Recombination-Generation via Defects or Levels in the Band gap

- Deep levels initially act as carrier recombination or trapping centers and adversely affect device performance.

- Deep levels can be produced by a variety of defects that include substitution and interstitial impurity atom, lattice vacancies or complex defects formed by a combination of two types of defects.

- The probability of the involvement of a phonon is very high in such transitions, which make them non radiative.

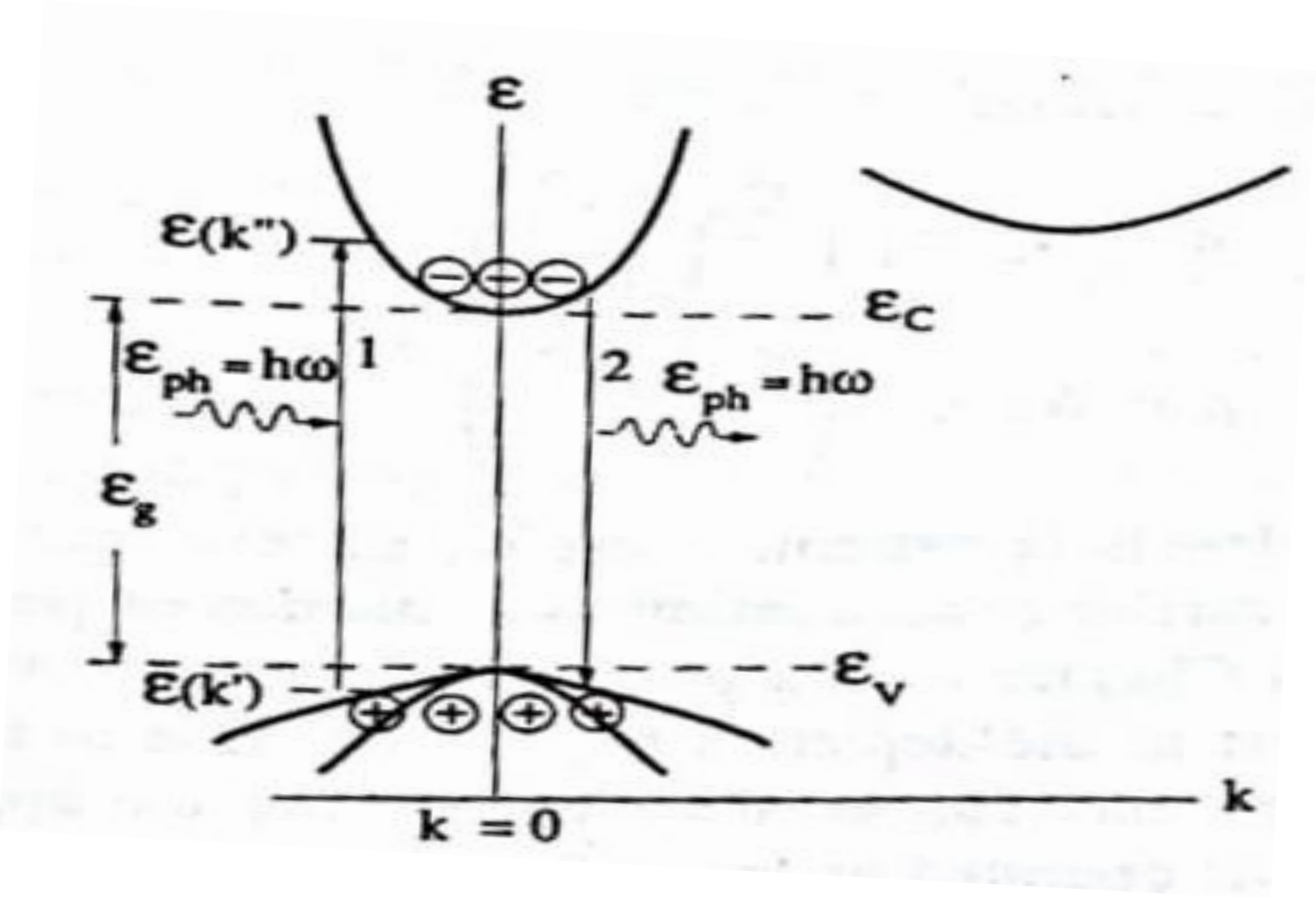


Figure: Band to band of absorption and recombination process in direct bandgap semiconductor

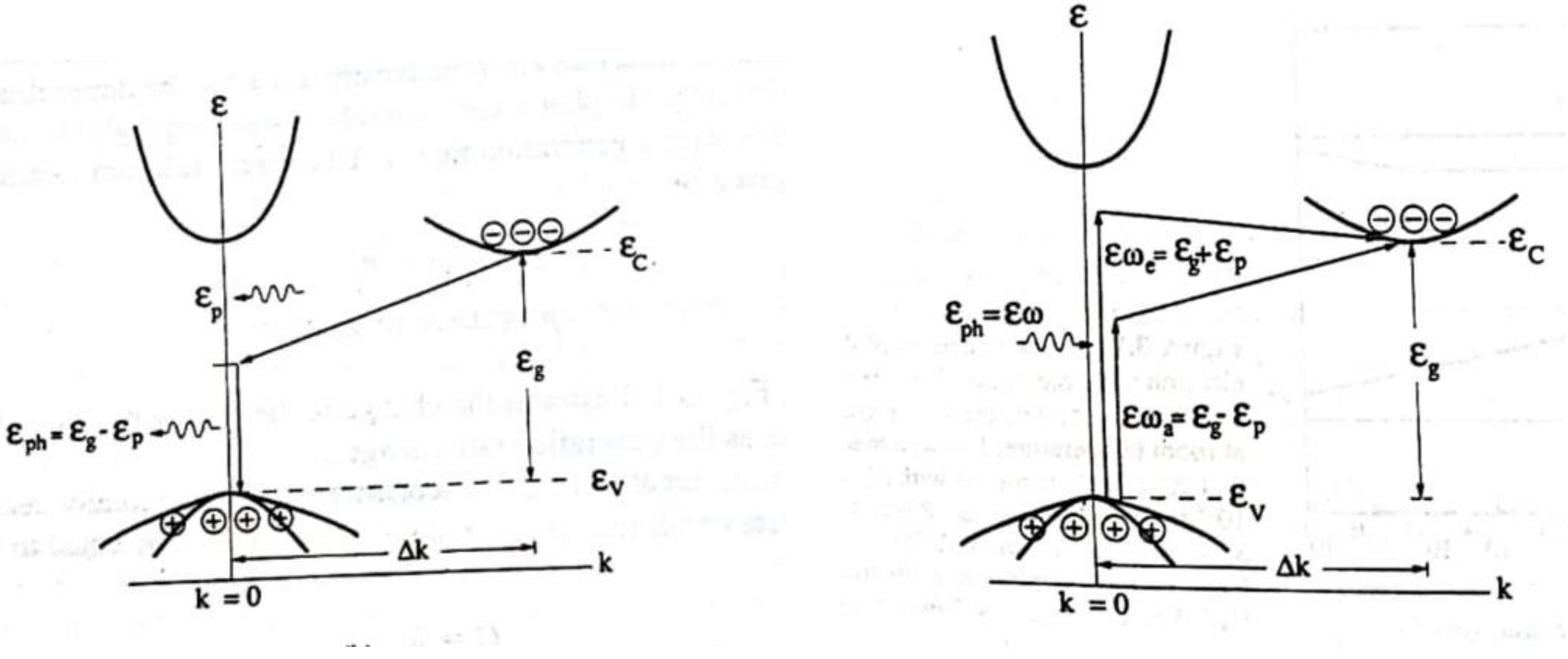
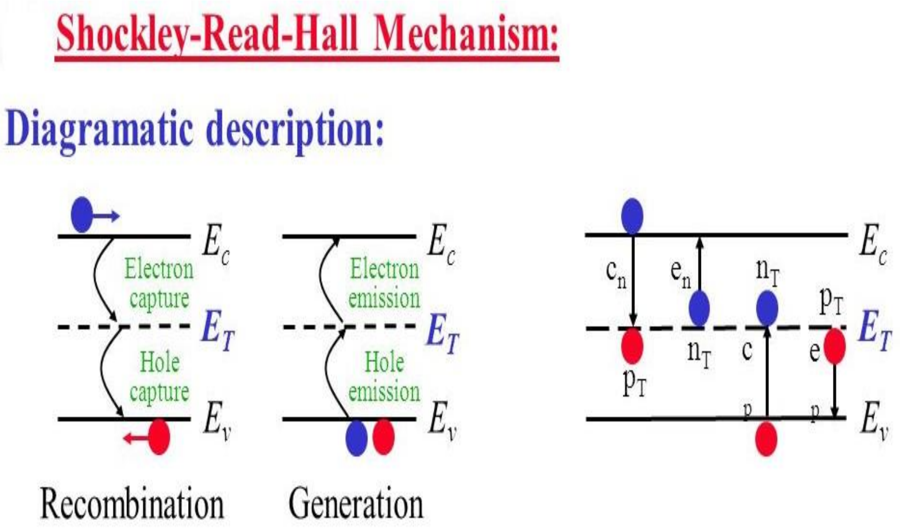


FIGURE: band to band absorption and recombination in indirect bandgap semiconductor

Shockley–Read–Hall (SRH) Recombination

- Shockley-Read-Hall recombination (SRH), also called trap-assisted recombination, the electron in transition between bands passes through a new energy state created within the bandgap by a dopant or a defect in the crystal lattice, such energy states are called traps.
- Non-radiative recombination occurs primarily at such sites. The energy is exchanged in the form of lattice vibration, a phonon exchanging thermal energy with the material.



Optoelectronics Devices & Circuits (MEC-166)

UNIT-II

By

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SYLLABUS

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M. Tech. (Digital Systems) Syllabus

MEC-166	**Optoelectronics Devices & Circuits**

Topics Covered	
UNIT-I	
Elements and compound Semiconductor, Electronic Properties of semiconductor, Carrier effective masses and band structure, effect of temperature and pressure on bandgap, Carrier scattering phenomena, conductance processes in semiconductor, bulk and surface recombination phenomena.	9
UNIT-II	
Optical Properties of semiconductor, EHP formation and recombination, absorption in semiconductor, Effect of electric field on absorption, absorption in quantum wells, radiation in semiconductor, Deep level transitions, Augur recombination's.	9
UNIT-III	
Junction theory, Schottky barrier and ohmic contacts, semiconductor heterojunctions, LEDs, Photo Detectors, Solar cells.	9
UNIT-IV	
Optoelectronics modulation and switching devices: Analog and Digital modulation, Franz-Keldysh and stark effects modulators, Electro-optic modulators. Optoelectronics Integrated Circuits (OEICs): Need for hybrid and monolithic integration, OEIC transmitters and receivers.	9

Textbooks

1.	Semiconductor optoelectronic Devices By Pallab Bhattachrya, Prentice Hall Publications.
2.	Physics of Semiconductor Devices, By S.M. Sze, Wiley Publication.

Key Points

- Optical Processes In Semiconductors
- Electron-Hole Pair formation and recombination
- Radiative and Nonradiative Recombination
- Band to band Recombination
- Absorption in semiconductors
- Effect of electric field on absorption: Franz-Keldysh and stark Effects
- Deep level transition
- Auger Recombination
- Bulk and surface recombination phenomena

Various Recombination Processes

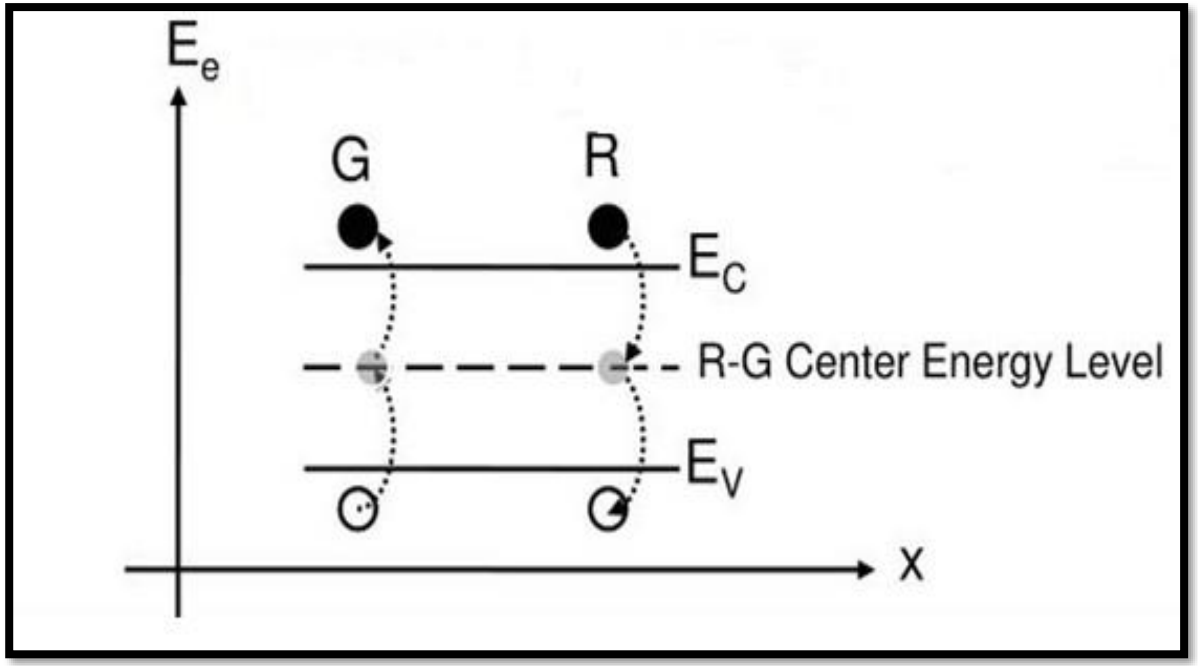
2. R-G Center Recombination

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**.

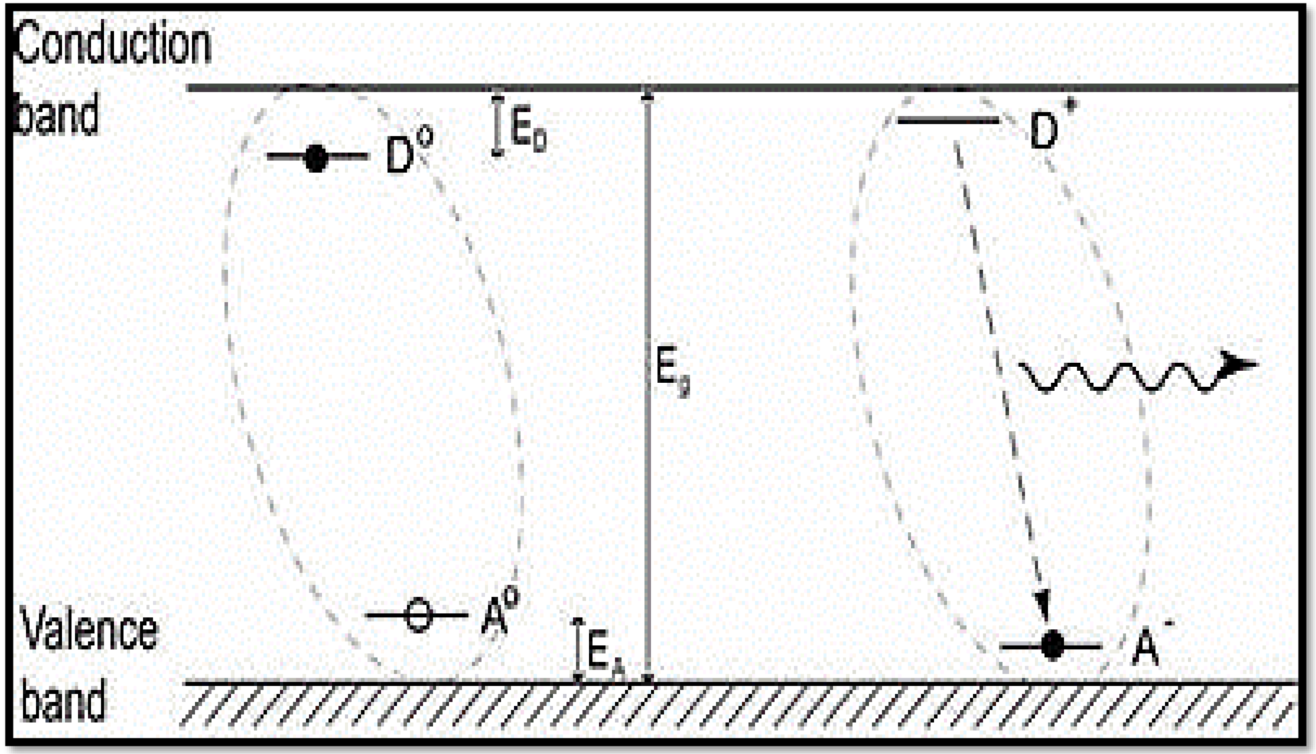


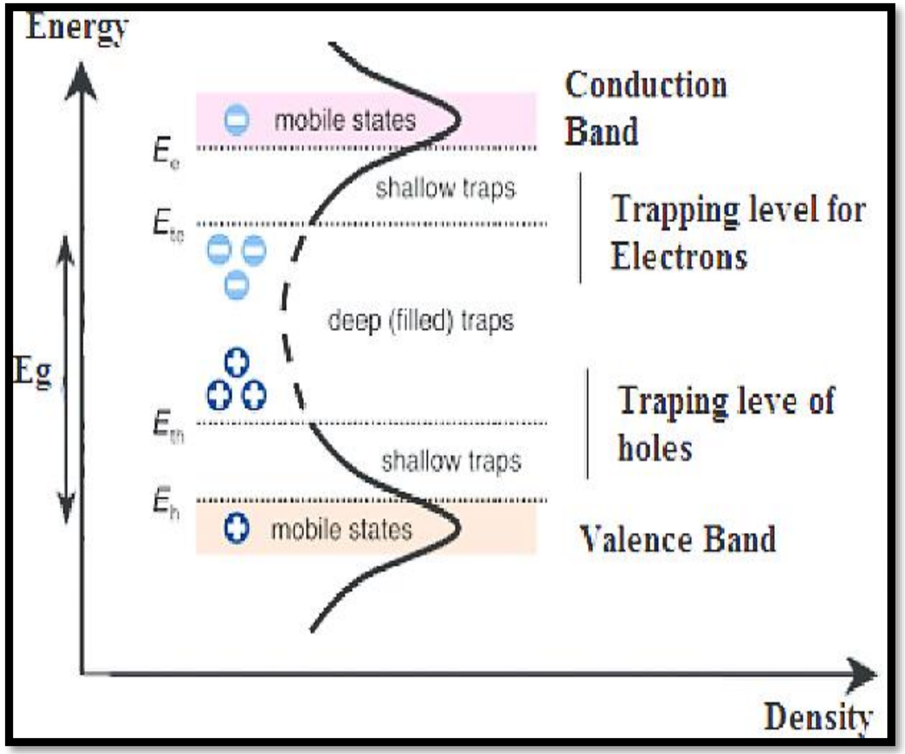
3. Recombination via Shallow Levels

- 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**.



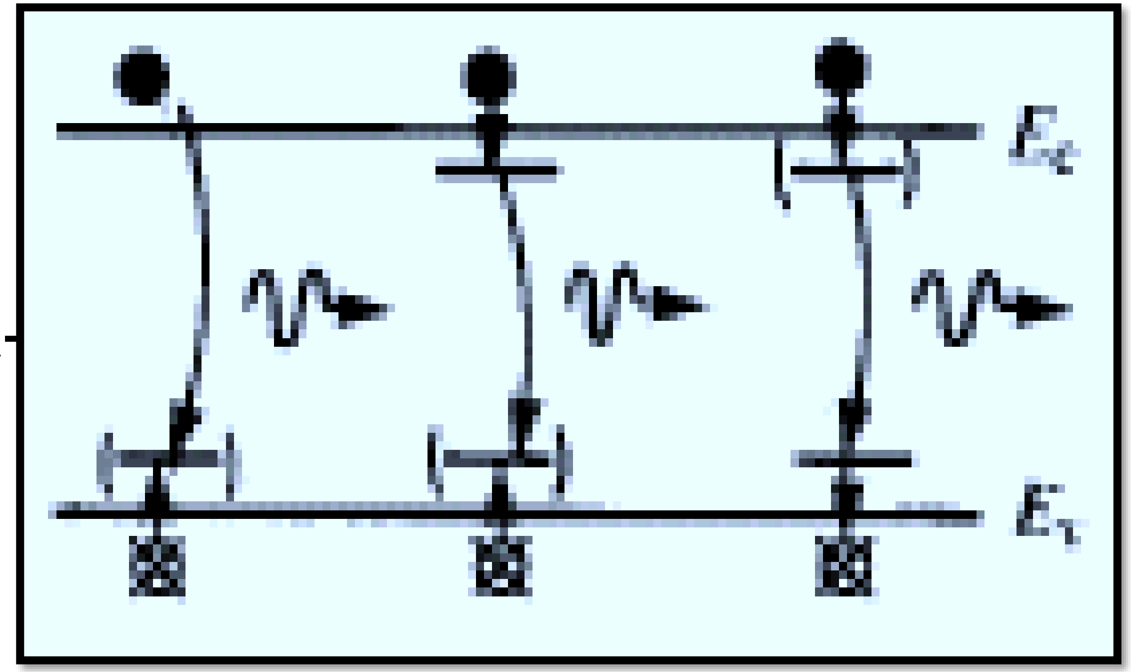


4. Recombination involving Excitons

- 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.**

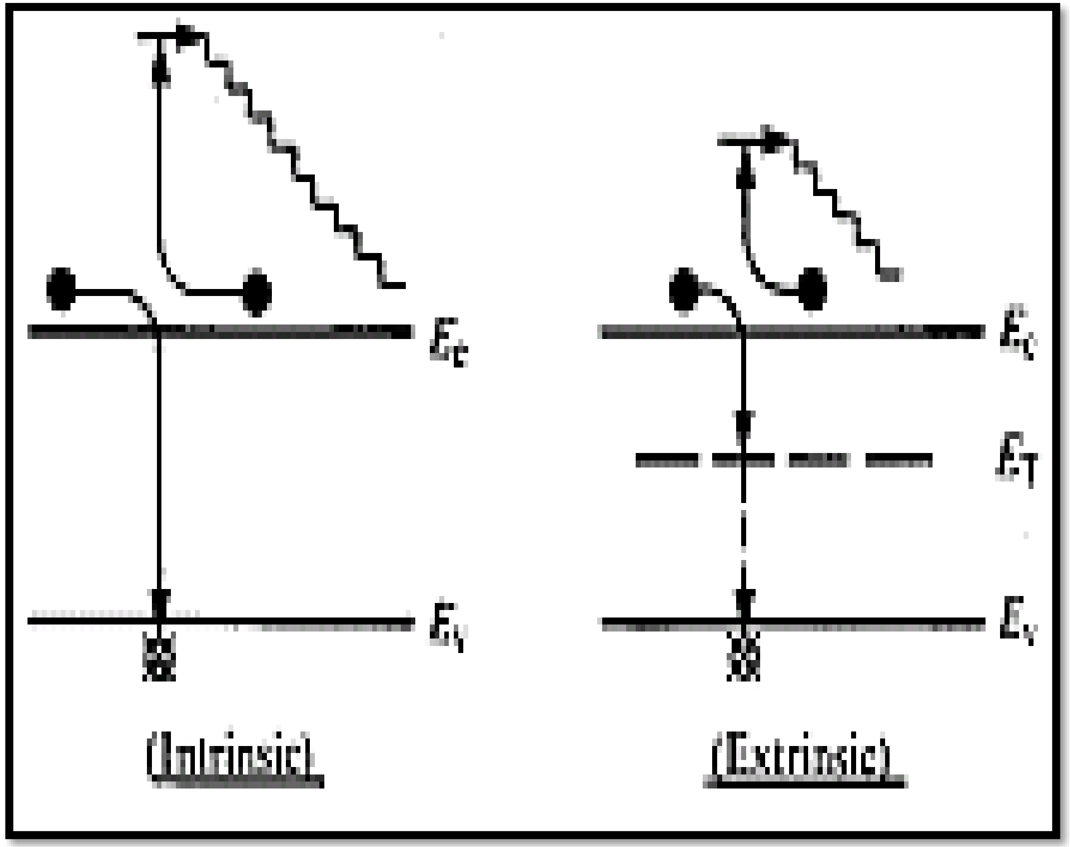
Various Recombination Processes

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.



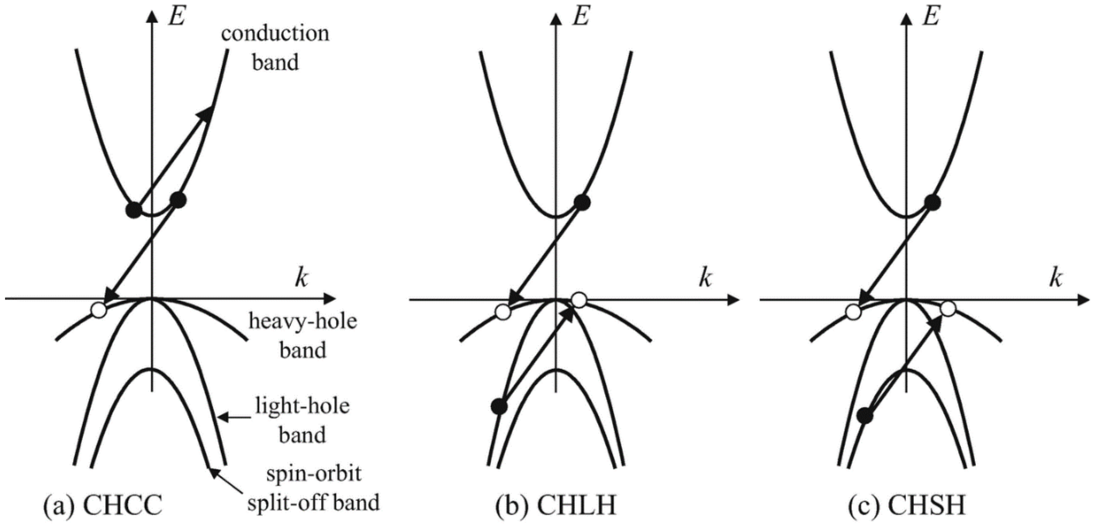
Auger Recombination

In Auger recombination the energy is given to a third carrier which is excited to a higher energy level without moving to another energy band. After the interaction, the third carrier normally loses its excess energy to thermal vibrations. Since this process is a three-particle interaction, it is normally only significant in non-equilibrium conditions when the carrier density is very high. The Auger effect process is not easily produced, because the third particle would have to begin the process in the unstable high-energy state.

The carrier concentration dependent radiative recombination rate leading to spontaneous emission can be expressed as:

$$R(n) = An + Bn^2 + Cn^3$$

In this equation the first term Shockley Read Hall Recombination, second term accounts for spontaneous radiative recombination and the third term accounts for Auger Recombination, which plays a significant role in operation of junction lasers.



Different possible band-to-band Auger recombination process in a direct bandgap semiconductor

The rate of Auger recombination, given by Cn^3, can be derived from the original analysis of Beattie and Landsberg.† This form of the Auger recombination rate breaks down at very high injection levels, when Boltzmann statistics need to by replaced by Fermi-Dirac statistics. A carrier lifetime for the Auger process can be defined as: $\tau_{Auger} = n/R_{Auger} = (Cn^2)^{-1}$, which is therefore a function of the concentration of the participating carriers. The Auger recombination coefficient C represents a fundamental characteristic of the semiconductor in that it sets a lower limit on the nonradiative recombination rates.

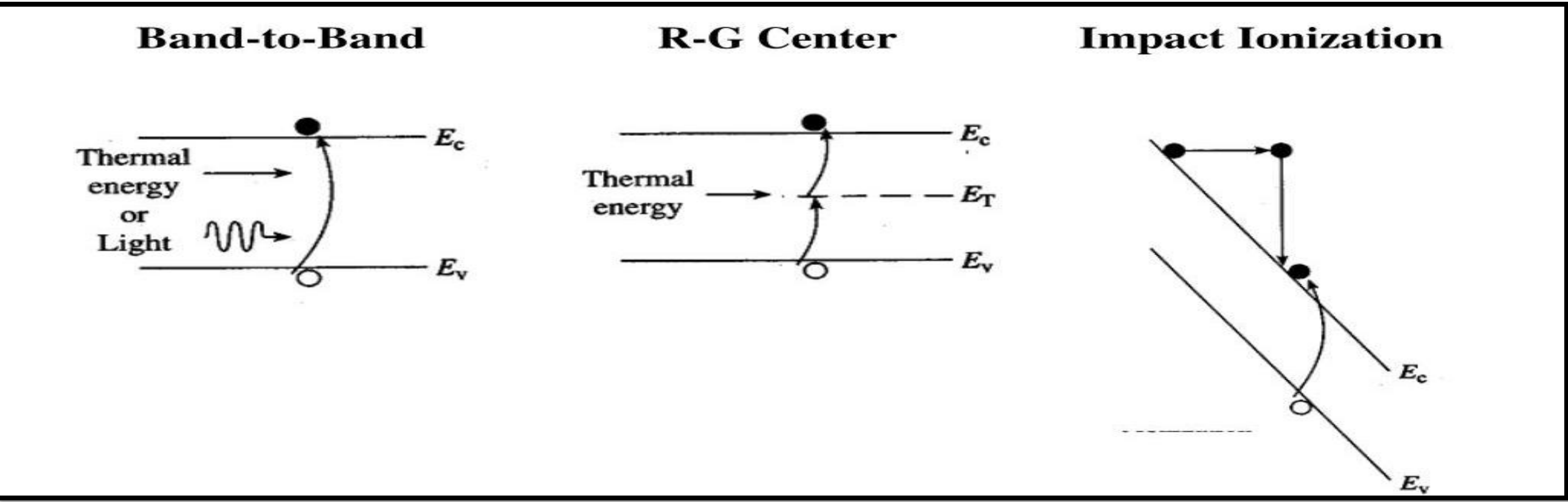
The different Auger processes shown in Fig. 3.23 are labeled CCCH, CHHL, and CHHS. Here C, H, L, and S stand for conduction, heavy-hole, light-hole, and split-off bands, respectively. For example, CCCH stands for the conduction-conduction-conduction-heavy hole process, dominant in n-type materials. The CHHL and CHHS processes are more dominant in p-type materials. The CHHS process also becomes more dominant as the bandgap of a material decreases. We have only described the band-to-band process here. Similar Auger transitions are also possible for impurity-band, donor-acceptor, phonon-assisted and trap-assisted recombinations.

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