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Effect of inertial ponderomotive force and self-focusing of the fundamental pulse on generation of second harmonic in magnetic plasma

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ABSTRACT

In this paper, nonlinear propagation of the intense ultra short pulses through under dense plasmas are investigated analytically. Using paraxial theory, the beam width parameter is evaluated as a function of the propagation distance. The effect of the inertial ponderomotive force, $\rho_m(\vec{u}\cdot\vec{\nabla})\vec{u}$, on intensity of the second harmonic pulse and self focusing of laser pulse are considered. It is shown that the second harmonic amplitude depends on the propagation distance periodically. It is shown that the inertial ponderomotive force affects efficiency of the second harmonic generation, but it does not affect beam width parameter of the second harmonic wave.

1. Introduction

Recently, there has been much interest in the interaction of high intensity ultra short laser pulses with plasma. There has been considerable interest in the interaction of intense laser beam with plasmas on account of its relevance to laser fusion and charged particle acceleration [1]. With the availability of high power laser beams, a large number of interesting nonlinear phenomena have been studied theoretically and experimentally. The self-focusing feature of powerful laser beams in dielectrics, semiconductors and plasmas are phenomena which have been extensively investigated in the recent years and this is primarily due to the dependence of complex dielectric constant on the intensity of propagation wave [2].

Many mechanisms can generate laser harmonics in plasma. In the case of the second harmonic generation, the main mechanism is the presence of density gradients in the plasma. Matsumoto [3] has presented both static and dynamic analysis of quasi-phase matched second harmonic generation by backward propagation interaction, where the second harmonic wave is generated in reflection. Malka et al. [4] have observed 0.1% conversion efficiency of the second harmonic generation of a laser in plasma created by optical field ionization. New short pulse laser technology has made possible the production of extremely intense laser sources at a multi-terawatt level. The focused intensities are obtained very high $\approx 10^{18}$ W/cm^2 and further developments are aimed at intensities exceeding $\approx 10^{21}$ W/cm^2 [5,6].

Salih et al. [7] have investigated the second harmonic generation of an intense self-guided right circularly polarized laser beam in the magnetized plasma. The efficiency of the second harmonic yield increases nonlinearly with the intensity of the fundamental laser due to the dependence of the spot size on it. Moreover, it enhances the efficiency of the second harmonic generation to higher levels due to electron cyclotron resonance. An intense Gaussian laser beam propagating through a

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preformed plasma channel gets self-focused due to radial ponderomotive forces on electrons and the subsequent plasma redistribution [8,9]. The ponderomotive force acting on electron consists of two forces: the inertial ponderomotive force, $\rho_m(\vec{u}\cdot\vec{\nabla})\vec{u}$, and Lorentz ponderomotive force, $\rho_q(\vec{u}\times\vec{B})$.

Wani et al. [10] have studied nonlinear propagation of Guassian laser beam in an inhomogeneous plasma under plasma density ramp. Gupta et al. [11] have studied effect of cross-focusing of two q-Guassian laser beam on excitation of electron plasma wave in collisional plasma. Mitigation of stimulated Raman backscattering by elliptical laser beam in collisionless plasma is considered [12]. Self-focusing of Hermite-cosh-Gaussian laser beam in semiconductor quantum plasma have been considered by Wani et al. [13]. Ouahid et al. [14] have considered Relativistic self-focusing of finite Airy-Gaussian beams in collisionless plasma using the Wentzel-Kramers-Brillouin approximation.

Askari et al. [15] have considered the effects of inertial pondromotive force and wiggler magnetic field on the efficiency of the second harmonic generation by neglecting the effect of self-focusing of the fundamental pulse. Furthermore, Askari et al. [16,17] have considered phase matching condition in the second harmonic and sum frequency generation.

The second harmonic generation is considered in an underdense plasma and in the presence of wiggler magnetic field by two causes. First, interaction of an ultra-short laser pulse with nonmagnetic isotropic plasma produces many nonlinear phenomena such as generation of odd harmonics. In the presence of a magnetic field, an isotropic plasma is converted to a non-isotropic plasma and leads to production of even harmonics. Second, the wave vector $\vec{k}_0$ of wiggler magnetic field acts as a virtual photon of quantum energy 0 and momentum $\hbar\vec{k}_0$ so that establish the conservation of the momentum. The conservation of the momentum satisfy the Gaussian phase matching condition, which is an important character to obtain a large output.

In this paper, the effect of inertial ponderomotive force $\rho_m(\vec{u}\cdot\vec{\nabla})\vec{u}$ on efficiency of the second harmonic generation in presence of wiggler magnetic field are considered by assuming the existence of self-focusing of the fundamental pulse and satisfying phase matching.

2. Theory

The continuity equations of electron number density and the average velocity, and the electromagnetic wave equation in cold plasma are given by following relations [18,19]

$$\frac{\partial n}{\partial t}+\vec{\nabla}\cdot n\vec{u}=0 \tag{1}$$

$$\frac{\partial \vec{u}}{\partial t}+\left(\vec{u}\cdot\vec{\nabla}\right)\vec{u}+\frac{e}{m}\vec{E}+\frac{e}{mc}\vec{u}\times\vec{B}+\nu\vec{u}=\vec{0} \tag{2}$$

$$\nabla^2\vec{E}-\vec{\nabla}\left(\vec{\nabla}\cdot\vec{E}\right)-\frac{1}{c^2}\frac{\partial^2\vec{E}}{\partial t^2}=\frac{4\pi}{c^2}\frac{\partial\vec{J}}{\partial t}. \tag{3}$$

Where $\vec{J}=-ne\vec{u}$, $\vec{B}$, $\vec{E}$, c, ν, $\vec{u}$, n, m and $e$are current density, magnetic and electric fields, the velocity of light in vacuum, electron collision frequency of plasma, average velocity, number density, mass and charge of electron, respectively. Also in Eq. (2), term $(\vec{u}\cdot\vec{\nabla})\vec{u}$ is called inertial force and collision term, $\nu\vec{u}$, is ignored in a plasma with weak collision.

Assume a plasma with uniform density $n_\circ$ in the presence of the following wiggler magnetic field

$$\hat{\vec{B}}=B_{\circ W}e^{ik_\circ z}\hat{e}_y, \tag{4}$$

where $B_{\circ W}$ and $k_\circ$ are amplitude and wave number of the background wiggler magnetic field. The symbol "∧" over quantities denotes their complex representation. Consider an intense and short laser pulse with frequencyω, the wave number k_1 in plasma, polarization in the x-direction and propagating through the plasma along the positive z-axis.

The electric field of the laser induces an oscillatory velocity $\hat{\vec{u}}_1^\circ$ at $(\omega,\vec{k}_1)$on plasma electrons. The velocity $\hat{\vec{u}}_1^\circ$ and the magnetic field $\hat{\vec{B}}_W(z)$ beat to exert a Lorentz ponderomotive force $\left(-e/2c\right)\left(\hat{\vec{u}}_1^\circ\times\hat{\vec{B}}_W\right)$ and imparts an oscillatory velocity $\hat{\vec{u}}_1^1$ at $(\omega,\vec{k}_1+\vec{k}_\circ)$; $\hat{\vec{u}}_1^1$ and $\hat{\vec{B}}_W(z)$ also exert a Lorentz ponderomotive force $\left(-e/2c\right)\left(\hat{\vec{u}}_1^1\times\hat{\vec{B}}_W\right)$ and gives the oscillatory velocity $\hat{\vec{u}}_1^2$ on electron at $(\omega,\vec{k}_1+2\vec{k}_\circ)$ and so on. The velocities $\hat{\vec{u}}_1^\circ$ and $\hat{\vec{u}}_1^1$ can also produce inertial pondromotive forces $\rho_m(\hat{\vec{u}}_1^\circ\cdot\vec{\nabla})\hat{\vec{u}}_1^\circ$ and $(\rho(\hat{\vec{u}}_1^\circ\cdot\vec{\nabla})\hat{\vec{u}}_1^1+\rho(\hat{\vec{u}}_1^1\cdot\vec{\nabla})\hat{\vec{u}}_1^\circ)/2$. Under this circumstance, it is better to solve Eqs. of (1)–(3) by means of perturbation expansion. For this purpose, quantities are shown as

$$\hat{n}=n_\circ+\left(\hat{n}_1^\circ+\hat{n}_1^1+\ldots\right)+\left(\hat{n}_2^\circ+\hat{n}_2^1+\ldots\right)+\ldots \tag{5}$$

$$\hat{\vec{u}}=\left(\hat{\vec{u}}_1^\circ+\hat{\vec{u}}_1^1+\ldots\right)+\left(\hat{\vec{u}}_2^\circ+\hat{\vec{u}}_2^1+\ldots\right)+\ldots \tag{6}$$

$$\hat{\vec{E}}=\left(\hat{\vec{E}}_1^\circ+\hat{\vec{E}}_1^1+\ldots\right)+\left(\hat{\vec{E}}_2^\circ+\hat{\vec{E}}_2^1+\ldots\right)+\ldots \tag{7}$$