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Instabilities Due to Absorption and Propagation of Laser Beams in Material with High Dielectric Constant

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Abstract: *An analysis of strain dependent material is done by the acoustic waves for parametric excitation. By the implementation of the hydrodynamic plasma analysis is perform in the collision dominated regime. One more analysis is done of parametric instability by using the couple mode theory. It is obtained that growth rate increases very highly by using the large value of dielectric constant material. So proper condition and necessary threshold value for excitation is calculated. In this paper results shows that that there is considerable growth rate for the PZT utilizing mention method for absorption and propagation. Experimental evaluation is generating by the implementation of the CO2 laser.*

Keywords: *HDM , CMT , plasma effects , HDC*

1. INTRODUCTION

The idea of frequency mixing, amplification of acoustic waves and attenuation in piezoelectric material has been implemented on different material from last few years. This is due to the collection of the carriers generated by the electric field which is contributed by the other waves as well. So any method that increase the carrier number can be increasing at first this will enhance the linear and parametric amplification of the coefficient. In the similar fashion the parameters of method which decrease the carrier number should need to decrease a lot. In Guha [21] the magneto static field collection of the carrier is done for the piezoelectric semiconductor.

Semiconductor plasmas are also the only solid state plasma in which it is possible to produce sizable departure from thermal equilibrium. Several types of instability can be excited in them. An instability effect was often well known for gaseous plasma. When one considers a semiconductor with its holes, electrons and ionized impurities as plasma and searches for the same type of instability one often finds the effect indeed. Several of these plasma instabilities can now be considered for probable useful new devices. The major practical interest in semiconductor-plasma instabilities is the possibility of adjusting the geometries of the applied electric and magnetic fields and the electro kinetic-wave propagation in the crystal as the physical conditions to maximize the growth rate of the propagating wave. The propagation characteristics of the electro -kinetic wave in a system are investigated from the dispersion relation.

In nonlinear wave propagation, the analysis of interaction depending on a particular physical situation is of great importance. As a consequence of nonlinear interactions between matter and wave, there arises phenomenon such as Parametric, Modulation and Stimulated scatterings to name a few. The most fundamental interaction is the Parametric Interaction. The understandings of these phenomena have lead to their successful application in the field like laser technology, laser spectroscopy, optical communication, photo physics, Photochemistry, Material Processing etc. It is well known fact that the study of matter wave interaction provides a tremendous insight that is helpful in analyzing the basic properties of the medium.

2. BACKGROUND

In last few decades the research in the field of semiconductor plasma has grown explosively. Various types of non liner wave interactions occur in semiconductor plasma(e.g. parametric , modulational ,stimulated and Brillouin scatterings)under suitable conditions giving rise to appreciable growth.

With the invention of the high power laser beams it give birth to the nonlinear field so researcher get more promising area as well. It was first predict by the Langmuir wave was first predicted by Sturrock (1957). After this Ginzburg and Zheleznyakov (1958)[19] have search in deep for the method of emission and the effect of that. After this coupled mode theory has been introduce on this chain and analysis of the nonlinear interaction with plasma material is done by Louisell (1960)[35]. The systematic development of nonlinear wave interactions by kinetic treatment was done by Kadomstsev and Petviashvili (1962)[36].

By Ikezi[30] and then Nambu[31] have proposed a new idea for the growth of the plasma crystal which has been done by putting heavy charged particle in an orders way inside a strongly coupled plasma. With this prediction many new field get open to study in condensed matter. While on the other side extensive experiment and theoretical work give different study on the absorbtion and propogation, etc.

By Ogg [24] and S.Ghosh and Saxena [1] give a study of acoustic wave amplification in materials in strain dependent dielectric constant after that Ginzberg [20] and shukla [9] give a study of propagation of plasma medium.

In [12,13,14] Ghosh and Agrawal give a study of parametric excitation of ultrasonic and helicon waves by laser beam .

By Ghosh and Dixit [15] give parametric decay of high power helicon wave in semiconducting plasma.

Recently D. Semedurs [3] have proposed idea of electro kinetic wave propagation in porous media.

By Ghosh and Thakur [26] give a study of classical where ion implantation is done by making some impurity in the semiconductor material. So the effect of the charged particle in the material gives different results of absorption.

In [29] explore the quantum effect on parametric amplification characteristics. They have employed the Quantum Hydrodynamic model (QHD) for the electron dynamics in the semi conductor plasma and predicted the parametric interaction of a laser radiation in unmagnetised piezoelectric semi conductor plasma. It is found that the Bohm potential in the electron dynamics enhances the gain coefficient of parametrically generated modes where as reduces the threshold pump intensity. QHD have been developed by Haas et al. [33, 34] the versatility of this approach is a promising development for analytical applications.

In the last few years some of the researchers has again start work on the dusty plasma as with their new approach of calculation it give more promising results. The agglomeration is done by the ion implantation in the semiconductor material. So the presence of this colloid as well as the charged moving particle will convert the medium in the multi-component medium of the semiconductor plasma. It is known fact that the study of wave propagation through a medium always provide information about the properties of the host material, therefore such ion-implanted semiconductor that resembles dusty plasma system become promising medium to study wave propagation phenomena during the last decade.

To the best of our knowledge no attempt has yet been to made to study the absorption and propagation of Laser beams in ferroelectric material (PZT) with high dielectric constant .

3. THEORETICAL FORMULATION

The dielectric constant are given by

$$\varepsilon = \varepsilon_0 (1 + gS) \tag{1}$$

Where ε_0 is the dielectric constant when the strain S is zero and g is coupling constant? Here Electric displacement is given by:

$$D = \varepsilon_o E + g SE \tag{2}$$

The Stress in the material is given by

T = CS-(ε_o g E^2)/2 (3) Hook' Law

Where C is elastic stiffness constant.

The basic equations used in the present analysis are as follows:-

$$\frac{\partial \upsilon_0}{\partial t} + \nu \upsilon_0 = \frac{e}{m} E_0 \cos(\Omega_0 t) \tag{4}$$

$$\frac{\partial \upsilon_1}{\partial t} + \left(\upsilon_0 \frac{\partial}{\partial x} \right) \upsilon_1 + \nu \upsilon_1 = \frac{e}{m} E_1 - \frac{k_B T \partial n_1}{m n_0 \partial x} \tag{5}$$

$$\frac{\partial n_1}{\partial t} + \left(\upsilon_0 \frac{\partial}{\partial x} \right) n_1 + n_0 \left(\frac{\partial}{dx} \upsilon_1 \right) = 0, \tag{6}$$

$$\frac{\partial E_1}{\partial x} = \frac{e n_1}{\in_0} - \frac{g E_0 \in_0}{\in_0} \frac{\partial^2 u}{\partial x^2}, \tag{7}$$

$$\frac{\partial^2 u}{\partial t^2} = C \frac{\partial^2 u}{\partial\ x^2} - \varepsilon_o g E_o \frac{\partial^2 E_1}{\partial\ x} \tag{8}$$

Equation (4) represents the zeroth-order equation of motion for electrons and shows that the electrons will oscillate under the influence of the high-frequency electric field $E_0 \cos(\Omega_0 t)$. Equations (5) and (6) are the first-order momentum transfer and continuity equations for electrons, respectively, k_B is the Boltzmann constant, and T the electron temperature. We have assumed scalar elastic constant and effective mass for the electrons. The space-charge field E_1 is determined by the Poisson relation (7), where the second term on the right-hand side gives the SDDC contribution to the polarization, n_1 is the electron density perturbation. Equation (8) is the equation of elasticity theory describing the motion of the lattice in the SDDC crystal, u is the lattice displacement and Q the mass density of the crystal.

We assume that the acoustic wave has an angular frequency Ω and wave number k such that $\Omega << \Omega_0$ and the low-frequency perturbations are proportional to exp $\left[i\left(\Omega t - kx\right)\right]$. the transverse acoustic wave is propagating in such a direction of the crystal that it produces a longitudinal electric field. Using (7) and (8) one obtains

$$\left[\Omega^2 - k^2\upsilon_S^2 - \frac{\in_0^2 \; g^2 E_0^2 k^2}{\rho \in_0}\right]u = \frac{\in_0 \; g \;\; E_0 e}{\rho \in_0} n_1 \quad (9)$$

Where $\upsilon_s = (C/\rho)^{1/2}$ is the transverse acoustic velocity in the crystal? Following the method adopted by Guha and Ghosh [8]. and differentiating (6) with respect to time and using (4) and (5), in the collision-dominated regime $(r >> k\upsilon_o \Omega)$ one obtains

$$\frac{\partial^2 n_1}{\partial \; t^2} + \nu \frac{\partial \; n_1}{\partial t} + \Omega_E^2 n_1 + \frac{en_1}{m} gE_o k^2 u = ikn_1 E \qquad (10)$$

Where $\Omega_R^2 = \Omega_P^2 + k^2(k_B T/m)$ Ω_p being the electron-plasma frequency in the lattice given by

$$\Omega_p = (e^2 n_o / m\varepsilon_o)^{1/2} \text{ and } \overline{E} = (e/m)E_o \cos(\Omega_o t).$$

Equation (10) can now be resolved into two components (fast and slow) by writing $n_1 = n_f + n_s$ (subscripts f and s represent the fast and the slow components, respectively). Hence one obtains.

$$\frac{\partial^2 n_f}{\partial \; t^2} + \nu \frac{\partial \; n_f}{\partial t} + \Omega_R^2 n_f = ikn_s \overline{E} \qquad (11)$$

and'

$$\nu \frac{\partial \; n_s}{\partial \; t^2} + \Omega_R^2 n_s + \frac{en_o}{m} gE_o k^2 u = ikn_f \overline{E} \qquad (12)$$

Now the fast component of the density perturbation has two components at frequencies $\Omega \pm \Omega_0$. Here we neglect the higher-order components at frequencies $\Omega \pm b\Omega_0$ *where* $b > 1$, as they are non resonant in contrast to $\Omega \pm \Omega_0$ since in our case $\Omega < \Omega_0 \left(\approx \Omega_p\right)$. Thus from (11) , we get

$$n_f = ikn_S \overline{E}\left[\begin{array}{l}\dfrac{1}{\Omega_R^2 - (\Omega + \Omega_o)^2 + i\nu(\Omega + \Omega_o)^2} \\ + \dfrac{1}{\Omega_R^2 - (\Omega - \Omega_o)^2 + i\nu(\Omega - \Omega_o)}\end{array}\right] \qquad (13)$$

Assuming $\Omega_o \approx \Omega_R(\Omega_P)$ and $\Omega \;\; << \Omega_o$

(13) Becomes

$$n_f = \frac{-ikn_S \overline{E}}{\Omega_R} \frac{2\delta}{v^2 + \delta^2} \qquad (14)$$

Where $\delta = \Omega_o - \Omega_R$

Now using (9) and (14) in (12), we get

$$\left[\Omega^2 - k^2\upsilon_S^2 - \frac{\in_0^2 \; g^2 E_0^2 k^2}{\rho \in_0}\right]\left[\Omega_R^2 + i\nu\Omega - \frac{k^2 E^2}{\Omega_R} \frac{2\delta}{v^2 + \delta^2}\right] \quad (15)$$
$$= -\Omega_P^2 \frac{\in_0^2 \; g^2 E_0^2 k^2}{\rho \in_0}$$

Equation (15) represents the general dispersion relation for parametric interaction of acoustic waves in the region $kl << l$ for SDDC materials irradiated with a spatially uniform laser beam.

4. GROWTH RATE AND THRESHOLD FIELD

From (15) it can be noticed that in the absence of the high-frequency oscillatory electric field $\left(i.e. E_0 = 0\right.$ and consequently the coupling term on the right-hand side of (15) is equal to zero), one obtains two uncoupled modes as

$$\Omega^2 - k^2\upsilon_S^2 = 0, \qquad (16a)$$

and

$$\Omega_R^2 - iv\Omega = 0, \tag{16b}$$

in which (16a) is the usual equation for the sound wave propagation in the elastic medium and (16b) represents the plasma wave propagation in a collision-dominated medium. Thus to study the parametric instability of acoustic waves, we proceed with the general dispersion relation (15) which can be written in simplified form as

$$\left(\Omega^2 - k^2\upsilon_S^2 - A\right)\left[\Omega_R^2 + iv\Omega - \frac{k^2E^2}{\Omega_R}\frac{2\partial}{r^2+\partial^2}\right] - \Omega_p^2 A = 0, \tag{17}$$

in which

$$A = k^2\upsilon_S^2\Gamma^2 \text{ and } \Gamma^2 = g^2\varepsilon 2E_o^2 / CE \circ$$

is the effective electromechanical coupling coefficient [13] for SDDC crystals.

To obtained the threshold electric field for the onset of the instability, the nature of the instability, the phase velocity, and the growth rate of the unstable mode, we assume

$\Omega_R^2 >> ir\Omega$ Whence (17) reduces to

$$\Omega^2 - k^2 r_S^2 - \frac{A}{G}\left(G \quad \Omega_v^2\right) - iv\Omega\frac{A}{G} = 0, \tag{18}$$

where

$$G = \Omega_R^2 - \frac{k^2\overline{E}^2}{\Omega_R}\frac{2\delta}{v^2+\delta^2}$$

It can be shown that the solution of (18) supports the existence of absolute instability with the aid of the method given by [16]. According to this method, for the existence of absolute instability there must exist a complex frequency $\Omega = (\Omega_r + i\Omega_i)$ with Ω_i <0 at which two roots from opposite halves of the complex k-plane will merge. To achieve this condition we rewrite (18) in the following form:

$$D_1k^4 + D_2k^2 + D_3 = 0, \tag{19}$$

Where

$$D_1 = \frac{2\sqrt{2}(1+\Gamma^2)\upsilon_S^2e^2E_o^2}{m^2\Omega_R v}$$

$$D_2 = \frac{2\sqrt{2}e^2E_o^2}{m^2\Omega_R v}\Omega^2 - \Omega_R^2(2-\Gamma^2)\upsilon_S^2$$

and

$$D_3 = -\eta\,\Omega_R^2\Omega^2$$

The solution of (19) is obtained as

$$k^2 = -\frac{D_2}{D_1} \pm \left(\frac{D_2^2}{2D_1^2} - \frac{D_3}{D_1}\right)^{½} \tag{20}$$

These roots will coalesce at

$$k_m = \pm\left(\frac{|D_2|}{D_1}\right)^{½} \tag{21}$$

only if

$$\frac{D_2^2}{2D_1} - D_3 = 0, \tag{22}$$

Provided that D_2 is negative, which is possible in our case $\Omega_R >> r$ Substituting the values of D_1 and D_2 in (21), we obtain

$$k_m = \pm\left[\frac{\Omega_R^3m^2v}{2\sqrt{2}e^2E_0^2} - \frac{\Omega^2}{2\upsilon_S^2}\right]^{½} \tag{23}$$

The solution of (22) yields (on separating the real and immaginary parts of $\Omega = \Omega_r + i\Omega_1$ as

$$\Omega_1 = \pm\left[\frac{\upsilon_S^2\Omega_R^3vm^2}{\sqrt{2}e^2E_0^2}\right]^{½} \tag{24}$$

and

$$\Omega_r = \sqrt{2}\,\Omega_1 \text{ or } 0.$$

Thus these two roots coalesce in the complex k-plane with $\Omega_i < 0$ at the value of k_m given by (23). Hence it is proved that the system supports the existence of an absolute instability.

Our next object is to obtain the threshold electric field for the onset of instability $(E....)$ and the initial growth rate $(|\Omega_1|)$ of the unstable mode well above the threshold.

To obtain the above, we rewrite our equation (18) as

$$\Omega^2 - iv\Omega\frac{A}{G}\left\{k^2\upsilon_S^2 + (G-\Omega_R^2)\frac{A}{G}\right\} = 0 \quad (26)$$

Which is a quadratic equation in terms of Ω and hence yields

$$\Omega = i\frac{\nu}{2}\frac{A}{G} \pm \frac{1}{2}\left[-\nu^2\frac{A^2}{G^2} + 4\left\{k^2\upsilon_S^2 + (G-\Omega_R^2)\frac{A}{G}\right\}\right]^{1/2} \quad (27)$$

Rationalization of (27) gives

$$\Omega_i = \frac{\nu}{2}\frac{A}{G} \quad (28)$$

provided that

$$4\left\{\frac{A}{G}\left(G-\Omega_R^2\right) - k^2\upsilon_S^2\right\} > \nu^2\frac{A^2}{G^2} \quad (29)$$

Thus the acoustic wave will grow only when $\Omega_1 < 0,\ i.e.\ G < 0$ and simultaneously condition (29) should be fulfilled which is possible in our case.

Thus the condition for the instability is obtained as

$$G < 0, \text{ i.e. } \Omega_R^2 - \frac{2k^2\overline{E}^2\delta}{\Omega_R(v^2+\delta^2)} < 0 \quad (30)$$

In order to satisfy condition (30) we require

$$\text{(i) } \delta > 0 \text{ i.e. } \Omega_o > \Omega_R \quad (31)$$

and

$$\frac{2k^2\overline{E}^2\delta}{\Omega_R(v^2+\delta^2)} > \left|\Omega_R^2\right| \quad (32)$$

The threshold value of the high-frequency oscillatory electric field E_{0th} is obtained from (32) as

$$E_{oth} = \frac{m}{ek}\left[\frac{\Omega_R^3(v^2+\delta^2)}{2\delta}\right]^{1/2} \quad (33)$$

To obtain the initial growth rate $|\Omega_1|$ well above the threshold and the phase velocity $\upsilon_\psi\left(=\Omega_r/k\right)$ of the unstable mode we use (27) and get

$$\left|\Omega_i\right| = \frac{\nu}{2}\frac{A}{|G|} \quad (34)$$

and

$$\upsilon_\psi = \frac{1}{2k}\left[4\left\{1\left(1-\frac{\Omega_R}{|G|}\right) + k^2\upsilon_S^2\right\} - \nu^2\frac{A^2}{G^2}\right]^{1/2} \quad (35)$$

It can be found from the work of Guha and Ghosh [8] that if we replace Γ^2 by the electromechanical coupling coefficient of piezoelectric crystals $\left(K^2 = \beta^2/C\in;\right)$ where β is the piezoelectric constant of the materials) in (34) and (35), we will get the growth rate and the phase velocity expressions for unstable acoustic waves in the instability region for piezoelectric crystals. The expression for the threshold electric field (33) is similar in both the materials.

5. RESULT AND DISCUSSION

The analytical results obtained are applied to a semiconductor PZT. The analytical investigation of the parametric instabilities of laser beams in PZT material with high dielectric constant material. We have assumed that the crystal is irradiated with a pulsed CO_2 laser of 10.6 um wavelength. In our study Standard and material dependent constants are required to analyze each changes in the material and plasma frequency then, here the parameters that get change are, Eo = electric field, k = wave numbers, Ω_i = growth rate.

Collision is depending on the electric field, plasma frequency, cyclotron frequency, electromagnetic wave velocity. This displacement cause the dispersion in the crystal which is depend on the Ωi ,so the growth rate will give the dispersion of the waves in the crystal frequency is high then growth rate is high vice versa.

Parameters: The physical constant by use in this paper is

$\varepsilon_0 = 3450 \quad e = 1.602\times10^{-19}$

$m = 0.09 \ \mathrm{m}_o,$

$g = \varepsilon_o/3,$

$\rho = 7.45\times10^3\, kgm^{-3},$

$\Omega_0 = 1.78\times10^{14}\, s^{-1}$

$v = 1.39\times10^{21}\, s-1$

The numerical estimations are plotted in fig 1 to 3. Fig. 1 is in between wave number Ko and threshold electric field Eoth it is shown that as the as the wave number increases in the experiment the threshold electric field decreases, while in term of pattern it is found that for lower value of the wave number threshold value decreases sharply while in the case of the higher values of wave number threshold decreases with lower decapitation rate.

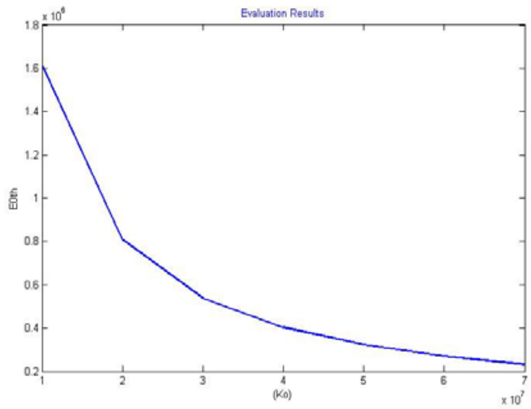

Fig. 1: Graph between Wave number Ko and Threshold Electric Field Eoth.

In Fig 2. Is in between the growth rate and electric field where dependency of growth rate on change in the electric field is shown. Here as shown in the graph it is found that with the increase in the electric field the growth rate also increase directly. So in order to get higher growth rate electric field should be keep high here wave number Ko is keep constant at 2×10^7.

Fig.3. Is in between the Growth rate and wave number k while electric field is set to Eo $=10^8 Vm^{-1}$ Here it represents the relation between the growth rate variations by changing the wave number. It is observed from the Fig. that the growth rate

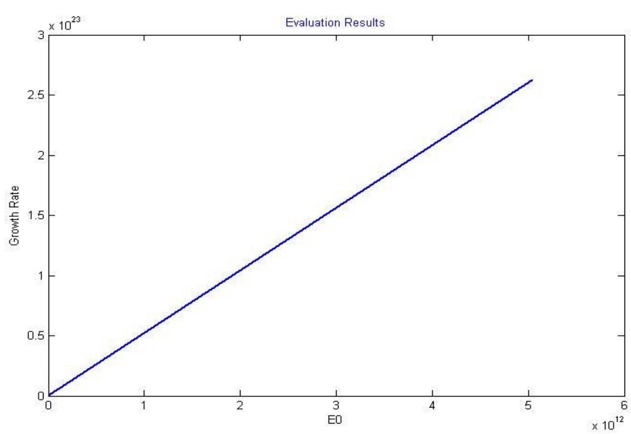

Fig. 2: Between Growth rate and electric field variation k while wave number is set to Ko = 2×10^7

Increases with increase in the wave number but at low values of wave number are it increases slowly, but for higher values sharp or gradual increase in growth rate is obtained.

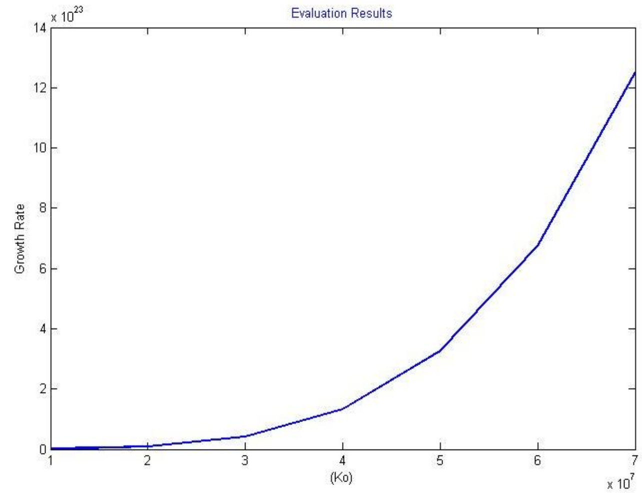

Fig. 3: Between Growth rate and wave number k while electric field is set to Eo = $10^8 Vm^{-1}$

6. CONCLUSION

As the requirement of the parametric excitation of the material with high dielectric constant is done by the use of the acoustic waves generate by the CO_2 Pump. Results show a considerable growth rate by controlling the parameter like Electric field and the wave number. So in order to generate a good propagation it can be easily achieve by the calculation which give threshold electric field, above which a good rate of growth is obtain. From the above referred work we concluded that the fundamental study of instabilities due to absorption and propagation of laser beams in PZT material with high dielectric constant is important for understanding of waves &

Instabilities phenomena and effective tool for the fabrication of optoelectronic devices such as optical resonators, optical parametric oscillators ect.

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