Propagation of extraordinary laser beam in cold magnetized plasma

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This article studies the evolution of spot size of an intense extraordinary laser beam in cold, transversely magnetized plasma. Due to the relativistic nonlinearity, the plasma dynamic is modified in the presence of transversely magnetic filed. In order to specify the evolution of the spot size of extraordinary laser beam, nonlinear current density is set up and the source dependent expansion method is used. It is shown that enhancing the external magnetic field decreases the spot-size of laser beam significantly, and thus the self-focusing effect becomes more important due to the extraordinary property of laser beam.

Keywords: spot size, extraordinary laser beam, transversely magnetized plasma, self-focusing.

1 INTRODUCTION

It is known that, a laser beam propagating in plasma with plasma frequency smaller than the laser frequency undergoes relativistic self-focusing as soon as its total power exceeds the critical values [1]. So, high power laser propagating through plasma can acquire a minimum spot size due to relativistic and ponderomotive self-focusing. When a laser pulse propagates through plasma embedded in a uniform magnetic field, the Lorentz force acting on plasma electrons introduces changes in relativistic mass and causes electron density perturbations, leading to modification in the propagation characteristics of the laser beam. It is revealed that transverse magnetization of plasma enhances the self-focusing property of the laser beam and the critical power is reduced due to the presence of the magnetic field [2, 3]. In the latest study on self-focusing of laser beam in magnetized plasmas, the extraordinary properties of laser wave has been ignored [2]. In fact, when laser propagates through plasma, a longitudinal electrostatic field is generated due to the panderomotive force acting on plasma electrons, and this makes the laser beam to be extraordinary. So, for an accurate investigation, we should take the extraordinary property of laser into account. In the present study, we analyze, the effect of the uniform external magnetic field on self-focusing property of an intense extraordinary laser pulse propagating in a cold, homogenous plasma. The magnetic field is perpendicular to the electric field and the direction of propagation of the radiation field. Nonlinear wave equation [4] is set up and the source dependent expansion method [5] is used to determine the evolution of the spot size of a laser beam having a Gaussian profile. The effect of transverse magnetization of plasma on the self-focusing property of the extraordinary laser beam is investigated.

2 NONLINEAR WAVE EQUATION

Consider a uniform plasma of electron density n_0. The plasma is embedded in a static magnetic field $B\hat{y}$. A high intensity extraordinary laser at (ω_0, k_0) propagates through it along $\hat{z}$, with electric field,

$$\boldsymbol{E} = E_0(\hat{x} + i\beta_0\hat{z})e^{i\theta_0} \tag{1}$$

where, $\theta_0 = (k_0 z - \omega_0 t)$, $\beta_0 = \dfrac{\omega_c}{\omega_0}\dfrac{\omega_p^2}{\omega_0^2 - \omega_{UH}^2}$.

and ω_p, ω_c, ω_{UH}, are the plasma frequency, electron cyclotron frequency, and upper-hybrid frequency, respectively [6].

In cold plasma, the plasma electrons are initially at rest and relativistic effects are ignored in the zeroth order. The response of plasma electrons to the pump wave is governed by the equations of motion and continuity,

$$\frac{d}{dt}(\gamma\vec{v}) = -\frac{e}{m}\left[\vec{E} + \frac{\vec{v}\times(\vec{B}_0 + \vec{B})}{c}\right] \tag{2}$$

$$\frac{\partial n}{dt} = -\frac{\partial}{\partial z}(nv_z) \tag{3}$$

Where $\vec{v} = v_x\hat{i} + v_z\hat{k}$ and γ is the relativistic factor. Assuming $v_x = v_x^{(1)} + v_x^{(2)} + v_x^{(3)}$, and expanding Eq.(2) in the mildly relativistic limit $(\gamma^{-1} < 1, \omega_c < \omega_0)$, we find the three orders of transverse electron velocities up to third order