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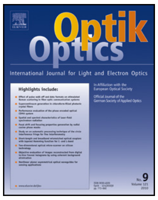

Original research article

Combined effects of density ripples and transverse magnetic field on the suppression of stimulated Raman scattering of X-mode laser in a plasma

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ABSTRACT

The present study shows that stimulated Raman Scattering of X-mode lasers may be suppressed significantly due to the presence of density ripples and transverse magnetic field in plasma. A laser propagating in magnetized plasma excites a primary upper hybrid wave and a sideband electromagnetic wave. Primary upper hybrid wave couples with density ripples and excites a secondary upper hybrid of same frequency but of longer wave number. Secondary wave is strongly Landau damped and diverts the energy available in feedback mechanism of Raman process. As a consequence, the growth rate of SRS reduces significantly. The growth rate of Raman process also decreases with applied magnetic field. The growth of Raman process is reduced ~ 40% when the ripple wave number is twice the propagation constant of pump laser (intensity 10^{15} W/ cm^2 at 1μm wavelength) in a 10% critical density plasma having electron temperature 1 keV.

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1. Introduction

Stimulated Raman scattering (SRS) of a laser propagating in a plasma, is studied extensively since late sixties due to its widespread applications in inertial confinement fusion [1–5]. High growth rate of stimulated Raman scattering is reported in various high intensity laser driven plasma studies [6–13]. In ICF, a high intensity laser beam is launched upon a hohlram having high atomic number. It produces x-rays which may start the implosion of the fusion pallets in the hohlrum. This implosion of fusion pallets indirectly forms underdense plasma having a scale length of only few millimetres. These conditions are conducive for the growth of SRS. SRS is a feedback process which reduces the net energy available with laser to heat the fusion pellets in ICF. SRS is therefore, not only a serious problem in ICF process and but also in other high power laser plasma interaction process such as laser wake field and beat wave accelerators [14,15]. In forward Raman scattering, an electron plasma wave having higher phase velocity accelerates the charged particle to very high energies and thus not only reduces the energy of incident laser beam but also maintain the symmetry required for ICF schemes. The main objective of the present work is to study the suppression of SRS utilizing stationary density ripple structure in magnetized plasma.

The density ripples in the plasma are produced by the beating of two counter propagating beams. If two counter propagating beam having same polarisation interfere with each other, the density profile of the electron in the plasma is modified on the time scale of nanoseconds. One can also produce high wavelength density ripple through the laser machining process.

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In this process, a high intensity short laser pulse with transverse is incident on inert gas jet and produces plasma in high intensity region. The hydrodynamic expansion of the plasma, after the transit of laser pulse, results in the reduction of the plasma density in these regions. This leads to formation of the periodic distribution in which high density neutral gas layer and low plasma density layer are placed alternatively. When a pump laser beam is allowed to pass through such periodic distribution, it ionizes the neutral gas and forms density ripple with amplitude of about 80% of equilibrium density. Pathak et al. [16] suggested the mechanism for suppression of SRBS in the density rippled plasma. Sati et al. [17] have studied the decay of an electromagnetic wave into two ion acoustic wave (IAW) in the presence of density ripple plasma. Barr and Chen [18] studied the SRS process in the under dense density ripple plasma.

Kirkwood et al. [19] experimentally showed the moderation of SRBS process for a pump electromagnetic beam with intensity, wavelength, with peak electron temperature and propagating in a CH plasma chamber with critical density, by changing the polarisation of an overlapping counter propagating beam. Such systems are suitable for the indirect ignition of fusion pallets and also results in high growth rate of SRS and SBS process. They observed that the growth rate was reduced by a factor in its early time, if counter propagating beams have same polarisation. The beating of two counter propagating beams resulted in the coupling of Primary Langmuir wave with an ion acoustic wave which suppressed the growth of SRS. Sharma and Sharma [20] also proposed a model in which localisation of electron plasma wave causes the suppression of SRBS. Sajal and Tripathi [21] theoretically analyzed the suppression of SRBS by five waves parametric model in which primary Langmuir wave decayed into a high wavelength secondary Langmuir wave moving in backward direction along with an ion-acoustic wave (IAW).

In Sec. 2, the coupling of Raman excited primary upper hybrid wave with corrugated plasma structure is examined. This coupling results into the excitation of the secondary upper hybrid wave of same frequency but larger wave number, which in turn modifies dispersion relation of primary wave. The modified dispersion relation is solved numerically to exhibit the suppression of present process. Sec. 3 is devoted to conclusions.

2. Instability analysis

Consider an X-mode laser beam propagating in corrugated plasma with the following electric and magnetic field profiles:

$$\begin{aligned}\vec{E}_0 &= (\hat{y} + i\alpha_0\hat{x})A_0 \exp[-i(\omega_0 t - k_0 x)]\\ \vec{B}_0 &= \frac{\vec{k}_0 \times \vec{E}_0}{\omega_0}\end{aligned} \tag{1}$$

Suppose the equilibrium density of plasma is n_0^0 and the pre-existing density ripples in the plasma are given by $n_e^q = n_q \ \exp(iq_0x)$. An external dc magnetic field is applied in z-direction $\vec{B}_s = B_s\hat{z}$. The propagating laser imparts an oscillating velocity to the plasma electrons whose velocity components are calculated by solving equation of motion.

$$v_{0x} = \frac{-\ eA}{m\left(\omega_0^2 - \omega_c^2\right)}\left[\omega_c - \alpha_0\omega_0\right]e^{-i(\omega_0 t - kx)}\ ;\ \ v_{0y} = \frac{-\ ieA}{m\left(\omega_0^2 - \omega_c^2\right)}\left[\omega_0 - \alpha_0\omega_c\right]e^{-i(\omega_0 t - kx)} \tag{2}$$

Here $\omega_c = eB/m$ is the cyclotron frequency of electron. The laser beam undergoes through SRS process, producing a PUHW and a back scattered electromagnetic wave with electric field $\vec{\mathrm{E}}_1 = \left(\hat{\mathrm{y}}+\mathrm{i}\alpha_1\hat{\mathrm{x}}\right)\mathrm{A}_1 \exp\left[-\mathrm{i}\left(\omega_1\mathrm{t}-\mathrm{k}_1\mathrm{x}\right)\right]$, where $\mathrm{k}_1 = \mathrm{k}\text{-}\mathrm{k}_0,\ \ \omega_1 = \omega - \omega_0$. The wave number k of PUHW for an under dense plasma is given by $\mathrm{k} = 2\mathrm{k}_0$. The wave number of the density ripple is defined as $\mathrm{q} = 2\mathrm{k}_0 + \delta$, where as δ is the mismatch between the wave number of the PUHW generated through SRBS process and the density ripple of plasma. The value of δ is zero for the density ripple plasma produced through beating of counter propagating wave.

The pump and back scattered beam exert a nonlinear ponderomotive force on the electrons at frequency $\omega = \omega_1 + \omega_0$ and wave vector $\mathrm{k} = \mathrm{k}_1 + \mathrm{k}_2$. The components of the ponderomotive force are given by

$$\begin{aligned}F_{px} &= \frac{ie^2}{2m}A_oA_1e^{-i(\omega t - kx)}\left[-\frac{(\omega_c - \alpha_0\omega_0)}{\left(\omega_0^2 - \omega_c^2\right)}\frac{(\omega_c - \alpha_0\omega_0)}{\left(\omega_1^2 - \omega_c^2\right)}k + \frac{(\omega_c - \alpha_0\omega_0)}{\left(\omega_0^2 - \omega_c^2\right)}\frac{k_1}{\omega_1} + \frac{(\omega_c - \alpha_1\omega_1)}{\left(\omega_1^2 - \omega_c^2\right)}\frac{k_0}{\omega_0}\right]\\ F_{py} &= -\frac{e^2}{2m}A_oA_1e^{-i(\omega t - kx)}\left[i\left(\frac{(\omega_c - \alpha_1\omega_1)}{\left(\omega_1^2 - \omega_c^2\right)}\frac{(\omega_0 - \alpha_0\omega_c)}{\left(\omega_0^2 - \omega_c^2\right)}k_1 + \frac{(\omega_c - \alpha_0\omega_0)}{\left(\omega_0^2 - \omega_c^2\right)}\frac{(\omega_1 - \alpha_1\omega_c)}{\left(\omega_1^2 - \omega_c^2\right)}k_0\right) + \frac{(\omega_c - \alpha_0\omega_0)}{\left(\omega_0^2 - \omega_c^2\right)}\frac{k_1}{\omega_1} + \frac{(\omega_c - \alpha_1\omega_1)}{\left(\omega_1^2 - \omega_c^2\right)}\frac{k_0}{\omega_0}\right]\end{aligned} \tag{3}$$

Now plasma electrons start oscillating under the influence of both ponderomotive force and PUHW with their velocity components as

$$\begin{aligned}v_{\omega,k}^{x} &= \frac{1}{m\left(\omega^2 - \omega_c^2\right)}\left[i\omega F_{px} - \omega ek\phi_{\omega,k} - \omega_c F_{py}\right]\\ v_{\omega,k}^{y} &= \frac{1}{m\left(\omega^2 - \omega_c^2\right)}\left[\omega_c F_{px} - iek\omega_c\phi_{\omega,k} + i\omega F_{py}\right]\end{aligned} \tag{4}$$

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