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Effect of Light Absorption on Self-focusing of Cosh-Gaussian Laser Beams in Collisional Plasma

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Abstract. In the present paper, the contribution of light absorption on self-focusing of cosh-Gaussian laser beams in collisional plasma is studied. The field distribution is expressed in terms of two transverse beam-width parameters, decentred parameters and linear absorption coefficient. Based on parabolic equation approach under Wentzel-Kramers-Brillouin (WKB) and the paraxial approximations, nonlinear differential equations governing the evolution of beam-width parameters are evaluated. The behavior of beam-width parameters with the normalized distance of propagation is studied for different values of decentred parameters and absorption coefficients in collisional plasma. The results are presented graphically and discussed.

INTRODUCTION

The phenomenon of self-focusing of laser beams in plasmas has been a subject of immense interest due to the fact that the manifestation of all nonlinear processes in plasmas is strongly affected by the transverse distribution of beam irradiance. The self-focusing [1] of laser beams is genuinely a nonlinear optical effect induced by modification of dielectric constant of plasma due to the intense laser field. In such self-action effect, the laser beams having non-uniform distribution of irradiance in a plane, normal to direction of propagation leads to non-uniform distribution of carriers along the wavefront, which further leads to a change in dielectric constant of plasma [2]. In laser-plasma interaction, there are three main mechanisms that lead to a change in the dielectric constant of plasma as follows: (i) the ponderomotive force, (ii) the collisions, and (iii) the relativistic effects. Review of literature highlights the fact that under the framework of these mechanisms, few studies have been attempted by considering the contribution of light absorption in self-focusing of laser beams in plasmas.

Armand [3] considered the effect of linear absorption on divergence of a beam. Virmani et al. [4] extended the formalism to include the imaginary part of the dielectric constant, in the analysis. The dependence of the imaginary part of the dielectric constant is in general as significant as that of the real part and hence neglecting it is justified only when the overall absorption is negligible and such case is not always. Hence, attempts have been made to account for the dependence of the imaginary part of the dielectric constant on irradiance profile of the beam. Yuen [5] is probably the first investigator to take account of this dependence. It is well known [6] that the nonlinear phenomena including self-focusing occur in the ionosphere for rather modest powers of radio stations; for periods exceeding the time of relaxation of electrons, the nonlinearity is essentially collisional. For the lower ionosphere, the collisions are predominantly with neutral atoms, while in the upper ionosphere, collisions with ions are predominant. The theory is readily applicable to other types of nonlinearities, for which the corresponding expressions for nonlinear part of dielectric constant are available. Therefore, in the studies on self-focusing of laser beams under different situations, light absorption has paved a vital role. Most of the studies [7-11] on self-focusing of laser beams

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in plasmas have been carried out by neglecting the contribution of light absorption. Besides, Navare *et al.*[12] have examined an impact of linear absorption on self-focusing of Gaussian beam by taking into account collisional nonlinearity. 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.*[13]. Self-focusing of cosh-Gaussian laser beam in plasma with linear absorption has been reported by Kant and Wani [14]. They have also extended their study to chirped Gaussian laser beam in collisional plasma [15]. Ouahid *et al.*[16] investigated an effect of light absorption on self-focusing of finite Airy-Gaussian laser beams under relativistic and ponderomotive regime. Patil *et al.*[17-19] have presented the influence of light absorption on self-focusing of Gaussian laser beam in different situations.

In the present paper the attention is being paid to address the new class of laser beam usually known as cosh-Gaussian beams and their self-focusing in collisional plasma with effect of linear absorption. In recent studies [20-25], such beam has been explored in different situations by neglecting absorption. In addition to adopting impact of absorption, we have considered two beam-width parameters along transverse dimensions of the beam. We rely on the paraxial approach introduced by Akhmanov *et al.* [1] and its extension by Sodha *et al.*[2].

EVOLUTION OF BEAM-WIDTH PARAMETERS

The wave equation governing the electric field vector of a laser beam in plasma with effective dielectric function ε can be written as

$$\nabla^2 E + \frac{\omega^2}{c^2}\varepsilon E = 0, \tag{1}$$

The effective dielectric function ε of plasma can also in general be written as [2]

$$\varepsilon = \varepsilon_0 + \phi(EE^*) + i\,\varepsilon_i\ , \tag{2}$$

where, ε_0 and $\phi(EE^*)$ are the linear and nonlinear parts of the dielectric function respectively, ε_i takes care of absorption and $\varepsilon_0 = 1 - \omega_p^2/\omega^2$ with $\omega_p = \left(4\pi\, n_0 e^2/m\right)^{1/2}$ as the plasma frequency, e, m and n_0 being the electronic charge, its rest mass and the electron density in absence of the beam respectively. The functional form of ϕ is different in different physical situations. In case of collisional plasma, it can be expressed as [2]

$$\phi(EE^*) = \frac{\omega_p^2}{\omega^2}\left[1 - (1 + \frac{\alpha}{2}EE^*)^{\frac{s}{2}-1}\right], \tag{3}$$

where, $\alpha = e^2 M / 6m\omega^2 K_B T_0$, M is the mass of ion, ω is the angular frequency of laser used, K_B is the Boltzmann constant, T_0 is the equilibrium plasma temperature and s is the parameter characterizing the nature of collisions. We restrict ourselves to the case of $s = 1$ which takes place for collisions of electrons with neutral particles.

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

$$A_0^{\ 2} = \frac{E_0^{\ 2}}{f_1 f_2} exp\left(-2k_i z\right) \times \begin{bmatrix} exp\left[\frac{b_1^{\ 2}}{4}\right]\left\{exp\left[-\left(\frac{x}{r_0 f_1} + \frac{b_1}{2}\right)^2\right] + exp\left[-\left(\frac{x}{r_0 f_1} - \frac{b_1}{2}\right)^2\right]\right\} \\ \times\, exp\left[\frac{b_2^{\ 2}}{4}\right]\left\{Exp\left[-\left(\frac{y}{r_0 f_2} + \frac{b_2}{2}\right)^2\right] + exp\left[-\left(\frac{y}{r_0 f_2} - \frac{b_2}{2}\right)^2\right]\right\} \end{bmatrix}^2, \tag{4}$$

where E_0 is the initial amplitude of laser with initial beam-width r_0, b_1 and b_2 are the decentred parameters of ChG beams with f_1 and f_2 as the corresponding beam-width parameters in *x* and *y* dimensions respectively.

Following the approach of Akhmanov *et al.*[1] and its extension by Sodha *et al.*[2], the beam-width parameter differential equations for ChG beams in collisional plasma are obtained as

$$\frac{d^2 f_1}{d\eta^2} = \frac{A_1}{f_1^3} + \frac{\rho_1^2 \omega_p^2 B_1 P \sqrt{1 + \frac{P\, exp\left(-2k_i'\eta\right)}{2 f_1 f_2}}\, exp\left(-4k_i'\eta\right)}{\omega^2 f_1 \left(p + 2\, exp\left(2k_i'\eta\right) f_1 f_2\right)^2}\ , \tag{5}$$

$$\frac{d^2 f_2}{d\eta^2} = \frac{A_2}{f_1^3} + \frac{\rho_2^2 \omega_p^2 B_2 P \sqrt{1 + \frac{P\, exp\left(-2k_i'\eta\right)}{2 f_1 f_2}}\, exp\left(-4k_i'\eta\right)}{\omega^2 f_1 \left(p + 2\, exp\left(2k_i'\eta\right) f_1 f_2\right)^2}\ , \tag{6}$$

where $A_{1,2} = 4\left(1 - b_{1,2}^2\right)$, $B_{1,2} = b_{1,2}^2 - 2$, $P = \alpha E_0^2$ and $\rho_{1,2} = r_0 \omega / c$ is the equilibrium beam radius, $\eta = z / k r_0^2$ is the dimensionless distance of propagation, $k_i' = k_i R_d$ is the normalized absorption coefficient, $R_d = k r_0^2$ is the Rayleigh length. Under critical condition, $f_1 = f_2 = 1$ at $\eta = 0$, the condition $d^2 f_1 / d\eta^2 = d^2 f_2 / d\eta^2 = 0$ leads to propagation of ChG laser beams without convergence or divergence i.e. self-trapped mode.

NUMERICAL RESULTS AND DISCUSSION

Equations (5) and (6) are nonlinear coupled, differential equations in which first term on right-hand side corresponds to the diffraction divergence of the beam and second term corresponds to nonlinear refraction of the beam due to self-focusing. These equations can be solved numerically by using numerical values, $\omega = 1.778 \times 10^{14}\ rad/s$ and $n_0 = 10^{19}\ cm^{-3}$. Fig. 1 shows the plot of equilibrium beam radii ρ_1 and ρ_2 against initial intensity parameter P for different values of decentred parameters b_1 and b_2.

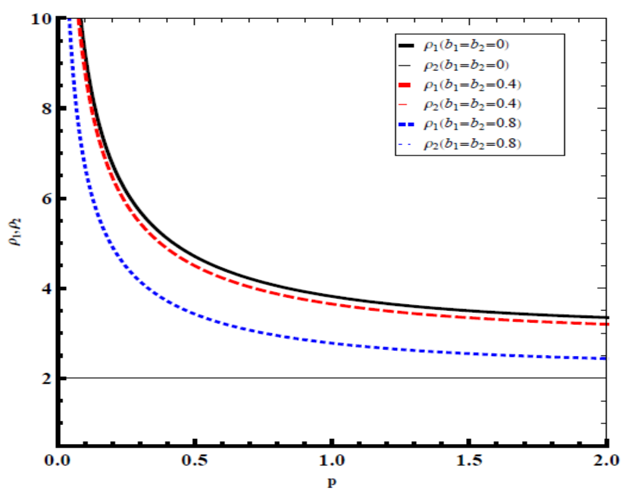

FIGURE 1. Variation of equilibrium beam radii ρ_1 and ρ_2 with initial intensity parameter P for different decentred parameters b_1 and b_2. $b_{1,2} = 0.0$ (solid curves), $b_{1,2} = 0.4$ (dashed curves), $b_{1,2} = 0.8$ (dotted curves).

From Fig. 1 it is seen that as value of decentered parameters increases, the critical curves shifts downward and attain minimum value. The region above the curves corresponds to the self-focusing and below it corresponds to defocusing. Fig. 2 shows the variation of beam-width parameters f_1 and f_2 against the dimensionless distance of propagation η for different absorption coefficients $k_i^{'} = 0.00, 0.02, 0.04$ with $b_1 = b_2 = 0.8$, $\rho_1 = \rho_2 = 6$ and $P = 1$. From this figure it is clear that stationary self-focusing of laser beam gets destroyed by taking into account the absorption. Subsequently, maximum of beam-width increases during the propagation in plasma. Finally the beam becomes too weak to control the diffraction and suffers steep steady divergence. As obvious, penetration decreases with increasing the absorption and decentred parameters too. Thus control parameters like absorption coefficient, decentred parameters, initial intensity parameter, equilibrium beam radius plays an important role in propagation dynamics of the laser beams in plasmas

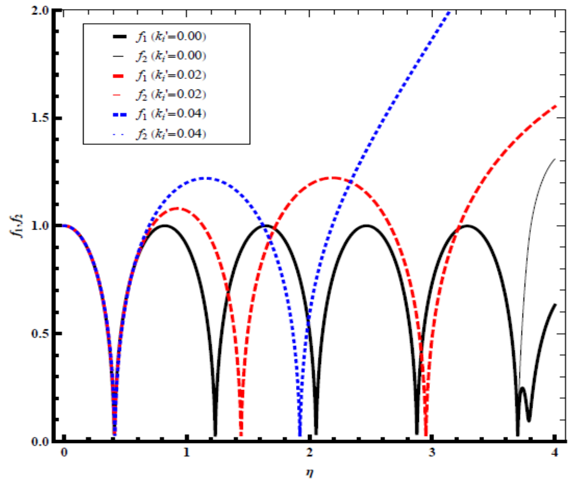

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FIGURE 2. Variation of beam-width parameters f_1 and f_2 as a function of η for different absorption coefficients $k_i^{'}$. $k_i^{'} = 0.00$ (Solid curves), $k_i^{'} = 0.02$ (dashed curves), $k_i^{'} = 0.04$ (dotted curves).

REFERENCES

1. S. A. Akhmanov, A. P. Sukhorukov, R. V. Khokhlov *Sov. Phys. Usp.*, **10**, 609-636 (1968).
2. M. S. Sodha, A. K. Ghatak, V. K. Tripathi, *Prog. Opt.* **13**, 169-265 (1976).
3. S. A. Armand, *Radio Eng. Electron. Phys.* **15**, 1753-1757 (1970).
4. C. J. K. Virmani, R. G. Gupta, V. K. Tripathi, *Optik*, **40**, 431-437 (1974).
5. S. Y. Yuen, *Appl. Phys. Lett.* **30**, 223-224 (1977).
6. A. V. Gurevich, *Nonlinear Phenomena in Ionosphere*, Springer, New-York, (1978).
7. S. D. Patil, M. V. Takale, V. J. Fulari, D. N. Gupta, H. Suk, *Appl. Phys.* B **111**, 1-6 (2013).
8. S. D. Patil, M. V. Takale, S. T. Navare, M. B. Dongare, V.J. Fulari, *Optik* **124**, 180-183 (2013).
9. S. D. Patil, M. V. Takale, *Phys. Plasmas* **20**, 072703 (2013).
10. S. D. Patil, M. V. Takale, *Phys. Plasmas* **20**, 083101 (2013).
11. S. D. Patil, M. V. Takale, *Phys. Plasmas* **21**, 064702 (2014).
12. S. T. Navare, M. V. Takale, S. D. Patil, V. J. Fulari and M. B. Dongare, *Opt. Laser Eng*. **50**, 1316-1320 (2012).
13. M. Aggarwal, S. Vij, N. Kant, *Commun. Theor. Phys*. **64**, 565-570 (2015).
14. N. Kant, M. A. Wani, *Commun. Theor. Phys*. **64**, 103-107 (2015).
15. M. A. Wani, N. Kant, *Commun. Theor. Phys*. **66**, 349-354 (2016).
16. L. Ouahid, L. Dalil-Essakali, A. Belafhal, *Opt. Quant. Electr.* **50**, 1-17 (2018).
17. S. D. Patil, M. V. Takale, T. S. Gill, *Eur. Phys. J. D* **69**, 163 (2015).
18. S. D. Patil, M. V. Takale, V. J. Fulari, T. S. Gill, *Laser Part. Beams* **34**, 669-674 (2016).
19. S. D. Patil, P. P. Chikode, M. V. Takale, *Journal of Optics (Springer)* **42**, 174-179 (2018).
20. S. D. Patil, M. V. Takale, S. T. Navare, V. J. Fulari, M. B. Dongare, *Journal of Optics (Springer)* **36**, 136-144 (2007).
21. S. D. Patil, M. V. Takale, S. T. Navare, M. B. Dongare, *Optik* **122**, 1869-1871 (2011).
22. S. D. Patil, M. V. Takale, *Laser Phys. Lett.* **10**, 115402 (2013).
23. M. Aggarwal, S. Vij, N. Kant, *Optik* **125**, 5081-5084 (2014).
24. B. D. Vhanmore, S. D. Patil, A. T. Valkunde, T. U. Urunkar, K. M. Gavade, M. V. Takale, *Laser Part. Beams* **35**, 670-676 (2017).
25. 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).