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Diffusion Induced Parametric Amplification/Attenuation of Acoustic Phonons in Magnetized Semiconductor Plasmas

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ABSTRACT

Assuming that the origin of the nonlinear interaction lies in the second-order optical susceptibility $\chi^{(2)}$ arising from the diffusion-induced nonlinear current density, and using straight-forward coupled mode theory, parametric amplification/attenuation of acoustic phonons is analytically investigated in a magnetized semiconductor plasma. The analysis deals with the qualitative behaviour of the threshold value of pump electric field E_{0th} for the onset of parametric amplification and parametric gain constant $g_a(\omega_a)$ with respect to excess doping concentration (via plasma frequency ω_p), applied magnetic field (via cyclotron frequency ω_c), and pump electric field E_0 for different values of diffusion coefficient D. The proper selection of ω_p, ω_c and E_0 enhances the gain profile, which may drastically reduce the fabrication cost of parametric devices based on this interaction.

Keywords
Parametric amplification/attenuation, acoustic phonon, semiconductor plasma, diffusion, magnetic field

INTRODUCTION

Parametric interaction (PI) of an intense laser beam (hereafter called ‘pump’) with nonlinear medium plays a distinctive role in nonlinear optics. Parametric processes have been widely used to generate tunable coherent radiation in a nonlinear crystal that is not directly available from a laser source [1, 2]. Parametric amplifiers, parametric oscillators, optical phase conjugation, pulse narrowing, squeezed state generation, etc. are some of the important devices and processes whose origin lies in PI in a nonlinear medium. Besides these technological uses, there are several other applications of PI in which basic scientists are interested [3, 4]. Although PI of waves has been extensively studied in the past few years [5-8], there are tremendous possibilities for further exploration and exploitation due to the poor agreement between theories and experiments [9-11]. The current trends in the field indicate that this old but fascinating phenomenon is still hotly pursued by both theoreticians as well as experimentalists, and an increasing number of interesting applications exploiting PI are being discovered or are yet to be discovered.

Recently, high mobility semiconductors have attracted much attention for their potential electronic and optical device applications. The high mobility of optically excited charge carriers makes diffusion effects particularly relevant in semiconductor technology as they (the charge carriers) travel significant distances before recombination. In most cases of investigations of nonlinear optical interactions particularly of parametric interactions, the nonlocal effects, such as diffusion of the excitation density that is responsible for the nonlinear refractive index change, have normally been ignored. It is well known fact that the origin of PI lies in the second order nonlinear optical susceptibility $\chi^{(2)}$ of the medium. Here, we have presented an analytical investigation of second-order nonlinearity due to carrier diffusion current in an n-type centrosymmetric semiconductor plasma. The vanishingly small second-order nonlinearity can be enhanced in centrosymmetric media by creating favourable conditions through the adjustment of material parameters, wave propagation properties and externally applied magnetic field [12]. Interestingly, we have shown that the diffusion of carriers may induce appreciable large second-order nonlinearity in a magnetized diffusive semiconductor, which may be termed as 'diffusion induced second order (DISO) nonlinearity' and may lead to amplification of the acoustic wave (AW) in a collision dominated semiconductor plasma ($\nu \gg \omega$) due to a pump of frequency $\omega_0 \gg \nu$, ν being the momentum transfer collision frequency [13]. Moreover, this DISO nonlinearity is found to maximize at considerably low magnetic field ($\omega_c \approx 0.01\omega_0$; ω_c being cyclotron frequency). This interesting feature of DISO nonlinearity may play an extremely important role in operation of parametric amplifiers, oscillators, tunable radiation sources etc. because the devices based on DISO nonlinearity will require very low magnetic field and thereby reducing their operating cost drastically.

In PI of AW the driving pump electric field introduces coupling between the AW and the electron-plasma wave (EPW). In the multimode theory of PIs, an acoustic perturbation in the lattice gives rise to an electron density fluctuation in the medium at the same frequency. This couples nonlinearity with the pump field and drives the EPW at the sum and difference frequencies. This electron density perturbation, in turn, couples nonlinearity with external field and may reinforce the original perturbation at the acoustic frequency. Thus, under certain conditions, the AW and EPW derive each other unstable at the expense of the pump electric field.

THEORETICAL FORMULATIONS

In order to study the PI arising due to the three-wave interaction in an n-type diffusive semiconductor, an analytical expression for the DISO optical susceptibility $\chi_d^{(2)}$ for the AW has been derived in the medium. The hydrodynamic model of n-type diffusive semiconductor plasma is considered. The suitability of this model seems without any loss of significant information, by replacing the streaming electrons with an electron fluid described by a few macroscopic parameters like average carrier density, average velocity etc. However, it restricts the analysis to be valid only in the limit $k_a l << 1$ (k_a the AW number, and l the carrier mean free path). We consider a spatially uniform ($|k_0| \approx 0$) pump field $\vec{E} = \hat{x}E_0 \exp(i\omega_0 t)$ which irradiate an n-type diffusive semiconductor medium immersed in a transverse static magnetic field $\vec{B}_0 = \hat{z}B_0$. The PI of pump generates an AW at $(\omega_a, \vec{k}_a)$ and scatters a side band wave at $(\omega_1, \vec{k}_1)$ supported by the lattice and electron plasma in the medium, respectively. The momentum and energy exchange between these waves can be described by phase-matching conditions: $\hbar\vec{k}_0 \approx \hbar\vec{k}_1 + \hbar\vec{k}_a$ and $\hbar\omega_0 \approx \hbar\omega_1 + \hbar\omega_a$. In the interaction of high frequency electromagnetic waves and acoustic waves, it has been assumed without any loss of generality $|\vec{k}_a| (\approx \vec{k}) \gg |\vec{k}_0|$ under the dipole approximation.

The basic equations describing PI of the pump with the medium are as follows:

$$\frac{\partial^2 u}{\partial t^2} - \frac{C}{\rho}\frac{\partial^2 u}{\partial x^2} + 2\Gamma_a \frac{\partial u}{\partial t} = \frac{1}{2\rho}\varepsilon(\eta^2 - 1)\frac{\partial}{\partial x}(\vec{E}_e.\vec{E}_1^*) \tag{1}$$

$$\frac{\partial \vec{v}_0}{\partial t} + \nu\vec{v}_0 = \frac{e}{m}\vec{E}_e \tag{2}$$

$$\frac{\partial \vec{v}_1}{\partial t} + \nu \vec{v}_1 + \left(\vec{v}_0 . \frac{\partial}{\partial x} \right) \vec{v}_1 = \frac{e}{m} \left(\vec{E}_1 + \vec{v}_1 \times \vec{B}_0 \right) \tag{3}$$

$$\frac{\partial n_1}{\partial t} + n_0 \frac{\partial v_1}{\partial x} + v_0 \frac{\partial n_1}{\partial x} + D \frac{\partial^2 n_1}{\partial x^2} = 0 \tag{4}$$

$$\vec{P}_{ao} = -\varepsilon(\eta^2 - 1)\nabla(\vec{u}.\vec{E}) \tag{5}$$

$$\frac{\partial \vec{E}_1}{\partial x} = \frac{n_1 e}{\varepsilon} + \frac{(\eta^2 - 1)}{\varepsilon_1} \vec{E}_e \frac{\partial^2 u^*}{\partial x^2} \tag{6}$$

$$D = \frac{k_B T}{e} \mu . \tag{7}$$

The subscripts 0 and 1 refer to the physical quantities related to pump and side-band wave, respectively.

Equation (1) represents the motion of lattice vibrations in the crystal in which $\vec{u}$, ρ, C, Γ_a and η are the relative displacement of oscillators from the mean position of the lattice, mass density, linear elastic modulus of the crystal, phenomenological acoustic damping parameter, and refractive index of the medium respectively. $\vec{E}_e$ represents the effective electric field, which includes the Lorentz force $\vec{v}_0 \times \vec{B}_0$ in the presence of an external magnetic field B_0. The right hand side of Eq. (1) is an external driving force $\vec{F}_u$ applied by the electromagnetic field.

Equations (2) and (3) represent the electron motion under the influence of the fields associated with the pump and side-band wave, respectively in which m and v are the electron effective mass and phenomenological momentum transfer collision frequency of electrons respectively. Equation (4) is the continuity equation including diffusion effects in which n_0, n_1 and D are the equilibrium and perturbed electron densities and diffusion coefficient respectively. In an acousto-optic (AO) medium an AW is generated due to the electrostrictive strain leading to the energy exchange between the electromagnetic and acoustic fields. Under the influence of the electromagnetic field, the ions within the lattice move in a non-centrosymmetrical position usually producing a contraction in the direction of the field and an expansion across it. The electrostatic force thus produced is the origin of the AO strain within the medium. Equation (5) describes that the AW generated due to the electrostrictive strain modulates the dielectric constant and gives rise to a nonlinear induced polarization P_{ao}. This polarization results in the coupling of the space-charge wave with traveling acoustic grating. The magnitude of space charge field thus depends on the refractive index grating strength that is proportional to the generated acoustic field strength. The space charge field therefore couples the pump and the signal field in the presence of the acoustic grating. The space charge field E_1 is determined from Poisson equation (6) where, ε_1 is the dielectric constant of the crystal. The diffusion coefficient D is determined from Einstein's relation (7) in which, k, T and μ are Boltzmann constant, electron temperature, and electron mobility respectively. The induced current density $J(x,t)$ in the present case is assumed to consist of a diffusion term only near thermal equilibrium at temperature T so that the analysis shall be confined only to the role of diffusion current on PI. The AW and side-band wave perturbations are assumed to vary as $\exp[i(k_{a,1}x - \omega_{a,1}t)]$.

The induced charge carriers are subjected to diffusion in the spatially varying intensity of the interfering beams, while the electric field associated with the resultant space charge operates through the AO effect to modify the refractive index of the medium. The three waves parametric coupling of the optical and acoustic (material density) waves in the semiconductor are assumed to occur due to bunching of the carriers produced by the fields associated with the various waves generated in the crystal as a result of the nonlinear mixing of the fundamental waves itself. Thus, any process such as diffusion, enhancing carrier bunching will lead to an amplification/ attenuation of the parametrically generated output signal.

The interaction of the pump with parametrically generated AW produces an electron density perturbation which, in turn, derives an EPW in the medium. Thus by using the standard approach [8], the equation of the EPW is obtained from Eqs. (1) – (7) as:

$$\frac{\partial^2 n_1}{\partial t^2} + \nu \frac{\partial n_1}{\partial t} + \bar{\omega}_p^2 n_1 + \nu D \frac{\partial^2 n_1}{\partial x^2} - \frac{n_0 e k_a^2}{m \varepsilon_1} E_e u^* = -\frac{e}{m} \frac{\partial n_1}{\partial x} E_e , \quad (8)$$

where $\bar{\omega}_p^2 = \omega_p^2 \left(1 + \frac{\omega_c^2}{\nu^2}\right)^{-1}$.

Here $\omega_p = \left(\frac{n_0 e^2}{m\varepsilon}\right)^{1/2}$ is the plasma frequency and $\omega_c = \frac{eB_0}{m}$ is the cyclotron frequency of the carriers.

In deriving Eq. (8), the Doppler shift due to traveling space charge wave is neglected under the assumption $\omega_0 >> k_0 v_0$. This equation describes coupling between the AW and side-band wave in the presence of an intense pump. The energy flow from the pump to the generated waves shall be maximum when the process is phase matched. Resolving Eq. (8) and using the rotating wave approximation (RWA), the slow component (n_s) associated with the AW that produces the density perturbation at frequency ω_a and the fast component (n_f) associated with side-band wave that produces the perturbation at frequency $\omega_1 \approx (\omega_0 \pm p\omega_a)$, p being an integer; are obtained.

By neglecting the off-resonant frequencies $p \geq 2$ [14], we get

$$\frac{\partial^2 n_f}{\partial t^2} + \nu \frac{\partial n_f}{\partial t} + \bar{\omega}_p^2 n_f + \nu D \frac{\partial^2 n_f}{\partial x^2} - \frac{n_0 e k^2}{m \varepsilon_1} (\eta^2 - 1) E_e u^* = -\frac{e}{m} \frac{\partial n_s^*}{\partial x} E_e \quad (9a)$$

and

$$\frac{\partial^2 n_s}{\partial t^2} + \nu \frac{\partial n_s}{\partial t} + \bar{\omega}_p^2 n_s + \nu D \frac{\partial^2 n_s}{\partial x^2} = -\frac{e}{m} \frac{\partial n_f^*}{\partial x} E_e . \quad (9b)$$

Eqs. (9) reveal that the slow and fast components of the electron density perturbations are coupled to each other via the pump electric field. Hence the presence of a pump field is the fundamental necessity for PI to occur.

The usage of Eqs. (1) and (9a,b) and mathematical simplification allow us to calculate the low- and high-frequency components of the density perturbations as:

$$n_f = \frac{n_0 e k^2 (\eta^2 - 1) E_e \Phi}{m \varepsilon_1} \quad (10a)$$

and

$$n_s = -\frac{\varepsilon_0 n_0 k^2 \omega_0^2 (\eta^2 - 1)^2 E_0 E_1^* \Phi}{2\rho(\omega_a^2 - k_a^2 v_a^2 + 2i\Gamma_a \omega_a)(\omega_0^2 - \omega_c^2 + 2i\nu\omega_0)} \quad (10b)$$

where $\delta_1^2 = \bar{\omega}_p^2 - \omega_1^2 - \nu Dk^2$ and $\delta_a^2 = \bar{\omega}_p^2 - \omega_a^2 - \nu Dk^2$ and $\Phi = \left[1 - \frac{\delta_1^2 \delta_2^2}{k^2 (e/m)^2 E_e^2}\right]^{-1}$.

The term $(\omega_a^2 - k_a^2 v_a^2 + 2i\Gamma_a \omega_a)$ represents AW dispersion in the presence of damping, Φ represents the dispersion of pump wave due to collision and diffusion of charge carriers and $n_0 e(\eta^2 - 1)$ is the AO coupling parameter in an electrostrictive medium.

We express the diffusion-induced current density at the acoustic frequency by the relation:

$$J_d(\omega_a) = eD \frac{\partial n_s}{\partial x}. \tag{11}$$

In the coupled-mode approach, the time integral of nonlinear current density $J_d(\omega_a)$ yields the nonlinear-induced polarization

$$P_d(\omega_a) = \int J_d(\omega_a) dt = \frac{\varepsilon_0 n_0 e D k^3 \omega_0^2 (\eta^2 - 1)^2 E_0 E_1^* \Phi}{2\rho\omega_a(\omega_a^2 - k_a^2 v_a^2 + 2i\Gamma_a \omega_a)(\omega_0^2 - \omega_c^2 + 2i\nu\omega_0)}. \tag{12}$$

The DISO susceptibility $\chi_d^{(2)}$ can be obtained by defining the nonlinear polarization as:

$$P_d(\omega_a) = \varepsilon_0 \chi_d^{(2)} E_0 E_1^*, \tag{13}$$

which gives

$$\chi_d^{(2)} = \frac{\varepsilon_0 n_0 e D k^3 \omega_0^2 (\eta^2 - 1)^2 \Phi}{2\rho\omega_a(\omega_a^2 - k_a^2 v_a^2 + 2i\Gamma_a \omega_a)(\omega_0^2 - \omega_c^2 + 2i\nu\omega_0)}. \tag{14}$$

The above equation reveals that diffusion of the carriers induces second-order nonlinearity in the medium which would otherwise be absent or vanishingly small in a centrosymmetric medium.

Now rationalizing Eq. (14), we obtain the real $\left[\chi_d^{(2)}\right]_r$ and imaginary $\left[\chi_d^{(2)}\right]_i$ parts of the complex DISO susceptibility $\chi_d^{(2)}$ using the relation $\chi_d^{(2)} = \left[\chi_d^{(2)}\right]_r + \left[\chi_d^{(2)}\right]_i$:

$$\left[\chi_d^{(2)}\right]_r = \frac{n_0 e D k^3 \omega_0^2 (\eta^2 - 1)^2 \Phi[(\omega_a^2 - k_a^2 v_a^2)(\omega_0^2 - \omega_c^2) - 4\nu\Gamma_a \omega_a \omega_0]}{2\rho\omega_a[(\omega_a^2 - k_a^2 v_a^2)^2 + 4\Gamma_a^2 \omega_a^2)][(\omega_0^2 - \omega_c^2)^2 + 4\nu^2 \omega_0^2]} \tag{15a}$$

and

$$\left[\chi_d^{(2)}\right]_i = \frac{-n_0 e D k^3 (\eta^2 - 1)^2 \Phi[\Gamma_a \omega_a (\omega_0^2 - \omega_c^2) + \nu\omega_0(\omega_a^2 - k_a^2 v_a^2)]}{2\rho\omega_a[(\omega_a^2 - k_a^2 v_a^2)^2 + 4\Gamma_a^2 \omega_a^2)][(\omega_0^2 - \omega_c^2)^2 + 4\nu^2 \omega_0^2]}. \tag{15b}$$

The above formulation reveals that the crystal susceptibility is influenced by the carrier concentration n_0 (via ω_p) and by the transverse dc magnetic field B_0 (via ω_c).

As is well-known, parametric amplification can be achieved at excitation intensities above a certain threshold value. This threshold nature can be obtained by setting $\left[\chi_d^{(2)}\right]_i = 0$ as:

$$E_{0th} = \frac{\delta_1 \delta_2}{(e/m)k}. \tag{16}$$

The amplification of the co-propagating waves in the electrostrictive medium is due to the linear dispersion effects in combination with the nonlinear processes. The steady state gain coefficient ($g_a(\omega_a)$) of a parametrically excited wave-form of the pump field exceeding a threshold value is obtained through the relation [15]:

$$g_a(\omega_a) = -\frac{k}{2\varepsilon_1}[\chi_d^{(2)}]_i E_0 = \frac{n_0 e D k^4(\eta^2-1)^2\Phi[\Gamma_a\omega_a(\omega_0^2-\omega_c^2)+\nu\omega_0(\omega_a^2-k_a^2v_a^2)]E_0}{2\varepsilon_1\rho\omega_a[(\omega_a^2-k_a^2v_a^2)^2+4\Gamma_a^2\omega_a^2)][(\omega_0^2-\omega_c^2)^2+4\nu^2\omega_0^2]} \quad (17)$$

The nonlinear parametric gain of the AW can be possible only if $\left[\chi_d^{(2)}\right]_i$ obtained from Eq. (15b) is negative, which is expected at pump electric field $|E_0| > |E_{0th}|$.

RESULTS AND DISCUSSION

We now analyze numerically the nature of dependence of E_{0th} and $g_a(\omega_a)$ on different parameters such as *k*, ω_p, ω_c etc. The semiconductor crystal used for this purpose is n-InSb at 77 K duly irradiated by a nanosecond pulsed 10.6 μm CO_2 laser. The physical constants used are [8]: $\rho = 5.8\times10^3\,\mathrm{kg\,m^{-3}}$, $m = 0.0145m_e$ (m_e the free mass of electron), $\nu = 3\times10^{11}\,\mathrm{s^{-1}}$, $\varepsilon_1 = 15.8$, $\omega_a = 10^{12}\,\mathrm{s^{-1}}$, $v_a = 4\times10^3\,\mathrm{ms^{-1}}$, $\omega_0 = 1.78\times10^{14}\,\mathrm{s^{-1}}$, $\Gamma_a = 2\times10^{10}\,\mathrm{s^{-1}}$, $\eta = 3.9$.

The dependence of E_{0th} on different parameters such as *k*, ω_p, ω_c etc. may be studied from Eq. (16). It is clear from this equation that an increase in the value of $\omega_c(B_0)$ will decrease the value of δ_1 and δ_2 and hence E_{0th}. As an illustration, Fig. 1 shows variation of E_{0th} as a function of AW number *k* for $n_0 = 10^{24}\,\mathrm{m^{-3}}$ and $\omega_c = 0.01\omega_0$. Curves (*a*), (*b*) and (*c*) represent the features for *D* = 0.2, 0.3 and 0.5 m^2s^{-1} respectively.

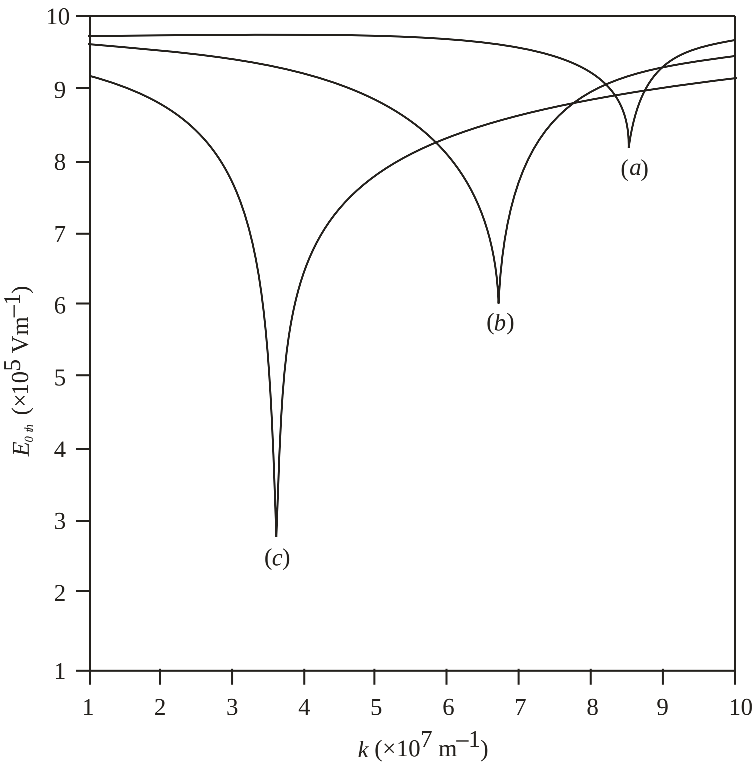

Fig. 1. Variation of threshold pump amplitude E_{0th} on AW number *k* for $n_0 = 10^{24}m^{-3}$, $\mu_c = 0.01\mu_0$. Curves (*a*), (*b*) and (*c*) are for *D* = 0.2, 0.3 and 0.5 m^2s^{-1} respectively.

It can be seen that in all the three cases E_{0th} decreases sharply with increase in k acquiring a minimum value $(E_{0th})_{\min} = 8.2\times10^5, 6\times10^5$ and $2.7\times10^5\,\mathrm{Vm}^{-1}$ at $k = 8.5\times10^7, 6.7\times10^7$ and $3.6\times10^7\,\mathrm{m}^{-1}$ for D = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively. The increase in value of D decreases the value of $(E_{0th})_{\min}$ and shifts towards a lower value of k. Using Eq. (16), it can be shown that at a particular value of ω_c the dip of E_{0th} corresponds to $k = \omega_p^2 \left(\frac{\omega_1}{\nu D}\right)^{1/2} \left(1 + \frac{\omega_c^2}{\nu^2}\right)^{-1} = k_m$ and thus influenced by the carrier concentration n_0 (via ω_p), the magnetic field B_0 (via ω_c), and diffusion coefficient D. Obviously, in a heavily doped sample, E_{0th} minimizes at particular value of k while an increase in applied magnetic field and/or diffusion of the carriers further minimizes $(E_{0th})_{\min}$ and shifts towards lower values of k.

The quantitative analysis of gain constant of AW $g_a(\omega_a)$ associated with parametric excitation process as a function of different parameters such as E_0, ω_p, ω_c etc. may be studied from Eq. (17).

Fig. 2 displays the variation of $g_a(\omega_a)$ with pump field E_0 for $n_0 = 10^{24}\,\mathrm{m}^{-3}$, $\omega_c = 0.01\omega_0$, $k = 5\times10^7\,\mathrm{m}^{-1}$. Curves ($a$), ($b$) and ($c$) represent the features for D = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively.

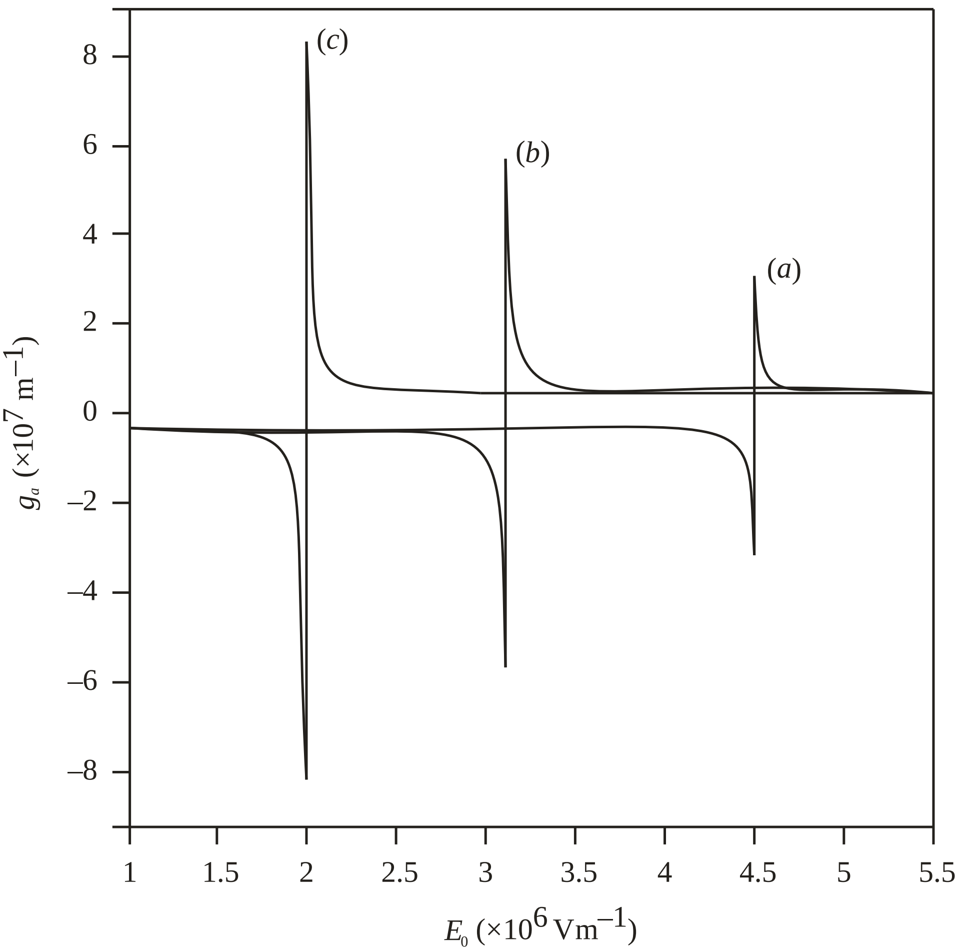

Fig. 2. Variation of gain constant of AW g_a with pump field E_0 for $n_0 = 10^{24}\mathrm{m}^{-3}$, $0.01\mu_0$, $k = 5 \times 10^7\mathrm{m}^{-1}$. Curves ($a$), ($b$) and ($c$) are for D = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively.

For these set of data, the values of E_{0th} is found to be equal to $4.5\times10^6, 3.2\times10^6$ and $2\times10^6\,\mathrm{Vm}^{-1}$ respectively. It may be inferred that in all the three cases, for $E_0 < E_{0th}$, $g_a(\omega_a)$ is negative (which indicates absorption) and remains almost constant with the increase in E_0. However, as E_0 approaches E_{0th}, $g_a(\omega_a)$ falls rapidly acquiring minimum value ($-3.2\times10^7, -5.8\times10^7$ and $-8.2\times10^7\,\mathrm{m}^{-1}$ for D = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively) followed by a very sharp rise making $g_a(\omega_a) = 0$ at $E_0 = E_{0th}$. Beyond this point, $g_a(\omega_a)$ becomes positive (which indicates amplification) and shoots up to its maximum value ($3.2\times10^7, 5.8\times10^7$ and $8.2\times10^7\,\mathrm{m}^{-1}$ for D = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively) beyond which the gain constant starts decreasing and becomes minimum. While comparing the results of curves (*a*), (*b*) and (*c*), it can be observed that with increasing *D*, $g_a(\omega_a)$ increases and the corresponding E_{0th} shifts towards lower values. A rise in gain constant is again witnessed if E_0 is further increased which may be explained as follows: The gain increases with E_0 overcoming the attenuation below threshold field and exhibit an abrupt rise due to modification of the effective second-order susceptibility which is induced by the space charge field. In the AO device, the AO interaction parameter is modulated by the diffusion current and the modified AW frequency $(\omega_a^2 - \nu D k^2)$ under the influence of the intense induced pump field E_0. Beyond this point, the intensity of space charge wave is increased resulting in a reverse transfer of energy from the AO field to the material waves in the resonant regime resulting in fall of gain. However as the pump field increases further, it becomes strong enough to derive the space-charge waves overcoming dragging effect due to frictional forces and thereby again exhibit rise in gain. Hence this variation pattern may be attributed to factor Φ in Eq. (17). Thus by suitably choosing the strength of pump field, we may control the amplification/attenuation characteristics of the medium for the generated AW.

Fig. 3 shows the variation of $g_a(\omega_a)$ with carrier concentration n_0 (via ω_p) for $\omega_c = 0.01\omega_0$, $k = 5\times10^7\,\mathrm{m}^{-1}$, $E_0 = 5\times10^6\,\mathrm{Vm}^{-1}$. Curves (*a*), (*b*) and (*c*) represent the features for *D* = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively. It is evident from Eq. (16) that E_{0th} reduces appreciably with an increase in carrier concentration (via parameters δ_1 and δ_2) and hence strongly depends upon it. It may be observed from Fig. 3 that at lower carrier concentration where the considered value of E_0 lies below the threshold value, the gain constant is negative and remains almost constant with increase in ω_p. However, as ω_p reaches the value for which E_0 becomes the threshold field, $g_a(\omega_a)$ falls rapidly acquiring a minimum value ($-2.4\times10^7, -4.8\times10^7$ and $-7.7\times10^7\,\mathrm{m}^{-1}$ for *D* = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively) followed by a sharp rise making $g_a(\omega_a) = 0$ (at $\omega_p = 8.4\times10^{13}, 6.7\times10^{13}$ and $3.6\times10^{13}\,\mathrm{s}^{-1}$ for *D* = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively). Beyond this point, $g_a(\omega_a)$ becomes positive and shoots up to its maximum value ($2.4\times10^7, 4.8\times10^7$ and $7.7\times10^7\,\mathrm{m}^{-1}$ for *D* = 0.2, 0.3 and 0.5 $\mathrm{m^2s^{-1}}$ respectively) beyond which the gain constant starts decreasing and saturates to a very small value. While comparing the results of curves (*a*), (*b*) and (*c*), it can be observed that increase in value of *D* decreases/increases peak value of $g_a(\omega_a)$ and shifts towards lower values of ω_p. This type of variation of $g_a(\omega_a)$ with n_0 agrees well with available literature [8].

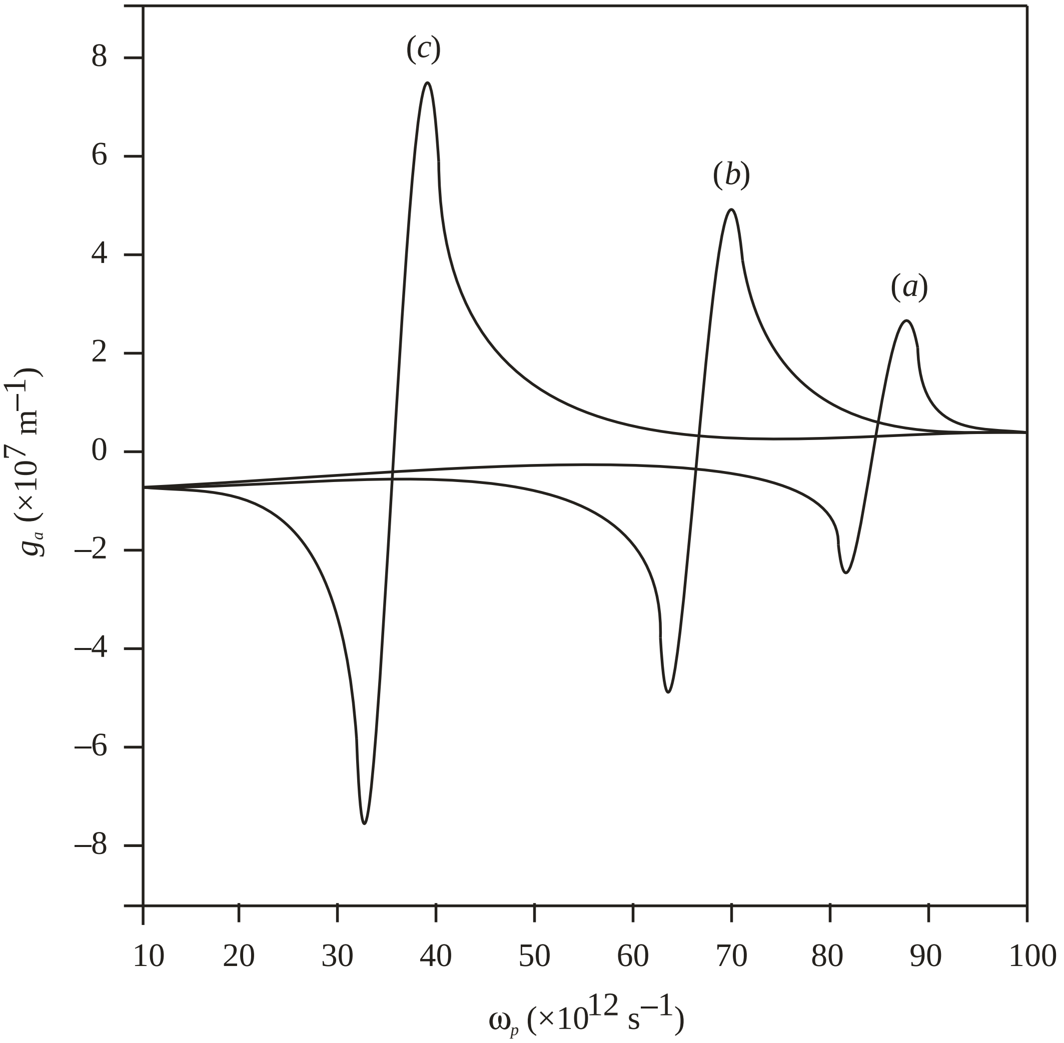

Fig. 3. Variation of gain constant of AW g_a with carrier concentration (via μ_p) for $0.01\mu_0$, $k = 5 \times 10^7 m^{-1}$, $E_0 = 5 \times 10^6$ Vm^{-1}. Curves (*a*), (*b*) and (*c*) are for *D* = 0.2, 0.3 and 0.5 m^{2}s^{-1} respectively.

Fig. 4 shows the variation of $g_a(\omega_a)$ with magnetic field B_0 (via ω_c) for $n_0 = 10^{24} m^{-3}$, $k = 5\times 10^7 m^{-1}$, $E_0 = 5\times 10^6 Vm^{-1}$. Curves (*a*), (*b*) and (*c*) represent the features for *D* = 0.2, 0.3 and 0.5 m^{2}s^{-1} respectively. At $\omega_c << \omega_0$, $g_a(\omega_a)$ increases sharply due to increase in parameter Φ and attains a maximum value ($8\times 10^7, 1.1\times 10^8$ and $1.7\times 10^8 m^{-1}$ at $\omega_c = 8.5\times 10^{13}, 7.2\times 10^{13}$ and $4.1\times 10^{13} s^{-1}$ for *D* = 0.2, 0.3 and 0.5 m^{2}s^{-1} respectively). A further increase in ω_c (when $\omega_c >> \nu$) causes a rapid decrease in parameter Φ and hence the growth rate of $g_a(\omega_a)$ of the AW. While comparing the results of curves (*a*), (*b*) and (*c*), it can be observed that increase in value of *D* increases $g_a(\omega_a)$ and shifts towards lower values of ω_c.

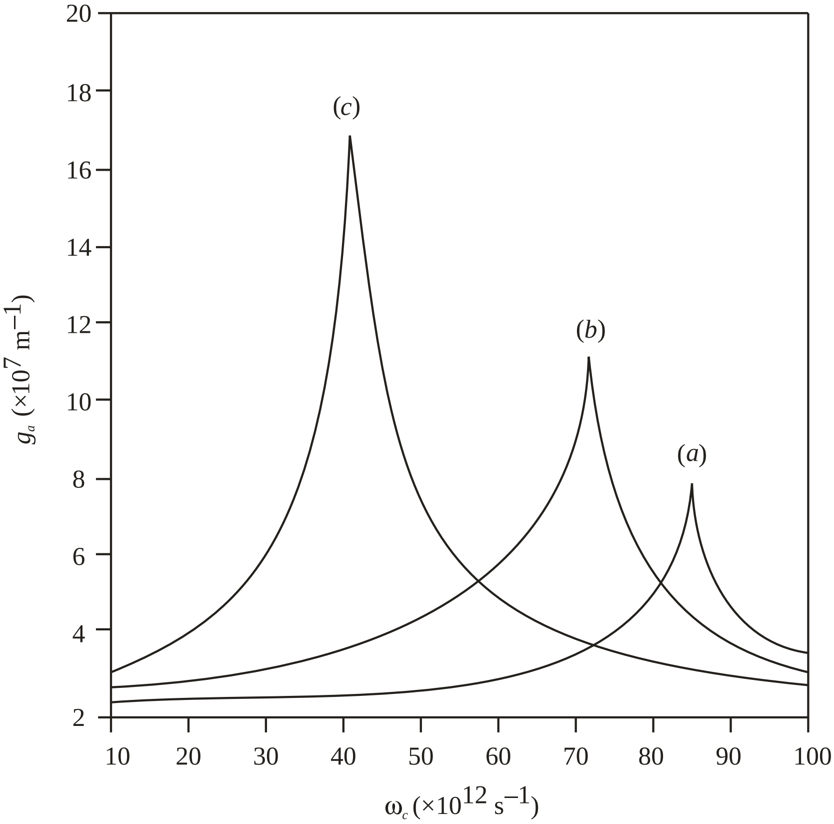

Fig. 4. Variation of gain constant of AW g_a with magnetic field (via μ_c) for $n_0 = 10^{24}$m^{-3}, $k = 5 \times 10^7$m^{-1}, $E_0 = 5 \times 10^6$ Vm^{-1}. Curves (*a*), (*b*) and (*c*) are for D = 0.2, 0.3 and 0.5 m^{2}s^{-1} respectively.

The above discussion thereby provides an insight into developing potentially useful diffusion-induced acousto-optical parametric amplifiers by incorporating the material characteristics of the medium.

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