ORIGINAL RESEARCH ARTICLE

ELECTROSTATIC LOWER HYBRID WAVE EXCITATION BY NONLINEAR INTERACTION OF TWO LASER BEAMS IN PLASMA

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ABSTRACT:

This paper introduces a method to create lower hybrid waves (LHW) by using two laser beams with a cosh Gaussian (ChG) shape that travel in opposite directions in a magnetized plasma channel. These beams interact with each other, creating a beating wave that has a specific frequency and wave vector. This beating wave applies a force on the electrons, which helps to generate lower hybrid waves in both uniform and non-uniform plasma environments. The laser beams act like a pump, providing the energy needed to excite the lower hybrid waves. The study looks at how the strength and power of these waves change with their frequency, especially when they are in resonance. The peaks observed in the results show that lower hybrid waves are being excited. The position and width of the laser beams also affect where these peaks appear. The results also examine how the waves move, escape, or get trapped within the magnetized plasma channel.

KEYWORDS: Lower Hybrid Wave, CHG Laser, Beat Wave, Convection Losses, Magnetized Plasma.

INTRODUCTION:

Great efforts of T. H. Maiman advent the era of laser physics [1] which enormously make a revolution in various research fields [2-3]. In the last few decades, the excitation mechanism of different waves have been studied in which lower hybrid waves are fascinating research field due to its wide application in plasma heating and current drive in fusion plasma [4-8]. Lü *et al.* [9] firstly developed the theory of the normalized intensity distribution of ChG laser beam propagation with the characteristics of parameters. They took the apertured and unapertured lens by passing it through the first order paraxial system. Mutual interaction of two intense ChG laser beams in collisionless plasma causes the strong self-focusing [10] phenomena at a relativistic ponderomotive regime. It also has the potential to generate terahertz radiation [11].

An excitation scheme of fast and slow plasma waves has been investigated by Liu and Tripathi using counter propagation of laser beams in hot plasma [12]. They obtained a growth rate greater than Raman backward scattering with frequency difference $\Delta\omega_0 = 2\omega_p$. Observing the recent scenario, some groups have developed many theories on counterpropagating beams in magnetized plasma. Verma *et al.* [13] studied stimulated Raman scattering by counterpropagating two X-mode laser beams. They have depicted the effect of the transverse magnetic field on it. The growth rate was reduced by increasing the magnetic field from 1kG to 3kG. In the stimulated Brillouin scattering case, the beat wave excites a pair of ion-acoustic and sideband electromagnetic waves. In this case, the growth rate is reduced with the applied magnetic field [14]. On the other hand, with the help of the excitation of a pair of lower and upper hybrid sideband waves, the growth rate was reduced upto half by increasing the applied magnetic field 60 T from 270 T [15].

Instability analysis of LHWs has been done by cyclotron interactions when a gyrating ion beam passes through a plasma cylinder with containing positive-negative ion species, and electrons [16]. The parametric instability analysis promises the excitation of the lower hybrid waves by the electron plasma waves. In this process, the decay of an electron plasma sideband wave and a lower hybrid wave was considered in the form of a cascade channel [17]. Decyk *et al.* [18] proposed the simulation of the LHWs excitation. In this study, the electron density profile controlled the electron temperature and wave-particle interaction. A radio frequency of 4.6 GHz has been used in the Alcator C-Mod Tokamak for the lower hybrid current drive experiment. The coupled frequencies have potential to achieve power up to 900 kW for the comparison of simulation and theoretical results [19].

The present motivation of this work is to explain the convective losses, escaping, and trapping of pump waves in a plasma channel. In this paper, we theoretically study the excitation of the lower hybrid waves by counterpropagating of two intense ChG laser beams in a magnetized plasma channel. The possible general method of this process has been shown in the pictorial diagram (Fig. 1). Mathematically, two high power ChG laser beams having frequencies ω_1, ω_2 higher than the electron cyclotron frequency, wave vectors $k_1,\ k_2$ propagate along the x-direction and are taken perpendicular to the static magnetic field. These waves exert ponderomotive force and induce oscillatory velocities at the beat wave frequency $\omega = \omega_1 - \omega_2$ and wave vector $\vec{k} = \vec{k}_1 + \vec{k}_2$. This force can drive the lower hybrid waves when $\omega_c \gg \omega \gg \omega_{ci}$ and $\omega \geq \omega_{LH}$. These results are in good agreement with the experimental analysis of Batanov *et al.* [20]. The beat wave excitation of lower hybrid waves in the homogeneous plasma is discussed in sec. 2. Further, in sec. 3, we have analyzed the mechanism of the beat wave in the inhomogeneous plasma. The result and discussion are given in sec 4. Conclusion is given in sec. 5.

LOWER HYBRID WAVE EXCITATION IN THE HOMOGENEOUS PLASMA:

Consider two cosh-Gaussian (ChG) laser beams with wavenumbers k_1 and k_2, frequencies ω_1 and ω_2, counterprogating in a plasma embedded with dc magnetic field $B_s\hat{z}$ along the x-direction and polarized in the z-direction. We take the laser electric field profile as

$$\vec{E}_j = \hat{z}E_{0j}\cosh\left(\frac{zd}{\Omega_0}\right)e^{-z^2/\Omega_0{}^2}e^{-i(\omega_j t - k_j x)}, \quad (1)$$

$$\vec{B}_j = c\vec{k}_j \times \vec{E}_j/\omega_j,$$

where j=1, 2 for two lasers, d is the decentred parameter, Ω_0 is the initial beam width, c is the velocity of light, $k_j = (\omega_j/c)\left(1 - \omega_p{}^2/\omega_j{}^2\right)^{1/2}$and $\omega_{1,2} \gg \omega_c = eB_s/mc$ is the electron cyclotron frequency, and ω_p is the plasma frequency.

These waves exert a ponderomotive force on the electrons,

$$\vec{F}_p = -(m/2c)\left(\overrightarrow{v_1} \times \overrightarrow{B_2^*} + \overrightarrow{v_2} \times \overrightarrow{B_1^*}\right) = e\boldsymbol{\nabla}\emptyset_p, \quad (2)$$

We can estimate the fractional power relation of ChG lasers beam going into the lower hybrid wave,

$$\frac{P_{LH}}{P_T} = \frac{4\omega L k^2 \Omega_0}{\pi c|E_1|^2}\frac{{\emptyset_p}^2}{v_{gz}\left(\frac{\partial\epsilon_1}{\partial\omega}\right)}, \quad (3)$$

$$\left|\frac{P_{LH}}{P_T}\right| = G\frac{\left(1 + \frac{k_z^2}{k^2}\cdot\frac{m_i}{m}\right)^{\frac{1}{2}}\left(1 + \frac{\omega_p^2}{\omega_c^2}\right)^{\frac{1}{2}}}{\omega_{pi}\cdot\frac{m_i}{m}\left[\frac{k_z k^2 - k_z^3}{k^4}\right]\frac{2\omega_{pi}{}^2}{k^2 v_{thi}^2}\cdot\frac{\omega_{ci}}{(\omega - \omega_{ci})^2}}\frac{e^2|E_{01}|^2}{m^2\omega_1{}^2\omega_2{}^2}\cosh^2\left(\frac{zd}{\Omega_0}\right)e^{-\frac{2z^2}{\Omega_0{}^2}}, \quad (4)$$

RESULTS AND DISCUSSION:

Typically, one can choose the beat wave frequency of the order $\omega_1 - \omega_2 \approx 1\ GHz$. In Fig. 2, we have plotted the graph between the normalized potential $|\emptyset/\emptyset_p|$ to the normalized frequency $(\omega - \omega_{ci})/\omega_{ci}$. It shows the increase in normalized potential with varying the normalized frequency. The increment in normalized potential is enhanced with varying the value of $k^2 v_{thi}^2/2\omega_{pi}{}^2$. In Fig. 3 we have plotted the graph between the normalized potential $|\emptyset/\emptyset_p|$ and the normalized frequency $(\omega_{pi}/\omega_{ci})$ keeping the $\omega_{pi}/\omega_{ci} < 1$. This shows that the variation in normalized potential is very small. The increment can also be seen by varying the value of $k^2 v_{thi}^2/2\omega_{pi}{}^2$.

CONCLUSIONS:

In present, the lower hybrid wave is excited by counterpropagating two high power ChG laser beams in the magnetized plasma channel. The transverse wavelength of lower hybrid waves is much closure to the plasma column, whereas the radius of the electron beam is shorter than the plasma column. These waves are excited by a self-generated magnetic field with the required condition $\omega_c \gg \omega \gg \omega_{ci}$. Here, we have encountered the laser beat wave instead of a single beam owing to achieve pulses of the period. The resonance condition of the lower hybrid waves is achieved by almost all possible frequencies withholding the condition $\omega \geq \omega_{LH}$. We have employed high power laser beams rather than normal pump wave. The stronger absorption mechanism occurred by laser beams due to the existence of high LHW amplitude. In the case of cyclotron waves, one cannot observe the lower hybrid wave because of its lower absorption behaviour.

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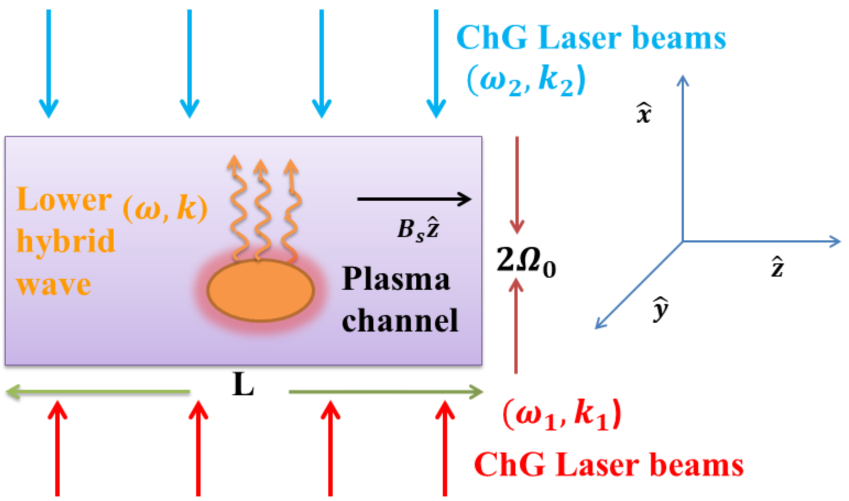

Figure 1: Schematic diagram of the lower hybrid wave excitation by counterpropagating of two ChG laser beams in magnetized plasma channel

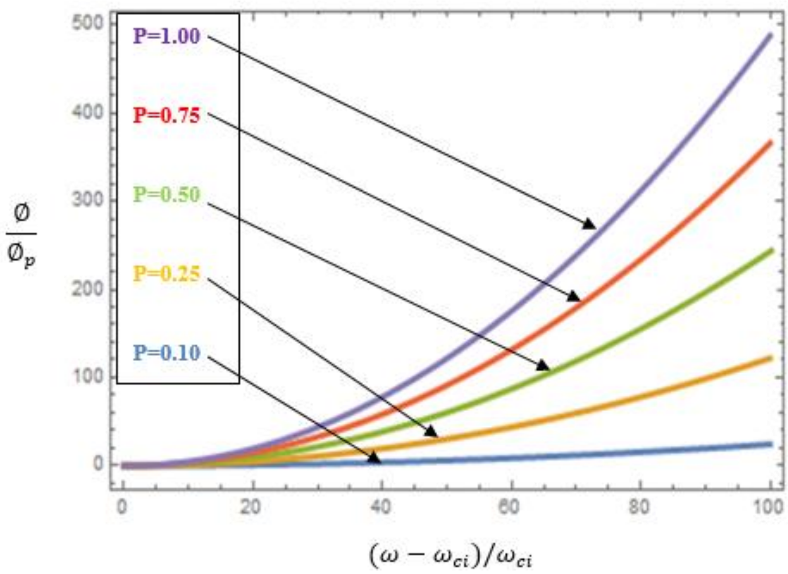

Figure 2: Variation of normalized potential amplitude as a function of normalized frequency $(\omega - \omega_{ci})/\omega_{ci}$ for the homogeneous plasma with taking following parameters: $k_z\Omega_0 = 0.1\ \omega_{ci}/\omega_{pi} = 0.2, \omega_p/\omega_c = 5, k_z/k = 0.1, m_i/m = 1024$ and $P = k^2 v_{thi}^2/2{\omega_{pi}}^2 = 0.1, 0.50, 1.00, 1.50, 2.00$

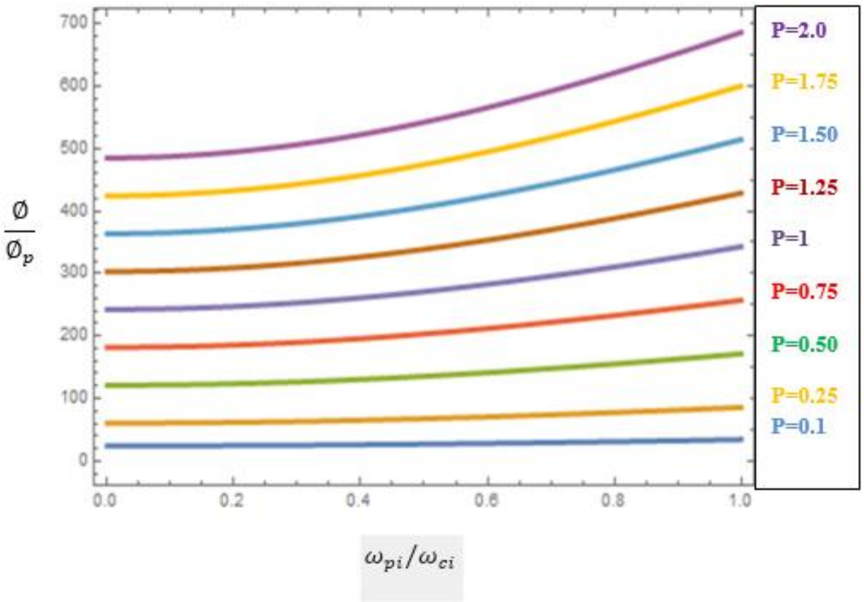

Figure 3: Variation of normalized potential amplitude as a function of normalized frequency $0 \leq \omega_{pi}/\omega_{ci} \leq 1$ for the homogeneous plasma with taking following parameters: $k_z\Omega_0 = 0.1$, $(\omega - \omega_{ci})/\omega_{ci} \sim 10^3$, $\omega_p/\omega_c = 5$, $k_z/k = 0.1$, $m_i/m = 1024$ and $P = k^2 v_{thi}^2/2{\omega_{pi}}^2 = 0.1, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00$