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Effect of Density Gradient on Longitudinal Phonon-Plasmon Interactions in Colloids Laden Semiconductor Quantum Plasmas

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Abstract: *Quantum hydrodynamic model of plasmas including Bohm potential and Fermi degenerate pressure has been employed to derive the linear dispersion relation for longitudinal phonon-plasmon interaction in inhomogeneous colloid laden semiconductor plasma, for two different cases in which colloidal grains are either stationary* $(\vartheta_{0d} = 0)$ *or streaming* $(\vartheta_{0d} \neq 0)$. *It is found that in the velocity regime* $\vartheta_{0e} < \vartheta_s < \vartheta_{0d}$, *one may get sound amplification even if the electron drift velocity is less than the sound velocity. It is hoped that the analysis may become useful in designing semiconductor devices using density gradient as controlling parameter for acoustic gain.*

Keywords: *Electron density gradient, Bohm potential, Acousto electric effect.*

1. INTRODUCTION

Motivated by the intense interest in the field of semiconductor quantum plasma [1-9], in the present paper using quantum hydrodynamic model of plasmas we have reported the results of the analytical investigations of the effect of density gradient on acoustic wave amplification characteristics in colloids laden semiconductor quantum plasmas and discussed the possibilities of using density gradient as controlling parameter to control growth of the unstable acoustic mode in the crystal.

The interaction between mobile carriers and acoustic vibrations is one of the imperatives in physics pedagogy and research. This interaction gives useful informations regarding the physical properties of the host medium. The amplification of sound waves by the application of electric field has been commercially exploited for the fabrications of several solid state devices. It is well established that for the amplification of sound wave to occur, the carrier drift velocity induced due to applied dc electric field should exceed the possible sound velocity in the crystal lattice. The presence of required large dc electric field if applied to a colloids laden semiconductor then the resultant streaming electron beams will stick on the neutral colloid particulates to make them negatively charged colloidal ions. The semiconductor plasma medium so created will behave like dusty plasma [10] with electrons, vibrating lattice ions and dust like colloid ions and therefore becomes an interesting host to study the acoustic wave amplification characteristics. A number of interesting phenomena have been observed in these colloid laden semiconductor plasmas. Ghosh and his coworkers reported the number of new modes [11, 12] and effective modifications [13-16] in the characteristic of the existing mode in these media.

Interesting to note that if the system has gradients of different parameters such as density, temperature, pressure, magnetic field etc. an additional carrier drift exist which enhances the carrier drift magnitude induced due to presence of dc electric field.

In media where wave functions of the neighbouring particles overlapped, the consideration of quantum correction becomes imperable while studying the characteristic of the wave propagating through these media. These wave function overlapping becomes possible only when the interparticle distances and thermal de-Broglie wave length of the plasma medium becomes comparable. As a newly emerging field in plasma physics, quantum systems have recently received attention of researchers. Quantum effects have been proved to play an important role in ultra small electronic devices [3, 4, 17-20]. The renewed observations of Landau damping, plasma echoes, drift waves, Debye screening, ion-acoustic waves etc. have been recently revisited with quantum corrections [5-9, 21-23]. Recently the present authors have analytically studied the quantum modifications in wave spectra of acousto electric modes in colloid laden semiconductor plasma in presence of magnetic field [24].

In this paper, motivated by the above state of art, a detailed study of the effect of in homogeneity due to density gradient on the acoustic wave amplification characteristics in magnetized colloid laden semiconductor quantum plasma has been presented. We have used quantum hydrodynamic model of plasmas to arrive at most general dispersion relation for acousto-electric wave propagation through inhomogeneous colloid laden semiconductor quantum plasma in presence of magnetic field. It is shown that the Bohm potential and density gradient both reduces the sound wave gain for robust charge colloids. In case of streaming colloids quantum effect is always found favourable for acoustic gain to occur.

The paper is organized in the following manner: in section 2, we outline the basic equations describing acoustic wave propagation and derive a dispersion relation for the acoustic wave in the ion-implanted inhomogeneous semiconductor quantum plasmas. In section 3, we present numerical results and discussion for two distinct cases when charged colloids are either stationary or streaming. In section 4, we briefly conclude the results obtained.

2. THEORETICAL FORMULATION

Let the implantation of metal ions in the semiconductor followed by the annealing procedure results into formation of colloidal particles. Now consider this implanted semiconductor be subjected to a dc electric field E_0, which is applied along the z-axis, and immerge in a magnetic field B_0 applied in the $x-z$ plane making an arbitrary angle θ with the z-axis. In the present paper we have analyzed the role of quantum effect through Bohm potential and density gradient ∇n_0 (assumed to be along propagation direction) on the acoustic wave propagation.

Using quantum hydrodynamic model of plasmas and following the procedure adopted by Steele and Vural [25], we obtain the following dispersion relation for phonon-plasmon interactions in inhomogeneous piezoelectric colloid laden semiconductor quantum plasma

$$(\omega^2-\kappa^2\vartheta_s^2)\left[1-\frac{\omega_{pe}^2(\kappa+i\Delta_d)}{\kappa\{\Omega_e+i\Delta_d\vartheta_{0e}\}\left\{(\Omega_e-i\nu_e)-\frac{\kappa(\kappa+i\Delta_d)}{(\Omega_e+i\Delta_d\vartheta_{0e})}V_F^2(1+\Gamma_e)\right\}+\left\{\frac{\omega_{ce}^2\sin^2\theta(\Omega_e-i\nu_e)}{\omega_{ce}^2\cos^2\theta-(\Omega_e-i\nu_e)^2}\right\}}\right.$$
$$\left.-\frac{\omega_{pd}^2}{(\Omega_d)(\Omega_d-i\nu_d)+\left\{\frac{\omega_{cd}^2\sin^2\theta(\Omega_d-i\nu_d)}{\omega_{cd}^2\cos^2\theta-(\Omega_d-i\nu_d)^2}\right\}}\right] = K^2\kappa^2\vartheta_s^2 \tag{1}$$

Where, $\omega_{pe}=\sqrt{e^2n_{0e}/\varepsilon m_e}$ and $\omega_{pd}=\sqrt{z_d^2e^2n_{0d}/\varepsilon m_d}$ are the plasma frequencies of electrons and colloids, respectively. In which, $n_{0e,d}$ are the unperturbed number densities of electrons and colloids, respectively and $K^2=(\beta^2/c\varepsilon)$ is the dimensionless electromechanical coupling coefficient. The density decay length $\Delta_d^{-1}(\Delta_d=\nabla n_0/n_0)$ is assumed to be larger than the wavelength under consideration.

In the collision dominated regime $(\omega \ll \upsilon_e, \upsilon_d$ and $k\vartheta_{0e} \ll \upsilon_e, k\vartheta_{0d} \ll \upsilon_d)$, using standard approximation [26] $k\vartheta_s/\omega=1+i\alpha$, equation (1) becomes (where α is << 1 is the gain per radian)

$$\alpha = \frac{1}{2}K^2\gamma_e(\omega_{\mathrm{Re}}/\omega\phi_e)(A+B)^{-1}\left[1+\frac{\omega_{Rd}}{\omega_{\mathrm{Re}}}\frac{\phi_e\gamma_e}{\phi_d\gamma_d}+\frac{\omega_{Rd}}{\omega_{\mathrm{Re}}}\frac{\omega^2\{1+(\Delta_d/\kappa)^2\}}{\omega_D^2\gamma_e\gamma_d\phi_e\phi_d}\right.$$

$$\left.-2\frac{\omega_{Rd}}{\omega_{\mathrm{Re}}}(\Delta_d/\kappa)\frac{\omega(2\gamma_e+1)}{\omega_D\gamma_e\gamma_d\phi_d}-\frac{(\Delta_d/\kappa)^2(\gamma_e+1)}{\gamma_e}\left\{1-\frac{\omega_{Rd}}{\omega_{\mathrm{Re}}}\frac{\phi_e(\gamma_e+1)}{\phi_d\gamma_d}\right\}\right] \tag{2}$$

Where

$$A=\left[\left(\frac{\omega_{\mathrm{Re}}}{\omega\phi_e}\right)^2\left(1+\frac{\omega^2}{\omega_D\omega_{\mathrm{Re}}}+\frac{\omega_{Rd}\phi_e\gamma_e}{\omega_{\mathrm{Re}}\phi_d\gamma_d}-(\Delta_d/\kappa)\frac{\omega_{Rd}\phi_e}{\omega_{\mathrm{Re}}\phi_d}\omega\left\{\frac{(\gamma_e+1)\phi_d}{\omega_{Rd}}+\frac{1}{\omega_D\phi_e\gamma_d}\right\}\right)\right]^2,$$

And

$$B=\gamma_e^2\left[1-\frac{\omega_{Rd}}{\omega_D\gamma_e\gamma_d\phi_e\phi_d}-(\Delta_d/\kappa)\frac{1}{\gamma_e}\left\{\frac{\omega}{\omega_D\phi_e}+\frac{\omega_{\mathrm{Re}}}{\omega\phi_e}-\frac{\omega_{Rd}(\gamma_e+1)}{\omega\phi_d\gamma_d}\right\}\right]^2.$$

In which $\omega_D=\vartheta_s^2/D_F'$ is the electron diffusion frequency, $D_F'=V_F'^2/\nu_e$, $V_F'^2=V_F^2(1+\Gamma_e)$, $\gamma_{e,d}=(\vartheta_{0e,d}/\vartheta_s-1)$, $\omega_{\mathrm{Re},d}=\omega_{pe,d}^2/\upsilon_{e,d}$, $\phi_{e,d}=\dfrac{1+(\omega_{ce,d}^2/\upsilon_{e,d}^2)}{1+(\omega_{ce,d}^2\cos^2\theta/\upsilon_{e,d}^2)}$. It can be infer from equation (2) that quantum effects appear in the parameter V_F', and density gradient in the parameter (Δ_d/k).

3. Results and Discussions

Using equation (2) an analytical investigation of the effects of density gradient and quantum correction term on the amplification characteristics of sound mode for two distinct cases in which charged colloids are either stationary $(\vartheta_{0d}=0)$ or streaming $(\vartheta_{0d}\neq 0)$ are discuss. For this, following set of numerical constants are consider (for n-InSb) at 77K: $m_e=0.014m_0$ (m_0 is the free electron mass), $m_d=10^{-27}kg$, $\in_L=17.54$, $\beta=0.054Cm^{-2}$, $\rho=5.8\times10^3 kg\,m^{-3}$, $n_{0e}=10^{24}m^{-3}$, $n_{0d}=10^{18}m^{-3}$, $\upsilon_e=3.5\times10^{11}s^{-1}$, $\upsilon_d=3.248\times10^{10}s^{-1}$, $B_0=0.5T$.

3.1. Stationary Colloids $(\vartheta_{0d}=0)$

For acoustic frequency in ultrasonic regimes and massive colloidal grains, we can assume $\vartheta_{0d}=0$ and $\gamma_d=-1$. It is clear that unless one considers the lowest part of the grain mass spectrum and very low frequency modes, the grain dynamics can be ignored safely with respect to the electron dynamics [27] without loosing any significant informations. Under this approximation equation (2) reduces to

$$\alpha\approx\frac{1}{2}K^2|\gamma_e|\left(\frac{\omega_{\mathrm{Re}}}{\omega\phi_e}\right)(C+D)^{-1}\left[1-\frac{\omega_{Rd}}{\omega_{\mathrm{Re}}}\frac{\phi_e|\gamma_e|}{\phi_d}\left\{1+\left(\frac{\omega}{\omega_D\phi_e|\gamma_e|}\right)^2-2(\Delta_d/\kappa)\left(\frac{2\omega}{\omega_D\phi_e|\gamma_e|}+\frac{\omega}{\omega_D\phi_e|\gamma_e|^2}\right)\right.\right.$$

$$\left.\left.+\left(\frac{\omega(\Delta_d/\kappa)}{\omega_D\phi_e|\gamma_e|}\right)^2+\frac{(\Delta_d/k)^2(1+|\gamma_e|)}{|\gamma_e|^2}\left(\frac{\omega_{\mathrm{Re}}}{\omega_{Rd}}\frac{\phi_d}{\phi_e}+(1+|\gamma_e|)\right)\right\}\right] \tag{3}$$

Where

$$C=\left(\frac{\omega_{\mathrm{Re}}}{\omega\phi_e}\right)^2\left[1+\frac{\omega^2}{\omega_D\omega_{\mathrm{Re}}}-\frac{\omega_{Rd}}{\omega_{\mathrm{Re}}}\frac{\phi_e|\gamma_e|}{\phi_d}-(\Delta_d/\kappa)\frac{\omega_{Rd}}{\omega_{\mathrm{Re}}}\frac{\phi_e}{\phi_d}\omega\left\{\frac{(|\gamma_e|+1)\phi_d}{\omega_{Rd}}-\frac{1}{\omega_D\phi_e}\right\}\right]^2,$$

And

$$D = |\gamma_e|^2 \left[1 + \frac{\omega_{Rd}}{\omega_D \phi_e \phi_d |\gamma_e|} - (\Delta_d/\kappa) \frac{1}{|\gamma_e|} \left\{ \frac{\omega}{\omega_D \phi_e} + \frac{\omega_{Re}}{\omega \phi_e} + \frac{\omega_{Rd}(|\gamma_e|+1)}{\omega \phi_d} \right\} \right]^2$$

From equation (3), it may be inferred that this mode will be amplified only when

$$\gamma_e > 0 \tag{4a}$$

And

$$\omega < \frac{(\omega_D \phi_e |\gamma_e|)}{\sqrt{\left[1+(\Delta_d/\kappa)^2\right]}} \left[\left(\frac{\omega_{Re} \phi_d}{\omega_{Rd} \phi_e |\gamma_e|} - 1 \right) + 2(\Delta_d/\kappa) \frac{\omega}{\omega_D |\gamma_e| \phi_e} \left(2 + \frac{1}{|\gamma_e|} \right) - \frac{(\Delta_d/k)^2 (1+|\gamma_e|)}{|\gamma_e|^2} \left(\frac{\omega_{Re} \phi_d}{\omega_{Rd} \phi_e} + (1+|\gamma_e|) \right) \right]^{1/2} \tag{4b}$$

We have found that in an n-type semiconductor consisting of colloid particles an extra condition (4b) is imposed to achieve the amplifying wave. This extra condition actually comes into picture mainly due to the presence of Bohm potential (i.e., quantum correction) in the fluid model of plasmas through ω_D. In case of homogeneous medium $(\Delta_d = 0)$ the second and third terms within the square bracket on RHS of equation (4b) vanishes. Hence one may infer that in presence of density gradient $(\Delta_d \neq 0)$ the numerical value of RHS of condition (4b) becomes larger; thus broader frequency range will be available for which one gets amplified mode. Hence, because of this extra condition in the inhomogeneous medium the instability criteria gets modified significantly. The Bohm potential and density gradient both together decide the upper limit of the wave frequency for which one gets amplification.

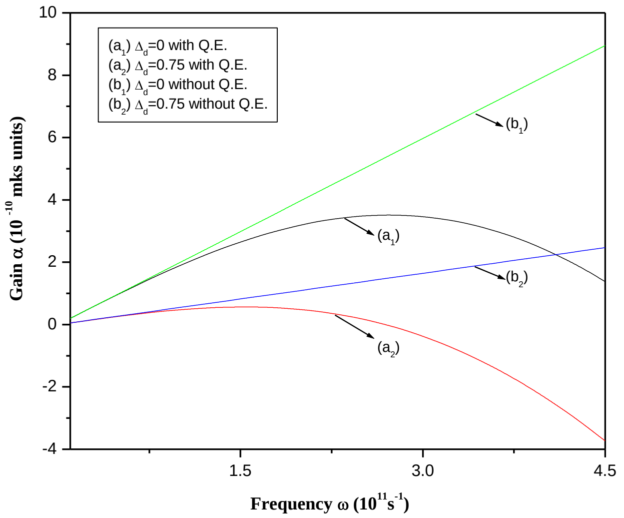

Figure 1. *Variation of gain α with wave frequency ω for different values of Δ_d at $E_0 = 10^4 Vm^{-1}$ with and without quantum effect for stationary colloids.*

Fig. 1 shows the variation of gain α with wave frequency ω for stationary colloids in presence and absence of quantum effect with density gradient (Δ_d) as parameter. It is evident from this Fig. that without quantum affect the gain per radian increases with the increase of wave frequency. On the other hand with quantum effect gain first increases with frequency, achieves a maximum value and then starts decreasing with increasing frequency. It may also be inferred from the graph that the acoustic gain per radian is always larger in homogeneous medium $(\Delta_d = 0)$ than in inhomogeneous medium $(\Delta_d \neq 0)$ for both the media. Hence, in homogeneity of the medium and the inclusion of quantum effect both not only reduce the value of gain when charged colloids are stationary but also impose a restriction on frequency range for which one gets amplification.

3.2. Streaming Colloids $(\vartheta_{0d} \neq 0)$

In this case we consider the dynamics of colloidal grains. To study the amplification characteristics of the acoustic wave, we will discuss different velocity regimes as follows:

3.2.1. When $\gamma_e, \gamma_d > 0$ *i.e.* $\vartheta_{0e}, \vartheta_{0d} > \vartheta_s$

In this velocity regime, the expression for gain per radian reduces to

$$\alpha \approx \frac{1}{2}K^2|\gamma_e|\left(\frac{\omega_{\text{Re}}}{\omega\phi_e}\right)(E+F)^{-1}\left[1+\frac{\omega_{Rd}\,\phi_e|\gamma_e|}{\omega_{\text{Re}}\phi_d|\gamma_d|}\left\{1+\left(\frac{\omega}{\omega_D\phi_e|\gamma_e|}\right)^2-2(\Delta_d/\kappa)\left(\frac{2\omega}{\omega_D\phi_e|\gamma_e|}+\frac{\omega}{\omega_D\phi_e|\gamma_e|^2}\right)\right.\right.$$
$$\left.\left.+\left(\frac{\omega(\Delta_d/\kappa)}{\omega_D\phi_e|\gamma_e|}\right)^2-\frac{(\Delta_d/k)^2(1+|\gamma_e|)}{|\gamma_e|^2}\left(\frac{\omega_{\text{Re}}\,\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e}-(1+|\gamma_e|)\right)\right\}\right] \tag{5a}$$

Where

$$E=\left(\frac{\omega_{\text{Re}}}{\omega\phi_e}\right)^2\left[1+\frac{\omega^2}{\omega_D\omega_{\text{Re}}}+\frac{\omega_{Rd}\,\phi_e|\gamma_e|}{\omega_{\text{Re}}\phi_d|\gamma_d|}-(\Delta_d/\kappa)\frac{\omega_{Rd}\,\phi_e}{\omega_{\text{Re}}\phi_d}\,\omega\left\{\frac{(|\gamma_e|+1)\,\phi_d}{\omega_{Rd}}+\frac{1}{\omega_D\phi_e|\gamma_d|}\right\}\right]^2,$$

And

$$F=|\gamma_e|^2\left[1-\frac{\omega_{Rd}}{\omega_D\,\phi_e\phi_d|\gamma_e||\gamma_d|}-(\Delta_d/\kappa)\frac{1}{|\gamma_e|}\left\{\frac{\omega}{\omega_D\phi_e}+\frac{\omega_{\text{Re}}}{\omega\phi_e}-\frac{\omega_{Rd}(|\gamma_e|+1)}{\omega\phi_d|\gamma_d|}\right\}\right]^2$$

One can infer from the above equation that wave be of amplifying nature only when

$$\omega>\frac{(\omega_D\phi_e|\gamma_e|)}{\sqrt{\left[1+(\Delta_d/\kappa)^2\right]}}\left[\left(\frac{\omega_{\text{Re}}\,\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e|\gamma_e|}+1\right)-2(\Delta_d/\kappa)\frac{\omega}{\omega_D|\gamma_e|\phi_e}\left(2+\frac{1}{|\gamma_e|}\right)\right.$$
$$\left.-\frac{(\Delta_d/k)^2(1+|\gamma_e|)}{|\gamma_e|^2}\left(\frac{\omega_{\text{Re}}\,\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e}-(1+|\gamma_e|)\right)\right]^{1/2} \tag{5b}$$

In case of streaming colloids when $\vartheta_{0e}, \vartheta_{0d} > \vartheta_s$, the Bohm potential and density gradient both impose a lower limit to the wave frequency (5b) above which one may achieve the wave amplification. Hence in this velocity regime density gradient and Bohm potential again modifies the wave characteristics effectively.

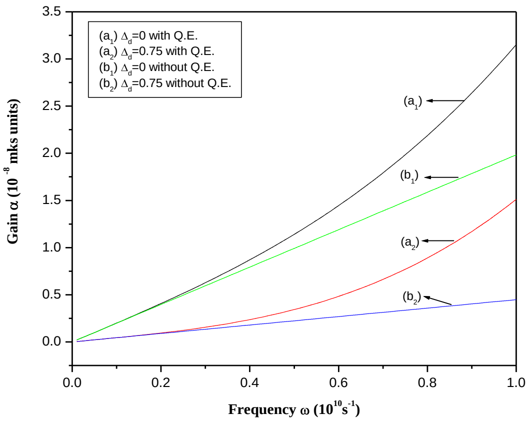

Figure2. *Variation of gain* α *with wave frequency* ω *for different values of* Δ_d *at* $E_0 = 10^4 Vm^{-1}$ *with and without quantum effect when* $\vartheta_{0e}, \vartheta_{0d} > \vartheta_s$.

Fig. 2 displays the gain per radian α versus wave frequency ω at different values of Δ_d, in the velocity regime $\vartheta_{0e}, \vartheta_{0d} > \vartheta_s$. It is evident that the α increases with ω for both cases (with as well as without quantum effect), but rate of increment in presence of quantum correction becomes faster than in the case when quantum correction is not considered. Also the gain per radian in presence of quantum correction is always larger in the frequency regime under consideration (equation 5b). It is also evident that the value of gain decreases with the increase in the value of in homogeneity parameter Δ_d. Hence it may be inferred from this figure that for streaming colloids in the velocity regime $\vartheta_{0e}, \vartheta_{0d} > \vartheta_s$ the density gradient reduces the acoustic gain whereas the quantum correction is found responsible for the increment in α.

3.2.2. When $\gamma_e > 0$ *and* $\gamma_d < 0$ *i.e.* $\vartheta_{0e} > \vartheta_s > \vartheta_{0d}$

In this regime equation (2) reduces to,

$$\alpha \approx \frac{1}{2}K^2|\gamma_e|\left(\frac{\omega_{Re}}{\omega\phi_e}\right)(G+H)^{-1}\left[1-\frac{\omega_{Rd}\,\phi_e|\gamma_e|}{\omega_{Re}\,\phi_d|\gamma_d|}\left\{1+\left(\frac{\omega}{\omega_D\phi_e|\gamma_e|}\right)^2-2\,(\Delta_d/\kappa)\left(\frac{2\omega}{\omega_D\phi_e|\gamma_e|}+\frac{\omega}{\omega_D\phi_e|\gamma_e|^2}\right)\right.\right.$$
$$\left.\left.+\left(\frac{\omega(\Delta_d/\kappa)}{\omega_D\phi_e|\gamma_e|}\right)^2+\frac{(\Delta_d/k)^2(1+|\gamma_e|)}{|\gamma_e|^2}\left(\frac{\omega_{Re}\,\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e}+(1+|\gamma_e|)\right)\right\}\right] \tag{6a}$$

Where

$$G=\left(\frac{\omega_{Re}}{\omega\phi_e}\right)^2\left[1+\frac{\omega^2}{\omega_D\omega_{Re}}-\frac{\omega_{Rd}\,\phi_e|\gamma_e|}{\omega_{Re}\,\phi_d|\gamma_d|}-(\Delta_d/\kappa)\frac{\omega_{Rd}\,\phi_e}{\omega_{Re}\,\phi_d}\omega\left\{\frac{(|\gamma_e|+1)\,\phi_d}{\omega_{Rd}}-\frac{1}{\omega_D\phi_e|\gamma_d|}\right\}\right]^2,$$

And

$$H=|\gamma_e|^2\left[1+\frac{\omega_{Rd}}{\omega_D\,\phi_e\phi_d|\gamma_e||\gamma_d|}-(\Delta_d/\kappa)\frac{1}{|\gamma_e|}\left\{\frac{\omega}{\omega_D\phi_e}+\frac{\omega_{Re}}{\omega\phi_e}+\frac{\omega_{Rd}(|\gamma_e|+1)}{\omega\phi_d|\gamma_d|}\right\}\right]^2$$

From equation (6a) one may infer that α will be positive in this velocity regime, only when

$$\omega<\frac{(\omega_D\phi_e|\gamma_e|)}{\sqrt{\left[1+(\Delta_d/\kappa)^2\right]}}\left[\left(\frac{\omega_{Re}\,\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e|\gamma_e|}-1\right)+2(\Delta_d/\kappa)\frac{\omega}{\omega_D|\gamma_e|\phi_e}\left(2+\frac{1}{|\gamma_e|}\right)\right.$$
$$\left.-\frac{(\Delta_d/k)^2(1+|\gamma_e|)}{|\gamma_e|^2}\left(\frac{\omega_{Re}\,\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e}+(1+|\gamma_e|)\right)\right]^{1/2} \tag{6b}$$

In this velocity regime, Bohm potential and density gradient both become responsible in deciding the upper limit of the wave frequency below which one may get wave amplification. Hence the Bohm potential and density gradient may be used as gain controller in acoustic amplifiers made up of piezoelectric semiconductors.

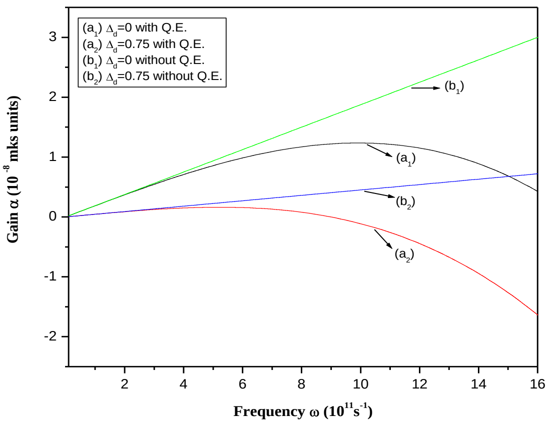

Figure3. *Variation of gain* α *with wave frequency* ω *for different values of* Δ_d *at* $E_0 = 8\times10^3 Vm^{-1}$ *with and without quantum effect when* $\vartheta_{0e} > \vartheta_s > \vartheta_{0d}$.

Fig. 3 shows the variation of the gain α with the wave frequency ω for different values of Δ_d in presence and absence of quantum correction term when $\vartheta_{0e} > \vartheta_s > \vartheta_{0d}$. It is found that in presence of quantum effect, initially the gains increase with frequency, achieve maximum values ($\alpha \approx 1.224\times 10^{-8}\ mksunits\ at\ \Delta_d = 0$ and $\alpha \approx 0.109\times 10^{-8}\ mksunits\ at\ \Delta_d = 0.75$) and then start decreasing with increasing wave frequency. On the other hand in absence of quantum effect, we found that gain is constantly increasing with increasing frequency. But for both (with and without quantum effect) the cases, as we move from homogeneous medium to inhomogeneous one, the value of gain constant decreases with the increase in the value of density gradient.

3.2.3. When $\gamma_e < 0$ and $\gamma_d > 0$ i.e. $\vartheta_{0e} < \vartheta_s < \vartheta_{0d}$

From equation (2) one can find, the gain per radian in this velocity regime as

$$\alpha \approx \frac{1}{2}K^2|\gamma_e|\left(\frac{\omega_{\mathrm{Re}}}{\omega\phi_e}\right)(I+J)^{-1}\left[1-\frac{\omega_{Rd}\,\phi_e|\gamma_e|}{\omega_{\mathrm{Re}}\phi_d|\gamma_d|}\left\{1+\left(\frac{\omega}{\omega_D\phi_e|\gamma_e|}\right)^2+2\,(\Delta_d/\kappa)\left(\frac{2\omega}{\omega_D\phi_e|\gamma_e|}-\frac{\omega}{\omega_D\phi_e|\gamma_e|^2}\right)+\left(\frac{\omega(\Delta_d/\kappa)}{\omega_D\phi_e|\gamma_e|}\right)^2+\frac{(\Delta_d/\kappa)^2(1+|\gamma_e|)}{|\gamma_e|^2}\left(\frac{\omega_{\mathrm{Re}}\,\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e}+(1+|\gamma_e|)\right)\right\}\right] \tag{7a}$$

Where

$$I=\left(\frac{\omega_{\mathrm{Re}}}{\omega\phi_e}\right)^2\left[1+\frac{\omega^2}{\omega_D\omega_{\mathrm{Re}}}-\frac{\omega_{Rd}\,\phi_e|\gamma_e|}{\omega_{\mathrm{Re}}\phi_d|\gamma_d|}+(\Delta_d/\kappa)\frac{\omega_{Rd}\,\phi_e}{\omega_{\mathrm{Re}}\phi_d}\,\omega\left\{\frac{(|\gamma_e|+1)\,\phi_d}{\omega_{Rd}}-\frac{1}{\omega_D\phi_e|\gamma_d|}\right\}\right]^2,$$

And

$$J=|\gamma_e|^2\left[1+\frac{\omega_{Rd}}{\omega_D\,\phi_e\phi_d|\gamma_e||\gamma_d|}+(\Delta_d/\kappa)\frac{1}{|\gamma_e|}\left\{\frac{\omega}{\omega_D\phi_e}+\frac{\omega_{\mathrm{Re}}}{\omega\phi_e}+\frac{\omega_{Rd}\,(|\gamma_e|-1)}{\omega\phi_d|\gamma_d|}\right\}\right]^2$$

One gets the amplification of acoustic wave in this velocity regime only when

$$\omega > \frac{(\omega_D\phi_e|\gamma_e|)}{\sqrt{\left[1+(\Delta_d/\kappa)^2\right]}}\left[\left(\frac{\omega_{\mathrm{Re}}\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e|\gamma_e|}-1\right)-2(\Delta_d/\kappa)\frac{\omega}{\omega_D|\gamma_e|\phi_e}\left(2-\frac{1}{|\gamma_e|}\right)-\frac{(\Delta_d/k)^2(1+|\gamma_e|)}{|\gamma_e|^2}\left(\frac{\omega_{\mathrm{Re}}\,\phi_d|\gamma_d|}{\omega_{Rd}\,\phi_e}+(1+|\gamma_e|)\right)\right]^{1/2} \tag{7b}$$

It can be inferred that in a frequency region defined by equation (7b), we may get sound amplification even if the electron drift is less than the acoustic speed. Hence in the presence of charged colloids one gets a new amplifying mode and therefore, this mode may be termed as colloids induced sound mode amplification in inhomogeneous piezoelectric semiconductor.

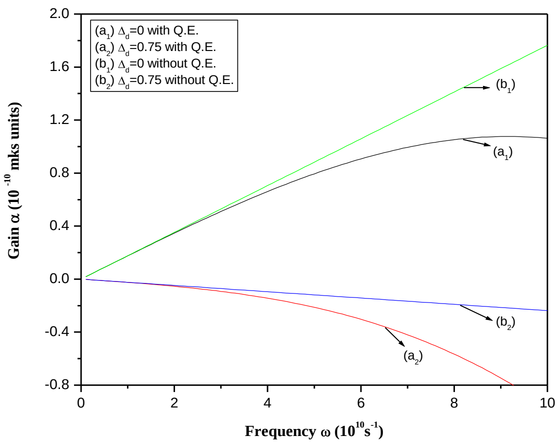

Figure 4. *Variation of gain α with wave frequency ω for different values of Δ_d at $E_0 = 10^2 Vm^{-1}$ with and without quantum effect when $\vartheta_{0e} < \vartheta_s < \vartheta_{0d}$.*

This novel mode strongly depends on the quantum correction made through $V_F^{'}$ and density gradient Δ_d.

The variation of acoustic gain per radian (α) with wave frequency (ω) is depicted in Fig. 4 using density gradient (Δ_d) as parameter when $\vartheta_{0e} < \vartheta_s < \vartheta_{0d}$. In this velocity regime we get amplifying sound mode even when electron drift velocity is less than the velocity of sound. It follows from the Fig. that amplification is possible only in uniform medium $(\Delta_d = 0)$ in presence as well as in absence of quantum effect. But as the medium changes into the non-uniform one $(\Delta_d \neq 0)$ the value of gain per radian decreases for both (with and without quantum effect) cases. Hence, in this velocity regime the density gradient and quantum effect cause to reduce the value of gain for colloids induced sound mode.

3.2.4. When $\gamma_e < 0$ and $\gamma_d < 0$ i.e. $\vartheta_{0e} < \vartheta_s > \vartheta_{0d}$

In this velocity regime one will get a decayed mode $(\alpha < 0)$ always. Therefore it is not considered for discussion.

4. CONCLUSION

In the present study, on the basis of quantum hydrodynamic (QHD) model a linear dispersion relation has been derived for the acousto-electric wave for two different media. The quantum effect via the Bohm potential and in homogeneity due to density gradient are found to play essential roles in deciding the amplification criteria and gain characteristics of sound wave. We found that the Bohm potential and density gradient reduce the gain of the sound wave when charged colloids are stationary $(\vartheta_{0d} = 0)$. In case of streaming colloids $(\vartheta_{0d} \neq 0)$, we found that the quantum effect is favourable only when electrons and colloids both drift faster than the acoustic speed otherwise quantum effect reduces the gain per radian. It may be added here that the homogeneous medium is the best suitable medium for obtaining the maximum gain. Finally, it is hoped that our results should be useful in understanding the amplification properties of sound wave in magnetized n-type piezoelectric semiconductor quantum plasma and may also become useful in designing the semiconducting devices using density gradient as controlling parameter.

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REFERENCES

[1] Manfredi G., How to model quantum plasmas, Fields Inst. Commun. 46, 263 (2005).

[2] Shukla P. K. and Eliasson B., Formation and dynamics of dark solitons and vortices in quantum electron plasmas, Phys. Rev. Lett. 96, 245001 (2006).

[3] Jung Y.D., Quantum-Mechanical Effects on Electron-Electron Scattering in Dense High-Temperature Plasmas, Phys. Plasmas 8, 3842 (2001); Opher M., Silva L.O., Dauger D.E., Decyk V.K. and Dawson J.M., Nuclear Reaction Rates and Energy in Stellar Plasmas: The effect of Highly Damped Modes, Phys. Plasmas 8, 2454 (2001).

[4] Bingham R., Mendonca J.T. and Shukla P.K., Plasma based charged-particle accelerators, Plasma Phys. Control. Fusion 46, R1 (2004); Marklund M. and Shukla P.K., Nonlinear collective effects in photon-photon and photon-plasma interactions, Rev. Mod. Phys. 78, 591 (2006).

[5] Shokri B. and Khorashady S.M., Anti-screening in magnetically quantized plasmas, Pramana 62, 1 (2004).

[6] Haas F., Garcia L.G., Goedert J. and Manfredi G., Quantum ion-acoustic waves, Phys. Plasmas 10(10), 3858 (2003).

[7] Haas F., Manfredi G. and Feix M., A multistream model for quantum plasmas, Phys. Rev. E 62(2), 2763 (2000).

[8] Anderson D., Hall B., Lisak M. and Marklund M., Statistical effects in the multistream model for quantum plasmas, Phys. Rev. E 65, 046417 (2002).

[9] Ali S. and Shukla P.K., Streaming instability in quantum dusty plasmas, Eur. Phys. J. D 41, 319 (2007).

[10] P.K. Shukla and A.A. Mamun, *Introduction to Dusty Plasma Physics,* IOP, Bristol, 2002.

[11] Ghosh S. and Thakur Preeti, Longitudinal electrokinetic waves in ion-implanted semiconductor plasmas, Eurp. Phys. J. D 31, 85 (2004).

[12] Ghosh S. and Thakur Preeti, Instability of circularly polarized electrokinetic wave in magnetized ion implanted semiconductor plasmas, Eurp. Phys. J. D 37, 417 (2006).

[13] Ghosh S., Sharma G.R., Khare Pragati and Salimullah M., Modified interactions of longitudinal phonon-plasmon in magnetized piezoelectric semiconductor plasmas, Physica B 315, 163 (2004).

[14] Ghosh S. and Khare Pragati, Acousto-electric wave instability in ion-implanted semiconductor plasmas, Eurp. Phys. J. D 35, 521 (2005).

[15] Ghosh S. and Khare Pragati, Effect of density gradient on acousto-electric wave instability in ion-implanted semiconductor plasma, Acta Physica Polonica A 109, 187 (2006).

[16] Ghosh S. and Khare Pragati, Acoustic wave amplification in ion-implanted piezoelectric semiconductor, Ind. J. Pure & Appl. Phys. 44, 183 (2006).

[17] Gardner C., The Quantum Hydrodynamic Model for Semiconductor Devices, SIAM J. Appl. Math. 54, 409 (1994).

[18] Gardner C.L. and Ringhofer C., Smooth quantum potential for the hydrodynamic model, Phys. Rev. E 53, 157 (1996).

[19] P.A. Markowich, C.A. Ringhofer and C. Schmeiser, *Semiconductor equation,* Springer, Vienna, 1990.

[20] Kremp D., Bornath Th., Bonitz M. and Schlanges M., Quantum kinetic theory of plasmas in strong laser fields, Phys. Rev. E 60, 4725 (1999).

[21] Suh N., Feix M.R. and Bertrand P., Ion-Acoustic Higher Order Non-Linear Structures in Quantum Dusty Plasma, J. Comput. Phys. 94, 403 (1991).

[22] Manfredi G. and Feix M., Theory and simulation of classical and quantum echoes, Phys. Rev. E 53, 6460 (1996).

[23] Shokri B. and Rukhadze A.A., Quantum surface waves in a thin plasma layer, Phys. Plasmas 6, 3450 (1999).

[24] Sharma Aartee, Yadav Nishchhal and Ghosh S., Modified acousto-electric interactions in colloids laden semiconductor quantum plasmas, IJSRP 3, 1 (2013).

[25] M.C. Steele and B. Vural, *Wave Interactions in Solid State Plasmas,* Mc-Graw Hill, NewYork, 1969, ch. 8, pp. 134-153.

[26] White D.L., Amplification of ultrasonic waves in piezoelectric semiconductors, J. Appl. Phys. 33, 2547 (1962).

[27] de Angelis U., The physics of dusty plasmas, Phys. Scripta 45, 465 (1992).