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Magneto-Optical properties of GaP single crystal

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Abstract

The temperature dependence of magneto-optical and magneto-photoconductivity measurements were carried out in the range of (200-330) K. A home made optical cryostat was used for the measurements. The measured room temperature value of the energy gap was found to be 2.211 eV. The temperature coefficient of energy gap was found to be -5.48 x 10^{-4} eV/K obtained by the optical absorption method and -4.90 x 10^{-4} eV/K from the measurements of photoconductivity. The magnetic field coefficient of energy gap was found to be temperature dependent with values of 1.34 x 10^{-3} eV/Tesla at 202 *K* and 2.67 x 10^{-3} eV/Tesla at room temperature, when the field used was up to 2.2 Tesla. The reduced effective mass of carriers are also calculated from both techniques and found to be changing from 0.034 m_0 to 0.021 m_0 when magneto-optical data was used in the calculations and from 0.052 m_0 to 0.032 m_0 when magneto-photoconductivity data was used as the temperature changed from 220 K to 330 K respectively.

Keywords: Magneto-Optical properties, photoconductivity, semiconductors, GaP

1. Introduction

Optical properties are the most direct and the simplest way to obtain information on the energy gap of semiconductors. These properties are useful in determining energy band structures [1] as well as design and analysis of opto-electric devices [2]. The energy gap in semiconductors can be modified by the effects of temperature as well as the magnetic field. However, the temperature dependence of energy gap is a basic property of semiconductor materials and the knowledge on such dependence is of great importance for applications in opto-electric devices [3].

Gallium phosphate (GaP) is one of the binary group III-V semiconductor compounds, and it is currently used for optical as well as opto-electrical applications [3].

Although the optical properties of this compound has been studied by many authors [1,4], but investigations of the magnetic field effect on these properties was found to be very limited compared to other III-V compounds. In this work, methods of optical transition were used to investigate the effect of both temperature and magnetic field on the energy gap of GaP.

2. Experimental technique

The GaP sample used in this work was a 6.344 mm × 3.081 mm × 0.716 mm in dimension which cut from a wafer of 1 mm thick. The wafer was originally cut from a large single crystal having a diameter of about 5 cm.

Since the optical properties of semiconductor materials vary with the wave length, measurements are usually made with a different monochromatic radiation. For this case, a monochromator type (Czeny-Tuner PM101 8B) was used to obtain radiation spectrum produced by a 1000 W tungsten lamp. The output beam from the monocromator was focused on the polished GaP sample through a light focusing unit. This unit which consisted of two convex lenses was used to steer the light beam on the sample through the first lens and collected the light to focus it on the detector through the second lens. The detection unit was a spectrometer type (Buasch and lamb Spectronic 21) with a solid state detector. The detector produces an output signal with an amplitude proportional to the intensity of the light.

For photoconductivity measurements in semiconductors, an Ohmic contact is needed. By the method of direct thermal evaporation, Au is used on n-type GaP single crystal whose the details are given in reference [5]. The coating system type (Edward E306 coating unit) was used for evaporation. Photoconductivity measurements consist of varying wavelength (λ) of the incident monochromator light produced by the system mentioned earlier. The corresponding values of the samples resistance (R) were

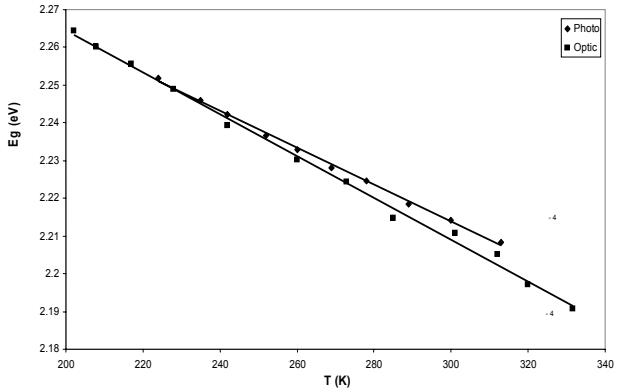


Figure 1. Temperature dependence of the energy gap from optical measurements.

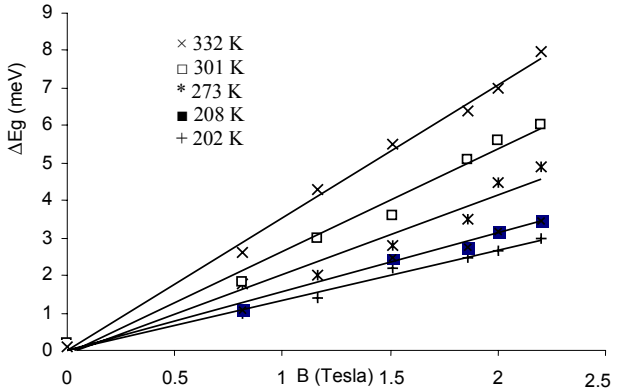


Figure 2. Energy gap shift (ΔEg) versus magnetic field (B) for various Temperature.

measured by using the *RCL* meter type (FLUKE PM 6306).

For the temperature dependence of measurements mentioned above, the sample was mounted on a low temperature optical cryostat [6]. The optical cryostat was fixed between two poles of a home made d-c electromagnet, which was capable to produce a stable magnetic field up to 2.2 Tesla. The sample temperature was controlled by using an electric heater made from 0.4 mm diameter copper wire. The temperature was measured by using a copper-constantan thermocouple. The sample thickness was measured using optical interference technique in an air wedge method. Details for these measuring systems are given in reference [5].

3. Results and analysis

3. 1. Optical transmition

If the incident light intensity, which is coupled into the sample, is denoted by I_o, then the transmitted intensity I that leaves a sample of thickness d is given by [7]:

$$I = I_o \frac{\left(1-R^2\right)\exp\left(-ad\right)}{1-R^2\exp\left(-2ad\right)}, \tag{1}$$

where R is the reflectivity and α is the absorption coefficient which is defined as the attenuation of the incident light per unit length of the path traversed in the sample. Near the absorption edge [8]:

$$1-R^2 exp(-2ad) \approx 1, \tag{2}$$

that is, R^2 exp(-2αd) is much less than unity. Equ. 1 can now be reduced to:

$$I = I_o\left(1-R^2\right)exp(-ad), \tag{3}$$

which is valid near the absorption edge for normal incidence, and providing that R is very low for a high quality polished surface sample, Equ. 3 can be rewritten as [9]:

$$I = I_o exp(-ad), \tag{4}$$

from which α can be deduced as:

$$\alpha = -\left(\frac{1}{d}\right)\ln\left(\frac{I}{I_o}\right). \tag{5}$$

The variation of the absorption coefficient α with photon energy $h\nu$ for indirect band to band allowed transition is of the from [7]

$$\alpha(hn) = A(hn - E_g)^2, \tag{6}$$

where A is an energy independent constant. The optical energy gap E_g was obtained by extrapolating the straight line portion of the $[\alpha(h\nu)]^{1/2}$ drawn versus $h\nu$ curve to a zero absorption [10, 11]. This process was repeated for temperatures from 202 K to 332 K. The obtained values of E_g were plotted versus their corresponding temperatures as shown in Figure 1. The least square best fit to this curve gives the temperature dependence of E_g as:

$$E_g = -5.48\times10^{-4}\ T\ + 2.3751\,\text{eV}. \tag{7}$$

This dependence is in good agreement with those results reported by others for the same above temperature range [10, 11].

The magnetic field effect on the energy gap was also investigated through measuring its effect on the optical absorption process mentioned above. The shift of the energy gap due to the effects of magnetic field $(\Delta Eg)_B$ for all investigated temperatures is shown in Figure 2. From this figure the change of energy gap by the magnetic field $(\Delta Eg)_B$ as a function of temperature is obtained. Figure 3 indicates that, the effect of applied magnetic field on energy gap in GaP is more sensitive at the higher temperatures than at lower ones. The effect may be due to the reduction of ionization impurity scattering mechanism, since impurity activation energy levels inside the band gap is inversely proportional to the temperature and that consequently increase the effects of the magnetic field on the energy gap [7].

The reduced effective mass m_r^* of carriers in semiconductors was calculated by using the relation [13].

$$\Delta E_g = \frac{e\hbar B}{2m_r^*}. \tag{8}$$

The temperature dependence of calculated values of m_r^* is shown in Figure 4. There are two expected reasons for this dependence: first, the existence of ionized impurity states below the conduction band vales (n-type)

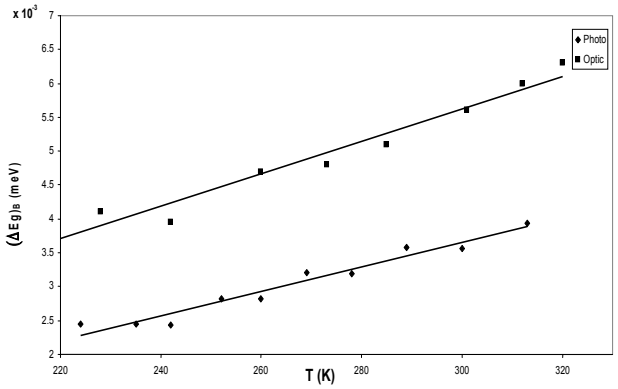


Figure 3. The temperature dependence of (ΔEg)B compared with that from photoconductivity measurements, B = 2.2 T.

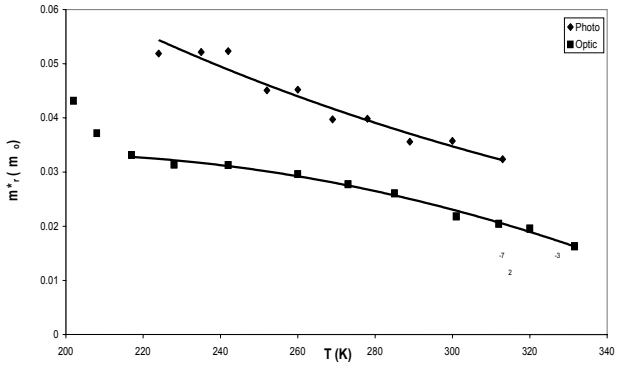
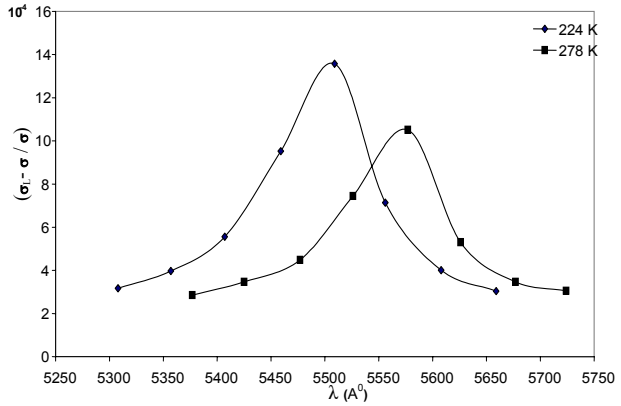


Figure 4. Temperature dependence of the average reduced effective mass measured from both optical absorption and photoconductivity.



Figue 5. Photosensitivity for GaP for temperatures 224 K and 278 K.

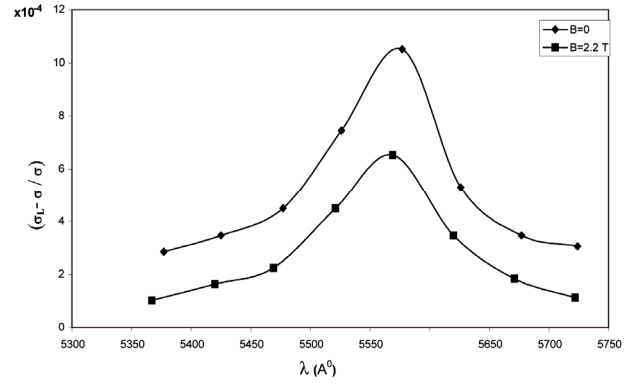


Figure 6. Variation of photosensitivity and magneto-photosensitivity with the wavelength at 278 K.

of semiconductor materials. These types of carriers will cause an ionized impurity scattering mechanism for the transition of electrons between the two energy bands. By increasing temperature such impurities will excite to conduction band states, leaving ionized state levels empty, then less electron scattering would be expected and that consequently gives smaller reduced effective masses [13]. The second expected reason is the temperature dependence of the conduction band structure valleys. The conduction band structure for GaP has an indirect energy transition at the point X , while its direct transition is at Γ . The temperature increase lowers the X -valley relative to that of Γ -valley. Since the electron-phonon scattering at X -valley has dominant contribution to the effective mass, the lowering of the X -valley as a result of temperature increase stimulates more impurity ionization, thereby reducing the carriers scattering. The latter effect leads to the smaller effective mass

3. 2. Magneto-Photoconductivity

The temperature dependence of sample resistance (R) was measured in both dark and under illumination. Figure 5, shows the sample photosensitivity $\frac{\sigma_L - \sigma}{\sigma}$ versus light wavelengths at two temperatures of 224 K and 278 K, where σ is $\frac{1}{R}$ for the dark conductivity and σ_L for the conductivity under the illumination. The spectrum peaks represent the highest optical absorption and they correspond to the energy gap of 2.252 eV and 2.224 eV for the two temperatures mentioned above respectively. Then the temperature dependence of Eg was obtained at the temperature range 224-313 K and was compared with that of the values derived from optical measurements, as they are shown in Figure 1. The least squares best fit give the energy gap-temperature dependence for the photoconductivity data as:

$$E_g = -4.9x10^{-4}T + 2.3606 \text{ eV} . \quad (9)$$

Effects of the magnetic field on samples photoconductivity were also measured under the effect of applied magnetic field. Figure 6, show photosensitivity versus incident light wavelength at the temperature 278 K, with and without the effect of magnetic field.

The increase in E_g under the effects of B arises from the Landau levels net shift of the energy gap due to the rising of the bottom of the conduction band and lowering the top of the valence band. The temperature dependence of energy gap magneto-sensitivity $(\Delta E_g)_B$ are the same for both measurements of optical absorption and

photoconductivity except that the latter has a lower sensitivity.

The average reduced effective mass (m_r^*) of carriers from photoconductivity measurements were also calculated. Their temperature dependence with that obtained from the optical absorption measurements are shown in Figure 4. The decrease of m_r^* with increasing the temperature are expected mostly to be due to carriers compensation [14, 15]. Higher values of m_r^*obtained from photoconductivity measurement may be due to both systematic and carriers scattering from photocurrent produced by samples photoconductivity.

4. Conclusions

The temperature dependence of the energy gap for GaP decreases linearly with increasing temperature similar to those reported earlier. The change in energy gap due to the effects of applied magnetic field is linear for constant temperature. But its sensitivity due to the magnetic field increases with increasing the temperature. Values of effective mass calculated from the magneto-optical interaction as a function of temperature is useful to investigate and analyze impurity activations inside the gap and the direct-indirect transition transformation process in semiconductors. The temperature coefficient of the energy gap decreases at the higher values of the applied magnetic field. The magnetic field coefficient of the energy gap increases at the high temperature region.

The photoconductivity results reveal that, the energy gap is more accurately determined from the spectral photoconductivity analysis. The reduced effective mass obtained from photoconductivity measurements are found to vary in the same manner as for values obtained from the magneto-optical measurements.

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