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

❖ Electron-Hole Pair recombination Rate

- Low Level Injection
- High Level Injection

❖ Absorption in semiconductors

- Band to band Recombination
- Indirect intrinsic transitions
- Exciton absorption
- Donor Acceptor and impurity-band absorption
- Low energy(long Wavelength) absorption

❖ Effect of electric field on absorption:

- Franz-Keldysh Effect
- stark Effects

Long-Energy(Long-wavelength) Absorption

- **Several types of transitions involving shallow impurity, bandedges, split bands, and free carriers give rise to resonances at very small energies in the absorption spectra**
- **These are observed as steps or peaks in the long wavelength region of absorption spectra.**
- **The different processes are briefly described below:**

➢Impurity-Band Transition-

- Impurity transition that have energies close to the bandgap.
- These higher-energy impurity-band transition usually require that the impurity levels are ionized(or empty).
- At low temperature, when these shallow impurity levels are usually filled with their respective carrier, those carrier can be excited to the respective bandedge by photon as shown in figure.
- For this absorption process the energy of the photon must be at least equal to the ionization energy of impurity.
- This energy usually correspond to the far infrared region of the optical spectrum.

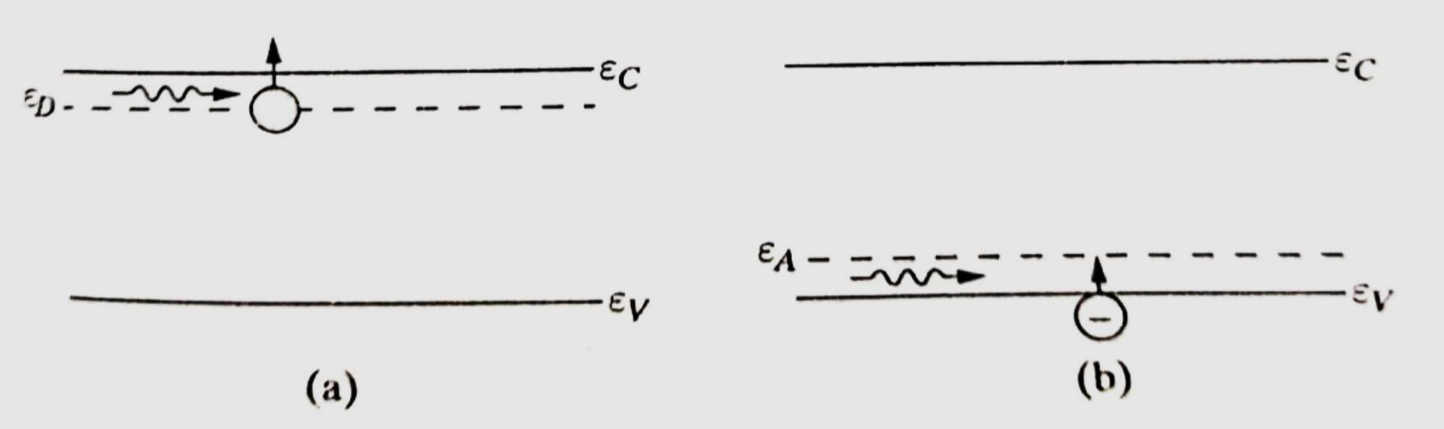


Figure: Low Energy (a) donor-band and (b) acceptor-band absorption transition.

➤Intraband -Transition-

- At the zone center the valence band structure of most semiconductors consists of the light-hole(LH), the heavy-hole(HH) bnads, and the split-off(SO) band.
- The three subbands are separated by spin-orbit interaction. In a p-type semiconductor the valence band is filled with the hole and the occupancy of the different band depend on the degree of doping and the position of the fermi level.
- Absorption of photons with the right energy can result in transition from LH to HH, SO to HH, and SO to LH bands, depending on the doping and temperature of the sample. These transition have been observed experimentally. They are normally not observed in n-type semiconductors.

➢Free carrier Absorption

- This mechanism involves the absorption of photon by the interaction of a free carrier within a band, which is consequently raised to a higher energy.
- The transition of the carrier to higher energy within the same valley must conserve momentum. This momentum change is provided by optical or acoustic phonons or by impurity scattering.
- Free-carrier absorption usually manifest in the long-wavelength region of the spectrum as a monotonic increase in absorption with a wavelength dependence of the from λ^p, where p range from 1.5 to 3.5.
- The value of p depends on the nature of the momentum-conserving scattering(i.e. the involvement of acoustic phonons, optical phonons or ionized impurities).
- The absorption coefficient due to free-carrier absorption can be expressed as.

$$\alpha = \frac{Nq^2\lambda^2}{4\pi^2 m n_r c^3 \epsilon_0}\left\langle\frac{1}{\mathrm{T}}\right\rangle$$

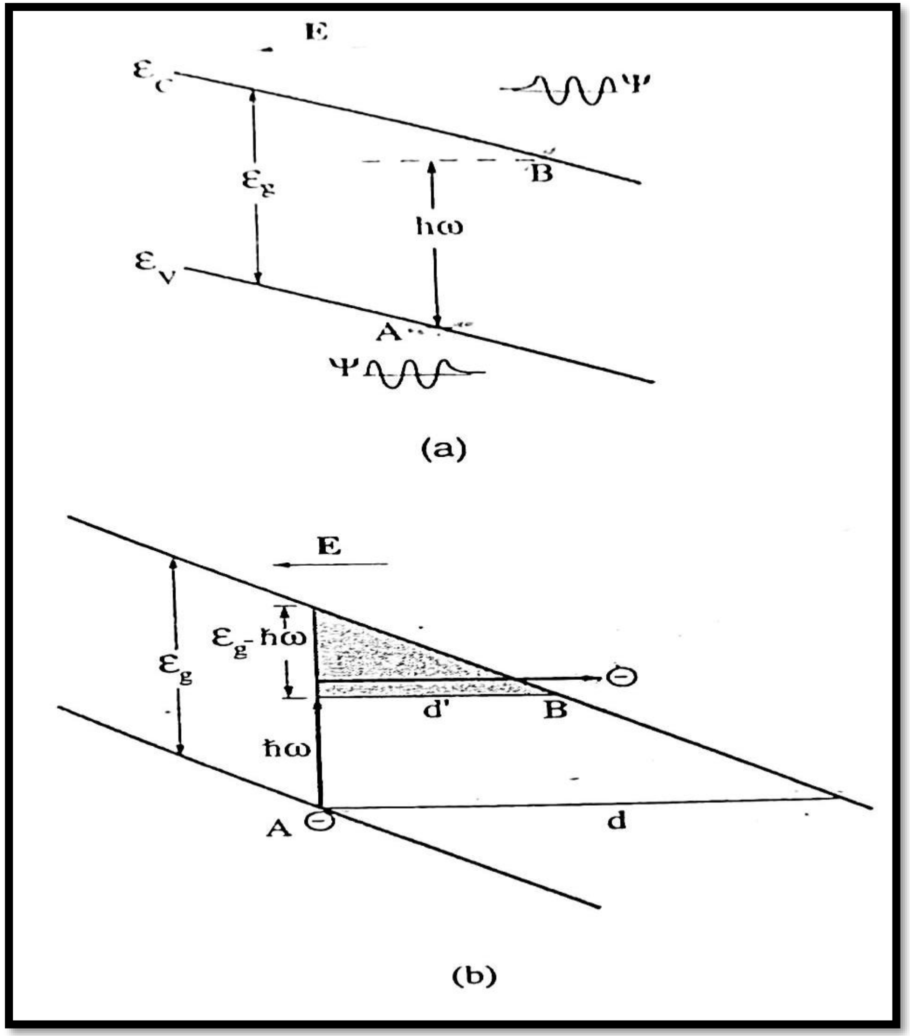
- Where N is the free-carrier concentration, n_r is the refractive index of the semiconductor, and $\left\langle\frac{1}{\mathrm{T}}\right\rangle$ is the average value of the inverse of the relaxation time of scattering process.

Effect of Electric Field on Absorption: FRANZ-KELDYSH AND STARK EFFECTS

- The change in absorption in a semiconductor in the presence of strong electric field is the ***Franz-Keldysh effect,*** which results in the **absorption of photons with energy less than the band gap** of the semiconductor.

- The energy bands of semiconductor in the presence of electric field E and with an incident photon of energy $\hbar\omega < \varepsilon_g$ are shown in figure (a) and (b).

- In figure (a) shows **the bending of bands due to applied electric field** and (b) shows **the absorption of photon with $\hbar\omega < \varepsilon_g$ due to carrier tunneling** (Franz-Keldysh effect).



Franz-Keldysh Effect

- The classical turning points are marked as A and B, the electron wave functions change from oscillatory to decaying behaviour.

- Thus electron in the energy gap is described by an **exponentially decaying** function $\boldsymbol{u_k e^{jkx}}$, where k is imaginary.

- With **increase of electric field**, the distance **AB decreases** and **the overlap** of the wave functions within the gap **increases.**

- In the **absence of a photon**, the valance electron has to tunnel through a triangular barrier of height ε_g and thickness d, given by

$$\boldsymbol{d = \frac{\varepsilon_g}{qE}}$$

Franz-Keldysh Effect

- With the assistance of an absorbed photon of energy $\hbar\omega < \varepsilon_g$, it is evident that the tunnelling barrier thickness is reduced to

$$d' = \frac{(\varepsilon_g - \hbar\omega)}{qE}$$

And the overlap of the wave function increases further and the valance electron can easily tunnel to the conduction band.

- **The net result is that a photon of energy $\hbar\omega < \varepsilon_g$ is absorbed.**

- **In this case, the transverse component of the momentum is conserved.**

- **The Franz-Keldysh effect is therefore, in essence, photon assisted tunnelling.**

Franz-Keldysh Effect

- The electric field dependent absorption coefficient is given by-

$$\alpha = K(E')^{1/2}(8\beta)^{-1}exp\left(-\frac{4}{3}\beta^{3/2}\right)$$

Here, $E' = \left(\frac{q^2E^2\hbar^2}{2m_r^*}\right)^{1/3}$, $\beta = \frac{\varepsilon_g - \hbar\omega}{E'}$ and **K** is a material dependent parameter and has value of $5 \times 10^4\ cm^{-1}\ (eV)^{-1/2}$ in **GaAs.**

- The exponential term is the tunnelling probability of an electron through a triangular barrier of height $(\varepsilon_g - \hbar\omega)$ and can be obtained from the well known **Wentzel-Kramers-Brillouin (WKB) approximation**.

Franz-Keldysh Effect

- The other factors are related to the upward transition of an electron due to photon absorption.

- Substituting appropriate values for the different parameters, it is seen that in GaAs $\boldsymbol{\alpha = 4\ cm^{-1}}$ at a photon energy of $\boldsymbol{\varepsilon_g - 20\ meV}$ with electric field **E ~ 10^4 V/cm.**

- This value of absorption coefficient is much smaller than the value of α at the band edge at zero field.

- Therefore, Franz-Keldysh effect will be small unless $\boldsymbol{E \geq 10^5\ V/cm}$.

Stark Effect

- The ***Stark effect*** refers to the **change in atomic energy upon the application of an electric field.**

- The electric field affects the higher order, or outer, orbits of the precessing electrons so that the center of gravity of the elliptical orbit and the focus are displaced to each other and linearly aligned in the direction of the electric field.

- As a result, there is splitting of the energy of the outer 2s or 2p states, and the energy shift is simply given by $\Delta\varepsilon = qdE$, where d is the eccentricity of the orbit. This is ***linear Stark effect.***

- The effect of electric field on ground state orbits also leads to an energy shift of the state, and that is the ***quadratic or second-order Stark effect.***


THANK YOU