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Dispersion and absorption of longitudinal electro-kinetic waves in ion-implanted semiconductor plasmas

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Excitation of modified electro-kinetic modes and novel properties introduced due to the presence of negatively charged colloidal particles in otherwise compensated semiconductor plasma are investigated. A compact linear dispersion relation for the electro-kinetic waves in colloids laden semiconductor plasma has been derived by using multi-fluid analysis and Maxwell's equations. This dispersion relation has been studied for slow and fast electro-kinetic modes. The presence of charged colloids significantly modify the dispersion and absorption characteristics of all possible modes even though colloidal particles, because of their heavy masses do not participate in wave propagation.

Keywords: Electrostatic waves, Electrostatic oscillations, Plasma effects, Doping, Ion-implantation, Colloids

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1 Introduction

During last decades, the research in the field of complex (dusty) plasmas has grown explosively. Firstly Ikezi[1] and then Nambu[2] have opened a new perspective by giving their theoretical predictions on arrangement of ordered structure of heavy charged particles inside strongly coupled plasma to form plasma crystal, which has been then demonstrated in a number of laboratory experiments[3-8]. Hence finds wide application in studying physical processes in condensed matter and in investigating the collective properties in strongly coupled plasma. On the other side, extensive theoretical as well as experimental works[9-15] have also been reported on the study of dispersion, absorption and scattering of linear and non-linear waves and various new low frequency waves in presence of charged dust particles in gaseous dusty plasma. In most of the studies, a fluid description in used and the dust is considered as the third component of the plasma, which can support only low frequency perturbations.

The presence of mobile charge carriers of both the signs and the implanted metal ions (such as Ag^+, Cu^+, Fe^+ etc) forming colloids in solids duplicates the dusty plasma medium and refers as "Colloids laden solid state plasma system". These types of ion-implanted solids become promising media to study wave spectrum. Though the ion implanted technique is expensive, but has a lot of advantages such as extremely accurate dose control, large range of doses, wide choice of masking the target material as well as low processing temperature as compared to all other cheaper ones. Colloid formation of metal ions by ion implantation technique in SiO_2 glasses has been carried out in number of laboratory experiments[16-21]. These implanted ions inside host material are neutralized during slowing down process and somehow agglomerate to form colloids.

A survey of available literature[16-21] reveals that the investigation of optical properties of implanted colloids formed within the host material have pursued in recent years. As in case of glasses, we believe that some of the colloids formed within the semiconductor might acquire a net negative charge due to various electron sticking processes that would change the balance between electron and hole densities in an otherwise compensated semiconductor that, in turns, can give rise to several novel phenomena. This has caught attention of researchers in recent years[22,23]. Salimullah *et al.*[22] have predicted first time the possible lattice

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formation in piezoelectric semiconductor plasma and later role of electron-phonon coupling in formation of plasma crystal was reported[23].

It is also expected that the presence of charged colloids can have a strong influence on the characteristics of usual plasma wave modes, even at a frequency where colloidal grains do not participate in wave motion. In these cases, the colloids may simply provide an immobile charge neutralizing background. Hence, they are expected to add new dimensions to well studied semiconductor plasma medium; as the charged dust grains do in case of gaseous plasma.

The electro-kinetic wave, which is a low frequency propagating wave supported by an electron stream is the basic negative energy carrying mode possible in semiconductor plasmas. Thus it has much fundamental importance in many space and laboratory plasma studies. Since random and static distribution of highly charged and massive colloids can change the dispersive properties of the medium, that may be responsible for low frequency waves to suffer strong modifications, the study of electro-kinetic waves in such a medium becomes important for better understanding of wave spectrum and medium properties.

To the best of our knowledge, no attempt has yet been made to study the influence of charged colloids on dispersion and absorption of waves in colloids laden semiconductor plasma except a few very recently reported works of Ghosh *et al*.[24,25] concerning excitations of novel electro-acoustic[24] and modified Alfven modes[25] in a colloids laden piezoelectric semiconductor plasma medium.

Motivated by the present status and the initial works of Ghosh *et al*.[24,25] in the present paper we have focused our attention on the dispersion and absorption characteristics of the longitudinal electro-kinetic wave in colloids laden semiconductor plasma medium in which negatively charged colloids are assumed to be stationary forming neutralizing background in the medium. The choice for electro-kinetic wave stems from the fact that it is fundamental negative energy carrying wave and can render an effective tool for understanding of wave spectrum and can be put to various favourable basic and device applications.

2. Theoretical Formulation

An ion-implanted semiconductor plasma system whose constituents are electrons, holes and negatively charged colloids has been considered. The colloidal grains may collect both electrons and holes, but due to high mobility of electrons, it is expected that the grains tend to acquire a net negative charge. These charged colloids act as a third component of the medium, and are expected to modify the plasma behaviour significantly.

It is assumed that all the colloids are of uniform size and are smaller than the wavelength under study as well as electron Debye radius; hence, they can be treated as negatively charged point masses[26]. The colloidal particles are assumed stationary by considering them massive enough to respond to the considered perturbations. Hence, the medium can be safely treated as multi-component plasma consisting of electrons, holes and stationary negatively charged colloids under hydrodynamic limit.

It has been reported by Cramer and Vladimirov[27, 28] that the presence of dust grains creates a charge imbalance in complex plasma medium and modifies waves and instability phenomena. The similar phenomena can also be expected to occur in colloids laden semiconductor plasma medium due to the sticking of electrons on the surface of colloids, which in turns became responsible for the modification as well as excitations of various waves.

To study the linear dispersion relation for low frequency electrostatics waves, a compensated semiconductor sample of infinite extent is considered in the presence of implanted colloidal particles, and the carrier motions are assumed to be entirely along the z-direction. Then the condition for charge neutrality in plasma with negatively charged colloids is given by

$$z_h n_{0h} = z_e n_{0e} + z_d n_{0d} \,, \qquad \ldots (1)$$

where n_α (α = e, h, d) is the number density, z_α is the charge states of electrons, holes and colloids, respectively, in which $z_d = q_d / e$ is the ratio of negative charges q_d resided over the colloidal grains to the charge e on electrons and it is assumed that $z_e = -1$ and $z_h = 1$ for further calculations.

When present complex medium corresponds to a situation that some of the electrons from the ambient semiconductor plasma are attached to the colloid surface; due to neutrality condition it is possible to have in such plasmas $n_{0e} \ll n_{0h}$, and a charge imbalance parameter δ may be introduced as

$$\delta = \frac{n_{0e}}{n_{0h}} < 1 \qquad \ldots (2)$$

This parameter measures the charge imbalance in the plasma medium, with the remainder of the negative charges residing on the colloidal particles, so that the total system remains charge neutral. The charging of colloids causes depletion of species (here electrons) of higher mobility however, the ratio of number density of electrons to that of the holes cannot be less than square root of the ratio of their masses[29], i.e.

$$\frac{n_{0e}}{n_{0h}} \geq \sqrt{\frac{m_e}{m_h}} \quad \ldots (3)$$

If each component has a mass m_α, charge state z_α, density n_α, thermal velocity $v_{t\alpha}$, momentum transfer collision frequency ν_α, and charge density ρ_α, then this multi-component plasma system is described by their continuity and momentum equations as

$$\frac{\partial n_\alpha}{\partial t} + \frac{\partial}{\partial z}\left(n_\alpha \vartheta_\alpha\right) = 0, \quad \ldots (4)$$

$$\frac{\partial \vartheta_{z1\alpha}}{\partial t} + \vartheta_{0\alpha}\frac{\partial \vartheta_{zi\alpha}}{\partial z} = \frac{z_\alpha q_\alpha}{m_\alpha}E_{z1} - \nu_\alpha \vartheta_{z1\alpha} - \frac{\vartheta_{t\alpha}{}^2}{\rho_{0\alpha}}\frac{\partial \rho_{1\alpha}}{\partial z} \quad \ldots (5)$$

Here the subscripts 0 and 1 used in Eqs (4) and (5) represent zeroth and first order quantities, respectively. It is assumed that all first order quantities are varying as exp $[i(\omega t - kz)]$, where ω and k are frequency and wave number of the electro-kinetic mode, respectively.

Following the procedure adopted by Steele and Vural [30], the dispersion relation for longitudinal electro-kinetic wave in presence of stationary negatively charged colloids in the background, is obtained as

$$\varepsilon(\omega,k) = 1 + \frac{\omega_{ph}^2(\delta/\mu)}{\left[(\omega - k\vartheta_{0e})^2 - i\nu_e(\omega - k\vartheta_{0e}) - k^2\vartheta_{te}^2\right]} + \frac{\omega_{ph}^2}{\left[(\omega + k\vartheta_{0h})^2 - i\nu_h(\omega + k\vartheta_{0h}) - k^2\vartheta_{th}^2\right]}. = 0 \quad \ldots (6)$$

where

$$\omega_{ph}^2 = \frac{e^2 n_{0h}}{\varepsilon m_h},\ \mu = \frac{m_e}{m_h}, \vartheta_{te} = \left(\frac{k_B T}{m_e}\right)^{\frac{1}{2}}, \vartheta_{th} = \left(\frac{k_B T}{m_h}\right)^{\frac{1}{2}}$$

and $\varepsilon = \varepsilon_0 \varepsilon_L$; ε_L being the lattice dielectric constant.

In Eq. (6), the second term on RHS is responsible for the modified character of electro-kinetic wave in colloids laden semiconductor plasma and the third term represents contribution of holes in the same medium. If we neglect the presence of holes and assume δ =1, Eq. (6) reduces to Eqs (4-3b) of Steele and Vural [30].

In order to study the wave spectrum characteristics of the longitudinal electro-kinetic mode in colloids laden semiconductor plasma medium, we shall study the dispersion relation under two different physical situations, which are appropriate under laboratory frame.

2.1 Case 1: Slow electro-kinetic mode $(\omega << kv_{te}, kv_{th})$

If the phase velocity of the wave is less than the thermal velocities of electrons and holes both, the mode may be termed as slow electro-kinetic mode. For this slow electro-kinetic mode, under collision dominated or low frequency regime ($\omega << \nu_e, \nu_h$), in the non-drifting plasma medium $(\vartheta_{0e} = \vartheta_{0h} = 0)$, for the sake of simplicity and without loss of any qualitative information, we may further assume that $\nu_e \approx \nu_h = \nu_0$. Then the compact dispersion relation [Eq. (6)] reduces to

$$1 - \frac{\omega_{ph}^2(\delta/\mu)}{\left(i\nu_e\omega + k^2\vartheta_{te}^2\right)} - \frac{\omega_{ph}^2}{\left(i\nu_h\omega + k^2\vartheta_{th}^2\right)} = 0 \quad \ldots (7)$$

Equation (7) may be written in the form of polynomial in ω as

$$-\omega^2\nu_0^2 + i\omega\,\nu_0\left(k^2\vartheta_{t+}^2 - \omega_{ph}^2 F\right) + \left\{k^2\left(k^2\vartheta_{te}^2\vartheta_{th}^2 + \omega_{ph}^2\vartheta_{t-}^2 - \vartheta_{th}^2\omega_{ph}^2 F\right)\right\} = 0. \quad \ldots (8)$$

In which

$$\vartheta_{t+}^2 = \vartheta_{th}^2 + \vartheta_{te}^2,\ \vartheta_{t-}^2 = \vartheta_{th}^2 - \vartheta_{te}^2, \text{ and } F = 1 + (\delta/\mu)$$

It can be inferred from Eq. (8) that if we consider some negative charges on stationary colloids, i.e. at δ <1, the magnitude of F reduces. This leads to the drastic modifications in the wave spectrum of the electrostatic wave propagating through a compensated semiconductor plasma medium.

We have considered that the first order perturbations of the form $\exp\left[i(\omega t - kz)\right]$ and so the wave may be growing in time when ($\omega_i < 0$) and causes temporal instability. Equation (8) being of second degree in complex wave frequency ($\omega = \omega_r + i\omega_i$), it is very easy to solve it analytically. Thus for real and positive values of k, one may obtain

$$\omega = -\frac{1}{2\nu_0}\left[-i\left(k^2\vartheta_{t+}^2 - \omega_{ph}^2 F\right) \pm \left(\alpha - \beta\right)^{1/2}\right], \qquad \ldots (9)$$

where

$$\alpha = 2k^2\vartheta_{t+}^2\omega_{ph}^2 F + 4k^4\vartheta_{te}^2\vartheta_{th}^2 + 4k^2\vartheta_{t-}^2\omega_{ph}^2 ,$$

and

$$\beta = k^4\vartheta_{t+}^4 + \omega_{ph}^4 F^2 + 4k^2\vartheta_{th}^2\omega_{ph}^2 F .$$

Equation (9) reveals that the slow electro-kinetic wave has two branches of propagation. It may also be revealed that both the branches may have different characteristics when $\alpha > \beta$ or $\alpha < \beta$. Let us discuss the amplification characteristics of these two branches of slow electro-kinetic wave when $\alpha < \beta$ and $\alpha > \beta$.

When $\alpha < \beta$: In this, regime the two modes obtained are purely aperiodic ($\omega_r = 0$) and their growth rates may be expressed as

$$\omega_{i1} = \frac{1}{2\nu_0}\left[\left(k^2\vartheta_{t+}^2 + \frac{\alpha}{2\sqrt{\beta}}\right) - \left(\omega_{ph}^2 F + \sqrt{\beta}\right)\right], \qquad \ldots (10)$$

$$\omega_{i2} = \frac{1}{2\nu_0}\left[\left(k^2\vartheta_{t+}^2 + \sqrt{\beta}\right) - \left(\omega_{ph}^2 F + \frac{\alpha}{2\sqrt{\beta}}\right)\right], \qquad \ldots (11)$$

The first aperiodic mode will be growing ($\omega_i < 0$) in nature if the condition

$$\left(\omega_{ph}^2 F + \sqrt{\beta}\right) > \left(k^2\vartheta_{t+}^2 + \frac{\alpha}{2\sqrt{\beta}}\right), \qquad \ldots (12)$$

is satisfied; and the second aperiodic mode will be amplified only when

$$\left(\omega_{ph}^2 F + \frac{\alpha}{2\sqrt{\beta}}\right) > \left(k^2\vartheta_{t+}^2 + \sqrt{\beta}\right). \qquad \ldots (13)$$

is satisfied. If one checks the conditions [Eqs. (12) and (13)] numerically using the data given in Sec.3, it is found that Eq. (12) can be satisfied easily but for the wavelength regime under study Eq. (13) cannot be satisfied. Hence, one may infer that second mode will always be decaying in nature under slow electro-kinetic mode regime.

When $\alpha > \beta$: It may be seen numerically that the said regime is not achievable with the physical parameters used in this problem. Hence of no use.

2.2 Case 2: Fast electro-kinetic mode ($kJ_{th} \ll \omega \ll kJ_{te}$)

If the phase velocity of the mode is less than electron thermal speed but more than the hole thermal speed, the mode may be termed as fast electro-kinetic mode. Thus for fast electro-kinetic mode under the assumption already discussed in Sec. 2.1, the dispersion relation (Eq.6) reduces to

$$1 - \frac{\omega_{ph}^2\left(\delta/\mu\right)}{\left(i\nu_e\omega + k^2\vartheta_{te}^2\right)} + \frac{\omega_{ph}^2}{\left(\omega^2 - i\omega\nu_h\right)} = 0 . \qquad \ldots (14)$$

Equation (14) may be rewritten as a polynomial in ω as

$$\omega^3\nu_0 - i\omega^2\left\{\nu_0^2 + k^2\vartheta_{te}^2 - \omega_{ph}^2\left(\delta/\mu\right)\right\}$$
$$+\omega\left(\omega_{ph}^2\nu_0 F - k^2\vartheta_{te}^2\nu_0\right) - ik^2\vartheta_{te}^2\omega_{ph}^2 = 0. \qquad \ldots (15)$$

Equation (15) being third order in ω is to be solved numerically to study the dispersion and amplification characteristics of three possible modes.

3 Results and Discussion

To have some numerical appreciations of the results obtained in Sec.2, following set of parameters for compensated semiconductor medium have been used: $m_e = 0.0815\, m_0$, m_0 being the free electron mass, $m_h = 4\ m_e$, $\varepsilon_L = 15.8$, $n_{0e} \approx n_{0h} = 10^{19}$ m^{-3}, $\nu_e \approx \nu_h = \nu_0 = 1.194 \times 10^{11}$ s^{-1} at 77 K.

For slow electro-kinetic mode one may infer from Eqs (10, 11) that both the modes are aperiodic in nature ($\omega_r = 0$), which indicate the absence of periodic oscillations under collision dominated regime. Here the charges in the plasma medium that are separated in space move to each other, but collisions with lattice prevent the appearance of oscillations ($\omega_r = 0$) and the modes become aperiodic in nature.

In the regime $\alpha < \beta$ the variations of absorption coefficients (ω_i) of both the slow electro-kinetic modes with positive real values of k with δ parameter are illustrated in Figs (1-2). Figure1 infers that this mode (the first mode) is amplifying ($\omega_i < 0$) in nature up to a particular wavelength and then starts decaying as k

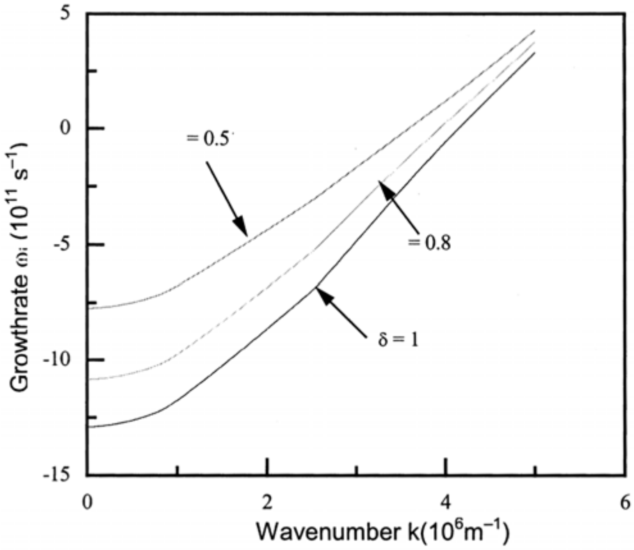

Fig. 1—Variation of growth rate of first aperiodic slow electro-kinetic mode with wave number

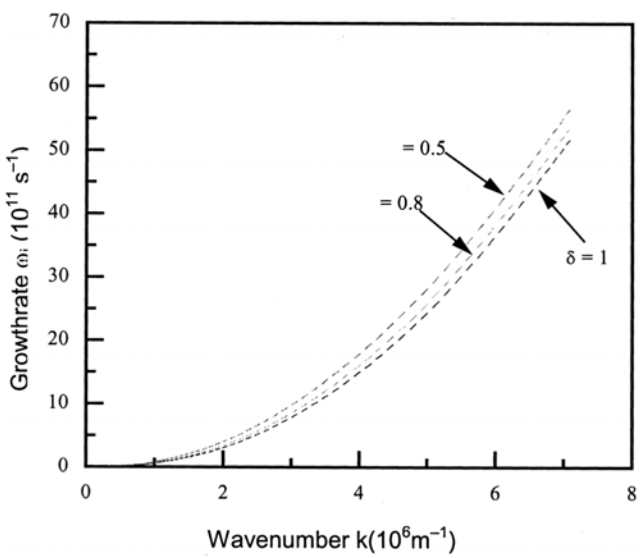

Fig. 2—Variation of growth rate of second aperiodic slow electro-kinetic mode with wave number

increases. It may be inferred from this graph that the growth rate decreases as k increases and becomes zero for a particular value of k (say k_m). Further increment in the value of k, becomes responsible for decaying mode whose decay rate keeps increasing with increment in k. As we increase δ, the growth rate increases and the cross-over value k_m also becomes larger. In the absence of implanted ions, the plasma medium has equal number densities of electrons and holes ($\delta = 1$); gain constant and k_m touches their maximum values. Hence it may be said that band of wave number for which one obtains amplifying mode and the magnitude of gain become larger with the increase in the value of δ.

It may be inferred from Fig. 2 that second slow electro-kinetic mode will always be of decaying nature ($\omega_i > 0$) for all possible values of δ. Here the absorption coefficient increases parabolically with the increment in k. When a fraction of colloids is charged, a charge imbalance (δ <1) is created in the medium. As a result, the absorption characteristic is quantitatively modified. The presence of charge imbalance does not alter the qualitative behaviour of the absorption characteristics but with the increase in charge imbalance (or decrease in the value of δ), the absorption coefficient effectively increases. Hence, it is quite evident that the charge imbalance created by the presence of colloids in the medium causes effective modification of absorption characteristics of both the possible aperiodic modes under slow electro-kinetic wave regime.

Under fast electro-kinetic wave limit, three modes of propagation are possible as may be seen from Eq. (15). The variations of phase constant (ω_r) and gain coefficients (ω_i) of all the three modes with wave number k for different values of charge imbalance parameter δ are depicted in Figs (3-5). Figure 3(a and b) display the variation of real frequency (ω_r) and growth rate (ω_i) of the first root of fast electro-kinetic wave with wave number k. Figure 3(a) illustrates the dispersion characteristics and suggests that the qualitative nature of the dispersion is identical for all possible values of δ. It may be inferred that this mode is propagating along negative z-direction; hence a contra-propagating mode. The magnitude of the phase constant first increases with increase in k; achieves maximum value at a critical value of k and then starts decreasing with k. This critical value of k increases with the increment in δ. As one goes on increasing k, the phase constant becomes zero and beyond that one gets non-propagating (aperiodic) mode. Here the wave number bandwidth, which allows propagation of the wave, increases as charge imbalance parameter increases.

Figure 3(b) infers that the mode is growing in nature up to $k \approx 1.2 \times 10^5$ m^{-1}, but in this region, the growth rate reduces with increasing k. At $k \approx 1.2 \times 10^5$ m^{-1}, ω_i becomes zero corresponding to all values of δ. If one goes beyond this point i.e. $k > 1.2 \times 10^5$ m^{-1}

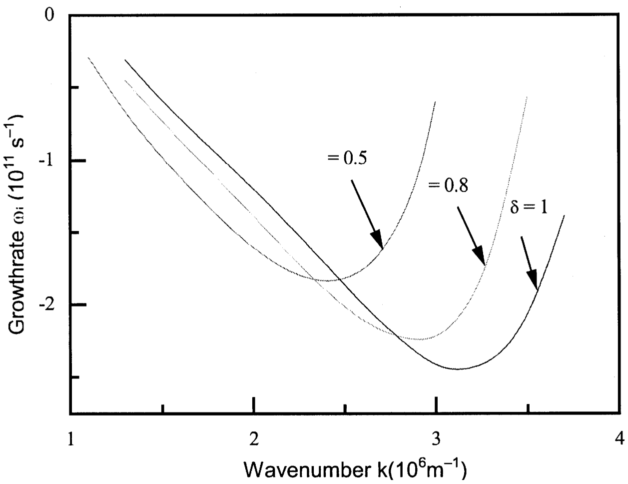

Fig. 3(a)—Variation of real frequency of first fast electro-kinetic mode with wave number

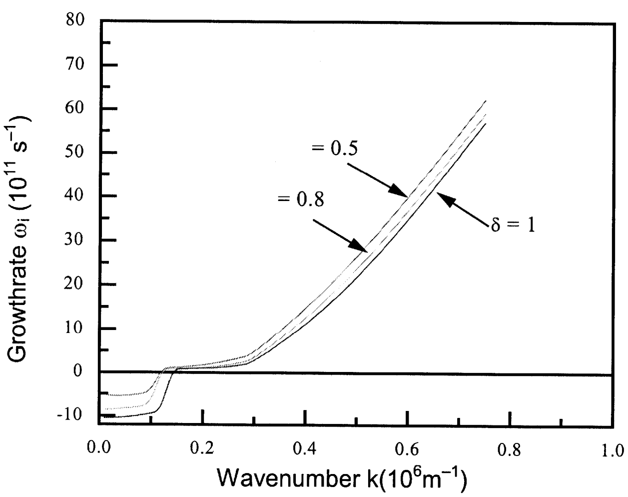

Fig. 3(b)—Variation of growth rate of first fast electro-kinetic mode with wave number

the mode becomes decaying in nature. Here it can also be seen that the growth rate is maximum for δ =1 and decreases as negative charge concentration on colloids increases or the magnitude of δ decreases.

Figure 4 [(a) and (b)] display the dependence of ω_r and ω_i of the second root of fast electro-kinetic wave on wave number *k*. It can be seen from Fig. 4(a) that in presence of charge imbalance, ω_r is positive and increases with increasing *k* acquiring a maximum value $\omega_{r_{max}} \approx 5 \times 10^3$ s^{-1} when $k \approx 2.35 \times 10^6$ m^{-1}. A slight increase in k beyond this point causes a sharp fall in ω_r making it vanish at k $\approx 2.36 \times 10^6$ m^{-1}. The sharp fall continues beyond this point and ω_r dips down to its minimum value $\omega_{r_{min}} \approx -7.27 \times 10^3$ s^{-1} at $k \approx 2.37 \times 10^6$ m^{-1}. For $k > 2.37\times10^6$ m^{-1}, ω_r again starts increasing and ultimately saturates. In other words, mode propagates in positive direction for 2.34×10^6 m^{-1}< $k < 2.36 \times 10^6$ m^{-1} and for $k > 2.36 \times 10^6$ m^{-1} it starts propagating in reverse direction. In absence of charge imbalance i.e. δ = 1, the said mode always propagates in positive direction. Its phase constant increases with k and reaches a maximum value at $k \approx 2.39 \times 10^6$ m^{-1}. After this point ω_r decreases sharply and attains zero value at $k \approx 2.41 \times 10^6$ m^{-1}. Hence, the charge imbalance modifies the dispersion characteristic not only quantitatively but also qualitatively.

Figure 4(b) shows the qualitative behaviour of ω_i as a function of wave number k for different values of δ. One may notice from this figure that the magnitude of growth rate as well as the range of wave number at which amplification occurs increases with increase in value of δ. Moreover, for each value of δ, there exists a critical wave number $k = k_{cr1}$ above which ω_i becomes negative and one achieves amplification in colloids laden semiconductors. This amplification increases sharply with increase of *k* and attains maximum value at $k \approx 1.2 \times 10^6$ m^{-1}. If we further increase *k*, growth rate starts reducing and beyond another critical value of $k = k_{cr2}$, amplification disappears completely. The amplification spectrum $k_{cr1} \leq k < k_{cr2}$ is broader at higher values of δ. Thus, one may enhance significantly the amplification by increasing slightly the charge imbalance parameter δ even for a fixed wavelength in colloids laden semiconductor. Shukla and Mamun[29] mentioned that charging of colloids causes depletion of species (here electrons) of higher mobility however, the ratio of number density of the electrons to that of the holes cannot be less than square root of their mass. Hence, this logic suggests that δ should not assume values less than 0.5 for the considered set of data.

Figure 5[(a) and (b)] show the variation of real frequency and growth rate of third root of fast electro-kinetic wave with *k*. It may be depicted from Fig. 5(a) that this mode is propagating along z-direction for all possible values of δ. In absence of charge imbalance i.e. for δ =1, the phase constant ω_r varies parabolically with increasing k and touches the zero level at $k = 3.7\times10^6$ m^{-1}. If one introduces charge imbalance i.e. for δ <1, the qualitative behaviour of phase constant

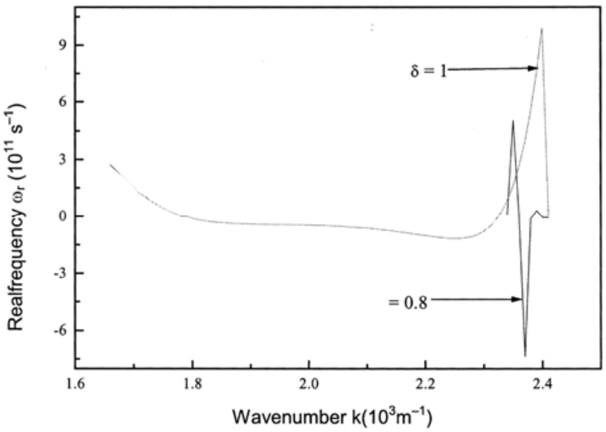

Fig. 4(a)— Variation of real frequency of second fast electro-kinetic mode with wave number

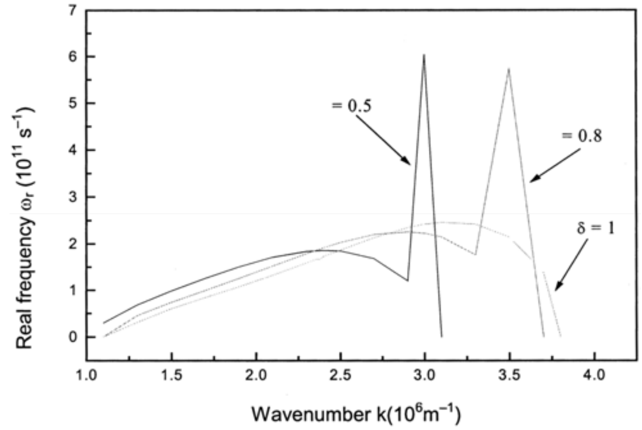

Fig. 5(a)— Variation of real frequency of third fast electro-kinetic mode with wave number

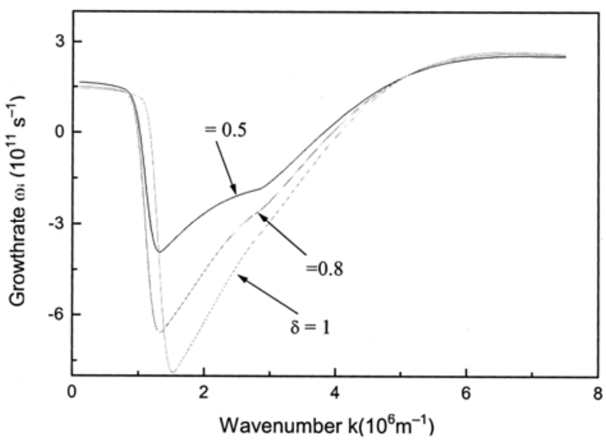

Fig. 4(b)— Variation of growth rate of second fast electro-kinetic mode with wave number

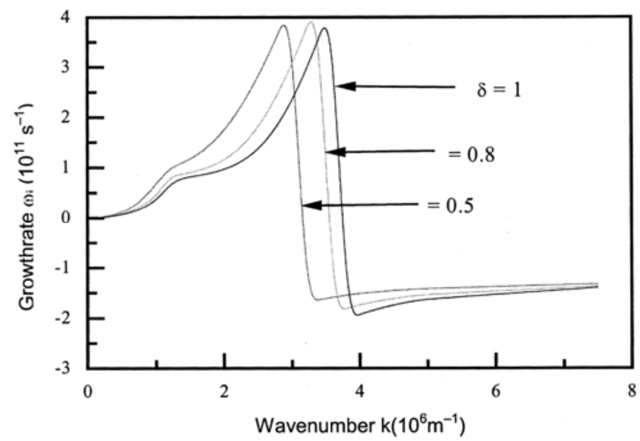

Fig. 5(b)— Variation of growth rate of third fast electro-kinetic mode with wave number

changes drastically. It first increases parabolically with k reaches to a minimum value at critical value of $k = k_{cr1}$ and then starts increasing sharply. A maximum value is achieved by it at $k = k_{cr2}$. For $k > k_{cr2}$ it suddenly decreases to zero as in the case for δ =1. The value of the wave number for which phase constant becomes zero decreases with the decrease in the value of δ. The maximum value of ω_r decreases and the critical value of k (k_{cr2}) increase with the increment in δ. In the charge imbalance situation when δ <1, the minimum value of the phase constants as well as k_{cr1} at which it is obtained, increase with the increment in δ.

At different constant values of δ, variations of growth rates of the third root of fast electro-kinetic mode with wave number k are depicted in Fig 5(b). The variations are qualitatively identical for all possible values of δ. At lower wave number regime, one always gets decaying mode. The growth coefficient first increases with k, touches a maximum value and then suddenly falls to zero at a particular wave number k_p. The value of k_p increases with the increase in the value of δ, the charge imbalance parameter. For $k > k_p$, one gets amplifying mode for all δ. The gain constant first increase with k achieves a maximum value and then saturates out in all cases. The wave number at which one gets maximum gain and the amplitude of maximum gain both increase with increase in δ. Hence, a direct effect of charge imbalance on the propagation and instability characteristics of the fast electro-kinetic wave has been seen in Figs(3-5).

We have shown that the dispersion and absorption properties of the longitudinal electro-kinetic waves are strongly modified when a portion of the negative charge resides on the colloids in semiconductor plasma. We have also found that as the portion of charge on the colloids increases, their role becomes increasingly effective. Thus, a fundamental study of dispersion and absorption characteristics of the longitudinal electro-kinetic waves in electron-hole plasma embedded with colloids is important for understanding of waves and instabilities phenomena and can be put to various interesting applications. For example the fast electro-kinetic mode, because of its strong absorption, may be used for significant heating of electron-hole plasma by introducing ion-particles in the medium. The slow electro-kinetic mode can favourably employed as material diagnostic tool owing to its low damping. It is also capable of providing a compact and less expensive tool for clearer understanding of many laboratories as well as astrophysical plasmas contaminated with colloidal grains.

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