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Research Article

Stimulated Raman scattering excited by incoherent light in plasma

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Abstract

Stimulated Raman scattering (SRS) excited by incoherent light is studied via particle-in-cell simulations. It is shown that a large bandwidth of incoherent light can reduce the growth of SRS and electron heating considerably in the linear stage. However, different components of the incoherent light can be coupled by the Langmuir waves, so that stimulated Raman backward scattering can develop. When the bandwidth of incoherent light is larger than the Langmuir wave frequency, forward SRS can be seeded between different components of the incoherent light. The incoherent light can only increase the time duration for nonlinear saturation but cannot diminish the saturation level obviously.

Keywords: Stimulated Raman scattering; Instability suppression; Incoherent light; Inertial confinement fusion

PACS Codes: 52.25.Os; 52.35.-g; 52.38.Bv

1. Introduction

Stimulated Raman scattering (SRS) in plasma is simply a pump laser decay into an electron plasma wave and a scattered light [1]. It may cause significant laser energy loss and hot electron production, where the latter can preheat the fusion targets. Therefore, SRS has been one of the key problems in laser-indirect-driven inertial confinement fusion [2–4]. Several methods have been proposed to suppress the SRS, such as introducing laser bandwidth [5,6] or polarization rotation [7], laser smoothing technique (smoothing by spectral dispersion, induced spatial incoherence and polarization smoothing) [8–11]. It is also shown that initial high temperature of plasma electrons can reduce the SRS growth [12,13].

In our previous work, we have studied the effects of finite bandwidth of incident lasers on SRS [6]. A considerable reduction of linear growth of SRS is found when the bandwidth is much larger than the SRS growth rate. In that work, the finite bandwidth is modeled by a sinusoidal-frequency-modulation around the central laser frequency. Recently, it is shown by theory and simulation that such modulated lasers with large bandwidth may be produced with a type of plasma optical modulators for intense lasers [14]. On the other hand, it is noted that such modulated lasers cannot completely suppress the SRS growth at later stage. Therefore it is necessary to investigate other possible schemes. Here we consider a type of partially incoherent light, which is composed of a large number of beamlets, each of which has different frequencies within a certain range, a random phase, and even a random polarisation. The SRS growth with such light beams is studied via particle-in-cell (PIC) simulations. Comparison of the

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results with those obtained with frequency modulated lasers of large bandwidth is made. The mechanisms of the SRS development due to the coupling between different frequency components of the incoherent light are analyzed.

2. Model of incoherent light beams

It is proposed that there are several schemes to model an incoherent light beam, such as spectral combining, short pulse stacking, and a mosaic of beamlets [15]. Here we consider a simple case where it is composed of a large number of coherent beamlets, each with a different frequency and a different phase:

$$a_{\mathrm{sum}} = \sum_{i=1}^{N} a_i \cos(\omega_i t + \phi_i), \tag{1}$$

where a_i is the field amplitude of the beamlet i normalised by $m_e\omega_i c/e$, which is related to the laser intensity with $a_i = \sqrt{I_i(\mathrm{W/cm^2})[\lambda_i(\mu\mathrm{m})]^2/1.37\times10^{18}}$. ω_i and λ_i are the corresponding frequency and wavelength, ϕ_i is a random phase in [-π,π], and N is the number of beamlets typically around a few hundreds. The frequency ω_i can be defined within certain bandwidth $\Delta\omega_0$ around a central frequency ω_0. If the frequency of the beamlets ω_i is uniformly distributed, the frequency gap of neighboring beamlets is simply $\delta\omega_i = \Delta\omega_0/(N-1)$. One can also let ω_i be randomly selected within $[\omega_0 - \Delta\omega_0/2, \omega_0 + \Delta\omega_0/2]$ in numerical simulation. Comparing with the model of sinusoidally modulated lasers with certain bandwidth used before [6] in the form of $a(t) = a_0\cos[\omega_0 t + b\sin(\omega_m t)]$, the present model can be considered as an extension now with arbitrary amplitude, frequency, and phase for the beamlets. Fig. 1 shows an example of the temporal structure and corresponding spectrum when taking $a_i = 0.004$, $\Delta\omega_0 = 15\%$, and $N = 100$. It shows that there are some fluctuations in the envelope profile, but overally the amplitude appears around $a_0 = \left(\sum_{i=1}^{N}|a_i|^2|\omega_i|^2\right)^{1/2} = 0.04$, which is expected according to energy conservation. Note that the coherence length between different components is just a few laser wavelengths, which is much shorter than that of the conventional laser light.

In addition to introducing random amplitude, frequency, and phase, one may introduce random polarization in the beamlets:

$$\boldsymbol{a}_{\mathrm{sum}} = \sum_{i=1}^{N} a_i\left[\cos(2\pi p_i)\widehat{\boldsymbol{e}}_y + \sin(2\pi p_i)\widehat{\boldsymbol{e}}_z\right]\cos(\omega_i t + \phi_i), \tag{2}$$

where p_i is a random number in [0,1], $\widehat{\boldsymbol{e}}_y$ and $\widehat{\boldsymbol{e}}_z$ are unit vectors in the transverse directions, assuming that all the beamlets propagate along the x-direction. Then the light wave can be considered to have two components polarized along the y and z directions, respectively. Averaged over assembly, it is obvious that each component contains half of the total power. This is equivalent to that each component appears with an amplitude of $a_i/\sqrt{2}$ in the y and z directions.

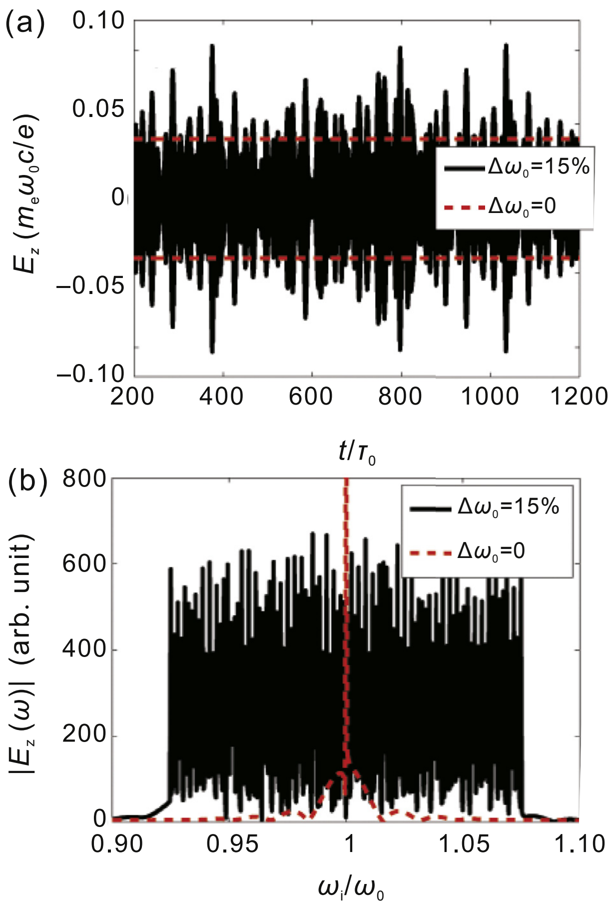

Fig. 1. (a) Temporal envelopes of the incident lights for both coherent and incoherent light, where the bandwidth of incoherent light is 15%, the red lines indicate the laser field amplitude level for coherent light. (b) Fourier transform of the incident light.

In the following, we carry out one dimensional PIC simulation to examine the effects of finite bandwidth and light incoherence on the generation of stimulated Raman scattering in both homogeneous and inhomogeneous plasmas.

3. SRS of incoherent light in homogeneous plasma

Numerical simulations using the PIC code KLAP [16] have been performed firstly in one-dimensional (1D) homogeneous plasma. We write the center frequency of a_{sum} as ω_0, and the corresponding wavelength is λ. In our simulations, we take the number of beamlets $N = 100$. The beamlets are semi-infinite with a 25λ rising edge in the front, each with the peak amplitude $a_i = 0.004$. The bandwidth $\Delta\omega_0$ of the incoherent light beam is normalized by ω_0. Here we take $\Delta\omega_0 = 15\%$. As a comparison, simulations for a coherent or partially coherent laser with sinusoidal modulation and the same laser power are also carried out, where its amplitude is $a = 0.04$ and its bandwidth is taken to be either $\Delta\omega_0 = 0$ or 15%, respectively. The length of the simulation box is 600λ, where the plasma occupies a region from 100λ to 500λ with a linear density ramp 10λ in the front. The homogeneous plasma density is $n_e = 0.08n_c$ with n_c to be the critical density, and the initial temperature is

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