# (MPM-202)
# Optoelectronics and Optical Communication System

UNIT-I (Optical Process in Semiconductors)

**Lecture-7**

by

Prof. D. K. Dwivedi
Physics and Material Science Department
Madan Mohan Malaviya University of Technology, Gorakhpur

SYLLABUS

## MPC-202 OPTOELECTRONICS AND OPTICAL COMMUNICATION SYSTEM Credits 4 (3-1-0)

### UNIT I: Optical process in semiconductors

Optoelectronic properties of semiconductor: effect of temperature and pressure on bandgap, carrier scattering phenomena, conductance processes in semiconductor, bulk and surface recombination phenomena, optical properties of semiconductor, EHP formation and recombination, absorption in semiconductors, effect of electric field on absorption.

### UNIT II: Optical sources and detectors

An overview of optical sources (Semiconductor Laser and LEDs), Optical Detectors: Type of photo detectors, characteristics of photo detectors, noise in photo detectors, photo transistors and photo conductors.

### UNIT III: Optical fiber

Structure of optical wave guide, light propagation in optical fiber, ray and wave theory, modes of optical fiber, step and graded index fibers, transmission characteristics of optical fibers, signal degradation in optical fibers; attenuation, dispersion and pulse broadening in different types of optical fibres.

### UNIT IV: Fiber components and optoelectronic modulation

Fiber components: Fibre alignments and joint loss, fiber splices, fiber connectors, optical fiber communication, components of an optical fiber communication system, modulation formats, digital and analog optical communication systems, analysis and performance of optical receivers, optoelectronic modulation.

# Electron-Hole Pair Recombination

- The recombination may be ***radiative or nonradiative*****.**
- **In a nonradiative recombination,** the excess energy due to recombination is usually imparted to phonons and dissipated as heat.
- **In a radiative transition,** the excess energy is dissipated as photons, usually having energy equal to the band gap.
- This is ***luminescent*** process, which is classified to the method by which electron-hole pairs are created.
- ***Photoluminescence*** involves the *radiative* recombination of electron-hole pairs created by injection of photons.

# Electron-Hole Pair Recombination

- ***Cathodoluminescence*** is the process of *radiative* recombination of electron-hole pair created by electron bombardment.

- ***Electroluminescence*** is the process of *radiative* recombination following injection with a p-n junction or similar device.

- In a semiconductor, one can define the nonequillibrium distribution functions for electrons and holes as

$$\boldsymbol{f_n(\varepsilon) = \frac{1}{1+exp\left(\frac{\varepsilon-\varepsilon_{fn}}{k_B T}\right)}} \qquad \textbf{(1)}$$

## Electron-Hole Pair Recombination

$$f_p(\varepsilon) = \frac{1}{1+exp\left(\frac{\varepsilon-\varepsilon_{fp}}{k_B T}\right)} \quad (2)$$

- These distribution functions define $\varepsilon_{fn}$ and $\varepsilon_{fp}$, the *quasi-Fermi levels* for electrons and holes, respectively.

- When the excitation source creating excess carrier is removed, $\varepsilon_{fn} = \varepsilon_{fp} = \varepsilon_F$.

- The difference $(\varepsilon_{fn} - \varepsilon_{fp})$ is measure of the deviation from the equilibrium.

- As with equilibrium statistics, we obtain for the nondegenerate case

# Electron-Hole Pair Recombination

$$\boldsymbol{f_n(\varepsilon) \cong exp\left(\frac{\varepsilon_{fn}-\varepsilon}{k_B T}\right)} \quad \textbf{(3)}$$

$$\boldsymbol{f_p(\varepsilon) \cong exp\left(\frac{\varepsilon_{fp}-\varepsilon}{k_B T}\right)} \quad \textbf{(4)}$$

And the nonequilibrium carrier concentrations are given by

$$\boldsymbol{n = N_C exp\left(\frac{\varepsilon_{fn}-\varepsilon_C}{k_B T}\right)} \quad \textbf{(5)}$$

$$\boldsymbol{p = N_C exp\left(\frac{\varepsilon_{fn}-\varepsilon_C}{k_B T}\right)} \quad \textbf{(6)}$$

# Electron-Hole Pair Recombination

- In a p-n junction under forward bias a large density of excess charge carriers exist in the depletion region and close to it on either side.

- The concentration of these carriers can be determined from the appropriate quasi-Fermi levels.

- Let n-type semiconductor with an equilibrium electron density $n_0$ ($= N_D$, the donor density) is uniformly irradiated with intrinsic photoexcitation (above-bandgap light) so as to produce $\Delta n$ electron-hole pairs with a generation rate G.

## Electron-Hole Pair Formation and Recombination

- The nonequilibrium electron and hole concentrations are given by

$$\boldsymbol{n} = \Delta\boldsymbol{n} + \boldsymbol{n_0} \quad \textbf{(7)}$$

$$\mathbf{p} = \Delta\boldsymbol{n} + {}^{\boldsymbol{n_i^2}}\!/_{\boldsymbol{n_0}} \quad \textbf{(8)}$$

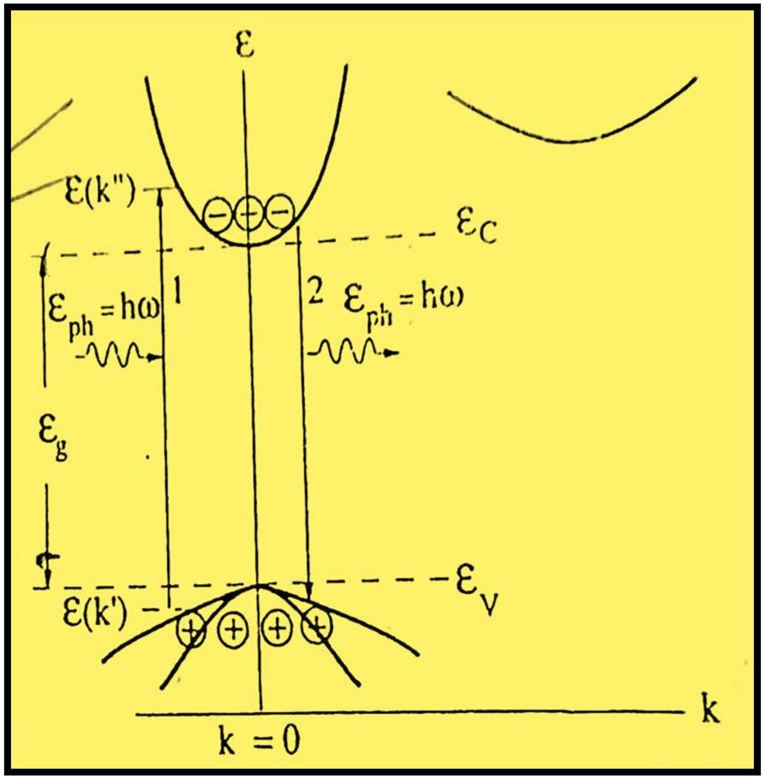
- Under steady state conditions the recombination rate must be equal to the generation rate:

$$\mathbf{G = R} \quad \textbf{(9)}$$

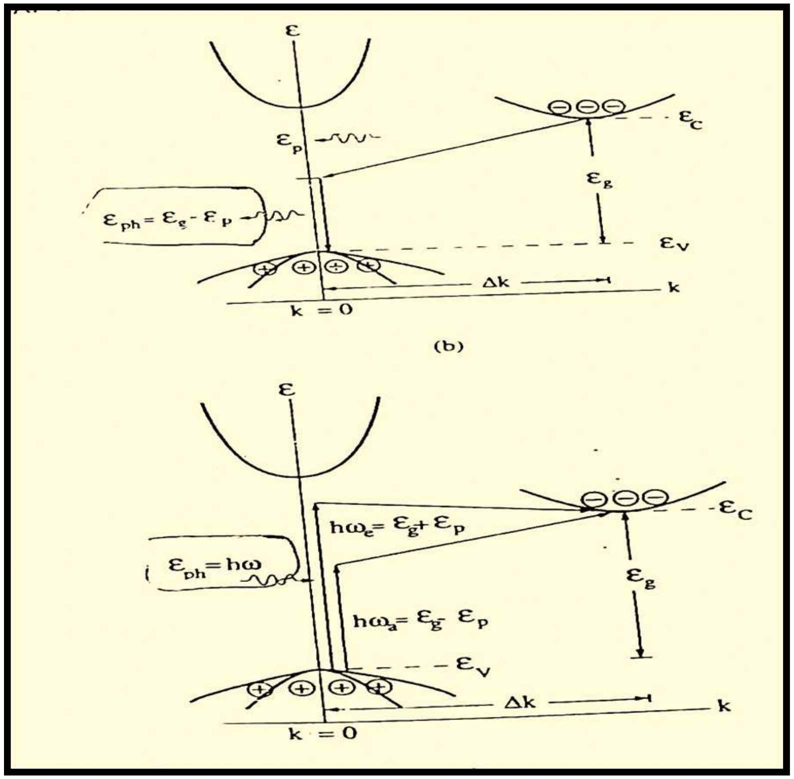
## Various Recombination Processes

# 1. Band-to-Band Generation and Recombination

**Direct Band gap Semiconductor**




**Indirect Band gap Semiconductor**



# Various Recombination Processes

- **Recombination rate** is defined as number of electron hole pair annihilated per unit volume per second

$$= Bnp$$

where, **B** is recombination rate and **n & p** are carrier concentration in C.B. and V.B. respectively.

- Band to band transition is not the only transition which generates or annihilates the pair.

# Various Recombination Processes

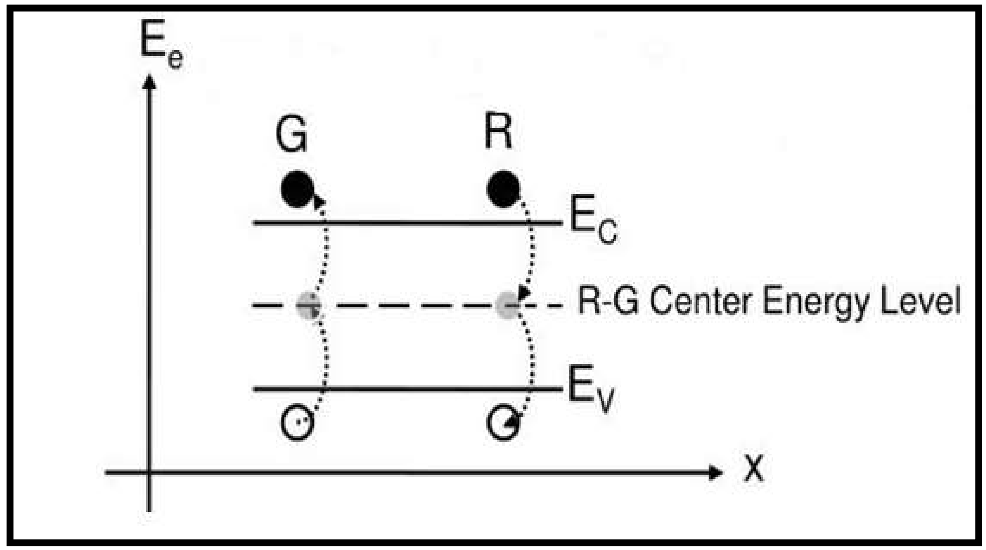
## 2. R-G Center Recombination

What is R-G center?

- Indirect Thermal Recombination
- S-R-H Centers ( Shockley-Read-Hall )
- Non-radiative recombination

In order to make an intrinsic semiconductor extrinsic we put some dopants which act as donors or acceptors & contribute e and h .

R-G centers are also impurities but the difference between dopants level and R-G centers is that dopant levels lies near band edge while **R-G center creates impurity level in the mid band gap**.



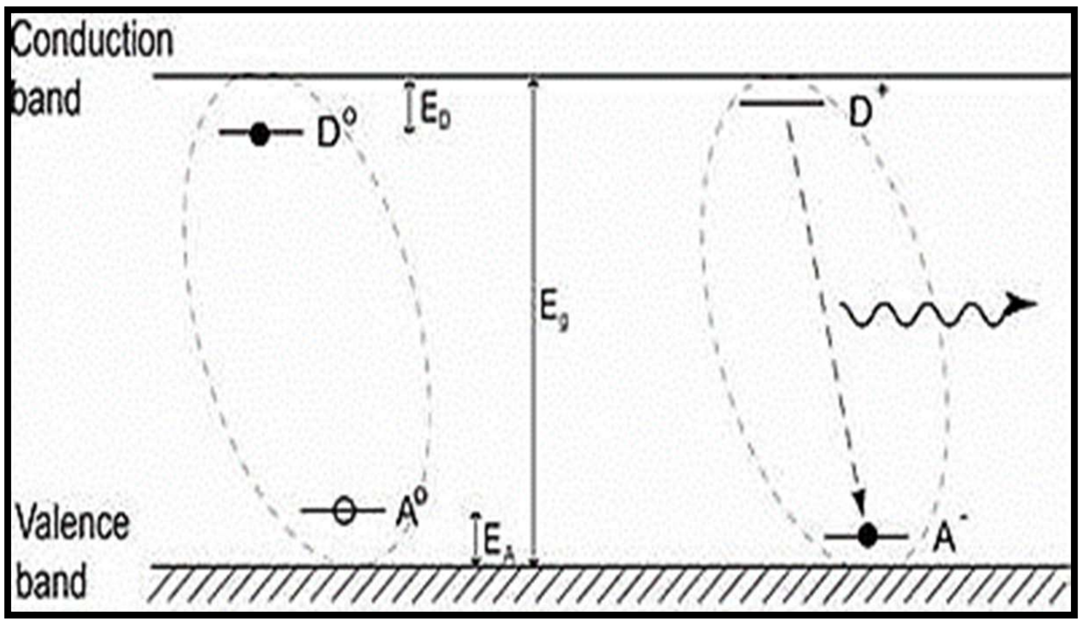
# Various Recombination Processes

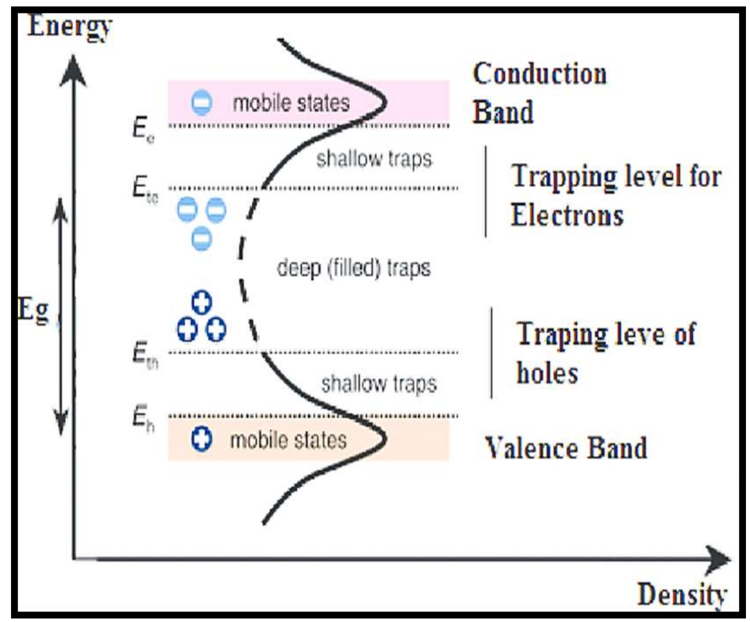
## 3. Recombination via Shallow Levels

- These are same as $N_D$ and $N_A$ -levels .
- Many of these recombination are going to be **radiative.**
- Shallow level centers are **inefficient R-G centers** in term of recombination – because the e- captured by the dopant level have two chances- either go back to the respective bands due to thermal fluctuation or it can recombine with e or hole respectively.

# Various Recombination Processes

- Since the level difference between dopant level and respective close band is less. Hence **the probability of recombination via shallow levels is very less**.



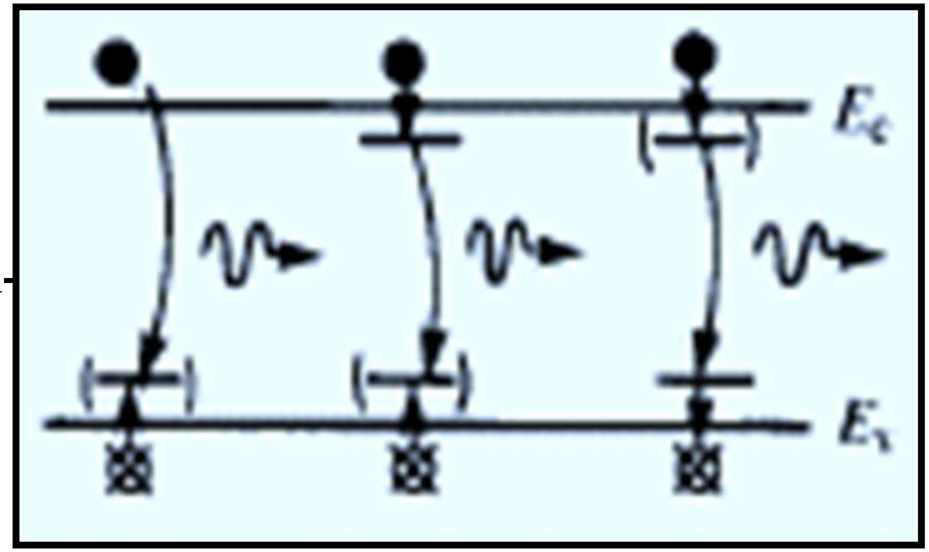
# Various Recombination Processes

## 4. Recombination involving Excitons

- When an electron in C.B. gets bound to the hole in valance band then they are no more independent rather they move as a whole and that entity i.e. e-h pair is called **'exciton'.**

- **Exciton which is bound to the donor or acceptor level is called bound exciton.**

- Energy released is not equal to the band-to-band recombination as is going to be in **sub-band gaps.**



## Various Recombination Processes

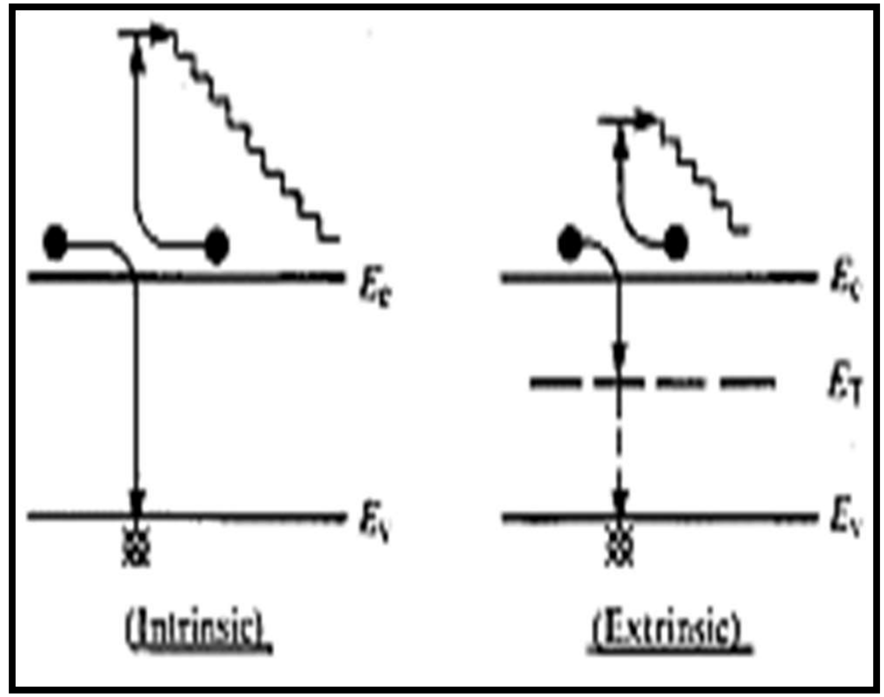
- This recombination dominates at low temperature not at room temperature.

- **It is a major light producing mechanism so mainly used in designing LEDs.**

# Various Recombination Processes

## 5. Auger Recombination

- Electron with very high energy in conduction band makes collision with other electron and same time it recombines with a hole in valance band.
- The energy generated in this process of recombination is given to the other electron and the energy of that electron goes to the higher kinetic energy level and that energy reduces in steps and lost as heat in the lattice and the second e comes back to its ground state.
- Non-radiative recombination and dominates at high carrier concentration or high doping.

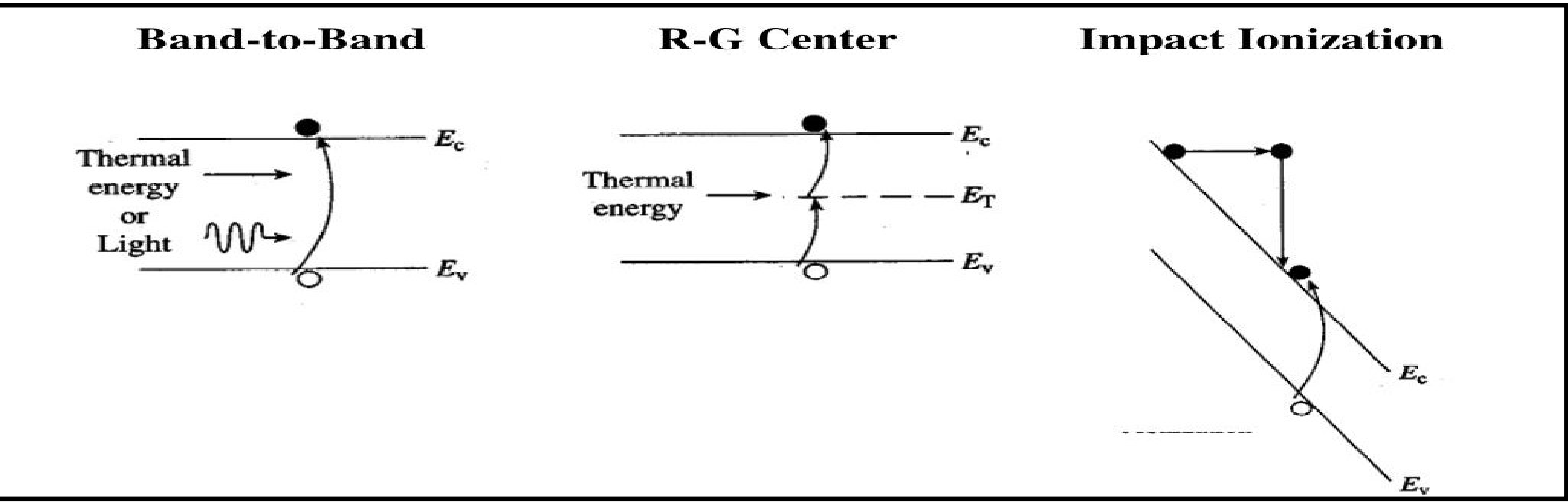


# Various Generation Processes

- Due to thermal generation
- Due to light absorption
- Due to electrical bias

- Due to thermal generation
- Due to light absorption

- e at high K.E. makes collision with another e in C.B. & loses its energy and the energy is given to e in V.B.
- then it excites to C.B.



## Generation via Impact Ionization Processes

- Impact ionization is a **very important** process.
- A key process where we have **collision of highly energetic carriers** with the crystal lattice generates e-h pair.
- It occurs at **high field.**
- It is a process by which one can get **multiplication of carriers** leads to **avalanche breakdown** .

**All the processes can occur at the same time in a material but as their rates of occurring can be different at a given condition so one or two may dominate.**


THANK YOU