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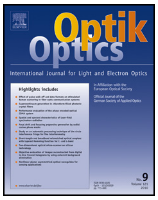

Original research article

Effect of self-focusing of elliptical laser beam on second harmonic generation in collisionless plasma

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ABSTRACT

In the present paper, effect of self-focusing of elliptical laser beam on second harmonic generation is investigated in collisionless plasma by making use of paraxial ray approximation. There is redistribution of carriers from high field region to low field region by ponderomotive force and hence transverse density gradient gets established in plasma. This transverse density gradient in turn generates the electron plasma wave at pump wave frequency. The electron plasma wave so generated interacts with pump wave there by producing second harmonic. Effect of variation in laser beam intensity and plasma density on second harmonic yield is also analyzed.

1. Introduction

The propagation of high power laser beams in underdense plasma is an active area of research both at theoretical as well as experimental level on account of its direct applicability to potential applications such as laser driven fusion, laser plasma accelerators, higher harmonic generation and X-ray lasers [1–10]. For success of these applications, it is essential that laser beam must propagate up to several Rayleigh length in plasma. During the propagation of high power beams over extended distances, various nonlinear phenomena such as stimulated Raman scattering, stimulated Brillouin scattering, filamentation and many more are generated [11–15]. Self-focusing phenomenon occupies a unique place amongst these nonlinear phenomena because all other phenomena are highly affected by it [16,17]. This phenomenon has attracted much attention on account of its direct relevance to optical harmonic generation, ionospheric radio propagation, X-ray lasers and in many other applications [18–25]. In self-focusing phenomenon, an intense laser beam changes the effective dielectric function of the medium mainly on account of ponderomotive force or due to non-uniform heating. In either case, carriers get redistributed if the initial beam power exceeds the critical power for self-focusing.

The harmonic generation of electromagnetic radiations in plasmas is very important non-linear process. It has drawn the attention of number of researchers on account of its practical applications [26–31]. This phenomenon could result in penetration of laser power to overdense region and hence provides valuable diagnostics of various plasma processes. Harmonic generation in laser-plasma interaction has been studied extensively both experimentally and theoretically [32–34]. From the past few years, a great deal of research has been focussed on second harmonic generation in laser produced plasmas

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[35–38]. Propagation of plane electromagnetic waves in homogeneous plasmas could not produce even harmonics. The main requirement of generation of second harmonic is presence of density gradients in plasmas. When electric vector of laser beam is parallel to density gradient established in plasmas, then electron plasma wave at pump wave frequency is produced. The electron plasma wave so generated further interacts with pump wave to produce second harmonic.

Most of the research work on process of harmonic generation is done with the assumption of a uniform laser pump. But most of the electromagnetic beams usually have non-uniform distribution of irradiance along the wavefront. Moreover, magnitude of generated harmonics is found to be higher for case of non-uniform irradiance distribution than that for uniform irradiance distribution. So, it provides a strong motivation to incorporate non-uniformity of laser beam, while investigating the phenomenon of harmonic generation. Self-focusing/defocusing phenomenon is exhibited by such beams. Effect of self-focusing of elliptical laser beam on scattering instabilities have already been studied in the past [39–42]. So, our motivation of present work is to study the effect of self-focusing of elliptical laser beam on the second harmonic generation in collisionless plasma.

In the present paper, effect of self-focusing of elliptical laser beam on second harmonic generation is investigated in collisionless plasma. In Section 2, second order differential equation governing the evolution of beam width parameter of laser beam has been set up with the help of paraxial ray approximation. In Section 3, amplitude of electron plasma wave has been evaluated. In Section 4, second harmonic yield is calculated and discussion of results is presented in Section 5.

2. Evolution of beam width parameter

In order to investigate the propagation of elliptical laser beam in plasma, the cylindrical co-ordinate system is adopted, in which direction of propagation is taken along Z-axis. As the laser beam propagates through plasma, the ponderomotive force pushes the electrons radially outwards on account of transverse density gradient, which leads to modification in background electron density (N_0). Following [43], the electron density in presence of laser beam (N_{0e}) may be written as

$$N_{0e} = N_0 \exp\left[-\frac{3}{4}\alpha\frac{m}{M}EE^\star\right] \tag{1}$$

where the non-linearity parameter α is given by

$$\alpha = \frac{e^2 M}{6k_B T_0 \gamma m^2 \omega^2} \tag{2}$$

where N_0 is the electron density in absence of beam, e and m represents the charge and mass of plasma electrons. k_B is Boltzmann's constant, $\gamma = 3$ is the ratio of specific heats for electron gas, and T_0 is the equilibrium plasma temperature, M is the mass of ion.

The transverse intensity distribution of an elliptical laser beam along the wave-front at $z = 0$ is given by

$$EE^\star|_{z=0} = E_{00}^2 \exp\left[-\frac{x^2}{a^2} - \frac{y^2}{b^2}\right] \tag{3}$$

where a and b corresponds to initial dimensions of the laser beam at $z = 0$ in x and y-directions respectively, E is the electric field vector of laser beam and E_{00} is the axial amplitude of the beam.

Starting from Maxwell's equations, the wave equation governing the electric field of laser beam in plasma can be written as

$$\nabla^2 E - \nabla(\nabla\cdot E) + \frac{\omega^2}{c^2}\epsilon E = 0 \tag{4}$$

In the WKB approximation, the second term $\nabla(\nabla\cdot E)$ of Eq. (4) can be neglected, which is justified when $(c^2/\omega^2)|(1/\epsilon)\nabla^2 \ln\epsilon| \ll 1$,

One can get

$$\nabla^2 E + \frac{\omega^2}{c^2}\epsilon E = 0 \tag{5}$$

where $\epsilon = \epsilon_0 + \Phi(EE^\star)$, here $\epsilon_0 = 1 - (\omega_p^2/\omega^2)$ and $\Phi(EE^\star) = (\omega_p^2/\omega^2)[1 - (N_{0e}/N_0)]$ are linear and non-linear parts of the dielectric constant and $\omega_p = \sqrt{4\pi N_0 e^2/m}$ is the electron plasma frequency.

Now, [43,44], the solution of E can be written as,

$$E = E_0 \exp[i(\omega t - k(S+z))] \tag{6}$$

$$E_0^2 = \frac{E_{00}^2}{f_1 f_2}\cdot\exp\left[\frac{-x^2}{a^2 f_1^2}\right]\exp\left[\frac{-y^2}{b^2 f_2^2}\right] \tag{7}$$

$$S = \frac{1}{2}x^2\frac{1}{f_1}\frac{df_1}{dz} + \frac{1}{2}y^2\frac{1}{f_2}\frac{df_2}{dz} + \Phi_0(z) \tag{8}$$