Threshold and gain characteristics of Brillouin back-scattered stokes mode in magnetized III-V semiconductors

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ABSTRACT

In this paper, a theoretical formulation is developed to study threshold and gain characteristics of Brillouin back-scattered Stokes mode (BBSM) in transversely magnetized doped III-V semiconductors. Expressions are obtained for threshold pump electric field $E_{0,th}$ and gain coefficients of BBSM (via effective Brillouin susceptibility $(\chi_B)_{eff}$) under different situations of practical interest, i.e. (i) electrostrictive coupling only (g_γ), (ii) piezoelectric coupling only (g_β), and (iii) electrostrictive and piezoelectric coupling both ($g_{\beta\gamma}$). Resonance conditions cause a sharp fall in threshold field and rise in gain coefficients of BBSM such that $g_\gamma < g_\beta < g_{\beta\gamma}$. The analysis establishes the importance of III-V semiconductors for obtaining large BBSM gain coefficients by controlling the material parameters and/or externally applied magnetic field. The dependence of BBSM gain coefficients on the magnetostatic field strength around resonance could be used in the fabrication of ultra-fast optical switching devices.

Keywords: *Stimulated Brillouin scattering, Stokes mode, III-V semiconductors, magnetic field.*

I. INTRODUCTION

Stimulated Brillouin scattering (SBS) is continuously receiving attention owing to its potential applications in diverse areas such as optical fiber Brillouin sensors [1, 2], laser induced fusion [3], pulse squeezing [4, 5], optical phase conjugation (OPC) [6, 7] etc. In the phenomenon of SBS, an intense pump and Brillouin scattered waves interact in the Brillouin active medium (here III-V Semiconductor) and excite an acoustic wave via electrostriction. The generated acoustic wave traveling in the medium, in turn, causes a periodic modulation of refractive index as a volume grating, which scatters the pump wave via Bragg diffraction. The scattered Stokes component is downshifted in frequency because of the Doppler shift associated with a grating moving at the acoustic velocity. The pump wave and Stokes components interfere to generate traveling intensity fringes. When the velocity and spacing of these fringes match the velocity and the wavelength of the acoustic wave, the acoustic wave is amplified via electrostriction. Such a positive feedback process leads to exponential growth of the Stokes components. The anti-Stokes component has much lower gain while the Stokes emission is more commonly observed [8]. In this paper, we therefore restrict ourselves to the Stokes component of scattered electromagnetic wave.

In the recent past, a great deal of theoretical research work on SBS has been explored in (*i*) centrosymmetric semiconductors by considering electrostrictive coupling only [9 - 11], and (*ii*) non-centrosymmetric semiconductors by considering piezoelectric coupling only [12 -14]; but nevertheless, the threshold value of pump electric field for the onset of SBS is observed very high and gain coefficient quite low. This demands more comprehensive efforts are needed in the theory of SBS. The motivation of the present study is to obtain large gain coefficient of Brillouin backscattered Stokes mode (BBSM) through an CO_2- n-InSb system by controlling the material parameters and/or externally applied magnetic field. For this we employ the well known hydrodynamic model of semiconductor plasma is employed. Using the coupled mode theory the BBSM gain coefficients are obtained under different situations of practical interest i.e. (i) electrostrictive coupling only (g_γ), (ii) piezoelectric coupling only (g_β), and (iii) electrostrictive and piezoelectric coupling both ($g_{\beta\gamma}$). The enhanced BBSM gain coefficient could be used for fabrication of fast optoelectronic devices such as optical phase conjugate mirrors with enhanced reflectivity.

Here, it should be worth pointing out that in comparison to other nonlinear optical materials, III-V semiconductor crystals offer considerable flexibility for fabrication of optoelectronic devices because [15 - 17]: (i) the large number of free electrons/holes available as majority charge carriers in doped semiconductors manifest many more exciting nonlinear optical phenomena, (ii) optical properties can be easily modified by compositions, micro-structuring and externally applied fields, (iii) observation of large nonlinear optical nonlinearities in the vicinity of band-gap resonant transitions, (iv) carrier recombination times can be altered through design of materials and device structures, (v) either absorption changes or refractive index changes can be utilized, (vi) devices may operate either at normal incidence or in waveguides, and (vii) devices are integrable with other optoelectronic components. Therefore, the III-V semiconductor crystals have been the natural choice for studying threshold and gain characteristics of BBSM.

II. THEORETICAL FORMULATIONS

The present formulation has been developed under the following assumptions: (i) the semiconductor crystal is assumed to be maintained at 77 K temperature (because at liquid nitrogen temperature the dominant mechanism for transfer of energy and momentum of electrons is due to scattering of acoustic phonons) [18], (ii) the first-order BBSM of pump wave is considered (because BBSM gain coefficient is four orders of magnitude higher than the Brillouin forward-scattered Stokes mode gain coefficient in piezoelectric low doped semiconductors) [13], and (iii)

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the semiconductor crystal is immersed in a transverse magnetostatic field (because in this configuration the Lorentz force contribution to $(\chi_B)_{eff}$ is maximum) [19].

The phenomenon of SBS occurs due to parametric coupling among three waves: the input strong pump beam field $E_0(x,t) = E_0 \exp[i(k_0 x - \omega_0 t)]$, the acoustic phonon mode $u(x,t) = u_0 \exp[i(k_a x - \omega_a t)]$, and the scattered Stokes mode of pump wave $E_s(x,t) = E_s \exp[i(k_s x - \omega_s t)]$. The momentum and energy conservation relations for these modes should satisfy the phase matching conditions: $\hbar \boldsymbol{k}_0 = \hbar \boldsymbol{k}_s + \hbar \boldsymbol{k}_a$ and $\hbar\omega_0 = \hbar\omega_s + \hbar\omega_a$. The time varying pump electric field produce density perturbations and is thus capable of deriving acoustic waves in a Brillouin active medium (here III-V semiconductor crystal). Let $u(x, t)$ be the deviation of a point x from its equilibrium position, so that the strain along the direction of pump wave is $\partial u/\partial x$. The equation of motion of $u(x, t)$ can be expressed as [20]:

$$\frac{\partial^2 u}{\partial t^2} = \frac{C}{\rho}\frac{\partial^2 u}{\partial x^2} - 2\Gamma_a \frac{\partial u}{\partial t} + \frac{(F^{(1)} + F^{(2)})}{\rho} \tag{1}$$

where ρ is the mass density of crystal. C represents the linear elastic modulus of the crystal such that the acoustic velocity is given by $v_a = \sqrt{C/\rho}$. The term $2\Gamma_a(\partial u/\partial t)$ has been introduced phenomenologically to include the acoustic damping [21]. $F^{(1)}\left(= \beta \frac{\partial(E_{1x})}{\partial x}\right)$ and $F^{(2)}\left(= \frac{\gamma}{2}\frac{\partial(E_0 E_{1x}^*)}{\partial x}\right)$ stand for first- and second-order forces arising due to thematerial properties such as piezoelectric and electrostriction of the crystal medium, respectively. Here β and γ are piezoelectric and electrostriction coefficients of the medium. It should be worth pointing out that in the presence of the time varying pump electric field the ions within the lattice move into nonsymmetrical position, usually producing a contraction in the direction of the field and an expansion across it. The electrostrictive force thus produced is the origin of the electrostriction in the medium. The coupling of pump electric field and elastic properties of the lattice gives rise to piezoelectric force in the medium. E_{1x} is the space charge electric field of the medium. The asterisk (*) stands for the conjugate of a complex entity.

In the previously reported works, the origin of the SBS has been taken into either first- or second order forces. In the present analysis, we considered both the piezoelectric and electrostrictive forces to study threshold and gain characteristics of BSSM.

The other basic equations of the analysis are:

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

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

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

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$$\vec{P}_{es} = -\gamma \frac{\partial u^*}{\partial x}(\vec{E}_0) \quad (5)$$

$$\frac{\partial E_1}{\partial x} + \frac{\beta}{\varepsilon}\frac{\partial^2 u}{\partial x^2} + \frac{\gamma}{\varepsilon}\frac{\partial^2 u^*}{\partial x^2}(E_0) = -\frac{n_1 e}{\varepsilon}. \quad (6)$$

where $\vec{E}_e = \vec{E}_0 + (\vec{v}_0 \times \vec{B}_0)$.

Eqs. (2) and (3) are the zeroth- and first-order electron momentum transfer equations, in which $\vec{v}_1$ and ν being the first-order oscillatory fluid velocity and collision frequency of an electron, respectively. $\vec{v}_0$ is the oscillatory fluid velocity of an electron of charge *-e* and effective mass *m* at pump wave frequency ω_0. In eq. (2), $\vec{E}_e$ represents the effective electric field which includes the Lorentz force $(\vec{v}_0 \times \vec{B}_0)$ due to external magnetic field. In eq. (3), we have neglected the effect due to $(\vec{v}_0 \times \vec{B}_1)$ by assuming that the propagating acoustic mode is producing a longitudinal electric field. Eq. (4) is the continuity equation for electrons, in which n_0 and n_1 are equilibrium and perturbed electron density, respectively. Eq. (5) illustrates that the acoustic wave generated via electrostrictive strain modulates the dielectric constant of the Brillouin medium and gives rise the nonlinear induced polarization P_{es}. Poisson's eq. (6) gives the space charge field E_1, in which $\varepsilon(=\varepsilon_0\varepsilon_1)$ is the dielectric constant of the Brillouin medium; ε_1 being the static dielectric constant of the medium.

The piezoelectric and electrostrictive forces generate a carrier density perturbation in the Brillouin active medium which can be obtained by using the method adopted by one of the present authors [13].

Differentiating eq. (4) and then putting the first-order derivatives of v_0 and v_1 from eqs. (2) and (3) and E_1 from eq. (6), we obtain

$$\frac{\partial^2 n_1}{\partial t^2} + \nu\frac{\partial n_1}{\partial t} + \bar{\omega}_p^2 n_1 + \frac{n_0 e k_s^2 u^*(A_1)}{m\varepsilon_1} E_0 E_s = i n_1 k_s \bar{E} \quad (7)$$

where $\bar{E} = \frac{e}{m}(\vec{E}_e)$, $A_1 = \frac{\beta^2\delta_1\delta_2}{|E_0|^2} + \frac{\beta\gamma\delta_1\delta_2}{E_0} + \gamma^2$, $\delta_1 = 1 - \frac{\omega_c^2}{(\omega_0^2 - \omega_c^2)}$, $\delta_2 = 1 - \frac{\omega_c^2}{(\omega_s^2 - \omega_c^2)}$, $\bar{\omega}_p = \frac{\omega_p \nu}{(\nu^2 + \omega_c^2)^{1/2}}$,

$\omega_c = \frac{e}{m}B_0$ (electron cyclotron frequency), and $\omega_p = \left(\frac{n_0 e^2}{m\varepsilon}\right)^{1/2}$ (electron plasma frequency).

The density perturbation n_1 can be expressed as: $n_1 = n_{1s}(\omega_a) + n_{1f}(\omega_s)$, where n_{1s} (slow frequency component) oscillates at acoustic wave frequency ω_a and n_{1f} (high frequency component) is associated with electromagnetic wave frequencies $\omega_0 \pm \omega_a$. The higher-order terms at frequencies $\omega_{s,p}(=\omega_0 \pm p\omega_a)$, for $p = 2,3,\ldots$, being off-resonant, are neglected. In the forthcoming formulation, we will consider only the first-order Stokes component of the back-scattered electromagnetic wave (i.e. first-order BBSM). Under rotating-wave approximation (RWA), eq. (7) leads to the following coupled equations:

$$\frac{\partial^2 n_{1f}}{\partial t^2}+\nu\frac{\partial n_{1f}}{\partial t}+\bar{\omega}_p^2 n_{1f}+\frac{n_0 e k_s^2 u^*(A_1)}{m\varepsilon_1}E_0E_s=-in_{1s}^*k_s\bar{E} \tag{8a}$$

and

$$\frac{\partial^2 n_{1s}}{\partial t^2}+\nu\frac{\partial n_{1s}}{\partial t}+\bar{\omega}_p^2 n_{1s}=in_{1f}^*k_s\bar{E}\,. \tag{8b}$$

Eqs. (8a) and (8b) reveal that the density perturbation components are coupled to each other via the pump electric field. By solving these equations and using eq. (1b), the expression for n_{1s} is obtained as

$$n_{1s}=\frac{\varepsilon_0 n_0 k_a k_s (A_1)(A_2)^{-1}}{2\varepsilon\rho(\omega_a^2-k_a^2v_a^2-2i\Gamma_a\omega_a)}E_0E_s^* \tag{9}$$

where $A_2=1-\frac{(\Omega_1^2-i\nu\omega_s)(\Omega_2^2+i\nu\omega_a)}{k_s^2\bar{E}^2}$, in which $\Omega_1^2=\bar{\omega}_p^2-\omega_s^2$ and $\Omega_2^2=\bar{\omega}_p^2-\omega_a^2$.

The nonlinear induced current density of BBSM can be obtained as

$$J_1(\omega_s)=n_0ev_1+n_{1s}^*ev_0=\frac{\varepsilon\nu\omega_p^2E_s}{(\nu^2+\omega_0^2)}+\frac{\varepsilon_0 k_a k_s\omega_p^2(\nu-i\omega_0)(A_1)(A_2)^{-1}}{2\rho(\omega_a^2-k_a^2v_a^2-2i\Gamma_a\omega_a)(\omega_c^2-\omega_0^2)}\left|E_0\right|^2E_s^*\,. \tag{10}$$

The time integral of induced current density yields nonlinear induced polarization as

$$P_{cd}(\omega_s)=\int J_{cd}(\omega_s)dt=\frac{\varepsilon_0 k_a k_s\omega_p^2\omega_0^3(A_1)(A_2)^{-1}}{2\rho\omega_s(\omega_a^2-k_a^2v_a^2-2i\Gamma_a\omega_a)(\omega_c^2-\omega_0^2)}\left|E_0\right|^2E_s^*\,. \tag{11}$$

The corresponding Brillouin susceptibility due to induced current density $(\chi_B)_{cd}$ is given by

$$(\chi_B)_{cd}=\frac{k_a k_s\omega_p^2\omega_0^3(A_1)(A_2)^{-1}}{2\rho\omega_s(\omega_a^2-k_a^2v_a^2-2i\Gamma_a\omega_a)(\omega_c^2-\omega_0^2)}\,. \tag{12}$$

In addition to $P_{cd}(\omega_s)$, the Brillouin active medium should also possess electrostrictive polarization $P_{es}(\omega_s)$, arising via interaction between pump wave and acoustic wave generated in the medium. It can be obtained from equations (1b) and (5) as:

$$P_{es}(\omega_s)=\frac{k_a k_s\omega_0^4\gamma^2\left|E_0\right|^2E_s^*}{2\rho(\omega_a^2-k_a^2v_a^2-2i\Gamma_a\omega_a)(\omega_c^2-\omega_0^2)^2}\,. \tag{13}$$

The corresponding Brillouin susceptibility due to electrostrictive polarization $(\chi_B)_{es}$ is given by

$$(\chi_B)_{es}=\frac{k_a k_s\omega_0^4\gamma^2}{2\varepsilon_0\rho(\omega_a^2-k_a^2v_a^2-2i\Gamma_a\omega_a)(\omega_c^2-\omega_0^2)^2}\,. \tag{14}$$

Using eqs. (12) and (14), we obtain the effective Brillouin susceptibility $(\chi_B)_{eff}$ as

$$(\chi_B)_{eff}=(\chi_B)_{cd}+(\chi_B)_{es}=\frac{k_a k_s\omega_0^4(\omega_a^2-k_a^2v_a^2+2i\Gamma_a\omega_a)(A_1)}{2\varepsilon_0\rho[(\omega_a^2-k_a^2v_a^2)^2+4\Gamma_a^2\omega_a^2)(\omega_c^2-\omega_0^2)}\times\left[1+\frac{\omega_p^2}{\omega_0\omega_s}(A_2)^{-1}\right]. \tag{15}$$

Rationalization eq. (15), the imaginary part of effective Brillouin susceptibility is given by

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$$(\chi_{Bi})_{eff} = \frac{k_a k_s \omega_0^4 \omega_a \Gamma_a (A_1)}{\varepsilon_0 \rho[(\omega_a^2 - k_a^2 v_a^2)^2 + 4\Gamma_a^2 \omega_a^2)(\omega_c^2 - \omega_0^2)} \times \left[1 + \frac{\omega_p^2}{\omega_0 \omega_s}(A_2)^{-1}\right]. \quad (16)$$

The threshold pump electric field $E_{0,th}$ for the onset of BBSM is obtained by putting $(\chi_{Bi})_{eff} = 0$ as

$$E_{0,th} = \frac{m(\omega_0^2 - \omega_c^2)}{e k_s \omega_0^2} \left|(\Omega_1^2 - i\nu\omega_s)(\Omega_2^2 + i\nu\omega_a)\right|^{1/2}. \quad (17)$$

Eq. (17) reveals that $E_{0,th}$ for the onset of BBSM is independent of β or γ (i.e. type of coupling for the occurrence of SBS process). Therefore the laser (pump wave) – semiconductor crystal interaction will be dominated by the phenomenon of SBS at $E_0 > E_{0,th}$.

We shall now extend the theoretical formulation for BBSM gain coefficient $g(\omega_s) = \frac{k_s}{2\varepsilon_1}(\chi_{Bi})_{eff} |E_0|^2$ [13] under different situations of practical interest.

(i) For both (piezoelectric and electrostrictive) couplings ($\beta \neq 0$, $\gamma \neq 0$):

$$[g(\omega_s)]_{\beta\gamma} = \frac{k_a k_s^2 \omega_0^4 \omega_a \Gamma_a (A_1) |E_0|^2}{2\varepsilon_0 \varepsilon_1 \rho[(\omega_a^2 - k_a^2 v_a^2)^2 + 4\Gamma_a^2 \omega_a^2)(\omega_c^2 - \omega_0^2)} \times \left[1 + \frac{\omega_p^2}{\omega_0 \omega_s}(A_2)^{-1}\right]. \quad (18)$$

(ii) For electrostrictive coupling only ($\beta = 0$, $\gamma \neq 0$):

$$[g(\omega_s)]_{\gamma} = \frac{k_a k_s^2 \omega_0^4 \omega_a \Gamma_a \gamma^2 |E_0|^2}{2\varepsilon_0 \varepsilon_1 \rho[(\omega_a^2 - k_a^2 v_a^2)^2 + 4\Gamma_a^2 \omega_a^2)(\omega_c^2 - \omega_0^2)} \times \left[1 + \frac{\omega_p^2}{\omega_0 \omega_s}(A)^{-1}\right]. \quad (19)$$

(iii) For piezoelectric coupling only ($\beta \neq 0$, $\gamma = 0$):

$$[g(\omega_s)]_{\beta} = \frac{k_a k_s^2 \omega_0^4 \omega_a \Gamma_a \beta^2 \delta_1 \delta_2}{2\varepsilon_0 \varepsilon_1 \rho[(\omega_a^2 - k_a^2 v_a^2)^2 + 4\Gamma_a^2 \omega_a^2)(\omega_c^2 - \omega_0^2)} \times \left[1 + \frac{\omega_p^2}{\omega_0 \omega_s}(A)^{-1}\right]. \quad (20)$$

III. RESULTS AND DISCUSSION

To have a numerical estimation of the results, we consider the n-InSb semiconductor crystal is assumed to be irradiated by pulsed CO_2 laser at 10.6 μm. The parameters of sample are [13, 14]: $m = 0.0145 m_e$ (m_e the free mass of electron), $\varepsilon_1 = 15.8$, $v_a = 4\times10^3\,\text{ms}^{-1}$, $\beta = 0.054\,\text{Cm}^{-2}$, $\gamma = 5\times10^{-10}\,\text{s}^{-1}$, $\Gamma_a = 2\times10^{10}\,\text{s}^{-1}$, $\rho = 5.8\times10^3\,\text{kg m}^{-3}$, $\omega_a = 2\times10^{11}\,\text{s}^{-1}$, $k_a = 5\times10^7\,\text{m}^{-1}$, $v_a = 4\times10^3\,\text{ms}^{-1}$, $\nu = 4\times10^{11}\,\text{s}^{-1}$ and $\omega_0 = 1.78\times10^{14}\,\text{s}^{-1}$.

The main focus of this formulation is to study threshold characteristics and gain coefficients of BBSM in transversely magnetized doped III-V semiconductors under above mentioned different cases.

The nature of dependence of the threshold pump electric field $E_{0,th}$ necessary for the onset of BBSM on different parameters such as externally applied magnetostatic field B_0 (in terms of ω_c/ω_0), doping concentration n_0 (in terms of ω_p/ω_0) etc. may be studied from eq. (17). The results for n-InSb are plotted in Figs. 1 and 2.

Fig. 1 shows the variation of $E_{0,th}$ with B_0 (in terms of ω_c/ω_0) for $\omega_p = 0.3\omega_0$. It can be observed that initially $E_{0,th}$ is remarkably high and remains constant for $\omega_c/\omega_0 \le 0.7$. An increase in B_0 causes a sharp fall in $E_{0,th}$ around $\omega_c/\omega_0 \approx 0.75$ (corresponding $B_0 = 10.6$ T). This fall arises due to resonance between scattered Stokes wave frequency and electron-cyclotron frequency (i.e. $\omega_s^2 \sim \omega_c^2$). A further increase in B_0 causes departure from resonance and $E_{0,th}$ increases and remains constant for $\omega_c/\omega_0 \approx 0.9$. With further increase in B_0 causes a deeper sharp fall in $E_{0,th}$ around $\omega_c/\omega_0 \approx 1$ (corresponding $B_0 = 14.2$ T). This fall arises due to resonance between pump wave frequency and electron-cyclotron frequency (i.e. $\omega_0^2 \sim \omega_c^2$). This behaviour reflects the fact $E_{0,th} \propto (\omega_0^2 - \omega_c^2)$ in confirmatory with eq. (17). With further increase in B_0 causes departure from this resonance condition and $E_{0,th}$ increases and saturates at higher B_0.

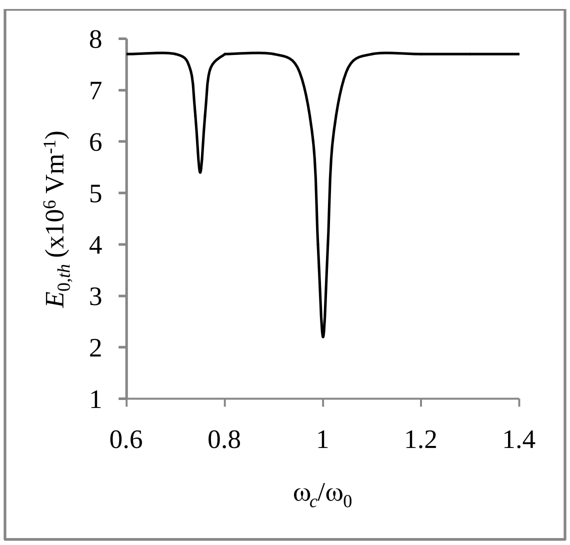

Fig. 1: Variation of $E_{0,th}$ with B_0 (in terms of ω_c/ω_0) for $\omega_p = 0.3\omega_0$.

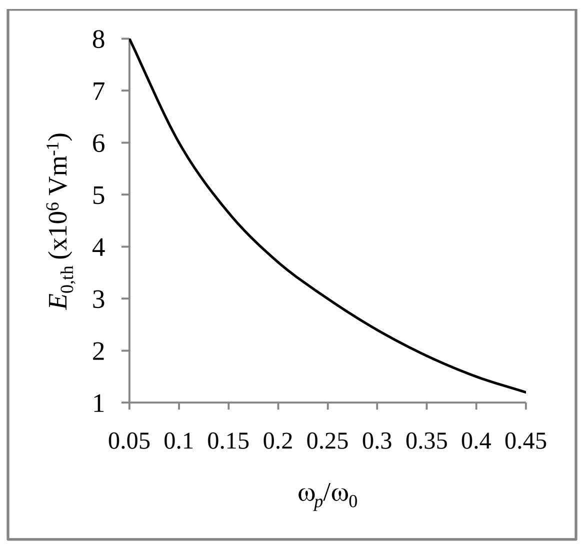

Fig. 2: Variation of $E_{0,th}$ with n_0 (in terms of ω_p/ω_0) for $\omega_c = \omega_0$.

A comparison between two resonance conditions yield the following ratio:

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$$\frac{(E_{0,th})_{\omega_0^2 \sim \omega_c^2}}{(E_{0,th})_{\omega_s^2 \sim \omega_c^2}} \approx 2.45 .$$

Fig. 2 shows the variation of $E_{0,th}$ with n_0 (in terms of ω_p/ω_0) for $\omega_c = \omega_0$. It can be observed that for smaller values of n_0, $E_{0,th}$ starts at a relatively high value but with increasing n_0, $E_{0,th}$ decreases parabolically. This behavior arises due to modified plasma frequency $\omega_{pm} \propto \left|(\Omega_1^2 - i\nu\omega_s)(\Omega_2^2 + i\nu\omega_a)\right|^{1/2}$ in eq. (17). Thus low threshold pump electric field is required to incite the SBS process in highly doped magnetized semiconductors.

The nature of dependence of BBSM gain coefficients due to electrostrictive coupling only (g_γ), piezoelectric coupling only (g_β), and electrostrictive and piezoelectric coupling both ($g_{\beta\gamma}$) on different parameters such as pump electric field $E_0(> E_{0,th})$, externally applied magnetostatic field B_0 (in terms of ω_c/ω_0), doping concentration n_0 (in terms of ω_p/ω_0) etc. may be studied from eqs. (18) – (20). The results for n-InSb are plotted in Figs. 3 – 5.

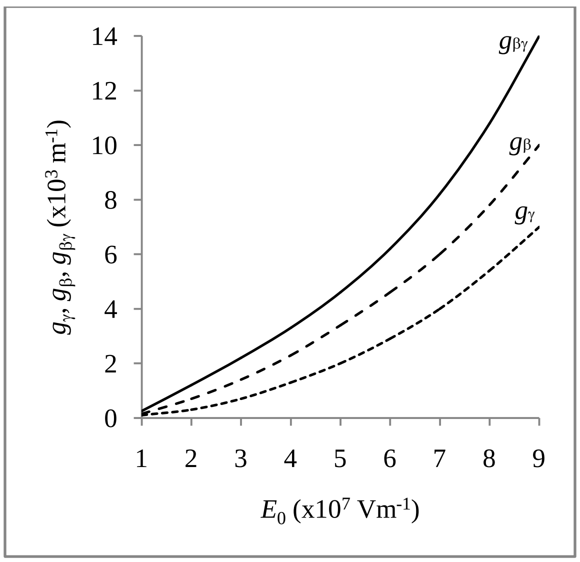

Fig. 3: Variation of BBSM gain coefficients with E_0 for $\omega_p = 0.3\omega_0$ and $\omega_c = \omega_0$.

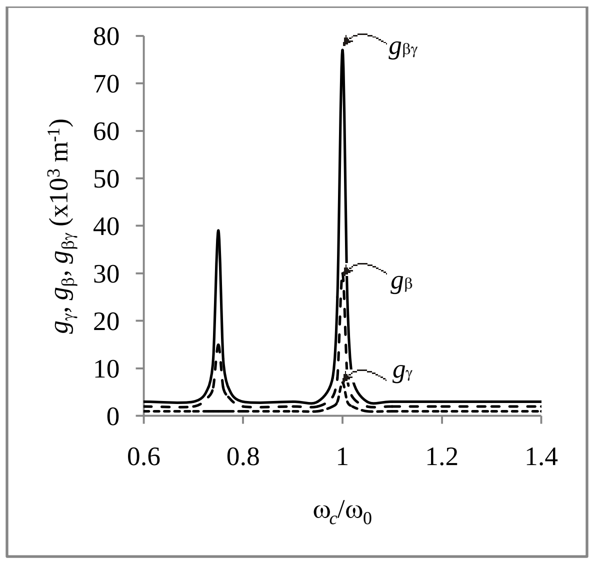

Fig. 4: Variation of BBSM gain coefficients with B_0 (in terms of ω_c/ω_0) for $\omega_p = 0.3\omega_0$.

Fig. 3 shows the variation of BBSM gain coefficients with E_0 for $\omega_p = 0.3\omega_0$ and $\omega_c = \omega_0$. It can be observed that in all the three cases the gain coefficients are negligibly small for smaller values of E_0. With increasing E_0, the gain coefficients increases gradually. Thus a larger E_0 yields higher gain coefficients of BBSM. While making a comparison among the three gain coefficients, we obtain $g_\gamma < g_\beta < g_{\beta\gamma}$. Moreover, with increase in E_0 the

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inequality is more pronounced. It should be pointed out that E_0 cannot be increased arbitrary because it may lead to optical damage of crystal. The range of E_0 considered in this study is well below the optical damage threshold of semiconductor crystal [22].

Fig. 4 shows the variation of BBSM gain coefficients with B_0 (in terms of ω_c / ω_0) for $\omega_p = 0.3\omega_0$ and $E_0 = 5 \times 10^7\,\mathrm{Vm}^{-1}$. It can be observed that in all the three cases the gain coefficients are negligibly small and remain constant for $\omega_c / \omega_0 \leq 0.7$. With increase in B_0 causes a sharp rise in gain coefficients g_β and $g_{\beta\gamma}$ around $\omega_c / \omega_0 \approx 0.75$ (corresponding $B_0 = 10.6\,\mathrm{T}$). This rise arises due to resonance condition: $\omega_s^2 \sim \omega_c^2$ ($g_\beta, g_{\beta\gamma} \propto (\omega_s^2 - \omega_c^2)^{-1}$ via parameter δ_2 in eqs. (18) and (20)). A further increase in B_0 causes departure from resonance and gain coefficients decreases and remains constant for $\omega_c / \omega_0 \approx 0.9$. With further increase in B_0 causes a enhanced sharp rise in gain coefficients around $\omega_c / \omega_0 \approx 1$ (corresponding $B_0 = 14.2\,\mathrm{T}$). This rise arises due to resonance condition: $\omega_0^2 \sim \omega_c^2$ ($g_\gamma, g_\beta, g_{\beta\gamma} \propto (\omega_0^2 \sim \omega_c^2)^{-1}$ in eqs. (18) – (20)). Beyond this point, we found that the gain coefficients become negligibly small and independent of magnetostatic field regime we considered. Thus the most striking feature of this analysis is that the applied magnetostatic field can be used as a control parameter to enhance the gain coefficients around resonance. It should be worth pointing out that around the resonance conditions ($\omega_s^2 \sim \omega_c^2, \omega_0^2 \sim \omega_c^2$), $v_{d,B} \approx v_a$; where $v_{d,B}$ is the magnetostatic field dependent drift velocity of electrons and v_a is the acoustic wave velocity. As a result of it more energy is transferred from pump wave to the acoustic wave, and eventually the acoustic wave gets amplified. In turn, the pump wave strongly interacts with amplified acoustic wave and as a result the strength of the BBSM enhances substantially. This dependence of BBSM gain coefficients on the magnetostatic field strength could be used in the fabrication of ultra-fast optical switching devices.

While making a comparison among the three gain coefficients it has been found that for the regime of magnetostatic field, the following inequality is satisfied: $g_\gamma < g_\beta < g_{\beta\gamma}$. Moreover, the BBSM gain coefficients are in the ratio $g_\gamma : g_\beta : g_{\beta\gamma} :: 1 : 15 : 38$ and $g_\gamma : g_\beta : g_{\beta\gamma} :: 1 : 4 : 11$ around $\omega_c \sim \omega_s$ and $\omega_c \sim \omega_0$, respectively.

A comparison between two resonance conditions yield the following ratio:

$$\frac{(g_\gamma, g_\beta, g_{\beta\gamma})_{\omega_0^2 \sim \omega_c^2}}{(g_\gamma, g_\beta, g_{\beta\gamma})_{\omega_s^2 \sim \omega_c^2}} \approx 3.45 .$$

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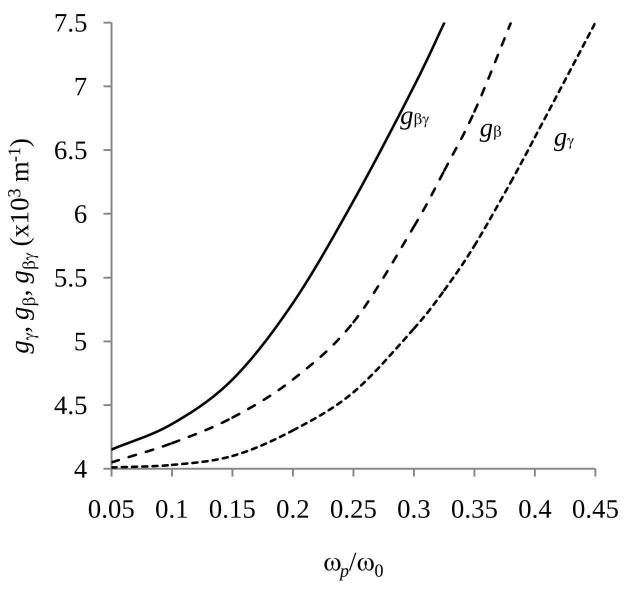

Fig. 5: Variation of BBSM gain coefficients with n_0 (in terms of ω_p/ω_0) for $\omega_c = \omega_0$ and $E_0 = 5\times10^7\,\mathrm{Vm}^{-1}$.

Fig. 5 shows the variation of BBSM gain coefficients with n_0 (in terms of ω_p/ω_0) for $\omega_c = \omega_0$ and $E_0 = 5\times10^7\,\mathrm{Vm}^{-1}$. It can be observed that for smaller values of n_0, the gain coefficients are relatively small but with increasing doping concentration, the gain coefficients increases quadratically for $\omega_p < 0.25\omega_0$ and linearly for $\omega_p > 0.25\omega_0$. Thus, a highly doped semiconductor yields larger SBS gain coefficients. An increase in doping concentration beyond the limit of this curve will make diffusion effects probable and the theoretical formulation needs to be modified; a work of future publication.

In conclusion, the study highlights the importance of electrostrictive and piezoelectric coupling in III-V semiconductors for obtaining large BBSM gain coefficients by controlling the material parameters and/or externally applied magnetostatic field and replaces the conventional idea of using high power pulsed lasers. The dependence of BBSM gain coefficients on the magnetostatic field strength around resonance could be used in the fabrication of ultra-fast optical switching devices. The analysis also suggests the possibility of optical phase conjugation. The enhanced BBSM gain coefficient could be used for fabrication of fast optoelectronic devices such as optical phase conjugate mirrors with enhanced reflectivity.

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