International Research Journal of Natural and Applied Sciences
ISSN: (2349-4077)
Impact Factor 5.46 Volume 6, Issue 02, February 2019
Website- www.aarf.asia, Email : editoraarf@gmail.com

Electrostatic Lower Hybrid Wave Excitation by two Laser Beams in Magnetized plasma

S P Mishra[a]

[a]Department of Physics, K. N. Govt. P. G. College, Gyanpur, Bhadohi-221304, India

Abstract

An analytical framework has been established to explore the excitation of electrostatic lower hybrid waves through the counterpropagation of two distinct laser beam profiles in a collisional plasma that is subjected to a static magnetic field. The interference of the two laser beams results in a nonlinear ponderomotive effect on the plasma electrons, which may effectively couple with the pre-existing electrostatic lower hybrid wave. The excitation of the lower hybrid wave is significantly enhanced when the interference of the two different laser beam profiles is aligned with the electrostatic lower hybrid wave. In cases where the beatings of the two laser beams possess a finite y-extent, the electrostatic lower hybrid wave exhibits an effective y-component wave number and a component of group velocity that aligns with the static magnetic field, leading to convective losses. The unique power profile shape of the electrostatic lower hybrid wave indicates that it can be further excited by variations in parameters such as the laser beam decentered parameter, beam width parameter, Hermite polynomial mode index, laser beam transverse propagation distance, electron-neutral collision frequency, and electron cyclotron frequency. This theoretical framework for the excitation of electrostatic lower hybrid waves may be applicable in processes such as electron heating and laser high harmonic generation.

Keywords: Lower hybrid wave, Electron cyclotron frequency, Collisional plasma, Ponderomotive force, Beat wave, Hermite cosh-Gaussian laser beam, Decentered parameter, Counter propagation

1. Introduction

In last few decades, interaction of high power laser beam with plasma is fascinating emerging field of research due to its wide applications in electrostatic wave excitation, electron heating, charged particle acceleration, parametric instability, high harmonic generation (Tyagi et al. 2016, 2017), terahertz radiation generation [Safari et al. 2018] and current dive experiments (Schmidt et al. 2011). Owing to possess of highly ionized state of matter, plasma is a good candidate for the interaction of highly intense and coherent electromagnetic radiation (laser beam). Many nonlinear phenomenon can be study by the interaction of laser beam radiation with this ionized state of matter. By choosing the different types of laser beams, we can tune and control the excited nonlinear phenomenon. The laser beam parameter and interacting medium species might be plays an effective role for the controlling enhancement in nonlinear phenomenon. A theoretical study of propagation property of Hermite cosh-Gaussian laser beam has been studied by using the ABCD matrix method. In this, the propagation property of considered beam is depend on the apertured and unperturbed geometry and also the amplitude distribution of beam profile can be tuned by varying the mode index and beam decentered parameter (Belafhal and Ibnchaikh 2000).

Lower hybrid wave is a kind of electrostatic wave, which existed in static magnetised plasma. This electrostatic wave can be excited by electron beam, beating of two laser beams, gyrating electron beam (Kumar and Tripathi 2004) and density modulation of electron beam (Sharma et al. 2013). For the nonuniform pump radiation, the decay process of two lower hybrid wave via the pump radiation is very significant at low density regime of plasma (Tripathi et al. 1979). Batanov et al. have given the first experimental observation on electrostatic lower hybrid wave excitation by counterpropagation way of interaction of two electron cyclotron wave (Batanov et al. 1995). In the magnetized plasma, the experimental studied revels that electron heating, process can be achieved at the lower hybrid range of frequency (Pinsker 2001). Further, via Landau damping process the propagation and absorption of lower hybrid wave has been studied in tokomaks (Pinsker 2015). At the ITER, many experimental and simulation studied of lower hybrid wave has been investigated for current drive experiment (Bonoli 2014). Electron plasma wave is an electrostatic wave that can have efficient potential to parametrically excite the lower hybrid wave in magnetized plasma. In this, the cascaded setup enhances the frequency of lower hybrid wave (Kuo 2003). Owing to possess of efficient confinement of plasmas, lower hybrid current drive experiment promising tool for high current drive efficiency (Schmidt et al. 2011). The interaction of a gyrating ion beam with plasma cylinder containing different types of ion species can have efficient potential to excite the electrostatic lower hybrid wave via the cyclotron damping process. In this, the growth rate was found maximum for the particular values of eigen function mode (Sharma et al. 2013). The large amplitude of extraordinary mode radiation can be parametrically decayed in to the two electrostatic waves. In this, the growth rate decay wave is directly dependent on the particular value of electron cyclotron frequency (Kumar and Tripathi 2010). The density fluctuations in the plasma causes the anomalous absorption of electrostatic lower hybrid wave in magnetized plasma medium (Kumar 2015).

The present study aim is to explain the electrostatic lower hybrid wave excitation by beating of two counterpropagating laser beams in plasma embedded with static magnetic field. Fig. 1 represents the schematic diagram of this theoretical investigation. Initially, the two different profile laser beams interact with plasma via counterpropagating way. The nonlinear ponderomotive force has efficient potential to drive the pre-existed space charge wave and thus excite the electrostatic lower hybrid wave. The power amplitude profile of electrostatic lower hybrid wave can be tuned and controlled by various laser parameters. In Sec. 2, the nonlinear coupling of two laser beams with plasma is given. The excitation scheme of electrostatic lower hybrid wave is governed in Sec. 3. The results and discussion of this excitation scheme is given in Sec. 4. Finally, Sec. 5 provides the summary and conclusion of this theoretical investigation.

2. Nonlinear Coupling

Herein, we have considered two laser beams Hermite cosh-Gaussian and cosh-Gaussian are counterpropagating in collisional plasma embedded with static magnetic field. These laser beams have wave numbers k_1 and k_2, frequencies ω_1 and ω_2 respectively and counterpropagating along the z-direction and polarized along y-direction. The static magnetic field is taken along y-direction.

The general electric field profile of Hermite cosh-Gaussian laser beam can be written as

$$\vec{E}_1(y,z) = \hat{y}E_{01}\,\mathrm{H}_m\left(\sqrt{2}\frac{y}{w_{0H}}\right)\cosh\left(\frac{yd}{w_{0H}}\right)\exp\left(-\frac{y^2}{w_{0H}^2}\right)e^{-i(\omega_1 t-k_1 z)} \tag{1}$$

where E_{01} is the electric field amplitude of Hermite cosh-Gaussian laser beam at the centre (y=z=0), m is the mode index associated with Hermite polynomials, w_{0H} is the initial laser beam width parameter, d is beam decentered parameter.

The general electric field profile of cosh-Gaussian laser beam can be written as-

$$\vec{E}_2(y,z) = \hat{y}E_{02}\cosh\left(\frac{yd}{w_{0C}}\right)\exp\left(-\frac{y^2}{w_{0C}^2}\right)e^{-i(\omega_2 t-k_2 z)} \tag{2}$$

where E_{02} is the electric field amplitude of cosh-Gaussian laser beam at the centre (y=z=0) and w_{0C} is the initial laser beam width parameter of cosh-Gaussian laser beam.

As the field of each laser beams interact with plasma, the electron associated with plasma imparts oscillatory velocity. A static magnetic field is taken along the y-direction $B_s\hat{y}$. We have considered the counterpropagation interaction of Hermite cosh-Gaussian and cosh-Gaussian laser beams in collisional plasma embedded with static magnetic field. By this interaction, the two laser beams beats with beat frequency $\omega = \omega_1 - \omega_2$ and beat wave number $k = k_1 - k_2$, exerts a nonlinear ponderomotive force to the plasma electrons with oscillatory velocity $\vec{\mathrm{v}}_j$.

$$\frac{d\vec{\mathrm{v}}_j}{dt} + \nu_e\vec{\mathrm{v}}_j = \frac{e}{m}(\vec{E}_j + \vec{\mathrm{v}}_j \times \vec{\mathrm{B}}_s\ ) \tag{3}$$

We can write the electron oscillatory along the y-direction as

$$\mathrm{v}_{jy} = \frac{\frac{e}{m}\mathrm{E}_j}{(-i\omega j + \nu_e)} \tag{4}$$

where j is the index (j=1, 2), e is the electronic charge, m is the electronic mass and ν_e is the collisional frequency between electron and neutral particle.

The expression of nonlinear ponderomotive force can be written as

$$\vec{\mathrm{F}}_P^{NL} = -\frac{e}{2c}\left((\vec{\mathrm{v}}_1 \times \vec{\mathrm{B}}_2{}^* + (\vec{\mathrm{v}}^*{}_2 \times \vec{\mathrm{B}}_1\right) = e\nabla\vec{\phi}_P^{NL} \tag{5}$$

The nonlinear ponderomotive potential can solved $\vec{\phi}_P^{NL} = -\left(\frac{m}{2e}\right)\overrightarrow{\mathrm{v}_1}.\overrightarrow{\mathrm{v}_2^*}$ and it can be written as

$$\vec{\phi}_P^{NL} = -\frac{e(E_{01}E_{02}^*)}{2m(-i\omega_1+\nu_e)(i\omega_2+\nu_e)}\mathrm{H}_m\left(\sqrt{2}\frac{y}{w_{0H}}\right)\cosh\left(\frac{yd}{w_{0H}}\right)\cosh\left(\frac{yd}{w_{0c}}\right)\ \exp\left(-y^2\left[\frac{1}{w_{0H}^2} + \frac{1}{w_{0c}^2}\right]\right)e^{-i\{(\omega_1-\omega_2)t-(k_1-k_2)z\}} \tag{6}$$

3. Lower hybrid wave excitation

Let this nonlinear ponderomotive force has efficient potential to drives an electrostatic space charge wave. Since lower hybrid wave is an electrostatic wave present in static magnetized plasma and this force might be couple the electrostatic lower hybrid wave with potential

$$\phi = \phi_0 e^{-i\omega t - \vec{k}.\vec{r}}. \tag{7}$$

The power escaped from this considered interaction region along y-direction can be expressed as

$$P_{LH} = A\omega \left(\frac{\partial \epsilon}{\partial \omega}\right)\left(\frac{\left|\vec{E}\right|^2}{8\pi}\right) \mathrm{v}_{gy}, \tag{8}$$

where v_{gy} is the group velocity of electrostatic lower hybrid wave along y-direction.

4. Results and Discussion

We have theoretically studied the electrostatic lower hybrid wave excitation by beating of counterpropagating Hermite cosh-Gaussian and cosh-Gaussian laser beam in collisional plasma embedded with static magnetic field. Herein, we consider the angular frequencies of Hermite cosh-Gaussian and cosh-Gaussian laser beams of the order $\omega_1 \sim 2.3 \times 10^{14} Hz$, $\omega_2 \sim 1.8 \times 10^{14} Hz$ respectively. The schematic diagram of this theory is shown in Fig. 1. Since lower hybrid wave is a particular type of electrostatic wave that can be existed in plasma embedded with static magnetic field. This electrostatic wave propagates perpendicularly and possesses small wave length as compared with Larmor radius of thermal particle (electrons and ions in plasma). Different groups have been theoretically and experimentally proposed the excitation scheme of lower hybrid wave in plasma by electron beam and electromagnetic wave. Our aim is to study the lower hybrid wave excitation by beating of laser beams via counter propagation way in plasma. As the two counterpropagating laser beams interact with plasma, it imparts the oscillatory velocity to the plasma electrons and drives a nonlinear ponderomotive force. We have neglected the ions motion as compared with electrons motion owing to possess of large mass (less mobility). This nonlinear force might have efficient potential to drive the space charge electric field in plasma and thus excite the electrostatic lower hybrid wave. The two laser beams are polarized along y-direction and hence we have considered the ponderomotive force along y-component. This depicts that large amplitude of electrostatic lower hybrid waves can be excited along the polarization direction of laser beat wave (y-direction).

Figs. 2(a)-2(b) shows the variation of normalized intensity of Hermite cosh-Gaussian laser beam as a function of normalized transverse distance of laser beam from y-axis for different value of decentered parameter. The beam decentred parameter is also known as waist width parameter and is associated with hyperbolic cosine term. For Hermite polynomial mode index m=3, the intensity profile of laser beam attains two lobes. The first one lobe is appeared at the centre of beam $y/w_{0H} = 0$ while the second one beam is appeared outer from the centre of beam. For beam decentered parameter d=0, the laser has Hermite-Gaussian profile and intensity profile attains two different lobes with slide different amplitude (second one peak has greater amplitude than first one peak). As the beam decentered parameter increases, the amplitude of laser intensity profile is increased at the second one lobe and no any proper shift in peak amplitude of laser beam intensity profile is observed at first one peak. It is point to be noticed that at the centre of beam (y=0), the variation of beam decentered parameter is unaffected on the intensity profile of laser beam while it is much more affective form the outer side of centre. At the second lobe and beam decentered parameter d=0, the normalized intensity profile of laser beam is appeared nearly 0.1481 for the normalized beam transverse propagation distance $y/w_{0H} \sim 1.05$. While at the second lobe and beam decentered parameter d=1.2, the normalized intensity profile of laser beam is appeared nearly 0.8133 for the normalized beam transverse propagation distance $y/w_{0H} \sim 1.40$. This shows that there is outer shift in peak with enhanced amplitude for the variation of laser beam decentered parameter. The analytical result shows that there is typical 450% enhance in peak amplitude of laser intensity profile for the variation of beam decentered parameter d=0 to d=1.2. The sensitiveness behaviour of beam decentered parameter has been demonstrated in Fig. 2(b). If we make a variation in beam decentered parameter with 0.01, then there is much more changed in intensity profile of Hermite cosh-Gaussian laser beam is observed.

The variation of normalized intensity of Hermite cosh-Gaussian laser beam as a function of normalized transvers distance of laser beam from y-axis for different value of laser beam width has shown in Fig. 3. Here, we can see that as the laser beam width is increased, the peak of intensity profile will not only shift outward from origin of beam but also peak profile gets broaden. The sharper laser beam width causes the much more transfer of energy and momentum to the electron and hence provide the large intensity. The intense and narrower profile of laser beam is obtained from sharper laser beam and it imparts the large energy to the particles present in the interacting medium.

Fig. 4 shows The variation of normalized intensity of Hermite cosh-Gaussian laser beam as a function of normalized transvers distance of laser beam from y-axis for different value of Hermite polynomial m. For laser beam decentered parameter d=2 and Hermite polynomial m=0, the laser beam attains purely cosh-Gaussian profile and intensity profile has two peaks at different values of normalized transverse distance of laser beam. The first one and second peak are appeared at normalized transverse beam of laser beam $y/w_{0H}{\sim}0.50$ and $y/w_{0H}{\sim}1.70$ respectively. In this the peak amplitude of second one peak is greater than first one peak. For laser beam decentered parameter d=2 and Hermite polynomial m=1, the laser beam attains Hermite cosh-Gaussian profile and intensity profile also attains two peaks at different values of normalized transverse distance of laser beam. The first one and second peak are appeared at normalized transverse beam of laser beam $y/w_{0H}{\sim}0.40$ and $y/w_{0H}{\sim}1.80$ respectively. In this one can notice that the peak amplitude of first one peak is much greater than second one peak. On comparing the first one peak of purely cosh-Gaussian and Hermite cosh-Gaussian laser beam (m=1) we can notice that there is enhancement in the peak amplitude of Hermite cosh-Gaussian laser beam is about to 1045% as compared with purely cosh-Gaussian laser beam. On the other hand, at second one peak, the intensity profile of Hermite cosh-Gaussian (for m=1) laser beam is greater about to 21% as compared with purely cosh-Gaussian laser beam.

5. Summary and Conclusions

In this present theoretical investigation, we analytically study the excitation of electrostatic lower hybrid wave by the counterpropagation of two different profile laser beams in plasma embedded with static magnetic field. For obtaining the basic equations such as oscillatory velocity and nonlinear ponderomotive force, we have used fluid theory and for obtaining the dispersion relation of lower hybrid wave, one have to use the kinetic theory. We have present the dependency of laser beam width parameter, beam decentered parameter, Hermite polynomial mode index m, electron-neutral collisional frequency and electron cyclotron frequency on excitation of lower hybrid wave. The electron-neutral collisional frequency and laser beam width parameter causes to decrease the power amplitude of lower hybrid wave whereas the beam decentered parameter, electron cyclotron frequency, Hermite polynomial mode index enhanced the power amplitude of lower hybrid wave. The maximum excitation of electrostatic lower hybrid wave is obtained as the two laser beat wave frequency typical becomes 0.998 times the electron plasma frequency. Thus, one can tune and control the spatial shape of power amplitude profile of electrostatic lower hybrid wave by varying these parameters. One may apply this theory of electrostatic lower hybrid wave excitation in electron heating, laser beam absorption and laser beam high harmonic generation process.

Acknowledgement

The authors would like grateful to Department of Physics and Principal, K. N. Govt. P. G. College, Gyanpur, Bhadohi for providing the research facilities.

References

Batanov, G. M., Petrov, A. Y., Kolik, L. V., Sarksyan, K. A., & Skvortsova, N. N.: Excitation of lower-hybrid wave by beating of two electron-cyclotron waves. Le Journal de Physique IV, 5(C6), C6-97 (1995).

Belafhal, A., and M. Ibnchaikh. "Propagation properties of Hermite-cosh-Gaussian laser beams." Optics Communications 186, no. 4-6: 269-276 (2000).

Bonoli, P. T.: Review of recent experimental and modeling progress in the lower hybrid range of frequencies at ITER relevant parameters. Physics of Plasmas, 21(6) (2014).

Kumar, A., & Tripathi, V. K.: Parametric decay of X-mode radiation into electron Bernstein and lower hybrid waves in a plasma. Physica Scripta, 82(2), 025501 (2010).

Kumar, A.: Anomalous absorption of a lower hybrid wave in a plasma with density fluctuations. Physica Scripta, 90(6), 065601 (2015).

Kuo, S. P. Parametric excitation of lower hybrid waves by electron plasma waves. Physics Letters A, 307(4), 244-248 (2003).

Lee, M. J., Shahmansouri, M., & Jung, Y. D.: Characteristics of lower-hybrid surface waves. Europhysics Letters, 125(6), 65001 (2019).

Liu, C. S., & Tripathi, V. K.: Fast and slow plasma waves excitation by counterpropagating lasers in a hot plasma. Physics of Plasmas, 9(9), 3995-3998 (2002).

Pinsker, R. I.: Introduction to wave heating and current drive in magnetized plasmas. Physics of Plasmas, 8(4), 1219-1228 (2001).

Pinsker, R. I.: Whistlers, helicons, and lower hybrid waves: the physics of radio frequency wave propagation and absorption for current drive via Landau damping. Physics of Plasmas, 22(9) (2015).

Purohit, G., Sharma, P., & Sharma, R. P.: Filamentation of laser beam and suppression of stimulated Raman scattering due to localization of electron plasma wave. Journal of Plasma Physics, 78(1), 55-63 (2012).

Safari, S., Niknam, A. R., Jahangiri, F., Jazi, B.: Terahertz radiation generation through the nonlinear interaction of Hermite and Laguerre Gaussian laser beams with collisional plasma: Field profile optimization, J. Appl. Phys. **123,** 153101 (2018).

Schmidt, A., P. T. Bonoli, O. Meneghini, R. R. Parker, M. Porkolab, S. Shiraiwa, G. Wallace, J. C. Wright, R. W. Harvey, and J. R. Wilson. "Investigation of lower hybrid physics through power modulation experiments on Alcator C-Mod." Physics of Plasmas 18, no. 5 (2011).

Sharma, J., Sharma, S. C., Jain, V. K., & Gahlot, A: Excitation of lower hybrid waves by a gyrating ion beam in a negative ion plasma. Physics of Plasmas, 20(3) (2013).

Shvets, G., & Fisch, N. J.: Parametric excitations of fast plasma waves by counterpropagating laser beams. Physical review letters, 86(15), 3328 (2001).

Tripathi, V. K., Liu, C. S., & Grebogi, C.:Parametric decay of lower hybrid waves in a plasma: Effect of ion nonlinearity. The Physics of Fluids, 22(2), 301-309 (1979).

Tyagi, Y., Tripathi, D., Kumar, A.: Bernstein wave aided laser third harmonic generation in a plasma, Phys. Plasmas **23,** 093115 (2016).

Tyagi, Y., Tripathi, D., Walia, K.: Laser second harmonic generation in a magnetoplasma assisted by an electrostatic wave, Phys. Plasmas **24,** 043104 (2017)

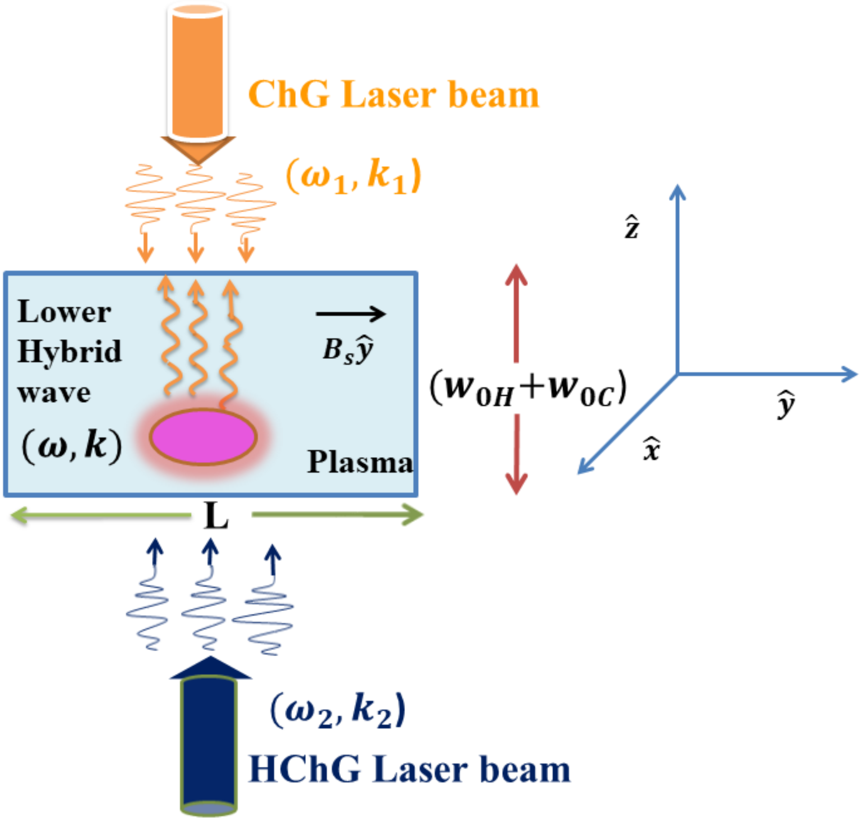

Fig. 1

Fig. 1: Schematic diagram of lower hybrid wave excitation in a collisional plasma

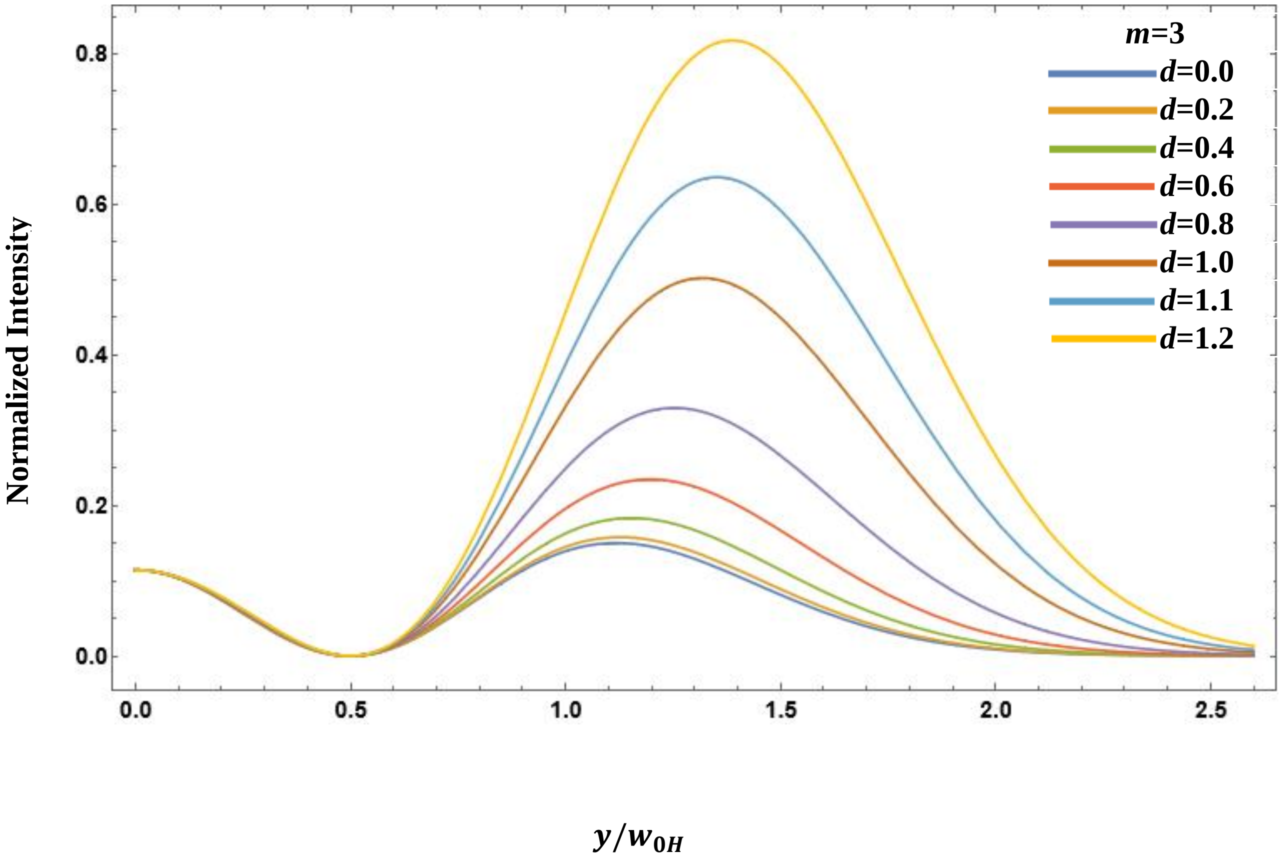

Fig. 2(a)

Fig. 2(a): Variation of normalized intensity of Hermite cosh-Gaussian laser beam with normalized beam transverse propagation distance from y-axis for different values of beam decentred parameter with range $0 \leq d \leq 1.2$ when m=3 and $w_{0H} = 10\mu m$

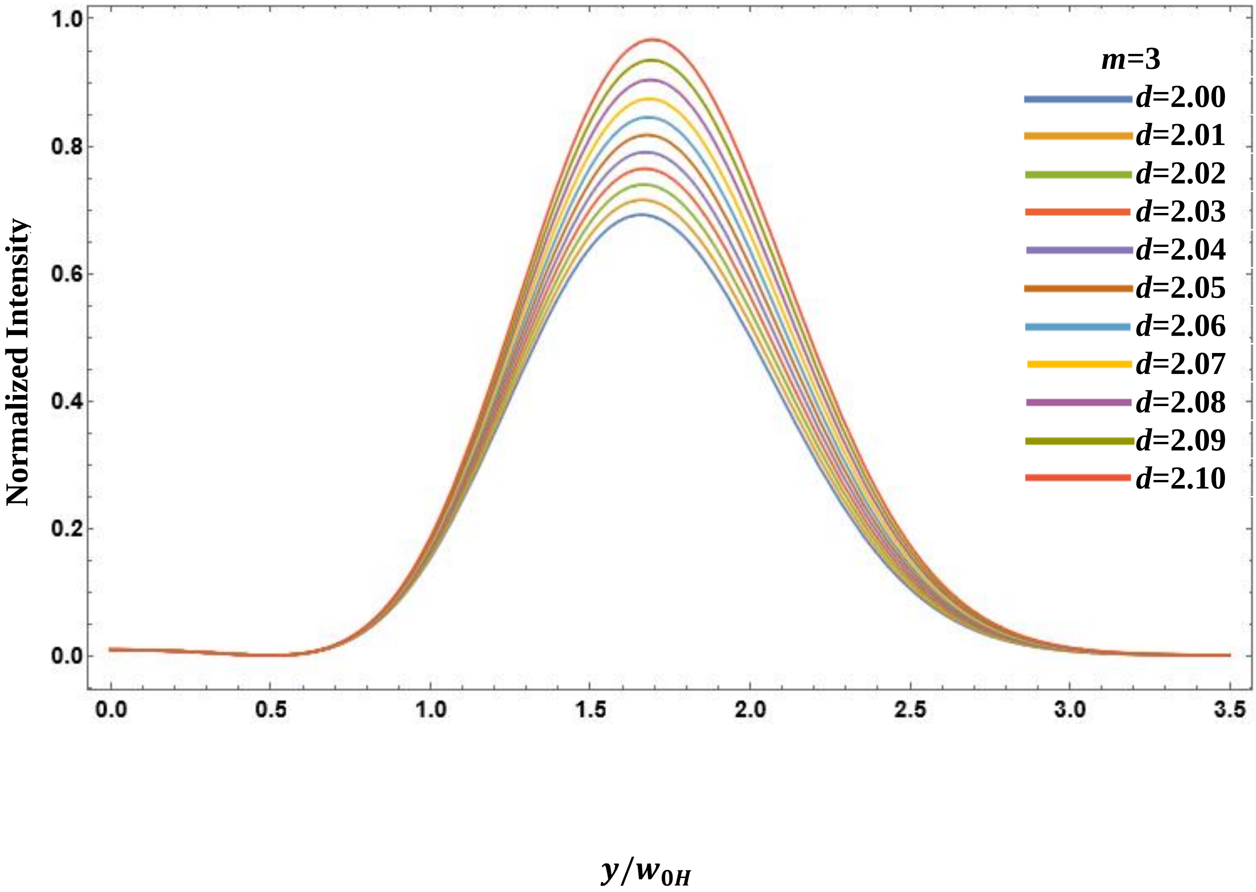

Fig. 2(b)

Fig. 2(b): Variation of normalized intensity of Hermite cosh-Gaussian laser beam with normalized beam transverse propagation distance from y-axis for different values of beam decentred parameter with range $2 \leq d \leq 2.1$ when m=3 and $w_{0H} = 10\mu m$

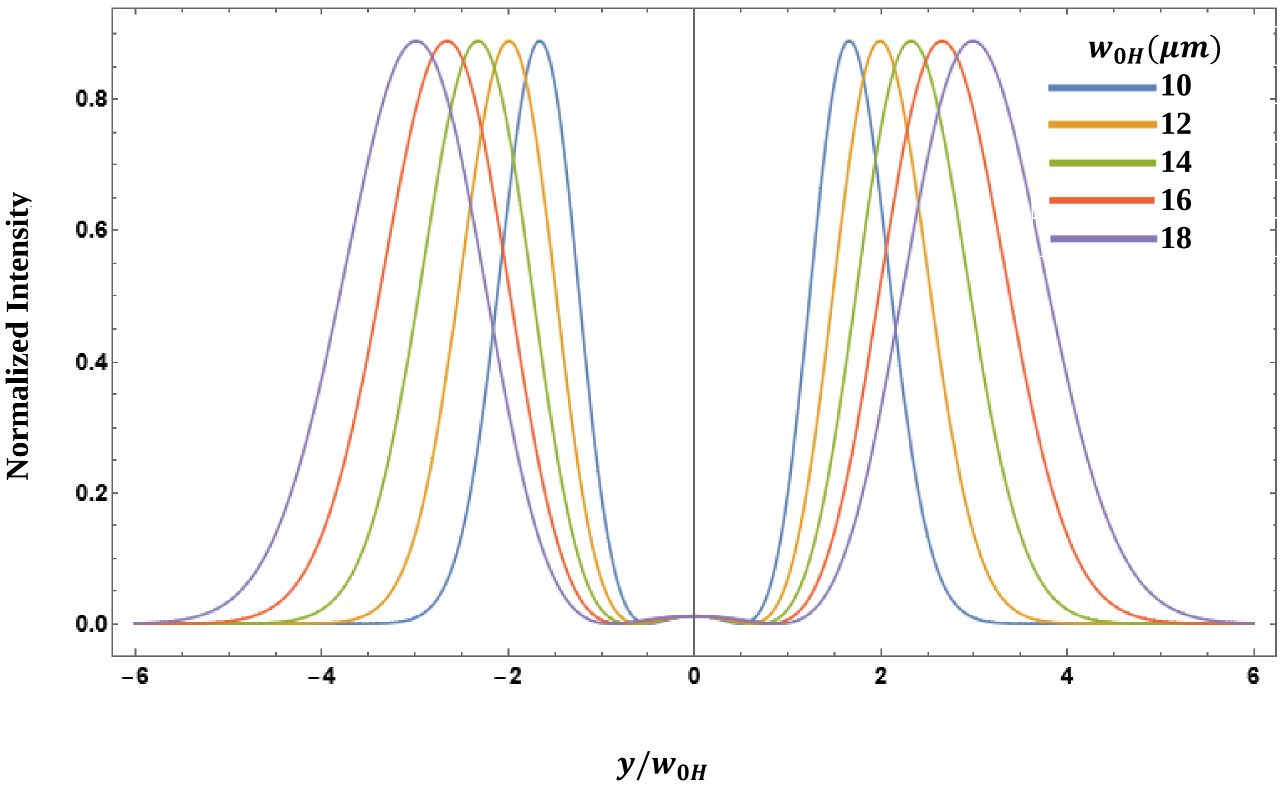

Fig. 3

Fig. 3: Variation of normalized intensity of Hermite cosh-Gaussian laser beam with normalized beam transverse propagation distance from y-axis for different values of laser beam width parameter w_{0H} when m=3 and d=1

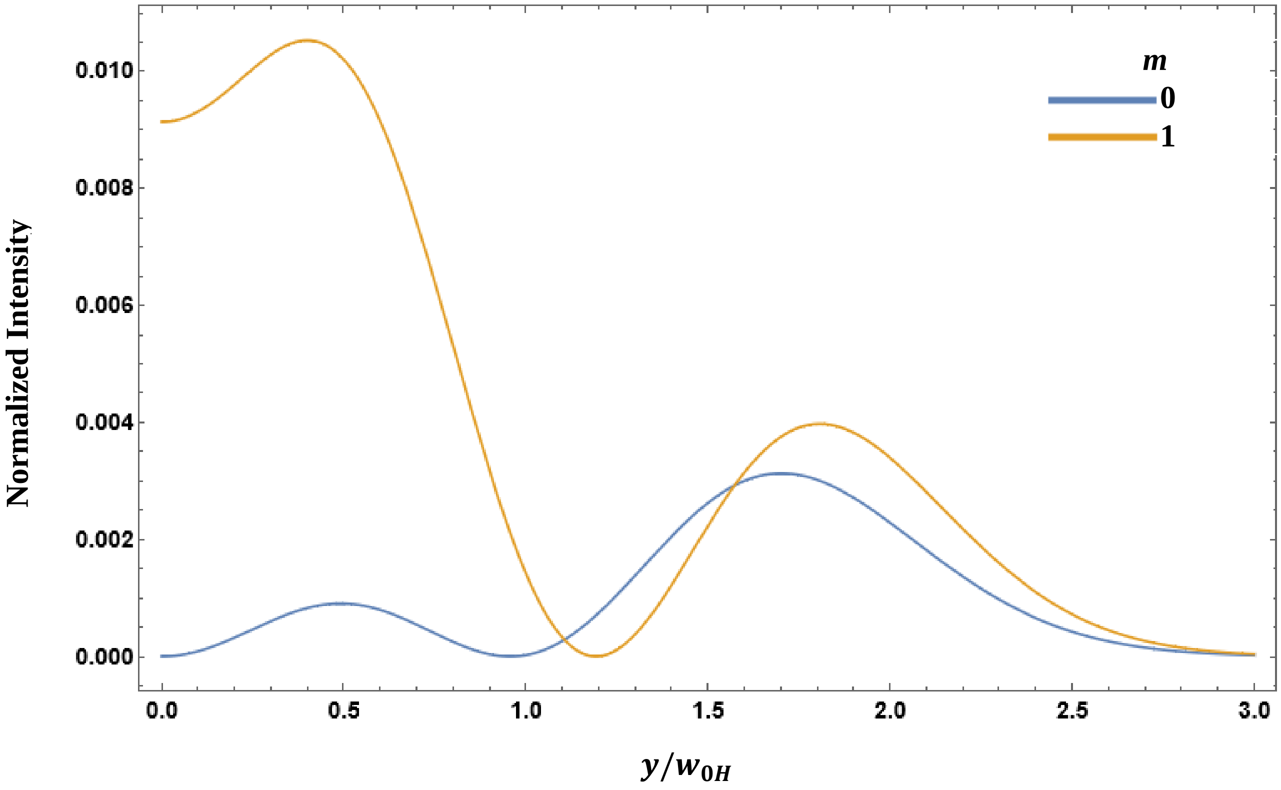

Fig. 4

Fig. 4: Variation of normalized intensity of Hermite cosh-Gaussian laser beam with normalized beam transverse propagation distance from y-axis for different values of Hermite polynomial m when d=1 and $w_{0H} = 10\mu m$