FEATURES OF ELASTIC ANISOTROPY OF GALLIUM ARSENIDE AND PHOSPHIDE CRYSTALS.

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Abstract: *The velocity and attenuation coefficient of acoustic waves with frequencies of 30–420 MHz in cubic crystals of gallium arsenide and phosphide along the crystallographic axes [100] and [110] were determined. Based on experimental data, the elastic anisotropy parameters of these crystals were determined for the first time simultaneously, both for real and imaginary elastic moduli. It is shown that the proposed approach is useful for predicting the general nature of the attenuation anisotropy of acoustic waves in crystals of cubic symmetry.*

Key words: crystals, gallium arsenide, gallium phosphide, acoustic waves, attenuation coefficient, elastic anisotropy parameters.

1. Introduction.

Cubic crystals of gallium arsenide and phosphide have a high acousto-optic quality factor [1] and are widely used as working media in acousto-optic devices in the visible (GaP) and infrared (GaAs) ranges. To improve the characteristics of these devices, in particular acousto-optic deflectors and modulators, it is necessary to know the anisotropy of the velocity and attenuation of acoustic waves. According to [2], all cubic crystals can be divided into crystals with positive or negative anisotropy of the second-order elastic moduli. Depending on the type of anisotropy, the orientation dependence of the velocity and attenuation coefficient in cubic crystals is qualitatively distinguished. For this purpose, in the present work, the elastic properties of these crystals were investigated and the elastic anisotropy parameters were determined, both for real and imaginary elastic moduli.

2. Experimental methods

Measurements of the velocity and attenuation of longitudinal and transverse acoustic waves were carried out in the frequency range of 30-420 MHz. The studied samples were parallelepiped-shaped, oriented with their long sides along the crystallographic directions [100], [110] with an accuracy of up to 10. The dimensions of the samples along the oriented side averaged 1 cm. All sample faces were processed by mechanical grinding and polishing to accuracy class 14.

To excite high-frequency longitudinal and transverse acoustic waves, piezoelectric transducers made of X- or Y-cut quartz, respectively, were used. Measurements were carried out on an ultrasonic setup in pulsed mode. The acoustic wave velocity V was determined either by the pulsed interference method with an accuracy of 0.01% [3, 4], or using a delay generator, allowing the time intervals between elastic pulses tdelay to be measured with an accuracy of 0.01 μs:

$$V = \frac{2L}{t_{back}}, \quad (1)$$

where L is the length of the sample being studied.

The amplitudes of the elastic pulses and the time intervals between them were also measured. The attenuation coefficient of the acoustic wave was calculated using the formula [2]:

$$\alpha = \frac{20\ell g\left(A_1 / A_2\right)}{2L}, \quad (2)$$

The accuracy of determining the acoustic wave velocity and attenuation coefficient using the acousto-optic method was approximately 0.2 and 5%, respectively.

Based on the measured values of the acoustic wave velocity V and attenuation α along specific crystallographic directions [100] and [110] and reference data from [1, 4], all independent real and imaginary components of the complex elastic constant tensor of gallium arsenide and gallium phosphide crystals were determined:

$$c_{ijkl} = c'_{ijkl} + c''_{ijkl} \,. \quad (3)$$

The attenuation along any direction was determined by the formulas [5, 6]:

$$\alpha = \frac{1}{2}\omega\frac{c''_{eff}}{\rho V^2}, \quad (4)$$

$$c''_{eff} = c''_{ijkl}\kappa_j\kappa_l\gamma_i\gamma_k, \quad (5)$$

where ρ is the density, ω is the angular frequency of the acoustic wave, κ_j and γ_i are the direction cosines of the wave vector and the displacement vector. The necessary relations for all independent components are given in Table 1, in which the expressions for the elastic moduli are given in matrix notation and are the same for the real and imaginary components of the complex elastic tensor.

3. Results of the experiment and their discussion

The measured values of the velocity and attenuation of acoustic waves along the crystallographic directions <100> and <110> are given in Table 1. In it, **q** and **γ** are the wave vector and polarization of the acoustic wave, respectively. The experimental values of the attenuation coefficient of acoustic waves were extrapolated to a frequency of 1 GHz according to the quadratic law [3]. Based on the obtained values, all independent real and imaginary components of the complex tensor of elastic constants of these crystals were determined, taking into account reference data on the dielectric and piezoelectric coefficients [1].

***Table 1**. Propagation velocity and attenuation coefficient of acoustic waves in GaP and GaAs crystals (ν=1 GHz, T = 293 K).*

q	γ	Expression C_{eff}	GaP		GaAs	
			V, 10^3 $m \cdot c^{-1}$	α, $dB \cdot mks^{-1}$	V, 10^3 $m \cdot c^{-1}$	α, $dB \cdot mks^{-1}$
[100]	[100]	c_{11}	5.82	6.25	4.73	10.25
	[001]	c_{44}	4.10	2.51	3,35	2.14
[110]	[110]	$\frac{c_{11}+c_{12}+2c_{44}}{2}$	6.43	3.85	5.24	8.65
	[1-10]	$\frac{c_{11}-c_{12}}{2}$	3.04	2.85	2.48	2.55

Like all crystals of cubic symmetry, gallium phosphide and gallium arsenide crystals have three independent real elastic moduli c'_{11}, c'_{44}, c'_{12} and three independent imaginary elastic moduli c''_{11}, c''_{44}, c''_{12}, which are determined from data on the velocity and attenuation of acoustic waves along the symmetry axes [7, 8]. For example, using the values of the velocity and attenuation of longitudinal (V_L,

α_L) and transverse (V_S, α_L) waves along the <100> direction, one can determine the real and imaginary constants c'_{11}, c''_{11}, c'_{44} и c''_{44}, which are the effective elastic moduli for this direction.

Using experimental data, the parameters of elastic anisotropy were calculated: both for real elastic moduli $\Delta c'$ and for imaginary elastic moduli $\Delta c''$ [7]:

$$\Delta c' = c'_{12} + 2c'_{44} - c'_{11} \quad (6)$$

$$\Delta c'' = c''_{12} + 2c''_{44} - c''_{11} \quad (7)$$

The results obtained showed that both the real and imaginary elastic anisotropy parameters in gallium arsenide and gallium phosphide crystals are positive.

With a positive anisotropy parameter, the velocity and attenuation of longitudinal waves are maximum in the [111] direction and minimum in the [100] direction. At the same time, the velocity and attenuation of transverse acoustic waves are maximum in the [100] direction and minimum in the [110] direction. It was found that the attenuation coefficients of acoustic waves, determined through the anisotropy parameter $\Delta c''$, agree well with the experimental attenuation values [9-11].

The values of the anisotropy parameter for real elastic moduli turned out to be approximately the same and equal to $\Delta c'=5.4\cdot10^{10}$ N/m2 for GaAs crystals and $\Delta c'=6.32\cdot10^{10}$ N/m2 for GaP crystals. The values of the anisotropy parameter for imaginary elastic moduli also turned out to be close in magnitude and equal to $\Delta c''=0.65\cdot10^{7}$ N/m2 for GaAs crystals and $\Delta c''=0.98\cdot10^{7}$ N/m2 for GaP crystals.

4. Conclusion

The results of the study showed good agreement between the experimental values of the acoustic wave attenuation coefficient along the specific directions [100] and [110] and the calculated values using the effective imaginary elastic constants, despite the relatively large error in determining the attenuation coefficient and, consequently, the imaginary elastic parameter. This approach will allow us to describe the anisotropy of the propagation velocity and attenuation coefficient of acoustic waves in cubic crystals of any symmetry and to select the most optimal crystal cuts for the development of acousto-optic deflectors and light modulators.

To establish general patterns for the entire class of cubic crystals, it is necessary to conduct similar studies in cubic crystals with a negative anisotropy parameter of elastic properties. The obtained results may be useful for predicting the general nature of acoustic wave attenuation anisotropy in cubic crystals.

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