ENHANCED NONLINEAR PONDEROMOTIVE FORCE BY BEATING OF TWO COPROPAGATING SUPER-GAUSSIANLASER BEAMS IN NANOCLUSTERED PLASMA

Abstract

In this chapter, we have formulated the nonlinear ponder motive force by beating of two high power super-Gaussian laser beam in plasma embedded with nanoclustered medium. The co propagating laser beam with slight difference frequency generates the beat wave. As the lasers beat wave interact with cluster, it is ionised and converts into plasma plume balls. The electron clouds of nanoclustered plasma attain oscillatory velocity. The imparted oscillatory velocity causes the nonlinear ponder motive force. The effective surface Plasmon's frequency resonantly enhanced the nonlinear process. This force is controlled and tuned by laser beam super-Gaussian index, electron-neutral collision frequency, laser beat wave frequency and beam width. Nonlinear ponder motive force is an important term in nonlinear process such as electron heating, parametric instability and harmonic generation.

Keywords: Ponder motive force, Nan cluster plasma, Beam width, Super-Gaussian laser beam, Plasmons

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I. INTRODUCTION

In last few decades, high power laser beam interaction with nano cluster plasma is special field of interest due to trem endous applications such as harmonic generation, current drive experiments, charged particle acceleration, electrostatic wave excitation, laser beam absorption and electron heating [1-7].Although earlier studied of excitation of electrostatic electron plasma wave has been investigated by some groups [8-11] but presence of surface plasmons resonance in clusters promises the efficient nonlinear property [12].The plasma embedded with nano clustered medium attained ambiguous property of matter on nano meter scale regime [13-14]. Clusters are excited and formed by the interaction of laser beam with materials [15]. Ponder motive force is a type of nonlinear force experienced by the oscillating inhomogeneous charged particle and is applicable in study of various nonlinear phenomenon [4-15]

Kumar[16] analytically studied the parametric coupling of electrostatic waves by extraordinary mode laser beam in magnetized clustered plasma.The electron plasma wave can be excitedby the nonlinear interaction of two intense laser beams in cluster medium[17].Antonsen et al. [18] have analyzed the PICsimulation of electrostatic waves for electron by the laser beam.With the occurrence of hydrodynamic expansion of cluster due to the interaction of laser beam, the Rayleigh scattering is taken into place [19].Tiwari and Tripathi [20]proposed that enhanced third harmonic generation can be obtained by the interaction of laser beam with clustered plasma medium.Parashar et al. [21]predicted that laser high order harmonic generation is studied in nanoclustered plasma via taking the paraxial ray approximation theory.

In present study, ouraimto explain the production of nonlinear ponderomotive force by the co propagation of two high power laser beam in collisional nanocluster plasma. As the two laser beams having slight difference frequency copropagate might be generated the laser beat wave. Beating process of two laser beam has efficient potential to produce the nonlinear ponder motive force between the oscillating electrons associated with nanoclustered plasma. The nonlinear ponder motive force has two components. The first component is along y-direction and second component is along z-direction. Here, we have taken the super-Gaussian laser beam polarization along the y-direction. Hence the y-component of nonlinear ponder motive force is much efficient. The nonlinear coupling scheme of laser beams is presents in Sec. 2. The results and discussion of nonlinear ponder motive force is explain in Sec.3. Finally, the summary this theory is given in Sec.4.

II. NONLINEAR COUPLING

Herein, we have considered a gas jet target which become the plasma plume balls via the laser beam interaction. The plasma is consisted in rippled form with suitable wave number. Let radius of spherical cluster be taken as r_c and the associated density of medium can be taken as

$$n_c = n_{c0} + n_{c\alpha}, \text{ and} n_{c\alpha} = n_{c\alpha 0} e^{i\alpha z}, \tag{1}$$

Where α is the rippled wave number,$n_{c\alpha 0}$ is the rippled cluster density at equilibrium condition andn_{c0} is equilibrium cluster density. The two high power laser beams with wave numbers $k_1$and k_2, frequencies ω_1 and ω_2, are nonlinearly interacted with nano cluster plasma medium in z-direction and polarization along y-direction. The general electric field profile of each laser beam with super-Gaussian profile can be written as

$$\vec{E}_j = \hat{y}E_0 \exp\left[-(y/w_0)^p\right]e^{-i(\omega_j t - k_j z)}, \tag{2}$$

Where w_0 is the beam width parameter of laser, $j = 1, 2$, p is the index of super-Gaussian,$\omega_p = n_0 e^2/\epsilon_0 m_e$is the electron plasma frequency. When high power laser beaminteracts with nanocluster plasma, then clusters are heated and on of the sudden it is ionized and directly converted into plasma plume balls. Further, weassume that only electrons cloud of nano medium responds to high power laser beam. Since the ions having largemass and thus assume immobile duringthe whole dynamical process.

The equation of motion of charged particle upto first-order approximationis governed by following Eq.

$$m\frac{d\vec{\mathrm{v}}_j}{dt} + m\nu\vec{\mathrm{v}}_j + m\frac{\omega_p^2}{3}\vec{\mathrm{r}}_j = -e\vec{E}_j, \tag{3}$$

The physical meaning of first term of above Eq. tells the rate change of electron momentum, the second term tell the damping force produced by electron-neutral collision, third term tells about the restoration due to oscillation of electrons and last term in right hand side of Eq. (3) is tells the applied laser electric force to the nano clustered electrons. Where$\vec{\mathrm{v}}_j$, ν, $\vec{\mathrm{r}}_j$ are the electron oscillatory velocity, electron-neutral collision frequency and excursion respectively. The term$\omega_p/\sqrt{3}$ is the effective plasmon frequency present due to nanoclustered plasma. On solving the Eq. (3), we can write the electron excursion (displacement) and oscillatory velocities as

$$\vec{\mathrm{r}}_j = \frac{e\vec{E}_j}{m\left(\omega_j^2 - \frac{\omega_p^2}{3} + i\nu\omega_j\right)}, \tag{4}$$

$$\vec{\mathrm{v}}_j = -\frac{ie\omega_j\vec{E}_j}{m\left(\omega_j^2 - \frac{\omega_p^2}{3} + i\nu\omega_j\right)}. \tag{5}$$

The beat wave of two high power laser beams in nano clustered plasma cause to production of ponder motive force to the electron associated with medium at the beat frequency $\omega = \omega_1 - \omega_2$ and beat wave number $k = k_1 - k_2$. The formula of nonlinear ponder motive potential and force can be written as

$$\phi_p^{NL} = -\left(\frac{m}{2e}\right)\overrightarrow{\mathrm{v}_1}.\overrightarrow{\mathrm{v}_2^*}, \text{ and } \vec{F}_P^{NL} = -\left(\frac{m}{2c}\right)\left(\overrightarrow{\mathrm{v}_1}\times\overrightarrow{\mathrm{B}_2^*} + \overrightarrow{\mathrm{v}_2}\times\overrightarrow{\mathrm{B}_1^*}\right) = e\boldsymbol{\nabla}\phi_p^{NL}, \tag{6}$$

$$\vec{F}_P^{NL} = -\frac{e^2E_0^2\omega_1\omega_2}{2m\left(\omega_1^2 - \frac{\omega_p^2}{3} + i\nu\omega_1\right)\left(\omega_2^2 - \frac{\omega_p^2}{3} + i\nu\omega_2\right)}\left[-2p\frac{y^{p-1}}{{w_0}^p}\hat{y} + ik\hat{z}\right] \times \exp\left[-2\left(\frac{y}{w_0}\right)^p\right]e^{-i(\omega t - kz)}, \tag{7}$$

III. RESULTS AND DISCUSSION

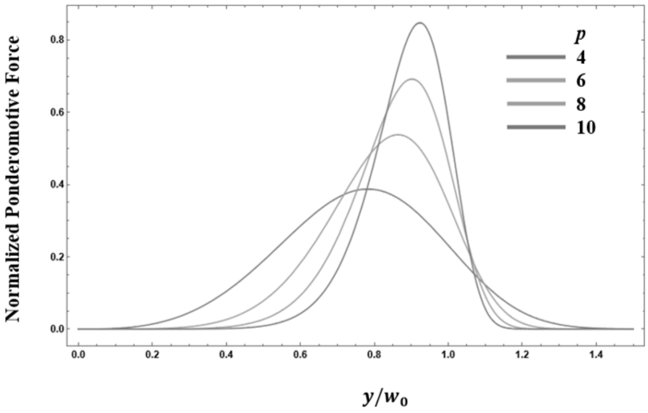

Figure 1: Variation of normalized nonlinear ponder motive force as a function of $y/w_0$for various values of super-Gaussian index p, when $\omega/\omega_p = 0.57$, $v/\omega_p = 0.05$.

The two co propagating super-Gaussian laser beams having slight difference frequency cause to generation of beam wave. The oscillating electronic clouds of clustered plasma experienced nonlinear force which is generally called as ponderomotive force. We have derived an analytical expression of nonlinear ponderomotive force (Eq. (7)). The typical values of laser beam frequencies is taken of the order $\omega_1 \sim 2.3 \times 10^{14} Hz$, $\omega_2 \sim 1.8 \times 1014Hz$. In practical purpose, these frequencies can be achieved by CO_2 and N_2O gas lasers respectively.

Figure 1 shows the variation of normalized nonlinear ponderomotive force as a function of laser beam transverse propagation distanced from y-axis for different values of super-Gaussian mode index p. For the value of $p \geq 4$, the laser beam is in super-Gaussian mode. It is to be noticed that as one increases the super-Gaussian mode index, the peak amplitude of nonlinear ponderomotive force is enhanced.The field amplitude laser beam is enhanced with increase in super-Gaussian mode index. As one increases mode index p=4 to p=6, the peak amplitude of ponderomotive forced is increased upto 37.4 %.

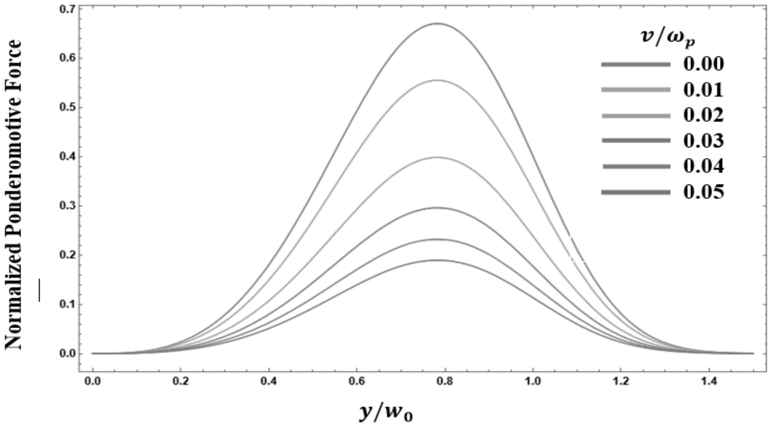

Figure 2: Variation of normalized nonlinear ponderomotive force as a function of y/w_0for various valueselectron-neutral collisional frequency, when ω/ω_p=0.57, p=4.

In Figure 2, we have studied the variation of normalized nonlinear ponderomotive force as a function of laser beam transverse propagation distanced from y-axis for different values of electron-neutral collisional frequency. For mode index p=4, peak amplitude of nonlinear ponderomotive force is obtained at transverse beam propagation distance $y/w_0 \sim 0.77$. Since collision is the integral part of experimental analysis and herein we have considered the electron-neutral collision. The amplitude of ponderomotive force is decreased with increase in collisional frequency. This shows that collision causes the decrease in electron oscillatory velocity and hence results the decrease in ponderomotive force. In this way, we can say that the spatial inhomogeneity and nonlinearity of medium might be decreased with the presence of electron-neutral collision.

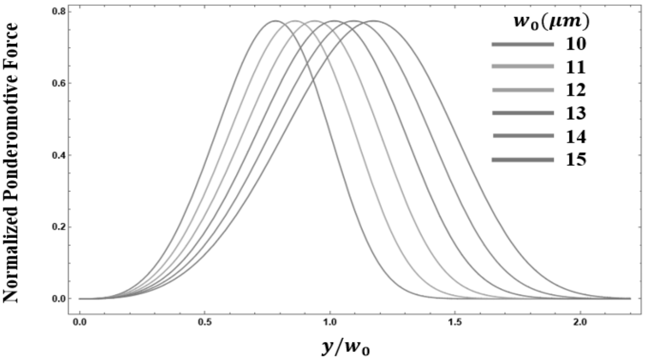

Figure 3: Variation of normalized nonlinear ponderomotive force as a function of $y/w_0$for various values of laser beam widthw_0, when $\omega/\omega_p = 0.57$, $v/\omega_p = 0.05$.

In Fig. 3, we have studied the variation of normalized nonlinear ponderomotive force as a function of laser beam transverse propagation distanced from y-axis for different values of laser beam width w_0.As one increases the laser beam width, the nonlinear ponderomotive force decreases. The physics behind this phenomenon states that the laser field intensity is very sharp for steeper laser beam width. Hence, the steeper laser beam width imparts larger oscillatory velocity to the electron associated with nanoclustered plasma. This large oscillatory velocity causes to produce of strong nonlinear ponderomotive force due to sharper laser beam width.

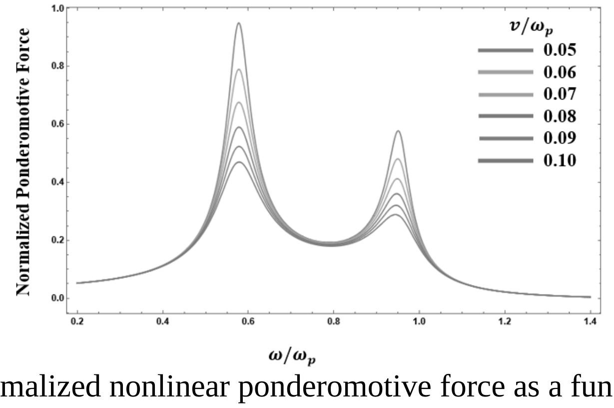

Figure 4: Variation of normalized nonlinear ponderomotive force as a function of laser beam normalized frequency for different values of electron-neutral collisional frequency, when p=4,$\omega/\omega_p = 0.57$, $y/w_0 = 0.5$.

Figure 4 shows the variation of normalized nonlinear ponderomotive force as a function of normalized laser beam frequency for different values of electron-neutral frequency. The nonlinear ponderomotive force has attain two intense peak profile at normalized laser beam frequency $\omega/\omega_p = 0.57$, $\omega/\omega_p = 0.95$ respectively. The two intense peak is appeared owing to presence of affective surface plasmon resonance at the surface of nanoclustered plasma. In which the primary resonance is stronger than secondary resonance. This predicts that the contribution of primary resonance is more efficient for production of large amplitude nonlinear ponderomotive force.It is to be noticed that as one increases the electron-neutral collisional frequency, the nonlinear ponderomotive force is decreased. The presence of electron-neutral frequency leads to decrease the dynamics of oscillating species as well as nonlinearity. Therefore, we can say that the presence of electron-neutral collisional frequency causes to negative effect in nonlinear ponderomotive force.

IV. SUMMARY AND CONCLUSIONS

In this present theoretical investigation, we have proposed the production of large nonlinear ponder motive force by two copropagating high power super-Gaussian laser beam in collisional nanoclustered plasma. The analytic expression of nonlinear ponderomotive force is derived by using the fluid theory. The different graphical profiles depict that nonlinear ponderomotive force can be optimized and controlled by varying the laser beam width, super-Gaussian index, laser beam frequency, laser beam propagation distance and electron-neutral collisional frequency. The presence of effective surface plasmon frequency plays an important role for resonant and efficient production of nonlinear ponderomotive force as the laser beam frequency becomes $\sqrt{3}$times plasma frequency.This enhanced and large amplitude nonlinear ponderomotive force can be used for electrostatic wave excitation [6].

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