

To Study of Quantum Effect on Modulational Instability of Laser Beam Using Ferroelectric Semiconductors

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Abstract:

Objective: The purpose of present paper to the study of modulational instability of high power laser radiation using ferroelectric semiconductor. In this paper fluid equation of quantum, hydrodynamic (QHD) applied parallel to the propagation of direction of x-axis and explore the modulational instability of laser radiation. We have analyzed the mechanisms of generation of electron acoustic wave due to electron pressure because of Fermi temperature.

Method: In this paper analysed that the quantum plasma relatively new and rapidly growing field of the plasma world. . In quantum plasma has been characterized by high plasma particle densities and low temperature, whereas in classical plasma which has high temperature and low densities. Using quantum hydrodynamic (QHD) equations of non-degenerating semiconductor plasma combining with the equation of motion of the charged fluid from Maxwell equation can be used to solve the problem of the modulational instability of high power laser radiation using ferroelectric semiconductor.

Findings: We have find out the modulational instability of laser radiation with the help of ferroelectric material and applied the fluid equation with addition of Bohm potential, coupled with Maxwell equations are applied for the analysis , also find the growth rate of modulational instability of laser radiation by the quantum effect and without the quantum effect. We have also find out the electron density, wave number of the perturbation mode and numerically analysed the quantum and without quantum effect. BaTiO₃ ferroelectric semiconductor are used for the numerically analysis at 77k and used different parameters set. In that paper analysed and compare, the ferroelectric semiconductor formed high growth rate as compared to piezoelectric semiconductor. Plotted graph between electric field E_0 with wave number k , the waves are formed linear in quantum effect and nonlinear in without quantum effect and also The variation of electric field E with the number density n_{e0} , steady state gain g_e with carrier density n_{e0} , steady state gain g_e with wave number k . In present paper, we have used ferroelectric semiconductor, and formed high growth rate as compared to piezoelectric semiconductor.

Applications: Plasmas can appear in nature in various forms and locations, which can be usefully broadly example plasma found in plasma displays, including TV screens. Inside

fluorescent lamps (low energy lighting), signs. Rocket exhaust and thrusters. The area in front of a spacecraft's heat shield during re-entry into the atmosphere. Inside a corona discharge ozone generator. Fusion research. Plasmas used in semiconductor device fabrication including reactive-ion etching, sputtering, surface cleaning and deposition. Laser-produced plasmas (LPP). Inductively coupled plasmas (ICP). Magnetically induced plasmas (MIP), Static electric sparks. Capacitively coupled plasmas (CCP). Dielectric Barrier Discharges (DBD)

Keyword: Modulational instability, QHD model, Ferroelectric material laser beam.

Introduction: The field of quantum plasma physics is dynamic and new rapidly field of physics. Since last many years, various investigators are worked out on that field.^[1] In quantum plasma has been characterized by high plasma particle densities and low temperature, whereas in classical plasma which has high temperature and low densities.

Quantum plasma have attracted a renewed attention in recent years the inclusion of quantum terms in the plasma fluid equation such as quantum diffraction effects modified equations of state^[2] and spin degree of freedom, leads a variety of new physical phenomena ^[3]. recently plasma such as linear and nonlinear quantum acoustic waves in a dense magnetized electron positron-ion plasma^[4], the structure of weak shock waves in quantum plasma^[5], quantum ion- acoustic waves in singled-walled carbon nanotubes^[6] stimulated scattering instabilities (SRS AND SBS) of electromagnetic waves in an ultracold quantum plasma^[7], modulational and parametric instabilities of acoustic waves in piezoelectric and ferroelectric semiconductor.^[8-11]

In present paper, we have been interested in the modulational instability of high power laser radiation using ferroelectric semiconductor. We have to consider the

presences of a low frequency of the electron acoustic waves are perturbation mode in the semiconductor mode^[12]. The mechanism of generation of electron acoustic waves due to electron pressure because of Fermi temperature, an electron field is generated in the ferroelectric semiconductor and that electric field produced phonon waves in vibrating lattice ion, the phonon and electron are coupled by the help of electric field and electrostatic waves is generated in the electron plasma of the semiconductor due to its own pressure. That electrostatic electron waves are called as the electron phonon acoustic waves or in other word the electron acoustic waves in ferroelectric semiconductor.^[12] The angular frequency of the incident laser radiation is quite high to the angular frequency of electron acoustic wave. In lower sideband, the three-wave interaction is important in the semiconductor plasma but in upper sideband is also important. The purpose of present paper we investigated to see that the modulational instability and growth rate of ferroelectric semiconductor.

Governing equation:

In the present paper, we have studied modulational instability of a laser beam in a ferroelectric semiconductor 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 ($\approx \omega_p$) $\gg v$. the basic equations are taking [13] and [14] are as follows:

$$dv_0/dt = (e/m)E_0 - vv_0 \quad (1)$$

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

$$\begin{aligned} dn_1/dt &= v_0 dn_1/dt + n_0 dv_1/dt \\ dE/dx &= en/\epsilon_0 - (\epsilon_0 g E_0 / \epsilon_0) d^2u/dx^2 \\ \rho du^2/dt^2 - 2\rho X_e du/dt + (\epsilon_0 g E_0 / \epsilon_0) dE/dx &= C d^2u/dx^2 \end{aligned} \quad (5)$$

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

$$du^2/dt^2 + v dn/dt + \omega_p^2 + \left(\frac{en_0(\epsilon_0 g E_0)}{m\epsilon_0^2} \right) d^2u/dx^2 = -iknE \quad (6)$$

and k_0 are angular frequency and wave number of the laser beam are implicit that

Where in above equation p is the pressure, $p = \frac{mV_F n_1^3}{3n_0^3}$, $\omega_p'^2 = \omega_p^2 + K^2 V_F^2$, $E = -e/m E_0$, $V_F' = V_F \sqrt{1 + \gamma_e}$, $V_F = \frac{2k_B T_F}{m}$ is the Fermi speed, k_B is Boltzmann constant and T_F Fermi temperature of electron. $\gamma_e = \frac{\hbar^2 k^2}{8mk_B T_F}$, $\omega_p = \sqrt{n_0 e^2 / m \epsilon_0}$

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 bands 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:

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

$$n(\omega_+ k_+) = \frac{ik^3 (\epsilon_0 g E_0)^2 n_0^2 e E_1}{m \epsilon_0^3 \rho (\omega^2 - k^2 v^2 + 2iX_e \omega) (\omega_p^2 - i\omega_{\pm} v - \omega_{\pm}^2 + ik_{\pm} E)} \quad (7)$$

$$n(\omega_{-}k_{-}) = \frac{ik^3(\epsilon_0 g E_0)^2 n_0^2 e E_1}{m\epsilon_0^3 \rho(\omega^2 - k^2 v^2 + 2iX_e \omega)(\omega_p^2 - i\omega_{\pm} v - \omega_{\pm}^2 + ik_{\pm} E)}$$

(8)

$$\frac{iek^3 \epsilon_0^2 g^2 |E_0| n_0^2 E_1}{m\epsilon_0^3 \rho(\omega^2 - k^2 v^2 + 2iX_e \omega)} \left[\omega_p^2 - i\omega_{\pm} v - \omega_{\pm}^2 + ik_{\pm} E \right]^{-1}$$

(9)

We have assumed that the sideband waves $n(\omega_{\pm}, k_{\pm})$ vary as $E_0 \exp[i(k_0 x - \omega_0 t)]$ equation (7) (8) and (9) 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 is 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 expressions of nonlinear current density of upper and lower band frequencies are given as:

$$J(\omega_{+}k_{+}) = n_1(\omega_{+}k_{+})ev_0 ,$$

$$J(\omega_{-}k_{-}) = n_1(\omega_{-}k_{-})ev_0$$

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:

From equations (10) and (11) are obtained the effective third order nonlinear susceptibility including quantum mechanical effects as

$$X_{eff} = \frac{\omega_p^2 \epsilon_0 g^2 k^4 (\delta^2 + v^2)}{m\epsilon_0^3 \rho((\omega^2 - k^2 v^2)^2 + 4X_e^2 \omega^2)(\omega_0^2 - k^2 v_0^2)} \left[\left(\delta^2 + v^2 - \frac{k^2 E^2}{\omega_0^2} \right) + \frac{4k^2 \delta^2 E^2}{\omega_0^2} \right]^{-1}$$

(12)

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

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

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

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

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

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

$$P_{eff} = \frac{i\omega_p^2 ek^3 \epsilon_0^2 g^2 |E_0| n_0^2 E_1}{m\epsilon_0^3 \rho(\omega^2 + k^2 v^2 + 2iX_e \omega)(\omega_0^2 - k^2 v_0^2)} \left[\omega_p^2 - i\omega_{\pm} v - \omega_{\pm}^2 + ik_{\pm} E \right]^{-1}$$

$$P_{eff} = \frac{i\omega_p^2 ek^3 \epsilon_0^2 g^2 |E_0| n_0^2 E_1 (\delta^2 + v^2)}{m\epsilon_0^3 \rho(\omega^2 + k^2 v^2 + 2iX_e \omega)(\omega_0^2 - k^2 v_0^2)} \left[\left(\delta^2 + v^2 - \frac{k^2 E^2}{\omega_0^2} \right) + \frac{4k^2 \delta^2 E^2}{\omega_0^2} \right]^{-1}$$

(10)

$$\nabla^2 = \omega_0 - \omega_p ,$$

The induced polarization due to cubic nonlinearities at modulational frequencies (ω_{\pm}) is defined as;

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

$$\alpha_{eff} = \frac{k}{2\varepsilon} X_{eff} |E_0^2| \quad (13)$$

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

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

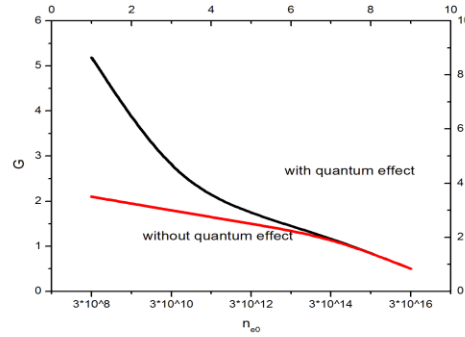
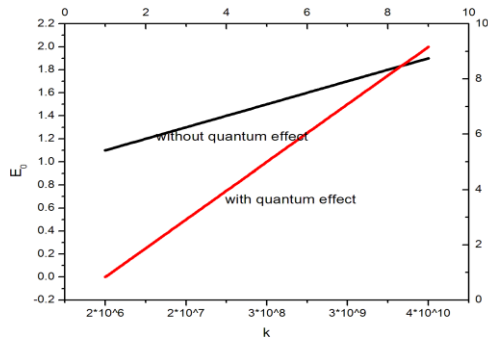
$$g = \frac{\omega_p^2 \varepsilon_0 g^2 k^4 (\delta^2 + v^2)}{2\varepsilon m \varepsilon_0^3 \rho ((\omega^2 - k^2 v^2)^2 + 4X_e^2 \omega^2) (\omega_0^2 - k^2 v_0^2)^2} \left[\left(\delta^2 + v^2 - \frac{k^2 E^2}{\omega_0^2} \right) + \frac{4k^2 \delta^2 E^2}{\omega_0^2} \right]^{-1} \quad (14)$$

$$E^{th} = \frac{m}{ek} (\omega^2 - k^2 v^2) \sqrt{\delta^2 + v^2} \quad (15)$$

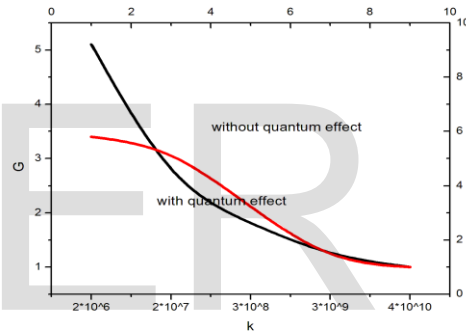
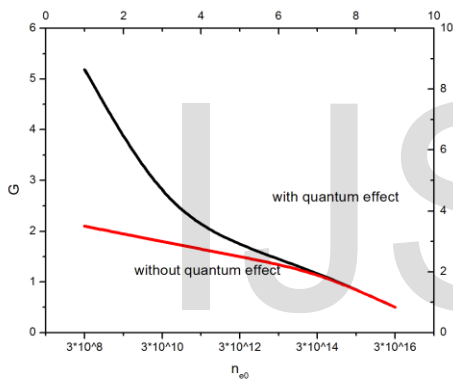
Numerical Analysis

Numerical analysis for BaTiO₃ semiconductor at 77k. The analysis is based on the following set of parameters, $m=0.09 m_0$, $\rho = 7.45 \times 10^3$, $\varepsilon_0 = 8.85 \times 10^{-12}$, $\vartheta = 6 \times 10^6$, $n_{e0} = 3 \times 10^{17}$, $\omega_0 = 2.06 \times 10^{16}$ where m_0 being free electron mass. The variation of electric field E_0 with wave number k is shown in fig 1. The estimate are plotted, the waves are formed linear in quantum effect and nonlinear in without quantum effect. The variation of electric field E with the number density n_{e0} is shown in fig 2. The variation of steady state gain g_e with carrier density n_{e0} is shown in fig3 and also plotted steady state gain g_e with wave number k is shown in fig3

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Fig(1) Variation of Electric field E_0 with wave number k with and without quantum effect and Fig(2) Variation of Electric field E_0 with number Density n_{e0} with and without quantum effect



Fig(3) Variation between Steady state gain g_e with wave number number density n_{e0} with and without quantum effect and Fig(4) Variation between Steady state gain g_e with number density n_{e0} with and without quantum effect.

Conclusion:

We have investigated the modulational instability of high power laser radiation using ferroelectric semiconductor plasma. The presences of low frequency of the electron acoustic waves are perturbation mode into the semiconductor mode^[14]. The fluid equations with inclusion of Bohm potential, coupled with the maxwells equations are employed. In this paper quantum effect play an important role enhancing the growth of the modulational instability. In addition the effect of different criterion. For example, electron density, wave number of the perturbation mode in numerically examined in quantum and without quantum effect and find out the growth rate of the modulational instability in presence of ferroelectric semiconductor. In present paper,

we have used ferroelectric semiconductor, and formed high growth rate of waves as compared to piezoelectric semiconductor.

Reference:

To Refer a Research Article:

1. Mattias Marklund And Padma K. Shukla. Nonlinear Collective Effects In Photon–Photon And Photon–Plasma Interactions. *Rev. Mod. Phys.* (2006); 78(2), 591-640. <https://doi.org/10.1103/RevModPhys.78.591>.
2. F. Haas, G. Manfredi, And M. R. Feix, “Multistream Model For Quantum Plasmas. *Physical Review E.* (2000); 62(2), 2763–2772. <https://doi.org/10.1103/PhysRevE.62.2763>.
3. M. Marklund And G. Brodin, “Dynamics Of Spin-1/2 Quantum Plasmas. *Physical Review Letters.* (2007); 98(2), 025001. <https://doi.org/10.1103/PhysRevLett.98.025001>.
4. S. A. Khan And W. Masood Linear And Nonlinear Quantum Ion-Acoustic Waves In Dense Magnetized Electron-Positron-Ion Plasmas. *Physics Of Plasmas.* (2008); 15, 062301. <https://doi.org/10.1063/1.2920273>.
5. Vitaly Bychkov, Mikhail Modestov, And Mattias Marklund .The Structure Of Weak Shocks In Quantum Plasmas, *Physics Of Plasmas.*(2008);15,032309. <https://doi.org/10.1063/1.2894565>.
6. Li Wei And You-Nian Wang, Quantum Ion-Acoustic Waves In Single-Walled Carbon Nanotubes Studied With A Quantum Hydrodynamic Model. *Phys. Rev.B.* (2007); 75, 193407. <https://doi.org/10.1063/1.2920273>.
7. A. P. Misra And Debjani Chatterjee ,Stimulated Scattering Instability In A Relativistic Plasma *Physics Of Plasmas.* (2018); 25(6), 062116. <https://doi.org/10.1063/1.5037955>
8. S. Guha, P.K. Sen, S. Ghosh. Modulational Instability Of A Laser Beam In A Longitudinal Magnetized Piezoelectric Semiconductor. *Physics Letters A.* (1979); 71(1), 149-151. [https://doi.org/10.1016/0375-9601\(79\)90904-6](https://doi.org/10.1016/0375-9601(79)90904-6).
9. S. Guha, P.K. Sen. Parametric Excitation Of Acoustic Waves In Piezoelectric Solid-State Magnetoplasma. *Physics Letters A.* (1979); 70(1), 61-63. [https://doi.org/10.1016/0375-9601\(79\)90328-1](https://doi.org/10.1016/0375-9601(79)90328-1).
10. S. Guha, P. K. Sen. Modulational Instability Of A Laser Beam In A Piezoelectric Semiconductor. *Journal Of Applied Physics.* (1979); 50(8), 5387-5390. <https://doi.org/10.1063/1.326640>
11. S. Ghosh, S. Dixit. 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).* (1985); 130(1), 219-224. <https://doi.org/10.1002/pssb.2221300121>
12. M.R. Amin Quantum Effect On Modulational Instability Of Laser Radiation In A Semiconductor Plasma, *Journal Of Applied Physics.* (2010); 107(2).023307. : <https://doi.org/10.1063/1.3295917>.
13. S. Guha, P. K. Sen, S. Ghosh Parametric Instability Of Acoustic Waves In Transversely Smagnetised Piezoelectric Semiconductors. *Physica Status Solidi (a).*

(1979); 52(2), 407-414.

<https://doi.org/10.1002/pssa.2210520206>

14. S. Ghosh, S. Dixit. Modulational Instability Of A Laser Beam In A Piezoelectric Material With Strain Dependent Dielectric Constant. *Physics Letters A*. (1986); 118(7), 354-356. [https://doi.org/10.1016/0375-9601\(86\)90324-5](https://doi.org/10.1016/0375-9601(86)90324-5)

15. F. Haas, G. Manfredi, M. Feix .Multistream model for quantum plasma, *Phys. Rev.E* (2000); 62, 2763. <https://doi.org/10.1103/PhysRevE.62.2763>.

16. G. Manfredi, F. Haas. Self-consistent fluid model for a quantum electron gas, *Phys. Rev. B* (2001);64, 075316. <https://doi.org/10.1103/PhysRevB.64.075316>.

17. M. Mahdavi and F. Khodadadi Azadboni. The Quantum Effects Role on Weibel Instability Growth Rate in Dense Plasma. *Advances in High Energy Physics*. 2015; 746212.

<http://dx.doi.org/10.1155/2015/746212>.

To Refer a Book

1. Introduction to Plasma Physics and Controlled Fusion, by Francis F. Chen, 3rd ed. 2016 Edition

2. *Wave Interactions in Solid State Plasmas* Martin C. Steele and Bayram Vural, 1969

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