Theoretical Investigation of the Interaction between Intense Laser and a Preformed Plasma Channel

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Summary

The energy to which particles can be accelerated in a laser-driven plasma accelerator is determined by the shortest of: the propagation distance over which the energy of the driving laser pulse, or pulses, is depleted (the depletion length); the distance for which the particles are correctly phased with the plasma wave (the dephasing length); and the distance for which the intensity of the driving laser pulse remains focused (defocusing length). For many acceleration experiments, particularly those aimed at demonstrating controlled acceleration of an injected bunch, the acceleration length is limited by defocusing of the pump radiation.

In order to overcome the limitations on the laser-plasma interaction length set by diffraction and refraction, it is necessary to guide or channel the laser pulse through the plasma. In general, guiding electromagnetic radiation requires a channel to be formed in which the refractive index is a function of radial distance from the axis of propagation. The topic of this thesis is the interaction of high power laser with a preformed plasma channel.

This thesis contains five chapters and two appendices. In the first chapter; an introduction and survey, an the importance of the interactions of high power lasers with plasma is shown. The generation of large amplitude electron plasma waves used in particle acceleration in table tap accelerators due to some parametric instabilities (SRS) has been

introduced. A review of the previous researches about interactions of high power laser with plasma containing preformed channel has been reported.

In chapter two "Parametric Processes in Plasma", the detailed theory of parametric instabilities caused by high power laser drivers is discussed. Three modes of waves supported by the plasma is introduced, namely, the electromagnetic wave, the electron plasma wave and the ion plasma wave (ion-acoustic wave). This thesis is mainly devoted to the generation of electron plasma wave and how to amplify and maintain its amplification for long distances inside the plasma. For this reason, the theory of "Stimulated Raman Scattering" (SRS) is fully investigated. The dispersion relations for the modes involved in this instability, and the domain of the resonance three waves interactions of the instabilities are written in full details. The effect of the ponderomotive force in initiating and maintaining the instability is shown to be very crucial. With high power lasers we cannot neglect the relativistic effects on the plasma medium. When the quiver velocity of plasma electrons approaches the speed of light, the mass of these electrons will increase and the whole physics of the medium will be changed. This is what discussed by the end of this chapter.

Chapter three is dealing with the interaction of high power laser with homogeneous plasma channel. In the beginning of this chapter a justification is made about why the fluid model is used to describe and formulate the problem of propagation of waves in plasma containing a preformed channel. The basic equations are derived according to this model and allowing for some approximations that make solving the system of the nonlinear differential equations obtained solvable. Fortunately; the problem of waves propagation in resonant homogenous plasma channel can be reduced to propagation in one dimension. By the end of this chapter the growth rates of the amplitudes of the waves have been derived, and found that these are the maximum growth rates can be found in this problem because the absence of the saturation effects which discussed in chapter four.

The main saturation effects such as: a) the changing of plasma density (inhomogenity of the plasma) , b) decay effects, and c) the relativistic effects, are discussed in chapter four. The propagation of high power laser in inhomogeneous plasma with linearly changing plasma density is discussed in details. The fluid model is again used to drive the system of equations involved in this case. The system of equations is highly nonlinear. Approximation are made to change the system of equations, using the perturbation theory, to a system of a linear second order differential equations with varying coefficients and fixed boundary conditions. The relativistic and damping effects are included in the model to account for the main saturation effects in the inhomogeneous plasma. The appropriate boundary conditions are fed to the system of equations and the final system of equations for the global wave propagation in inhomogeneous plasma is ready to be solved.

Chapter five is devoted to the result and discussion. To find an analytical solution of the system of equation derived in chapter four, (WKB) approximations must be used. But, using the approximation will destroy the global nature of the problem. This approximation fails at resonance and reflection points of the waves. In the problem involved there are two resonance points for forward and backward propagating waves, and two reflection points; one for electron plasma wave and another for electromagnetic wave. So a computational solution is seeking for. A main FORTRAN program to solve the system of equations, using appropriate numerical methods for solution, is written, and a number of ready made subroutines are linked to the main program. This program is tested for special cases and then used to get the results and figures for the whole set of the parameters suggested to describe the solution. Discussions to the results are made by the end of chapter five and suggestion for future works.