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

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

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

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 ε_{fn} and ε_{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

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

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

And the nonequilibrium carrier concentrations are given by

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

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

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 Δn 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 Mechanisms

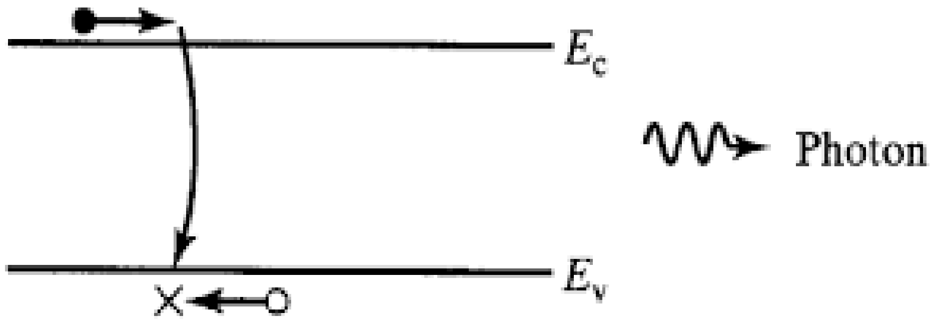
- Carrier recombination can happen through multiple relaxation channels.
- The main ones are **band-to-band recombination**, **Shockley read hall (SRH), Auger recombination** and **Surface recombination**.
- These decay channels can be separated into **radiative** and **non-radiative recombination.**

➢ Radiative Recombination: The excess energy is dissipated to photon & usually having energy equal to band gap.

➢ Non-Radiative Recombination: The excess energy is dissipated to phonon and heat is dissipated.

Band-to-band radiative recombination

- Band-to-band recombination is the name for the process of electrons jumping down from the conduction band to the valence band in a radiative manner. During band-to-band recombination, a form of spontaneous emission, the energy absorbed by a material is released in the form of photons .
- Generally these photons contain the same or less energy than those initially absorbed.



(a) Band-to-band recombination

Recombination-Generation via Defects or Levels in the Band gap

- In band to band downward transition their is a small probability of emission of phonons, in which recombination becomes non radiative.

- Such nonradiative recombination take place more likely via levels with in the band gap of the semiconductor as shown in figure given below-

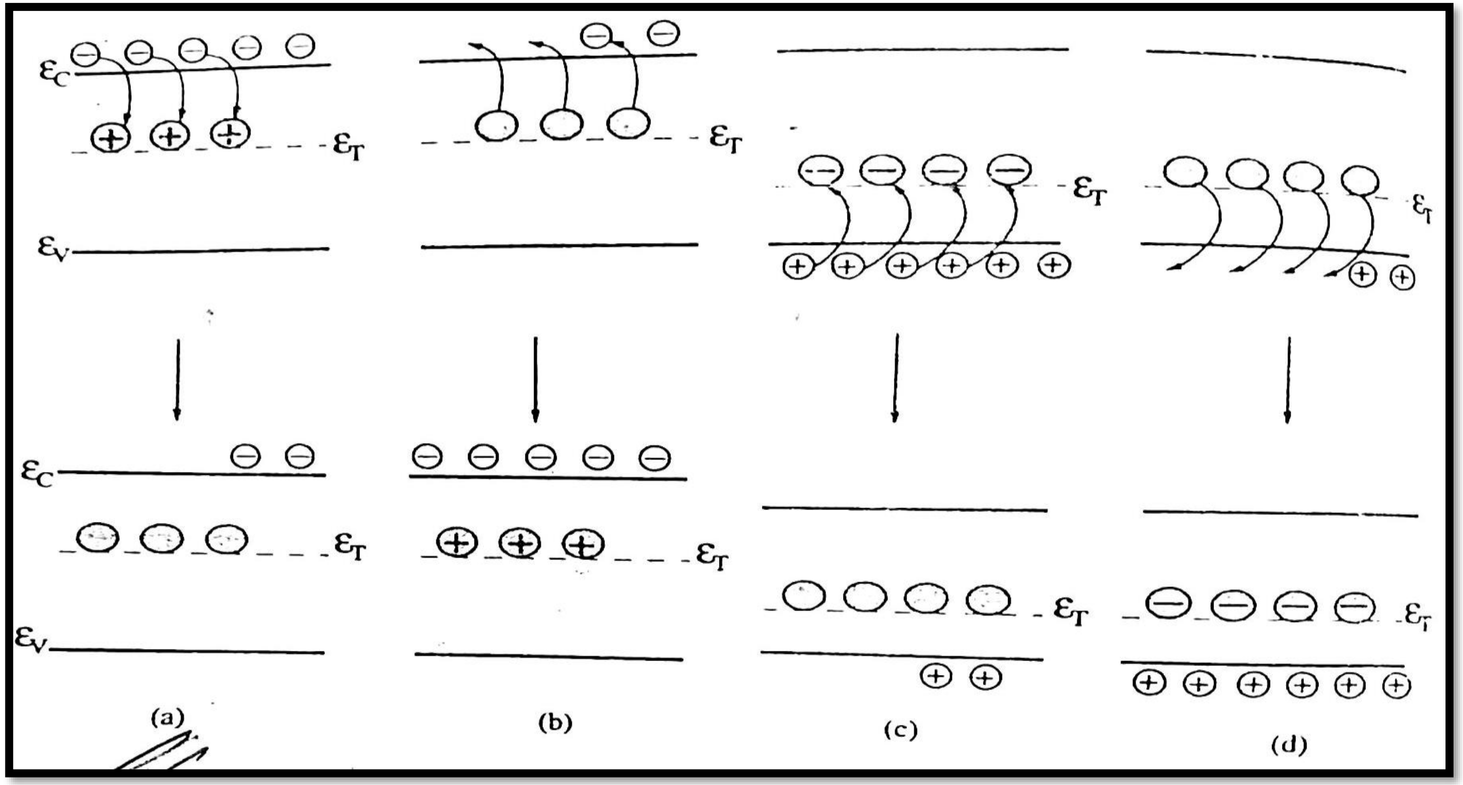


Illustration of (a) electron capture, (b) electron emission, (c) hole capture, and (d) hole emission. The deep levels in (a) and (b) are electron traps and those in (c) and (d) are hole traps


Thank you