Faraday effect and $\lambda$-modulation absorption spectra of GaP

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Abstract. There are presented the absorption optical spectra of GaP measured by $\lambda$-modulation method at room temperature in the spectral region from 505 nm to 700 nm. It is not possible even by $\lambda$-modulation to be registered at room temperature the wave bands due to the exciton-phonon interaction. The absorption spectra of GaP carried out by a $\lambda$-modulation can be separated exactly in the spectral parts as follows: the transmittance region where the absorption is too slightly expressed; the region determined by the phonon-assisted indirect transitions; the region of the interband absorption. The purpose of Faraday rotation measurements is to establish the influence of the exciton-phonon interaction on the magneto-optical effect. The magneto-optical effect has been investigated by a $\varphi$-modulation. The spectral dependence of $dn/d\lambda$ in the transmittance region is determined by the $\varphi$-modulated spectra.

1. Introduction
GaP is a III-V semiconductor with cubical lattice (point group of symmetry $\bar{4}3m$). GaP has partial ionic bond and indirect gap. The GaP crystals are optical isotropic. GaP crystals attracted considerable attention due to the wide range of applications in the opto-electronic [1].

There are presented the results of Faraday rotation investigations in the transmittance region and at the absorption edge of GaP crystals. Faraday rotation spectra are compared with optical conventional and $\lambda$-modulation absorption spectra. The purpose of the investigation is to be determined the influence of the phonon-assisted indirect transitions on the Faraday effect.

2. Experimental
The GaP single crystals were grown by epitaxy method. The investigated samples were about 0.1 mm thickness and double polished faces along the (100) direction. The experimental results include conventional and $\lambda$-modulation absorption spectra and spectra of the magneto-optical effect. The absorption spectra have been measured in the transmittance region and at the absorption edge from 505nm to 700nm using SPM-2 monochromator. $\lambda$-modulation method has been realized by a quartz plate which vibrates before the output monochromator slit. The modulated signal is measured with Lock-in nanovoltmeter type 232 B (Unipan). $\lambda$-modulated absorption spectra are characterized by the derivative with respect to wavelength of the absorption coefficient.

The magneto-optical rotation angle $\varphi$ can be measured using a static system Polarizer–Crystal–Analyzer (P-C-A). P and A are placed at a crossed position and the crystal (C) is in magnet field. The electric vector of the linear polarized light transmitted trough the C rotates on angle $\varphi$. The light
intensity is described by \( I = I_0 \sin^2 \varphi \), where \( I_0 \) is the intensity of the incident on the crystal light. The determination of the angle \( \varphi \) by the static method is connected to great inexactness. The accuracy measurement of \( \varphi \) increases considerable using a dynamic (vP-C-A) system in which the P vibrates with angle \( \gamma = \gamma_0 \sin \omega t \) (\( \gamma_0 \leq 3^0 \)). The variable signal with frequency \( \omega \) conditioned by the vibrating P is measured by Selective nanovoltmeter type 233 (Uhipan). The (vP-C-A) system is at first without crystal and with P and A at a crossed position (figure 1a). This is the initially zero position of P and A, which can be exactly determined as follows: the A must be orientated on a few small angles \( \vartheta \) (\( \vartheta = 1^0, 2^0, 3^0, 4^0 \)) left and right with a respect to zero position. The intensity of the light transmitting through the system vP-C-A is determined by the expression:

\[
I = I_0 \sin^2(\theta + \gamma_0 \sin \omega t)
\]

The equation (1) can be presented for small angels \( \gamma \) and \( \vartheta \) in the form:

\[
I \approx I_0(\theta + \gamma_0 \sin \omega t)^2 = I_0 \left( \frac{\gamma_0^2}{2} + \vartheta^2 \right) + \vartheta(2I_0\gamma_0) \sin \omega t - \frac{I_0\gamma_0^2}{2} \cos 2\omega t
\]

The selective nanovoltmeter adjusted on frequency \( \omega \) registers a signal which is determined only by the second term in (2). Therefore the signal depends linearly on \( \vartheta \). The dependence \( I = f(\pm \vartheta) \) can be presented with two straight lines. The zero position corresponds to the cross point of these lines. The rotating angle \( \varphi \) determines the new zero position in the case of vP-C-A with a crystal in magnet field (figure 1b). The analyzer must be placed in position \( A' \) to be measured the angle \( \varphi \) using the described procedure. The accuracy of the rotating angle determination by \( \varphi \)-modulation is \( \sim 0.05^0 \).

Figure 1. The system vP-C-A a) without crystal (P vibrates harmonic with amplitude \( \gamma_0 \)); b) with a crystal in magnet field.

3. Results

The conventional spectrum of the absorption coefficient \( \sqrt{\alpha(\hbar \omega)} \) is shown in figure 2. It includes the transparent region, the range of the indirect transitions, Urbach’s rule range and the low-energy section of the absorption edge (figure 3). \( \lambda \)-modulated absorption spectrum (figure 3) and \( \varphi \)-modulated spectrum of the magneto-optical rotation are measured in the same energy region. Verdet constant (V) and the spectrum of \( \frac{1}{V}(\lambda^3) \) (figure 4) are calculated on the basis of \( \varphi \)-modulated spectrum. The relationship between the rotation angle \( \varphi \) and V is \( V = \varphi/Bd \). d is the samples thickness, B is the magnetic induction (B = 0.97 T). ([V] = deg/mmT)
4. Discussion

The conventional and differential spectra of the absorption coefficient of GaP in the transparent region (from 525nm to 700nm) are smooth structureless lines. The cross points of the straight lines \( \sqrt{\alpha (\hbar \omega)} \) with the abscissa demarcate the region of the indirect transitions (2.22–2.26 eV) in figure 2. The phonons which assist the indirect transitions can not be identified at 300K, because the phonon excitation is too strong at this temperature. It is expedient to be considered for the interpretation of Faraday rotation an effective phonon \( E_{\text{eph}} \). It substitutes all the combination of acoustic and optical phonons which determine the indirect light absorption at room temperature. The middle value of the interval \( (E_g - E_{\text{eph}}, E_g + E_{\text{eph}}) \) in figure 2 corresponds to the energy \( E_g \) of the indirect gap (2.24 eV) in accordance with the data in [1]. Therefore, the half of the interval width gives the phonon energy [4] i.e the energy of the effective phonon \( E_{\text{eph}} \) in our case \( (0.02 \text{ eV}) \).

\( \lambda \)-modulated absorption spectra give an opportunity for an exactly separation of the investigated spectral interval in two parts: I\(^{\text{st}}\) spectral region (the transparent region for \( \lambda > 560\text{nm} \)), where the signal is zero and II\(^{\text{nd}}\) spectral region (525nm < \( \lambda < 560\text{nm} \)), where appears a structure in the signal (figure 3). The II\(^{\text{nd}}\) region includes the indirect transitions and the beginning of the absorption edge. The linear approximation of the low energy flank of the curve in the II\(^{\text{nd}}\) spectral region crosses the abscissa at 2.24 eV. This value corresponds to the energy of the indirect gap.

\[ \frac{1}{V} = A \lambda^2 + B. \]

The reciprocal value of Verdet constant can be expressed as a linear function of \( \lambda^2 \):

\[ \ln \alpha = C + D \hbar \omega / T \] (C and D are constants, T is the temperature). The straight line \( \ln \alpha = f (\hbar \omega) \) crosses the abscissa at 2.24 eV (figure 5).
The spectrum of $dn/d\lambda$ can be calculated by Becquerel formula $V/\lambda = \lambda'(dn/d\lambda)$, where $\lambda'$ is a constant and $n$ is the refractive index of the crystal (figure 6).

![Figure 4. Spectrum of dependence $1/V = f(\lambda^2)$ of GaP.](image)

![Figure 5. Urbach's dependence of absorption coefficient.](image)

![Figure 6. Experimental spectrum of $\lambda'dn/d\lambda$.](image)

5. Conclusion
1) Faraday rotation is experimental determined by $\varphi$-modulation from 505nm to 700nm. Static and $\lambda$-modulated absorption spectra are measured in the same spectral region. 2) It is established that the reciprocal value of Verdet constant depends linearly on $\lambda^2$ in the transmittance region and in the region of the indirect transitions. 3) It has been shown that the Urbach’s rule is also valid and the straight line ln(\alpha(h\omega)) crosses the energy axis at 2.24 eV which corresponds to the energy of the indirect gap.

References
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