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Cross-focusing Effect of Two Intense Laser Beams on Electron Plasma Wave Excitation

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Abstract: This paper presents the effect of relativistic and ponderomotive nonlinearity on cross-focusing of two intense laser beams in a collisionless and unmagnetized plasma. It should be noted here that while considering the self-focusing due to relativistic electron mass variation, the electron ponderomotive density depression in the channel may also be important. Therefore/these two nonlinearties may simultaneously affect the self-focusing process. These nonlinearities depend not only on the intensity of one laser but also on the second laser. Therefore, one laser beam affects the dynamics of the second beam and hence the process of cross-focusing takes place. The electric field amplitude of the excited electron plasma wave (EPW) has been calculated. Comparison of the theory with the recent experimental observations has also been presented.

Introduction

Laser intensities have increased in the past few years to reach the enormous value of 10^{20} W/cm^2 (peak power are currently exceeding tens of terawatt). The electric field at the focus of such a laser is around 300 GV/cm. The generation of large electric field in plasmas by high power lasers has been studied for several years in the context of particle acceleration [1]. Conventional particle acceleration techniques are approaching; fundamental limits to the accelerating field due to material breakdown threshold. New techniques are now being investigated to overcome, breakdown limitation [2], some of these techniques are beat-wave [3-7], wakefield [8,9] and self-modulated wakefield accelerators [10-12]. The beating between two copropagating electromagnetic waves in plasma can generate a longitudinal electron plasma wave with high electric field and relativistic phase velocity. The mechanism is called beat - wave accelerator. If the electron plasma frequency ω_p is close to the difference frequency between the two laser beams, a resonance effect results, and the charge separation produce a field up to several GV/cm. A relativistic particle with the right phase can catch the wave and gain energy. Two types of lasers have been considered for this purpose: the CO_2 laser at wavelength near 10μm, and the Nd laser near 1 μm. The first evidence of plasma wave generated by this method, detected by optical diagnostic, came from the UCLA group using two frequencies CO_2 laser [13]. The same group injected 2 MeV electrons from a Linac and succeeded to accelerate them up to 9.1 MeV [14]. The corresponding gradient was 0.7 GV/cm on a length of 1cm. Ebrahim *et al*. [15] accelerated 12.5 MeV injected electrons up to 29 MeV in similar experiment. Accelerated electrons by using Nd laser have been reported by Amiranoff *et al.* [16-17]. Electrons injected at energy of 3 MeV observed to be accelerated up to 3.7 MeV after the plasma. The energy gain is compatible with a peak electric field of the order of 0.6 GV/m.

The available theories on beat wave process

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are not taking into proper account of relativistic cross- focusing of two lasers. Therefore, in this paper we have investigated the cross-focusing of two lasers at relativistic nonlinearity. It should be noted here that while considering the self-focusing due to relativistic electron mass variation, the electron ponderomotive density depression in the channel might also be important [8,18-20]. Therefore, these two nonlinearties may simultaneously affect the self-focusing process. But it should be kept in mind that the electron ponderomotive nonlinearity is set-up when the laser pulse length is comparable or longer than the time required for ion acoustic wave to travel the beam radius ($\tau = r_o / c_s$, here r_o is the beam width and c_s is the ion acoustic speed) while the relativistic nonlinearity can be set-up even with respect to the shortest possible laser pulses.

In the present paper we have discussed the effect of relativistic and ponderomotive nonlinearity on cross-focusing of lasers and hence on the plasma wave power. In the next section, we present model equations including the nonlinear effective dielectric constant of the plasma, and derived the differential equations governing the nature of the dimensionless beam width parameters of the two copropagating Gaussian laser beams when the effect of resonantly excited electron plasma wave is not taken into account. In the same section, we present an expression for the nonlinear effective dielectric constant of the plasma due to ponderomotive nonlinearity only, and derive the differential equations governing the nature of the dimensionless beam width parameters of the two copropagating Gaussian laser beams when the effect of resonantly excited electron plasma wave is taken into account.

The expression for the electric field of the plasma wave excited at the beat frequency has been derived, taking proper account of the transverse inhomogeneity of the beam. The expression for the power associated with the plasma wave has also been derived and numerical calculation has been made.

Model Equations

Consider the propagation of two coaxial Gaussian laser beams of angular frequencies, ω_1 and ω_2 along the z direction in unmagnetized, collisionless plasma. The intensity distribution of the beams is given by

$$E_{1,2} . E^*_{1,2} |_{z=0} = E^2_{10,20} e^{-r^2/r^2_{10,20}} \qquad (1)$$

where r is the radial coordinate of the cylindrical coordinate system and $r_{10,20}$ are the initial beam widths. The dielectric constant of the plasma is given by

$$\varepsilon_{10,20} = 1 - \frac{\omega^2_{po}}{\omega^2_{1,2}} \qquad (2)$$

where ω_{po} is the electron plasma frequency, given by $\omega^2_{po}=4\pi n_e e^2/m_o$ in CGS system (e and m_o are the charge and rest mass of the electron respectively, and n_e is the density of plasma electrons).

The general expression for the plasma frequency in relativistic and ponderomotive non-linearity is:

$$\omega^2_p = \frac{\omega^2_{po} (N_{oe} / N_o)}{\gamma_o} \qquad (2a)$$

where γ_o is the relativistic factor given by

$$\gamma_o = \left(1 + \frac{e^2 E_1 . E^*_1}{m^2_0 \omega^2_1 c^2} + \frac{e^2 E_2 . E^*_2}{m^2_0 \omega^2_2 c^2} \right) \qquad (3)$$

and

$$N_{oe} = N_o \exp\left(-\frac{3}{4}\frac{m_o}{M}\right)(\alpha_1^{`} E_1 . E_1^* + \alpha_2^{`} E_2 . E_2^*) \qquad \text{(3a)}$$

where

$$\alpha^{`}_{1,2} = \frac{e^2 M}{18\, k_B T_o m_0^2 \omega_{1,2}^2} \qquad \text{(3b)}$$

Here T_o is the equilibrium temperature of the plasma, k_B is the Boltzmann's constant and N_o is the electron concentration in the absence of the laser beam. The other symbols have their usual meanings.

Using Eqs. (3) and (2), the intensity-dependent effective dielectric constant of the plasma can be expressed as:

$$\varepsilon_{1,2} = \varepsilon_{10,20} + \phi(E_1 . E_1^* + E_2 . E_2^*) \qquad (4)$$

where ϕ is the nonlinear part of the dielectric constant.

By using the Taylor expansion of the dielectric constant around r = o, the equation can be rewritten as:

$$\varepsilon_{1,2} = \varepsilon_{f1,2} + \gamma_{1,2} r^2$$

where

$$\gamma_{1,2} = -\frac{\omega_{p0}^2}{\omega_{1,2}^2} EXP\left(-\left(\frac{3}{4}\frac{m_o}{M}\right)\left(\frac{\alpha_1^- E_{10}^2}{f_1^2} + \frac{\alpha_2^- E_{20}^2}{f_2^2}\right)\right)\left\{\frac{1}{2}\left[\frac{\alpha_1^{`} E_{10}^2}{f_1^4 r_{10}^2} + \frac{\alpha_2^{`} E_{20}^2}{f_2^4 r_{20}^2}\right]\left[1 + \frac{\alpha_1 E_{10}^2}{f_1^2} + \frac{\alpha_2 E_{20}^2}{f_2^2}\right]^{-3/2}\right.$$
$$\left. + \left[1 + \frac{\alpha_1 E_{10}^2}{f_1^2} + \frac{\alpha_2 E_{20}^2}{f_2^2}\right]^{-1/2}\left(-\frac{3}{4}\frac{m_o}{M}\right)\left[\frac{\alpha_1^{`} E_{10}^2}{f_1^4 r_{20}^2} + \frac{\alpha_2^{`} E_{20}^2}{f_2^4 r_{20}^2}\right]\right\} \quad \text{.......... ....(5)}$$

$$\alpha_{1,2} = \frac{e^2}{m_0^2 \omega_{1,2}^2 c^2}$$

and

where E_{10} and E_{20} are the linearly polarized electric fields of two laser beams. The relation between the electric field and laser beam intensity (power per unit area) is given by $I_t = (c / 8\pi) E_t . E_t^*$ W/cm^2 in vacuum. In writing Eq. (5) the solutions for E_1 and E_2 at finite z inside the plasma are used in conjunction with Eq. (7). Here f_1 and f_2 are the dimensionless beam width parameters of the laser beams and other symbols are defined there.

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

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

In writing Eq. (6) the term $\nabla(\nabla . E)$ has been neglected, which is justified as long as $(\omega^2_{po}/\omega^2_{1,2})(1/\varepsilon 1,2) \ln \varepsilon_{1,2} \ll 1$. To solve equation (6), the WKB approximation has been used. Following the standard techniques [21,22], one can write

$$E_{1,2} = A_{1,2}(r,z) \exp[-i(k_{1,2}(z)\, z + S_{1,2}(r, z))] \qquad (7)$$

Substituting for $E_{1,2}$ from Eq. (7) in Eq. (6) and separating the real and imaginary parts, one obtains:

$$2\frac{\partial^2 S_{1,2}}{\partial z}+\left(\frac{\partial S_{1,2}}{\partial r}\right)^2=\gamma_{1,2}r^2+\frac{1}{A_{1,2}}\left(\frac{\partial^2 A_{1,2}}{\partial r^2}+\frac{1}{r}\frac{\partial A_{1,2}}{\partial r}\right) \quad (8)$$

$$\frac{\partial A^2_{1,2}}{\partial z}+\frac{\partial S_{1,2}}{\partial r}\frac{\partial A^2_{1,2}}{\partial r}+A^2_{1,2}\left(\frac{\partial^2 S_{1,2}}{\partial r^2}+\frac{1}{r}\frac{\partial S_{1,2}}{\partial r}\right)=0 \quad (9)$$

The solutions of Eqs. (8) and (9) can be written as:

$$S_{1,2}=\frac{r^2}{2}\frac{1}{f_{1,2}}\frac{df_{1,2}}{dz}+\Phi_{1,2}(z) \quad (9a)$$

$$A^2_{1,2}=\frac{E^2_{10,20}}{f^2_{1,2}}\exp\left(-\frac{r^2}{r^2_{10,20}f^2_{1,2}}\right) \quad (9b)$$

where $f_{1,2}$ are the dimensionless beam width parameters given by

$$\frac{d^2 f_{1,2}}{dz^2}=\frac{c^2}{\omega^2_{1,2}r^4_{10,20}f^3_{1,2}}+\gamma_{1,2}f_{1,2} \quad (10)$$

In order to calculate the nonlinear phase shift one requires $\Phi_{1,2}$ (z). Here the intensity of the laser is more important than its phase. Therefore $\Phi_{1,2}$ is not required in further analysis. The following set of parameters has been used in the numerical calculation: λ_1 = 1.053 μm, λ_2 = 1.064 μm, T_e = 20 eV, $\omega_{p0} = 0.1\omega_I$, r_{10} = 60 μm, r_{20} = 70 μm, $I_1 = 2\times 10^{17}$ W/cm^2 and $I_2 = 9\times10^{16}$ W/cm^2. The results are presented in Fig. 1.

So far most of the experimental studies of beat wave [7,13,16,17 and 23] are in collisionless regime of moderate laser power where the ponderomotive nonlinearity is dominating over the relativistic nonlinearity. In order to appreciate the effect of excited electron plasma wave (EPW) on the cross-focusing of the lasers and accelerating electric field, the cross-focusing of two laser beams in ponderomotive case has also been studied and the power of the generated EPW has been calculated. The analytical /numerical results are compared with the available experimental observations.

The general expression for the plasma frequency in ponderomotive nonlinearity case is given by

$$\omega^2_p=\omega^2_{po}(N_{oe}/N_o) \quad (11)$$

where N_{oe}/N_o is the modified electron concentration due to ponderomotive force.

$$N_{oe}=N_o\exp\left(-\frac{3}{4}\frac{m_o}{M}\right)(\alpha_1' E_1.E_1^*+\alpha_2' E_2.E_2^*+\alpha_1' E.E^*) \quad (12)$$

At resonance when $\omega_p \cong \omega_1-\omega_2$, the electric vector of EPW will be $E.E^* \gg E_1.E_1$, $E_2.E_2^*$. Therefore, Eq. (12) can be rewritten as:

$$N_{oe}\cong N_o\exp\left(-\frac{3}{4}\frac{m_o}{M}\right)(\alpha` EE^*) \quad (13)$$

By using the Poisson's equation one can obtain the electric vector E of the electron plasma wave excited at difference frequency, thus

$$E.E^{*} = \left(\frac{\omega_{po}^{2} m_o}{\Delta k_e}\right)^2 \left(\frac{N_{20}}{N_o}\right)^2 \qquad (14)$$

where (N_{20}/N_0) is the density associated with the electron plasma wave excited at beat wave frequency given by Eq. (12) but relativistic effect is neglected.

Using Eq. (13) in Eq. (11), and by making use of Eq. (14), the dielectric constant is expanded by using Taylor expansion around r = 0. One can assume $\frac{3}{4}\alpha \frac{m}{M} E.E^{*} < 1,$ the dielectric constant can be written as:

$$\varepsilon_{1,2} = \varepsilon_{f1,2} + \eta_{1,2} r^2 \qquad (15)$$

where

$$\eta_{1,2} = -\frac{2}{3}\left(\frac{\frac{3}{4}\alpha_1' \frac{m}{M} E_{10}^2}{f_1^4}\right)^{1/3} \left(\frac{\frac{3}{4}\alpha_2' \frac{m}{M} E_{20}^2}{f_2^4}\right)^{1/3} \left(\frac{3}{2}\frac{V_{th}^2}{\omega_{1,2}^2 \Delta k^2}\right)^{1/3} \qquad (16)$$

$$\left[\Delta k^2 + \left(\frac{2}{r_{10}^2 f_1^2} + \frac{2}{r_{20}^2 f_1^2}\right)\right]^{2/3} \left(\frac{1}{r_{10}^2 f_2^2} + \frac{1}{r_{20}^2 f_2^2}\right)$$

Following the same technique of previous case, one can write the equation governing the beam width parameter of laser beams as:

$$\frac{d^2 f_{1,2}}{dz^2} = \frac{c^2}{\omega_{1,2}^2 r_{10,20}^4 f_{1,2}^3} + \eta_{1,2} f_{1,2} \qquad (17)$$

In order to plot the power (P) of the excited plasma wave at beat frequency, Eq. (17) derived by Sodha *et al.* [24] has been used. The same set of parameters of previous case has been chosen with low level of intensity $I_1 = 7.6\times10^{14}$ W/cm^2 and $I_2 = 1.3\times10^{14}$ W/cm^2 and the plots are given in Figs. 3 and 4.

Excitation of Plasma Wave at Difference Frequency

Following the standard method, the equation governing the plasma wave in hot plasma can be written as

$$\frac{\partial^2 N}{\partial t^2} + 2\Gamma_e \frac{\partial N}{\partial t} - v_{th}^2 \nabla^2 N - \frac{e}{m_o}\nabla.(NE) = \nabla.\left(\frac{N}{2}\nabla(V.V) - V\frac{\partial N}{\partial t}\right) \qquad (18)$$

where $2\Gamma_e$ is the Landau damping factor given by [25], v_{th}^2 is the electron thermal velocity; **E** is the sum of the electric vectors of the electromagnetic (EM) field and the self-consistent field, and V is the sum of the drift velocities of the electron in the EM field and the self-consistent field. Therefore, the equation for the electron plasma wave at the difference frequency ($\Delta\omega = \omega_1 - \omega_2$) reduces to

$$-(\omega_1-\omega_2)^2 N_1 + 2i\Gamma_e (w_1 - w_2) N_1 - V_{th}^2\nabla^2 N_1 + (\omega_{po}^2/\gamma_0) N_1 \cong \tfrac{1}{4} N_o \nabla^2 (V_{10} \cdot V_{20}^{*}) \qquad (19)$$

where N_1 is the component of the electron density oscillating at frequency $\Delta\omega$ and $V_{10,20}$ ($= eE_{1,2}/m_o i\omega_{1,2}\gamma_0$) are the drift velocities of electrons in the pump field at frequencies, ω_1 and ω_2. Eq. (19) contains two plasma waves (both at difference frequency), the first, one supported by the hot plasma and the second because of the source term at the difference frequency. The solution of Eq. (19), within WKB approximation can be written as [22]:

$$N_1 = N_{10}(r, z) \exp[-i(k z + s)] + N_{20}(r, z) \exp[-i\{k_1 - k_2) z + (s_1 - s_2)\}] \qquad (20)$$

where $k^2 = [(\omega_1 - \omega_2)^2 - \omega_p^2]/V_{th}^2$, N_{10} and N_{20} are the slowly varying real functions of the space coordinate. Substituting for N_1 from Eq. (20) in Eq. (19), the equation for N_{10} and N_{20} can be obtained by equating the coefficient of exp [-i (kz + s)] and exp [-i $\{k_1 - k_2) z + (s_1 - s_2)\}$] in the resulting equation. The equation for N_{20} is given by

$$N_{20}/N_0 = \frac{e^2 E_{10} E_{20}\left[\Delta k^2 + \left(\frac{2}{r_{10}^2 f_1^2} + \frac{2}{r_{20}^2 f_2^2}\right)\right] e^{-\frac{r^2}{2}\left(\frac{1}{r_{10}^2 f_1^2} + \frac{1}{r_{20}^2 f_2^2}\right)}}{4\gamma_0^2 m_0^2 \omega_1 \omega_2 f_1 f_2 (\Delta\omega^2 - 3V_{th}^2 \Delta k^2 - \omega_{po}^2 (N_{0e}/N_0)/\gamma_0)} \qquad (21)$$

and the equation for N_{10} after splitting into real and imaginary parts can be written as:

$$N_{10} = \frac{B_1^2}{f^2} \exp\left(-\frac{r^2}{a_0^2 f^2}\right) \exp(-2k_i z) \qquad (22)$$

where $k_i = \Gamma e\,(\omega_1 - \omega_2)/k\, V_{th}^2$, a_o and B_1 are the constants to be determined by the boundary condition such that the magnitude of the generated plasma wave at z=0 is zero, and f is the beam width parameter of plasma wave. By using Poisson's equation one can obtain the electric vector E ($\Delta\omega$) of the plasma wave excited at the difference frequency as:

$$E(\Delta\omega) = -\frac{ie\,\omega_{po}^2 (k_1 - k_2) E_{10} E_{20}}{4 m_0 \gamma_0 \varepsilon'(\Delta\omega, \Delta k) \omega_1 \omega_2 (\omega_1 - \omega_2)^2} \qquad (23)$$

where

$$\varepsilon'(\Delta\omega, \Delta k) = 1 - \frac{\omega_{po}^2}{(\omega_1 - \omega_2)^2}$$

$$k_{1,2} = \frac{\omega_{1,2}}{c}\left(1 - \frac{\omega_{po}^2}{\omega_{1,2}^2}\right)^{1/2}$$

The power associated with the plasma wave incident across the transverse section at z can be obtained by integrating E.E* over r from 0 → ∞ as:

$$P = \left(\frac{1}{8\pi}\frac{V_g}{2}\right)\int_0^\infty 2\pi r E(\Delta\omega) E^*(\Delta\omega)\, dr$$

$$P = \left(\frac{V_g}{2c}\right)\left(\frac{\omega_{po}^2}{4\omega_1\omega_2}\right)(P_1 P_2)^{1/2}\left(\frac{v_1}{r_{10}\,\omega_1}\frac{v_2}{r_{20}\,\omega_2}\right)\frac{(G_2 r_{10} r_{20} \omega_1 \omega_2 f_1 f_2)^2}{\gamma_0^2 (r_{10}^2 f_1^2 + r_{20}^2 f_2^2)} \qquad (24)$$

where

$$G_2 = \frac{\left[\Delta k^2 + \left(\frac{2}{r_{10}^2 f_1^2} + \frac{2}{r_{20}^2 r_2^2}\right)\right]}{f_1 f_2 [\Delta\omega^2 - V_{th}^2 \Delta k^2 - \omega_{po}^2 (N_{oe}/N_o)/\gamma_o]} \times \frac{1}{\Delta k}$$

Here $P_1\left(= \frac{c}{8\pi}\pi r_{10}^2 E_{10}^2\right)$ and $P_2\left(= \frac{c}{8\pi}\pi r_{20}^2 E_{20}^2\right)$ represent the total powers of the two beams, $V_{1,2}\left(=\dfrac{eE_{10,20}}{m_o\omega_{1,2}}\right)$ is the velocity of electrons in field, and

$$V_g = V_{th}\left[1-\left(\frac{\omega_{po}}{\Delta\omega}\right)^2\right]^{1/2}$$

is the group velocity. In order to plot the power of the excited plasma wave (P) at beat frequency when the cross-focusing of the two laser beams is taken into account, the same set of parameters of relativistic and ponderomotive case in "Model Equations" section has been used in the numerical calculations. The results are presented in Fig. 2.

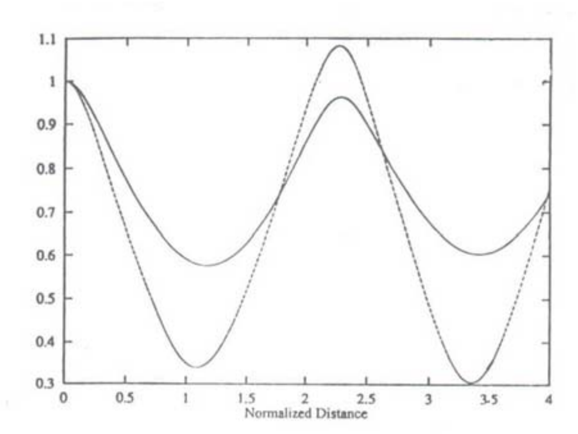

Fig. l Variation of the dimensionless beam width parameters $f_{1,2}$ versus the distance of propagation when the relativistic and ponderomotive nonlinearity is taken into account.
(solid curve for f_1 and dotted curve for f_1)

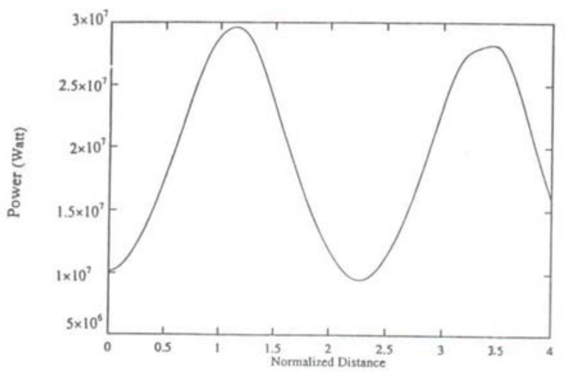

Fig. 2 Variation of the total power (Watt) of electron plasma wave (EPW) versus the distance of propagation when the relativistic and ponderomotive nonlinearity are taken into account.

Discussion

The beating between two copropagating lasers in plasma can generate a longitudinal electron plasma wave with a high electric field and relativistic phase velocity. This mechanism (beat wave) is efficient if the electron plasma frequency, ω_p is close to the difference frequency between the two laser beams. The available experiments and theories are in ponderomotive nonlinearity regime. Therefore, to estimate the strength of the accelerating field which can be used to accelerate the electrons to very high energy, the variation of the beam width parameters of the relativistic laser beams and the power of electron plasma wave generated by beating of these two relativistic laser beams in plasma have been studied.

For initial plane wave front of the laser beams, the initial conditions used here are $f_{1,2}$=1 and $df_{1,2}/dz$=0 at z=0. Fig. 1 depicts the variation of the dimensionless beam width parameters f_1 and f_2 of two beams when the powers of both beams are appropriate for relativistic self-focusing ($\alpha_1 E_{10}^2$ =0.16 and $\alpha_2 E_{20}^2$ = 0.075) and resonantly excited EPW is not taken into account. It is apparent that the beams are oscillating (focused and then defocused), showing that the two laser beams copropagating in plasma (cross-focusing) modify each other's characteristic of relativistic self-focusing. The minimum diameter of first beam f_1 is 36 μm and of the second beam f_2 is 24 μm. This can be explained using Eq. (10). As the beams propagate the nonlinear term (second term) dominates, causing the values of f_1 and f_2 to decrease. The beam width diameters f_1 and f_2 continuously decrease until the beams sizes become very small. When the beams sizes are too small, the diffraction term (first term) dominates resulting in the increase of the value of f_1 and f_2.

Figure 2 shows the variation of plasma wave power versus the distance of propagation when the effect of the relativistic and ponderomotive nonlinearity is taken into account. The strength of peak accelerating field produced by EPW is around 75 GV/m.

In order to have an appreciation of the effect of excited electron plasma wave on accelerating field, the authors studied such effects in ponderomotive regime for the same set of parameters as taken in experimental work [17], with laser intensities in the range of 10^{14} W/cm^2. The theoretical results are compared with the experimental observations. The variation of beam width parameters f_1 and f_2 with the distance of propagation is presented in Fig. 3. It is apparent that the behavior of f_1 and f_2 is decreasing with distance of propagation. The variation of plasma wave power versus the distance of propagation is shown in Fig. 4. The predicted peak of accelerating field in this case comes out to be around 1 GV/m which is higher than the measured one 0.6 GV/m [17]. The effect of resonantly excited electron plasma wave is very significant and modifies the behavior f_1 and f_2 and hence the plasma wave power gets affected significantly. In this model some of the physical aspects like stimulated scattering, and structure of laser focal spot, have not been included which might cause some loss in the plasma wave power. These aspects can form part of future work.

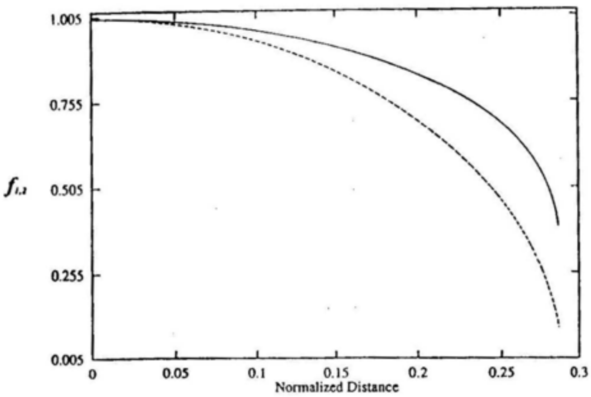

Fig. 3 Variation of the dimensionless beam width parameters $f_{1,2}$ versus the distance of propagation when the resonantly excited EPW is taken into account in ponderomotive nonlinearity. (solid curve for f_1 and dotted curve for f_2)

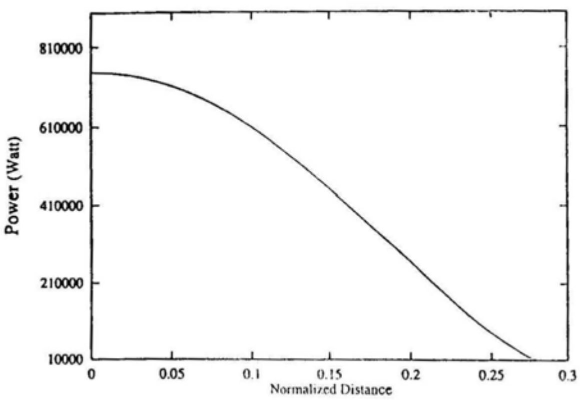

Fig. 4 Variation of the total power (Watt) of electron plasma wave (EPW) versus the distance of propagation when the resonantly excited EPW is taken into account in ponderomotive nonlinearity case.

The present semi-analytical study in paraxial approximation is the first effort to highlight the effect of cross-focusing of two intense laser beams on electron plasma wave power and hence on accelerating electric field generated by beat wave process at relativistic nonlinearity. The present investigation concludes that the cross-focusing of two laser beams affect the beat wave excitation process.

In ponderomotive case the result predicted by this theory and those obtained from experiments are nearly in agreement with each other.

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تأثير تقاطع حزمتي ليزر عالي القدرة عند منطقة البؤرة على تهيج موجة البلازما الالكترونية

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الخلاصة

في هذا البحث تمت دراسة تأثير القوة الكابسة اللاخطية على تقاطع ليزرين عند منطقة البؤرة في بلازما لا تصادمية وغير ممغنطة. اظهرت الدراسة ان اللاخطيتين اللتان تؤثران على التبئير الذاتي لحزمة الليزر داخل البلازما هما تغير كتلة الالكترون عند السرع النسبية وتغير كثافة القوة الكابسة. هاتين اللاخطيتين تعتمدان على قدرة كلا الليزرين وليس كل ليزر لوحده. تم حساب المجال الكهربائي لموجة البلازما الالكترونية وقورنت النتائج النظرية المستخلصة مع بعض النتائج التجريبية الحديثة .