**Enhanced Nonlinear Ponderomotive Force by Beating of Two Copropagating super-Gaussian Laser Beams in Nanoclustered Plasma**

**S P Mishra1a, Arvind Kumar2, Asheel Kumar2 and Ashish Varma1b**

1Laser Plasma and Material Research Group, Department of Physics, K. N. Govt. P. G. College, Gyanpur, Bhadohi-221304, India

2Plasma Physics Research Group, Department of Physics, University of Allahabad, Prayagraj, India-211002

a,bEmail: drspmishra2001@gmail.com, varmaashish331@gmail.com,

**Abstract**

In this chapter, we have formulated the nonlinear ponderomotive force by beating of two high power super-Gaussian laser beam in plasma embedded with nanoclustered medium. The copropagating 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 ponderomotive force. The effective surface plasmons frequency resonantly enhanced the nonlinear process. This force is controlled and tuned by laser beam super-Gaussian index, electron-neutral collisional frequency, laser beat wave frequency and beam width. Nonlinear ponderomotive force is an important term in nonlinear process such as electron heating, parametric instability and harmonic generation.

**Keywords:** Ponderomotive force, Nanocluster plasma, Beam width, Super-Gaussian laser beam, Plasmons

**1. Introduction**

In last few decades, high power laser beam interaction with nanocluster plasma is special field of interest due to tremendous 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 nanoclustered medium attained ambiguous property of matter on nanometer scale regime [13-14]. Clusters are excited and formed by the interaction of laser beam with materials [15]. Ponderomotive 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 excited by the nonlinear interaction of two intense laser beams in cluster medium [17]. Antonsen et al. [18] have analyzed the PIC simulation 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, our aim to explain the production of nonlinear ponderomotive force by the copropagation 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 ponderomotive force between the oscillating electrons associated with nanoclustered plasma. The nonlinear ponderomotive 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 ponderomotive force is much efficient. The nonlinear coupling scheme of laser beams is presents in Sec. 2. The results and discussion of nonlinear ponderomotive force is explain in Sec. 3. Finally, the summary this theory is given in Sec. 4.

**2. 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 and the associated density of medium can be taken as

, and

where is the rippled wave number, is the rippled cluster density at equilibrium condition and is equilibrium cluster density. The two high power laser beams with wave numbers and , frequencies and , are nonlinearly interacted with nanocluster 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

where is the beam width parameter of laser, , is the index of super-Gaussian, is the electron plasma frequency. When high power laser beam interacts with nanocluster plasma, then clusters are heated and on of the sudden it is ionized and directly converted into plasma plume balls. Further, we assume that only electrons cloud of nano medium responds to high power laser beam. Since the ions having large mass and thus assume immobile during the whole dynamical process.

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

 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 nanoclustered electrons. Where , , are the electron oscillatory velocity, electron-neutral collisional frequency and excursion respectively. The term 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

The beat wave of two high power laser beams in nanoclustered plasma cause to production of pondermotive force to the electron associated with medium at the beat frequency and beat wave number . The formula of nonlinear ponderomotive potential and force can be written as

 and

**3. Results and Discussion**



**Fig. 1: Variation of normalized nonlinear ponderomotive force as a function of for various values of super-Gaussian index p, when , .**

The two copropagating 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 , . In practical purpose, these frequencies can be achieved by CO2 and N2O gas lasers respectively.

Fig. 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 , 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 %.

**Fig. 2: Variation of normalized nonlinear ponderomotive force as a function of for various values electron-neutral collisional frequency, when , .**

In Fig. 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 . 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.



**Fig. 3: Variation of normalized nonlinear ponderomotive force as a function of for various values of laser beam width , when , .**

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 . 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.



**Fig. 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, , .**

Fig. 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, 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.

**4. Summary and Conclusions**

In this present theoretical investigation, we have proposed the production of large nonlinear ponderomotive 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 times plasma frequency. This enhanced and large amplitude nonlinear ponderomotive force can be used for electrostatic wave excitation [6]**.**

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