ORIGINAL RESEARCH ARTICLE

EXCITATION OF ELECTRON BERNSTEIN WAVE BY TWO LASER BEAMS IN MAGNETIZED PLASMA

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ABSTRACT:

In this present paper, we have analytically studied a theory of electron Bernstein wave excitation by copropagating two Hermite-Gaussian laser beams in a collisional plasma under a static magnetic field. The two Hermite-Gaussian laser beams generate a nonlinear ponderomotive force at the beat wave frequency $\omega = (\omega_1 - \omega_2)$ and wave vector $k = k_1 - k_2$. The exerted ponderomotive force on plasma electrons leads to impart oscillatory velocity. This ponderomotive force has significant potential to excite the space charge wave and electrostatic electron Bernstein wave in plasma. The power profile amplitude of the electron Bernstein wave has been derived. The variation of power profile with laser beam propagation distance, mode index associated with Hermite polynomial, laser beam width, beat wave frequency, parameter b, electron cyclotron frequency and electron-neutral collision frequency is discussed through graphical analysis. We have obtained the resonant excitation condition of the electron Bernstein wave for different laser parameters and electron cyclotron frequency. The field optimization property of Hermite-Gaussian laser beam with electron Bernstein wave is discussed. This excited large amplitude electron Bernstein wave might be applicable in laser anomalous absorption process, harmonic generation, and plasma electron heating.

KEYWORDS: Nonlinear Interaction, Beat Wave, Beam Width, Static Magnetic Field, Hermite-Gaussian Laser Beam, Electron Bernstein Wave, Excitation.

1. INTRODUCTION:

The nonlinear interaction of laser beam with plasma has been an interesting field of interest due to its vast field applications such as soft X-ray emission, terahertz radiation generation, charged particle acceleration, parametric decay process. The coupling of two or more laser beams in both magnetized plasma and unmagnetized plasma is vital for nonlinear phenomena. Plasma deserves as a good candidate for interaction of both electrostatic as well as electromagnetic wave in comparison with other medium.

Electron Bernstein wave is a kind of electrostatic wave which present in static magnetized plasma with large perpendicular component of wave number. The frequency of this electrostatic wave lies in the harmonics of electron cyclotron waves. Electron Bernstein wave has several applications such as plasma electron heating, charged particle acceleration [Kumar and Tripathi 2011], harmonic generation [Tyagi *et al.,* 2016], noninductive current generation [Shevchenko *et al.,* 2002]. Many researchers have been studied the electron Bernstein wave excitation by electron beam [Jain and Tripathi 1987; Kumar and Tripathi 2004] and laser beam in plasma. The first experiment of electron Bernstein wave excitation mechanism is developed by Pierre and Braun [Pierre and Braun 1989]. Electron Bernstein wave is excited by gyrating relativistic electron beam in Maxwellian distribution of plasma [Kumar and Kumar 2004] and relativistic electron beam in non-Maxwellian distribution of plasma. Laing and Diver [Laing *et al.,* 2013] proposed the theoretical formalism of electron Bernstein wave dispersion relation in ultra-relativistic pair plasmas for pulsar atmospheric application. Reverse field pinch cause the strong heating of overdence plasma through electron Bernstein wave [Seltzman *et al.,* 2017].

In this paper, we have studied the electron Bernstein wave excitation by nonlinear interaction of two high power Hermite-Gaussian laser beams in collisional plasma with static magnetic field. The formalism of power going in to electron Bernstein wave is analytically derived. The schematic of this theory of electron Bernstein wave excitation is shown in Fig.1. The two Hermite-Gaussian laser beams having wave numbers k_1, k_2 and frequencies ω_1, ω_2 copropagate in collisional plasma with static magnetic field and it cause to generate the beat wave with frequency $\omega = \omega_1 - \omega_2$ and wave vector $\vec{k} = \vec{k}_1 - \vec{k}_2$. The laser beat wave exert nonlinear ponderomotive force to the plasma electrons with oscillatory velocity. This nonlinear ponderomotive force has much potential to excite the electron Bernstein wave in collisional plasma. The electron Bernstein wave excitation strongly depends on laser beat wave frequency, electron cyclotron frequency, collisional frequency, laser beam width and parameter b. Sec. 2 provides the nonlinear coupling of laser beams. Results and discussion of this theory is presented in Sec. 3. Finally, Sec. 4 provides the summary and conclusions part.

2. NONLINEAR BEAT WAVE COUPLING:

Consider a plasma with background electron density n_0 and where collision between electron and neutral particles takes place. Here, two Hermite-Gaussian laser beams with wave numbers k_1 and k_2, frequencies ω_1 and ω_2, copropagating in a collisional magnetized plasma with modulated plasma density profile $n = n_0 + n_\alpha e^{-i\alpha z}$ where n_α is the amplitude of density ripple and α is rippled wave number. A dc external magnetic field B_s is applied along the direction of beam propagation (i.e., the z-axis). The electric field profile of Hermite-Gaussian laser beam can be expressed as

$$\vec{E}_j(r,z) = \hat{r} E_{0j} H_m\left(\frac{\sqrt{2}r}{w_{0H}}\right) \exp\left(-\frac{r^2}{w_{0H}^2}\right) e^{-i(\omega_j t - k_j z)} \quad (1)$$

where j=1, 2 for two lasers, r is the radial distance from the centre, m is the mode index associated with the Hermite polynomial function, w_{0H} is the beam width and E_{0H} is the amplitude of the Hermite-Gaussian electric field. Now, let's consider the interaction of Hermite-Gaussian laser beams with collisional plasma. The electric field of Hermite-Gaussian laser beams exerts a nonlinear ponderomotive force on plasma electrons. It imparts the oscillatory velocity to the plasma electrons and which can be written as

$$\vec{v}_j = -\frac{e\vec{E}_j}{m_e(i\omega_j - v_e)}. \quad (2)$$

where m_e is the mass of electron associated with plasma and v_e is the collisional frequency between neutral and electron.

Due to gradient in the field, the nonlinear ponderomotive force of two copropagating Hermite-Gaussian laser beams is obtained by solving the equation of motion as

$$\vec{F}_p = -(m_e/2c)\left(\vec{v}_1 \times \vec{B}_2^* + \vec{v}_2^* \times \vec{B}_1\right) = e\nabla\phi_p, \quad (3)$$

Consider the plasma with collisional background with having rectangular X-Y cross section of interaction area as A. The spot size of laser beam may be taken as relation $k_z \sim 1/w_{0H}$. If laser beams have finite beam width in z-extent, then Bernstein wave might be convected out form interaction region. We can get an estimate expression of ϵ_i by using the laser beat wave interaction in plasma as consider length L and width $2w_{0H}$.Therefore, we can write the stored energy of Bernstein wave in the interaction volume $2w_{0H}A$ as

$$W_{EB} = 2w_{0H} A\omega\left(\frac{\partial\epsilon}{\partial\omega}\right)\left(\frac{E^2}{8\pi}\right), \quad (4)$$

We can find out a relationship between the power going into the electron Bernstein wave and total incident power of two Hermite-Gaussian laser beams. For this, we can take the fractional power of two laser beams going into the electron Bernstein wave and it can be written as

$$\left|\frac{P_{EBW}}{P_T}\right| = \frac{4L\omega w_{0H}\,\emptyset_p^2}{\pi E_0^2 c v_{gz}\left(\frac{\partial\epsilon}{\partial\omega}\right) H_m^2\left(\frac{\sqrt{2}r}{w_{0H}}\right) exp\left(-\frac{2r^2}{w_{0H}^2}\right)}, \quad (5)$$

3. RESULTS AND DISCUSSION:

Here, we consider two Hermite-Gaussian laser beams instead of only single laser beam owing to study the beat wave excitation of electrostatic waves. Beat wave is generated by copropagating two Hermite-Gaussian laser beam. The two laser beams exert a nonlinear ponderomotive force on plasma electrons and it cause to impart the oscillatory velocity to the plasma electrons. Since electron Bernstein wave is an electrostatic wave with large perpendicular wave vector as compared with parallel component. The large amplitude of electron Bernstein wave is excited in collisional plasma with static magnetic field by two high power Hermite-Gaussian laser beams. The possible schematic of beat wave excitation of electron Bernstein wave is shown in Fig. 1.

The variation of normalized power profile of electron Bernstein wave as a function of normalised laser beam propagation distance for different values of Hermite mode index is shown in Fig. 2. The power profile is purely Gaussian for mode index m=0. Peak is appeared at normalized beam propagation distance $r/w_{0H} = 0$. Further, if one increases the mode index (m=1), the peak of power profile is shifted towards the laser propagation distance. In this mode, peak is appeared at normalized beam propagation distance r/w_{0H}~0.72. For mode index (m=2), the power profile attains two lobes and it also shifted towards the laser beam propagation distance. At this mode, the first peak is appeared at normalized beam propagation distance $r/w_{0H} = 0$ and the second peak is appeared at normalized beam propagation distance r/w_{0H}~1.1. It is interesting to note that the amplitude of second peak has attained the greater profile as compared with first peak. The physics behind this phenomenon can be explained by gain in energy and momentum with increase in mode index. As one increases the mode index associated with Hermite polynomial, the power profile become more abaxial. This abaxiality of peak profile leads to much more excitation of electron Bernstein wave.

In Fig. 3, we have plotted the variation of normalized power profile of electron Bernstein wave as a function of normalized laser beam propagation distance for different values of normalized collisional frequency. For Hermite mode index m=2, one can see that the power profile attains two lobes. It is to be noted that between these two lobes, the normalized power profile become almost zero at normalized beam propagation distance r/w_{0H}~0.5. As the laser beam interacts with plasma, the collision effect has been taken into account. The collision effect is due to electron and neutral particles. As one increases the collisional frequency, the normalized power profile of excited electron Bernstein wave is decreased. Therefore, we can say that collision frequency cause to decrease in power profile of electron Bernstein wave.

4. SUMMARY AND CONCLUSIONS:

In this present work, we have analytically studied the excitation of electron Bernstein wave by two copropagating high power Hermite-Gaussian laser beam in collisional plasma with static magnetic field. Kinetic theory is employed to derive electron Bernstein wave dispersion relation [Kumar and Tripathi 2005]. We have obtained the extreme condition for electron Bernstein wave excitation. One can tune and control the power amplitude profile of electron Bernstein wave by optimizing the laser and plasma parameters. This excited large amplitude electron Bernstein wave might be applicable in laser absorption process, harmonic generation [Tyagi *et al.,* 2016] and plasma electron heating.

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