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Properties of Relativistic Thermal Electrons in Plasma Channel by Propagation of Intense Laser Radiation

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***Abstract* - A strong electromagnetic laser beam over under dense plasma ousts electrons and ions from the central spot by the ponderomotive force and create a path in the form of channel. Transport characteristics of supra thermal electrons has been observed in the route of electromagnetic laser beam propagation and having energy bands of thermal character. Often one finds two different species of electron with two distinct thermal characteristics. Based on this idea in this paper we work on an analytical investigation of transport characteristics that generates such electron distributions through relativistic ponderomotive pressure. Corresponds to the values of laser and plasma frequency two species of electron with two different thermal characteristics are characterized by dimensionless beam width parameter and dimensionless power. Necessity of dielectric function of plasma on dimensionless power in relativistic ponderomotive laser plasma interaction process has been calculated. The change in the value of beam width parameter with distance of propagation has also been observed for different parameters of plasma for both species of electron with distinct thermal characteristics.**

I. INTRODUCTION

The transport characteristics involved in laser-based plasma interaction, up to 10^{17} W/cm^2, are now well unstated; on other side, a large number of fundamental issues remain open in the study of the ultrahigh intensity relativistic interaction regime. At very high laser power, transport characteristics of the laser-electron interaction may lead to nonlinear interaction, thus, resulting in an extensive variation of new phenomena. Now it has become possible to produce supra thermal electrons in a plasma as observed in recent experiments with solid targets [1], preformed plasmas [2], or pulsed gas jets [3]. The fast ignitor concept [4], applicable to the inertial confinement fusion (ICF), enhances the interest in this process as well as in laser beam propagation and channel formation in plasma. The channel formation procedure can be improved by the growing effects of ponderomotive pressure and relativistic self-focusing which increase the laser beam intensity during propagation. In the article we have made a critical study, followed by mathematical calculations to observe transport phenomena of supra thermal electrons in plasma. In section II mathematical formulation are presented for the transport phenomena with two different species of electrons with distinct temperature. Result and discussion are made in section III with experimental significance.

II. MATHEMATICAL FORMALISM

For a circularly polarized beam the ponderomotive pressure that separately accelerated the two electron fluid components is given by [5].

$$\mathrm{F}_{h,c} = -(\omega_{ph,c}^2/2\omega^2)\,\nabla I \sim n_{h,c}\,\nabla I \qquad (1)$$

the suffix h and c denotes hot and cold electron, m_0 is the rest mass of the electron and $n_{h,c}$ is the density of hot and cold electrons. The relativistic Lorentz factor γ depends on the electric field **E**. The factor γ for a circularly polarized beam of frequency 'ω' is given by

$$\gamma = \left[1 + (e/m_0\omega c)^2 E^2\right]^{1/2} \qquad (2)$$

Following [6], the self-focusing equation can be written as

$$\varepsilon_0(z)\frac{d^2 f}{dz^2} = \left(\frac{c^2}{r_0^4\omega^2} + \frac{\varepsilon_1(r,z)}{r^2} f^4\right) \qquad (3)$$

The parameter 'f' is the beam width parameter, which can be defined as $r(z) = r_0 f(z)$ (4)

r_0 being the beam width at $z = 0$. Using dimensionless variables, $\xi = (ze / r_0^2 \omega)$ and $\rho = (r_0 \omega / c)$ equation (3) can be represented as

$$\varepsilon_0(f)\frac{d^2 f}{d\xi^2} = \left\{1 + \rho^2 \frac{r_0^2}{r^2}\varepsilon_1(r, f) f^2\right\}\frac{1}{f^3} \quad (5)$$

The z variable in $\varepsilon_0(z)$ and $\varepsilon_1(r, z)$ has been replaced by 'f', which is a function of z only. The effective dielectric function due to ponderomotive pressure with relativistic nonlinearity comes out as

$$\varepsilon = 1 - \Omega_{ph,c}^2\left(1 + \alpha^2 EE^*\right)^{-1/2} - \frac{\Omega_{ph,c}^2}{2}\left(1 + \alpha^2 EE^*\right)^{-3/2} \quad (6)$$

here $\alpha = (e / m_0 \omega c)$ and $\Omega_{ph,c} = (\omega_{ph,c} / \omega)$

$$EE^* = \sqrt{\frac{\varepsilon_0(1)}{\varepsilon_0(f)}}\left(\frac{E_{00}^2}{f^2}\right)\exp\left(-\frac{r^2}{r_0^2 f^2}\right) \quad (7)$$

Using equation (7) in equation (6) and substituting $p = \alpha^2 EE^*$ and replacing $\exp(-r^2 / r_0^2 f^2)$ by $(1 - r^2 / r_0^2 f^2)$ in paraxial approximation one obtains

$$\varepsilon_0(f)\frac{d^2 f}{d\xi^2} = \left\{1 - \rho^2 \frac{\Omega_{ph,c}^2 p}{2}(1 + p)^{-3/2}\right\}\frac{1}{f^3} \quad (8)$$

For $(d^2 f / d\xi^2)$ to vanish equation (8) requires at $z = 0$ ($f = 1$),

$$\rho_0^2 = \frac{2}{\Omega_{ph,c}^2}\frac{(1 + p_0)^{3/2}}{p_0} \quad (9)$$

Equation (9) expresses the dimensionless beam width ρ_0 (at $f = 1$) as a function of a dimensionless quantity p_0 proportional to E_{00}^2 and hence, also to the initial beam power.

III. RESULTS AND DISCUSSION

For the analysis of transport phenomena, we arrive at distinct set of equations for nonlinear dielectric function in a two electron temperature plasma given by equation (6), relativistic self-focusing equation (8) and the critical power by equation (9). The function of equation (9) can be drawn, as a curve in the (p_0, ρ_0) plane and in known as the critical curve as shown in Fig. 1. Here we draw two different critical curves with respect to cold electron $(\omega_p/\omega)^2 = 0.7$ and hot electron $(\omega_p/\omega)^2 = 1.2$. If the initial value of p and ρ of a laser beam are in such a way that the (p_0, ρ_0) lies on the critical curve the value of $(d^2f/d\xi^2)$ will be disappear at $\xi = 0$ ($z = 0$) since the original value of $(df/d\xi)$ is zero, the value of $(df/d\xi)$ endures to be zero as the beam propagates along the plasma. Hence, the original value of 'f', which is unity (at $z = 0$), will become unchanged. Thus, the laser beam propagates without any variation in its width. This type of propagation is known as uniform waveguide propagation. For original point (p_0, ρ_0) of the laser beam lying under the critical curve $(d^2f/d\xi^2) > 0$ and for the points lying on the other side $(d^2f/d\xi^2) < 0$, thus, for the original point not lying on the critical curve the beam width parameter will either decreases or increases, as the laser beam propagates. The f versus ξ graphs have been obtained by numerically investigation of equation (8) and are represented in Fig. 2. The (p_0, ρ_0) coordinates for these three sets of curves for cold electron and hot electron are (2.5, 3.0), (3.0, 2.0) and (3.0, 1.0). From the figure it is appear that hot electrons converge and diverges sooner as related to cold electrons. The above condition is attributed to the statistic that thermal wavelength of hot electron is less as compared to cold electrons. As a outcome, self-focusing increases, hence channel creation phenomena can be improved by relativistic self-focusing which increase the laser beam intensity and generates supra thermal electrons.

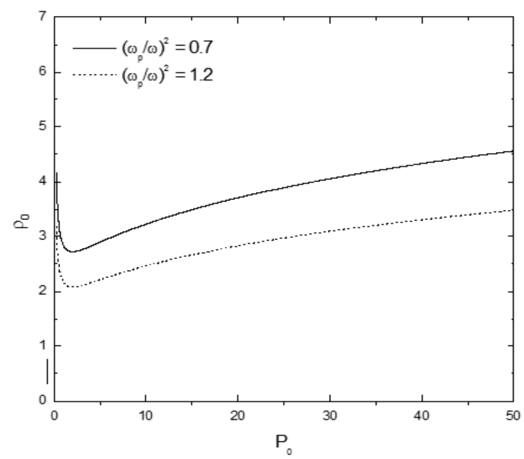

Fig. 1. Variation of dimensionless initial beam width versus dimensionless initial beam power.

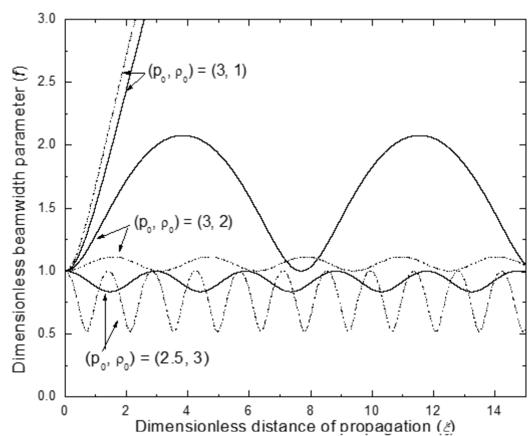

Fig. 2. Variation of beam width parameter f versus dimensionless distance of propagation ξ for $(\omega_p / \omega)^2 = 0.7$ (solid line) and $(\omega_p / \omega)^2 = 1.2$ (dotted line).

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