THE MODULATIONAL INSTABILITY OF A LASER PLASMA BEAM IN A PIEZOELECTRIC MATERIAL WITH STRAIN DEPENDENT DIELECTRIC CONSTANT: QUANTUM EFFECT

ManishaRaghuvanshi, Sanjay Dixit
Department of physics, Govt. M.V.M college shivajinagar,
Barkatullah University, Bhopal India

Abstract: In the present paper we shall show that the modulational instability of an intense Laser beams of piezoelectric material $BaTiO_3$ with SDDC using quantum hydrodynamic model.
We analysis is carried out through the nonlinear dispersion relation of modulational and the threshold value of pump electric field (E_0). An expression for the growth rate of acoustic wave through with the quantum and without quantum effect and also the compered the growth rate between them.

Keyword: QHD model, modulational instability, SDDC (strain dependent dielectric constant), nonlinear dispersion relation, acoustic wave.

Introduction: The study of frequency modulational instabilities of semiconductor plasma are became gradually visible as one of the most active field in solid state plasma. The modulational instability of propagation laser beams has been investigated analytically and theoretically by many researchers. Microwave devices and its techniques are playing an important role for density of doping concentration noise amplifier oscillatiors and other optical devices and its measurement. Pantell and soohoo [1] has investigated the phenomena of piezoelectric effect.Ghosh and dixit [2] has explained the effect of Relativistic mass variation of the electron of M.I of laser beam in semiconductor plasma. Pekar[3] and ogg [4] shows that the dependency of the dielectric constant on the deforming of the materials and also shows that the interaction of electron and phonon. Many authors are analytically explained that the modulational instability amplification of acoustic wave and nondegenrate plasma in used of piezoelectric material with SDDC however in all these studies quantum effect are not taken due to the account of investigation.

In recent years, quantum plasma is a relatively new and rapidly growing field of plasma research on account of its potential application in nanoparticles, semiconductor devices Fermi plasma particle. Laser solid interaction the quantum effect may become important in a variety of environment when the plasma temp is law and particle density high .the dispersion caused by strong density correlation due to quantum fluctuations can play important role on propagation of quantum plasma. Using magneto hydrodynamic model for the plasma hass and manfried [5] and markland and shukla [6] develop the qhd model of quantum plasma qhd model is vastly used in wave instability and propagation of quantum plasma.

In the fields of nonlinear optics and fluid dynamics, modulational instability or sideband instability is a phenomenon whereby deviations from a periodic waveform are reinforced by nonlinearity, leading to the generation of spectral-sidebands and the eventual breakup of the waveform into a train of pulses. The instability is strongly dependent on the frequency of the perturbation. At certain frequencies, a perturbation will have little effect, whilst at other frequencies, a perturbation will grow exponentially.

Theoretically Formulation

In the present paper we have studied modulational instability of a laser beam in a piezoelectric material with SDDC using quantum hydrodynamic model. A high frequency laser beam $E_0\, exp[i(k_0x-\omega_0t)]$ is the applied parallel to the propagation of direction along x-axis and ω_0 and k_0 are angular frequency and wave number of the laser beam are implicit that $\omega_0\ (\approx \omega_p) \gg v$. The basic equations following Guha et. al [8] and Manfried [6] are as follows:

$$dv_0/dt = (e/m)E_0 - vv_0 \tag{1}$$

$$dv_1/dt + (v_0\nabla)v_1 + v_1\vartheta = (e/m)E_1 - \frac{1}{mn}\nabla p + \frac{\hbar^2}{4m^2n_0}\nabla^3 \tag{2}$$

$$dn_1/dt = v_0\, dn_1/dt + n_0\, dv_1/dt \tag{3}$$

$$dE/dx = en/\varepsilon_0 - \left(\beta/\varepsilon_0\right) d^2u/dx^2 \tag{4}$$

$$\rho\, du^2/dt^2 - 2\rho X_e\, du/dt + \beta\, dE/dx = C\, d^2u/dx^2 \tag{5}$$

Where v_0 *and* v_1 are the Zeroth and first order oscillatory fluid velocities of electron, m is effective mass of electron and e is the charge of electron, ϑ is the electron collision frequency, ρ is the mass density of crystal.

Using equation (1) - (5) the collision dominated regime ($\nu >> k\vartheta_0$) we obtain,

$$du^2/dt^2 + v\, dn/dt + \omega_p'^2 + \left(en_0\beta/m\varepsilon_0\right) d^2u/dx^2 = -\, dn/dt\, E \tag{6}$$

Where in above equation p is the pressure, p $= \frac{mV_F n_1^3}{3n_0^2}$, $\omega_p'^2 = \omega_p^2 + K^2V_F$, $E = -\, e/m\, E_0$, $V_F' = V_F\sqrt{1+\gamma_e}$, $V_F = \frac{2k_BT_F}{m}$ is the Fermi speed, k_B is Boltzmann constant and T_F Fermi temperature of electron. $\gamma_e = \frac{\hbar^2k^2}{8mk_{\beta T_F}}$, $\omega_p = \sqrt{n_0e^2/m\varepsilon}$

The density perturbation n in the plasma assumed to vary $E_0\ \exp[i(k_0x-\omega_0t)]$, density perturbation are produced force wave disturbance at $(\omega_0+\omega)$ the upper (antistoke) and $(\omega_0-\omega)$ the lower (stoke) wave side band frequencies. The upper and lower side bands frequencies produced are forced waves can be expressed after simplification as. This modulation process under consideration must fulfill the phase matching conditions and using equation (6) the expression of modulational frequencies can be written as:

$\omega = \omega_1 + \omega_0$ and $k = k_1 + k_0$, known as the momentum and energy conservation relations.

$$n(\omega_+\, k_+) = \frac{ik^3\beta^2n_0eE_1}{m\varepsilon\rho(\omega^2-k^2v^2+2iX_e\omega)\,(-\omega_\pm^2 - i\omega_\pm v + \omega_p'^2 + ik_\pm E)} \tag{7}$$

$$n(\omega_- \, k_-) = \frac{ik^3\beta^2 n_0 eE_1}{m\varepsilon\rho(\omega^2-k^2v^2+2iX_e\omega)\,(-\omega_\pm^2 - i\omega_\pm v + \omega_p'^2 + ik_\pm E)} \quad (8)$$

We have assumed that the sideband waves n $(\omega_\pm, k_\pm)$ vary as $E_0 \, exp[i(k_0x - \omega_0 t)]$ equation (7) and (8) reveal that the sideband waves are coupled to the acoustic mode via the density perturbation under the influence of a strong pump field. $\omega_+ = \omega + \omega_0$, $\omega_- = \omega - \omega_0$. The density perturbation are producing the sideband frequencies and its effect on the dispersion and acoustic waves .in the present work, we shall try to analyze the modulational instability of laser beam. The expression of nonlinear current density of upper and lower band frequencies is given as:

$$J(\omega_\pm) = n_1(\omega_\pm)ev_0 ,$$

The induced polarization of the modulational frequencies P $(\omega_\pm)$ as the time integral of nonlinear current density J $(\omega_\pm)$ can be expressed as:

$$P(\omega_\pm) = \int J(\omega_\pm)\, dt$$

The diffusion polarization of modulational frequencies of upper and lower band frequencies can be expressed as

$$P_{eff} = P(\omega_+) + P(\omega_-)dt$$

$$P_{eff} = \int J(\omega_+)dt + \int J(\omega_-)dt$$

Since the total effective polarization are modulational frequencies of upper and lower band frequencies can be expressed as follow that

$$P_{eff} = \frac{i\omega_p^2\,\omega E_0 E\varepsilon A}{m(\omega_s^2+k^2v_s^2+2iX_e\omega_s)(\omega_0^2-k^2v_0^2)\left[-\omega_\pm^2 - i\omega_\pm v + \omega_p'^2 + ik_\pm E\right]}$$

$$P_{eff} = \frac{i\omega_p^2\,\omega E_0 E\varepsilon A}{m(\omega_s^2+k^2v_s^2+2iX_e\omega_s)(\omega_0^2-k^2v_0^2)}\left[-\omega_\pm^2 - i\omega_\pm v + \omega_p'^2 + ik_\pm E\right]^{-1}$$

$$P_{eff} = \frac{\omega_p'^2\omega_p^2\varepsilon Ak^2\, E_0^2\, E(\delta^2+v^2)}{m^2(\omega_s^2+k^2v_s^2+2iX_e\omega_s)(\omega_0^2-k^2v_0^2)}\left[\left(\delta^2+v^2-\frac{k^2E^2}{\omega_0^2}\right)+\frac{4k^2\delta^2E^2}{\omega_0^2}\right]^{-1} \quad (9)$$

$$\delta = \omega_0 - \omega_p' \;,\; A = k^2K^2V^2 \;,\; k = \frac{\beta^2}{\varepsilon c}$$

The induced polarization due to cubic nonlinearities at modulational frequencies ($\pm\omega$) is defined as ;

$$P_{eff} = \epsilon_0 X_{eff}^{(3)} |E_0|^2 E \quad (10)$$

From equations (9) and (10) are obtained the effective third order nonlinear susceptibility including quantum mechanical effects as

$$X_{eff} = \frac{\omega_p'^2\omega_p^2\varepsilon Ak^2\,(\delta^2+v^2)}{m^2(\omega_s^2+k^2v_s^2+2iX_e\omega_s)(\omega_0^2-k^2v_0^2)}\left[\left(\delta^2+v^2-\frac{k^2E^2}{\omega_0^2}\right)+\frac{4k^2\delta^2E^2}{\omega_0^2}\right]^{-1} \quad (11)$$

$$X_{eff} = \frac{\omega_p'^2\omega_p^2\varepsilon_1 Ak^2\,(\delta^2+v^2)(\omega_s^2-k^2v_s^2)}{m^2\left((\omega_s^2-k^2v_s^2)^2+4X_e^2\omega_s^2\right)(\omega_0^2-k^2v_0^2)^2}\left[\left(\delta^2+v^2-\frac{k^2E^2}{\omega_0^2}\right)+\frac{4k^2\delta^2E^2}{\omega_0^2}\right]^{-1} \quad (12)$$

In order to explore the possibility of modulational amplification in a semiconductor, we employ the relation

$$\alpha_{eff} = \frac{k}{2\varepsilon_1} X_{eff} |E_0^2| \tag{13}$$

In general, to determine the threshold value of the pump amplitude of the modulational amplification $P_{eff} = 0$

$$E^{th} = \frac{m}{2ek}(\omega_0^2 - k^2 v_0^2)\sqrt{\delta^2 + v^2} \tag{14}$$

Thus the growth rate of the modulated beam for pump amplitudes well above the threshold electric field can be obtained from equations (12) and (13) as

$$g = \frac{\omega_p^2 \omega_p^2 \varepsilon_1 A k^2 \ (\delta^2 + v^2)(\omega_s^2 - k^2 v_s^2)}{m^2 2\varepsilon_1 \left((\omega_s^2 - k^2 v_s^2)^2 + 4X_e^2 \omega_s^2 \right)(\omega_0^2 - k^2 v_0^2)^2} \left[\left(\delta^2 + v^2 - \frac{k^2 E^2}{\omega_0^2} \right) + \frac{4k^2 \delta^2 E^2}{\omega_0^2} \right]^{-1} \tag{15}$$

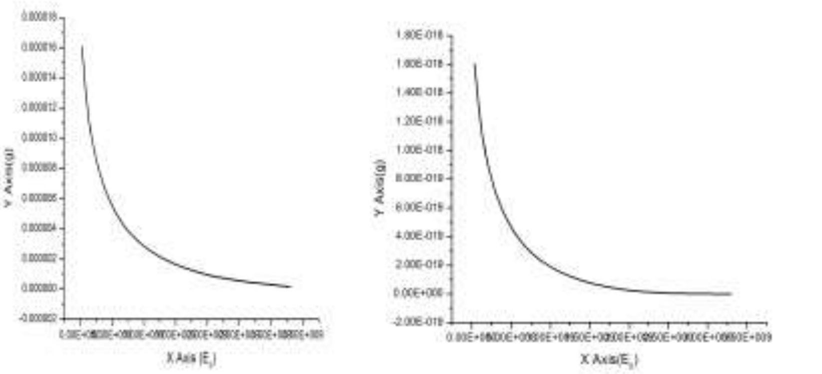

Figure1: shows the variation of the growth rate (E_0) and g with the quantum and without quantum effect

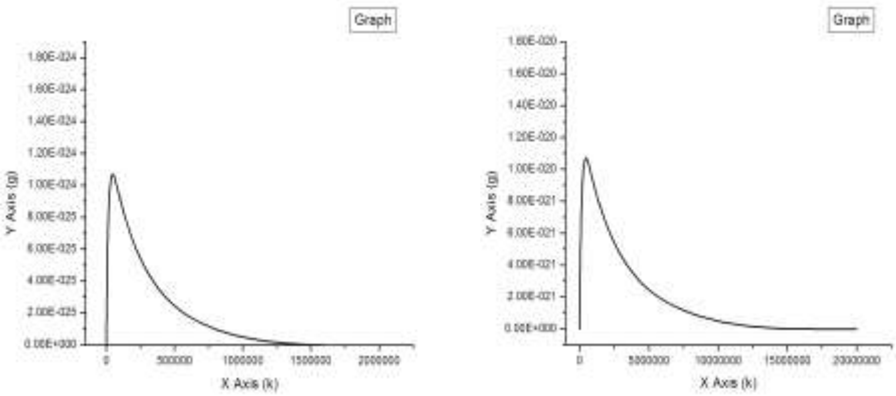

Figure2: shows the variation of the growth rate (k) and (g) with the quantum and without quantum effect

Result:

The above discussion reveals that the amplification of acoustic waves due to modulational of a laser beam can be obtained using QHD model. The growth rate of a crystal with SDDC in piezoelectric material. If we compared the growth rate of piezoelectric and ferroelectric material. In ferroelectric material wave instability are not continuous its break at the point but in piezoelectric material wave instability are varied. The analytical results obtained are applied piezoelectric semiconductor like $BatiO_3$ at 77k. The physical constant involve are $\varepsilon_1 = 15.8$, $X_e = 5 \times 10^{-10} Fm^{-1}$, $\rho = 5.8 \times 10^3 kgm^{-3}$, $\omega = 2 \times 10^{11}$, $\omega_0 = 1.78 \times 10^{14} s^{-1}$, $\beta = 0.054 cm^{-1}$ $\omega_p = 1.36 \times 10^{16}$, V= 4×10^4

Acknowledgement:

The authors are thankful to Dr. Sanjay Dixit, Assistant Professor (department of physics) Barkatullah University Bhopal, for useful discussions at the final stage of the manuscript

Reference:

1. Acoustic Propagation in the Presence of Drifting Carriers and an Oscillating Electromagnetic Field *R. H. Pantell*, and *J. SooHoo*,Journal of Applied Physics **41**, 441 (1970)

2 S. Ghosh, S. Dixit. (1985) Effect of Relativistic Mass Variation of the Electron on the Modulational Instability of Laser Beams in Transversely Magnetised Piezoelectric Semiconducting Plasmas. *physica status solidi (b)* **130**:1, 219-224. Online publication date: 1-Jul-1985.

3. Pekar S I 1966 Sov. Phys. JETP 22 431

4. Ogg N R 1967 Phys. Lett. 24A 472

5. G. Manfredi, F. Haas, Self-consistent fluid model for a quantum electron gas, Phys. Rev. B 64, 075316 (2001)

6. Nonlinear collective effects in photon–photon and photon–plasma interactions Mattias Marklund and Padma K. Shukla Department of Physics, Umea University, SE–901 87 Ume ˚ a, Sweden ˚ ∗ (Dated: Accepted version, submitted Feb. 3, 2006, to appear in Rev. Mod. Phys. 78 (2006))

7. S. Guha, P. K. Sen, S. Ghosh. (1979) parametric instability of acoustic waves in transversely magnetised piezoelectric semiconductors. *Physica Status Solidi (a)* **52**:2, 407-414. Online publication date: 16-Apr-1979.

8. S. Guha, P.K. Sen, S. Ghosh. (1979) Modulational instability of a laser beam in a longitudinal magnetized piezoelectric semiconductor. *Physics Letters A* **71**:1, 149-151.
Online publication date: 1-Apr-1979.

9. S. Guha, P.K. Sen. (1979) parametric excitation of acoustic waves in piezoelectric solid state magnetoplasma. Physics Letters A 70:1, 61-63.
Online publication date: 1-Feb-1979.

10. S. Ghosh, S. Dixit. (1985) Effect of Relativistic Mass Variation of the Electron on the Parametric Instability of Acoustic Waves in Transversely Magnetised Piezoelectric Semiconducting Plasmas. *physica status solidi (b)* **127**:1, 245-252.

11. F. Haas, G. Manfredi, M. Feix, Multistream model for quantum plasma, Phys. Rev. E 62, 2763 (2000)

12. S. Ghosh, S. Dixit. (1986) Modulational instability of a laser beam in a piezoelectric material with strain dependent dielectric constant. *Physics Letters A* **118**:7, 354-356.Online publication date: 1-Nov-1986

13. S. Guha, P. K. Sen. (1979) Modulational instability of a laser beam in a piezoelectric semiconductor. *Journal of Applied Physics* **50**:8, 5387-5390.
Online publication date: 29-Jul-2008.