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Magnetic Effect on the Optical Energy Gap of $ZnGeP_2$ Single Crystal

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Abstract

The magneto-optical effect was investigated for the chalcopyrite compound $ZnGeP_2$,the change in the energy gap due to the magnetic field was measured to be ≈ 0.002 eV at room temperature. The temperature coefficient of $\Delta E_{g.B}(T)$was found to be 1.67 $X10^{-4}$ eV/K in the temperature range(300-400)K. The reduced effective mass of carriers m^* was calculated and it found to decrease with increasing temperature.

***Keywords**: $ZnGeP_2$, Magneto-optical effect, Semiconductor compounds, Optical properties*

Introduction

The compound $ZnGeP_2$, belongs to the group II-IV-V_2 semiconductors, which crystallize in the chalcopyrite structure. Its energy gap, at room temperature is. (1.85-2.00) eV.[1] which is termed as a pseudo direct gap relative to that of the indirect gap of its binary analog gap[2]. Temperature dependence of the optical properties also has been investigated and the temperature coefficient of the energy gap reported to be in the range of (4.99 to 5.18) $x10^{-4}$ eV/k in the temperature ranges (300-400) K. In this work, the result of an

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investigation of the magnetic effect on the fundamental optical absorption edge of single crystal of this compound is presented.

Experimental Technique

The experimental setup for magneto-optical measurement is shown in the block diagram in figure (1). The measurements are made in the temperature range (300-400) K for a magnetic field of 0.7 tesla. Details for the sample holder and heating system, temperature as well as optical measurements are shown in figure (1).

1- monochromator 6- chopper
2- lens —V lamp
3- sample 8-recorder
4- heater 9-thermocouple
5- detector 10-magnetic pole

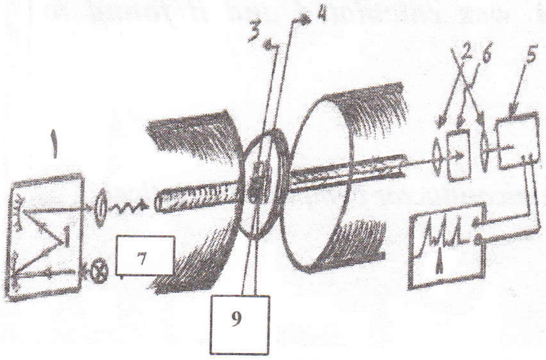

Fig.(1): Schematic diagram of the optical arrangement for the absorption measurement

The optical beam passing through the hole in the first magnet pole strikes the sample and the transmitted beam passes through the next pole- hole into the optical detector. The magnetic field, B, was measured using the teslameter which is capable to detect up to 10^{-3} tesla. The teslameter showed a uniform magnetic field in a circular area of 2 cm in diameter in which gives 0.7 tesla for 1cm apart. The intensity of the field was capable to make a reasonable change in the optical energy gap of $ZnGeP_2$.

The geometrical magnet gap mentioned above was suitable for the shape and the size of the optical samples of $ZnGeP_2$. Single crystals used in this work have been prepared by the method of solution growth [3] ,However preparation techniques for the optical samples used in this work have been discussed elsewhere [1].

Theoretical Aspects

For normal incidence of mono-chromatic radiation, the ratio of the transmitted,I, to the incidence portion ,I_0, for a uniform sample thickness , d, is given by the relation [2] :

$$T = I/I_o = exp(-\alpha d) \quad \text{......................} (1)$$

where α is the optical absorption coefficient which can be calculated using equation (1).The rapid rise of α with increasing photon energy $h\nu$ is due to carriers being raised from the valence band (VB) to the conduction band (CB) and is given by the power law (2):

$$\alpha(h\nu) = A(h\nu - E_{g})^{\tilde{n}} \quad \text{..............} (2)$$

Where E_g is the optical band gap energy , A is characteristic parameters of the bands [4], and $\tilde{n}$ is a number which characterizes the transition process and is equal to (1/2) for direct allowed transition,and 3/2 for forbidden transitions, (with different K-values). While it is equal to 2 and 3 for indirect allowed and forbidden transitions respectively [5]. When a magnetic field B is applied to a solid, the frequency of the orbital motion of the electrons is much greater than the reciprocal collision time, so that an electron can make several complete orbits between two collisions. In this case, one can neglect the collisions, consequently, the motion of electrons would be expected to break down if $\omega_o<\tau> >>1$, where ω_o is the angular frequency of electrons, $<\tau>$ is the expected value of the mean free time, a condition which may also be expressed in the form $B\mu_\beta > 1$, where μ_β is the electron Bohr magneton . With this condition, one should expect the motion of an electron to be in a periodic orbit and so to be quantized. When an electron moves in a circular orbit of radius r with a period $2\pi/\omega_o$will have angular momentum $m^*\omega_o r^2$, according to elementary quantum theory it should be equal to nh, where n is an integer equal or greater than one , thus one has:

$$r^2= nh/ m^* \omega_o \text{ .... } (3)$$

where m^* is reduced effective mass of carriers and $\omega_o =eB/m^*$ is the angular frequency and $h=h/2\pi = 1.054 \times 10^{-34}$ J.sec, and the kinetic energy,E, of the electron is given by :

$$E = ½ m^*\omega_o^2 r^2 = ½ nh\, \omega_o\text{.........}(4)$$

So that the lowest energy in the conduction band is now no longer equal to zero but it is equal to $(½h\omega_o)$. *The* bottom of the conduction band is, therefore, raised by an amount proportional to the applied magnet field. A proper quantum mechanical treatment [6] shows that for free electrons only odd values of **n** are permitted, the allowed energy levels are then given as [7] :

$$E_n = (n +½)\, h\, \omega_o \text{ .... } (5)$$

where n is any positive integer and the levels are referred to as Landau levels. If the magnetic field is directed along the z-axis, the quantization will only refer to motion in the x- and y-directions, the particle will be free to move parallel to thez-axis.

The energy of an electron in the conduction band is then given by the equation:

$$E=(n +½)\, h\omega_o + (h^2/2m^*)K^2_z \text{ .... } (6)$$

This equation is applicable also in semiconductors provided that the carrier density is degenerate then it can be rewritten in a new form for a conduction band as :

$$E=(n+½)h\omega_C+h^2 K^2/2m^*_c\text{.................} (7)$$

where ω_C and m_c^* are the angular frequency and the effective mass of electrons in the conduction band respectively Which is plotted as a function of K_z, Then one obtains for each ,n, a parabola, where the individual parabolas are a distance $2B\mu_\beta^* = h\, \omega_c$ apart ,as shown in figure (2). If $\mu_\beta^* = e\, h/2m^*_c c$ then equation (7) becomes:

$$E=(n +½)\, ehB/ m^*_c c + h^2 K^2_z/2m^*_c \text{ ....} (8)$$

Where c is the speed of light in vacuum .To a certain extend the band splits here into parabolic energy zones that overlap. The band edge that results form K_z=0,n=0 is raised by $B\, \mu^*_\beta$ after the magnetic field has been applied, and equation (8) reduces to:

$$E_o(0)=½e\, h\, B/m^*_c c \text{ ....}(9)$$

The same effect should occur for valence band:

$$E_o(0)=½e\,\hbar\,B/m^*_v c........(10)$$

where m^*_v is the effective mass of holes. . Then the total increase in the energy gap, which is due to the magnetic field then, will be given by:

$$\Delta E=½\ e\hbar B c^{-1}\{(1/m^*_c)+(1/m^*_v)\}......\ (11)$$

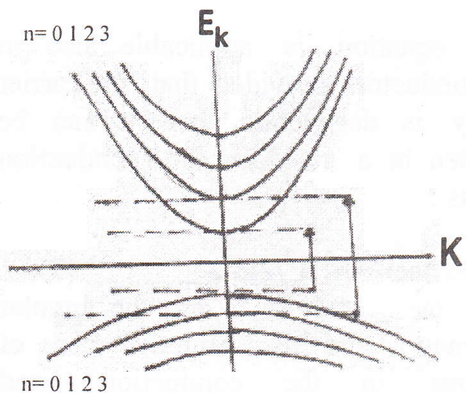

Fig.(2):Transition between Landau levels

Results And Discussion

Magneto-optical absorption measurements were made for a single crystal compound $ZnGeP_2$ at temperature ranges from 300K to 400K. When B=0 Tesla the logarithm of the optical absorption coefficient varies linearly with the logarithm of the incident energy,hv, according to equation (2).The slops of the plots of figures 3 and 4 yield ń= ½ which corresponds to a direct allowed transition process . E_g could also be estimated from this equation by plotting $[\alpha\ (h\nu)]^2$ versus ,hv, and the intercept of the straight line with hv-axis gives the value of ,Eg,. The energy gap will affect by the magnetic field and it increases with increasing the field as shown in the figure (3) and (4) for the temperatures 343K and 400K respectively.

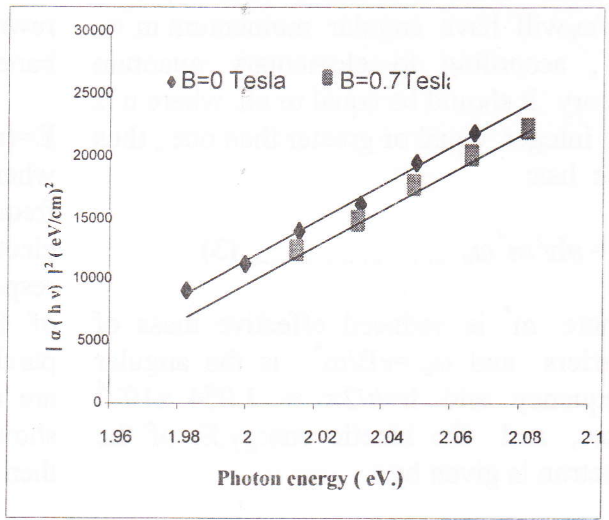

Fig.(3): The linear relation of the$[a(hv)]^2$ as a function of photon energy before and after applying the magnetic field at 343 K on $ZnGeP_2$, the χ^2 =0.9987 for B=0.7 Tesla line and χ^2 =0.9962 for B= 0 Tesla line.

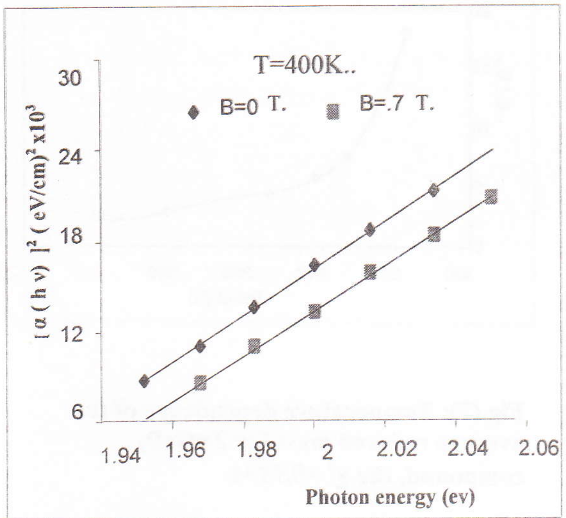

Fig.(4):The linear relation of the $[\alpha(h\nu)]^2$ as a function of photon energy before and after applying the magnetic field at T=400K on $ZnGeP_2$. the χ^2 =0.9993 for B=0.7

The values of the energy gap E_g before and after applying the magnetic field $E_{g,B}$ are plotted versus temperature in the temperature ranges 300-400K as shown in figure(5). However, the temperature dependence of E_g for $ZnGeP_2$ is given elsewhere [1]. Figure (6) shows a linear dependence of $\Delta E_{g,B}(T)$ on temperature according to the equation (12):

$$\Delta E_{g,B}(T)=0.17\times10^{-3}T-0.0538 \quad \text{........ (12)}$$

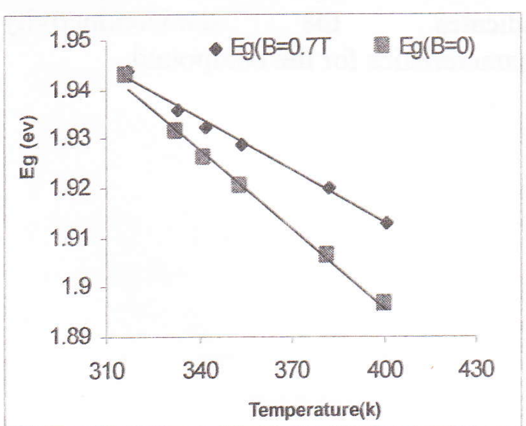

Fig.(5)Temperature dependence of the energy gap before and after applying the magnetic field for ZnGeP2, the χ^2 =0.9913 for B=0.7 Tesla line and χ^2 =0.9946 for B= 0 Tesla line

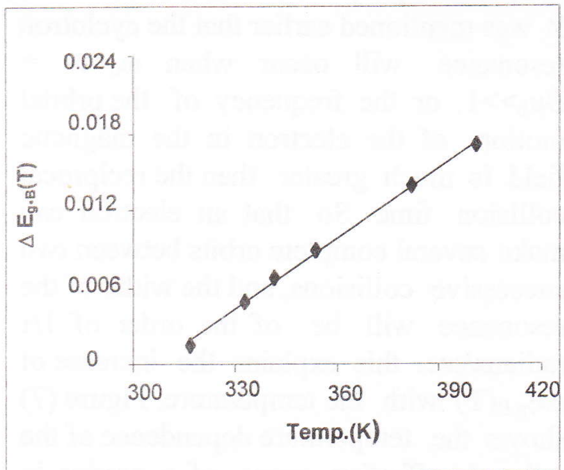

Fig.(6) $\Delta E_{g\cdot B}(T)$ due to the magnetic effects (B) as a function of temperature. the χ^2 =0.998 .

This dependence on temperature can be explained as follows:
In a degenerate semiconductor the mean free path of carriers L is depending on the Carrier concentration N and their mobilities μ_N according to the equation [8]:

$$L_N=(h/2e)(3N/\pi)^{1/3}\mu_N \quad \text{...............(13)}$$

In the investigated temperature range, the carrier concentration in the semiconductor increase with increasing temperature, due to the following equation [9]:

$$N=2(2\pi k_\beta T/h^2)^{3/2}(m_c^* m_v^*/m^2)^{3/4}\exp(-E_g/k_\beta T) \quad \text{..........................(14)}$$

While, μ_N, in general decreases with increasing, T, but it has much smaller values than that of N. Then ,L, and consequently, mean free time, τ, of carriers increase with increasing temperature [10].

It was mentioned earlier that the cyclotron resonance will occur when $\omega_o<\tau> = B\mu_\beta >> 1$, or the frequency of the orbital motion of the electron in the magnetic field is much greater than the reciprocal collision time So that an electron can make several complete orbits between two successive collisions, and the width of the resonance will be of the order of $1/\tau$ radians/sec. this explains the increase of $\Delta E_{g,B}(T)$ with the temperature. Figure (7) shows the temperature dependence of the reduced effective mass of a carrier in $ZnGeP_2$ in the temperature range 300-400K, which were calculated from equation (11).

The increase of the mean free time with increasing temperature also explains the decrease of reduced effective mass of the carriers .The dependence of the reduced effective mass of carriers on temperature is:

$$(m_r^*/m_o)=2E\text{-}6T^4-0.0027T^3+1.5166T^2-373.64T+34504 \ldots\ldots (15)$$

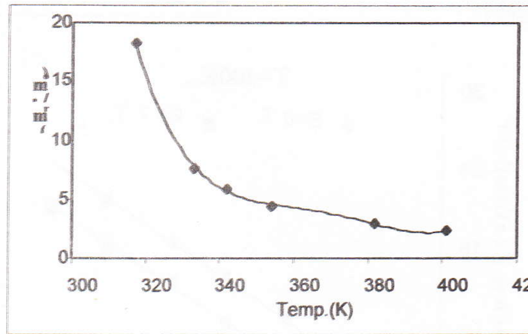

Fig.(7): Temperature dependence of the average reduced mass for $ZnGeP_2$ compound, the χ^2 =0.9994.

Conclusion

1- The change of the energy gap in $ZnGeP_2$ due to a magnetic field is an indication of the semiconductor degeneracy .

2- The temperature dependence of the change in the energy gap due to the magnetic field $\Delta E_{g,B}(T)$, according to the formulae:

$$\Delta E_{g,B}(T)= 0.17x10^{-3}\, T-0.0538\,.$$

3- The decrease of the reduced effective mass of carriers with temperature indicates the semiconductivity characteristics for the compound.

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کاری بواری موگناتیسی لەسەر بۆشاییە ووزەی ڕووناکیتاک کریستاڵی $ZnGeP_2$

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پوختە

توێژینەوە لەسەر ڕوانگە موگناتۆ–ڕوناکیەکانی نیمچە گەیەنەری $ZnGeP_2$ ئەنجام درا کەتیایدا گۆڕانی بۆشاییە ووزە لەژێرکاری بواری موگناتیسدا نزیکەی 0.002 ئەلیکترۆن ڤۆڵت بوو لەپلەی گەرمای ژوردا ، وە بینراکە بڕی گۆڕانی بۆشاییە وزەی تایبەت بەبواری موگناتیسی $\Delta E_{g,B}(T)$ *دەگۆڕێت لەگەڵ پلەی گەرمی بەهاوکۆلکەی گۆڕانی* $1.67X10^{-4}$ *ئەلکترۆن ڤۆڵت /پلەی گەرمی. لەنێوان پلەی گەرمی* 300 تا 400 *کلڤن . وەبارستەی کاریگەری لێکراوەی هەڵگرەکان* m_r^* دیاری کراو (ژمێردرا) وە بۆمان دەرکەوت لەگەڵ پلەی گەرمیدا کەم دەکات .

تأثير المجال المغناطيسي على فجوة الطاقة البصرية البلورة الأحادية للمركب $ZnGeP_2$

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الخلاصة

تم بحث التاثيرات المغناطيسية البصرية للمركب شبه الموصل $ZnGeP_2$ ، وجدت أن تغير فجوة الطاقةالناجمة عن تاثير مجال المغناطيسي تساوي حوال0.002 إلكترون – فولت في درجة حرارة الغرفة.و يتأثر مقدار تغير فجوة الطافة الخاص بالمجال المغناطيسي $\Delta E_{g,B}(T)$ بدرجات الحرارة وان قيمة معامل هذا التغير تساوي $1.67X10^{-4}$ الكترون –فولت /درجة الحرارة .في مدى الدرجات الحراري *300* - 400 كافن تم حساب الكتلة المختزلة لحوامل الشحنات و في الدرجات الحرارية المبينة أعلاه وتبين بأنها تقل مع زيادة درجة الحرارة.

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