

Optoelectronics Devices & Circuits (MEC-166)



UNIT-I

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 <u>Pallab Bhattacharya</u> , Prentice Hall Publications.	
2.	Physics of Semiconductor Devices, By S.M. Sze, Wiley Publication.	

Electronic Properties of Semiconductors

- Carrier effective mass and bandstructure
- Effect of temperature and pressure on bandgap
- Carrier Scattering phenomena
- Effect of scattering on mobility of carriers
- Semiconductor statistics
- Conduction process in semiconductors
- Bulk and surface recombination phenomena

Effective Mass of Charge Carriers

- The electron is acted upon by **two forces**: an **external field** and by force arising from the **periodic potential** of the lattice.
- The equation of **motion for an electron** in a perfect lattice with no scattering is:

$$\mathbf{F} = m_e^* \frac{dv_g}{dt} \quad (1.1)$$

- Where F is the force action on the electron, v_g is the group velocity of the wave packet describing the electron motion, and m_e^* is the electron effective mass, given by:

$$m_e^* = \hbar^2 \left(\frac{d^2\epsilon}{dk^2} \right)^{-1} \quad (1.2)$$

Equation (1.2) implies that the motion of electron can be treated in semiclassical manner provided quantum mechanical interaction with lattice are accounted for.

- The function $\left(\frac{d^2\epsilon}{dk^2} \right)^{-1}$ is plotted against k , the wave vector, in Fig 1.2 which is not true picture in real material.

- It is seen that the value is **positive** for small **electron energies**.
- As the electron energy increases, the value of the function become indeterminate and then become negative. This is the region of ϵ -k curve which is **concave downward**.
- Quantum mechanically, a carrier with a negative mass and negative charge is interpreted as an equivalent charged particle with positive mass and positive charge and this the hole.
- As expected From the above discussion, the **conduction band is concave upward**, and the **valence band is concave downwards**.
- Plot of (a) ϵ and (b) $(\frac{d^2\epsilon}{dk^2})^{-1}$ versus wavevector k as obtained from the solution of Schrodinger equation for one dimensional lattice.

Effective Mass of Charge Carriers

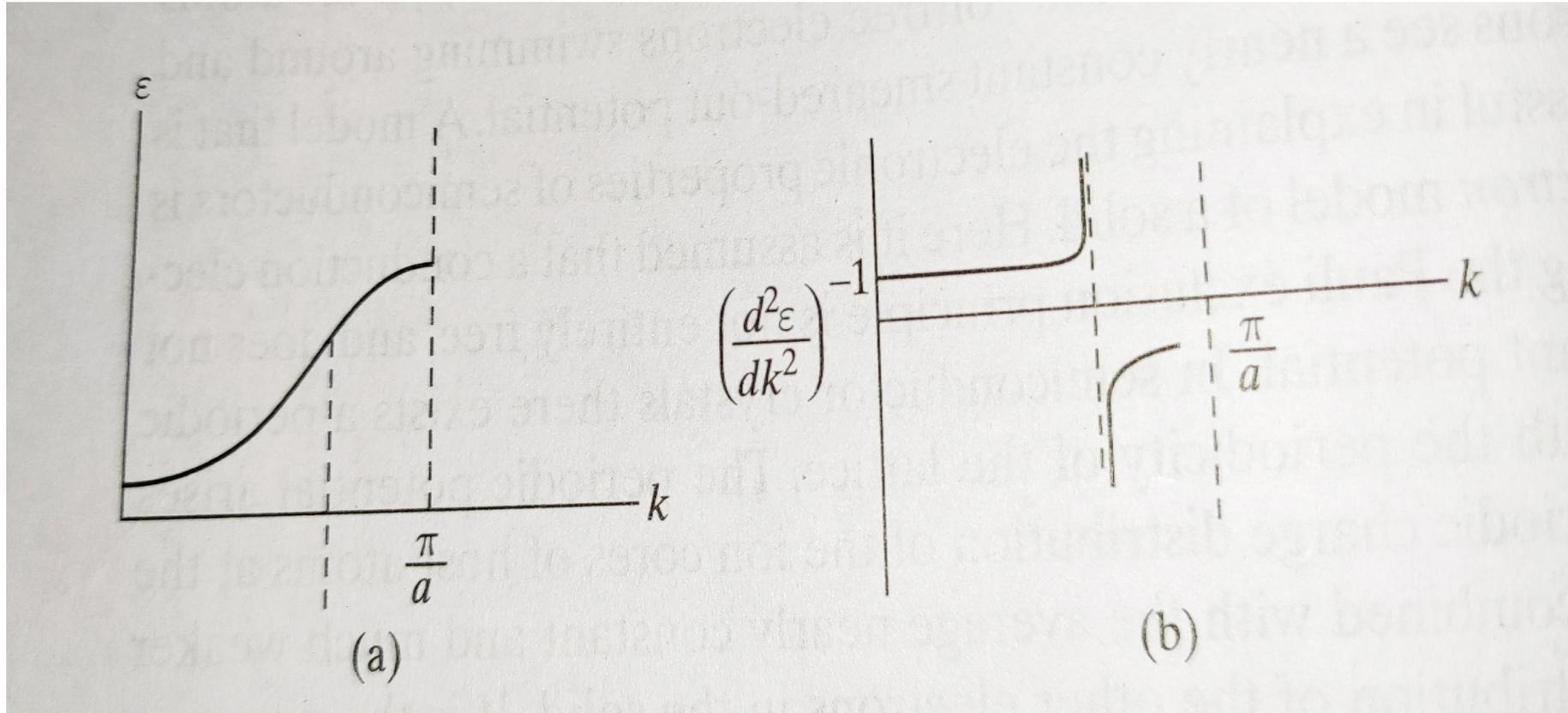


Figure 1.2: Plot of (a) ϵ and (b) $\left(\frac{d^2\epsilon}{dk^2}\right)^{-1}$ versus wavevector k as obtained from the solution of Schrodinger equation for one dimensional lattice.

$K = \pi/a$ denotes the boundary of the first Brillouin zone. The value of k at which $\left(\frac{d^2\epsilon}{dk^2}\right)^{-1}$ and the effective mass attain negative values corresponds to the point of maximum slope of the curve $\epsilon(k)$.

Carrier Effective Mass

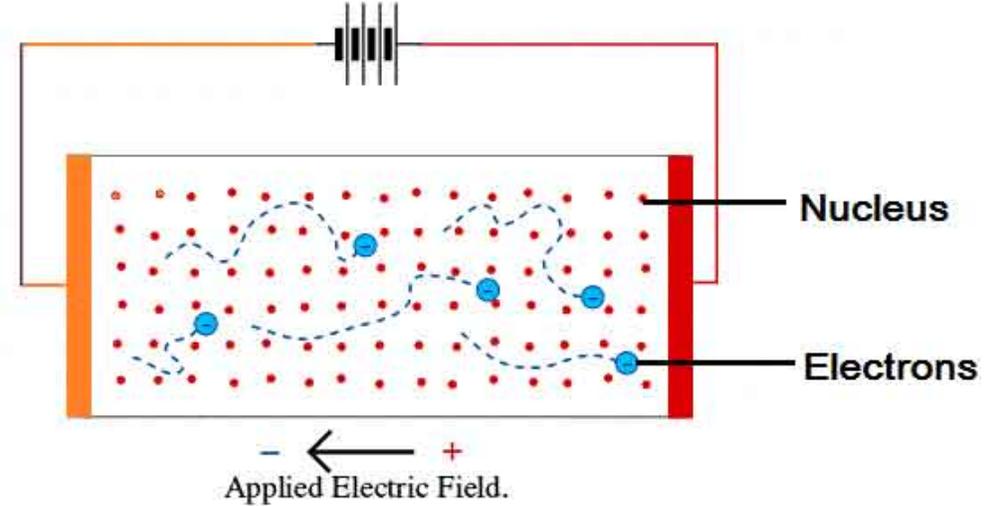
- If the momentum in a semiconductor is given by-

$$p = \hbar k$$

where p and k are vector quantities

then this momentum is known as ‘crystal momentum’.

- The electron moves in a material not freely but in the influence of its internal electrostatic field with mass m_e and applied external electric field ($-eE$).
- But it directly responds to the external electric field as a free particle of mass m_e^* i.e. effective mass.
- Thus an electron with mass equal to effective mass can be treated as a free electron of mass m_e^* without considering the influence of the internal field.



Band Structure of GaAs

- It is (III-V) ternary and quaternary alloy which is varied over their composition ranges and their band structures changes.
- The binary compound **GaAs is direct bandgap** material with **bandgap of 1.43eV** at room temperature.
- The lowest minimum in conduction band is at the (000) point in the first Brillouin zone. This is the zone centre in k-space.
- Under normal condition, electrons in conduction band of GaAs will occupy this minimum.
- For reference we call the **direct (k=0) conduction band minima Γ (000) valley**.
- The electron energy in this band is related to wave vector by:

$$\epsilon(k) = \frac{\hbar^2 k^2}{2m_e^*} \quad (1.3)$$

- There are two higher lying **indirect minima X(100) and L(111) valley** in GaAs conduction band, but they are sufficiently low for above Γ valley that few electrons reside there.
- For X and L minima above equation is not valid which are along (100) and (111) directions.
- There are three valleys in valence band maxima **HH(Heavy hole), LH(Light hole) and S0(Split off)**

Energy band diagram of GaAs

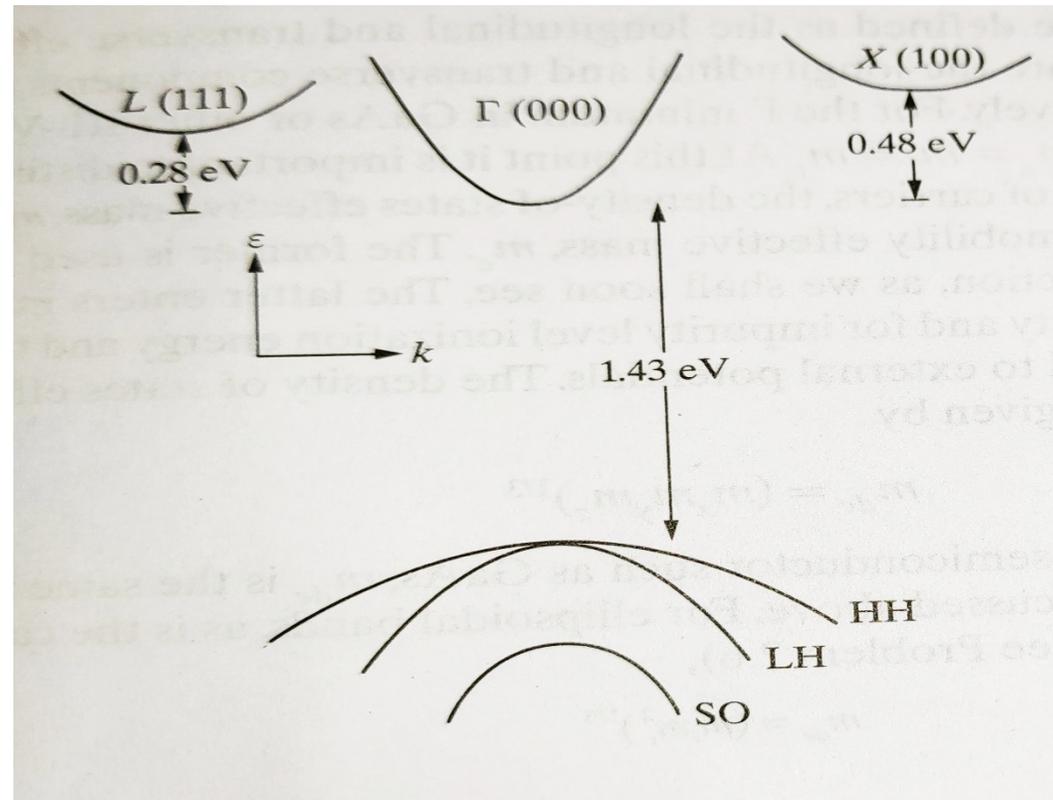


Figure 1.3: Simplified E-K diagram showing the various conduction band minima and valence band maxima in GaAs.

Band Structure of GaAs... conti

- Since the constant energy surfaces are ellipsoids of revolution as shown in figure.1.4
- There are three equivalent X-minima and four equivalent L-minima. The energy-wave vector dependency now becomes:

$$\epsilon(k) = \frac{\hbar^2}{2} \left(\frac{k_x^2}{m_x} + \frac{k_y^2}{m_y} + \frac{k_z^2}{m_z} \right) \quad (1.4)$$

- Here the **effective mass** depends on the direction of k and as such is a tensor quantity **m_{ij}** defined

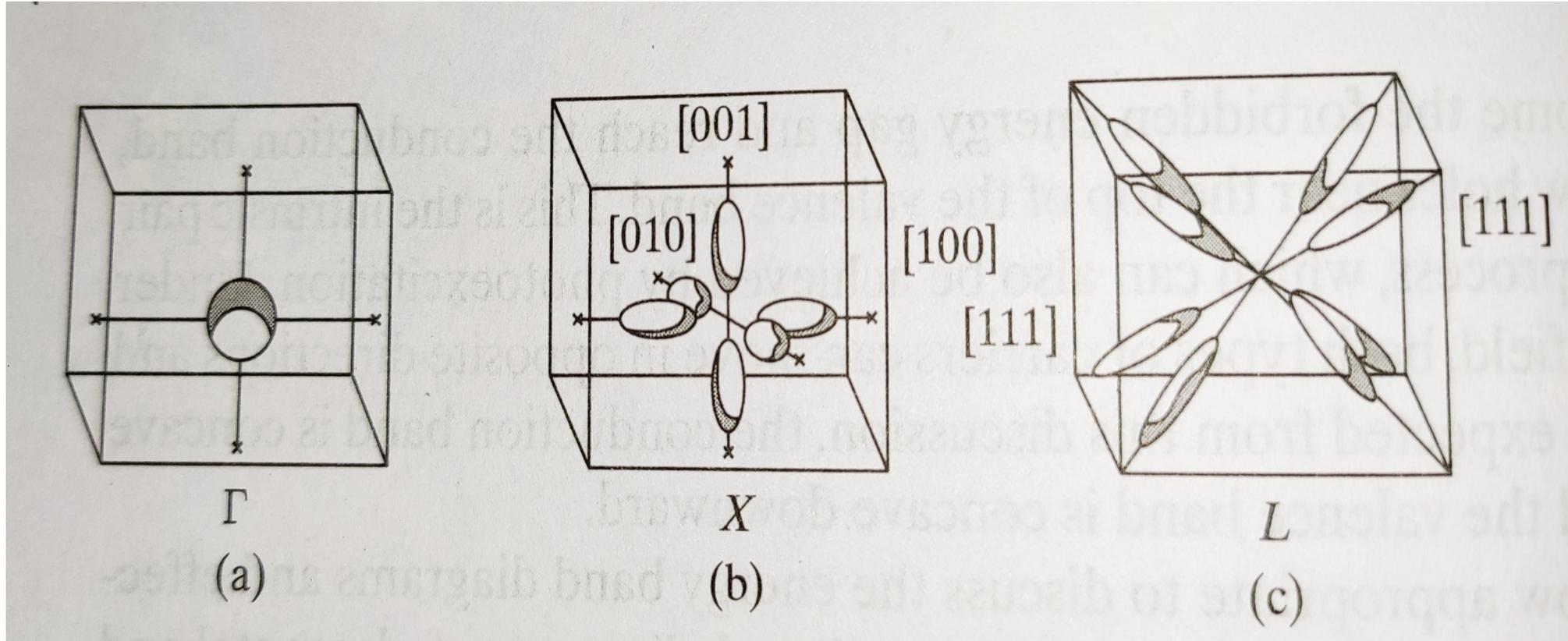
by:

$$m_{ij} = \hbar^2 \left(\frac{\partial^2 \epsilon}{\partial k_i \partial k_j} \right)^{-1} \quad (1.5)$$

- Because of the rotational symmetry of the ellipsoids of equal energy, the electron energy equation is simplified to:

$$\epsilon(k) = \frac{\hbar^2}{2} \left(\frac{k_l^2}{m_l} + \frac{2k_t^2}{m_t} \right) \quad (1.6)$$

- Where m_l and m_t are defined as longitudinal and transverse effective mass and k_l and k_t are the longitudinal and transverse components of wave vector respectively.



- Figure 1.4: constant energy surfaces for Γ , L , and X minima in GaAs.

Effect of Temperature on Bandgap in Semiconductors

- The band-gap energy of semiconductors tends to decrease with increasing temperature. When temperature increases, the amplitude of atomic vibrations increase, leading to larger interatomic spacing. The interaction between the lattice phonons and the free electrons and holes will also affect the band gap to a smaller extent.
- **Varshni modal** proposed an empirical formula, which define the relation between temperature with bandgap.

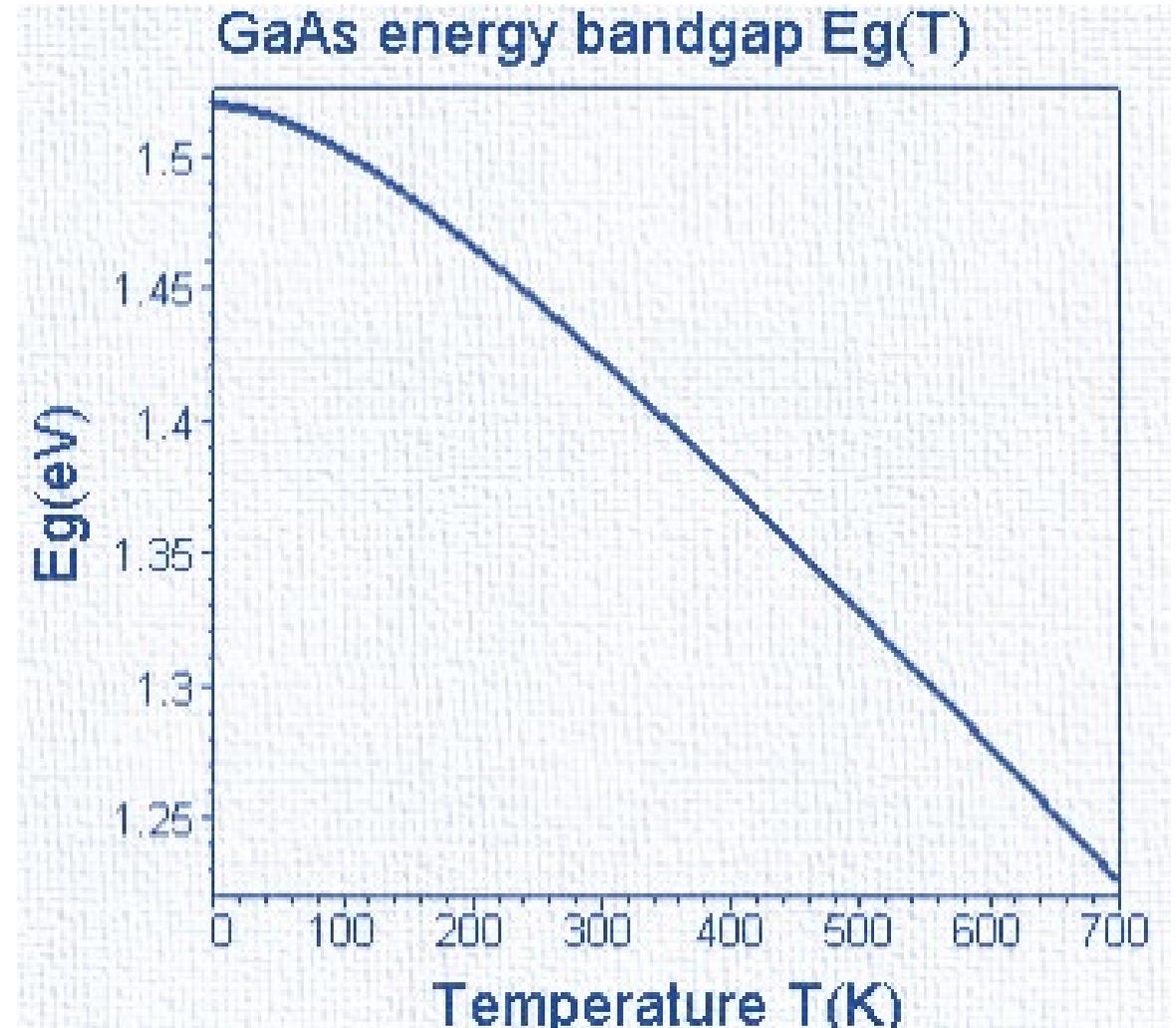
$$E_g(T) = E_g(0) - \frac{AT^2}{T+B} \quad (1)$$

- Where $E_g(0)$ is the band gap of the semiconductor at 0 K and A & B are constants, which have been determined from fitting of measured data.

Semiconductor	$E_g(0)$ (eV)	A (eV/K ²)	B (K)
GaAs	1.519	5.405×10^{-4}	204
InP	1.421	4.906×10^{-4}	327

- The values of A,B and $E_g(0)$ for GaAs and InP are shown in table.

- Energy bandgap plot with temperature for GaAs, which shows that the energy bandgap decreases with increasing the temperature.



Effect of Pressure on Bandgap in Semiconductors

- When a hydrostatic pressure is applied to compound semiconductor then interatomic spacing decreases, which results an increment in the fundamental energy bandgap.
- In general, all the energy levels in a semiconductor are shifted, and the change can be expressed by the equation

$$\epsilon_g(p) = \epsilon_g(0) + \epsilon_1 \Delta a \quad (2)$$

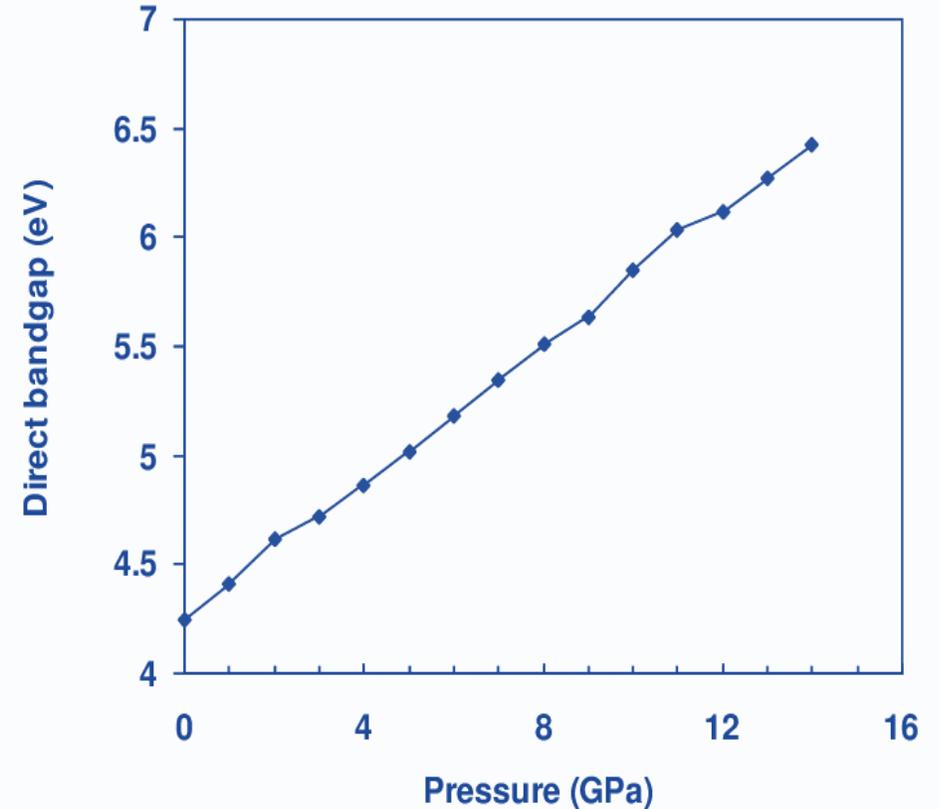
- The equation (2) represents a linear change in energy level with small change in lattice constant (Δa).
- $\epsilon_g(0)$, ϵ_1 represents the energy level without the application of hydrostatic pressure and pressure coefficient or deformation potential respectively. The change in energy gap of a semiconductor can be expressed by the equation

$$\epsilon_g(p) = \epsilon_g(0) \pm (\epsilon_{1c} + \epsilon_{1v}) \Delta a \quad (3)$$

- Where ϵ_{1c} and ϵ_{1v} are pressure coefficients for the conduction and valance bands.

Continue.....

- Energy bandgap plot with pressure for ZnS, which shows that the energy bandgap increases with increasing the pressure.
- In summery, the optical properties of compound semiconductors have been affected by temperature and pressure.



Effect of pressure on bandgap of ZnS

THANK YOU

