

§56. Potential Study of Ion Beam Driven Fast Ignition Laser Fusion

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In conventional fast ignition laser fusion, where the laser produced fast electrons heat the imploded core in a few ~ several tens picoseconds, the heating efficiency required for achieving high gain has not been obtained in detailed integrated simulations and experiments because of too high energy of generated fast electrons and of the large beam divergence. As the alternative heating scheme, the laser-produced ion beam driven fast ignition is getting much attention. Compared to the electron beam, the energy conversion efficiency of heating laser to ion beam is much low. But the beam divergence is small and the energy of generated fast ions is suitable for core heating. The total evaluation of ion beam driven fast ignition, which includes beam generation, transport and core heating, is indispensable to discuss the performance of ion driven fast ignition. In the present study, we develop the simulation codes for ion driven fast ignition and carry out the integrated simulations for foundational experiments and for evaluation of ignition requirements for reactor-grade core. Also, we conduct the foundational and integrated experiments in FIREX project.

The research progress in fiscal year 2013 is shown in the following.

(1) Code Developments

The particle-based ion transport code has been developed and coupled to the fusion burning code "FIBMET" (radiation-hydro base code including fusion reactions and fusion-products transports).

(2) Numerical Simulations:

(a) For FIREX-I experiments, we have evaluated the ion acceleration performance (Fig.1) by 2D PIC simulations, where the plane CD target is irradiated by intense laser pulses (intensity $I_L = 10^{19} \sim 10^{20} \text{ W/cm}^2$, wavelength $\lambda_L = 1 \mu\text{m}$, pulse duration $\tau_L = 1 \text{ ps}$). The slope temperature increases in proportional to $I_L^{2/3}$. The conversion efficiency of 1~3% and the beam divergence of $30^\circ \sim 60^\circ$ were obtained. We also evaluated the role of ion beam in core heating in addition to electron beam (Fig.2). To achieve 5keV core temperature, the

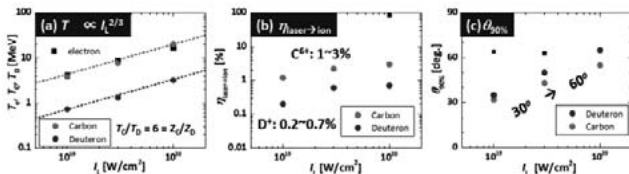


Fig.1 Dependence of ion beam properties on irradiated laser intensity. (a) the slope temperature, (b) the energy conversion efficiency of laser to ion beam and (c) the beam divergence are shown, respectively.

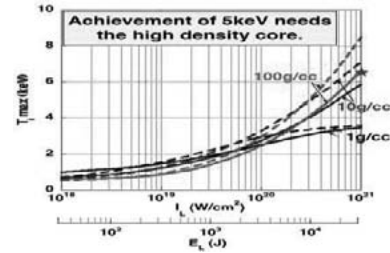


Fig.2 Heated core temperature as a function of laser intensity (laser energy), where the pulse duration of 1.5ps, spot size of 50mmf, and conversion efficiency of laser to electron beam of 40% are assumed. For electron spectrum, we applied numerical scaling by Wilks¹⁾ and Haines²⁾. As for ion beam properties, we used the hole boring model³⁾ and assumed the monochromatic beam.

required laser parameters are the energy $E_L = 5 \text{ kJ}$, $\tau_L = 1.5 \text{ ps}$, spot size $\phi_L = 20 \mu\text{m}$ and intensity $I_L = 10^{21} \text{ W/cm}^2$.

(b) For a reactor-grade core, we have evaluated ignition requirements for ion driven fast ignition (Fig.3). For minimizing the beam energy, the particle energy of 50~200MeV and pulse duration of a few ps are required.

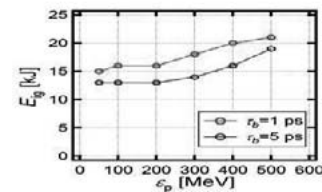


Fig.3 Required ion beam energy for ignition as a function of energy of fast ion, where the monochromatic C^{6+} beam with no beam divergence and spherical DT core (density of 300 g/cm^3 and areal density of 3 g/cm^2) are assumed.

We have also evaluated the condition of ion beam generation (target density and laser intensity) by radiation pressure acceleration (RPA)⁴⁾ required for ignition using 2D PIC simulations. As the results, when a carbon target with the density of $n_i = 70 n_{cr}$ (n_{cr} is laser classical critical density) is irradiated by the circularly polarized laser pulse with the intensity of $6 \times 10^{22} \text{ W/cm}^2$, we obtained a suitable beam spectrum (central energy in energy spectrum of 210MeV, and energy spread of 140MeV).

(3) Experiments:

Due to the limitation of shot number, we have conducted 3 shots for integrated experiments where the spherical solid CD targets with tip-less cone were used, and obtained significant signal of laser accelerated fast ion.

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