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Effect of cross focusing of two laser beams on the growth of laser ripple in plasma

GUNJAN PUROHIT, H.D. PANDEY, AND R.P. SHARMA
Centre for Energy Studies, Indian Institute of Technology, New Delhi1, India
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Abstract

This article presents an effect of cross focusing of two laser beams on the growth of a laser ripple in laser-produced plasmas. The mechanism of nonlinearity is assumed to be ponderomotive force, arising because of the Gaussian intensity distribution of the laser beams. The dynamical equation governing the laser ripple intensity has been set up and a numerical solution has been presented for typical laser plasma parameters. It is found that the change in the intensity of the second laser beam can affect the growth of the laser ripple significantly.

Keywords: Lasers; Nonlinearity; Ponderomotive; Ripple

1. INTRODUCTION

There has been considerable interest in the interaction of intense laser beams with plasmas because of its relevance to laser fusion and charged particle acceleration. In laser-induced fusion, the most important problem is the efficient coupling of the energy of the laser beam to plasma to heat the latter. In this coupling process, many nonlinear phenomena such as self-focusing, filamentation instabilities, stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS) and so forth (Kruer, 1988) play a crucial role.

Filamentation instability or hot spot formation by laser beam in plasmas has been studied in detail (Kruer, 1988). This instability may also arise because of small-scale fluctuations in the intensity distribution of the pump laser beam. This perturbation could grow inside the plasma, leading to the phenomena of filamentation.

In the past decade, several new laser beam smoothing techniques, namely, random phase plates (RPP; Kato *et al*., 1984), smoothing by spectral dispersion (SSD; Lehmberg *et al*., 1987), and induced spatial incoherence (ISI; Skupsky *et al*., 1989), have been used for controlling natural intensity nonuniformities in laser beams. These techniques introduce randomness into the laser beam through spatial and/or temporal incoherence to produce a smooth laser intensity distribution in a focal spot region. This, in turn, improves the efficiency of laser energy coupling to the plasma and uniformity of fuel compression in inertial confinement fusion (ICF) targets.

In the present article, we have investigated the growth of the laser ripple when a second laser beam is also present. To keep the mathematics simple but to understand the nonlinear mechanism, we have considered the ripple superimposed on one laser beam only. Because of the ponderomotive nonlinearity, the dynamical equation governing the intensity of the laser ripple depends on the total intensity of both lasers. Therefore, by changing the intensity of the second laser, one can control the growth of the ripple in the plasmas.

In Section 2, we present an analysis of the nonlinear effective dielectric constant of the plasma and derive the differential equations governing the nature of the laser ripple intensity in plasma. In Section 3, a brief discussion and conclusions of the numerical results of the present investigation are presented.

2. MODEL EQUATIONS

Consider the propagation of two coaxial Gaussian laser beams of frequencies ω_1 and ω_2 along the z direction. The initial intensity distributions of the beams are given by

$$\mathbf{E}_1 \cdot \mathbf{E}_1^*|_{z=0} = E_{10}^2 e^{-r^2/r_{10}^2}$$

$$\mathbf{E}_2 \cdot \mathbf{E}_2^*|_{z=0} = E_{20}^2 e^{-r^2/r_{20}^2}, \quad (1)$$

Address correspondence and reprint requests to: R.P. Sharma, Centre for Energy Studies, Indian Institute of Technology, New Delhi1-110016, India. E-mail: rpsharma@ces.iitd.ernet.in

where r is the radial coordinate of the cylindrical coordinate system and r_{10} and r_{20} are their initial beamwidths. The expression for ponderomotive force in the presence of two beams can be written as (Schmidt, 1973)

$$F = -\left(\frac{e^2}{4m}\right)\left[\left(\frac{1}{\omega_1^2}\right)\nabla \mathbf{E}_1 \cdot \mathbf{E}_1^* + \left(\frac{1}{\omega_2^2}\right)\nabla \mathbf{E}_2 \cdot \mathbf{E}_2^*\right], \quad (2)$$

and the modified electron concentration because of ponderomotive force can be written as

$$N_{0e} = N_0 \exp\left[-\frac{3}{4}\left(\frac{m}{M}\right)(\alpha_1 \mathbf{E}_1 \cdot \mathbf{E}_1^* + \alpha_2 \mathbf{E}_2 \cdot \mathbf{E}_2^*)\right],$$

where

$$\alpha_{1,2} = \frac{e^2 M}{18 k_B T_0 m^2 \omega_{1,2}^2}. \quad (3)$$

e and m are the electronic charge and mass, respectively, M is the mass of ion, k_B is Boltzmann constant, T_0 is the equilibrium temperature of the plasma, and N_0 is the electron concentration in the absence of the beams. The effective dielectric constant of the plasma at frequencies ω_1 and ω_2 can be written as

$$\varepsilon_{1,2} = \varepsilon_{01,2} + \phi_{1,2}(\mathbf{E}_1 \cdot \mathbf{E}_1^*, \mathbf{E}_2 \cdot E_2^*),$$

where

$$\varepsilon_{01,2} = 1 - \left(\frac{\omega_{p0}^2}{\omega_{1,2}^2}\right)$$

$$\phi_{1,2} = \left(\frac{\omega_{p0}^2}{\omega_{1,2}^2}\right)\left\{1 - \exp\left[-\frac{3}{4}\left(\frac{m}{M}\right)(\alpha_1 \mathbf{E}_1 \cdot \mathbf{E}_1^* + \alpha_2 \mathbf{E}_2 \cdot \mathbf{E}_2^*)\right]\right\} \quad (4)$$

where $\phi_{1,2}$ is the nonlinear part of the dielectric constant and $\omega_{p0}^2 = (4\pi N_0 e^2)/m$ is the electron plasma frequency. By using the Taylor expansion of the dielectric constant around $r = 0$, the equation can be rewritten as

$$\varepsilon_{1,2} = \varepsilon_{f_{1,2}} + \gamma_{1,2} r^2$$

$$\gamma_{1,2} = -\frac{\omega_{p0}^2}{\omega_{1,2}^2}\left[\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{r_{10}^2 f_1^4} + \frac{\alpha_2 E_{20}^2}{r_{20}^2 f_2^4}\right)\right] \times \exp\left[-\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{r_{10}^2 f_1^2} + \frac{\alpha_2 E_{20}^2}{r_{20}^2 f_2^2}\right)\right]$$

and

$$\varepsilon_{f_{1,2}} = \varepsilon_{01,2} + \frac{\omega_{p0}^2}{\omega_{1,2}^2}\left\{1 - \exp\left[-\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{r_{10}^2 f_1^2} + \frac{\alpha_2 E_{20}^2}{r_{20}^2 f_2^2}\right)\right]\right\}. \quad (5)$$

The wave equation governing the electric vectors of the two beams in plasma can be written as

$$\frac{\partial^2 E_{1,2}}{\partial z^2} + \frac{1}{r}\frac{\partial E_{1,2}}{\partial r} + \frac{\partial E_{1,2}}{\partial r^2} + \frac{\omega_{1,2}^2}{c^2}\varepsilon_{1,2} E_{1,2} = 0. \quad (6)$$

In writing Eq. (6), we have neglected the $\nabla(\nabla \cdot \mathbf{E})$ term, which is justified as long as

$$\left(\frac{\omega_{p0}^2}{\omega_{1,2}^2}\right)\left(\frac{1}{\varepsilon_{1,2}}\right) \text{In}\, \varepsilon_{1,2} \le 1.$$

The solution for $E_{1,2}$ can be written as (Akhmanov *et al.*, 1968; Sodha *et al.*, 1976, 1979)

$$E_{1,2} = A_{1,2} e^{[-ik_{1,2}(z+S_{1,2})]}$$

$$A_{1,2}^2 = \left(\frac{E_{1,20}^2}{f_{1,2}^2}\right)\exp\left(-\frac{r^2}{r_{1,20}^2 f_{1,2}^2}\right)$$

$$S_{1,2} = (r^2/2)\beta_{1,2}(z) + \phi_{1,2}(z)$$

$$\beta_{1,2}(z) = \frac{1}{f_{1,2}}\frac{df_{1,2}}{dz}, \qquad k_{1,2}(z) = \frac{\omega_{1,2}}{c}\varepsilon_{f_{1,2}}^{1/2}, \quad (7)$$

where the dimensionless beam width parameter equation $f_{1,2}$ is given by

$$\frac{d^2 f_{1,2}}{dz^2} = \frac{c^2}{\omega_{1,2}^2 r_{1,20}^2 \varepsilon_{01,2} f_{1,2}^3} + \frac{\gamma_{1,2} f_{1,2}}{\varepsilon_{01,2}}. \quad (8)$$

For initial plane wavefronts of the beams, the initial conditions on $f_{1,2}$ are

$$f_{1,2} = 1 \qquad \text{and} \qquad df_{1,2}/dz = 0 \quad \text{at } z = 0.$$

Let a perturbation be superimposed on the first beam such that its initial intensity distribution is given by

$$\mathbf{E}_{01} \cdot \mathbf{E}_{01}^*|_{z=0} = E_{100}^2 \left(\frac{r}{r_{100}}\right)^{2n} \exp\left(-\frac{r^2}{r_{100}^2}\right), \quad (9)$$

where n is a positive number and r_{100} is the width of the ripple. By changing the value of n, the position of the ripple changes. The total electric vector of the laser having ripple superimposed on it can be written as

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_{01}, \quad (10)$$

where $\mathbf{E}_{01}$ is the ripple superimposed on the first laser beam. The total electric vector $\mathbf{E}$ satisfies the wave equation

$$\nabla^2 \mathbf{E} - \nabla(\nabla \cdot \mathbf{E}) + \frac{\omega_1^2}{c^2}\varepsilon_1 \mathbf{E} = 0. \quad (11)$$

In the WKB approximation, the second term of Eq. (11) can be neglected. This is justified because one has $(\omega_{p0}^2/\omega_1^2)(1/\varepsilon_1)$ In $\varepsilon_1 \leq 1$, and the electric vectors of the main beam $\mathbf{E}_1$ and the ripple $\mathbf{E}_{01}$ satisfy the equations

$$\nabla^2 \mathbf{E}_1 + \frac{\omega_1^2}{c^2}\varepsilon_1(\mathbf{E}_1\cdot\mathbf{E}_1^*, \mathbf{E}_2\cdot\mathbf{E}_2^*)\mathbf{E}_1 = 0 \tag{12}$$

$$\nabla^2 \mathbf{E}_{01} + \frac{\omega_1^2}{c^2}\varepsilon_1(\mathbf{E}\cdot\mathbf{E}^*)\mathbf{E}_{01} + \frac{\omega_1^2}{c^2}[\phi_1(\mathbf{E}\cdot\mathbf{E}^*) - \phi_1(\mathbf{E}_1\cdot\mathbf{E}_1^*, \mathbf{E}_2\cdot\mathbf{E}_2^*)]\mathbf{E}_1 = 0, \tag{13}$$

respectively. To obtain the solution of Eq. (13), we express

$$\mathbf{E}_{01} = A_{01}(r,z)e^{(-k_1 z)}, \tag{14}$$

where $A_{01}(r,z)$ is a complex function of its argument. Substituting for $\mathbf{E}_{01}$ from Eq. (14) into Eq. (13) we get the following equation within the WKB approximation:

$$-2ik_1\frac{\partial A_{01}}{\partial z} + \left(\frac{\partial^2 A_{01}}{\partial r^2} + \frac{1}{r}\frac{\partial A_{01}}{\partial r^2}\right) + \frac{\omega_1^2}{c^2}\phi(\mathbf{E}\cdot\mathbf{E}^*)A_{01} + \frac{\omega_1^2}{c^2}[\phi(\mathbf{E}\cdot\mathbf{E}^*) - \phi_1(\mathbf{E}_1\cdot\mathbf{E}_1\cdot\mathbf{E}_1^*, \mathbf{E}_2\cdot\mathbf{E}_2^*)]A_{01}e^{(-ik_1 S_1)} = 0. \tag{15}$$

Further, substituting for A_{01} in Eq. (15)

$$A_{01} = A_{010}(r,z)e^{[-ik_1 S_{10}(r,z)]},$$

where $A_{010}(r,z)$ is a real function and S_{10} is the eikonal; we obtain the following equations after separating the real and imaginary parts

$$2\frac{\partial S_{10}}{\partial z} + \left(\frac{\partial S_{10}}{\partial z}\right)^2 = \frac{1}{k_1^2 A_{010}}\left(\frac{\partial^2 A_{010}}{\partial r^2} + \frac{1}{r}\frac{\partial A_{010}}{\partial r}\right) + \frac{\phi_{eff}}{\varepsilon_{01}}, \tag{16a}$$

where

$$\phi_{eff} = \phi_1(\mathbf{E}\cdot\mathbf{E}^*) + \frac{\omega_{p0}^2}{\omega_1^2}\left[\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2}e^{(-r^2/r_{10}^2 f_1^2)} + \frac{\alpha_2 E_{20}^2}{f_1^2}e^{(-r^2/r_{20}^2 f_2^2)}\right)\right] \times \exp\left[-\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2}e^{(-r^2/r_{10}^2 f_1^2)} + \frac{\alpha_2 E_{20}^2}{f_2^2}e^{(-r^2/r_{20}^2 f_2^2)}\right)\right] \times 2\cos^2\phi_p$$

and

$$\frac{\partial A_{010}^2}{\partial z} + \frac{\partial S_{10}}{\partial r}\frac{\partial A_{010}^2}{\partial r} + A_{010}^2\left(\frac{\partial^2 S_{10}}{\partial r^2} + \frac{1}{r}\frac{\partial S_{10}}{\partial r}\right) + \left[\frac{\omega_1^2}{c^2}\frac{1}{k_1}\frac{\omega_{p0}^2}{\omega_1^2} \times \left[\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2}e^{(-r^2/r_{10}^2 f_1^2)} + \frac{\alpha_2 E_{20}^2}{f_2^2}e^{(-r^2/r_{20}^2 f_2^2)}\right)\right] \times \exp\left[-\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2}e^{(-r^2/r_{10}^2 f_1^2)} + \frac{\alpha_2 E_{20}^2}{f_2^2}e^{(-r^2/r_{20}^2 f_2^2)}\right)\right] \times \sin 2\phi_p\right]A_{010}^2 = 0, \tag{16b}$$

where ϕ_p is the angle between the electric vectors of the main laser beam (one) and the ripple. In writing Eq. (16) we have expanded

$$\phi(\mathbf{E}\cdot\mathbf{E}^*) = \phi_1(\mathbf{E}_1\cdot\mathbf{E}_1^*, \mathbf{E}_2\cdot\mathbf{E}_2^*) + \left.\frac{d\phi_1}{d\mathbf{E}\cdot\mathbf{E}^*}\right|_{(\mathbf{E}\cdot\mathbf{E}^* = \mathbf{E}_1\cdot\mathbf{E}_1^* + \mathbf{E}_2\cdot\mathbf{E}_2^*)} \times [\mathbf{E}\cdot\mathbf{E}^* - (\mathbf{E}_1\cdot\mathbf{E}_1^* + \mathbf{E}_2\cdot\mathbf{E}_2^*)].$$

Following Akhmanov *et al.* (1968), the solutions of Eqs. (16a) and (16b) can be written as

$$A_{010}^2 = \frac{E_{100}^2}{f^2}\left(\frac{r}{r_{100}f}\right)^{2n}\exp\left(-\frac{r^2}{r_{100}^2 f^2}\right)\exp\left(-2\int_0^z k_i(z)\,dz\right)$$

$$S_{10} = \frac{r^2}{2}\beta(z) + \phi_1(z)$$

$$\beta(z) = \frac{1}{f}\frac{df}{dz}$$

$$k_i(z) \approx \frac{1}{2}\frac{\omega_1^2}{c^2}\frac{1}{k_1}\frac{\omega_{p0}^2}{\omega_1^2}\left[\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2(z)} + \frac{\alpha_2 E_{20}^2}{f_2^2(z)}\right)\right] \times (\sin 2\phi_p)\exp\left[-\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2(z)} + \frac{\alpha_2 E_{20}^2}{f_2^2(z)}\right)\right], \tag{17}$$

where f is the dimensionless beam width parameter of the ripple and $\phi(z)$ is a constant. For an initially plane wave front, $df/dz = 0$ and $f = 1$ at $z = 0$. Substituting for A_{010} and S_{10} from Eq. (17) into Eq. (16a) and expanding around $r = r_{100} fn^{1/2}$ by Taylor expansion, we get

$$\phi_{\text{eff}} = \phi_{\text{eff}}(r = r_{100} fn^{1/2}) + \phi' r^2, \tag{18a}$$

where

$$\phi' = \frac{d\phi_{eff}}{dr^2}\bigg|_{r^2=r_{100}^2 f^2 n}$$

$$= -\left(\frac{\omega_{pe}^2}{\omega_1^2}\right)\exp\left[-\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2}e^{-nr_{100}^2 f^2/r_{10}^2 f_1^2} + \frac{\alpha_2 E_{20}^2}{f_2^2}e^{-nr_{100}^2 f^2/r_{20}^2 f_2^2}\right)\right]$$

$$\times\left[\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{r_{10}^2 f_1^4}e^{-nr_{100}^2 f^2/r_{10}^2 f_1^2} + \frac{\alpha_2 E_{20}^2}{r_{20}^2 f_2^4}e^{-nr_{100}^2 f^2/r_{20}^2 f_2^2}\right)\right.$$

$$+ n^{n/2}\frac{E_{100}}{E_{10}}e^{-k_i(z)}2\cos\phi_p\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2} + \frac{\alpha_2 E_{10}^2}{f_2^2}\right)$$

$$\times\exp\left[-\frac{n}{2}\left(1+\frac{r_{100}^2 f^2}{r_{10}^2}\right)\right]$$

$$\times\left\{\frac{3}{4}\frac{m}{M}\left(\frac{a_1 E_{10}^2}{r_{10}^2 f_1^4}e^{-nr_{100}^2 f^2/r_{10}^2 f_1^2} + \frac{\alpha_2 E_{20}^2}{r_{20}^2 f_2^4}e^{-nr_{100}^2 f^2/r_{20}^2 f_2^2}\right) - \frac{1}{2r_{10}^2}\right\} - 4\cos^2\phi_p$$

$$\times\left\{\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{r_{10}^2 f_1^4}e^{-nr_{100}^2 f^2/r_{10}^2 f_1^2} + \frac{\alpha_2 E_{20}^2}{r_{20}^2 f_2^4}e^{-nr_{100}^2 f^2/r_{20}^2 f_2^2}\right)\right.$$

$$\left.\left.\times\frac{3}{4}\frac{m}{M}\left(\frac{\alpha_1 E_{10}^2}{f_1^2}e^{-nr_{100}^2 f^2/r_{10}^2 f_1^2} + \frac{\alpha_2 E_{20}^2}{f_2^2}e^{-nr_{100}^2 f^2/r_{20}^2 f_2^2}\right)\right\}\right]. \quad (18b)$$

Using Eqs. (18a), (18b), and (16a), we get the following equation for f after equating the coefficient of r^2:

$$\frac{d^2 f}{dz^2} = \frac{c^2}{\omega_1^2 \varepsilon_{01} r_{100}^4 f^3} + \frac{\phi' f}{\varepsilon_{01}}. \quad (19)$$

Equation (19) determines the focusing/defocusing of a ripple. It is apparent from Eq. (17) for A_{010}^2 that the ripple grows/decays inside the plasma and the growth rate is k_i. The growth rate depends on the intensity of the main beams, the phase angle ϕ_p, and parameters of the pump wave and plasma. The following set of parameters has been used in the numerical calculations: $r_{10} = 15\ \mu$m, $r_{20} = 20\ \mu$m, r_{100}, $= 10\ \mu$m, $\omega_1 = 1.778 \times 10^{15}$ rad/s, $\omega_2 = 1.778 \times 10^{14}$rad/s, $\omega_{po} = 0.95\ \omega_2$, $2\phi_p = 3\pi/2$, $n = 2.8$ and 3.

3. DISCUSSION AND CONCLUSIONS

It is obvious from the present analysis that because of the coupling between the main beams and the ripple, the ripple can grow in the plasma. The growth rate of the ripple (k_i) is given by Eq. (17), which depends on the effective intensity of the main beam in the plasma, electron density in the plasma, frequency of the laser beams, and the phase angle ϕ_p. It is clear from the equation that, when $\sin 2\phi_p$ is positive, the ripple will not grow and it will be attenuated at a distance of the order of $1/k_i$. The ripple will grow only when $\sin 2\phi_p$ is negative. From Figure 1, we observe the variation of $\exp k_i(z)$ of the ripple with the normalized distance of propagation for different powers of the second laser beam. It is obvious from the graph that the growth rate of the ripple increases with the distance of propagation. When the power of the second beam is increased, a similar effect has been found, but the growth rate is decreased.

Equation (8) is the fundamental equation for cross focusing of two laser beams when the ripple is not present on the first laser beam. On neglecting the contribution of the second beam in Eq. (8), one can obtain the usual ponderomotive self-focusing of the first beam. With the simultaneous propagation of two laser beams, the ponderomotive nonlinearity introduced in the plasma depends on the total intensity of the two beams, and the behavior of f_1 is also governed by f_2, and vice versa. In other words, the self-focusing of one beam is affected by the presence of another beam; this is referred to as cross focusing. The first term on the right-hand side of Eq. (19) represents the diffraction phenomenon of the ripple. The second term, which arises from the ponderomotive nonlinearity, describes nonlinear refraction. The relative magnitude of these terms determines the focusing/defocusing behavior of the ripple. If the first term is large in

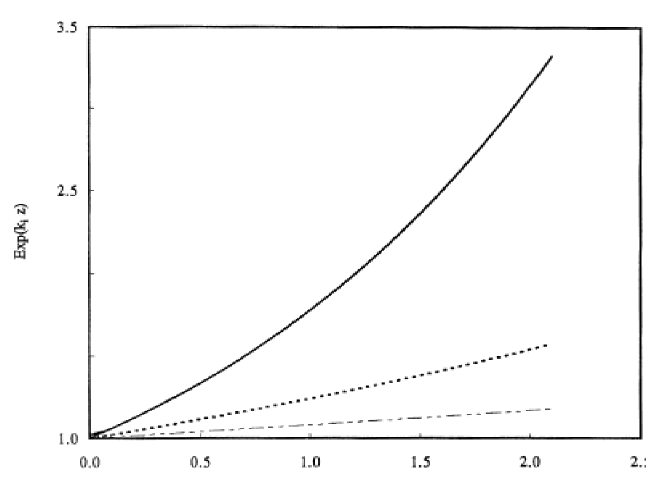

Fig. 1. Variation of $\exp(k_i z)$ for the two beams with the normalized distance of propagation $\xi(= zc/\omega_1^2 r_{10}^2)$ for a fixed power of the first beam $[3/4\ (\mathrm{m/M})\alpha_1 E_{10}^2 = 3]$ and different powers of the second beam. Solid line, dotted line, and semi-dotted line are for $3/4\ (\mathrm{m/M})\alpha_2 E_{20}^2 = 3$, 4, and 5, respectively.

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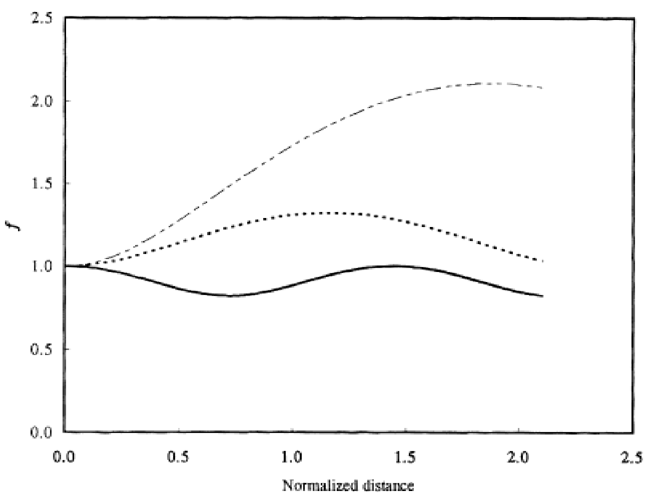
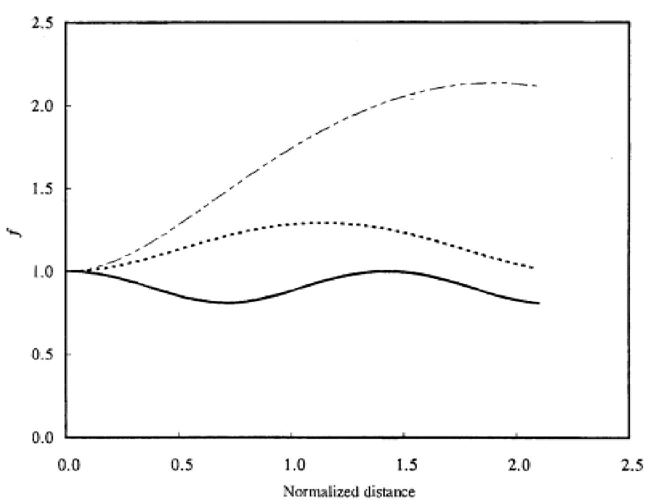
comparison to the second term, the diffraction dominates over the nonlinear phenomena, leading to defocusing of the ripple. When second term is larger than the first term, self-focusing of the ripple is observed. The growth rate (k_i) contributes significantly to focusing/defocusing of the ripple. The variations of the beam width parameter f of the ripple with the distance of propagation is illustrated in Figures 2a,b for fixed $2\phi_p = 3\pi/2$ but for different powers of the second laser beam in two cases when $n = 2.8$ (Fig. 2a) and $n = 3$ (Fig. 2b). When the power of the second laser beam is increased, the ripple shows diverging behavior continuously. The focusing/defocusing of the ripple is found to be considerably affected by the power of the main beams, phase angle between the electric vectors of the first laser beam, but not much affected by the parameter n.

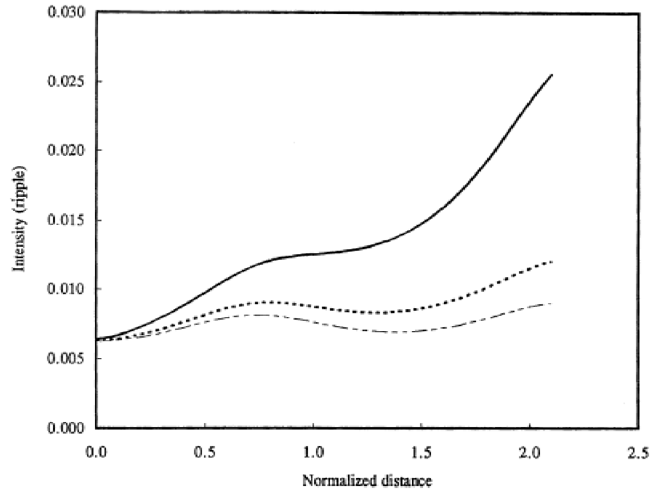


(a)

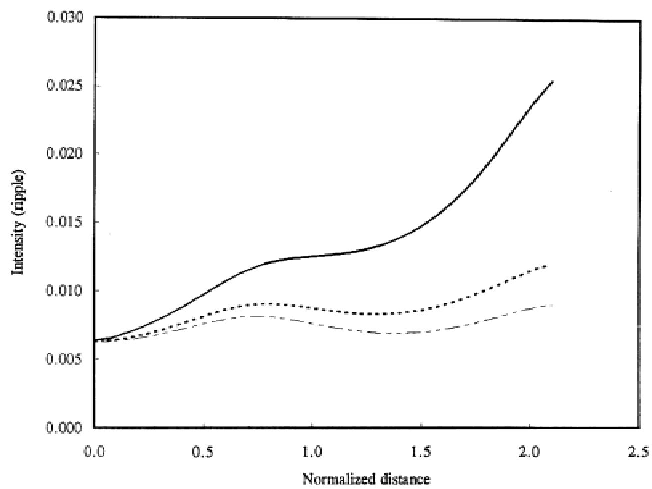


(b)

Fig. 2. a: Variation of dimensionless beam width parameter (f) of the ripple with the normalized distance of propagation $\xi(= zc/\omega_1^2 r_{10}^2)$ for a fixed power of the first beam [3/4 $(\text{m/M})\alpha_1 E_{10}^2 = 3$, $n = 2.8$, and $2\phi_p = 3\pi/2$] and different powers of the second beam. b: Variation of dimensionless beam width parameter (f) of the ripple with the normalized distance of propagation $\xi(= zc/\omega_1^2 r_{10}^2)$ for a fixed power of the first beam [3/4 $(\text{m/M})\alpha_1 E_{10}^2 = 3$, $n = 3.0$, and $2\phi_p = 3\pi/2$] and different powers of the second beam. Solid line, dotted line, and semi-dotted line are for 3/4 $(\text{m/M})\alpha_2 E_{20}^2 = 3$, 4, and 5, respectively.



(a)



(b)

Fig. 3. a: Variation in intensity of the ripple with the normalized distance of propagation $\xi(= zc/\omega_1^2 r_{10}^2)$ for a fixed power of the first beam [3/4 $(\text{m/M})\alpha_1 E_{10}^2 = 3$, $n = 2.8$, and $2\phi_p = 3\pi/2$] and different powers of the second beam. b: Variation in intensity of the ripple with the normalized distance of propagation $\xi(= zc/\omega_1^2 r_{10}^2)$ for a fixed power of the first beam [3/4 $(\text{m/M})\alpha_1 E_{10}^2 = 3$, $n = 3.0$, and $2\phi_p = 3\pi/2$] and different powers of the second beam. Solid line, dotted line, and semi-dotted line are for 3/4 $(\text{m/M})\alpha_2 E_{20}^2 = 3$, 4, and 5, respectively.

Figure 3a,b depicts the variation of normalized intensity of the ripple at $r = r_{100} f n^{1/2}$ in the plasma with the normalized distance of propagation for fixed $2\phi_p = 3\pi/2$, but for different values of the ripple position parameter n. For fixed power of two laser beams, intensity of the ripple increases with the distance of propagation because growth rate (k_i) affects significantly the intensity dynamics of the ripple. It is obvious from the graphs that the intensity of the ripple is decreased by increasing the power of the second laser beam. When the power of the second laser beam is increased, the nonlinearity, which governs the growth of the laser ripple, becomes affected [see Eq. (17)]; therefore, the ripple intensity behaves as shown in Figures 3a,b.

In conclusion, two laser beams copropagating in plasma modify each other's characteristics of ponderomotive self-focusing. One important result that comes from the present analysis is that we can control the fluctuations on the first laser beam by increasing the power of the second laser beam. This study may be useful in beat wave excitation, laser plasma coupling where the filamentation process plays a very important role. This will be a part of a future investigation.

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REFERENCES

Akhmanov, S.A., Sukhorukov, A.P. & Khokhlov, R.V. (1968). *Soviet Phys. Usp.* **10**, 609.

Kato, Y., Mima, K., Miyaraga, N., Arinaga, S., Kitagawa, Y., Nakatsuka, M. & Yamanaka, C. (1984). *Phys. Rev. Lett.* **53**, 1057.

Kruer, W.L. (1988). *The Physics of Laser Plasma Interactions.* New York: Addison-Wesley Publishing Company.

Lehmberg, R.H., Schmitt, A.J. & Bodner, S. (1987). *J. Appl. Phys.* **62**, 2680.

Schmidt, G. (1973). *Phys. Fluids* **16**, 1676.

Skupsky, S., Short, R.W., Kessler, T., Craxton, R.S., Letzring, S. & Soures, J.M. (1989). *J. Appl. Phys.* **66**, 3456.

Sodha, M.S., Ghatak, A.K. & Tripathi, V.K. (1976). *Prog. Optics* **13**, 171.

Sodha, M.S., Govind., Tewari, D.P., Sharma, R.P. & Kaushik, S.C. (1979). *J. Appl. Phys.* **50**, 158.

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