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MHD computations for plasma trapping in open magnetic field devices for high neutron flux production

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Abstract

Results of numerical simulations on plasma trapping by an open high magnetic field configuration in cylindrical geometry are presented. The plasma is produced by the interaction of ultrashort high intensity laser beam with a molecular beam, of neutral deuterium clusters, that enters the external applied mirror-like magnetic field of the order of 150 Tesla. For the study of the spatial and temporal evolution of the trapped plasma a 1+1/2-D MHD code has been developed in cylindrical coordinates. The neutron production efficiency is calculated as a function of the physical and the geometrical parameters as well as the value of the external magnetic field.

Introduction

In recent years there has been an increasing interest in study of plasma trapping from ultrashort high intensity laser beam interaction with gas[1],[2],[3] in order to accelerate ions and produce neutrons. The application of a high intensity external magnetic field, allows the high density and temperature plasma trapping for relatively long time, increases the number of ion collisions in the interaction volume and improve the neutron production [1],[2],[3],[4],[5]. The aim of present work is to carry out numerical calculations on spatial and temporal evolution of the main physical parameters of the produced deuterium plasma such as density, pressure, expansion velocity and temperature as well as to estimate the neutron number per laser shot. The selection of the initial conditions of this problem such as plasma density, temperature, laser beam spot and intensity of external magnetic field, correspond to potential experimental setup.

Physical and mathematical model

A high-density neutral deuterium cluster beam can penetrate in an external mirror-like applied magnetic field configuration (fig.1) and interact with an ultrashort high intensity laser beam. Such interactions accelerate deuterium ions, to relatively high kinetic energies, due to Coulomb explosion, enabling the production of neutrons through D-D nuclear fusion reaction.[4] Typical initial plasma conditions have been selected for the electronic density up to 10^{19} cm^{-3} and for the temperature up to 50 keV in order to allow comparisons with recent experiments [3].

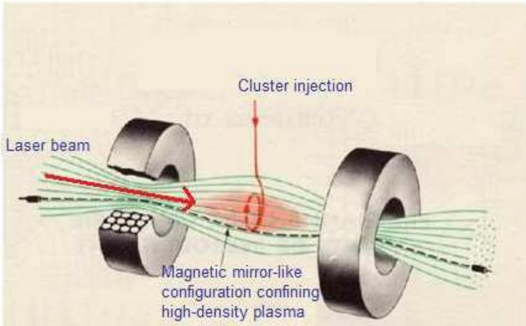
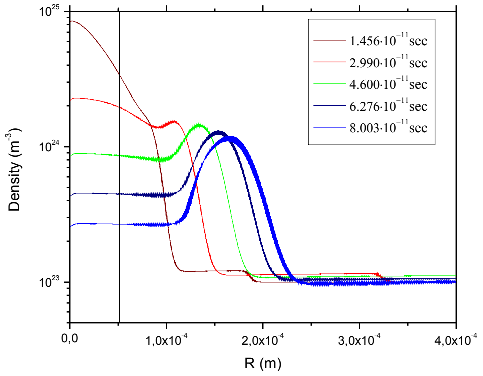


Fig.1: The proposed setup concerning the magnetic field topology, the cluster penetration in the center of the mirror-like configuration and the interaction with the pulsed laser beam

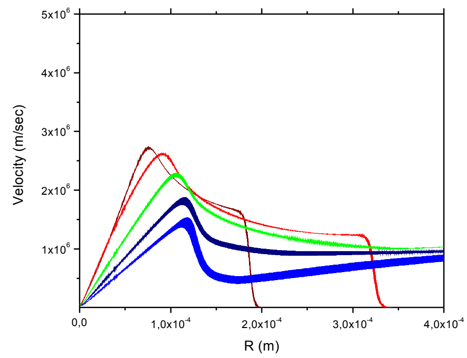
For the numerical study a MHD code in cylindrical coordinates has been developed in 1+1/2 dimension which corresponds to the Eulerian shock tube model treatment in radial direction and Lagrangian formulation in the axial direction. The shock tube model consists of a Riemann problem which involves the solution of a system of nonlinear hyperbolic differential equations, for one-dimensional flow, including a jump discontinuity in the initial data. Our physical model concerns the propagation of a laser-induced shock wave from a high pressure region (of 50μm radius) to another (of 400μm radius) of two orders of magnitude lower. These regions represent two areas of different plasma densities at the interaction volume due to the Gaussian-like spatial distribution of the focused laser beam. The plasma parameters are plotted as functions of the expansion radius for different time intervals with or without the application of a high intensity magnetic field.

Numerical simulation results

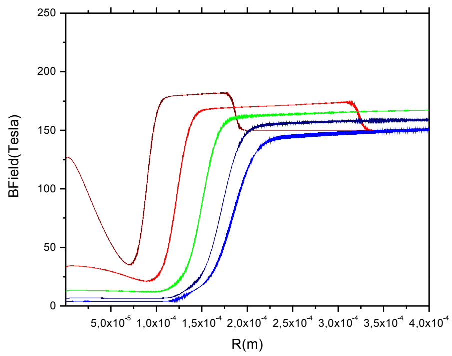
Figure 2 shows a series of numerical results concerning the spatial and temporal evolution of the D-ions plasma parameters, with an external applied magnetic field of 150 Tesla. The different curves referred to time intervals from the laser plasma production up to 80 picoseconds. During this relatively short trapping time the plasma density remains relatively high, up to 10^{18} cm^{-3} enabling a neutron production up to few 10^5 neutrons per laser shot. For longer time trapping, up to tens of nanoseconds, the plasma density remains relatively high due to applied high magnetic field and the neutron production increases up to 10^9 neutrons.



(a)



(b)



(c)

(d)

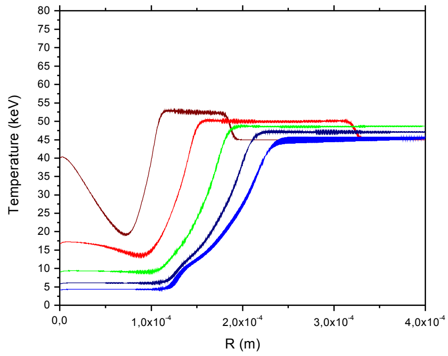


Fig.2 Radial dependence of D-ions plasma parameters (a) plasma density, (b) plasma velocity, (c) magnetic field, (d) temperature for initial value of the external magnetic field B=150T. Curve colors correspond to the following time intervals: Brown = 1.456e-11sec, Red =2.990e-11sec, Green = 4.600e-11sec, Deep blue=6.275e-11sec, Blue = 8.003e-11sec

Conclusions

The results of the present 1+1/2-D code are in good agreement with experiments [1],[2],[3] for the case of zero external magnetic field[4]. As it was also been calculated for a relatively long trapping time corresponding to tens of nanoseconds and a magnetic field of 150 Tesla the plasma density remains high and the plasma is trapped in a relatively small interaction volume. The neutron production is of the order of 10^5 -10^6 during the first 80 picoseconds of the plasma evolution and growth up to 10^9 for the longer, tens of nanoseconds, trapping time. Finally, by increasing the focal diameter of the laser spot it is possible to have relatively higher interaction volume and high plasma density for longer trapping time improving by a factor of 10^2 the neutron production.

Acknowledgements

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