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Effect of Light Absorption and Critical Beam Power on Self-focusing of Gaussian Laser Beam in Collision less Magnetized Plasma

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Abstract. In the present paper, authors have studied the effect of light absorption and critical beam power on self-focusing of Gaussian laser beam propagating through collisionless magnetized plasma. The field distribution in the medium is expressed in terms of beam-width parameter and absorption coefficient. Usual parabolic equation approach under WKB and paraxial approximations is employed to obtain the differential equation for beam width parameter. It is found that critical critical beam power and absorption coefficient play vital role in propagation of Gaussian laser beam in collisionless magnetized plasma. The behavior of beam-width parameter with the normalized distance of propagation is studied at various values of critical beam power with different absorption levels in magnetized plasma. The results are presented in the form of graphs and discussed.

INTRODUCTION

It is well known that the interaction of high intensity laser beam with plasma is attractive due to its relevance to laser-particle acceleration [1], fast ignition for inertial confinement fusion [2], etc. Phenomenon of self-focusing [3] plays a vital role on account of the fact that the other nonlinear effects arrived in laser-plasma interaction are highly sensitive to the irradiance distribution of along the wavefront of the beam, which is significantly affected by self-focusing [4]. Furthermore, the plasma based applications demand the laser beam to propagate over several Rayleigh lengths without divergence or loss of energy. The basic physical mechanism responsible for self-focusing of laser in plasmas is the nonlinearity in the dielectric constant of the plasma. So far the main thrust of recent studies on self-focusing of laser beams in plasmas has been directed towards the propagation characteristics of a Gaussian beam [5-10] due to its salient features that are advantageous in simplifying the mathematical complexities involved in the theoretical treatment of various nonlinear optical effects.

The self-focusing of laser beams in plasma by considering ponderomotive nonlinearity has attracted a lot of interest in previous research in the last few decades. Osman *et al.*[11] have presented the numerous theoretical discussions on the concept of ponderomotive self-focusing at laser-plasma interaction. Several studies have been attempted to explore the ponderomotive self-focusing of laser beams in different situations. It has been suggested that role of light absorption [12] is important in self-focusing of laser beams in plasmas. Navare *et al.*[13] have examined an impact of linear absorption on self-focusing of Gaussian beam by taking into account collisional nonlinearity. They have suggested that absorption destroys the stationary oscillatory self-focusing character during propagation through plasma. Effect of linear absorption on self-focusing of quadruple Gaussian laser beam in an inhomogeneous magnetized plasma with ponderomotive non-linearity has been studied by Aggarwal *et al.*[14]. Self-

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focusing of cosh-Gaussian laser beam in plasma with linear absorption has been reported by Kant and Wani [15]. They highlighted the combined effect of plasma density ramp and absorption on self-focusing of laser. They have also extended their study to chirped Gaussian laser beam in collisional plasma [16]. Ouahid *et al.*[17] investigated an effect of light absorption on self-focusing of finite Airy-Gaussian laser beams under relativistic and ponderomotive regime. Patil *et al.*[18-22] have presented the influence of light absorption on self-focusing of Gaussian laser beam in different situations.

In the present paper, we have studied an influence of absorption and critical beam power on self-focusing of Gaussian laser beam in collisionless magnetized plasma. We rely on the paraxial approach introduced by Akhmanov *et al.* [3] and its extension by Sodha *et al.*[4].

THEORETICAL FRAMEWORK

The wave equation governing the propagation of laser beam in magnetized plasmas is given as [4]

$$\frac{\partial^2 E_\pm}{\partial z^2}+\frac{1}{2}\left(1+\frac{\varepsilon_{0\pm}}{\varepsilon_{0zz}}\right)\left(\frac{\partial^2 E_\pm}{\partial r^2}+\frac{1}{r}\frac{\partial E_\pm}{\partial r}\right)+\frac{\omega^2}{c^2}\left(\varepsilon_\pm E_\pm\right)=0 \tag{1}$$

where, $\varepsilon_{0zz}=1-\omega_p^2/\omega^2$ and $\varepsilon_{0\pm}$ is the effective dielectric function of the plasma, which can, in general be expressed as [4]

$$\varepsilon_\pm=\varepsilon_{0\pm}+\phi_\pm(EE^*)+i\,\varepsilon_i \tag{2}$$

where, $\varepsilon_{0\pm}$ and $\phi_\pm(E_\pm E_\pm^*)$ are the linear and nonlinear parts of the dielectric function respectively, ε_i takes care of absorption. In case of collisionless magnetized plasma $\varepsilon_{0\pm}$ and $\phi_\pm$ can be expressed as,

$$\varepsilon_{0\pm}=1-\frac{\omega_p^2}{\omega(\omega\,\mu\,\omega_c)} \tag{3}$$

$$\phi_\pm(A_{00}^2)=\frac{\omega_p^2}{2\omega(\omega\,\mu\,\omega_c)}\left[1-\exp(-\alpha E_\pm E_\pm^*)\right] \tag{4}$$

Here, $\omega_p=\left(4\pi\, n_0 e^2/m\right)^{1/2}$ is the plasma oscillation frequency and $\omega_c=eB_0/mc$ is cyclotron frequency, e and m are the electronic charge and rest mass respectively, $\alpha=3m\alpha_0/4M$, $\alpha_0=e^2/6m\omega^2K_BT_0$, n_0 being the unperturbed density of plasma electrons, M is the mass of ion, ω is the angular frequency of laser used, K_B is the Boltzmann constant, B_0 is static magnetic field and T_0 is a equilibrium plasma temperature.

Within the framework of WKB and paraxial approximations, the intensity distribution of Gaussian laser beam propagating along z axis is given by

$$A_{0\pm}^2=\frac{E_{0\pm}^2}{f_\pm^2}\exp\left(-\frac{r^2}{r_0^2 f_\pm^2}-4k_i z\right) \tag{5}$$

Where $E_{0\pm}$ is an initial laser intensity with initial beam-width r_0 and $f_\pm$ is the dimensionless beam-width parameter.

Following approach given by Akhmanov *et al.*[3] and its extension by Sodha *et al.*[4], the dimensionless beamwidth parameters $f_\pm$ is obtained as,

$$\frac{\partial^2 f_\pm}{\partial \xi_\pm^2}=\frac{1}{\varepsilon_{0\pm}}\frac{1}{f_\pm^2}\left\{\frac{12\delta_\pm^2}{3}-\frac{\exp\left(-8k_i\,\rho_\pm\,\xi_\pm\right)\,\exp\left(\exp\left(-4k_i\rho_\pm\xi_\pm\,p_\pm/f_\pm^2\right)\right)p_\pm\,\rho_\pm^2\,\gamma_\pm\,\delta_\pm}{2}\right\} \tag{6}$$

where $\gamma_\pm=\Omega_p^2/1-\Omega_c$, $\Omega_p=\omega_p/\omega$, $\Omega_c=\omega_c/\omega$, $p_\pm=\alpha E_{0\pm}^2/f_\pm^2$ and $\rho_\pm=r_0\omega/c$. The quantity $p_\pm$ which is dimensionless and proportional to $E_{0\pm}^2$ represents the dimensionless beam power on a suitably chosen scale. The beam width parameters $f_\pm$ is a function of $\xi_\pm$ with $\xi_\pm = z / k_\pm r_0^2$ as the normalized propagation distance.

NUMERICAL RESULTS AND DISCUSSION

Equation (6) is second order nonlinear differential equation governing the evolution of a laser beam which represent variation of beam width parameter $f_\pm$ with normalized distance of propagation $\xi_\pm$ through collisionless magnetized plasma. Here, $\pm$ sign in this equation indicates extraordinary and ordinary modes of polarization of laser respectively. In present paper, only extraordinary mode is taken into consideration. The first term on right-hand side of Eq.(6) represents diffraction divergence of the beam while second term is responsible for self-focusing of the beam. Thus self-focusing or defocusing of the beam depends on the relative competition of two terms on right-hand side of Eq.(6). In our previous work [23], it is highlighted that pre-conditioning of the critical power at the beginning of propagation can determine propagation dynamics of the beam effectively. In the present paper, to explore the effect of absorption on self-focusing, the numerical interval of critical beam power for self-focusing is used as $000333926 < p_{0+} < 7.75349$. The detailed discussion on numerical interval of critical beam power is given in our earlier study [23-25].

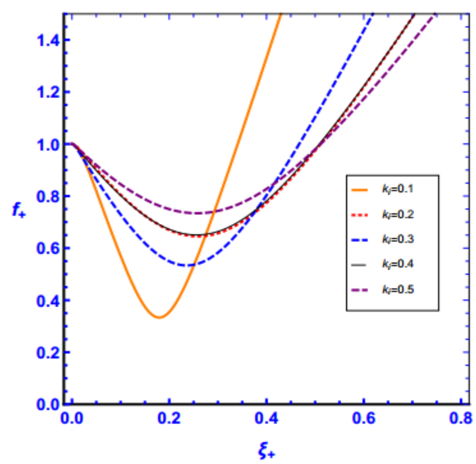

FIGURE 1. Variation of beam-width parameter f_+ as a function normalized distance of propagation ξ_+ for different absorption coefficients in collisionless magnetized plasma.

Fig. 1 illustrates the variation of the beam-width parameter f_+ with normalized propagation distance ξ_+ for $p_{0+} = 0.9$ for different absorption levels k_i ranging from 0.1 to 0.5. The curves demonstrate that beam-width parameter first decreases and then increases sharply with increase in k_i. However, with the increase in k_i, weakening of self-focusing effect takes place and minimum value of f_+ shifts towards higher values of ξ_+.

Further at a given absorption level, increase in critical beam power causes substantial reduction in self-focusing length as shown in Fig.2. It is interesting to note that self-focusing becomes stronger with increase in p_{0+} but weakens due to absorption. It would be interesting to control both critical beam power and absorption level so as to propagate the beam without convergence or divergence during propagation through plasma.

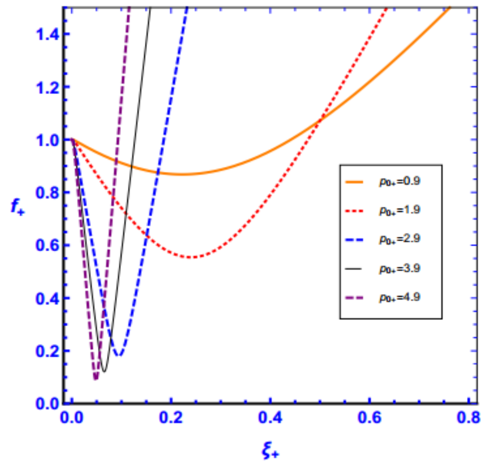

FIGURE 2. Variation of beam-width parameter f_+ as a function normalized distance of propagation ξ_+ for different critical beam powers in collisionless magnetized plasma.

REFERENCES

1. V. Malka, *Phys. Plasmas* **19**, 055501 (2012).
2. S. Atzeni, *Eur. Phys. Lett.* **109**, 45001 (2015).
3. S. A. Akhmanov, A. P. Sukhorukov, R. V. Khokhlov *Sov. Phys. Usp.*, **10**, 609-636 (1968).
4. M. S. Sodha, A. K. Ghatak, V. K. Tripathi, *Prog. Opt.* **13**, 169-265 (1976).
5. S. D. Patil, M. V. Takale, V. J. Fulari, D. N. Gupta, H. Suk, *Appl. Phys.* B **111**, 1-6 (2013).
6. S. D. Patil, M. V. Takale, S. T. Navare, M. B. Dongare, V.J. Fulari, *Optik* **124**, 180-183 (2013).
7. S. D. Patil, M. V. Takale, *Phys. Plasmas* **20**, 072703 (2013).
8. S. D. Patil, M. V. Takale, *Phys. Plasmas* **20**, 083101 (2013).
9. S. D. Patil, M. V. Takale, *Phys. Plasmas* **21**, 064702 (2014).
10. A. T. Valkunde, S. D. Patil, B. D. Vhanmore, T. U. Urunkar, K. M. Gavade, M. V. Takale, D. N. Gupta *Optik* **158**, 1034-1039 (2018).
11. F. Osman, R. Castillo, H. Hora, *J. Plasma Phys*. **61**, 263-273 (1999).
12. M. S. Sodha, L. A. Patel, R. P. Sharma, *J. Plasma Phys.* **49**, 3707-3713 (1978).
13. S. T. Navare, M. V. Takale, S. D. Patil, V. J. Fulari and M. B. Dongare, *Opt. Laser Eng*. **50**, 1316-1320 (2012).
14. M. Aggarwal, S. Vij, N. Kant, *Commun. Theor. Phys*. **64**, 565-570 (2015).
15. N. Kant, M. A. Wani, *Commun. Theor. Phys*. **64**, 103-107 (2015).
16. M. A. Wani, N. Kant, *Commun. Theor. Phys.* **66**, 349-354 (2016).
17. L. Ouahid, L. Dalil-Essakali, A. Belafhal, *Opt. Quant. Electr.* **50**, 1-17 (2018).
18. S. D. Patil, M. V. Takale, T. S. Gill, *Eur. Phys. J. D* **69**, 163 (2015).
19. S. D. Patil, M. V. Takale, V. J. Fulari, T. S. Gill, *Laser Part. Beams* **34**, 669-674 (2016).
20. S. D. Patil, M. V. Takale, *AIP Conf. Proc.* 1728, 020129 (2016).
21. S. D. Patil, A. T. Valkunde, B. D. Vhanmore, T. U. Urunkar, K. M. Gavade, M. V. Takale, *AIP Conf. Proc.* ***1953*** *(1),* 140046 (2018).
22. S. D. Patil, P. P. Chikode, M. V. Takale, *Journal of Optics (Springer)* **42**, 174-179 (2018).
23. T. U. Urunkar, A. T. Valkunde, B. D. Vhanmore, K. M. Gavade, S. D. Patil, M. V. Takale, *AIP Conf. Proc.* **1953** (1), 140087 (2018).
24. T. U. Urunkar, S. D. Patil, A. T. Valkunde, B. D. Vhanmore, K. M. Gavade, M. V. Takale, *Commun. Theor.Phys*. **70**, 220-224 (2018).
25. T. U. Urunkar, S. D. Patil, A. T. Valkunde, B. D. Vhanmore, K. M. Gavade, M. V. Takale, *Laser Part. Beams* **36**, 254-260 (2018).