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INVESTIGATION OF SOME ACOUSTIC AND ELECTROACOUSTIC PROPERTIES OF $Bi_{12}GeO_{20}$[1]

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A change of attenuation of the longitudinal ultrasonic wave (UW) propagated along $\langle 111 \rangle$ direction as a function of frequency and intensity of the ultraviolet light has been investigated as well as the frequency dependence of the attenuation of this wave in dark sample. The obtained results are in good agreement with White's theory of the attenuation of the ultrasonic waves on conduction electrons in piezoelectric seminconductors.

1. Introduction

Since the first report on $Bi_{12}GeO_{20}$ (BGO) [1] a large number of research teams have investigated its properties. The piezoelectric [2,3] , electrooptic [4,5] , elastooptic [6], photoelectric [7-10] ,and some acoustic and lattice vibration properties [11,13] have been studied. It has been shown that BGO has piezoelectric and acoustic properties in the same cathegory as $LiNbO_3$ and $LiTaO_3$. Moreover, its photoconductivity yields new possibilities of its applications. In the present time the crystals of BGO are widely used in science and technique as high sensitivity read write volume holographic storage, photorefractive and information processing elements.

The present study was done to obtain more information on acoustic and electroacoustic properties of the BGO single crystal.

2. Experiomental procedure and results

The single crystal of BGO belongs to cubic crystal class 23. The samples of the crystal had shape of a parallelepiped which edges had dimensions approximately 1 cm x 1 cm x 3cm. The longer dimension of the sample was in $\langle 111 \rangle$ direction with respect to crystalographic axis. All surfaces of the sample were optically polished and parallel to each other.

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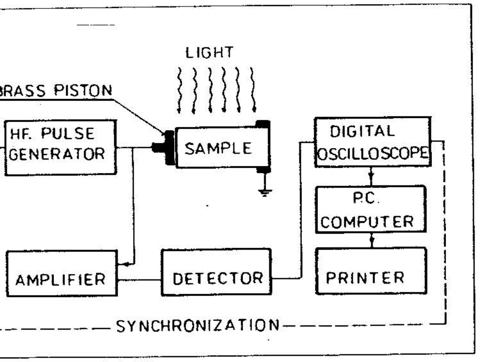

Fig.1. The experimental set up for investigation of acoustic and electroacoustic properties of BGO.

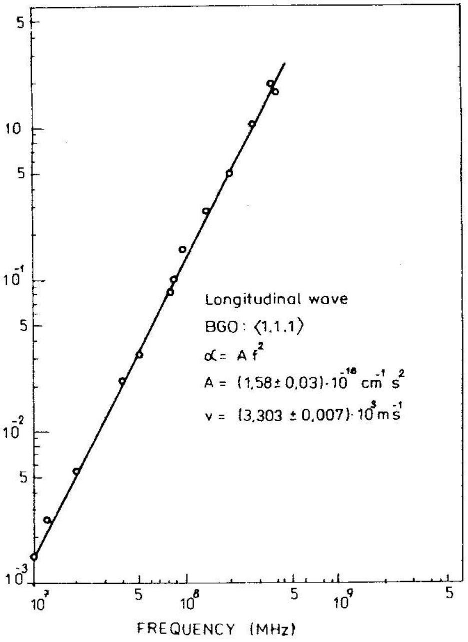

Fig.2. The frequency dependence of the attenuation coefficient of the longitudinal ultrasonic wave propagated in ⟨111⟩ direction in dark crystal of BGO at room temperature.

A longitudinal ultrasonic wave propagated along ⟨111⟩ direction has been generated ng piezoelectric surface excitation of the sample. The longitudinal ultrasonic wave opagated in ⟨111⟩ direction is according to [14] generated when the ⟨111⟩ surface is ited by an external high frequency electric field the electric strength vector of which perpendicular to this surface. Thus only brass piston which is slightly pressed to the face served as an electrode delivering electric field to excite the surface. The same

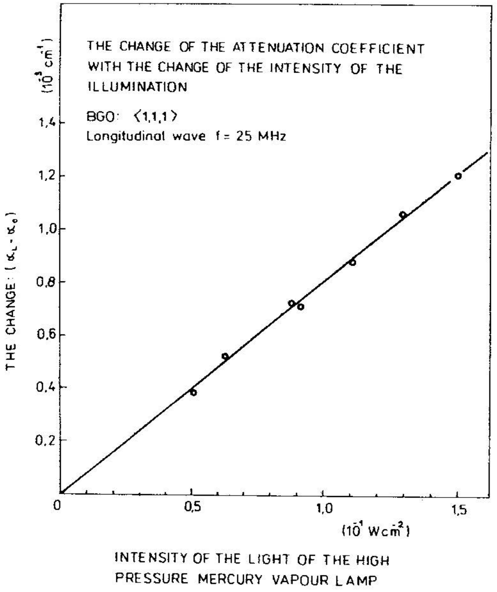

Fig.3. The change of the attenuation coefficient of the longitudinal wave propagated in ⟨111⟩ direction of the BGO crystal as a function of the light intensity of the high pressure mercury vapour lamp at room temperature.

piston served also as a receiver electrode of the field occuring during reflections of the ultrasonic pulses. The block diagram of the experimental set up for the investigation of the acoustic and electroacoustic properties of the BGO crystal is shown in Fig.1. The apparatus worked as follows. High frequency pulses (5 MHz to 300 MHz) from the pulse generator generate via piezoelectric effect longitudinal ultrasonic pulses. Each ultrasonic pulse generates a h.f. signal during its reflection from the surface. The received h.f. pulses are amplified and then after detection led to the digital oscilloscope where a train of echoes can be observed. The digitalized information from the oscilloscope can be stored by PC computer, visualized on its screen or printed. Using this equipment we have obtained more than 100 echoes in the frequency range from 10 to 50 MHz and about 5 echoes at 300 MHz. The ultrasonic attenuation coefficient can be precisesly measured from the exponential decay of train of the echoes. Velocity of the wave can be determined from the time distance of the echoes. Using this procedure the frequency dependence of the attenuation coefficient as well as its change due to illumination by the light of the high pressure mercury vapour lamp (MVL) has been measured. Velocity of the ultasonic wave has been measured too. Fig 2. shows the frequency dependence of the attenuation coefficient of the longitudinal ultrasonic wave propagated in ⟨111⟩ directin of the BGO. The attenuation coefficient $\alpha_0 = Af^2$, where $A = (1,58 \pm 0,3) \times 10^{-18} \mathrm{cm}^{-1}\mathrm{s}^2$.

The velocity $v_0 = (3.304 \pm 0.007) \times 10^3 \mathrm{ms}^{-1}$. All data have been obtained at room temepratture in the dark sample.

The BGO single crystal is a photoconducting semiconductor. The longitudinal ultrasonic wave propagated in its ⟨111⟩ direction is piezoelectrically active one ,it means

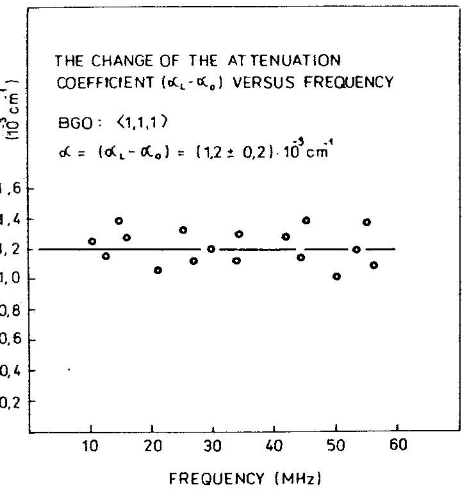

Fig.4. The change of the attenuation coefficient of the longitudinal ultrasonic wave propagated in ⟨111⟩ direction of the BGO crystal at constant illumination by the light of the mercury vapour lamp as a function of its frequency at room temperature.

at it is accompanied with a high frequency electric field,the strength vector of which parallel to the wave vector of the ultrasonic wave. According to White's theory [15] the acoustic wave propagation in piezoelectric semiconductors the attenuation coicient and the velocity of the acoustic waves depend on electric conductivity of the stal, and thus in photoconducting materials also on their illumination.

Investigating the attenuation and velocity as a function of the total intensity of the VL we have obtained the results presented in Fig.3. One can see in Fig 3. that change of the attenuation coefficient is a linear function of the total intensity of MVL so that $\alpha = \alpha_L - \alpha_O = K_L I$, where α_L is the attenuation coefficient in illuminated sample, α_O is the attenuation coefficient in the dark sample, $K_L =$ $8 \pm 0.1) \times 10^{-2}\mathrm{W}^{-1}\mathrm{cm}$, and I is the total intensity od the MVL.

Fig.4. shows that attenuation due to electrons does not depend on frequency and its lue at I = 0.15 $\mathrm{Wcm}^{-2}$is $\alpha = (1.2{\pm}0.2){\times}10^{-3}\mathrm{cm}^{-1}$. The change of the velocity of the rasonic wave with illumination has been smaller than the error of the measurement.

3. Theoretical discusion

According to White the attenuation coefficient due to conducting electrons in piezoctric semiconductor can be expressed by the relation

$$\alpha = \frac{K^2}{2\mathrm{v}} \frac{\omega_C}{1 + (\frac{\omega_C}{\omega} - \frac{\omega}{\omega_D})^2} \tag{1}$$

ere ω is the angular frequency of the ultrasonic wave, $\omega_D = \mathrm{v}^2 e/\mu k T$, $\omega_C = \sigma/\varepsilon$, v is velocity of the ultrasonic wave, ε is the permittivity, μ is the mobility of electrons, σ is the electric conductivity, K is the electromechanical coupling coefficient, T is the temperature, and k is the Boltzman's constant.

The measured value σ at I = 0.1 Wcm^{-2} was $\sigma = 4.3 \times 10^{-6}\Omega^{-1}\mathrm{m}^{-1}$ and $\mu = (5.5 \pm 0.5) \times 10^{-4}\mathrm{V}^{-1}\mathrm{m}^2\mathrm{s}^{-1}$. The value of the permittivity according to [16] $\varepsilon = 33.3{\times}10^{-11}\mathrm{Fm}^{-1}$. Using these values we get $\omega_C = 1.3{\times}10^4\mathrm{s}^{-1}$ and $\omega_D = 7.66{\times}10^{11}\mathrm{s}^{-1}$. The angular frenquency in our case has been in the range $6 \times 10^7\mathrm{s}^{-1}$ to $4 \times 10^9\mathrm{s}^{-1}$. Thus $\omega_C \ll \omega$ and $\omega_D \gg \omega$, and so $\omega_C/\omega \ll 1$ and also $\omega/\omega_D \ll 1$.

Using this approximation the formula (1) can be written in the form

$$\alpha = \frac{K^2 \omega_C}{2v} \tag{2}$$

The formula (2) shows that the attenuation coefficient due to electrons does not depend on frequency. Using this formula and experimental data for α and v the coefficient of the electromechanical compling K can be calculated. We have got $K = (0.2 \pm 0.03)$.

4. Conclusions

1 We measured the frequency dependence of the attenuation coefficient of the longitudinal ultrasonic wave propagated in ⟨111⟩ direction in dark sample of BGO at room temperature. The quadratic dependence $\alpha_0 = Af^2$, where $A = (1.58 \pm 0,3) \times 10^{-18}\mathrm{cm}^{-1}\mathrm{s}^2$ shows that Akhiere's mechanism takes place in the dissipation of the acoustic energy in the dark sample of BGO.

2 The measured value of the velocity of the longitudinal ultrasonic wave in ⟨111⟩ direction in dark sample of BGO at room temperature $v_0 = (3.304{\pm}0.007){\times}10^3\mathrm{ms}^{-1}$ is in very good agreement with the calculated value $v = 3.255 \times 10^3\mathrm{ms}^{-1}$.No change of the velocity with the illumination has been observed within the error of the mesasurement.

3 The change of the attenuation coefficient does not depend on frequency and is a linear function of the intensity of the high pressure mercury vapour lamp. This results are in very good agreement with White's theory of attenuation of ultrasonic waves due to conducting electrons in piezoelectric semiconductors. Using the experimental results the coefficient of the electromechanical coupling has been calculated: $K = (0.2 \pm 0.03)$.

Since the BGO crystal has very low room temperature acoustic losses and high electromechanical coupling it is very suitable for fabrication of signal processing acoustoelectric devices.

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