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# Phase Conjugation via Stimulated Brillouin Scattering in Semiconductor Quantum Plasmas

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## Abstract

*Using quantum hydrodynamic model (QHD) an analytical investigation is made for the determination of phase conjugation reflectivity of an electromagnetic wave via stimulated Brillouin scattering in a centrosymmetric, doped semiconductor medium. Effect of Bohm potential on the phase conjugate reflectivity is studied through the quantum corrections in classical hydrodynamic equations. Present paper deals with the qualitative behavior of threshold pump intensity for the onset of OPC-SBS (optical phase conjugation-stimulated Brillouin scattering) and phase conjugate reflectivity with respect to doping concentration with and without quantum corrections. The numerical estimates are made for n-type InSb crystal at 77K duly shined by pulsed 10.6 $\mu m$ $CO_2$ laser. Phase conjugate reflectivity with and without quantum effect is found to increase with the pump intensity. Consequently OPC-SBS becomes a possible tool in phase conjugate optics even under not-too-high power laser excitation by using moderately doped n-type semiconductors. It is found that the Bohm potential in the electron dynamics enhances the phase conjugate reflectivity. Above the threshold pump field maximum phase conjugate reflectivity equal to 80% is obtained at pump intensities below optical damage threshold of the crystals. The main utility of the analysis lies in establishing the potential of quantum correction through Fermi temperature and Bohm Potential terms for the reduction in the threshold pump intensity and enhancement in OPC-SBS reflectivity of the said process have been realized.*

**Keywords:** Optical Phase Conjugation, Stimulated Brillouin Scattering, Quantum effect.

## Introduction

Optical phase conjugation (OPC) combines in itself aesthetic and pragmatic attractiveness, a synthesis that has made OPC a subject of general attention. In recent years, applications of nonlinear optical effects based on field induced indices such as optical phase conjugation have attracted a great deal of attention. Nonlinear systems can be used to make the performance of a real optical system that of an ideal distortion free system without the need of holding impossible precise tolerances in manufacture. Active optical circuitry in integrated circuit geometries may well be possible in near future which will lead to practical realization of all optical computing.

Brillouin scattering is used most commonly for phase conjugation and pulse compression. An important advantage of OPC-stimulated Brillouin scattering (SBS) is the fact that optical phase self conjugation is realized in this method. The earliest observation of the OPC phenomenon was made in the experiments of SBS in 1972[1,2]. For OPC, backward SBS is preferred over other techniques because it initiates at lower threshold and has negligible frequency shift and high conversion efficiency[3,4]. SBS phase conjugation can improve the output spatial profiles by reducing the optical distortions and combine the multiple beams into a large-aperture coherent beam. Also, SBS develops in transparent media and, accordingly, the problem of optical breakdown in SBS media is not so acute. SBS has also proven to be an effective way to produce slow light in optical fibers at room temperatures[5]. These advantages have made SBS a good candidate for practical applications. Although SBS has been extensively studied in last decades[6,7], theoretical predictions and experimental observations are far apart[8-11]; hence comprehensive efforts in SBS theory are required.

An application is often most appealing if it is operative with CW laser beams. This would require a nonlinear medium with an extremely large nonlinearity. Several such media have recently been found[12]. Semiconductors represent universally recognized materials with the high optical nonlinearity. Direct gap semiconductors can have large optical field induced refractive index through saturation in absorption either at the band edge (InSb)[13]or at an exciton transition line (GaAs)[14]. The electro-optical properties of semiconductors form the basis of the latest and current technological revolutions in the field of fiber-optic communications whose light sources, amplifiers and detectors are semiconductor devices. Eventhough the electron density in semiconductors is much lower than in metals; the great degree of miniaturization of semiconductor devices and nanoscale objects are such that the de Broglie wavelength of the charge carriers can be comparable to the spatial variation of the doping profiles. Hence, typical quantum mechanical effects, such as tunneling, are expected to play a central role in the behavior of optoelectronic components to be constructed in the next years[15-19]. Theoretically the first problem of quantum plasma physics dealt with the exchange of energy between an individual electron and a collective motion of many particles. In 1934, Bloch extended his famous work of the preceding year[20] on the stopping power of charged particles to include the quantization of the excited states of the Fermi gas. He treated these not as states with holes and excited particles but as states of sound like oscillations of the gas. There is noticeable interest for quantum plasmas due to their wide-ranging applications in different environments, such as in ultra small electronic devices[21], in superdense astrophysical systems (particularly, in the interior of Jupiter, white dwarfs and superdense neutron stars)[22], in high-intensity laser-produced plasmas[23], in metallic nanostructures, in nonlinear quantum optics[24] and in dusty plasmas. Recently an extensive parametric investigation of the dependence of the longitudinal pulse compression mechanism on the electron density in cold quantum plasmas, and the role of the Fermi temperature in thermal quantum plasmas is also reported[25]. It is concluded in these reports by Salimullah et al.[26] that the strong quantum effect arising through the Bohm potential and the ion polarization effect can give rise to a new oscillatory behavior of the screening potential beyond the shielding cloud which could explain a new type of possible robust ordered structure formation in the quantum magnetoplasma.

The stimulus for the present study stems from the fact that it may lead to better description of dynamics of physical observable and simulate the main characters of quantum effects. This motivates the development of quantum hydrodynamic (QHD) model for semiconductor plasma medium. Thus the main purpose of present paper is to examine quantum effects via Fermi temperature and Bohm potential on phase conjugation characteristics of SBS in centrosymmetric semiconductor plasma medium by employing QHD model for the electron dynamics. Stimulated Brillouin scattering (SBS) is an important third-order nonlinear optical effect that has been widely used for efficient phase conjugate reflection of high-power lasers[27]. An incident laser beam can scatter with the periodic refractive index variations associated with a propagating acoustic wave. The scattered light, depending on the propagation direction of the acoustic wave, will be Stokes or anti-Stokes shifted by the frequency of the acoustic wave. The process is stimulated because the interference of the incident and scattered wave can lead to an amplification of the acoustic wave, which then tends to pump more energy into the scattered wave. Effect of Bohm potential on the phase conjugation reflectivity in SBS is studied through the quantum corrections in classical hydrodynamic equations. Using coupled mode theory, an analytical investigation of the third-order optical susceptibility due to the nonlinear interaction of an intense pumping light with internally generated acoustic perturbation due to the electrostriction in the medium is presented.

Present paper is organized in the following fashion: Section 2 is divided into two parts: Theoretical formulations for third-order optical susceptibility and phase conjugate reflectivity are given in subsections 2.1 and 2.2, respectively. In section 3, numerical estimations are made for n-InSb crystal duly irradiated by a $CO_2$ laser.

**Theoretical Formulations: Effective Brillouin Susceptibility:** In this section we deal with the theoretical formulation of Brillouin susceptibility ($\chi_B$) for the Stokes component of the scattered electromagnetic wave in doped semiconductor using QHD model. We have considered the well-known hydrodynamic model of homogenous one-component (electron) plasma under thermal equilibrium. In order to determine the third-order Brillouin susceptibility arising from the nonlinearly induced and the electrostrictive polarizations, the spatially uniform pump electric field $E_0 \exp(i\omega_0 t)$ is applied along the direction of wave propagation $\vec{k} = k\hat{x}$. As the crystal is assumed to be centrosymmetric, the effect of any pseudopotential can be neglected for analytical simplicity without loosing any important information.

There are various models available to study the quantum effects in plasma for example Wigner-Poisson model[9-11] which involves an integro-differential system, Schrodinger-Poisson model and the popular QHD model. QHD model is used in the present work since it is a reduced model that allows straightforward investigation of collective dynamics. In the high density regimes the quantum diffraction effects are disregarded although quantum statistical effects (Fermi-Dirac statistics) are still taken into account in the choice of the equation of state. It is a fact that when plasma is cooled to an extremely low temperature the de Broglie wavelength of the charge carriers could become comparable to the dimensions of the system. In such situations, ultracold plasma behaves like a Fermi gas and quantum mechanical effects are expected to play a central role in the behaviour of charged particles. Therefore plasma system may be considered as one dimensional zero temperature Fermi gas. For definiteness, we assume that the plasma particles in one dimensional zero temperature Fermi gas obey the pressure law[28,29] given as

$$P = \frac{mV_F^2 n_1^3}{3n_0^2} , \tag{1}$$

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 of electrons. $n_0$ 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. Therefore, Equation (1) can be stated as equation of state pertaining to a one dimensional zero temperature Fermi gas.

Following Guha et al.[30] and Manfredi[31], the other basic equations employed are

$$\frac{\partial^2 u}{\partial t^2}-\frac{C}{\rho}\frac{\partial^2 u}{\partial x^2}+2\Gamma_a\frac{\partial u}{\partial t}=\frac{\gamma}{2\rho}\frac{\partial}{\partial x}\left(E_0E_{1x}^*\right) \quad (2)$$

$$\frac{\partial \upsilon_0}{\partial t}+\nu\upsilon_0=\frac{e}{m}E_0 \quad (3)$$

$$\frac{\partial \upsilon_1}{\partial t}+\nu\upsilon_1+\left(\upsilon_0\cdot\frac{\partial}{\partial x}\right)\upsilon_1=\frac{e}{m}E_1-\frac{1}{mn_0}\frac{\partial P}{\partial x}+\frac{\hbar^2}{4m^2n_0}\frac{\partial^3 n_1}{\partial x^3} \quad (4)$$

$$\upsilon_0\frac{\partial n_1}{\partial x}+n_0\frac{\partial \upsilon_1}{\partial x}=-\frac{\partial n_1}{\partial t} \quad (5)$$

$$P_{es}=-\gamma E_0\frac{\partial u^*}{\partial x} \quad (6)$$

$$\frac{\partial E_1}{\partial x}=\frac{n_1 e}{\varepsilon}+\frac{\gamma}{\varepsilon}E_0\frac{\partial u^*}{\partial x} \quad (7)$$

One dimensional QHD model (Equation (1)- (7)) includes quantum pressure term and quantum Bohm potentials[32]. The quantum statistics is included in the model via the equation of state (Equation (1)) which takes into account the Fermionic character of the electrons. Disregarded the quantum diffraction effect the charge density can be obtained from the potential through an algebraic equation[33] and Poisson equation should not modified to include quantum contribution. In other applications in semiconductor physics, the Bohm potential is responsible for tunneling and differential resistance effects[34]. Equation (2) represents the motion of the lattice in the crystal, where $\rho$ is the mass density of the crystal, $u$ is the displacement of the lattice, $\Gamma_a$ is the phenomenological damping parameter of acoustic mode, $C$ is the elastic constant, and $\gamma$ is the electrostriction coefficient of the crystal. The driving term in the right-hand side of Equation (2) has its origin in the electrostrictive force induced by the pump electric field via the process of electrostriction. Equation (3) and (4) are the zeroth and first order oscillatory fluid velocities of an electron of effective mass m and charge $e$. $\nu$ is the phenomenological electron collision frequency. The quantum correction in the Equation (4) appears through the Fermi temperature and the third term on right hand-side. In this equation, we have neglected the effect due to $\vec{\upsilon}0\times\vec{B}1$ by assuming that the acoustic wave is propagating along such a direction of the crystal as to produce a longitudinal electric field, e.g. in InSb if $k$ is taken along (011) and the lattice displacement along (100), the electric field induced by the wave is longitudinal. Conservation of charge is represented by the continuity Equation (5). Equation (6) reveals that the acoustic wave generated due to electrostrictive strain modulated the dielectric constant and gives rise to an electrostrictive induced polarization $P_{es}$. At very high frequencies of the field which is quite large as compared to the frequencies of the motion of the electrons in the medium, the polarization of the medium is considered on neglecting the interaction of the electrons with one another and with the nuclei of the atoms. The space charge field $E_1$ is determined by the Poisson Equation (7) where $\varepsilon$ is the dielectric constant of the semiconductor.

The electrostrictive force gives rise to a carrier density perturbation within the Brillouin active medium. In a doped semiconductor, this density perturbation can be obtained by using the standard approach[30] as

$$\frac{\partial^2 n_1}{\partial t^2}-\varpi_p^2 n_1+\nu\frac{\partial n_1}{\partial t}-\frac{n_0\gamma\overline{E}k^2u^*}{\varepsilon}=\overline{E}\frac{\partial n_1}{\partial x} \quad (8)$$

with

$$\overline{E}=\left(\frac{e}{m}E_0\right),\qquad \varpi_p^2=\omega_p^2+k^2V_F^{'2}$$

$$V_F^{'}=V_F\sqrt{1+\gamma_e}\quad,\qquad \gamma_e=\frac{\hbar^2k^2}{8mK_BT_F}$$

In the deriving Equation (8), we have neglected the Doppler shift under the assumption that $\omega_0>>\nu>k\upsilon_0$. $\omega_p=\left(\frac{n_0e^2}{m\varepsilon}\right)^{1/2}$ is the plasma frequency. It is evident that the second term on left hand side of Equation (8) gives the combined effect of quantum and Fermi dispersion.

The perturbed electron concentration $n_1$ will have two components those can be designated as slow and fast ($n_1=n_{1s}+n_{1f}$). The slow component $n_{1s}$ is associated with the low frequency acoustic wave $(\omega_a)$, whereas the fast component $n_{1f}$ oscillates at the electromagnetic wave frequencies $(\omega_0\pm\omega_a)$. The higher-order terms with frequencies $\omega_0\pm p\omega_a$ $(p=2,3,4,....)$ being off resonant are neglected. Here we will consider only the Stokes component of the scattered electromagnetic wave ($\omega_1=\omega_0-\omega_a$, $\vec{k}_1=\vec{k}_0-\vec{k}_a$). Now for these modes, the stimulated Brillouin process under consideration should satisfy the phase matching conditions $\hbar\omega_0=\hbar\omega_1+\hbar\omega_a$ and $\hbar k_0=\hbar k_1+\hbar k_a$ known as the energy and momentum conservation relations. We have considered the photon energy ($\hbar\omega_1$) slightly below the band-gap energy ($\hbar\omega_g$), this assumption allows the optical properties of the sample to be influenced considerably by the free charge carrier and remain unaffected by the photo induced interband transition mechanism.

The following coupled equations are obtained from Equation (8) under rotating wave approximation (RWA):

$$\frac{\partial^2 n_{1s}}{\partial t^2} + \nu \frac{\partial n_{1s}}{\partial t} - \varpi_p^2 n_{1s} = \overline{E} \frac{\partial n_{1f}^*}{\partial x} \quad (9a)$$

and

$$\frac{\partial^2 n_{1f}}{\partial t^2} - \varpi_p^2 n_{1f} + \nu \frac{\partial n_{1f}}{\partial t} - \frac{n_0 \gamma \overline{E} k^2 u^*}{\varepsilon} = \overline{E} \frac{\partial n_{1s}^*}{\partial x} \quad (9b)$$

Subscripts $s$ and $f$ stand for slow and fast components, respectively. Asterisk (*) represents complex conjugate of the quantities.

It can be inferred from Equation (9a) and (9b) that the slow and fast components of the density perturbation are coupled to each other via the pump electric field. Thus it is obvious that the presence of the pump field is the fundamental necessity for SBS to occur.

Using Equation (9a) and (9b), we obtain

$$n_{1s} = \frac{-n_0 \gamma^2 k^2 E_0^2 E_1}{2\varepsilon\rho\left(\omega_a^2 - k^2 \upsilon_a^2 - 2i\Gamma_a \omega_a\right)} \left[ \frac{\left(\delta_1^2 - i\omega_a \nu\right)\left(i\omega_1 \nu - \delta_2^2\right)}{k^2 \left|\overline{E}\right|^2} - 1 \right]^{-1} \quad (10)$$

where $\upsilon_a = \sqrt{C/\rho}$ is the acoustic velocity in the medium.

It is evident from the above expression that $n_{1s}$ depends upon magnitude of the pump intensity ($I_{in}$) and produced affect the propagation characteristics of the generated waves. Hence using the density perturbation and following the standard approach we obtain nonlinear induced polarization as

$$P_{cd}(\omega_1) = \frac{-e n_0 \gamma^2 k^2 E_0^2 E_1(\omega_1)}{2\varepsilon\rho\omega_0\omega_1\left(\omega_a^2 - k^2 \upsilon_a^2 + 2i\Gamma_a \omega_a\right)} \left[ \frac{\left(\delta_1^2 - i\omega_a \nu\right)\left(i\omega_1 \nu - \delta_2^2\right)}{k^2 \left|\overline{E}\right|^2} - 1 \right]^{-1} \quad (11)$$

It is well known that the origin of the SBS process lies in that component of $P_{cd}(\omega_1)$ which depends on $E_0^2 E_1$, the corresponding third-order susceptibility is the Brillouin susceptibility $\left(\chi_B\right)_{cd}$.

The electrostrictive strain interacts with the pump wave in the Brillouin active medium giving rise to an electrostrictive polarization $P_{es}\left(\omega_1\right)$ which is analogous to polarization due to molecular vibrations in the stimulated Raman scattering phenomenon. Thus besides the nonlinear induced polarization due to the perturbed current density, the system should also possess an electrostrictive polarization. This electrostrictive polarization $P_{es}\left(\omega_1\right)$ may be obtained from Equation (6) and (7) as

$$P_{es}\left(\omega_1\right) = \frac{-\gamma^2 k^2 E_0^2 E_1\left(\omega_1\right)}{2\rho\left(\omega_a^2 - k^2 \upsilon_a^2 + 2i\Gamma_a \omega_a\right)} \quad (12)$$

In a doped centrosymmetric crystal the total induced nonlinear polarization proportional to $E_0^2 E_1(\omega_1)$ with finite electrostrictive coupling is given by

$$P_{nl}(\omega_1) = P_{cd}(\omega_1) + P_{es}(\omega_1)$$

$$= \frac{-\gamma^2 k^2 E_0^2 E_1(\omega_1)}{2\rho\left(\omega_a^2 - k^2 \upsilon_a^2 + 2i\Gamma_a \omega_a\right)} \left[ 1 + \frac{\omega_p^2}{\omega_0\omega_1} \left[ \frac{\left(\delta_1^2 - i\omega_a \nu\right)\left(i\omega_1 \nu - \delta_2^2\right)}{k^2 \left|\overline{E}\right|^2} - 1 \right] \right]^{-1}$$

$$= \varepsilon_0 \chi_B E_0^2 E_1(\omega_1) \quad (13)$$

Hence the effective Brillouin susceptibility can be obtained from Equation (13) as

$$\chi_B = \frac{-\gamma^2 k^2}{2\rho\varepsilon_0\left(\omega_a^2 - k^2 \upsilon_a^2 + 2i\Gamma_a \omega_a\right)} \left[ 1 + \frac{\omega_p^2}{\omega_0\omega_1} \left[ \frac{\left(\delta_1^2 - i\omega_a \nu\right)\left(i\omega_1 \nu - \delta_2^2\right)}{k^2 \left|\overline{E}\right|^2} - 1 \right] \right]^{-1} \quad (14)$$

From the above expression, it is evident that $\chi_B$ depends upon materials parameters, such as equilibrium carrier density $n_0$ via the electron plasma frequency $\omega_p$ and also affected by the quantum correction term through $\delta_1^2 = \varpi_p^2 + \omega_a^2$ and $\delta_2^2 = \varpi_p^2 + \omega_1^2$. On neglecting the dispersion of the acoustic wave (i.e. $\omega_a^2 \approx k^2 \upsilon_a^2$) imaginary part of the susceptibility can be written as

$$\chi_{Bi} = \frac{\gamma^2 k^2}{4\rho\varepsilon_0 \Gamma_a \omega_a} \left[ 1 + \frac{\omega_p^2}{\omega_0\omega_1} [V] \right] \quad (15)$$

where

$$[V] = \frac{k^2 \left|\overline{E}\right|^2 \left[ \omega_1 \nu \omega_a - k^2 \left|\overline{E}\right|^2 - \delta_1^2 \delta_2^2 \right]}{\left[ \left[ \omega_1 \nu \omega_a - k^2 \left|\overline{E}\right|^2 - \delta_1^2 \delta_2^2 \right]^2 + \left[ \delta_1^2 \omega_1 \nu - \delta_2^2 \nu \omega_a \right]^2 \right]},$$

in which $\chi_B = \chi_{Br} + \chi_{Bi}$, subscripts $r$ and $i$ to the quantities represent the real and imaginary parts, respectively.

**OPC – SBS Reflectivity:** If a phase conjugate replica of an input wave can be generated, this new wave will propagate in reverse direction through the dielectric medium regaining everywhere the original form of input wave. For this we consider the irradiation of a semiconducting crystal by a near band gap resonant laser pump with excitation intensity above the threshold value required for the onset of SBS in the crystal with finite optical attenuation. The electromagnetic pump mode undergoes stimulated scattering process via its interaction with the phonons in the medium. We deal with the scattering only due to acoustic phonons so that the interaction yields the scattered Brillouin modes only. The propagation of the pump as well as the Brillouin mode through the material can be represented by the generalized electromagnetic wave equation.

$$\nabla^2 E - \frac{1}{C_1^2}\frac{\partial^2 E}{\partial t} = \mu_0 \frac{\partial^2 P_{nl}}{\partial t^2} \quad (16)$$

We have considered only the transverse electric field propagating along the x direction with the field variation given by $\exp[i(\omega t - kx)]$. $P_{nl}$ represents the total induced nonlinear polarization in the centrosymmetric crystal comprising the linear as well as the nonlinear components and is given by

$$P_{nl}(x,t) = \varepsilon_0[\chi^{(1)} + \chi^{(3)}|E(x,t)|^2 + ......]E(x,t) \quad (17)$$

Here, $\chi^{(1)}$ is the linear susceptibility corresponds to the linear optical effects while $\chi^{(3)}$ is third-order nonlinear susceptibility responsible for phenomena of third harmonic generation, optical bistability, optical phase conjugation.

We assume that the pump is propagating along the –*x* direction while the backscattered Stokes mode is propagating along the +*x* direction. Using slowly varying envelope approximation (SVEA), we obtain the wave equation for $E_0(\omega_0, k_0)$ and $E_1(\omega_1, k_1)$ as

$$\frac{\partial E_0}{\partial x} = \alpha_0 E_0 - i\alpha_{r0}E_0 - \frac{i\omega_0^2}{2k_0^2}\chi_0^{(3)}|E_1|^2 E_0 \,, \quad (18)$$

$$\frac{\partial E_1}{\partial x} = \alpha_1 E_1 - i\alpha_{r1}E_1 - \frac{i\omega_1^2}{2k_1^2}\chi_1^{(3)}|E_0|^2 E_1 \,, \quad (19)$$

where $\alpha_{0,1} = \omega_{0,1}^2\chi_{0,1}^{(1)}/2k_{0,1}c^2$, $\alpha_{r0,1} = \omega_{0,1}^2\chi_{r0,1}^{(1)}/2k_{0,1}c^2$.

Here $\alpha_{0,1}$ is the background absorption coefficient of the crystal at frequency $\omega_{0,1}$ while $\alpha_{r0,1}$ is a contribution arising due to the real part of the complex linear susceptibility $\chi^{(1)}(=\chi_r^{(1)} + \chi_i^{(1)})$ that governs the linear dispersive properties of the crystal. $\chi_{0,1}^{(3)}$ is the third order optical susceptibility at frequency $\omega_{0,1}$. For a phase conjugate scattered wave, the phase matching conditions enable one to take $k_0 = -k_1$, such that $k_a = 2k_0$; also we consider $|k_0| = |k_1| = k$ with $|k_a| = 2k$. We also assume that $\omega_1 \cong \omega_0$ and $\alpha_1 \cong \alpha_0 = \alpha$.

Using the above basic equation and applying the condition for $\alpha L < 1$ at the entrance window $x = L$. We can find the threshold value of the excitation intensity as

$$I_{0th} \geq \frac{\eta\varepsilon_0 c^3 k\alpha_{E1}}{\omega^2|\chi_B|} \,, \quad (20)$$

which depends upon the crystal as well as the pump photon energy. It appears worth mentioning at this point that for pump intensities in the vicinity of $I_{0th}$, the Stokes mode intensity is reasonably small and hence, $\alpha_{E1}$ may be taken to be around $\alpha$, the crystal background absorption coefficient.

The OPC-SBS reflectivity at the entrance window $x = L$ is found to be

$$R = |\xi(x = L)|^2 = \left|\frac{E_1(0)}{E_0(L)}\right|^2 \exp[2(K - \alpha_{E1})L] \,, \quad (21)$$

where L is the length of the semiconductor waveguide.

In the present analysis $E_1(0)$ the field associated with the Stokes mode at $x = 0$, is known as the noise field for the SBS process and its origin lies in the spontaneous scattering. Above equation clearly indicates that the reflectivity is dependent on the pump intensity and the material dimension in addition to the effective absorption coefficient of the crystal $\alpha_{E1}$ that depends on the Stokes mode intensity $|E_1|^2$.

## Results and Discussion

In this section we study the nature of the dependence of OPC-SBS reflectivity $|\xi(x = L)|^2$ on system parameters. Since optical band gap of InSb is 0.180 eV which corresponds to the infrared region wavelength of the order of 1 $\mu m$, hence for the onset of SBS in the medium one requires a laser with wave length 1 $\mu m$ or more and its intensity should be more than the threshold intensity ($\geq 5\times10^{12} Wm^{-2}$) obtained. For numerical estimation the physical parameters used are $m = 0.014m_0$, $m_0$ being the free electron mass, $\varepsilon_1 = 15.8$, $\gamma = 5\times10^{-10} Fm^{-1}$, $\rho = 5.8\times10^3 kgm^{-3}$, $\omega_1 = 2\times10^{11} s^{-1}$, $\omega_0 = 1.78\times10^{14} s^{-1}$, $\nu = 4\times10^{11} s^{-1}$, $n_0 = 3\times10^{24} m^{-3}$. Using the above parameters we have performed numerical analysis of quantum effect on OPC-SBS reflectivity in semiconductor plasma.

The threshold value of pump intensity required for the onset of optical phase conjugation via SBS process is determined. Finite OPC-SBS reflectivity can be achieved only when $I_0(L) > I_{0th}$.

Figure 1 illustrates the variation of threshold pump intensity for OPC-SBS reflectivity (with and without quantum effect) with number density of electron $n_0$. It is observed that in both the cases threshold electric field decreases gradually with increasing value of $n_0$. It is found that the threshold field for OPC-SBS reflectivity is strongly affected by quantum correction. Quantum effects sufficiently reduce the required threshold field intensity.

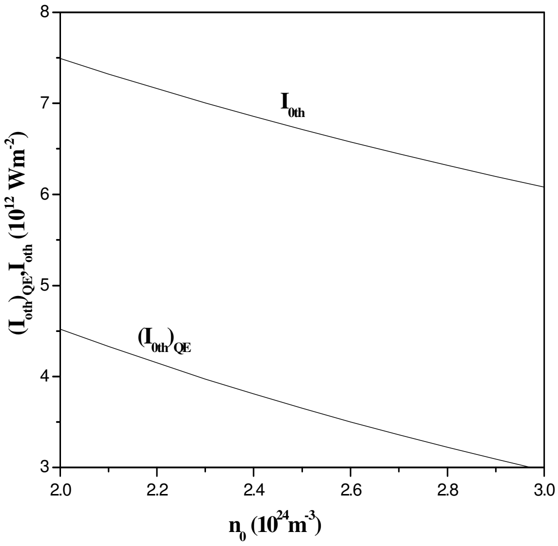


**Figure-1**
**Variation of threshold pump intensity ($I_{0,\ th}$) of the OPC-SBS process with number density $n_0$ at wave number $k = 3\times10^8 m^{-1}$**

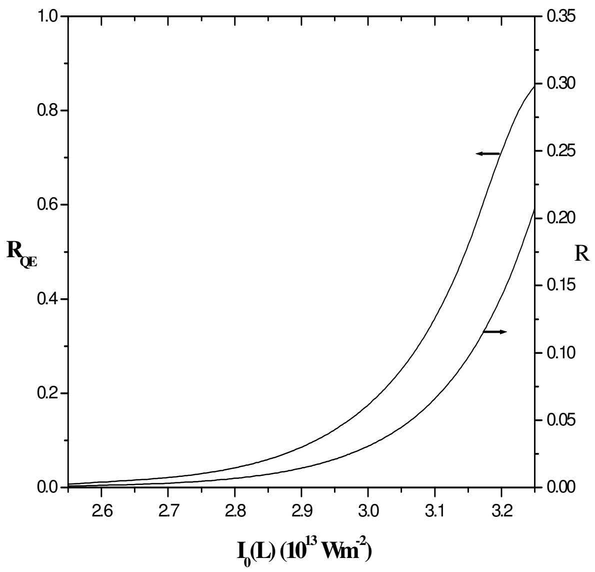


**Figure-2**
**Variation of OPC-SBS reflectivity $R = |\xi(x = L)|^2$ with pump intensity $I_0(L)$ at $k = 3\times10^8 m^{-1}$ and $n_0 = 3\times10^{24}$ $m^{-3}$**

In Figures 2 and 3, nature of phase conjugation reflectivity is examined by including and excluding the quantum correction term. The nature of variation of OPC-SBS reflectivity $R_{QE}$ (with quantum effect) and $R$ (without quantum effect) with pump intensity $I_0(L)$ is shown in Figure 2. In both the cases, reflectivity increases on increasing $I_0(L)$. Quantum effects are found to increase the magnitude of reflectivity. Figure 3 depicts the variation of reflectivity (with and without quantum effect) with free carrier density $n_0$. It may be observed that reflectivity increases parabolically with increase in the carrier density. Quantum effects are found to be favourable in achieving the higher reflectivity at particular values of wave number and pump intensity.

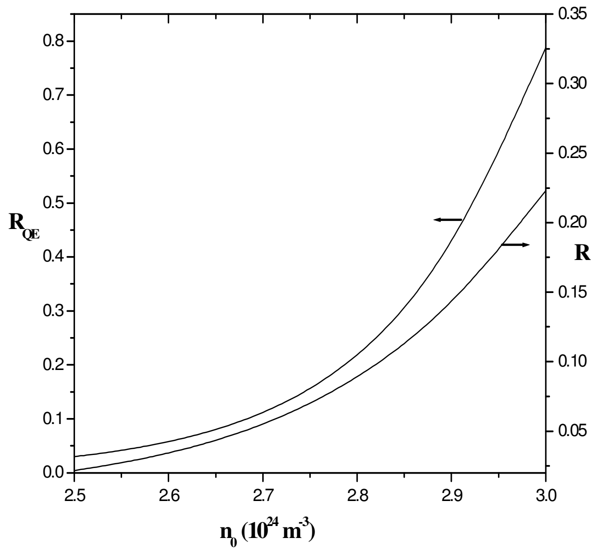


**Figure-3**
**Variation of OPC-SBS Reflectivity $R = |\xi(x = L)|^2$ with number density $n_0$ at $k = 3\times10^8 m^{-1}$ and $E_0 = 8\times10^7 Vm^{-1}$**

## Conclusion

Using QHD model, the quantum effect on characteristics of phase conjugation via stimulated Brillouin scattering in semiconductor quantum plasma medium has been investigated. It is found that the electron dynamics is modified drastically at higher electron number density of semiconductor due to presence of quantum correction terms. This modification is found responsible in reducing the threshold requirement for OPC-SBS and subsequently makes fabrication of devices based on OPC-SBS cheaper. Effective quantum correction enhances the OPC-SBS reflectivity by about 60% and hence this parameter region is favourable for fabrication of OPC mirrors from semiconductors.

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