ELECTRON BERNSTEIN WAVE ASSISTED LASER BEAM ABSORPTION IN MAGNETIZED PLASMA

S P MISHRA
Department Of Physics
K. N. Govt. P. G. College, Gyanpur, Bhadohi-221304, India

Abstract

In this paper, we have conducted a theoretical investigation into the absorption of electrostatic electron Bernstein waves facilitated by a Hermite cosh-Gaussian (HChG) laser beam in plasma that is subjected to a static magnetic field. The electron Bernstein wave plays a crucial role in enabling strong nonlinear coupling. The combined influence of the electron Bernstein wave and the HChG laser beam generates both linear and nonlinear current densities. We have developed an analytical framework for the absorption coefficient. When the coupled mode of the electron Bernstein wave-assisted HChG laser beam is in phase with the nonlinear current density, it results in resonant absorption. The graphical representation confirms that the nonlinear absorption coefficient is significantly influenced by the static magnetic field (electron cyclotron frequency), the Hermite polynomial m, the width parameter of the laser beam, the frequency of the laser beam, the beam decentered parameter d, the thermal velocity of electrons, and the parameter b. The absorption process of the laser is greatly enhanced even with a minimal contribution from the electron Bernstein wave. The decentered parameter of the laser beam, associated with the cosine term, is particularly sensitive and plays a vital role in determining the absorption coefficient. This enhanced and tunable absorption process of the electron Bernstein wave-assisted HChG laser may have applications in second and third harmonic generation as well as in plasma electron heating.

Keywords:Electron Bernstein wave, Electron cyclotron, Hermite cosh-Gaussian laser beam, Decentered parameter, Absorption coefficient

1. Introduction

Over the last few decades, interaction of laser beam with plasmas has emerged the engrossing field of research due to its nonlinear phenomenon such as harmonic generation [Tyagi et al 2016; Tyagi et al 2017], parametric instability, anomalous absorption, electron heating, terahertz radiation generation [Safari et al 2018], self-focusing [Patil et al 2013]. The anomalous absorption of electromagnetic as well as electrostatic wave in plasma is interesting due to promising the electron heating, charge particle acceleration and terahertz radiation generation. Plasma deserve as a good candidate for the interacting medium owing to possess the high conducting and high particle (electron and plasma) density. This medium might be supported the electrostatic and electromagnetic wave. A kind of electrostatic wave which has large perpendicular component wave vector as compared with parallel component and special harmonic of electron cyclotron wave is generally known as electron Bernstein wave. This electrostatic wave exists in plasma in the presence of static magnetic field. The assisted electron Bernstein wave (electrostatic wave) with different profile laser beam (electromagnetic wave) provides the enhanced nonlinear phenomenon such as second harmonic generation, third harmonic generation, electron heating and absorption in plasma.These nonlinear phenomena might be enhanced in the presence of magnetic field in plasma [Verma et al 2015; Verma et al 2016; Ghaffari-Oskooei et al 2015]. The field optimization property of different spatial shape laser beam can be used for tuning the absorption process in plasma.

In this present study, we theoreticallyinvestigate the electrostatic wave assistedHChG laser beam absorption in plasma embedded with static magnetic field. This HChG laser beam couples with the pre-existed electrostatic electron Bernstein wave in magnetized plasma at couple wave number $k_1 = k + k_0$ and couple wave frequency $\omega_1 = \omega + \omega_0$. For the nonlinear current density, we have followed the Fluid model. In this present proposed theoretical model, we have formulated the effective absorption coefficient of combined effect of electron Bernstein wave assisted HChG laser beam. In Sec. 2, the nonlinear coupling of HChG laser beam with electrostatic electron Bernstein wave is given.In Sec. 3, The effective absorption coefficient of electron Bernstein wave aided laser beam absorption coefficient is formulated. The graphical results and discussion of this proposed theory is given in Sec. 4.Finally, in Sec. 5, we present the summary and conclusion of this theory.

2. Laser Coupling with Bernstein Wave

Consider the magnetized plasma ($\overrightarrow{B_s} \parallel \hat{z}$)having equilibrium electron density n_0.A Hermite cosh-Gaussian laser beam is propagating along z-direction and polarized along y-direction in plasma embedded with static magnetic field. The general electric field profile of this laser beamin cartesian coordinate system is written as

$$\vec{E}(y,z) = \hat{y} E_0 H_m \left(\frac{\sqrt{2}y}{w_{0H}}\right) \cosh\left(\frac{yd}{w_{0H}}\right)$$
$$\exp\left(-\frac{y^2}{w_{0H}^2}\right) e^{-i(\omega_0 t - k_0 z)}, \qquad (1)$$

whereE_0 is the electric field amplitude of laser beam at its central position (y=0, z=0),w_{0H} is the initial laser beam width, d is the beam decentered parameter, ω_0 and k_0 is the laser frequency and wave number respectively, $H_m$is the Hermite polynomial and m stands for mode index related with Hermite function.As the HChGlaser beam interacts with plasma, the electron associated with plasma is imparted oscillatory velocity. The oscillatory velocity of the electrons in plasma is governed by the following equation

$$\vec{\mathrm{v}}_{\omega_0} = e\vec{E}/m(i\omega_0), \qquad (2)$$

where e is the electronic charge and m is the mass of electron.

Since magnetized plasma holds the electrostatic as well as electromagnetic waves. Electron Bernstein wave is a kind of electrostatic wave that can be excited in plasma with static magnetic field. Therefore, here we can consider that electron Bernstein wave might be pre-existed in plasma.The potential profile of this electrostatic wave is taken as $\phi = \phi_0 e^{-i(\omega t - \boldsymbol{kr})}$.

The electron Bernstein wave frequency is written as

$$\omega = l\omega_c \left(1 + \frac{I_l(b) e^{-b}}{1 + k^2 \mathrm{v}_{th}^2 / 2\omega_p^2}\right), \quad (3)$$

where l is the integer associated with modified Bessel function ($I_l(b)$), ω_c is the electron cyclotron frequency, ω_p is the electron plasma frequency, v_{th} is the electron thermal velocity and parameter$b = k_\perp^2 \mathrm{v}_{th}^2 / 2{\omega_c}^2$.

The perturbation of electron density due to electron Bernstein wavecan beexpressed as

$$n_e = \frac{k^2}{4\pi e} \chi_e \phi, \qquad (4)$$

3. Effective Absorption Coefficient

The time average power dissipation per unit volume of electron Bernstein wave aided HChG laser beam can be expressed as

$$P_{diss} = \frac{1}{8} \frac{n_e^2 \omega_p^2}{\omega_0 n_0^2} \mathrm{Re}\left[\frac{\left(\frac{\omega_1^2 \omega_p^2}{2\sqrt{\pi}|k_\perp|^3 \mathrm{v}_{th}^3} e^{-\omega_1^2 / k_1^2 \mathrm{v}_{th}^2} + i\frac{\omega_p^2}{4\pi\omega_1}\right) \left|E_{\omega_0}\right|^2}{\omega_1 \left\{1 + i\frac{4\pi}{\omega_1}\left(\frac{\omega_1^2 \omega_p^2}{2\sqrt{\pi}|k_\perp|^3 \mathrm{v}_{th}^3} e^{-\omega_1^2 / k_1^2 \mathrm{v}_{th}^2} + i\frac{\omega_p^2}{4\pi\omega_1}\right)\right\}}\right], \qquad (5)$$

The energy flow per unit area per unit time is defined by pointing vector ($P_L = \frac{CE_{\omega 0}^2}{8\pi}$). The power dissipation of electron Bernstein wave aided HChGlaser beam in z-extent can be written as

$$dP_L = -P_{diss} dz. \qquad (6)$$

One can obtain the expression of effective absorption coefficient by using the Eq. (6) as

$$\alpha_i = \frac{\pi}{2cE_0^2}\frac{n_e^2\omega_p^2}{\omega_0 n_0^2}\mathrm{Re}\left[\frac{\left(\frac{\omega_1^2\omega_p^2}{2\sqrt{\pi}|k_\perp|^3\mathrm{v}_{th}^3}e^{-\omega_1^2/k_1^2\mathrm{v}_{th}^2} + i\frac{\omega_p^2}{4\pi\omega_1}\right)|E_{\omega 0}|^2}{\omega_1\left\{1 + i\frac{4\pi}{\omega_1}\left(\frac{\omega_1^2\omega_p^2}{2\sqrt{\pi}|k_\perp|^3\mathrm{v}_{th}^3}e^{-\omega_1^2/k_1^2\mathrm{v}_{th}^2} + i\frac{\omega_p^2}{4\pi\omega_1}\right)\right\}}\right], \tag{7}$$

4. Results and Discussion

In the present theoretical investigation, we have present a theory of electron Bernstein wave assisted Hermite cosh-Gaussian laser beam absorption in magnetized plasma. The schematic diagram of this theory is shown in Fig. 1. The presence of electron Bernstein wave cause to enhance in absorption process of laser beam in magnetized plasma. The coupling of laser beam with electron Bernstein mode is given. Electron Bernstein wave is an electrostatic wave that possess large perpendicular component wave vector and its growth rate lies on the harmonics of electron cyclotron wave.Fig. 2 shows the variation of normalized effective absorption coefficient of electron Bernstein wave assisted Hermite cosh-Gaussian laser beam as a function of normalized laser beam propagation distance from y-axis for different values of mode index associated with Hermite polynomial. As one increase the mode index of Hermite polynomial, the vortex of absorption profile is enhanced. For the mode index m=1, the absorption profile attains single weak peak at normalized propagation distance ($y/w_0 \sim 0.70$). The absorption profile attains two peaks (first appear around origin and second appear around $y/w_0 \sim 1.2$) that are greater amplitude as compared to previous one.Further, if one takes the mode index m=3, the amplitude of absorption profile attains larger values as compared to mode index m=1, 2. At this mode, the intense peak appear at $y/w_0 \sim 0.44$ and $y/w_0 \sim 1.52$ respectively.Therefore, one can conclude that effective absorption coefficient can be increased with increase in Hermite mode index.

The variation of normalized effective absorption coefficient as a function of normalized laser beam propagation distance from y- axis for different values beam decentered parameter is shown in Fig. 3. The laser beam decentered parameter is also known as waist width parameter and is associated with hyperbolic cosine term.For the Hermite mode index m=2, one can see that the absorption coefficient is enhanced with increase in laser beam decentered parameter. As one can see that the amplitude of absorption profile attains lower (at both peak) for beam decentered parameter d=0. It is interesting to notice that with increase in beam decentered parameter the absorption amplitude attains higher peak at second lobe as compared to first peak. The first peak remains unchanged with the variation of laser beam decentered parameter. The increase in beam decentered parameter cause to well focusing of laser beam with the plasma. The nonlinearity is increased with increase in beam decentered parameter. This enhanced nonlinearity leads to increase in nonlinear current density and cause to enhance in absorption process of laser beam. In this way, one can say that the required absorption coefficient can be achieved with the variation in beam decentered parameter associated with cosh term.

In Fig. 4, we have plotted the variation of normalized effective absorption coefficient as a function of normalized laser beam propagation distance from y- axis for different values of laser beam width. It is observed that with increase in laser beam width there is an increase in envelop of peak profile. The wider envelop of peak profile cause to less absorption as compared with steeper and intense peak. The lower value of beam width leads to generation of higher intensity and thus cause to imparting maximum energy to plasma for coupling the large amplitude electron Bernstein wave with it. This leads to generate the nonlinearity and cause to intense absorption as one takes the lower beam width of laser beam.

5. Summary and Conclusions

Aided of electron Bernstein wave with HChG laser beam gives rise to greatly enhance absorption coefficient in plasma as compared with only laser beam. The absorption coefficient is also affected due to the presence of static magnetic field. Field optimization property of HChG laser beam promises the required nonlinear coupling and thus results the absorption coefficient. The parameter associated with electrostatic electron Bernstein wave such as electron thermal velocity, parameter b and electron Bernstein wave frequency and HChG laser beam such as beam frequency, beam decentered parameter associated with cosine term d, Hermite polynomial m and laser beam width are affects the absorption phenomena. The graphical profile depicts that electron Bernstein wave assists the strong nonlinear coupling and promises the enhance laser absorption. The HChG laser beam decentered parameter and beam width can be used for required absorption coefficient.

Acknowledgement

The author would like thankful Department of physics and Principal, K. N. Govt. P. G. College, Gyanpur-Bhadohi for providing the research facilities.

References

Ahmad A., and Tripathi V. K. Nonlinear absorption of femtosecond laser on a metal surface embedded by metallic nanoparticles, Appl. Phys. Lett. **89** 153112 (2006)

Bendib A. Nonlinear collisional absorption and induced anisotropy in plasmas heated by an intense laser field, Physics of Plasmas **24** 070702 (2017)

Deepika, Chauhan P., Varshney A., Singh D. B. and Sajal V. Enhanced absorption of surface plasma wave by metal nano-particles in the presence of external magnetic field, J. Phys. D: Appl. Phys. **48** 345103 (2015)

Ghaffari-Oskooei S. S., Aghamir M. “Scattering of electromagnetic waves from a magnetized plasma column at oblique incidence,” Phys. Plasmas **118** 023304 (2015)

Kumar A. and Tripathi V. K., “Electron Bernstein wave excitation by counterpropagating electromagnetic waves in a plasma,” Phys. Plasmas 12 102308 (2005a)

Kumar A. and Tripathi V. K. Bernstein mode aided anomalous absorption of laser in a plasma, Physics of Plasmas **12** 012313 (2005 b)

Kumar G. and Tripathi V. K. Anomalous absorption of surface plasma wave by particles adsorbed on metal surface, Appl. Phys. Lett. **91** 161503 (2007)

Kumar A. Anomalous absorption of a lower hybrid wave in a plasma with density fluctuations, Phys. Scr. **90** 065601 (2015)

Patil S. D., Takale M. V., Fulari V. J., Gupta D. N., and Suk H. Combined effect of ponderomotive and relativistic self-focusing on laser beam propagation in a plasma, Appl. Phys. B **111** 1–6 (2013)

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

Sharifian M., Ghoveisi F., Farrashbandi N. F. Inverse Bremsstrahlung absorption in under-dense plasma with Kappa distributed electrons, AIP Advances **7** 055107 (2017)

Sharma S. and Vijay A. Nonlinear laser absorption over a dielectric embedded with nanorods, Laser and Particle Beams, 1–5 (2019)

Sid A., Nonlinear inverse bremsstrahlung absorption in laser-fusion plasma corona Phys. Plasmas **1** 1523395 (2003)

Singh R. and Sharma A. K. Anomalous absorption of a whistler in rippled density plasma, Phys. Scr. **82** 015503 (2010)

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

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

Verma K., Sajal V., Baliyan S., Kumar R. and Sharma N. K. “Stimulated Brillouin side-scattering of the beat wave excited by two counterpropagating X-mode lasers in magnetized plasma,” Phys. Plasmas **22** 062106 (2015)

Verma K., Sajal V., Kumar R. and Sharma N. K. “Suppression of decay instability of the nonresonant beat wave excited by two counterpropagating x-mode lasers in magnetized plasma,” Phys. Plasmas **23** 012109 (2016)

Yadav M., Mandal S., and Kumar A., Nonlinear absorption and harmonic generation of laser in an assembly of CNT's. *Phys. Plasmas***26** 073110 (2019)

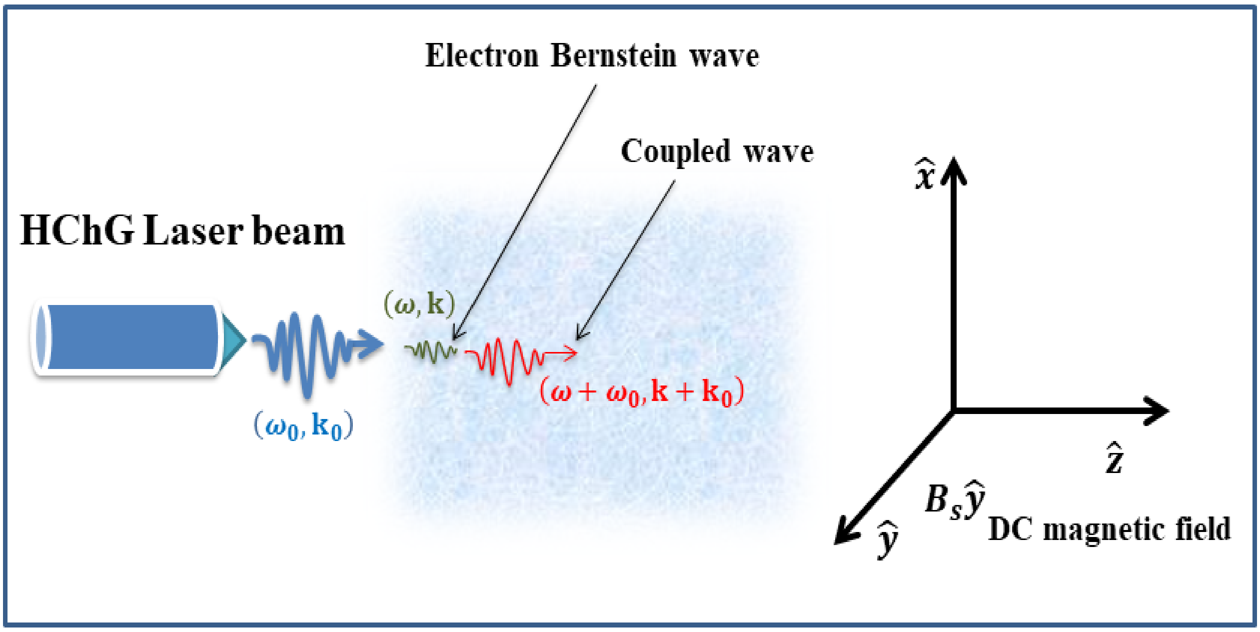

Fig. 1

Fig. 1: Schematic diagram of electron Bernstein wave assisted HChG laser beam absorption in plasma embedded with static magnetic field.

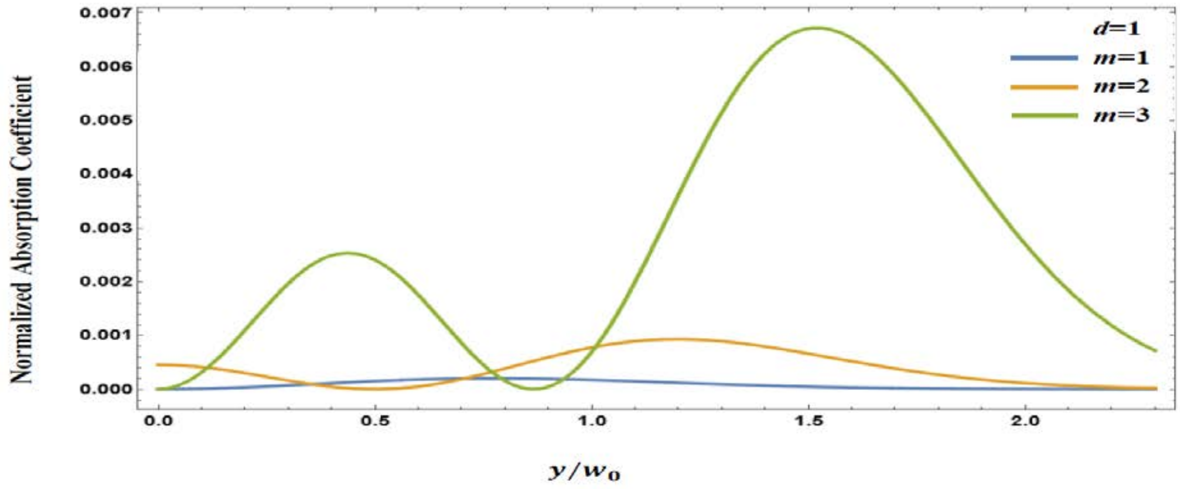

Fig. 2

Fig. 2: Variation of normalized absorption coefficient with normalized laser beam propagation distance from y-axis for different values of Hermite mode index m, when d=1, b=1.8, $\omega_1/\omega_p = 0.5$, $\omega_c/\omega_p = 0.2$, $\omega/\omega_p = 0.02$, $\mathrm{v_{th}}/c = 0.2$

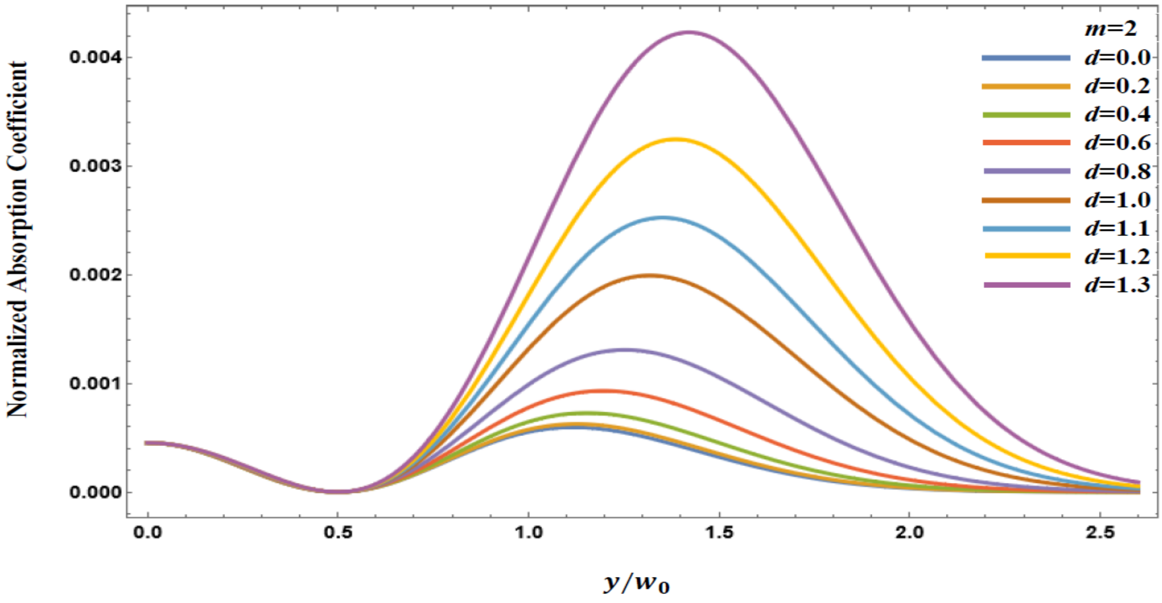

Fig. 3

Fig. 3: Variation of normalized absorption coefficient with normalized laser beam propagation distance from y-axis for different values of laser beam decentered parameter d, when m=2, b=1.8, $\omega_1/\omega_p = 0.5$, $\omega_c/\omega_p = 0.2$, $\omega/\omega_p = 0.02$, $\mathrm{v_{th}}/c = 0.2$

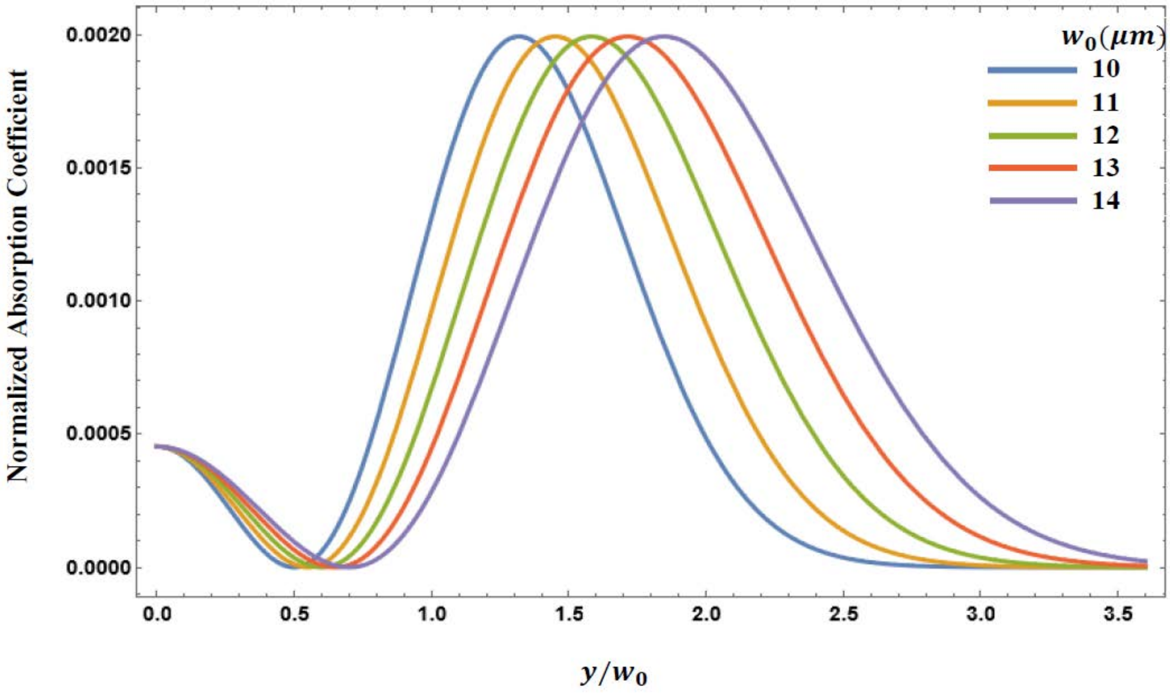

Fig. 4

Fig. 4: Variation of normalized absorption coefficient with normalized laser beam propagation distance from y-axis for different values of laser beam width w_0 when m=2, b=1.8, $\omega_c/\omega_p = 0.2$, $\omega/\omega_p = 0.02$, $\mathrm{v_{th}}/c = 0.2$