Efficient Electron Acceleration By Circularly Polarized Laser On A Plasma Density Ramp

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Abstract: Efficient electron acceleration on a descending plasma density ramp is observed by a CP (Circularly Polarized) laser. A CP laser pulse traverses along positive z-direction, where an electron with few MeVs is injected in its direction in plasma. The laser's ponderomotive force is increased due to enhancement in group velocity of laser on a plasma density ramp. It is investigated that electron energy gain enhances swiftly at low plasma density, which proves as an improved platform for efficient electron acceleration.
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1. Introduction

Laser plasma interaction is always been an interesting part of study for researchers, scholars as well as scientists for the betterment of various applications due to phenomenon associated with it like harmonic generation, self focusing, THz radiation generation as well as particle acceleration [1-10]. If we talk about self focusing, one can understand it as a phenomenon in which a laser beam modifies their front medium due to their non-linear reaction in a plasma. THz wave generation is also a current topic, in which THz wave is produced due to laser beating in a plasma [11, 12].

Laser-assisted electron acceleration also appears as an interesting field of research. Various schemes which can realize electron acceleration are Laser beat wave acceleration (LBWA), Plasma wake-field acceleration (PWFA) and direct laser acceleration (DLA). In case of DLA mechanism, electrons are directly accelerated due to short pulse (fs) lasers. In DLA scheme, there is negligible limit on laser duration or threshold intensity [13-15]. Moreover, CP laser assisted DLA in plasma is also very interesting process as it can achieve acceleration gradients up to many GVs/m, which overlooks the acceleration gradients generated by usual radio frequency accelerators [16]. Due to DLA method, high-field acceleration over several centimetres can be realized due to femtosecond (fs) lasers by currently manufactured plasma micro-optic [17].

Also, plasma structure plays an vital role on the eminence of electron energy gain. In the field of Harmonic generation [18], self focusing [19] and electron acceleration [20], the plasma ramps have been taken for enhancing the efficiency of the relevant phenomenon for various applications. Sprangle *et al* [21] have observed electron acceleration by a dual stage injection-acceleration design [22], due to higher plasma density at the injection phase and a lower density at the acceleration phase.

In this short research article, we have investigated DLA due to CP laser in descending plasma density structure. We have solved the coupled equations and estimated the electron energy gain. The theoretical considerations are given in section 2, the basic equations for electron momentum gain and energy gain are shown in 3rd section and finally a brief conclusion is expressed.

2. Theoretical considerations

The CP laser traverses in a plasma channel having descending density ramp along z-axis. The CP laser vector potential is described as:

$$\mathrm{A} = A_0[\hat{x}\cos-(\omega t + kz) + \hat{y}\sin-(\omega t + kz)\exp\left[-\frac{[t-(z-z_0)/v_g]^2}{\tau^2} - \frac{r^2}{r_0^2}\right], \tag{1}$$

where, z_0 is described as the laser pulse peak initial position, here , ω is the laser pulse's angular frequency, r_0 is laser beam initial spot size, v_g is group velocity and $\omega_p^2 = 4\pi n(z')e^2/m$ presents relativistic plasma frequency, $n(z') = n_0\cos(z'/d)$, $z' = z/\xi_0$, n_0 is electron density at origin, d is a constant, wave vector k is a function of z as $k(z) = \left(\frac{4\pi e^2}{m_0 c^2}\right)^{1/2} n(z')$, here m_0 is rest mass of electron.

3. Downward density ramp plasma assisted electron acceleration

In order to explain the motion of electron in the plasma, the momentum, energy gain equation for electron are:

$$\frac{dP_x}{dt} = e\frac{\partial A_x}{\partial t} + ev_z\frac{\partial A_x}{\partial z}, \tag{2}$$

$$\frac{dP_y}{dt} = e\frac{\partial A_y}{\partial t} + ev_z\frac{\partial A_y}{\partial z}, \tag{3}$$

$$\frac{dP_z}{dt} = -ev_x\frac{\partial A_x}{\partial z} - ev_y\frac{\partial A_y}{\partial z}, \tag{4}$$

The final equation describing electron energy is:

$$\frac{d\gamma}{dt} = \frac{e}{m_0 c^2}(v\cdot A). \tag{5}$$

Here, $p_{x,y,z}, v_{x,y,z}$ are the radial, azimuthal and longitudinal components of momentum, and velocities respectively.

Equations (2)-(5) are coupled equations and are numerically worked out to get higher energy gain. The laser and plasma optimum parameters are taken for achieving electron energy gain effectively. The parameters which are optimized are as given, and a_0 =20($I \sim 5.52\times10^{20} W/cm^2$), plasma density n_0 taken in this manuscript lies in the range $(5-8)\times10^{19}$ cm^{-3}.

4. Results and discussions

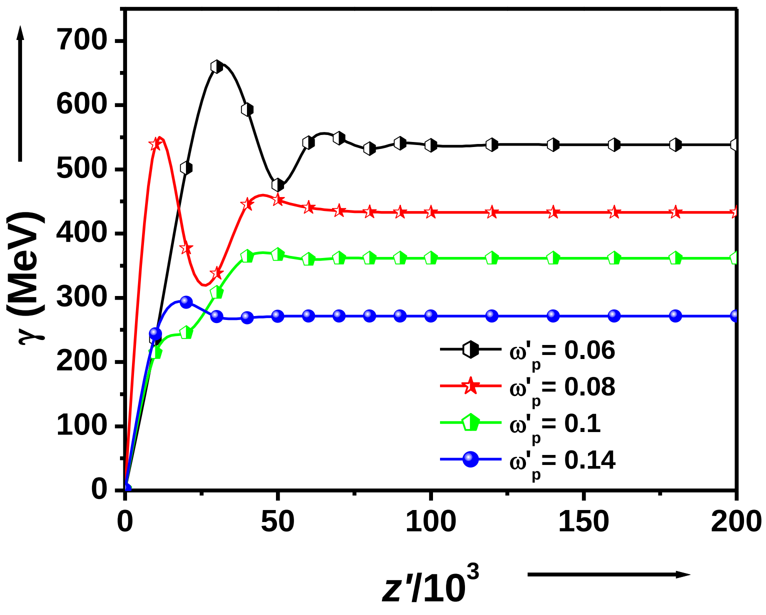

Figure 1 – Plot of γ and z' for various values of plasma frequency ω_p' at $a_0 = 20$. Remaining optimized parameters are r_0' =300, p_{y0}, p_{z0}=0.1, p_{x0}=1.

In the above figure, we have observed the variant of γ and z' with increasing plasma densities. It can be seen from the graph that at the lower frequency ω_p', electron energy gain γ is effectively enhanced. At ω_p' =0.14, electron gains energy to 272 MeV, which elevates to 538 MeV at ω_p' =0.06. Hence, downward plasma density ramp traps electron effectively to ensure its resonance with the CP laser electric field and hence facilitates its better interaction with a CP laser .

5. Conclusion

The downward plasma density ramp configuration is utilized for better energy gain with a circular polarization of the laser. The resultant electron energy gain is found higher on a descending plasma density ramp as compared to consistent density plasma.

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