Optoelectronics Devices & Circuits (MEC-166)

UNIT-II

By

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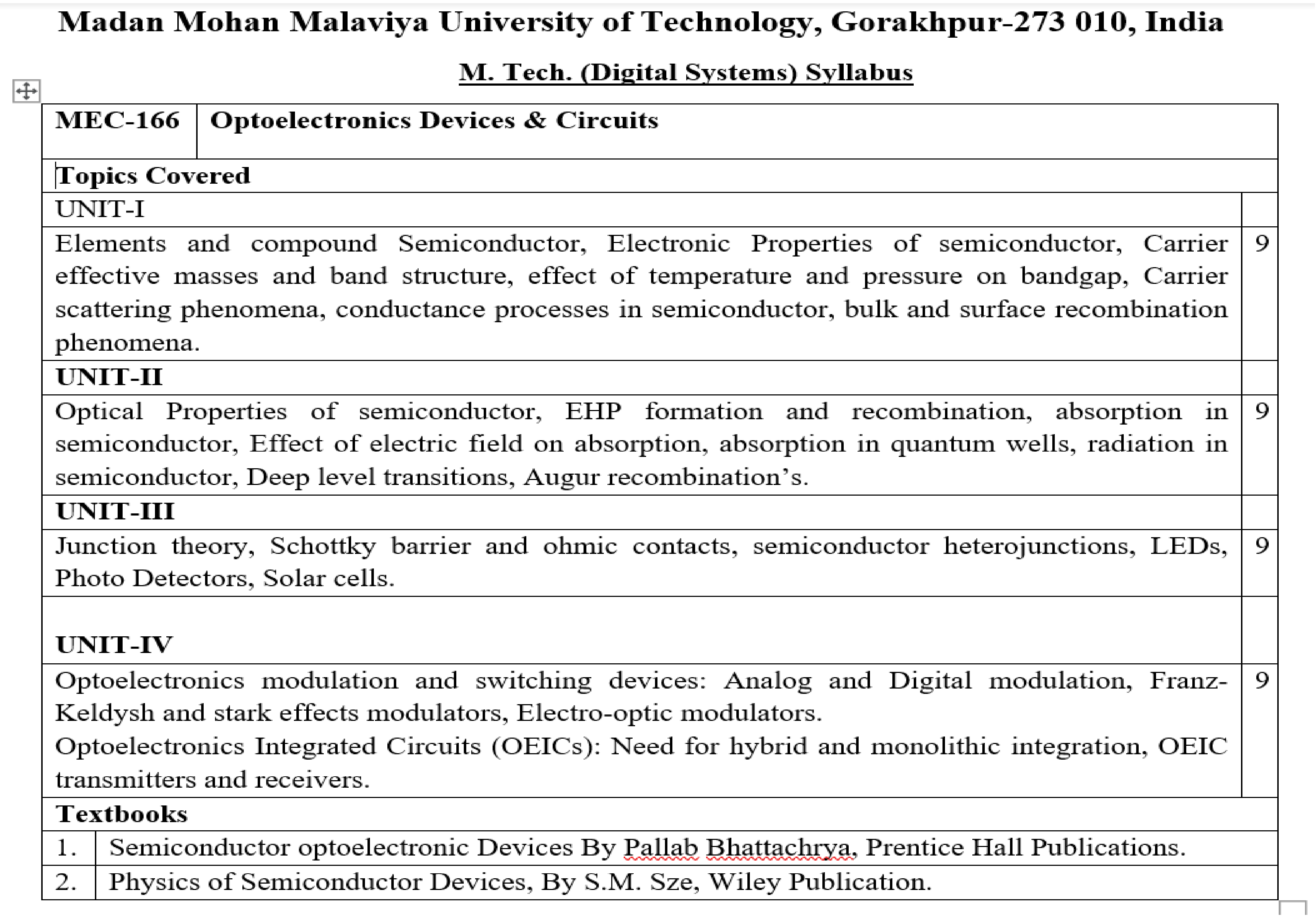
SYLLABUS



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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

Absorption in Semiconductors

- The measurement of absorption and emission spectra in semiconductors constitutes an important aspect of materials characterization.

- They not only provide information on the bandgap, but the measurements also provide information on direct and indirect transitions, the distribution of states, defects and impurities.

- The absorption spectrum spans a wide energy (or wavelength) range, extending from the near bandgap energies to the low energy transitions involving free carriers and lattice vibrations (near bandgap transitions).

Absorption in Semiconductors

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

Indirect Intrinsic transition

- The momentum or wavevector change required in an indirect transition may be provided by single or multiple phonons, although the probability of the latter to occur is very small. There are optical and acoustic phonons.
- Each of these has transverse and longitudinal modes of vibrations, with characteristic energy and momentum.
- In indirect transition process conservation of momentum requires:

$$k'' \pm k_p = k' + k_{ph} \qquad (3.51)$$

Where k'' and k' are the electron wavevectors for the final and initial states, k_p is the wavevector of the phonon, and k_{ph} is the wavevector of the absorbed photon.

- Since the latter is small, the conservation of momentum for an indirect transition can be expressed as

$$k'' - k' = \pm k_p \qquad (3.52)$$

- Similarly, the conservation of energy for the two cases of phonon emission and absorption can be expressed as

$$\hbar\omega_e = \varepsilon_C - \varepsilon_V + \varepsilon_p \qquad (3.53)$$

$$\hbar\omega_a = \varepsilon_C - \varepsilon_V - \varepsilon_p \qquad (3.54)$$

- Where the left- hand side represents the energy of the photon absorbed.
- From this energy state the electron finally reaches the indirect valley by phonon scattering. The intermediate energy state of the electron is termed a *virtual* state, in which the carrier resides until a phonon of the right energy and momentum is available for the scattering process.
- Indirect transition probabilities involving virtual state can be calculated using a second-order time-dependent perturbation theory.
- The total probability is obtained by a summation over these energy states, as long as each particular transition conserves energy between initial and final states.

- For a transition with phonon absorption,

$$\alpha_a(\hbar\omega) \propto \frac{(\hbar\omega - \varepsilon_g + \varepsilon_p)^2}{e^{\varepsilon_p/K_B T} - 1} \qquad (3.55)$$

- For a photon energy $\hbar\omega > (\varepsilon_g - \varepsilon_p)$. Similarly, for a transition with phonon emission the absorption coefficient is given by

$$\alpha_e(\hbar\omega) \propto \frac{(\hbar\omega - \varepsilon_g - \varepsilon_p)^2}{1 - e^{-\varepsilon_p/K_B T}} \qquad (3.56)$$

for $\hbar\omega > (\varepsilon_g + \varepsilon_p)$. Since for $\hbar\omega > (\varepsilon_g + \varepsilon_p)$ both phonon emission and absorption are possible, under these conditions

$$\alpha(\hbar\omega) = \alpha_a(\hbar\omega) + \alpha_e(\hbar\omega) \tag{3.57}$$

The temperature dependence of the absorption coefficient is illustrated in Fig. 3.5. At very low temperatures, the density of phonons available for absorption becomes small and therefore α_a is small. With increase of temperature, α_a increases. The shift of the curves to lower energies with increase of temperature reflects the temperature dependence of ε_g. In fact, the plots of $\sqrt{\alpha_e}$ and $\sqrt{\alpha_a}$ extrapolate to the energy axis at $(\varepsilon_g + \varepsilon_p)$ and $(\varepsilon_g - \varepsilon_p)$, respectively. This is a convenient technique to experimentally determine the bandgap.

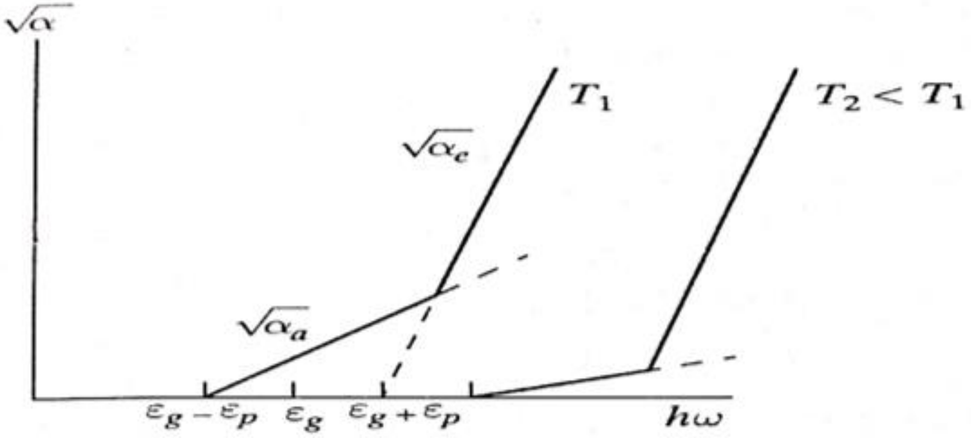

Figure 3.5: Energy dependent absorption coefficient due to phonon emission and absorption as a function of temperature.

Exciton Absorption

- In a very pure semiconductors, where the screening effect of free carriers is almost absent.
- Electrons and holes produces by the absorption of a photon of near- bandgap energy pair to form an exciton.
- This is the free exciton.
- The binding energy of the exciton, ε_{ex} , is calculated by drawing analogy with the Bohr atom for an impurity center, and is quantized. It is therefore expressed as

$$\varepsilon_{ex}^{i} = \frac{-m_r^* q^4}{2\,(4\pi\epsilon_r\epsilon_o\hbar)^2} \cdot \frac{1}{l^2}\,, l = 1,2,3……..$$

$$= \frac{-13.6}{l^2}\frac{m_r^*}{m_o}\left(\frac{1}{\epsilon_r}\right)^2 (eV) \qquad (3.58)$$

Here m_r^* is the reduced effective mass of the exciton given by Eq.3.36 and l is the integer.

- Such excitons are also known as ***effective mass*** **or** ***Wannier excitons***.

- The optical excitation and formation of excitons usually manifest themselves as a series of sharp resonances (peaks) at the low energy side of the band edge in the absorption spectra of direct bandgap semiconductors.
- The total energy of the exciton is given by

$$\varepsilon_{\mathrm{ex}} = \frac{\hbar^2 k_{ex}^2}{2\,(m_e^* + m_h^*)} - \varepsilon_{ex}^{l} \qquad (3.59)$$

Where the first term on the right is the kinetic energy of the exciton.

- The kinetic energy contributes to a slight broadening of the exciton levels. For a direct transition conservation of momentum requires that $k_{ex}^2 \cong 0$.

Donor-accepter and Impurity-band absorption

- Intentionally or unintentionally, both the donor and accepter levels are simultaneously present in the semiconductor.
- Depending upon the temperature and the state of occupancy of the impurity levels, it is possible to raise the electron from the accepter to the donor level by absorption of photon.
- *The energy of the photon is given by:*

$$\hbar\omega = \varepsilon_g\text{-}\varepsilon_D\text{-}\varepsilon_A + \frac{q^2}{\varepsilon_0\varepsilon_r r} \qquad (1)$$

Where the last term on right hand side accounts for coulomb interaction between the donor and acceptor atoms in substitutional sites, which result in a lowering of their binding energies.

- Another absorption transition can occur between ionized impurity level and opposite band edge called **impurity-band transition.**

- This can be understood as follow. Assume that at very low temperatures the donor and acceptor atoms are neutral.
- If they are brought closer together the additional orbiting electron of the donor becomes “shared” by the acceptor as in a covalent bond become more ionize, resulting in a lowering of their binding energy.
- Since the donor and acceptor are located at discrete substitutional sites in the lattice, r varies in finite increments, being the smallest for nearest neighbors.

Therefore for ground state of impurities, the energies ε_D and ε_A corresponds to the most distant pairs and $\hbar \hat{=} \varepsilon_g$-$\varepsilon_D$-$\varepsilon_A$

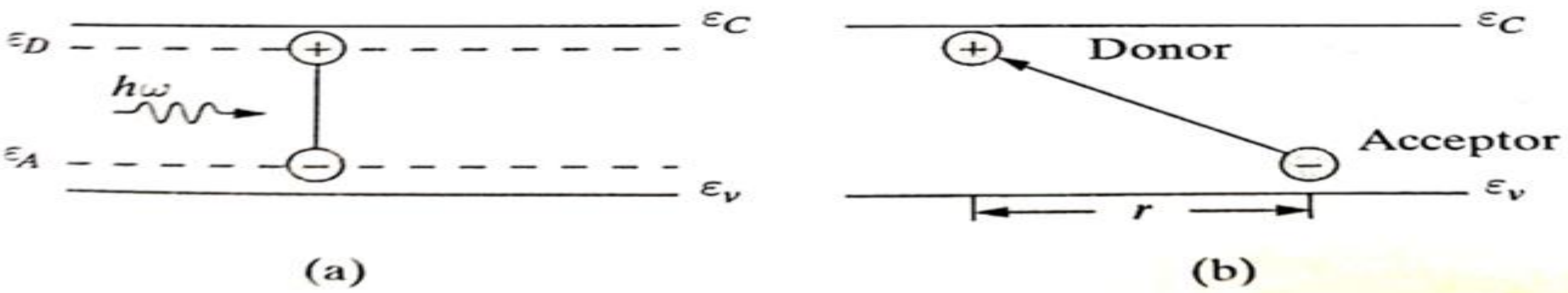

Fig: Illustration of photon absorption due to donor-acceptor transition. The separation between the impurity centers, r, is shown in (b)

- The absorption spectrum is largely altered if the doping level is increased and gradually taken to the point of degeneracy.
- For example, in a degenerately doped n-type semiconductor is direct the fermi level ε_{fn}, is above the conduction bandedge.
- If the semiconductor is direct bandgap then for the conservation of momentum, the transition resulting from the absorption of a photon will involve states in the conduction band that are at higher than $\varepsilon_g+\varepsilon_{fn}$.
- This shift of the absorption to higher energies due to doping-induced band filling is called the Burstein-Moss shift.
- An indirect band semiconductor will be similarly affected, except that phonons need not be involved in the transition. Momentum is conserved by impurity scattering.

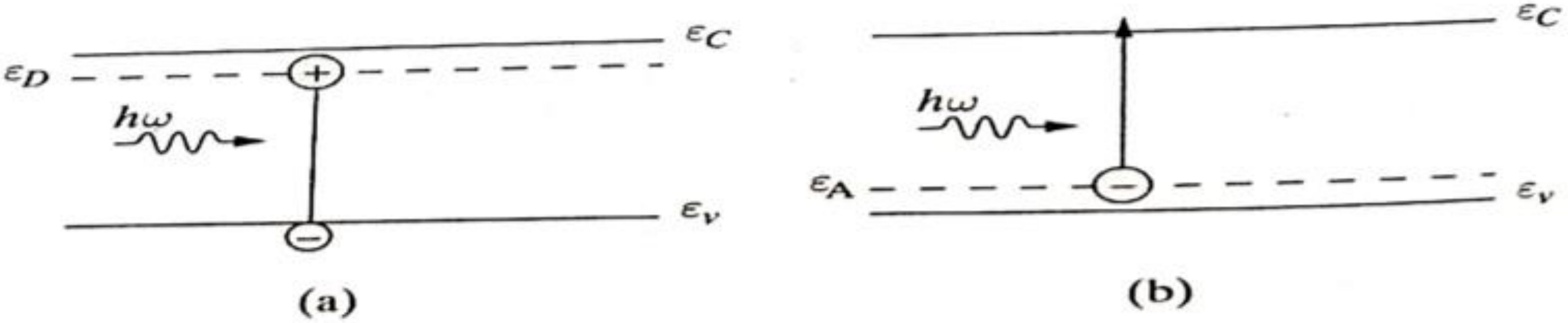

Fig: Illustration of (a) donor band and (b) acceptor-band absorption transition.

THANK YOU