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RESEARCH ARTICLE

Role of uniform and exponential density profiles on propagation dynamics of *q*-Gaussian laser beams in underdense collisional plasma

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Abstract In the studies of laser–plasma interaction, the density profile plays a crucial role. Hence, the comparative study of uniform and exponential density profiles on the propagation dynamics of q-Gaussian laser beams in underdense collisional plasma has been carried out. The nonlinear dependence of the dielectric constant in collisional plasma employed here is primarily due to heterogeneous heating of carriers along the wavefront of the laser beam. The significant effects of the exponential density profile on the propagation dynamics of the q-Gaussian laser beams for a wide range of q have been observed. The nonlinear differential equation for beam-width parameter f is set up by following the Akhmanov's parabolic equation approach under WKB and paraxial approximations. Additionally, the plots of nonlinear dielectric function ϕ against the normalized propagation distance ξ reveal internal consistency with the curves of beam-width parameter. The results are shown graphically and discussed.

Keywords Exponential density ramp · q-Gaussian · Underdense collisional plasma · Self-focusing

Introduction

One of the most important developments in the nonlinear optics was the introduction of laser as a fundamental source of energy has advanced rapidly [1]. Many novel phenomena were seen, and a great deal of interest was generated by the study of how high-intensity laser beams interacted with different types of media. Akhmanov et al. [2] have introduced the self-focusing of laser beams for nonlinear media, and its pedagogical straightforward development to plasmas was given by Sodha et al. [3]. The propagation of intense laser beams in plasma is crucial in various applications such as laser-based electron acceleration [4–7], high harmonic generation [8, 9], inertial confinement fusion [10], production of X-ray lasers [11], etc. The collisional plasma dynamics is basically dominated by local collisional forces rather than collective actions in it. Amongst several mechanisms which are responsible for the nonlinearities in the plasma due to the interaction of laser, the nonlinearity induced by heating of carriers has been of immense importance. In this case, propagation of a laser beams with non-uniform intensity distribution in plasma leads to a non-uniform temperature gradient. Moreover, the non-uniform re-arrangement of carriers because of transverse fluctuations in electric field is a major source of the field-dependent dielectric constant in collisional plasma [3]. The magnitude of the collisional nonlinearity is more effective than that of the ponderomotive force nonlinearity in a steady state. Self-focusing/defocusing of the beams takes place because of this self-induced inhomogeneity in dielectric function of the collisional plasma [12].

After the development of petawatt-class laser technology, Patel et al. [13] experimentally studied the Vulcan Nd:glass petawatt laser and observed that its intensity profile is deviated from the Gaussian intensity distribution. Nakatsutsumi et al. [14] recommended such intensity distribution as q-Gaussian distribution specified in the form, $I(r) = I_0\left[1 + \left(r^2/q{r_0}^2\right)\right]^{-q}$. By fitting the experimental data for a given laser system, parameters q and r_0 can be obtained which are linked to deviation from the Gaussian intensity distribution and initial spot size of laser beam,

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