Effects of electron temperature on dielectric function and localization of laser beams in underdense collisional plasma*

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Effects of electron temperature on dielectric function and localization of laser beams in underdense collisional plasmas are investigated. Simulation results show that the electron temperature has a strong effect on the dielectric constant and the laser beam localization. It is observed that due to the influence of the electron temperature, the dielectric function presents some interesting and complicated nonlinear variations, and gives rise to the laser beam localization. Moreover, the amplitudes of the beam width and the beam intensity are subjected to continuously oscillatory variation in the region of localization. In addition, the effects of several parameters on the dielectric function and the beam localization are discussed.

Keywords: underdense collisional plasmas, electron temperature, dielectric function, laser beam localization

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1. Introduction

The nonlinear interaction of lasers with plasma has been a subject of active research for decades due to its relevance to laser driven fusion.[1,2] The increasing use of high power laser beams in various applications has attracted worldwide interest in laser–plasma interaction.[3] Many laser–matter interaction applications, such as in laser plasma accelerators[4] and laser fusion,[5] depend critically on the transmitted laser energy through the plasma. The nonlinear interactions of the high power laser beam with the plasma are considered in various situations, particularly, in the stimulated Raman scattering (SRS) process and in the electron plasma wave (EPW). In SRS, the incident laser beam decays into a scattered wave and an electron plasma wave. The EPW produces superthermal electrons that penetrate and preheat the target core. The scattered wave represents a substantial amount of wasted energy, i.e., energy that would otherwise couple to the target. SRS can even produce energetic electrons that can preheat the fusion fuel and change the compression ratio.[5] So understanding the interaction of a laser with plasma is crucial for the design of the target in laser driven fusion.

If the wave frequency of interest ω is smaller than the electron collision frequency ν, the plasma can be said to be collisionless. In collisionless plasma, nonlinearity arises through the ponderomotive force-induced redistribution of the plasma. It is well known that various laser–plasma parameter instabilities, such as beam self-focusing and filamentation,[6] harmonic generation[7] and SRS,[8] might be generated from the interaction of lasers with plasma. These instabilities affect the laser–plasma coupling efficiency and eventually affect the efficiencies of the absorbtion and the transformation of the laser energy in the laser driven fusion.

For collisional plasma, many researchers have carried out many investigations. Collisional plasma mainly includes intense collisional plasma and underdense collisional plasma. For intense collisional plasma, the laser–plasma interaction, fast-electron generation, transport in the fast ignition,[9] nonlinear collisional absorption of the laser light[10] and superthermal electrons generated by the relativistic laser pulses[11] have been investigated theoretically. In ex-

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perimental studies, the dynamics of a dense laboratory plasma jet[12] and the stimulated Brillouin and Raman scattering from a randomized laser beam[13] have been reported. For underdense collisional plasma, a simulation study of fast ignition with ultrahigh intensity lasers,[14] a numerical investigation of the non-local electron transport in laser-produced plasma[15] and research on the scattering of light waves by the electron electrostatic waves in the laser-produced plasma[16] have been carried out. In particular, due to the wide application prospect, lots of research has focused on the beam self-focusing of the plasma. A review of the transient self-focusing of the laser pulses (i.e., laser beam localization) in the ionizing gases and plasma was made by Esarey *et al.*[17] Existing results on the relativistic self-focusing of the short laser pulses in the plasma were interpreted[18] by using the particle code WAKE. Bharuthram *et al.*[19] considered the transient and the time periodic self-focusing of a laser beam in plasma. Recently, Sharma P and Sharma R P[20] reported the laser beam localization and found that the laser beams were highly located in the two-dimensional spatial coordinate. Sodha *et al.*[21] studied the effect of self-focusing on the third harmonic generation by using a Gaussian beam in the one-dimensional spatial coordinate. In general, a lot of work on the interaction of lasers with plasma mainly focuses on the dependence of the spatial coordinate.

In spite of the great achievement in the collisional nonlinearity and in the beam localization, so far we have not formed an impressed analysis of the effects of the electron temperature on the dielectric function and the laser beam localization. Especially, for the interaction of lasers with plasma, the dependence of the electron temperature on the spatial–temporal coordinate has received less attention. In the present work, we modify the simple analytical model that describes the evolution of the nonlinear interaction of lasers with underdense collisional plasma and the dependence of the electron temperature on the spatial–temporal coordinate parameter. We will show that the electron temperature strongly affects the dielectric function and the laser beam localization, the dielectric function presents complicated nonlinear variations and the laser beams become highly localized due to the influence of the electron temperature.

2. Electron temperature and dielectric function in underdense collisional plasma

The drift velocity $\boldsymbol{V}_{\rm e}$ of the electrons in underdense collisional plasma is governed by

$$m\frac{{\rm d}\boldsymbol{V}_{\rm e}}{{\rm d}t} = -e\boldsymbol{E} - m\nu_{\rm e}\boldsymbol{V}_{\rm e}, \tag{1}$$

where m is the electronic mass, e is the charge of one electron and $\nu_{\rm e}$ is the effective frequency of the electron collision. In an uniform alternating electric field of frequency ω ($\boldsymbol{E} = \boldsymbol{E}_0\exp({\rm i}\omega t)$) switched on at $t = 0$, from the above equation, we obtain

$$\boldsymbol{V}_{\rm e} = \frac{-e\boldsymbol{E}_0}{m(\nu + {\rm i}\omega)}({\rm e}^{{\rm i}\omega t} - {\rm e}^{-\nu_{\rm e}t}). \tag{2}$$

For the time period and $t \gg 1/\nu_{\rm e}$, Eq. (2) becomes

$$\boldsymbol{V}_{\rm e} = \frac{-e\boldsymbol{E}_0\,{\rm e}^{{\rm i}\omega t}}{m(\nu_{\rm e} + {\rm i}\omega)}. \tag{3}$$

The energy balance of the electrons in the plasma can be expressed as

$$\frac{\rm d}{{\rm d}t}\left(\frac{3}{2}k_BT_{\rm e}\right) = -e\,{\rm Re}(\boldsymbol{E}\cdot\boldsymbol{V}_{\rm e}) - \frac{3}{2}k_{\rm B}\delta\nu_{\rm e}(T_{\rm e} - T_0), \tag{4}$$

where the first term on the right-hand side represents the rate of ohmic heating per electron, the second term represents the rate of energy loss of an electron due to the collisions with the heavy particles, $T_{\rm e}$ denotes the electron temperature in the presence of the field, k_B is the Boltzmann's constant, T_0 is the temperature of the plasma (electrons and ions) in the absence of the pulse, δ is the fraction of the excess energy lost in an electron collision with heavy particles ($\sim 2m/M$) and M is the effective mass of the scattering (ion or neutral particle). Substituting Eq. (3) into Eq. (4), we obtain

$$\frac{{\rm d}T_{\rm e}}{{\rm d}t} + \delta\nu_{\rm e}(T_{\rm e} - T_0) = \frac{e^2\nu_{\rm e}\boldsymbol{E}\cdot\boldsymbol{E}^*}{3m\omega^2k_{\rm B}}. \tag{5}$$

When the electron collision frequency is much smaller than the wave frequency ω, we assume the Gaussian laser beam to be in the form of $\boldsymbol{E}\cdot\boldsymbol{E}^* = E_0'^2\exp(-r^2/r_0^2)F(t'/\tau)$, where E_0' is the initial electric field, r_0 is the initial beam width and $F(t'/\tau)$ is the temporal function. Let the electron temperature be expressed as $T_{\rm e} = T_0 + T_{\rm s}$, where $T_{\rm s}$ is the change of the electron temperature, the constant mean free path of the electron collision will be

$$\nu_{\rm e} = \nu_0(T_{\rm e}/T_0)^{1/2} = \nu_0\left(1 + \frac{T_{\rm s}}{T_0}\right)^{1/2}. \tag{6}$$

Substituting $T_{\rm e}$, $V_{\rm e}$, and $\boldsymbol{E}\cdot\boldsymbol{E}^*$ into Eq. (5), we obtain the energy balance equation in the form of

$$\frac{{\rm d}T_{\rm s}}{{\rm d}t'}+\delta\nu_0\left(1+\frac{T_{\rm s}}{T_0}\right)^{1/2}T_{\rm s} = \frac{e^2\nu_0}{3m\omega^2k_{\rm B}}\left(1+\frac{T_{\rm s}}{T_0}\right)^{1/2}\frac{A_{00}^2}{f^2}e^{-r^2/r_0^2f^2}F(t'/\tau), \quad (7)$$

where A_{00} is the initial laser beam intensity and f is the parameter of the beam width. Introducing the dimensionless variables $t'/\tau=\tau'$ and $T_{\rm s}/T_0=T_{\rm p}$, the above equation can be rewritten as

$$\frac{{\rm d}T_{\rm p}}{{\rm d}\tau'}+\delta\nu_0\tau(1+T_{\rm p})^{1/2}T_{\rm p} = \frac{\tau\nu_0}{T_0}\frac{e^2}{3m\omega^2k_{\rm B}}(1+T_{\rm p})^{1/2}\frac{A_{00}^2}{f^2}\,{\rm e}^{-r^2/r_0^2f^2}F(t'/\tau). \quad (8)$$

In the paraxial approximation, the electron temperature can be expressed in the following form,

$$T_{\rm p}\approx T_{\rm p0}-\frac{r^2}{r_0^2}T_{\rm p2}, \quad (9)$$

where $T_{\rm p0}$ and $T_{\rm p2}$ are components of the electric temperature. Substituting $T_{\rm p}$ into Eq. (8) and equating the coefficients of r^0 and r^2 on both sides of the resulting equation, we obtain

$$\frac{{\rm d}T_{\rm p0}}{{\rm d}\tau'}+\delta\nu_0\tau\left(T_{\rm p0}+\frac{1}{2}T_{\rm p0}^2\right) = \frac{\tau\nu_0}{T_0}\frac{e^2}{3m\omega^2k_{\rm B}}\frac{A_{00}^2}{f^2}\left(1+\frac{T_{\rm p0}}{2}\right)F(t'/\tau), \quad (10)$$

$$\frac{{\rm d}T_{\rm p2}}{{\rm d}\tau'}+\delta\nu_0\tau(T_{\rm p0}T_{\rm p2}+T_{\rm p2}) = \frac{\alpha A_{00}^2}{f^2}\left[\frac{T_{\rm p0}}{2}+\frac{1}{f^2}\left(\frac{T_{\rm p0}}{2}+1\right)\right]F(t'/\tau), \quad (11)$$

where

$$\alpha=e^2\tau\nu_0/(3m\omega^2k_{\rm B}T_0),$$

and

$$\alpha A_{00}^2=\omega_{\rm p0}^2\tau\nu_0A_{00}^2/(12\omega^2\pi k_{\rm B}T_0N_{\rm e0})$$

are the dimensionless incident laser intensities, which depend on the initial conditions and the parameters of the laser beam. $\omega_{\rm p0}$ and $N_{\rm e0}$ are the initial electron plasma frequency and the electron density, respectively. Assuming that the redistribution of the electrons due to the change of the radial distribution of the electron temperature is fast, we may use the steady state equation

$$n_{\rm e} = n_0\frac{2T_0}{T_2+T_0} = n_0\frac{2T_0}{T_{e0}+T_0}\left(1+\frac{T_{e2}}{T_{e0}+T_0}\frac{r^2}{r_0^2}\right), \quad (12)$$

where $n_{\rm e}$ and n_0 are the electron densities in the presence and in the absence of the pulse, respectively, T_0 is the initial electron temperature, and T_{e0} and T_{e2} are components of the axial electron temperature. The nonlinear dielectric function is a crucial physical parameter in the collisional plasma and affects the laser beam propagation in the plasma. Using the above equation, it may be expressed in the paraxial approximation as

$$\varepsilon=1-\frac{4\pi n_{\rm e}e^2}{m\omega^2}=\varepsilon_0-\frac{r^2}{r_0^2}\varepsilon_2, \quad (13)$$

where the first term on the right-hand side is the linear part ε_0 and the second term is the nolinear part ε_2. We have

$$\varepsilon_0=1-\frac{\omega_{\rm p0}^2}{\omega^2}\frac{2}{2+T_{\rm p0}},\quad \varepsilon_2=\frac{\omega_{\rm p0}^2}{\omega^2}\frac{2T_{\rm p2}}{(2+T_{\rm p0})^2}, \quad (14)$$

where $\omega_{\rm p0}$ is the electron plasma frequency, ω is the wave frequency. Substituting ε_0 and ε_2 into Eq. (13) yields the equation of the dielectric function as

$$\varepsilon=1-\frac{\omega_{\rm p0}^2}{\omega^2}\frac{2}{2+T_{\rm p0}}-\frac{r^2}{r_0^2}\frac{\omega_{\rm p0}^2}{\omega^2}\frac{2T_{\rm p2}}{(2+T_{\rm p0})^2}. \quad (15)$$

Through such a change, the nonlinear dielectric function is obtained and the function explains the electron temperature dependence. Equations (10), (11), and (15) express the electron temperature and the dielectric constant in underdense collisional plasma. Obviously, the electron temprature is a function of time and the dielectric constant is related to the electron temperature and the time.

3. Laser beam propagation in underdense collisional plasma

Let us consider the propagation of a Gaussian laser beam of frequency ω along the z direction. The initial radial irradiance intensity distribution of the beam is given by

$$\boldsymbol{E}\cdot\boldsymbol{E}^*=E_0^{'2}\exp(-r^2/r_0^2)F(t'/\tau), \quad (16)$$

where r is the radial coordinate of the cylindrical coordinate system and r_0 is the initial beam width. The equation governing the electric field of the incident laser beam in the underdense collisional plasma can be written as

$$\boldsymbol{\nabla}^2\boldsymbol{E}-\boldsymbol{\nabla}(\boldsymbol{\nabla}\cdot\boldsymbol{E})=\frac{\varepsilon}{c^2}\frac{\partial^2\boldsymbol{E}}{\partial t'^2}. \quad (17)$$

For transverse field $\boldsymbol{E}$ (i.e., linearly polarized), $\boldsymbol{\nabla}(\boldsymbol{\nabla}\cdot\boldsymbol{E})$ can be neglected in Eq. (17) as long as $(\omega_{\rm p}^2/\omega_0^2)\times(1/\varepsilon)\ln\varepsilon \ll 1$. Assuming the variation of the electric field to be

$$\boldsymbol{E} = \boldsymbol{A}_0(r,z,t')\exp[{\rm i}(\omega t' - k_0 z)], \tag{18}$$

Where $\boldsymbol{A}_0$ is the amplitude of electric field and k_0 is the number of beam. we obtain the following equation

$$-k_0^2 A_0 - 2{\rm i}k_0\frac{\partial A_0}{\partial z} + \boldsymbol{\nabla}^2 A_0 + \frac{1}{V_{\rm g}}\cdot\frac{\partial A_0}{\partial t'} = -\frac{\omega^2}{c^2}\varepsilon A_0, \tag{19}$$

where A_0 is a complex function of the space, $k_0 = \omega\varepsilon_0^{1/2}/c$ is the wave number of the laser beam in the plasma, $V_{\rm g} = kc^2/\omega\varepsilon$ is the group velocity and the intensity-dependent dielectric constant is given by $\varepsilon = \varepsilon_0 - (r^2/r_0^2)\varepsilon_2$. We further assume the variation of A_0 to be

$$A_0 = A_0'(r,z,t')\exp[-{\rm i}k_0 S_0(r,z,t')], \tag{20}$$

where S_0 is a real function of the space. Substituting Eq. (20) into Eq. (19) and separating the real and the imaginary parts in the resulting equation, we obtain the real part as

$$2\frac{\partial S_0}{\partial z} + \left(\frac{\partial S_0}{\partial r}\right)^2 = \frac{\omega^2}{k_0^2 c^2}\varepsilon + \frac{1}{k_0^2 A_{00}}\left(\frac{1}{r}\frac{\partial A_{00}}{\partial r} + \frac{\partial^2 A_{00}}{\partial r^2}\right), \tag{21}$$

and the imaginary part as

$$\frac{\partial^2 A_0'}{\partial z} + A_0'^2\left(\frac{\partial S_0}{\partial r} + \frac{\partial^2 S_0}{\partial r^2}\right) + \frac{\partial A_0'^2}{\partial r}\frac{\partial S_0}{\partial r} = 0. \tag{22}$$

To solve the coupled Eqs. (21) and (22), we assume the modified $A_0'^2$ in the paraxial region to be

$$A_0'^2 = \frac{A_{00}^2}{f^2}\exp\left(-\frac{r^2}{r_0^2 f^2}\right)F(t'/\tau), \tag{23}$$

where f is the dimensionless beam width in the paraxial region and

$$S_0 = S_{00}(z,t) + \frac{r^2}{r_0^2}S_{02}(z,t), \quad S_{02} = \frac{r_0^2}{2f}\frac{{\rm d}f}{{\rm d}z}. \tag{24}$$

Substituting Eqs. (13), (23) and (24) into Eq. (21), and equating the coefficients of r^2 on both sides of the resulting equation, we obtain the equation governing the beam width f in the paraxial region as

$$\frac{{\rm d}^2 f}{{\rm d}z^2} = \frac{1}{k_0^2}\left(\frac{1}{r_0^4 f^3} - \frac{\omega^2}{c^2}\frac{f}{r_0^2}\varepsilon_2\right). \tag{25}$$

Let $\xi = zc/(\omega r_0^2)$ and $\beta = r_0\omega/c$, of which $\beta = r_0\omega/c$ are the dimensionless distance of the propagation and the dimensionless initial beam width, respectively. Substituting Eqs. (13) and (14) into Eq. (25), we can obtain the modified Eq. (26) of the beam width in the paraxial region as

$$\frac{{\rm d}^2 f}{{\rm d}\xi^2} = \frac{2+T_{\rm p0}}{2+T_{\rm p0}-2\omega_{\rm p0}^2/\omega^2}\frac{1}{f^3} - \frac{2T_{\rm p2}\omega_{\rm p0}^2/\omega^2}{(2+T_{\rm p0})(2+T_{\rm p0}-2\omega_{\rm p0}^2/\omega^2)}\beta^2 f. \tag{26}$$

The first term on the right-hand side of Eq. (26) represents the diffraction of the beam, the second term corresponds to the nonlinear part. The beam width equation depends on the electron temperature and the spatiotemporal coordinate parameters.

4. Numerical results and analyses

In this work, coupled Eqs. (10), (11), (14), (23) and (26) are solved numerically. The dependence of the beam on the electron temperature and the spatial–temporal coordinate is also investigated. Numerical computations have been performed to obtain the appreciable results of the variations of the electron temperature ($T_{\rm p0}$, $T_{\rm p2}$), the dielectric function (ε_0, ε_2), the laser beam width f and the laser beam intensity $A_0'^2$. Corresponding specific parameters are illustrated in figures.

4.1. Variation of electron temperature

Figure 1 displays the variation of the electron temperature with time τ'. For the initial condition $T_{\rm p0} = T_{\rm p2} = 0$ at $\tau' = -4$, it is noted that the electron temperature presents the quasi-periodic variation with $\delta\nu_0\tau'$. Moreover, $T_{\rm p0}$ and $T_{\rm p2}$ first increase and then decrease with the increase of time τ', i.e., take on an oscillatory variation. The above nonlinear variations of $T_{\rm p0}$ and $T_{\rm p2}$ are due to the nonuniform radial distribution (ponderomotive force) of the laser beam, which has a corresponding redistribution of electron temperature leading to the quasi-periodic variation in the value of $\delta\nu_0$. However, they may be caused by the following process. The energetic electrons produced first absorb continuous laser energy during the stimulated Raman scattering, thereby leading to the continuous rise of electron temperature; then the hot electrons preheat other plasma and matters (such as the fusion fuel), and the electron temperature decreases. The

parameter αA_{00}^2 obviously affects the electron temperature. The maxima of $T_{\rm p0}$ and $T_{\rm p2}$ increase obviously with the increase of αA_{00}^2.

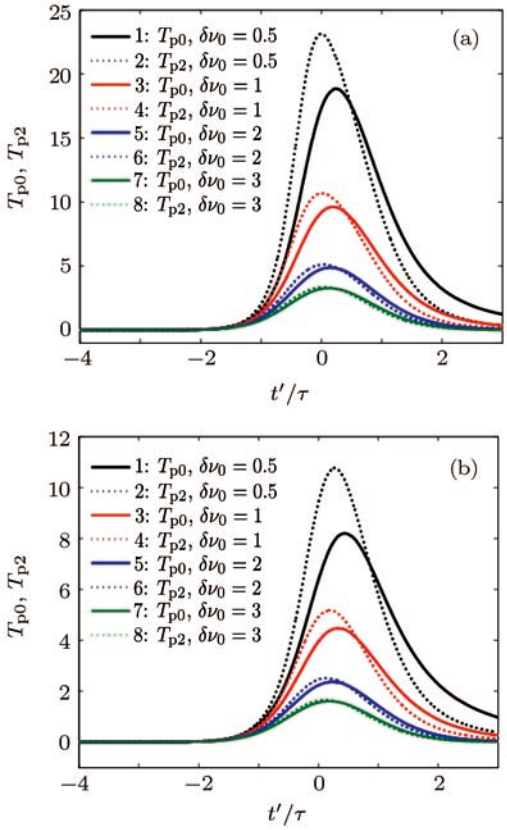


Fig. 1. (colour online) Variations of axial electron temperature ($T_{\rm p0}$ and $T_{\rm p2}$) with dimensionless retarded time $\tau'(= t'/\tau)$ at $z = 0$ for different parameters $\delta\nu_0$ and αA_{00}^2 in the Gaussian pulse. (a) $\alpha A_{00}^2 = 10$, (b) $\alpha A_{00}^2 = 5$.

4.2. Variation of dielectric function with electron temperature

Figure 2 shows the variations of dielectric function (ε_0, ε_2) at $\xi = 0$ for different pulse widths. One can clearly see that due to the influence of the electron temperature, ε_0 and ε_2 also nearly display an oscillatory quasi-periodic variation with $\delta\nu_0\tau'$. Furthermore, the dielectric function presents some valuable information. The ε_0 shows one maximum and ε_2 shows two maxima within the interval of $[-4, 3]$ for τ', with the first maximum larger than the second one. Furthermore, the linear part ε_0 is always larger than the nonlinear part ε_2. The numerical calculation results are in accordance with the facts. Our results show that the electron temperature strongly affects the dielectric function and leads to the interesting and complicated nonlinear variation. The parameters $\delta\nu_0$ and $\omega_{\rm p0}^2/\omega^2$ obviously affect the dielectric constant. The maxima of ε_0 and ε_2 decrease steadily with the increase of $\delta\nu_0$. As shown in Fig. 2, with the increase of $\omega_{\rm p0}^2/\omega^2$, the maximum of ε_0 decreases slightly and the initial value of ε_0 decreases obviously, while the maximum of ε_2 increases.

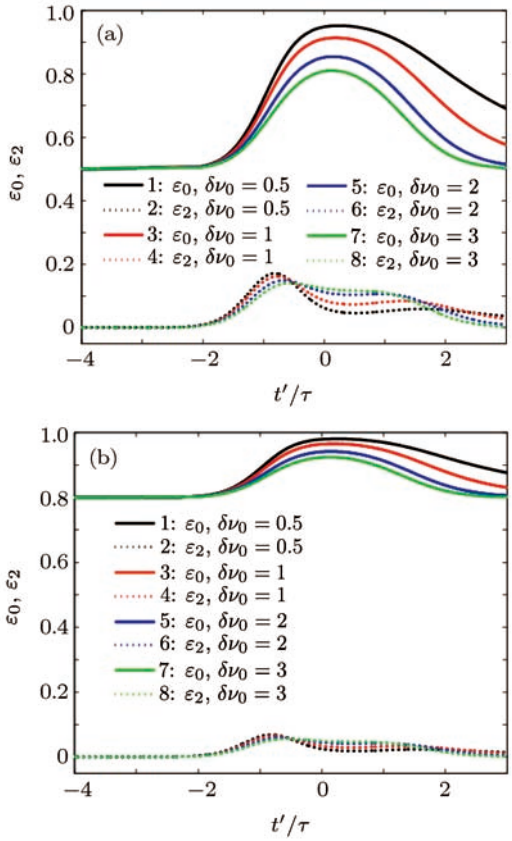


Fig. 2. (colour online) Variations of axial dielectric function (ε_0 and ε_2) with dimensionless retarded time t'/τ at $z = 0$ for different parameters $\delta\nu_0$, $\alpha A_{00}^2$and $\omega_{\rm p0}^2/\omega^2$ in the Gaussian pulse. (a) $\alpha A_{00}^2 = 10$, $\omega_{\rm p0}^2/\omega^2 = 0.5$, (b) $\alpha A_{00}^2 = 10$, $\omega_{\rm p0}^2/\omega^2 = 0.2$.

4.3. Variation of beam width and normalized beam intensity

Figure 3 displays the variations of beam width f with the dimensionless distance of propagation ξ for different values of τ' in the case of a Gaussian pulse. It can be seen that the beam width suffers steady divergence in some regions (such as 1 and 2 in Figs. 3(a) and 3(c) and 7 in Figs. 3(b) and 3(d)), since the nonlinearity does not build up to a sufficient level. However, the beams present steady oscillatory convergence in some spatial–temporal regions (such as 4-7 in Figs. 3(a) and 3(c) and 1-6 in Figs. 3(b) and 3(d)). In the present paper, we focus mainly on the steady oscillatory convergence region. The phenomenon implies the laser beam localization in the underdense collisional plasma. The variation of f has obvious periodicity along the distance of propagation ξ and the amplitude of the beam width is subjected to

the continuously oscillatory variation. In addition, every maximum of beam width f is obviously shifted by the same time τ'. The steady oscillatory behaviours of the laser beam width could lead to some important applications, which is in agreement with the classical theory of laser–plasma interaction.[7,10] A fairly steady periodic oscillation and a relatively small amplitude variation of f are more beneficial to the increase of the laser absorption and conversion efficiencies. If the amplitude variation of f is too large, the influence of the laser diffraction will be significantly larger than the nonlinear influence, which will significantly reduce the laser absorption and conversion efficiencies. It should be noted that in the steady oscillatory convergence region, with the increase of $\omega_{\rm p0}^2/\omega^2$, the pulse width of f decreases obviously, which implies the promotion of the beam localization.

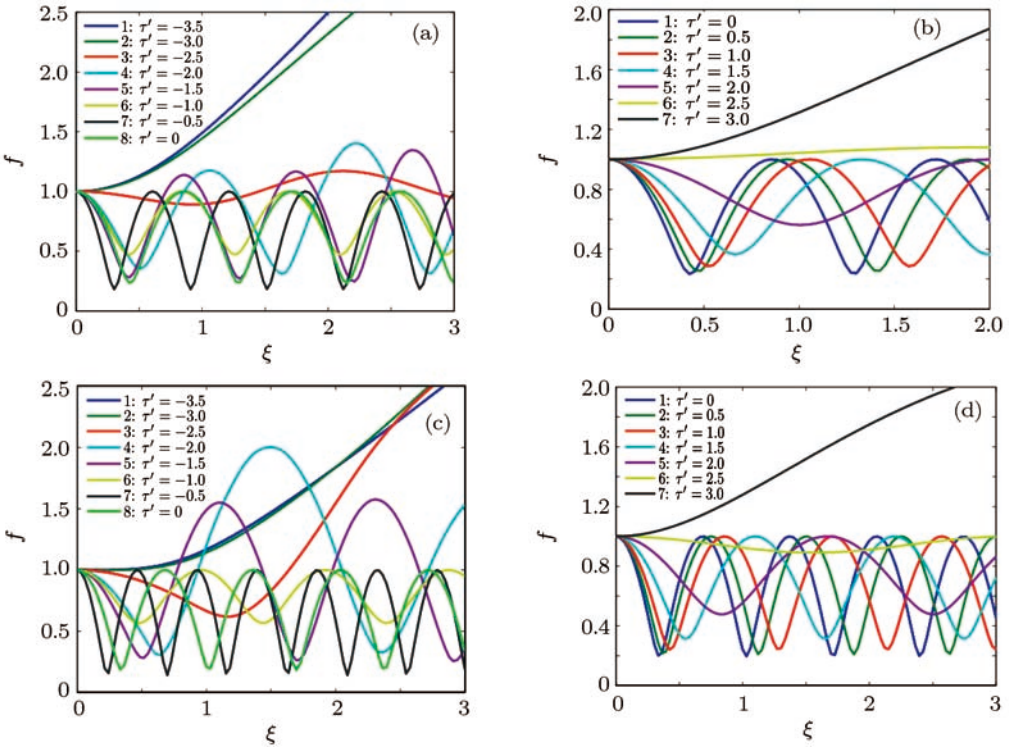


Fig. 3. (colour online) Variations of beam width parameter f with dimensionless distance of propagation ξ for different parameters $\delta\nu_0$, αA_{00}^2, β^2, and $\omega_{\rm p0}^2/\omega^2$ in the Gaussian pulse. $\delta\nu_0 = 1$, $\alpha A_{00}^2 = 10$, $\beta^2 = 100$, ((a) and (b)) $\omega_{\rm p0}^2/\omega^2 = 0.5$, ((c) and (d)) $\omega_{\rm p0}^2/\omega^2 = 0.75$.

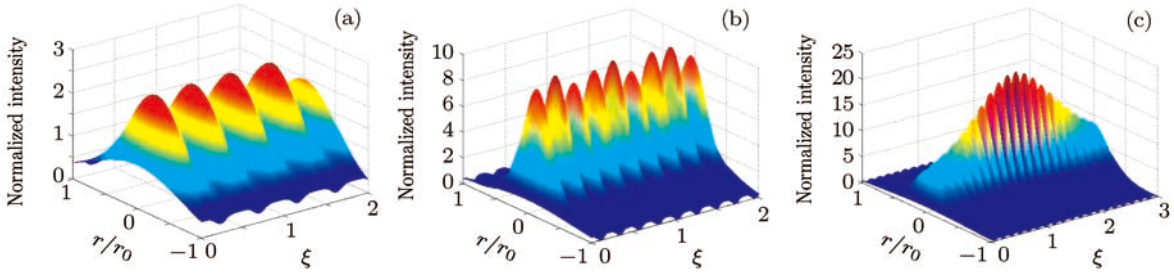


Fig. 4. (colour online) Variations of laser beam intensity with normalized distance ξ and radial distance r for (a) $\omega_{\rm p0}^2/\omega^2\alpha A_{00}^2 = 5$, $\beta = 10$, (b) $\alpha A_{00}^2 = 10$, $\beta = 10$, (c) $\alpha A_{00}^2 = 10$, $\beta = 15$ in the paraxial region. $\omega_{\rm p0}^2/\omega^2 = 0.5$.

Figure 4 displays the variation of laser beam intensity $A_0'^2$ (see Eq. (23)) with propagation distance ξ and radial distance r. Under the influence of the electron temperature, the laser beam propagating through the plasma becomes localized, which is due to the fact that when a laser beam propagates through the plasma, the nonlinear variation of the electron temperature creates the radial pressure gradient of the

electron, leading to the variation of the refractive index and causing the laser beam to be localized in some spatial–temporal regions. In addition, the laser beam intensity presents oscillatory variation along the distance of propagation ξ and an increase in β, thus the oscillation phenomenon becomes more obvious. Moreover, with the increase of αA_{00}^2, the beam localization increases obviously.

5. Conclusion

In the present paper, the nonlinear dielectric constant and laser beam localization in the underdense collisional plasma are investigated based on the wave and the dielectric constant equations. Our results show that when the laser beam propagates through the underdense collisional plasma, the electron temperature presents a quasi-periodic variation with $\delta\nu_0$ in dimensionless retarded time τ', which then creates the radial pressure gradient of the electron, leads to the oscillatory quasi-periodic variation of the refractive index and gives rise to the steady oscillatory convergence of the beam width and the localization of the beam in some spatial-temporal regions. The simulation results show clearly that the electron temperature has a strong effect on the dielectric constant and the laser beam localization. In addition, we find that the amplitudes of the beam width and the beam intensity are subjected to continuously oscillatory variation in the localization region.

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