INFLUENCE OF CONDUCTIVE AND VISCOUS LIQUID ON PROPERTIES OF BLEUSTEIN-GULYAEV WAVE IN PIEZOELECTRIC CRYSTALS

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An interesting feature of Bleustein-Gulyaev acoustic waves is their inherent anomalous resisto-acoustic effect (ARAE). 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. 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. In this paper, the influence of the viscosity of a liquid on the magnitude of this effect is studied. A study of the cumulative effect of the viscosity and conductivity of a liquid contacting potassium niobate crystal on the ARAE for Bleustein-Gulyaev wave has shown that the shear elastic modulus of liquid viscosity has the greatest influence on its magnitude. It was found that the greater the dielectric constant of the medium, the less the anomalous resisto-acoustic effect at the same values of its viscosity and conductivity. A study of the effect of mechanical boundary conditions on the ARAE for Bleustein-Gulyaev wave in YX potassium niobate showed that as the viscosity of a liquid increases, the value of ARAE decreases and at a certain viscosity value it disappears. For weak piezoelectrics BaTiO3, CdS, ZnO the value of the positive change in phase velocity of Bleustein-Gulyaev wave due to ARAE initially increases with increase liquid viscosity reaches the maximum and then decreases. The results obtained can be useful in the development of sensors for biological fluids.

Keywords: no more than five words (Bleustein-Gulyaev waves, anomalous resisto-acoustic effect, conductive and viscous liquid, piezoelectric materials)

1. Introduction

As known the change of boundary conditions leads to the dramatically change of the acoustic wave characteristics. This effect is used for development of lot chemical and biological acoustic sensors. Now the investigations of the influence of electrical boundary conditions on the characteristics of various types of acoustic waves are very popular. The appearance of new materials possess strong piezoeffect (potassium niobate, piezoceramics, etc) is allowed to find new effects connected with the changing electrical boundary conditions. There are anomalous resisto-acoustic effect [1-3], effect of the wave types transformation [4], effect of hybridization of acoustic waves in piezoelectric plates [5].

In whole the analysis of the literature shown that investigations of acoustic waves in structures with different boundary conditions are very popular now [6, 7]. It is connect with searching of the waves characterized by high phase velocity, small attenuation in presence of liquid, high thermosta-
These characteristics allow to develop new acoustoelectronic signal processing devices and sensors with enhanced or unique characteristics [8, 9].

As it was said above an interesting feature of Bleustein - Gulyaev acoustic waves is their inherent anomalous resisto-acoustic effect. 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. 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.

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

2. **Theoretical analysis**

The propagation of Bleustein-Gulyaev wave in YX CdS, ZnO, YX barium titanate and YX potassium niobate crystals which are contacted with conductive and simultaneously viscous liquid has been analyzed. The geometry of the problem is presented on Fig.1.

![Figure 1: Geometry of the problem.](image)

For theoretical analysis we used equation system consisting of elastic medium motion equation [10]

\[ \rho \frac{\partial^2 U_j}{\partial t^2} = \frac{\partial T_{ij}}{\partial x_j}, \] (1)

Laplace’s equation:

\[ \frac{\partial D_j}{\partial x_j} = 0, \] (2)

and piezoelectric crystal state equations:

\[ T_{ij} = C_{ijkl} \frac{\partial U_i}{\partial x_k} + e_{ijk} \frac{\partial \Phi}{\partial x_k}, \] (3)

\[ D_j = -\varepsilon_{jk} \frac{\partial \Phi}{\partial x_k} + e_{ijk} \frac{\partial U_i}{\partial x_k}. \] (4)

Here \( \rho \) is the medium density, \( U_i \) is the component of mechanical particles displacement, \( t \) is the time, \( T_{ij} \) is the component of mechanical stress tensor, \( x_j \) are coordinates, \( D_j \) is component of electrical displacement, \( C_{ijkl}, e_{ijk}, \) and \( \varepsilon_{jk} \) are elastic, piezoelectric and dielectric constants, respectively, and \( \Phi \) is electrical potential.

We used the condition of quasistatic approximation:

\[ E_i = -\frac{\partial \Phi}{\partial x_i}, \] (5)

where \( E_i \) is the component of electric field intensity.

It is necessary to write the equation system for viscous conductive and isotropic liquid in Maxwellian representation [3, 11, 12]:

\[ \rho^v \frac{\partial^2 U_i}{\partial t^2} = \frac{\partial T_{ij}^v}{\partial x_j}, \] (6)
\[ T_{ij}^{\text{liq}} = C_{ijkl}^{\text{liq}} \partial U_i^{\text{liq}} / \partial x_k. \]  

Here \( \rho_{\text{liq}} \) and \( C_{ijkl}^{\text{liq}} \) are liquid density and its complex elastic constants, respectively. The nonzero components of the liquid elastic constants in matrix form are given by

\[
\begin{align*}
C_{11}^{\text{liq}} &= C_{22}^{\text{liq}} = C_{33}^{\text{liq}} = C_{11}^{\text{liq}} + j \omega \eta_{11}^{\text{liq}} \\
C_{12}^{\text{liq}} &= C_{13}^{\text{liq}} = C_{23}^{\text{liq}} = C_{12}^{\text{liq}} + j \omega \eta_{12}^{\text{liq}} \\
C_{44}^{\text{liq}} &= C_{55}^{\text{liq}} = C_{66}^{\text{liq}} = j \omega \eta_{44}^{\text{liq}}
\end{align*}
\]

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

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

\[
\frac{\partial D_i^{\text{liq}}}{\partial x_i} = \delta_i^{\text{liq}},
\]

\[
\frac{\partial J_i^{\text{liq}}}{\partial x_i} + \frac{\partial \delta_i^{\text{liq}}}{\partial t}.
\]

Here \( D_i^{\text{liq}}, \delta_i^{\text{liq}}, \) and \( J_i^{\text{liq}} \) are the component of electrical displacement, space charge density, and component of the current density, respectively.

The constitutive equations for liquid are

\[
D_i^{\text{liq}} = -\epsilon_i^{\text{liq}} \partial \Phi^{\text{liq}} / \partial x_i
\]

\[
J_i^{\text{liq}} = -\sigma_i^{\text{liq}} \partial \Phi^{\text{liq}} / \partial x_i + d_i^{\text{liq}} \partial \delta_i^{\text{liq}} / \partial x_i
\]

Here \( \epsilon_i^{\text{liq}}, \sigma_i^{\text{liq}}, \) and \( d_i^{\text{liq}} \) are permittivity, bulk conductivity, and diffusion coefficient of liquid.

The mechanical and electrical boundary conditions at the plane \( x_3 = 0 \) were written as

\[
U_i = U_i^{\text{liq}}; T_{13} = T_{13}^{\text{liq}};
\]

\[
\Phi = \Phi^{\text{liq}}; D_3 = D_3^{\text{liq}}; J_3^{\text{liq}} = 0
\]

The above equations with the boundary conditions have been solved by the method described in [13].

### 3. Results and discussion

We plotted the dependencies of the phase velocity of a Bleustein – Gulyaev wave in YX CdS, ZnO, YX barium titanate and YX potassium niobate crystals on a bulk liquid conductivity for different values of a liquid viscosity. The corresponding dependencies for potassium niobate are presented on Fig. 2.

It can be see that anomalous resisto-acoustic effect exists at certain 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 reduces with increasing the liquid viscosity for strong piezoelectric like potassium niobate. Previous analysis shown that the increasing the liquid viscosity leads to reducing the Bleustein-Gulyaev electric field penetration depth [14]. In connection with this increase in the liquid conductivity has a weak effect on the BG wave localization depth, which in turn leads to a decrease and then disappearance of the anomalous resisto-acoustic effect. It should be noted that the
greater the liquid conductivity the greater liquid viscosity influences on the wave penetration depth and increases its location near the piezoelectric surface.

In this paper we investigated ARAE in weaker piezoelectrics BaTiO3, CdS, ZnO. It was found that in this case value of the positive change in phase velocity of Bleustein-Gulyaev wave due to ARAE initially increases with increase liquid viscosity reaches the maximum and then decreases. We suppose that such behavior is connected with differences in localization of investigated wave at the boundary condition changing on the surfaces of various piezoelectrics.

![Graph](image)

Figure 2: Dependencies of the phase velocities of Bleustein-Gulyaev wave in YX potassium niobate crystal on bulk conductivity of viscous liquid at $\varepsilon_{\text{aq}} = 2.5$ for $\eta_{\text{aq}} = 0$ (1), 2 kPa\(\times\)s (2), 5 kPa\(\times\)s (3), 9 kPa\(\times\)s (4).

4. Conclusion

The influence of the liquid viscosity on the anomalous resisto-acoustic effect was considered. It has been found that the value of positive change in the phase velocity due to anomalous resisto-acoustic effect reduces with increasing the liquid viscosity. 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 weak effect on the BG wave localization depth, which in turn leads to a decrease and then disappearance of the anomalous resisto-acoustic effect. For weaker piezoelectrics BaTiO3, CdS, ZnO the value of the positive change in phase velocity of Bleustein-Gulyaev wave due to ARAE initially increases with increase liquid viscosity reaches the maximum and then decreases. We suppose that such behavior is connected with differences in localization of investigated wave at the boundary condition changing on the surfaces of various piezoelectrics. Obtained results can be used to better understand the fundamental physics of the propagation of weakly inhomogeneous piezoelectric waves. Also it can be used for development of acoustic liquid viscosity sensors.

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