Original Research Article

Influence of Quantum Effects on Amplitude Modulation in n-InSb Semiconductor

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ABSTRACT

The effect of quantum mechanical corrections in semiconductor plasma has been analytical investigated through modulational instability in piezoelectric semiconductor materials. In a semiconducting crystal each energy level can be occupied at most by two electrons owing to the spatial overlapped the wave functions. The energy level occupation is described by the Fermi-Dirac rather than Boltzmann distribution function and Fermi-Dirac distribution functions having new quantum forces associated with the quantum Bohm potentials. In this paper, our main aim to explore the modification in the modulational characteristics of semiconductor plasmas using quantum hydrodynamic model. The results show significant changes in the modulational characteristics due to the quantum effects, highlighting the importance of considering quantum hydrodynamic models in semiconductor plasma studies. This research provides valuable insights for understanding the behavior of n-type InSb crystals under laser illumination at low temperatures. The numerical estimates are made for n-type InSb crystal at 77K duly shined by pulsed 10.6 μm CO_2 laser.

Keywords:Quantum Plasma; Laser-plasma interaction; Parametric Interaction [Put four to eightkeywords } (Arial,inclined, 10 font, justified)

1. INTRODUCTION

The field of modulational amplification can be traced from early experiments in communications between satellites in which modulational signal is impressed on the optical beam by an electro-optic modulator [1]. Present day commercially available external phase or intensity modulator limits the maximum bandwidth achievable to hundreds of MHz [2-3]. Such application of the theoretical and experimental tools of nonlinear optics caused a renewed interest and an ever-increasing activity in the field [4-5]. Most of this interest can be outlined to potential applications in Q-switching of lasers for generation of giant optical pulses, mode locking and optical beam deflection [6]. Diffraction of light by sound waves was predicted by Brillouin in 1922 [7] and was verified experimentally in 1932 [8].

A sound wave consists of a sinusoidal perturbation of the density of the material or strain which travels at the sound velocity. The Sound wave causes a traveling modulation of the index of refraction of the medium. This modulation interacts with the fields of incident and diffracted beams giving rise to additional electric polarization of the medium causing exchange of power between the incident and diffracted beams. The phenomena of modulational instability in a semiconducting medium may be described in terms of electric polarization equations which are cubic functions of the electric field amplitudes. The third order nonlinear optical susceptibility is in general a complex quantity and is capable of describing the interference between various resonant and nonresonant processes [9]. The third order susceptibility tensor can be conveniently used to explain the modulation process in a Kerr active medium [10].

In a semiconducting crystal, each energy level can be occupied at most by two electrons owing to the spatial overlap of the wave functions and the need to obey the Pauli exclusion principle. The energy level occupation is described by the Fermi-Dirac rather than the Boltzmann distribution function. Electron gas in a metal or highly dense semiconductor is the most obvious example in which both plasma and quantum mechanical effects work concurrently. There has been an accrued interest in quantum effects in semiconductors, motivated by applications in ultrasmall electron devices [11] and in Laser-Plasma interactions [12]. In dense quantum plasmas, there are new pressure laws associated with the Fermi-Dirac distribution functions and new quantum forces associated with the quantum Bohm potential. These forces significantly alter the collective behavior of dense quantum plasmas. It is well known [13] that in quantum plasmas, the de Broglie wavelength of the charge carriers is comparable to the dimension of the plasma. In such a situation the plasma behaves like a Fermi gas and quantum mechanical effects are expected to play a significant impact on electron dynamics of the medium.

The modulational instability of propagating beams has been studied theoretically by several authors [14-18] due to its vast technological potentialities. Recently the present authors have reported their study on quantum effect on parametric amplification characteristics in semiconductor plasmas. [19]. As far authors knowledge goes no such attempt has been made to study modulational characteristics in quantum semiconductor plasmas. Therefore, in the present paper, to explore the modification in the modulational characteristics of semiconductor plasmas as a result of quantum effect correction, the author hereby used the quantum hydrodynamic (QHD) model developed by Manfredi, Haas and others [20-23] to simulate the main characteristics of quantum effect.

Thus, in the present paper, we have obtained the third-order susceptibility leading to the growth of the modulated waves and the threshold field required to incite the transverse modulation instability process with the influence of quantum effect and presented in section 2. Section 3 deals with the numerical estimations of the growth rate of the modulated signal wave influenced by the external parameters. These analyses are made for n-InSb semiconductor crystals duly irradiated by a CO_2 laser.

2. THEORETICAL FORMULATION

To study the transverse modulation interaction and the consequent amplification of the frequency modulated waves in a highly doped piezoelectric semiconductor arising due to nonlinear effective optical susceptibility χ_{eff} of homogeneous semiconductor plasma of infinite extent is considered. The classical hydrodynamic model of homogeneous semiconductor plasma of infinite extent (i.e. kl<<1, k being the wave number of the acoustic wave and l the mean free path of the electron) has been extended to include the essential quantum corrections resulting into one component quantum plasma described by the following QHD model. The spatially uniform (wave vector $\left|\vec{k}_0\right| \approx 0$) pump electric field

$E_0 \exp(-i\omega_0 t)$ is applied parallel to the wave vector $\vec{k}$ along the *x*-axis. Here the electric field has been assumed to be uniform in space under dipole approximation.

Due to the fact that when plasma is cooled down to an extremely low temperature, the de Broglie wavelength of the charge carriers can be comparable to the dimension of the system. In such situations, ultracold plasma behaves like Fermi gas and quantum mechanical effects are expected to play a central role in the behavior of charged particles. The electron gas in a metal or semimetal is the most obvious example in which both plasma and quantum effects work concurrently. On the other hand, it is well known from statistical mechanics that the quantum effect becomes more important when the temperature is lower than the Fermi temperature T_F and relevant statistical distribution changes from Maxwell-Boltzmann to Fermi-Dirac [24].

The QHD model used for one component quantum plasma here includes quantum pressure term and quantum Bohm potential. The quantum statistics is included in the model through the equation of state which takes into account the Fermionic character of the electrons. The basic equations following Guha et. al [25] and Manfredi [26] are as follows.

$$\frac{\partial \upsilon_0}{\partial t} + \nu \upsilon_0 = \frac{-e}{m} E_0 \qquad (1)$$

$$\frac{\partial \upsilon_l}{\partial t} + \nu \upsilon_l + \left(\upsilon_0 . \frac{\partial}{\partial x} \right) \upsilon_1 = \frac{-e}{m_l} E_1 - \frac{1}{mn} \frac{\partial P}{\partial x} + \frac{\hbar^2}{4m^2 n_0} \frac{\partial^3 n_1}{\partial x^3} \qquad (2)$$

$$\upsilon_0 \frac{\partial n_1}{\partial x} + n_0 \frac{\partial \upsilon_1}{\partial x} = -\frac{\partial n_1}{\partial t} \qquad (3)$$

$$\frac{\partial E_1}{\partial x} + \frac{\beta}{\varepsilon} \frac{\partial^2 u}{\partial x^2} = \frac{-e n_1}{\varepsilon} \qquad (4)$$

$$\rho \frac{\partial^2 u}{\partial t^2} - 2\rho\gamma_s \frac{\partial u}{\partial t} + \beta \frac{\partial E_1}{\partial x} = C \frac{\partial^2 u}{\partial x^2} \qquad (5)$$

$$P = \frac{m V_F^2 n_1^3}{3 n_0^2} \qquad (6)$$

where P stands for Fermi pressure with $V_F = \left(\frac{2K_B T_F}{m} \right)$ as the Fermi speed in which K_B is the Boltzmann constant and T_F is the Fermi temperature. n_0 and n_1 are equilibrium and perturbed carrier densities, respectively. Pressure is interpreted as a result of velocity dispersion around the mean velocity of the fluid. ρ is the mass density of the crystal, u is the displacement of the lattice, C is the elastic constant, and γ_s is the electrostriction coefficient of the crystal.

Eqs. (1) and (2) are the equations of motion for the carriers with zeroth and first-order oscillatory fluid velocities (υ_0, υ_1) of carriers with effective mass m and charge e. The quantum effects are represented by the $\hbar$ dependent term in Eq. (2), which is called the Bohm potential. If one puts the last term in Eq. (2) equal to zero, the relation reduces to classical hydrodynamic equation. It is well known that Bohm potential is responsible for tunneling and differential resistivity in semiconductor physics. ν is the phenomenological electron collision frequency. The space charge field E_1 is determined by the Poisson eq. (4)

where ε is the dielectric constant of the semiconductor. The pump magnetic field in eq. (2) is neglected by assuming $\omega_p \approx \omega_0$.

Physically in a modulational instability process an acoustic perturbation created in the medium under the influence of a strong pump source gives rise to an electron density perturbation at the acoustic frequency, which couples nonlinearity with the pump wave and drives the acoustic wave at modulated frequencies. Following, Guha et al. [25] and using eqs (1) - (6) in the collision dominated regime ($\nu >> k\upsilon_0$) we obtain,

$$\frac{\partial^2 n_1}{\partial t^2} + \overline{\omega}_p^2 + \nu \frac{\partial n_1}{\partial t} + \frac{n_0 e \beta}{m\varepsilon}\frac{\partial^2 u}{\partial x^2} = -\overline{E}\frac{\partial n_1}{\partial x} \qquad (7)$$

$$\overline{E} = -\frac{e}{m}E_0, \overline{\omega}_p^2 = \omega_p^2 + k^2 V_F^{'}, \; V_F^{'} = V_F\sqrt{1+\gamma_e}, \; \gamma_e = \frac{\hbar^2 k^2}{8mk_B T_F}$$

The Doppler shift has been neglected here under the assumption ($\omega_0 >> \nu > k\upsilon_0$). Where $\omega_p = \sqrt{n_0 e^2 / m\varepsilon}$ is the plasma frequency.

The density perturbation associated with phonon mode n_s is assumed to vary as $\exp[i(k_s x - \omega_s t)]$ with angular frequency ω_s and wave number k_s. The initial laser beam thus oscillates with this density perturbation to produce enforced wave disturbance at the upper $\omega_0 + \omega_s$ and lower $\omega_0 - \omega_s$ sideband frequencies [27]. This modulation process under consideration must fulfill the phase matching conditions, $k_0 = k_1 \pm k_s$, $\omega_0 = \omega_1 \pm \omega_s$ known as the momentum and energy conservation relations. Here we have considered only the resonant side band frequencies ($\omega_0 \pm \omega_s$) on assuming a long interaction path (by considering the crystal to be of infinite extent) the higher order scattering terms, being off-resonant, are neglected [28]. Using eq. (7) the density perturbations oscillating at the forced wave frequencies, i.e. upper and lower sideband frequencies may be expressed as.

$$n_1(\omega_+, k_+) = \frac{ik^3\beta^2 n_0 e E_1}{m\varepsilon\rho(\omega_s^2 - k^2V_s^2 + 2i\gamma_s\omega_s)}[\overline{\omega}_p^2 - \omega_+^2 - i\nu\omega_+ + ik_s\overline{E}]$$

(8a)

$$n_1(\omega_-, k_-) = \frac{ik^3\beta^2 n_0 e E_1}{m\varepsilon\rho(\omega_s^2 - k^2V_s^2 + 2i\gamma_s\omega_s)}[\overline{\omega}_p^2 - \omega_-^2 - i\nu\omega_- + ik_s\overline{E}]$$

(8b)

where $\omega_+ = \omega_s + \omega_0$ and $\omega_- = \omega_s - \omega_0$

In deriving Eqs (8), it has been assumed that the sideband waves $n_1(\omega_\pm, k_\pm)$ vary as $\exp[i(\omega_\pm t - k_\pm x)]$. Equation (8) reveal that the sideband waves are coupled to the acoustic mode via the density perturbation under the influence of a strong pump field. It is also evident from the above expression that $n_1(\omega_\pm, k_\pm)$ depends upon the magnitude of the pump intensity. The density perturbations thus produced at the sideband frequencies affect the dispersion and amplification characteristics of the generated waves.

In the present work, while analyzing the modulational interaction, the effect of the transition dipole moment has been neglected with a view to study the contribution of nonlinear current density on the induced polarization of the medium. The induced nonlinear current densities for the upper and lower sidebands are given by

$$J(\omega_\pm) = -n_1(\omega_\pm)e\upsilon_0 \qquad (9)$$

Henceforth treating the induced polarization at the modulated frequencies $P(\omega_{\pm})$ as the time integral of the nonlinear current density $J(\omega_{\pm})$, we may write

$$P(\omega_{\pm}) = \int J(\omega_{\pm})\, dt \tag{10}$$

The total effective nonlinear polarization of the modulated wave is obtained as

$$P_{eff} = P(\omega_{+}) + P(\omega_{-}) \tag{11}$$

It is essential that for resonant modulation interaction to occur both the side bands should contribute equally and this modulation is then transferred to the acoustic mode which in turn becomes amplified. In highly doped regime by assuming $\omega_p \approx \omega_0 (\approx \omega_{\pm})$ and $\omega_p >> \nu, \omega_s$, we obtain total effective polarization using eqs. (8) to (9) as

$$P_{eff} = \frac{2\omega_p^2 e^2 \varepsilon A k^2 |E_0|^2 E_s (\delta^2 + \nu^2)}{m^2 \omega_0^2 (\omega_s^2 - k^2 V_s^2 + 2i\gamma_s \omega_s)} \left[\left(\delta^2 + \nu^2 - \frac{k^2 \overline{E}^2}{\omega_0^2} \right)^2 + 4 \frac{k^2 \overline{E}^2 \delta^2}{\omega_0^2} \right]^{-1} \tag{12}$$

where $\delta = \omega_0 - \overline{\omega}_p$ $A = k^2 K^2 V_s^2$, $K = \beta^2 / \varepsilon C$

To incite the modulational amplification in the medium, the pump amplitude must exceed certain threshold value $E_{0,th}$ to supply minimum required energy to the medium. In order to determine the threshold value of the pump amplitude required for the onset of the modulational amplification, we set $P_{eff} = 0$ and obtain,

$$E_{0,th} = \frac{m\omega_0}{ek} \sqrt{\delta^2 + \nu^2} \tag{13}$$

It can be observed from Eq (13) that the transverse modulational instability of the signal wave has a nonzero intensity threshold and this value is found to be influence by the quantum effect through the term $\delta\left(= \omega_0 - \overline{\omega}_p\right)$.

The induced polarization due to cubic nonlinearities at modulated frequencies ($\omega_{\pm}$) is defined as

$$P_{eff} = \varepsilon_0 \chi_{eff}^{(3)} |E_0|^2 E_s \tag{14}$$

From eqs. (12) and (14), one may obtain the effective third order nonlinear susceptibility including quantum mechanical effects as

$$\chi_{eff}^{(3)} = \frac{2\omega_p^2 e^2 \varepsilon A k^2 (\delta^2 + \nu^2)}{m^2 \omega_0^2 (\omega_s^2 - k^2 V_s^2 + 2i\gamma_s \omega_s)} \left[\left(\delta^2 + \nu^2 - \frac{k^2 \overline{E}^2}{\omega_0^2} \right)^2 + 4 \frac{k^2 \overline{E}^2 \delta^2}{\omega_0^2} \right]^{-1} \tag{15}$$

The effective nonlinear susceptibility characterizes the steady state optical response of the medium and is influenced by the quantum mechanical correction through $\delta\left(= \omega_0 - \overline{\omega}_p\right)$. The above formulation reveals that the third order optical susceptibility is also influenced by the equilibrium carrier concentration through $\omega_p \neq 0$. Rationalization of Eq. (15) gives the real and imaginary parts of the effective third order optical susceptibility as

$$\mathrm{Re}\left[\chi_{eff}^{(3)}\right] = \frac{2\omega_p^2 e^2 \varepsilon A k^2 (\delta^2 + \nu^2)(\omega_s^2 - k^2 V_s^2)}{m^2 \omega_0^2 \left[(\omega_s^2 - k^2 V_s^2)^2 + 4\gamma_s^2 \omega_s^2) \right]} \left[\left(\delta^2 + \nu^2 - \frac{k^2 \overline{E}^2}{\omega_0^2} \right)^2 + 4 \frac{k^2 \overline{E}^2 \delta^2}{\omega_0^2} \right]^{-1} \tag{16}$$

$$\mathrm{Im}\left[\chi_{eff}^{(3)}\right]=\frac{4\omega_p^2 e^2\varepsilon\, Ak^2\,(\delta^2+\nu^2)\,\gamma_s\,\omega_s}{m^2\omega_0^2\left[\left(\omega_s^2-k^2V_s^2\right)^2+4\gamma_s^2\omega_s^2)\right]}\left[\left(\delta^2+\nu^2-\frac{k^2\overline{E}^2}{\omega_0^2}\right)^2+4\frac{k^2\overline{E}^2\delta^2}{\omega_0^2}\right]^{-1} \quad (17)$$

Dispersion characteristics of the modulated wave may be studied through the real part of effective third order optical susceptibility. It can be observed from equation (16) that there is an intensity dependent refractive index $\left[\mathrm{Re}\left[\chi_{eff}^{(3)}\right]\right]$ leading to the possibility of focusing or defocusing of the propagating beam. However, for nondispersive mode, i.e. for $\omega_s = k\upsilon_s$, we observe an anomalous dispersion characteristics of the medium.

Imaginary part of effective third order optical susceptibility (eq (17)) may be employed to obtain the gain characteristics of the modulational instability process. In order to explore the possibility of modulational amplification in a semiconductor, we employ the relation

$$\alpha_{eff} = \frac{-k}{2\varepsilon_1}\left[\chi_{eff}^{(3)}\right]\left|E_0\right|^2 \quad (18)$$

where α_{eff} is the effective nonlinear absorption coefficient of third order. The nonlinear steady state growth of the modulated signal is possible only if α_{eff}, obtainable from Eq. (18) is negative.

Thus the growth rate of the modulated beam for pump amplitudes well above the threshold electric field can be obtained from equations (17) and (18) as

$$g_{QE} = \frac{2\omega_p^2 e^2 Ak^3\,(\delta^2+\nu^2)\,\gamma_s\omega_s}{m^2\omega_0^2\left[\left(\omega_s^2-k^2V_s^2\right)^2+4\gamma_s^2\omega_s^2)\right]}\left[\left(\delta^2+\nu^2-\frac{k^2\overline{E}^2}{\omega_0^2}\right)^2+4\frac{k^2\overline{E}^2\delta^2}{\omega_0^2}\right]^{-1}\left|E_0\right|^2 \quad (19)$$

It has seen that both dispersion as well as amplification characteristics of modulational instability are effectively modified by quantum effect through $\delta\left(=\omega_0-\bar{\omega}_p\right)$.

3. RESULTS AND DISCUSSION

The analytical investigations for transverse modulational instability and the consequent amplification of modulated waves resulting from the transfer of modulation from the pump wave to the modulated wave are dealt with in the present section. The analytical results obtained are applied to a nearly centrosymmetric semiconductor like n-InSb at 77K irradiated by a pulsed 10.6μm CO_2 laser. The physical constants involved are $\varepsilon_1 = 15.8$, $\gamma_s = 5\times10^{-10}$ Fm^{-1}, $\rho = 5.8\times10^3$ kgm^{-3}, $\omega_1 = 2\times10^{11}$ s^{-1}, $\omega_0 = 1.78\times10^{14}$ s^{-1}, $\nu = 4\times10^{11}$ s^{-1}, $n_0 = 3\times10^{24}$ m^{-3}, $\beta = 0.054$ Cm^{-2}.

The numerical estimations of the wave number depending of the threshold field required for the onset of modulational amplification processes is plotted in Fig. 1.

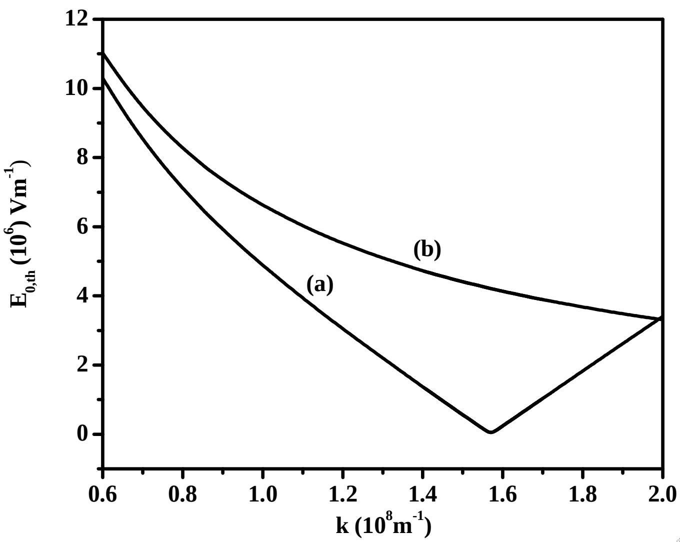

Fig. 1. Variation of threshold electric field $E_{0,th}$ (presence (curve - a) and absence (curve-b) of quantum effect) with wave number *k*.

It can be observed from Fig. 1 that the threshold field $E_{0,th}$ continuously decreases with increasing wave number *k* in absence of quantum effect evident from curve b. From the expression (Eq. (13)) for threshold electric field, it may be seen that k is present in the denominator as well as in quantum correction term $\delta = (\omega_0 - \varpi_p)$ through ϖ_p =($\sqrt{\omega_p^2 + k^2 V_F^{'}}$). Therefore resonance between ϖ_p and ω_0 will also affect threshold characteristics in presence of quantum effect. Hence as evident from curve a, initially at lower k values when $\varpi_p < \omega_0$, $(E_{0th})_{QE}$ decreases with *k*. At $k = 1.56 \times 10^8 m^{-1}$, $\varpi_p \approx \omega_0$ condition is achieved resulting into a minima in the characteristics. At this minima $(E_{oth})_{QE} \approx 5.4 \times 10^4 Vm^{-1}$ is obtained. Now on increasing k beyond this value, ϖ_p becomes greater than ω_0 and this induces linear increment in the threshold value with *k* in presence of quantum correction term. It may also be inferred from this figure that, the magnitude of E_{0th} is always greater than that of $(E_{0th})_{QE}$. Thus, it may be interpreted that quantum effects play a significant role in reducing the threshold electric field $(E_{0th})_{QE}$ which is of prime importance for fabrication of any nonlinear device.

The dependence of the gain constant (in presence and absence of quantum effect) with pump field E_0 is shown in Fig. 2. The gain constant decreases with increase in pump electric field in both the cases. It is found that modulational gain constant is strongly affected by the quantum correction. It actually increase the magnitude of gain constant as evident from curve a.

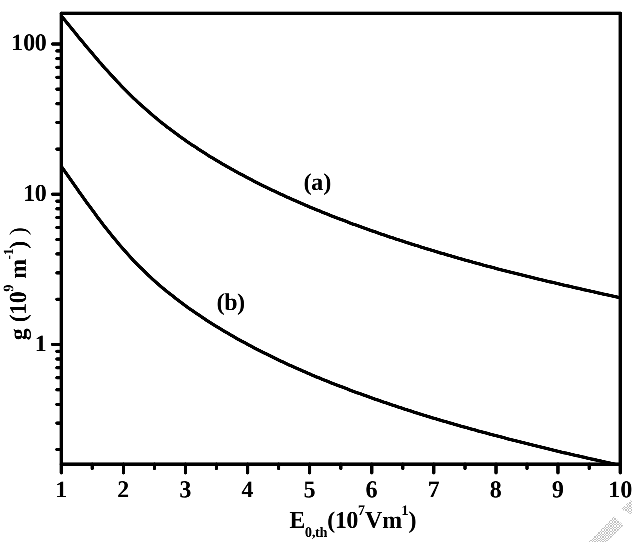

Fig. 2. Variation of gain constant g (presence (curve – a) and absence (curve – b) of quantum effect) with pump electric field E_0.

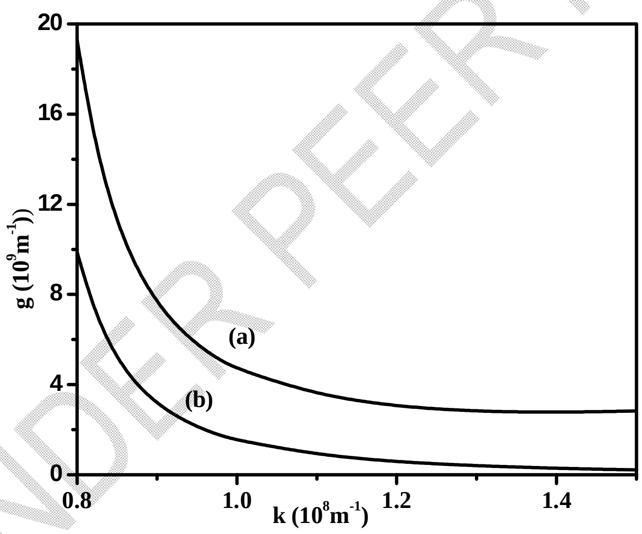

Fig. 3. Variation of gain constant g (presence (curve - a) and absence (curve -b) of quantum effect) with wave number *k*.

Fig. 3 illustrates the variation of gain constant (in presence and absence of quantum effect) with wave number k. Presence of quantum effect is found to be favorable in achieving the higher modulational gain. It is observed that in both the cases gain constant decays parabolically with increasing value of k and towards the higher wave number regime it becomes nearly independent of *k*.

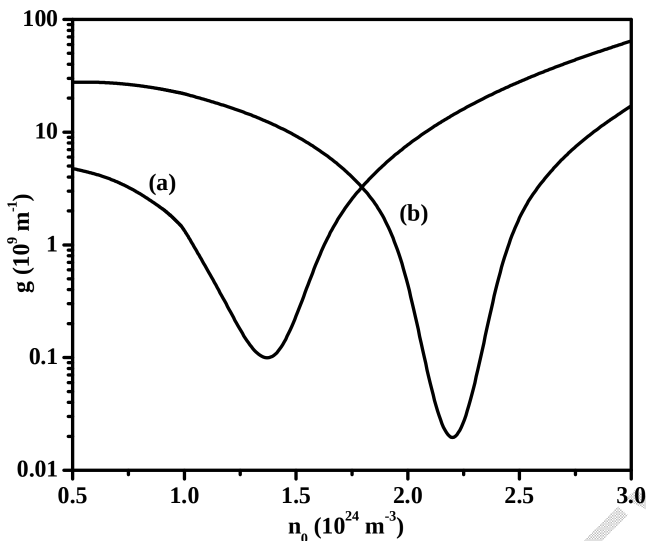

Fig. 4. Variation of gain characteristics g (presence (curve - a) and absence (curve - b) of quantum effect) with number density n_0.

Fig. 4 depicts the variation of gain constant with free carrier density n_0. Again a close look at the Eq. (17) reveals the critical dependence of gain constant on n_0 via $\delta\left(=\omega_0-\bar{\omega}_p\right)$ term. In low doping regime where $\omega_0>\bar{\omega}_p$, the value of δ is positive and consequently gain decreases with n_0. As we increase the doping concentration the value of plasma frequency increases. At a particular doping concentration $\bar{\omega}_p$ resonates with ω_0. At this resonance condition $\omega_0 \approx \bar{\omega}_p$ when $n_0 = 1.3\times10^{24} m^{-3}$ in presence of quantum correction and $n_0 = 2.2\times10^{24} m^{-3}$ in absence of quantum correction term, modulational gains achieves the minimum value. It is also inferred from this figure that the quantum correction shifts the minima towards lower n_0 value. A little departure from this point makes $\delta\left(=\omega_0-\bar{\omega}_p\right)$ negative and eventually the modulational gain increases with doping concentration. The qualitative behavior of both the curves are identical. Carrier densities of such high magnitudes are quite relevant to semiconductors of the III-V group and have been extensively employed by several workers to study their various characteristics [29-30]

However the doping should not exceed the limit for which the plasma frequency ω_p exceeds the input pump frequency ω_0, because in the regime when $\omega_p > \omega_0$ the electromagnetic pump wave will be reflected back by the intervening medium. It may be thereby concluded that moderately doped semiconductors are the most appropriate hosts for modulational instability process.

It is found that the magnitudes of threshold electric field for the onset of modulational amplification is $5.4\times10^4 Vm^{-1}$ when quantum effects are included and $4.9\times10^6 Vm^{-1}$ when quantum effects are not included. The corresponding excitation intensities are in regime $2.6\times10^{9}Wm^{-2}$ to $1.2\times10^{11}Wm^{-2}$. Such pump intensities are very easily obtainable by using frequency-doubled CW and pulsed 10.6 μm CO_2 laser. The ability to achieve these excitation intensities with commonly used lasers makes the phenomenon of modulational amplification accessible for experimental study and modulational processes may excite easily in moderately doped piezoelectric semiconductors even at lower pump intensities.

4. CONCLUSION

Based on the above discussions, the following conclusions may be drawn:

1. The quantum effect in the electron dynamics of the semiconductor plasma enhances drastically the gain constant of the modulational amplification in moderately doped semiconductors. This enhancement in gain constant allows for more efficient amplification of signals in these materials, making them ideal for applications requiring high amplification.

2. The inclusion of quantum effects in modulational processes opens up new possibilities for improving signal amplification in semiconductor devices. Quantum Effects Significantly Influence Modulational Instability particularly through the quantum Bohm potential, have a substantial impact on the modulational instability characteristics in n-type InSb semiconductor plasmas. These quantum effects alter the amplitude and stability of wave modulations, emphasizing the need to incorporate quantum considerations in analyzing semiconductor plasmas.

3. The QHD model is Crucial for Accurate Prediction in Laser-Illuminated Environments. The model reveals modifications in the modulational stability and amplitude due to quantum effects, offering an essential framework for more accurate predictions in applications involving semiconductor crystals exposed to laser fields, particularly at low temperatures.

REFERENCES

1. Rigrod W. W., &Kaminow I. P. (1963). Wide band microwave light modulation, proc. IEEE, vol 51, p. 137.
2. Okawachi Y., Sharping J. E., Xu C., & Gaeta A. L. (2006). Bandwidth shaping of parametric gain spectra in microstructure fiber, *Opt. Express* **14**, 12022–12027.
3. Oda S. & Maruta A. (2006). All-optical quantization scheme based on fiber nonlinearity, *Opt. Express* **14**, 7895–7902.
4. Dransfeld K. (1963). Kilomegacycle ultrasonics, Sci. Am., vol, 208, P. 60.
5. Adler R. (1967). Interaction between light and sound" IEEE spectrum, vol. 4, p. 42.
6. Fowler V. J. & Schlafer J. (1966). A survey of laser beam deflection techniques," Proc. IEEE, vol. 54, p. 1437.
7. Brillouin L. (1922). Diffusion de la Lumiera et des rayons X par un corps transparent hogene" Ann. Physiqe, Vol. 17, p. 88.
8. Debye P. & Sears F. W. (1932). On the scattering of light by supersonic waves," pro. Nat. Acad. Sci. U. S., vol. 18, p. 409.
9. Bloembergern N. (1965). Nonlinear optics, Benjamin, New York.

10. Hanna D. C., Cotter A. &Yuratich V. I. (1984). Nonlinear Optics of Free Atoms and Molecules, Springer –Verlag, Berlin, chap. III.
11. Markowich P. A., Ringhofer C.A. & Schmeiser C. (1990). Semiconductor Equations, Springer-Verlag, New York.
12. Killian T. C. (2006). Ultracold Neutral Plasmas, Nature (London) **441**, 298.
13. Manfredi G. (2005). How to Model Quantum Plasmas," *Field Inst. Commun.***46**, 263.
14. Sharma G. & Ghosh S. (2000). Modulational instability of electron plasma waves in a quantum plasma," *Eur. Phys. J. D.***11**, 301–307.
15. Shukla P. K. & Mamun A. A. (2004). Dust-acoustic waves in quantum dusty plasmas," *Phys. Plasmas***11**, 1233–1235.
16. Ghosh S. & Yadav N. (2007). Nonlinear analysis of ion-acoustic solitary waves in an electron-positron-ion quantum plasma, *Acta Physica Polonica A***112**, 29–40.
17. Nimje N., Dubey S. & Ghosh S. (2010). Modulational instability of quantum ion-acoustic waves in a multi-ion quantum plasma," *Indian J. Phys.***84**, 1569–1587.
18. Nimje N., Dubey S. & Ghosh S. (2010). Head-on collision of ion-acoustic solitary waves in quantum electron-ion plasmas," *Eur. Phys. J. D.***59**, 223–231.
19. Ghosh S., Dubey S. & Vanshpal R. (2010). Modulational instability of ion-acoustic waves in quantum dusty plasmas," *Phys. Lett. A***375**, 43–47.
20. Haas F., Manfredi G. & Feix M. R. (2000). Quantum Landau damping," *Phys. Rev. E***62**, 2763.
21. Manfredi G. & Haas F. (2001). Self-consistent fluid model for a quantum electron gas," *Phys. Rev. B***64**, 075316.
22. Haas F., Manfredi G. & Goedert J. (2001). Quantum ion-acoustic waves," *Phys. Rev. E***64**, 026413.
23. Haas F., Garcia L. G., Goedert J. & Manfredi G. (2003). Quantum ion-acoustic instability in a dense plasma," *Phys. Plasmas***10**, 3858.
24. Nagy I. (1995). Dynamical correlation effects on stopping power," *Phys. Rev. B***52**, 1497.
25. Guha S., Sen P. K., & Ghosh S. (1979). Plasma effects on the energy levels of a charged particle in a magnetic field," *Phys. Stat. Sol (a)***52**, 407.
26. Manfredi G. (2006). How to Model Quantum Plasmas," *Field Inst. Commun.***46**, 263.
27. Lashmore-Davies C. N. (1976). The stability of electrostatic waves in a finite temperature plasma," *Phys. Fluids***19**, 587.
28. Yariv A. (1985). Optical Electronics, Holt Saunders International Editions, New York, 3rd edn.
29. Uzma C., Zeba I., Shah H. A. &Salimullah M. (2009). Nonlinear electrostatic waves in a quantum electron-ion plasma," *J. Appl. Phys.***105**, 013307.
30. Amin M. R. (2010). Nonlinear quantum ion-acoustic waves in dense electron-positron-ion plasmas," *J. Appl. Phys.***107**, 023307.