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Study of shear-horizontal waves in structure "piezoelectric-viscous and conductive liquid"

Iren KUZNETSOVA[1]; Vladimir KOLESOV[1]; Vladimir ANISIMKIN[1]; Zhenghua QIAN[2]; Feng ZHU[2]; Alena GORBUNOVA[3]

[1] Kotelnikov Institute of Radio Engineering and Electronics of RAS, Russia

[2] Nanjing University of Aeronautics and Astronautics, China

[3] M.V. Lomonosov Moscow State University, Physical Dept., Russia

ABSTRACT

Recently it has been found that velocity of shear-horizontal surface acoustic waves initially increase as the conductivity of the layer located on the surface of the piezoelectric medium increases. At a certain value of conductivity the velocity of such waves reaches a maximum and with a further increase in conductivity begins to decrease. The same effect was found for conductive liquid and shear horizontal wave in piezoelectric media. In this work the influence of viscosity of a liquid on the magnitude of this effect is theoretically studied. It was found that for Bleustein-Gulyaev wave in cadmium sulfate as the viscosity of a liquid increases the value of above effect decreases and at a certain value of viscosity it disappears. We used a liquid characterized by low permittivity as 2.5. The results obtained can be useful in the development of sensors for biological liquids.

Keywords: Bleustein-Gulyaev wave, CdS, viscous and conductive liquid

1. INTRODUCTION

It is well known, that the change of electrical and mechanical boundary conditions leads to the significant changes of the acoustic wave parameters [1]. This effect is very useful for development of various acoustic sensors. One type of such sensors are devices that work in contact with a liquid [2]. The biological sensors can be implemented based on such devices. The waves with a shear-horizontal polarization are usually used for the design of such sensors [3]. These waves are characterized by a weak emission of acoustic energy in a liquid medium [4]. One of these types of waves are the Gulyaev-Blustein waves [5]. It has recently been shown that when the conductivity of a fluid changes in contact with a piezoelectric, an anomalous resistive-acoustic effect (ARAE) occurs [6].

This effect consists in increasing the velocity of the acoustic wave as the conductivity of the layer located on the surface of the piezoelectric medium increases [7]. When a certain value of the conductivity of the contacting medium is reached, the velocity of the Bleustein-Gulyaev wave reaches a maximum, and with a further increase in conductivity begins to decrease. This effect has the most value for potassium niobate due to its high level of piezoactivity [7].

It is necessary to note that very often the biological liquids are characterized by various value of viscosity. From this point of view, it has interest to study how viscosity can influence on value of aforementioned anomalous resisto-acoustic effect [8].

In this paper, the influence of the viscosity of a liquid on the magnitude of this effect in cadmium sulfide is studied.

2. THEORETICAL ANALYSIS

The propagation of Bleustein-Gulyaev wave in a structure "YX cadmium sulfide - conductive and viscous liquid" has been analyzed. The geometry of the problem is presented in Fig.1.

[1] kuziren@yandex.ru
[2] qianzh@nuaa.edu.cn

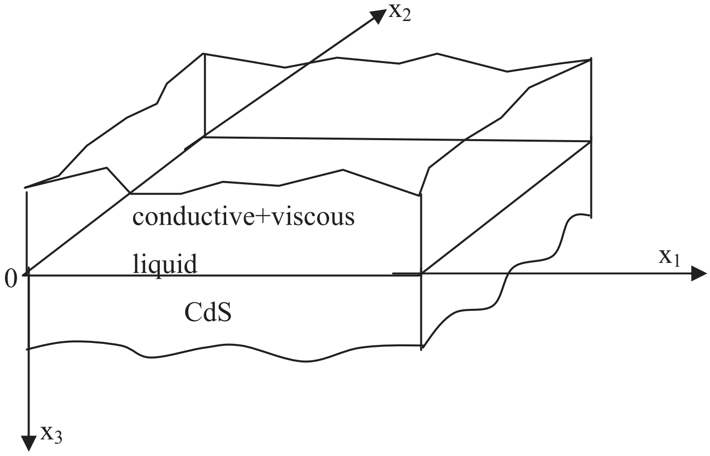

Figure 1- Geometry of the problem

For theoretical analysis the equation system consisting of elastic medium motion equation (1), Laplace's equation (2), and piezoelectric crystal state equations(3), (4) were used [9]

$$\rho\,\partial^2 U_i \big/ \partial t^2 = \partial T_{ij} \big/ \partial x_j \tag{1}$$

$$\partial D_j \big/ \partial x_j = 0\,, \tag{2}$$

$$T_{ij} = C_{ijkl}\,\partial U_l \big/ \partial x_k + e_{kij}\,\partial\Phi \big/ \partial x_k\,, \tag{3}$$

$$D_j = -\varepsilon_{jk}\,\partial\Phi \big/ \partial x_k + e_{jlk}\,\partial U_l \big/ \partial x_k\,. \tag{4}$$

Here ρ is medium density, U_i are components of mechanical particles displacement, t is time, T_{ij} are components of mechanical stress tensor, x_j are coordinates, D_j are components of electrical displacement, C_{ijkl}, e_{ijk}, and ε_{jk} are elastic, piezoelectric and dielectric constants, respectively, and Φ is electrical potential.

We used the condition of quasistatic approximation:

$$E_i = -\,\partial\Phi \big/ \partial x_i\,, \tag{5}$$

where E_i are the components of electric field intensity.

It is necessary to write the equation system for viscous conductive and isotropic liquid in Maxwellian representation [6, 10, 11]:

$$\rho^{lq}\,\partial^2 U_i^{lq} \big/ \partial t^2 = \partial T_{ij}^{lq} \big/ \partial x_j\,, \tag{6}$$

$$T_{ij}^{lq} = C_{ijkl}^{lq^*}\,\partial U_l^{lq} \big/ \partial x_k\,. \tag{7}$$

Here ρ_{lq} and $C_{ijkl}^{lq^*}$ are liquid density and its complex elastic constants, respectively. The nonzero components of the liquid elastic constants in matrix form are given by

$$\begin{gathered} C_{11}^{lq^*} = C_{22}^{lq^*} = C_{33}^{lq^*} = C_{11}^{lq} + j\omega\eta_{11}^{lq} \\ C_{12}^{lq^*} = C_{13}^{lq^*} = C_{23}^{lq^*} = C_{12}^{lq} + j\omega\eta_{12}^{lq} \\ C_{44}^{lq^*} = C_{55}^{lq^*} = C_{66}^{lq^*} = j\omega\eta_{44}^{lq} \end{gathered} \tag{8}$$

where η_{11}^{lq} and η_{44}^{lq} are longitudinal and shear components of viscosity, ω is angular frequency of the wave, and j = $(-1)^{1/2}$ is the imaginary unit. $\eta_{12}^{lq} = \eta_{11}^{lq} - 2\eta_{44}^{lq}$.

Due to the liquid is not only viscous but also conductive we have to write the Poisson equation and the charge conservation equation:

$$\partial D_i^{lq} \big/ \partial x_i = \delta^{lq} \tag{9}$$

$$\partial J_i^{lq} / \partial x_i + \partial \delta^{lq} / \partial t \quad (10)$$

Here D^{lq}, δ^{lq}, and J_i^{lq} are the components of electrical displacement, space charge density, and component of the current density, respectively.

The constitutive equations for liquid are

$$D_i^{lq} = -\varepsilon^{lq} \, \partial \Phi^{lq} / \partial x_i \quad (11)$$

$$J_i^{lq} = -\sigma_{lq} \, \partial \Phi^{lq} / \partial x_i + d^{lq} \, \partial \delta^{lq} / \partial x_i \quad (12)$$

Here ε^{lq}, σ^{lq}, and d^{lq} are permittivity, bulk conductivity, and diffusion coefficient of liquid.

The mechanical and electrical boundary conditions at the plane $x_3=0$ were written as

$$U_i = U_i^{lq}; T_{i3} = T_{i3}^{lq} \quad (13)$$

$$\Phi = \Phi^{lq}; D_3 = D_3^{lq}; J_3^{lq} = 0 \quad (14)$$

The above equations with the boundary conditions have been solved by the method described in [5].

3. RESULTS AND DISCUSSION

We calculated the dependency of the phase velocity of a Bleustein – Gulyaev wave in YX cadmium sulfide crystal on a bulk liquid conductivity for different values of a liquid viscosity. We found that anomalous resisto-acoustic effect exists for all investigated values of the liquid viscosity; i.e. the velocity of the Bleustein-Gulyaev wave rises, reaches its maximum, and then falls as the liquid bulk conductivity grows. The analysis shows that the value of positive change in the phase velocity due to ARAE $(\Delta V/V)^+_{max}$ increases with increasing the liquid viscosity. The corresponding dependence is presented in Fig. 2.

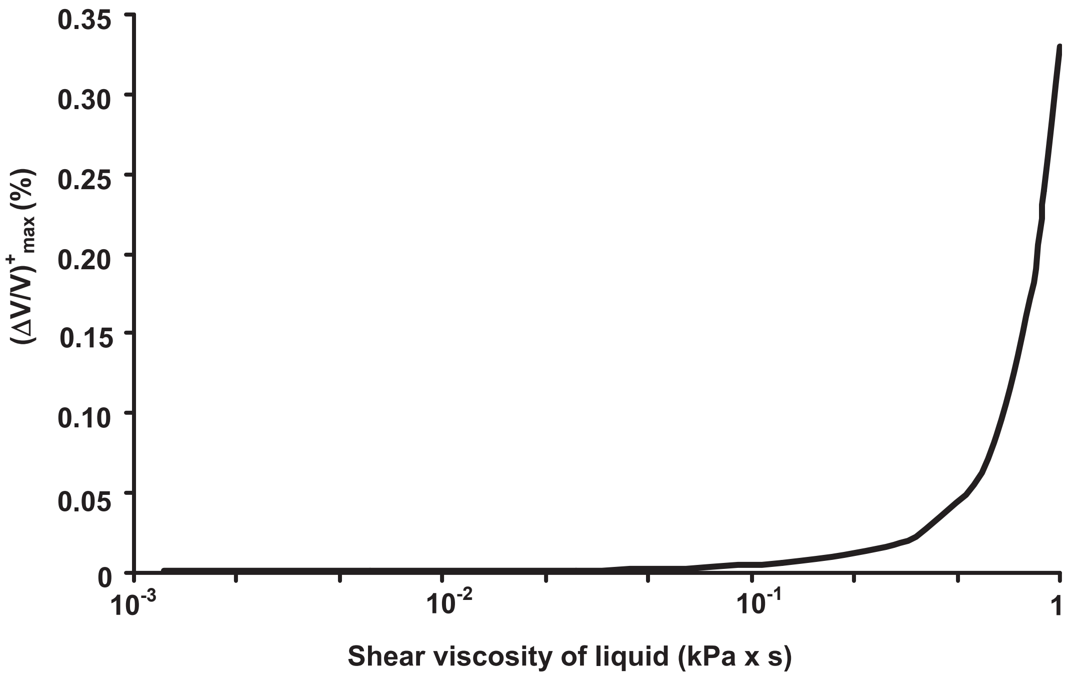

Figure 2- Dependence of the value of positive change in the phase velocity of Bleustein-Gulyaev wave in YX CdS due to ARAE versus shear viscosity of liquid

Previously [8, 12] it was shown that for strong piezoelectric like potassium niobate the value of positive change in the phase velocity due to ARAE $(\Delta V/V)^+_{max}$ decreases with increasing the liquid viscosity. Previous analysis shown that the increasing the liquid viscosity leads to reducing the

Bleustein-Gulyaev electric field penetration depth [8]. In connection with this increase in the liquid conductivity has a weak effect on the BG wave localization depth for strong piezoelectrics, which in turn leads to a decrease and then disappearance of the anomalous resisto-acoustic effect. But for weak piezoelectric like CdS increase in the liquid conductivity has a strong effect on the BG wave localization depth, which in turn leads to a increase of the anomalous resisto-acoustic effect.

4. CONCLUSION

The influence of the liquid viscosity and conductivity on the characteristics of Bleustein-Gulyaev waves was considered. It has been found that the value of positive change in the phase velocity due to anomalous resisto-acoustic effect increases with increasing the liquid viscosity for weak piezoelectrics. This could be explained by the fact that the increasing the liquid viscosity leads to reducing the Bleustein-Gulyaev electric field penetration depth. In connection with this increase in the liquid conductivity has a strong effect on the BG wave localization depth in weak piezoelectrics, which in turn leads to a increase of the anomalous resisto-acoustic effect. Obtained results can be used to better understand the fundamental physics of the propagation of weakly inhomogeneous piezoective waves. Also it can be used for development of acoustic liquid viscosity sensors

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