Optik 123 (2012) 67–72

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

The anomalous penetration of intense circularly polarized electromagnetic beam through overdense magnetized plasma

Meenu Asthana Varshney [a], Bhavna Rathore [a,b], Dinesh Varshney [b,c,*]

[a] Department of Physics, M. B. Khalsa College, Indore 452002, India
[b] School of Physics, Vigyan Bhavan, Devi Ahilya University, Khandwa road Campus, Indore 452001, India
[c] School of Instrumentation, USIC Bhavan, Devi Ahilya University, Khandwa road Campus, Indore 452001, India

ARTICLE INFO

Article history:
Received 1 June 2010
Accepted 25 October 2010

PACS:
52.38.−r
52.38. Fz
52.38.Hb
52.38.kd

Keywords:
Relativistic laser–plasma interaction
Magnetized plasma
Anomalous penetration
Cyclotron resonance effect
Inhomogeneous plasma

ABSTRACT

The steady state nonlinear propagation of an intense, circularly polarized electromagnetic beam in an inhomogeneous magnetized plasma has been investigated in paraxial approximation. The laser induces a large oscillatory velocity on electrons, raising their mass and lowering the plasma frequency. Further, rising due to cyclotron resonance effect. The propagation of the electromagnetic waves in magnetized plasma in both the extraordinary and ordinary mode is analyzed. The nonlinearity in dielectric function is considered in presence of external magnetic field due to saturation effects for arbitrary large intensity, which leads to focusing/defocusing of the beam. The focusing effect along with magnetic field helps in the process of anomalous penetration of the beam by enhancing the depletion of the plasma from the axial region. The penetration increases with the incident beam power up to some critical value beyond which it rises abruptly when all electrons have been driven out of the axis. The cyclotron resonance effect awfully supports the laser beam to propagate inside the overdense plasma region. Numerical computations are performed for typical parameters of relativistic laser–plasma interaction applicable for underdense and overdense plasma.

© 2011 Elsevier GmbH. All rights reserved.

1. Introduction

The study of magnetized plasma has been extensively used in a wide range of physical contexts starting from laboratory experiments [1] to astrophysics, [2] space physics, solar physics, etc. However, plasmas are inhomogeneous in nature, and to account for such plasmas is interesting and significant. For the case of inhomogeneous magnetoplasma with density gradients, there has been a series of investigations [3–6]. Research in this process has acquired further importance with the availability of high-power laser beam and its relevance to inertial-confinement fusion plasmas. It is required that intense laser beams be propagated through long-scale underdense plasmas to achieve successful controlled nuclear fusion.

The physics of interaction of such laser pulses with the plasmas substantially differ form that of the lower intensity cases. When the plasma is irradiated by such lasers with intensities up to $\sim 10^{20}$ W/cm^2, electrons oscillating in the field of the waves are strongly relativistic. An equally ubiquitous, although less studied, effect accompanying laser–matter interaction is the generation of ultra-strong magnetic field in the plasma. Magnetic field can have a significant effect on the over all propagation and plasma dynamics [7]. Extremely high magnetic field play an essential role in the particle transport, propagation of laser pulses, laser beam self-focusing, penetration of laser radiation into the overdense plasma, and the plasma electron and ion acceleration [8]. Experiments and simulations [9] relevant to Fast ignition scheme of fusion have reported propagation of intense short laser pulse to long distance with self-focusing offsetting the diffraction divergence.

Laser light may self-focus and propagate in underdense and overdense plasma, via ponderomotive, thermal and relativistic effects. Earlier, we have studied relativistic self-focusing of laser beam in an inhomogeneous plasma [10]. The focusing of a Gaussian electromagnetic beam in a radially inhomogeneous medium with saturating and multiphoton absorption has also been studied [11]. The propagation of intense electromagnetic beams in a slightly inhomogeneous medium has been investigated on the basis of ray optics [12]. The steady state self-focusing of a Gaussian electromagnetic beam in a magnetized plasma has been studied for moderate intensities [13,14]. The propagation regimes have been investigated due to ponderomotive and collisional nonlinearity in

* Corresponding author at: School of Physics, Vigyan Bhavan, Devi Ahilya University, Khandwa road Campus, Indore 452001, India. Tel.: +91 7312467028; fax: +91 7312465689.
E-mail addresses: vdinesh33@rediffmail.com, meenuv13@rediffmail.com (D. Varshney).

0030-4026/$ – see front matter © 2011 Elsevier GmbH. All rights reserved.
doi:10.1016/j.ijleo.2010.10.051

presence of external magnetic field [15]. The importance of the magnetic field and simulation of the effect of a uniform external magnetic field on radiation self-focusing has also been demonstrated [16]. In all of these investigations, it is noticed that magnetic field plays an important role in the context of laser beam propagation and guidance. The self-effect of the waves in the plasma in a fixed magnetic field has a number of investigating features and needs to be studied.

In the present work, we study nonlinear propagation of an intense laser beam in inhomogeneous plasma in presence of external magnetic field. The effect of a self-generated magnetic field on the density-profile modification in laser–plasma interactions are investigated by means of calculating the field structure with the assumption of plane electromagnetic waves propagating into one-dimensional inhomogeneous magnetized plasma. In Section 2 analytical formulations is presented. The wave equation has been solved in paraxial and WKB approximation by expanding the dielectric tensor for arbitrary large nonlinearity and intensity, incorporating the wave magnetic field in the relativistic factor. Both the extraordinary and ordinary modes of wave propagation have been considered in the analysis. Numerical results and discussions are made in Section 3 for typical parameters of relativistic laser–plasma interaction. Based on the analytical formulation the graphical plots show that the relativistic oscillation of the mass and magnetic field increases propagation, making penetration of the laser beam in overdense plasma. Conclusions are written in Section 4.

2. Analytical formulation

2.1. Effective dielectric tensor

Consider the propagation of circularly polarized Gaussian laser beam initially through homogenous magnetized plasma at equilibrium density and temperature. The self-generated or externally applied magnetic field is considered to be along z direction. The beam is polarized along x–y plane. At $z=0$, the intensity distribution of the beam is given by

$$\mathbf{E}_{\pm}^2 = E_{oo\pm}^2 \ \exp\left(\frac{-r^2}{r_{o\pm}^2}\right) \tag{1}$$

The factor $\mathbf{E}_{\pm} = E_x \pm iE_y$ represents the electric vector of the extraordinary and ordinary mode respectively, where $E_{oo\pm} = E_{\pm}\,(r=0, z=0)$, '$r$' is being the radial coordinate in cylindrical coordinate system and $r_{o\pm}$ characterizes the initial beam width. The relativistic equation of motion in presence of external magnetic field is

$$\frac{\mathrm{d}}{\mathrm{d}t}(\gamma m\vec{v}_e) = -e\left[\vec{E}_L + \frac{1}{c}\vec{v}_e \times (\vec{B}_L + \vec{B}_o)\right] \tag{2a}$$

where γ is the relativistic Lorentz factor which depends on electric field $\vec{E}_L$ of laser beam, $\vec{B}_L$ and $\vec{B}_o$ denotes magnetic field of laser beam and induced magnetic field or externally applied magnetic field respectively.

Consider a circularly polarized wave of frequency ω, the relativistic factor γ with an induced magnetic field [7] is written as

$$\gamma = \left[1 + \alpha^2 E_L{}^2\left(1 \mp \frac{\omega_c}{\gamma\omega}\right)^{-2}\right]^{1/2} \tag{2b}$$

Here, $\omega_c = (e\mathbf{B}_0/mc)$ is the cyclotron frequency and $\alpha = (e/m\omega c)$.

At high intensity self-generated axial magnetic field or externally applied magnetic field makes the dielectric tensor direction dependent. Consequently, dielectric function of the plasma shows anisotropic behaviour.

Considering the time variation of the fields as $e^{i\omega t}$, we obtain the steady state solution of Eq. (2a). Following Sodha et al. [17] and Asthana et al. [18], the effective dielectric tensor in a magnetized plasma due to relativistic variation of mass with an induced magnetic field for both the modes of propagation can be written as

$$\varepsilon_{\pm} = \varepsilon_{xx} \mp \varepsilon_{xy} = \varepsilon_{o\pm} + i\varepsilon_{2\pm}(E_{\pm}\cdot E_{\pm}^{*}) \tag{3a}$$

and

$$\varepsilon_{zz} = \varepsilon_{ozz} + \varepsilon_2(E_{\pm}\cdot E_{\pm}^{*}) \tag{3b}$$

where the different components are the following

$$\varepsilon_{o\pm} = \left[1 - \frac{\omega_p^2}{\omega^2(1 \mp \omega_c/\omega)}\right], \tag{4a}$$

$$\varepsilon_{ozz} = \left[1 - \frac{\omega_p^2}{\omega^2}\right], \tag{4b}$$

$$\varepsilon_{2\pm} = \frac{\omega_p^2}{\omega^2(1 \mp \omega_c/\omega)}\left\{1 - \left[1 + \frac{\alpha^2 E_{\pm}^2}{(1 \mp \omega_c/\omega\sqrt{1+\alpha^2 E_{\pm}^2})}\right]^{-1/2}\right\}, \tag{5a}$$

and

$$\varepsilon_2 = \frac{\omega_p^2}{\omega^2}\left\{(1 + \alpha^2 E_{\pm}^2)^{-1/2}\right\}. \tag{5b}$$

with $\omega_p{}^2$ $(=4\pi ne^2/\gamma m)$ is the relativistic plasma frequency incorporating induced magnetic field defined through Eq. (2b).

It is known that the relativistic dependence of the mass of electron on its speed leads to the nonlinear dielectric function, which depends on electric vector of the wave. Since the relativistic effect on the dielectric function occur through plasma frequency, it should manifest itself in a time of the order of period of plasma oscillation viz., $\omega_p{}^{-1}$. Hence, effective dielectric constant for saturating non-linearity and arbitrary large intensity for both the modes of propagation can be written, splitting as

$$\varepsilon'_{\pm}(r,z) = \varepsilon'_{o\pm}(z) + \varphi'_{\pm}(r,z) \tag{6}$$

where $\varepsilon'_{o\pm}(z) = \varepsilon_{o\pm}(o,z)$ and $\varphi'_{\pm}(r,z) = [\varepsilon'_{\pm}(r,z) - \varepsilon'_{o\pm}(z)]$, which turns out to be proportional to r^2 in the paraxial approximation (please see Eq. (17)).

2.2. Wave equation

The wave equation governing the propagation of the laser beam in plasma is

$$\nabla^2 E_{\pm} - \nabla(\nabla\cdot E_{\pm}) + \left(\frac{\omega^2}{c^2}\right)\varepsilon'_{\pm}E_{\pm} = 0 \tag{7}$$

In the slowly varying envelope approximation, the evolution of the electric field envelope in a relativistic magnetoplasma is given by

$$\mathbf{E}_{\pm} = A_{1\pm}\ \exp\left[i(\omega t - \int_0^z k_{\pm}dz)\right] \tag{8}$$

where $A_{1\pm}$ is the complex quantity and $k_{\pm} = (\omega/c)\varepsilon'^{1/2}_{\pm}$ is the wave number corresponding to the extraordinary and ordinary mode propagating independently in magnetized plasma.

Taking into account the cylindrical symmetry of the beam, we transform Eq. (7) into cylindrical coordinates, with azimuthal symmetry and substitute for electric field (Eq. (8)), the wave equation for $A_{1\pm}$ to be slowly varying reduces to

$$-2ik_{\pm}\frac{\partial A_{1\pm}}{\partial z} + \frac{1}{2}\left(1 + \frac{\varepsilon_{o\pm}}{\varepsilon_{ozz}}\right)\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)A_{1\pm} + \frac{\omega^2}{c^2}\varepsilon'_{\pm}A_{1\pm} = 0 \tag{9}$$

Download English Version:

https://daneshyari.com/en/article/848306

Download Persian Version:

https://daneshyari.com/article/848306

Daneshyari.com