ Indirect Intrinsic

### Transitions:

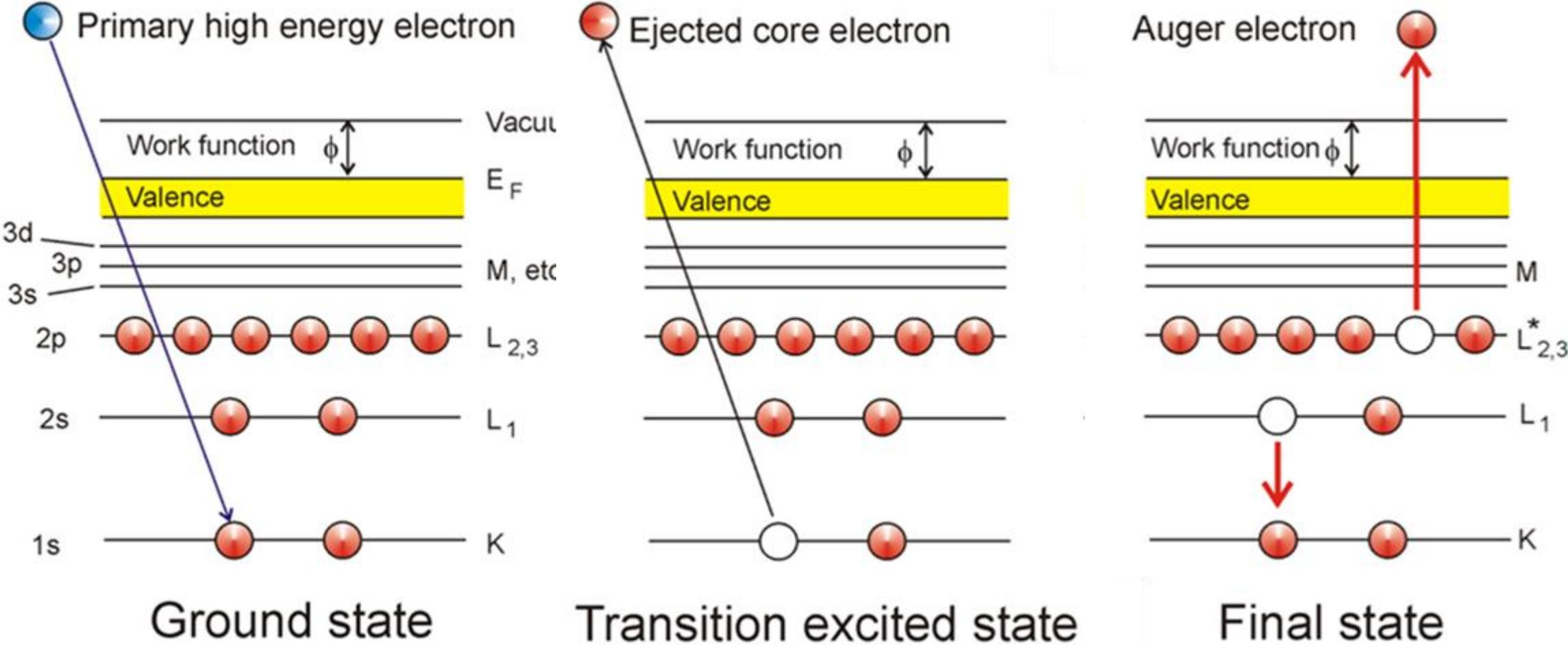
- **Mechanism:** Requires a **Phonon** (lattice vibration) to conserve momentum.



# Absorption & Indirect Intrinsic Transitions



# Absorption & Indirect Intrinsic Transitions



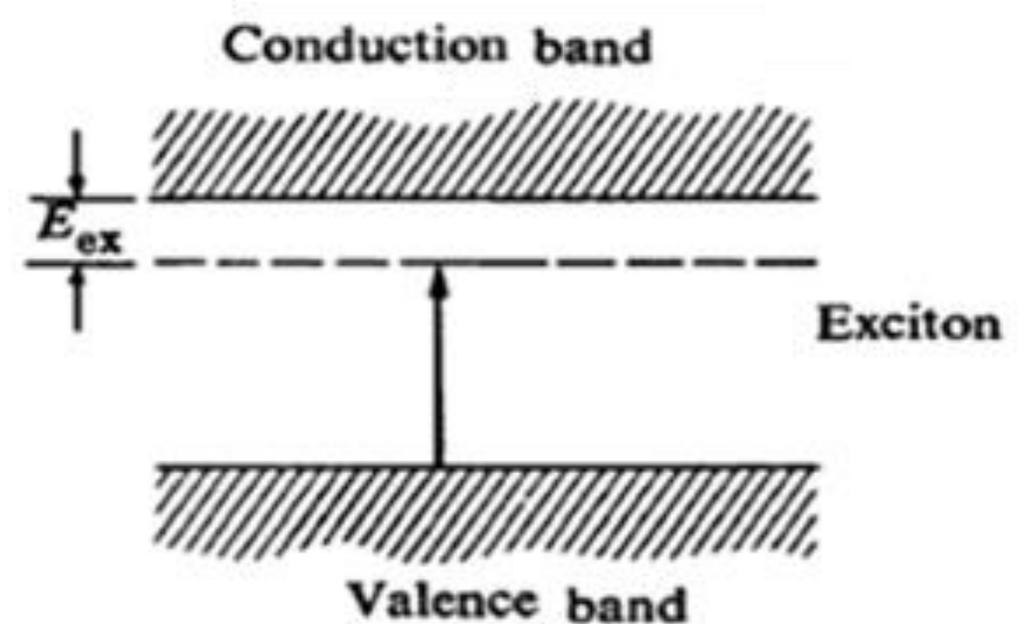
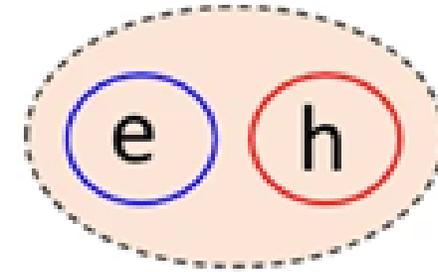
# Exciton and Impurity-Based Absorption

## ➤ Exciton Absorption:

- Formation of a bound e-h pair via:

$$\text{Coulomb attraction } U = \frac{e^2}{4\pi\epsilon\epsilon_0 r}.$$

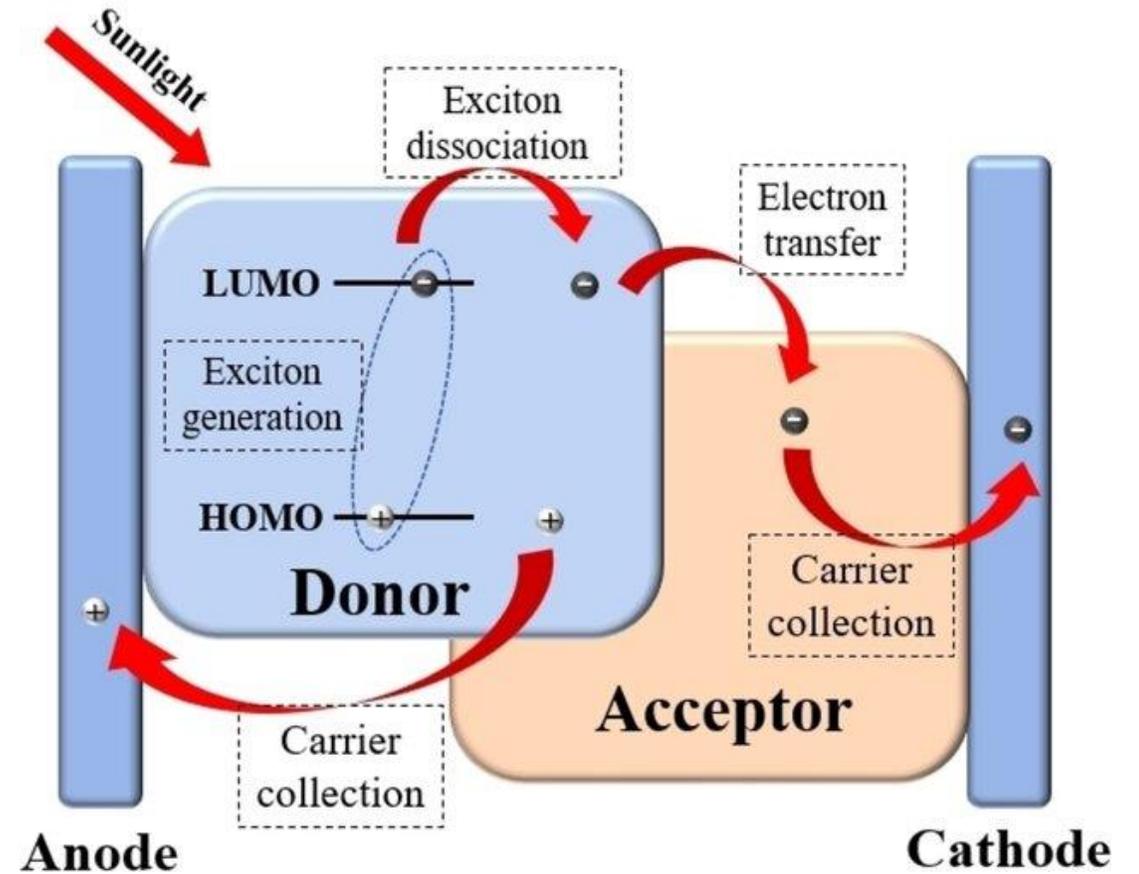
- Creates a sharp absorption peak at  $E < E_g$
- $h\nu = E_g - E_{ex}$ : energy of the photon involved in exciton absorption
- $E_{ex}$  (about 0.01 eV) is the exciton binding energy.



## Exciton and Impurity-Based Absorption

### ➤ Donor-Acceptor (D-A) Absorption:

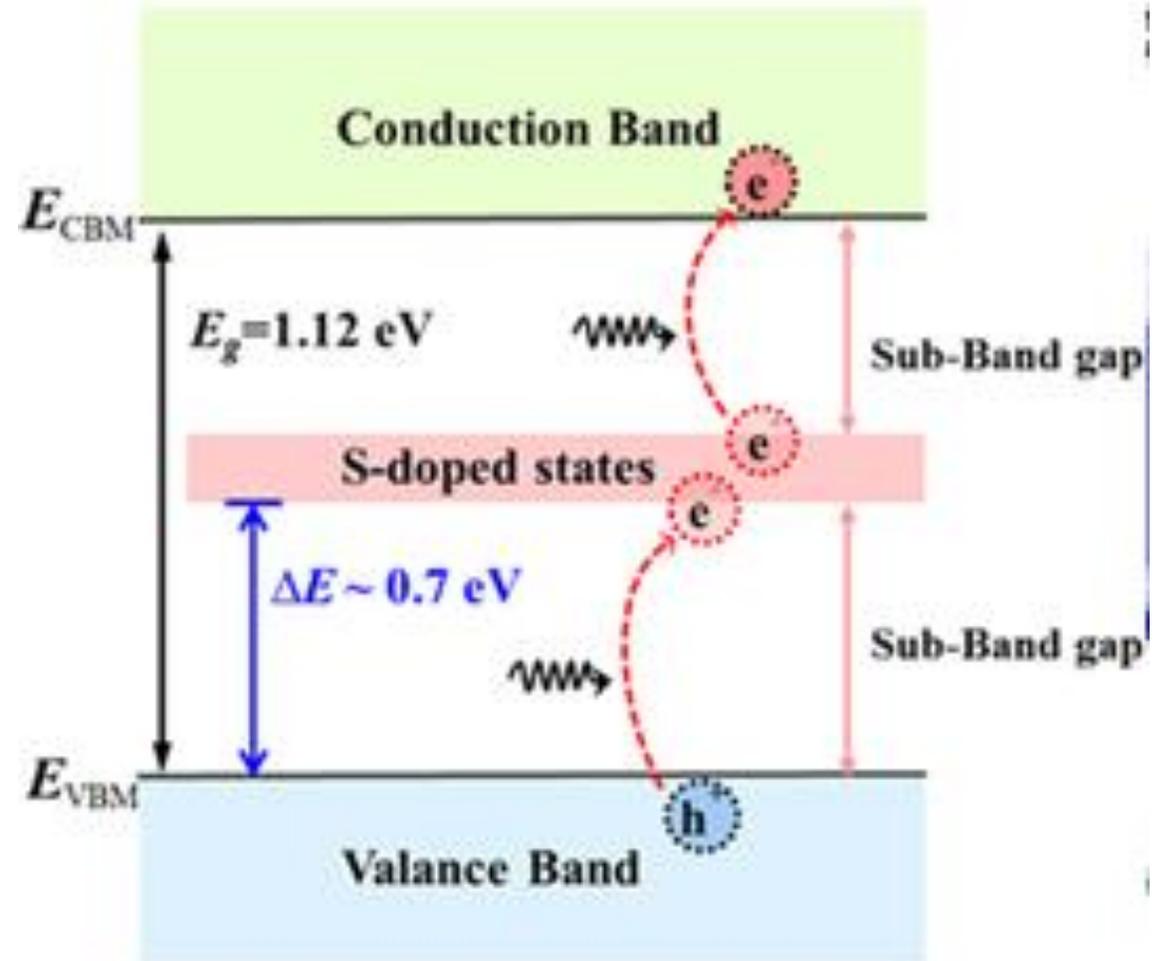
- Transitions between compensated impurity levels.
- Energy depends on the spatial distance between the donor and acceptor.



# Exciton and Impurity-Based Absorption

## ➤ Impurity-Band Absorption:

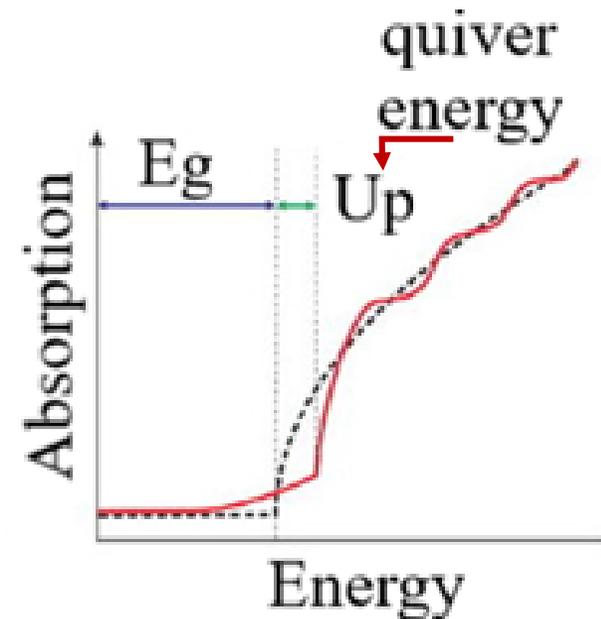
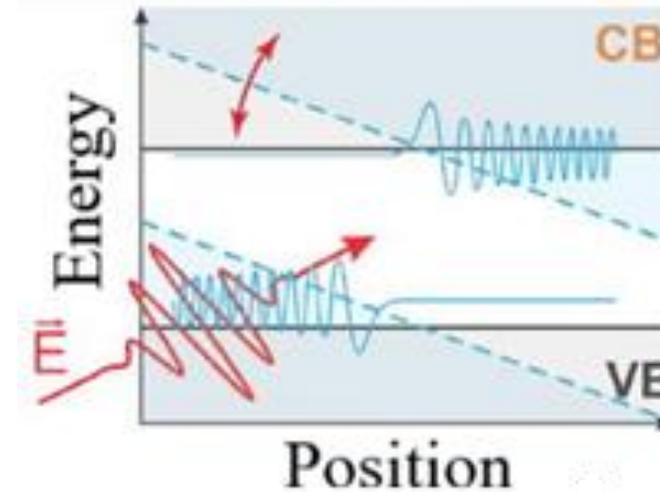
- Occurs in heavily doped semiconductors where impurity states merge into a band.
- Allows for "sub-band gap" absorption.



# Effect of Electric Field on Absorption

## ➤ Franz-Keldysh Effect:

- In bulk crystals, an electric field causes "band tilting."
- Allows wavefunctions to overlap in the forbidden gap (tunneling).
- **Observation:** A red-shift in the absorption edge (absorption below  $E_g$ ).

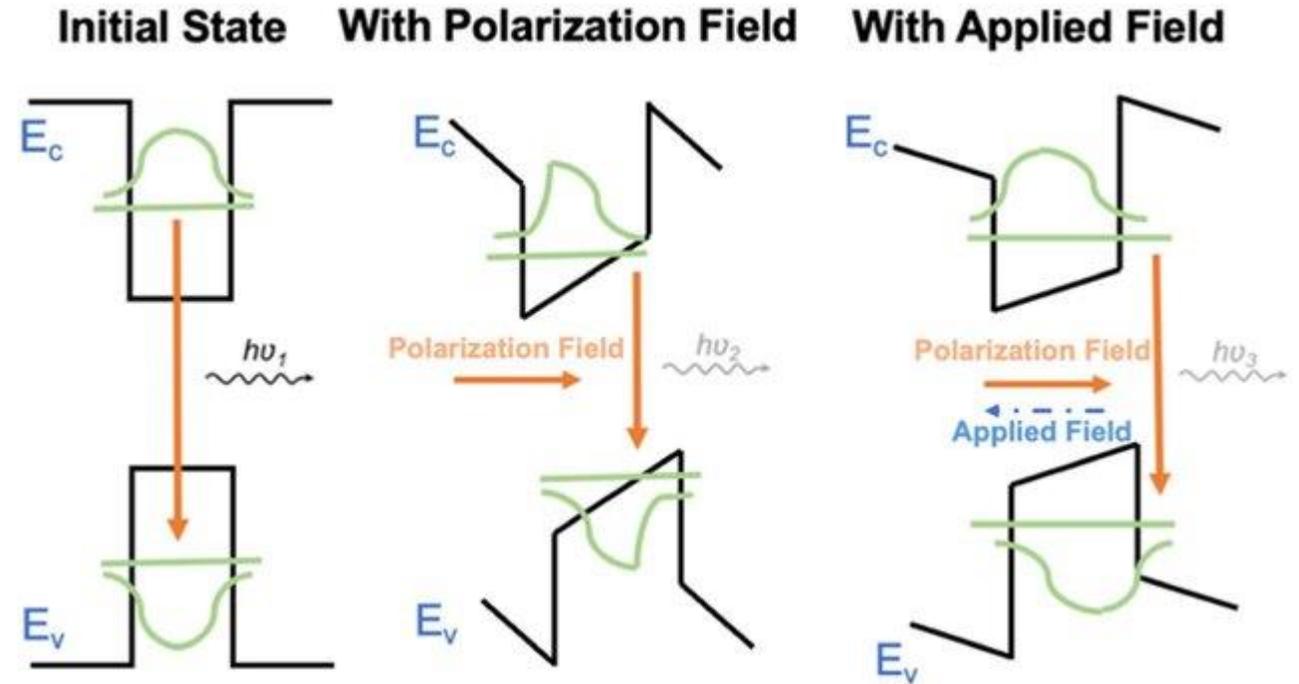


# Effect of Electric Field on Absorption

## ➤ Quantum-Confined Stark Effect

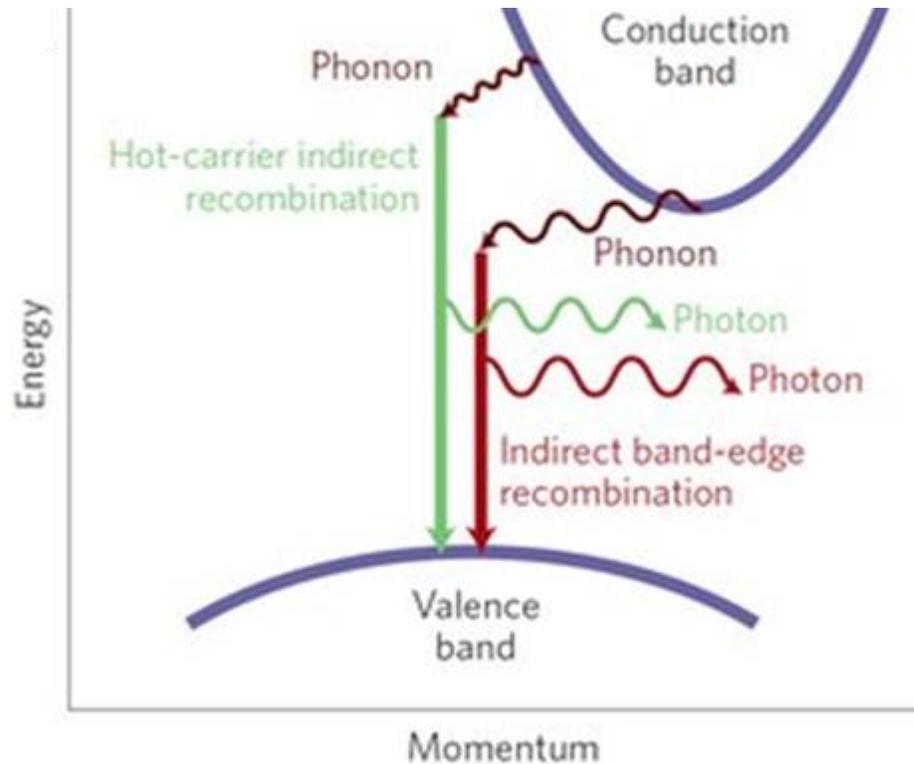
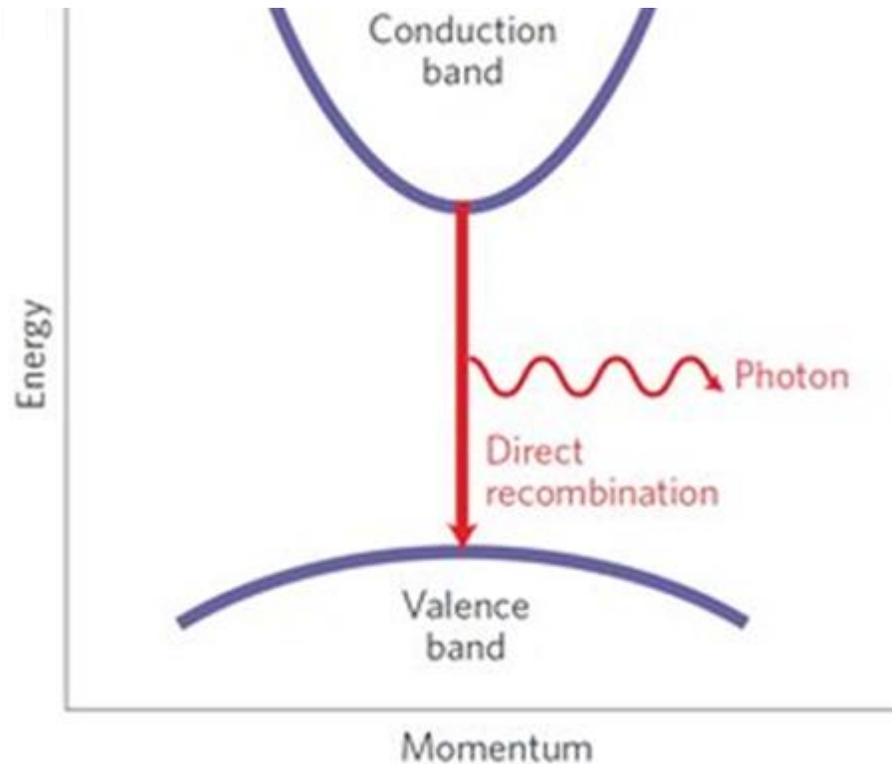
(QCSE):

- Observed in Quantum Wells.
- Field shifts the confined energy levels, significantly changing the absorption spectrum.
- Used in modern high-speed optical modulators.



# Radiation in Semiconductors

- **Radiative Recombination:** An excited electron drops to a lower energy state, emitting a photon.



# Radiation in Semiconductors

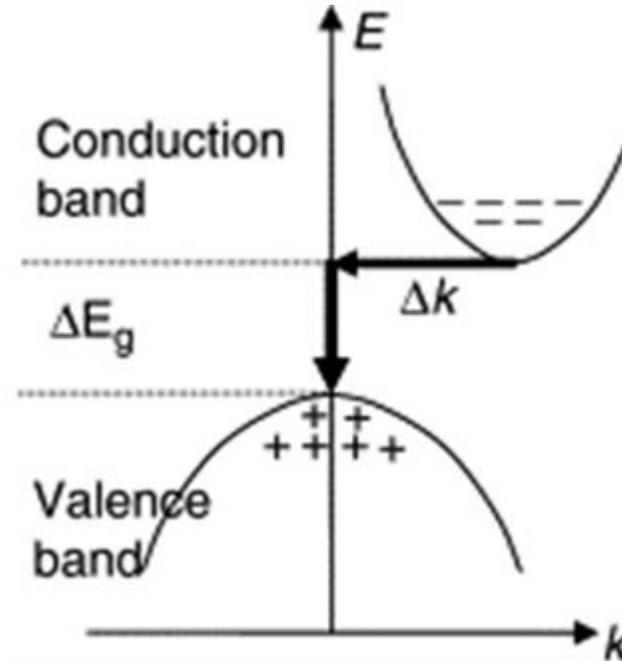
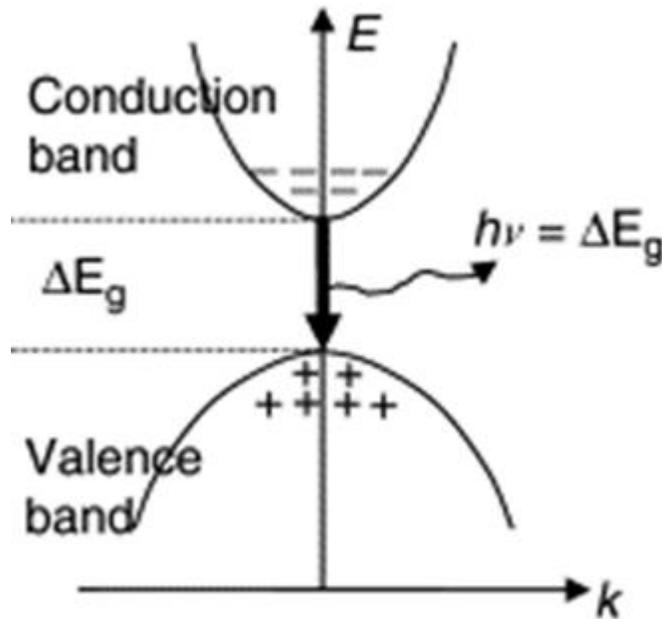
## ➤ Efficiency:

- High in **Direct Band Gap** (e.g., GaAs, GaN).
- Low in **Indirect Band Gap** (e.g., Si)  
due to the need for phonon assistance.

Radioactive  
recombination ↓

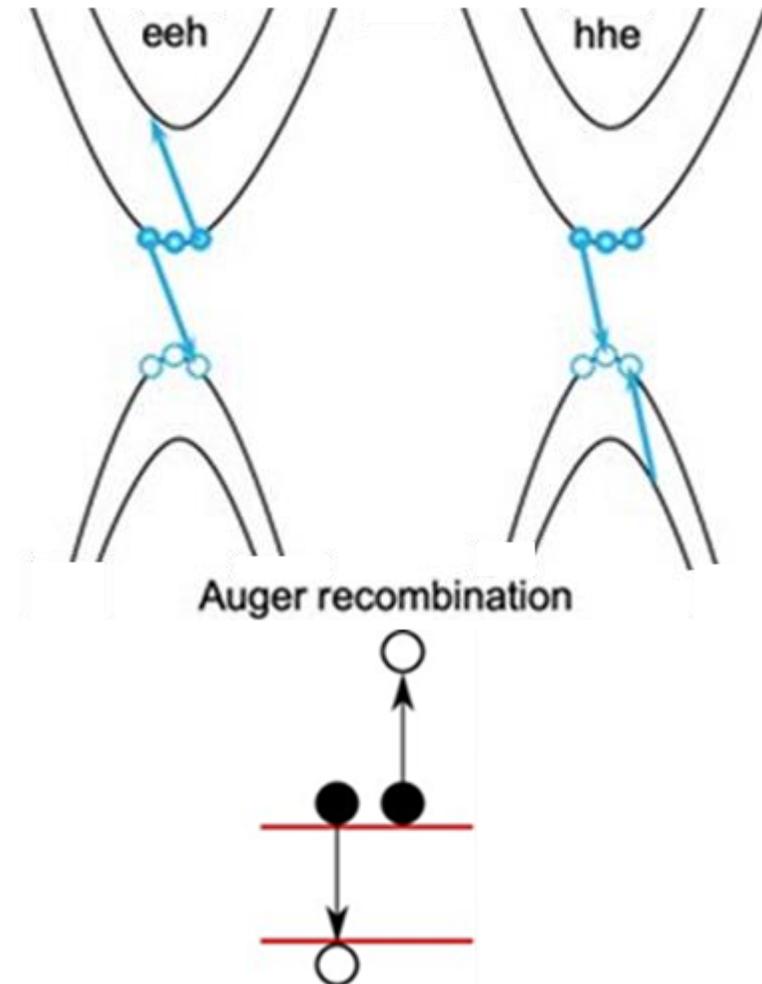
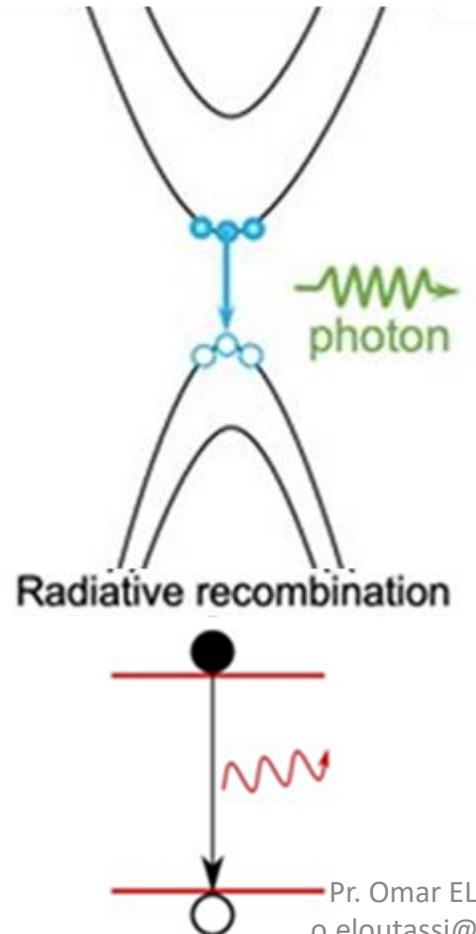
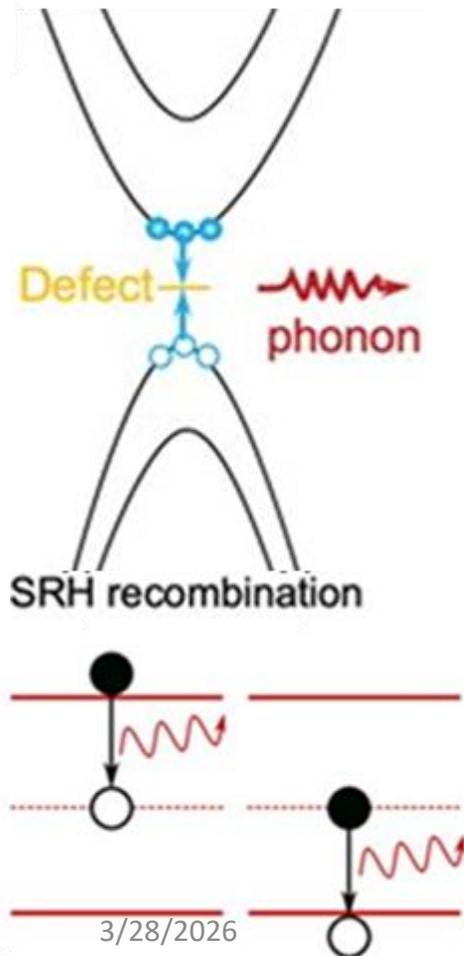
$$\eta_{rad} = \frac{R_{rad}}{R_{rad} + R_{non-rad}}$$

↓  
Non-radioactive  
recombination



# Radiation in Semiconductors

- **Non-Radiative Competition:** Shockley-Read-Hall (SRH) and Auger recombination reduce light output.



## Relation Between Absorption & Emission

### ➤ Van Roosbroeck-Shockley Relation:

- Links the spontaneous emission rate to the absorption coefficient.

$$R(\hbar\omega) = \frac{(\hbar\omega)^2 n^2}{\pi^2 c^2 \hbar^3} \cdot \alpha(\hbar\omega) \cdot \frac{1}{\exp(\hbar\omega/k_B T) - 1}$$

$\alpha(\hbar\omega)$ : The absorption coefficient of the material.

$n$ : The refractive index.

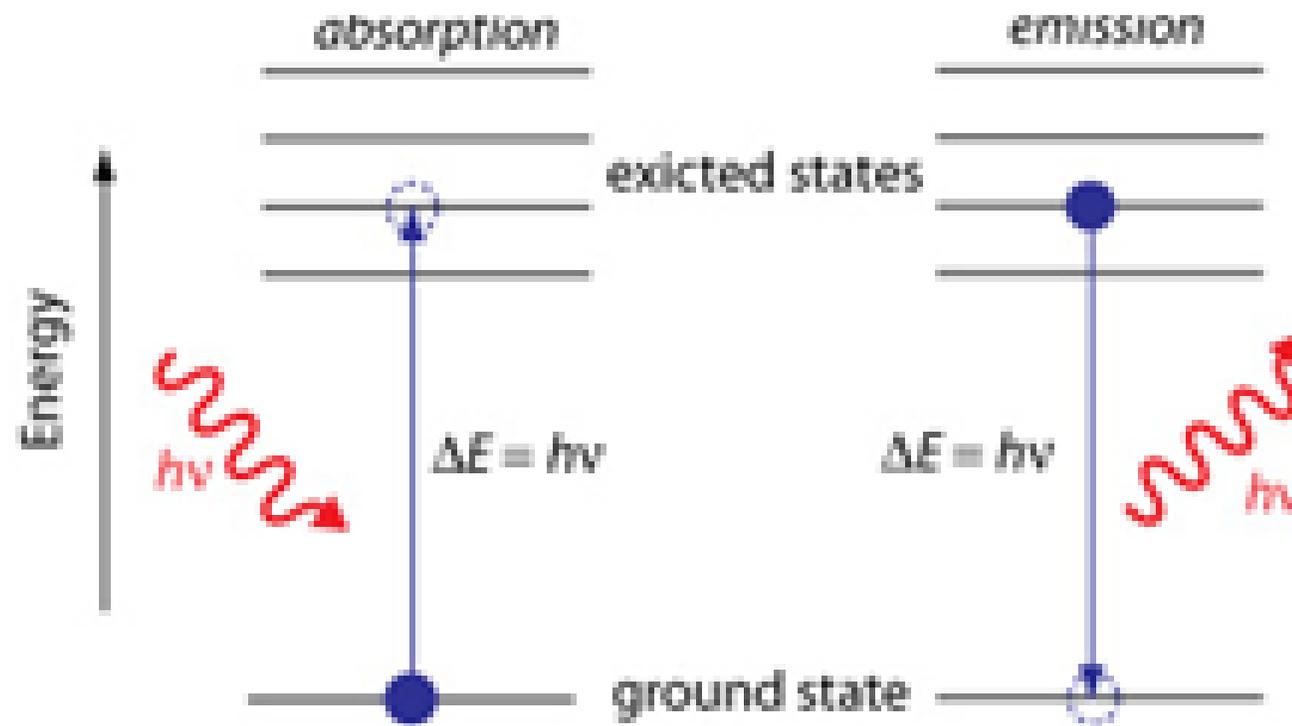
$k_B T$ : Thermal energy (Boltzmann constant multiplied by absolute temperature).

$\hbar\omega$  : The density of photon modes and the Planck distribution for thermal photons

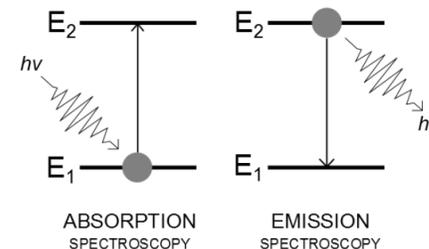
# Relation Between Absorption & Emission

## ➤ Van Roosbroeck-Shockley Relation:

- **Principle:** In thermal equilibrium, the rate of photon absorption must equal the rate of photon emission.

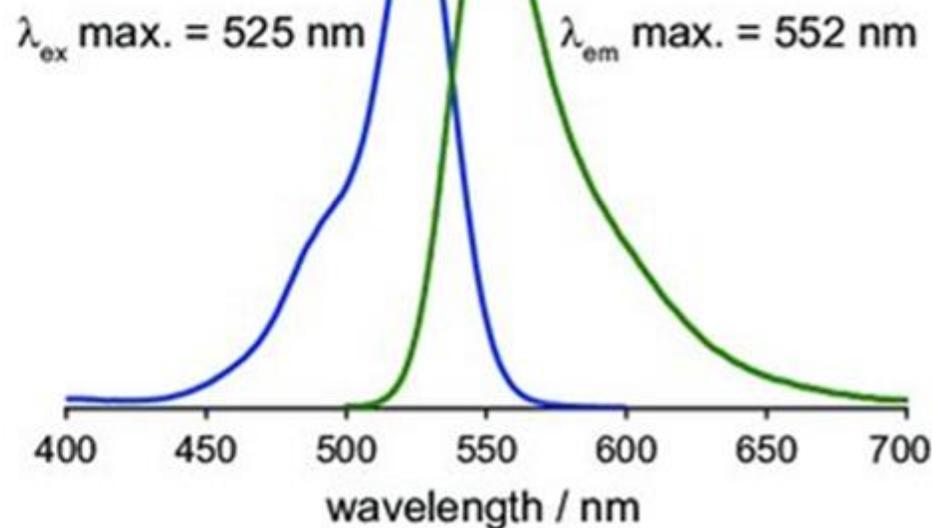
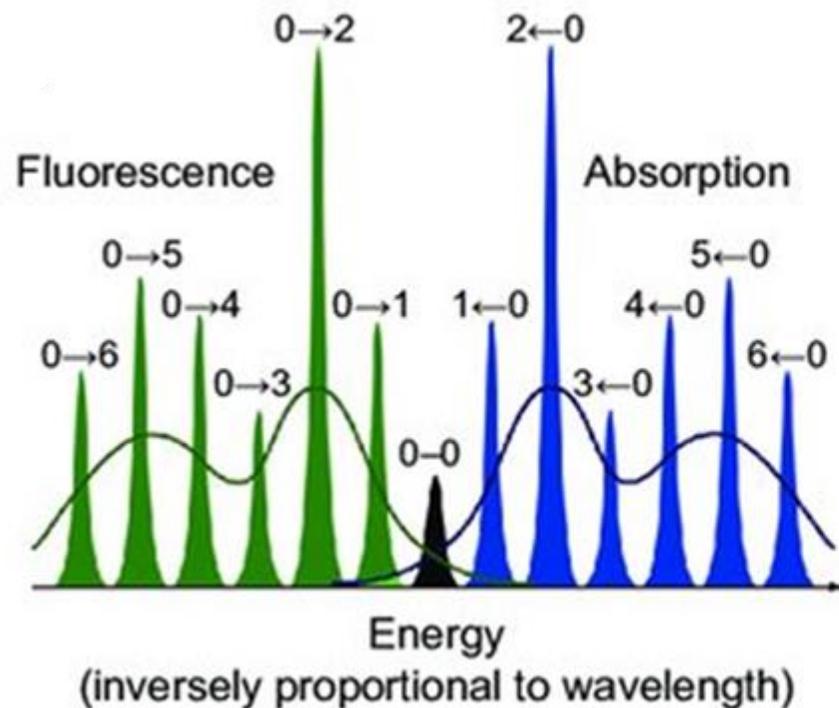


# Relation Between Absorption & Emission



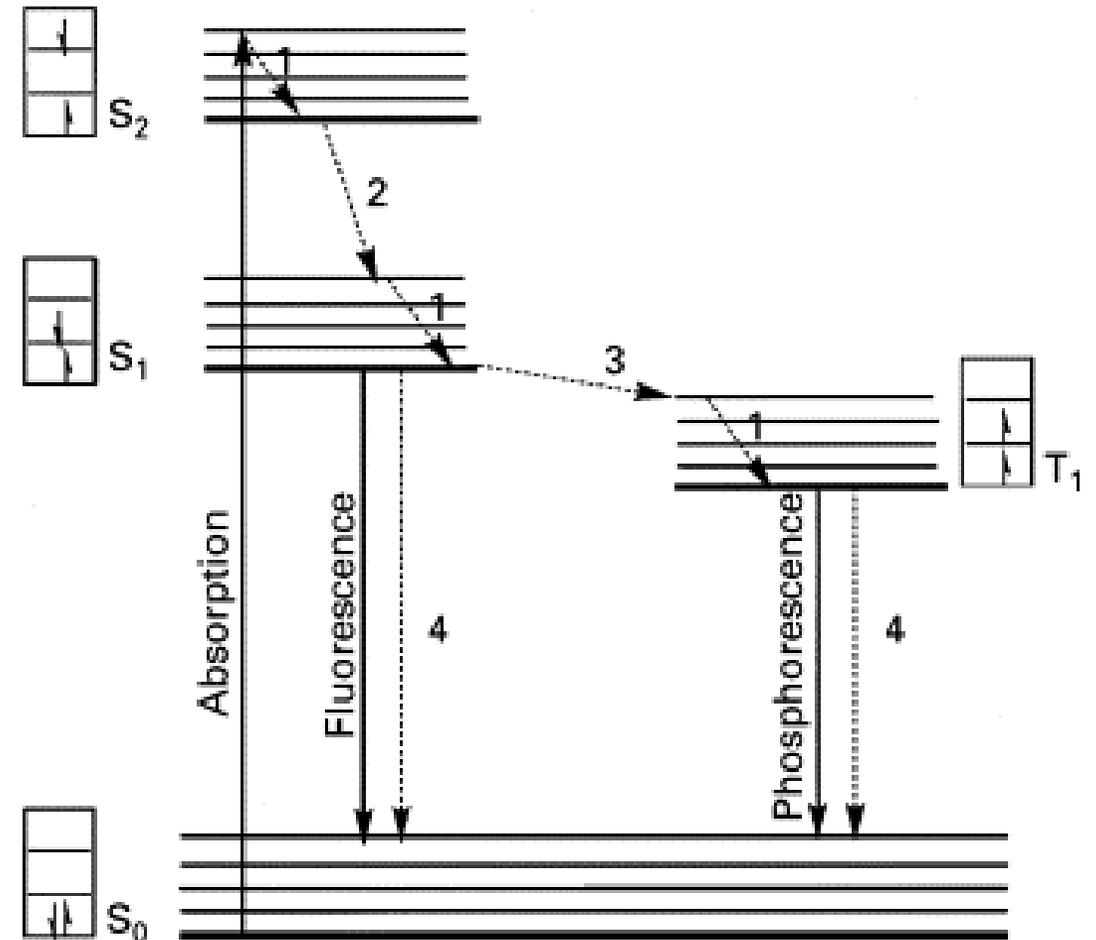
## ➤ Spectral Relationship:

- Emission spectra usually peak at slightly lower energies than absorption (Stokes shift).
- The absorption spectrum defines the "density of states" available for emission.



## Near Band Gap Radiative Transitions

- **Definition:** Transitions involving states very close to the edges of the conduction and valence bands.



# Near Band Gap Radiative Transitions

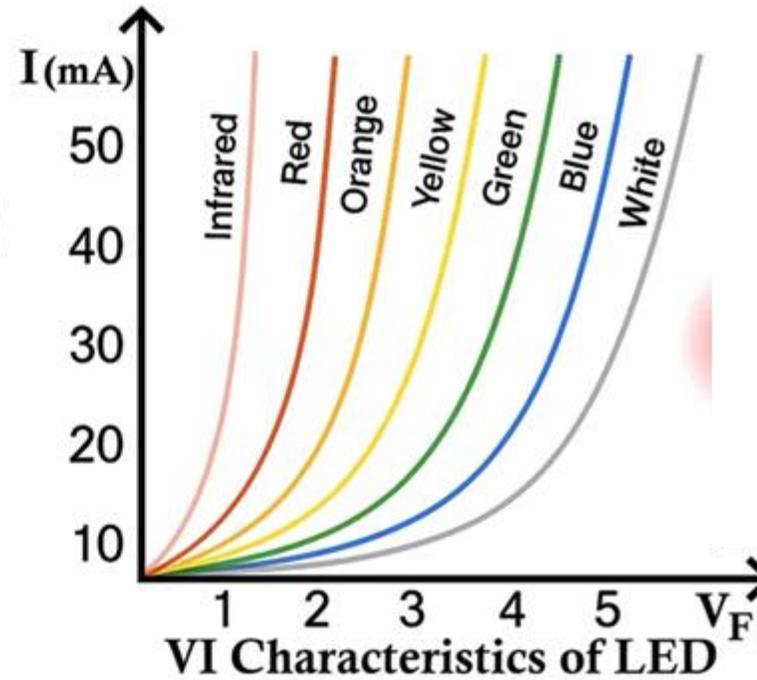
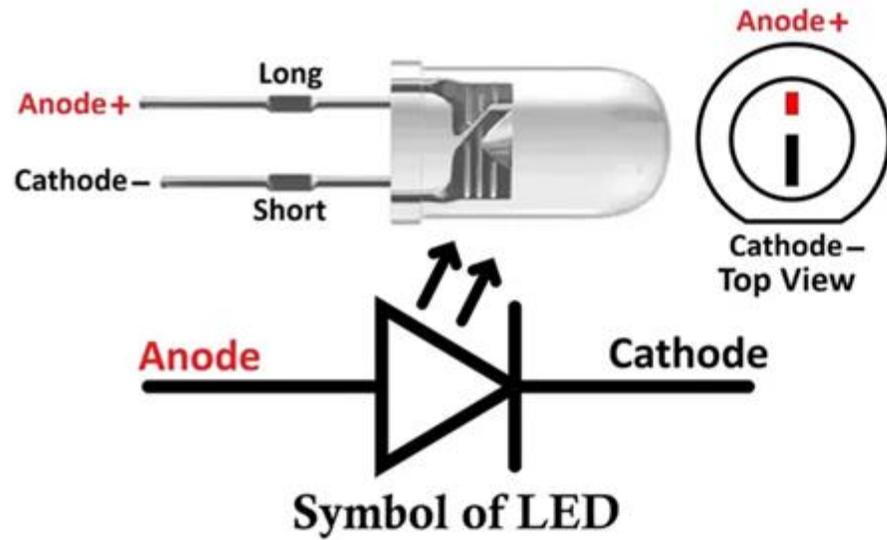
## ➤ **Primary Mechanisms:**

- **Band-to-Band:** Free electron recombining with a free hole.
- **Free-to-Bound:** Transition between a band and an impurity level.
- **Excitonic Decay:** Recombination of bound excitons (dominant at low temperatures/high purity).

➤ **Significance:** These transitions determine the peak wavelength and "color" purity of LEDs and Semiconductor Lasers.

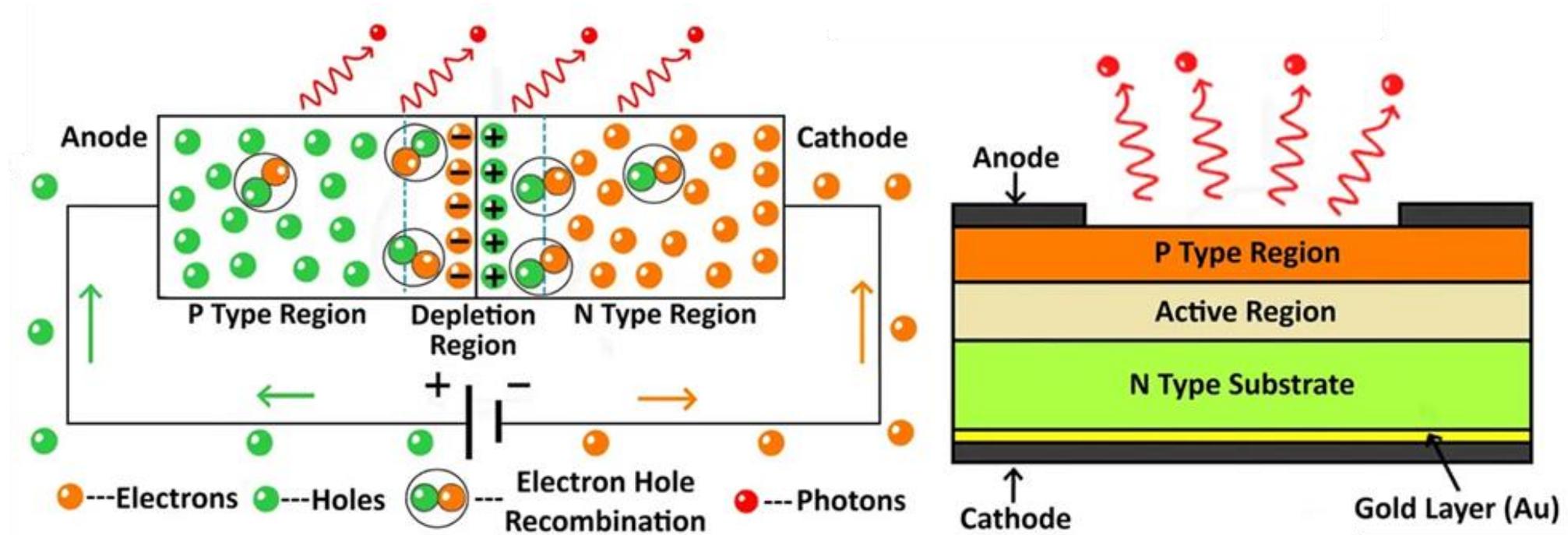
# Application

## Light Emitting Diode LED



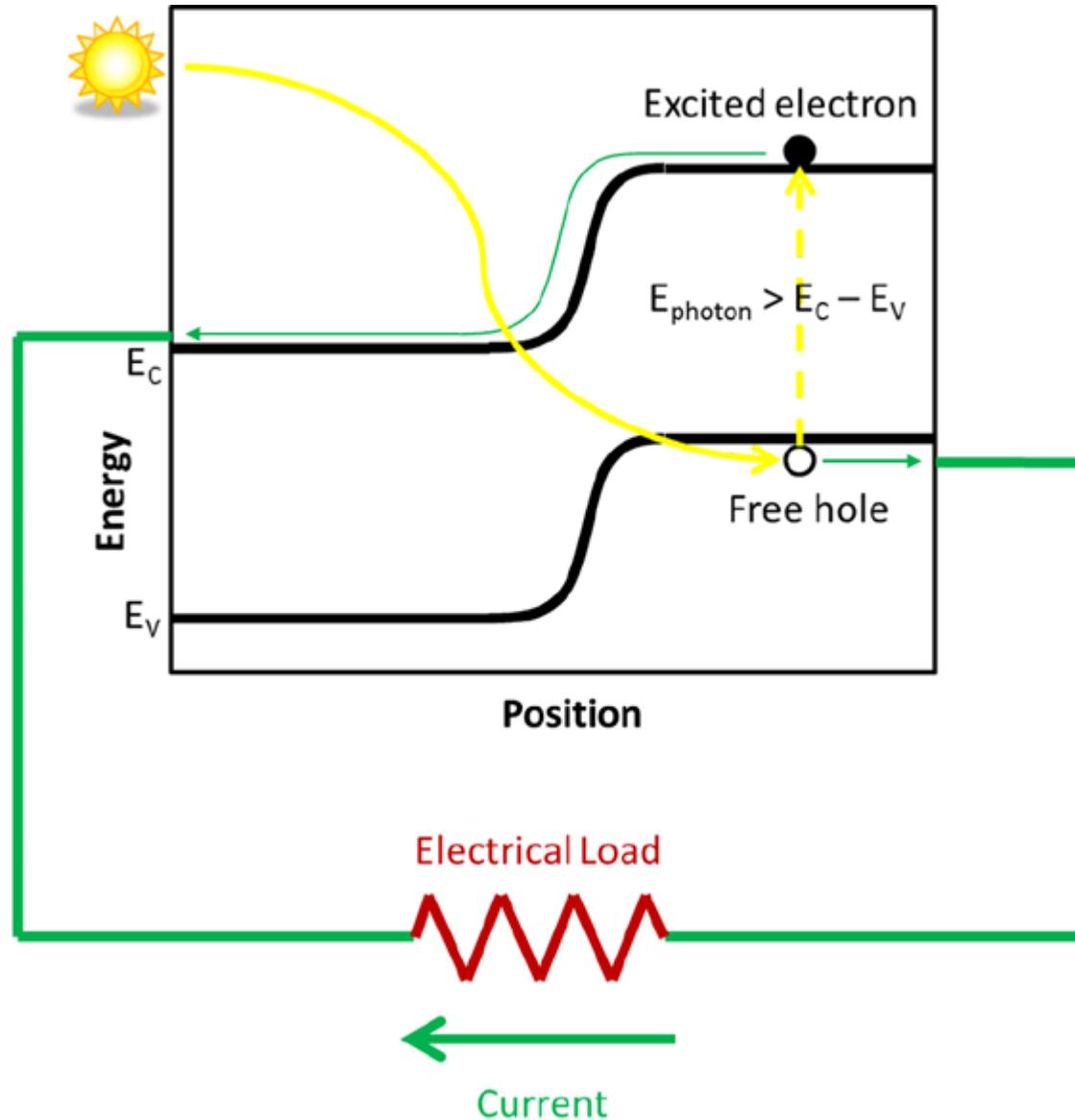
# Application

## Working of LED



# Application

## Solar cell



# End chapter 2

[Video](#)

<https://www.youtube.com/watch?v=8hp-Vp9YrLo&t=202s>