УДК 533.9

Plasma Formation under Intense Chirped Pulse Propagation

Hilal S. (ITMO), **Ismagilov A.O.** (ITMO), **Tcypkin A.N.** (ITMO), **Melnik M.V.** (ITMO)
Scientific supervisor – Associate Professor, PhD, Melnik M.V. (ITMO)

Introduction. Chirped laser pulses have become a pivotal tool in ultrafast optics, enabling precise control over plasma formation and dynamics. The key interest of chirped pulses, is that they involve varying the frequency of a pulse over time, leading to have the potential of controlling plasma properties more precisely by modifying the energy deposition rate in the medium [1]. This study seeks to investigate how varying chirp rates can influence plasma density and electron dynamics, thereby advancing the fundamental understanding of this interaction.

Body. In this work, the effect of chirp on plasma density and frequency will be explored using the density matrix formalism [2]. The model consists of three differential equations. The first equation describes the propagation of the chirped pulse electric field, taking into account both linear and nonlinear effects. The second equation describes the evolution of the current density of quasifree electrons under the influence of the applied electric field. While, the third equation characterizes the dynamics of electron excitation from the ground state to higher energy states. In the non-resonant approximation, this equation accounts for the influence of the square of the electric field on the excitation process and incorporates the rapidly broadening spectrum of the ultrashort pulse in the nonlinear medium.

The current study extends this approach by incorporating the full propagation dynamics of chirp pulses. Specifically, the model addresses the interplay of diffraction, dispersion, and nonlinear effects including the third order nonlinearity (Kerr effect) and a fifth order plasma nonlinearity that induces a defocusing effect. This comprehensive framework aims to elucidate the mechanisms underlying plasma formation in the filament region enabling to study the effect of pulse chirp on plasma properties.

The theoretical model captures the essential physics of laser–plasma interactions. In the propagation regime, the effects of diffraction and dispersion are meticulously accounted for to accurately describe the spatial and temporal evolution of the chirped pulse. The third order nonlinearity, characterized by the Kerr effect, is known to induce self-focusing, which is a critical process in high-intensity pulse propagation. However, as the pulse intensity increases, the onset of a fifth order plasma nonlinearity becomes significant. This plasma nonlinearity introduces a defocusing effect that counterbalances the Kerr-induced focusing, thus playing a crucial role in stabilizing the filamentation process.

Conclusion. This study advances our understanding of chirp pulse propagation in nonlinear media by integrating the effects of diffraction, dispersion, and both third and fifth order nonlinearities. The ability to manipulate plasma formation via chirp control opens new avenues for the optimization of laser–plasma interactions in filamentation processes. Future work will focus on experimental validation of these theoretical predictions and on exploring the broader parameter space to further refine plasma control strategies.

List of sources used:

1. Zare S. The effect of chirp parameter on laser propagation in collisional quantum plasma //Results in Optics. – 2022. – T. 9. – P. 100284.
2. Stumpf S. A., Korolev A. A., Kozlov S. A. Few-cycle strong light field dynamics in dielectric media //Laser Optics 2006: Superintense Light Fields and Ultrafast Processes. – SPIE, 2007. – T. 6614. – C. 59-70.