Gallium Phosphide

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Abstract

Gallium phosphide is commercially one of the most promising III-V semiconductor because of its application to opt-electronics due to wide band gap and thermal stability. A wide variety of theroetical and experimental works have given detailed information about the physical properties of the material. This paper will discuss some of the physical properties of the gallum phosphide semiconductor.

Introduction

Some of the atoms from group III of the periodic table combine with the atoms of group V to form "III-V" semiconducting compound, in a particular gallium phosphide (GaP) semiconductor. The gallium phosphide is commercially one of the most important "III-V" semiconductor because of its application to electroluminesent devices.

Structure of Gallium Phosphide

Most of the compound semiconductor of groups "III-V" crystallize into the cubic zinc blende form. The gallium phosphide (GaP) compound possesses the cubic zinc blende structure. Where each atom is at the centre of the regular tetrahedron, at the four corners of which lie atoms of the other kind.

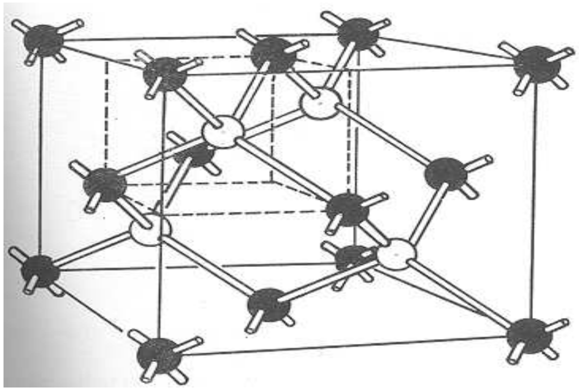

Figure 1: *Cubic Unit cell of the zinc blende Structure containing eight atoms [2].*

The unit cell of the cubic zinc blende structure is same as the diamond form except that the two different kinds of the atom occupy alternate positon in the lattice. The space group is F$\bar{4}$3m (schoenflies, T_{d^2}) and the point grroup is $\bar{4}3m(T_d)$. The two sub lattices being displaced relative to each other by one of quarter of the body diagonal of the cube. The cubic zinc blend structure which is simplest crystals lacking a center of symmetry and hence capable of exhibiting pizeoelectric and related effects depending on a polar symmetry. The lattice constant a is the distance between the lattice points of primitive cubic refrence lattice. For Gallium phosphide (GaP) lattice constant'a'is $5.45A^0$. The lattice constant of a semiconductor can expand or contract when impurity atoms are incorporated. The crystal density is one of the simplest and most important parameter. There are four molecules in a unit cell of the zinc blende lattice.

Crystal structure	zinc blende
Density	$4.14gmcm^{-3}$
Number of atoms in cm^{-3}	4.94×10^{22}
Melting point	1480^0C
Refractive index	3.37
Lattice constant	$5.45A^0$
Thermal conductivity	$1.1W/cmC$
Specific heat capacity (C_p)	0.313 J/g K

Properties of Gallium Phosphide

1. Electronic Enegry-Band Structure

The atoms gallium and phosphorus have 3 and 5 electrons respectively outside a core of closed shell with an s^2p^1 and s^2p^3 electronic configuration. Between them, therefore atoms have an average of four valence electrons per atom avilable for binding. These are three possible bonding in combination of gallium and phosphorus. 1. covalent 2. ionic and 3. neutral

For covalent bonding each phosphorus atom donates an electron to gallium atom each with four valence electrons. These combine to form sp^3 hybrid and tetrahedral bond. For pure ionic bonding we may suppose that gallium donates 3 electrons to phosphorus, forming Ga^{+3} and P^{3-} ions, each with spherically symmetrical closed shells configuration. These ions would be hold together in the crystal by purely electrostatic forces. The propertiesof a material may provide information on its ionic character. If there is a transfer of charge which is related to elctronegativity of two kinds of atoms. In the neutral bond gallium and phosphorus retain their electrons so that there is no charge difference between these atoms.

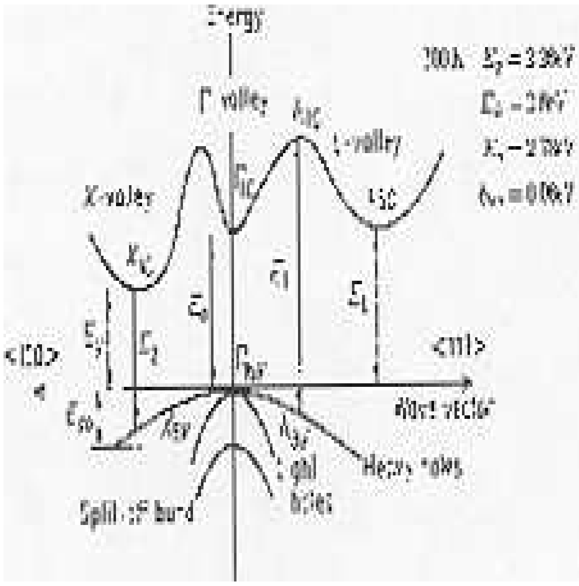

Figure 2: *Band structure of GaP[3].*

The transitions between the states which are not vertical in an energy band diagram are called indirect tansitions. Gallium phosphide is known to be a more suitable material to study some of the indirect band gap optical process. Since it has three an indirect band gap with energy gaps E_g = 2.885 ev(direct) and E_g = 2.338ev (indirect) at 0^0 K, E_g = 2.338 ev (direct) and E_g = 2.61 (indirect) at 300^0K respectively. These energy are just large enough to sustain resonably efficient luminescent for red, yellow and grenish light, even at 300^0 K. The temprature dependence of the direct energy gap is given by the relation, $E_g(T) = Eg(0) - (\alpha T^2)/(\beta + T)$ Where, $E_g(0)$ is band gap at 0 K. The temprature depndence E_g is mainly due to the electron phonon interactions,β is proportional to debye temprature. The effective density of conduction and valence bands are, $3.4 \times 10^{15} T^{3/2} cm^{-3}$

and $3.6 \times 10^{15} T^{3/2} cm^{-3}$ respectively.
The band gap and effective masses depend on a pressure. The dependencece of band gap with pressure is given by the relation, $E_g(p) = E_0 + ap + bp^2$, where pressure is in K bar.The spin orbit splitting energy in this material is very small.

2. Thermal Properties

Study of the thermal properties of solid gives connection with the fundamental physical properties like a thermal energy of a solid. The heat capacity at constant pressure c_P versus temprature for GaP is shown below. The specific heat of the GaP increases monotonically with temprature. At low temprature C_p and C_v are nearly the same, but c_p exceeds c_v at higher temprature as result of thermal expansion of the crystal lattice. The specific heat capacity of GaP is 0.313J/g K at 300 K.

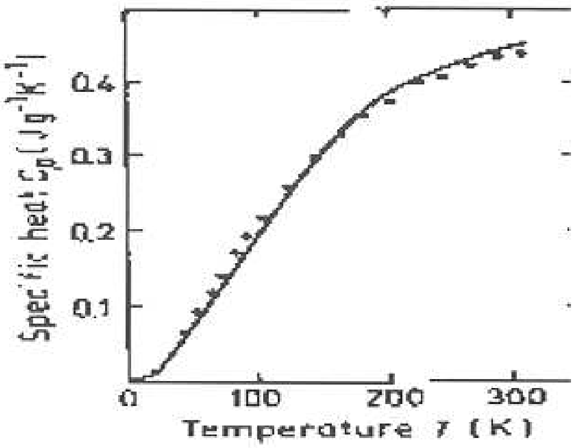

Figure 3: *Temprature dependence of specific heat capacity [3].*

The debye temprature θ_D can be used in charaterzing the excitation of phonons and to describe various lattice theramal phenomena. The debye tempartures of GaP are θ_D= 495 at 300^0 K and θ_D =446 at 0 K. strain tensor[e] by the relation,
Strain tensor is proportional to the Temprature(T). The proportionally constant is α is the linear thermal expansion coefficient. Which is given by the relation, $\alpha_{th} = (1/a)(\frac{\partial a}{\partial T})$, Where a is crystal lattice parameter, in the negative expansion coefficient is due to the entropy contribution of the Gibb's free energy.
Lattice thermal conductivity results essentially from interaction between phonons and from the scattering of phonons by crystalline imperfection. Thermal conductivity of semiconductor plays an important role in the design of power dissipation.

The temprature dependence of thermal condcutivity of Gap is shown below. This graph shows that the the thermal conductivity of pure single crysystal is zero at 0 K and rises approximately exponetially to a maximum near 30 K, falls some how faster than 1/T and then varies approximately as 1/T to the melting point. Thermal conductivity of GaP is 1.1 W /cm C at 300 K.

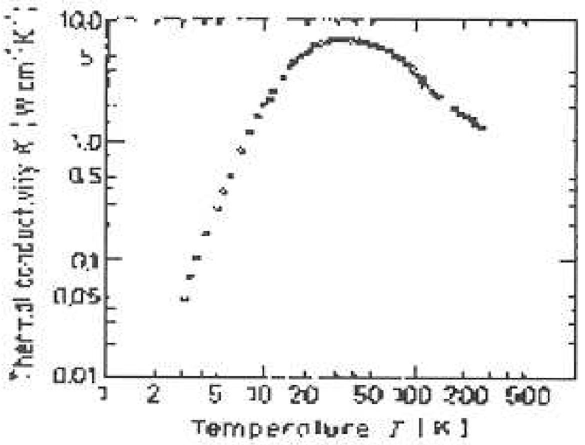

Figure 4: *Temprature dependence of thermal conductivity[3].*

3. Optical properties

The band structure of a semiconductor is closely related to the dielectric function $\epsilon(\omega)$ of a material. since GaP is an indirect band gap semiconductor. Studies of the optical properties of solid have proved to be a powerful tool in understaning of electronic structure of the solids. The complex dielectric function equation $\epsilon(\omega)$ of real and imaginary parts are related to the Kramers Kroning relation. Bascially, it describes the optical properties of the medium at all photon energies. Knowledge of optical properties is very important in the design and analysis of such optoelectronics devices. The dielectric constant of Gap depends on temprature since it increases from 10.75-11.1 in the static dielectric constant of GaP between 1.6 K and room temprature. The dielectic constant, (ϵ) consists of two parts. Which are due to electronic and lattice. The contribution of the electronic part of the static dielectric constant is obtained by measuring the refractive index (ϵ is n^2) as a function of energy

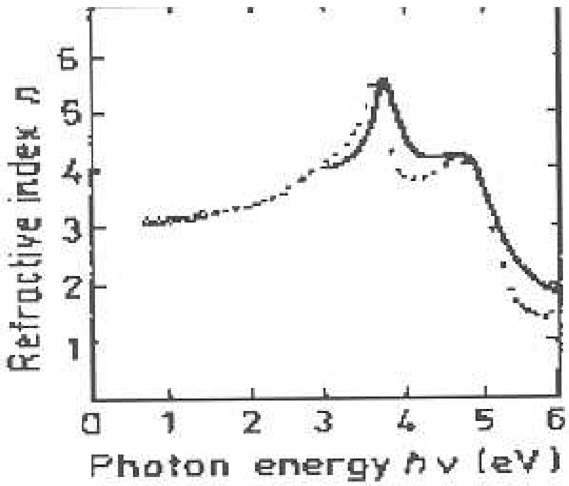

Figure 5: *Refractive-index dispersion for GaP at 300K [3].*

Figure 5 shows that the experimentally determined refractive index at 300 K versus photon energy. The peak is due to the transition of electrons.

Piezoelectricity

This is generated due to electronic polarization by application of stress to a crystal lacking a centre of symmetry. The gallium phosphide lacks centre of symmetry or inversion. Piezoelectricity tensor has only one component e_{14}. The experimental calculated value for Gap is$e_{14} = -0.1C/m^2$.

Application of Gallium Phosphide

The semiconductor gallium phosphide(GaP) due to its large energy gap E_g 2.78 ev at 300k and good thermal stability is potential matieral for optical and high temprtute device, light emiting red and green diodes and transistors, optoelectronics devices, bipolar transistors(BJTs) and rectifiers as semiconductor and lasers and electronic refrigeration.

References

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