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

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Objective

In conventional fast ignition laser fusion using laser-produced fast electrons as a core heating source, the heating efficiency required for achieving high gain has not been obtained in detailed integrated simulations and experiments yet because of too high energy of generated fast electrons and of the large beam divergence. As the alternative heating scheme using a laser-produced ion beam as a core heating source 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. In the present collaborative research, we numerically evaluate the ignition requirements (heating laser properties and target design) for ion-driven fast ignition. Also, possibility to enhance the heating efficiency in the FIREX [1] experiments using ion beam generated by the present heating laser LFEX is numerically and experimentally investigated.

Summary of research progress in 2014

(1) Code development; the beam fusion routine has been developed and installed into a coupled beam transport and plasma hydro code, which enables us to calculate the neutron spectrum from D-D beam fusion.

(2) Numerical Simulation; 2D PIC simulations were carried out to evaluate the properties of ion beam generated by a LFEX-class laser. The beam ion transport simulations were conducted to calculate the probabilities of D-D beam fusion by laser-accelerated deuteron and the neutron spectrum from the beam fusion for the fundamental experiment using a CD thin foil.

(3) Fundamental Experiment: To identify the ion acceleration by LFEX laser, we have irradiated a CD thin foil by LFEX laser and measured ion spectra by Thomson parabola spectrometer.

Ion beam properties in fundamental experiments

For enhance the heating efficiency in FIREX experiments, in addition to the electron beam, we proposed to use the ion beam accelerated by laser radiation pressure [2] at the laser-plasma interaction surface. To clarify the ion beam properties, we conducted the PIC simulations and fundamental experiments using a thin CD foil (20 μm thickness) and GXII+LFEX laser system. The energy spectra for D^+ and C^{6+} obtained from PIC simulations for laser intensity $I_L = 10^{19} \sim 10^{20}$ W/cm^2 are shown in Fig.1. The maximum energy of C^{6+} for $I_L = 10^{20}$ W/cm^2 is less than 40 MeV. Compared with an imploded core size expected in FIREX ($\rho R \sim 0.1$g/cm^2), the range of 40-MeV C^{6+} is small, so the C^{6+} will contributes to the core heating efficiently. As for D^+, the range becomes comparable to the twice of the core ρR at E_D (energy of D^+) ~ 3 MeV. So, the laser intensity should be lower than 3x10^{19} W/cm^2 to use the D^+ for core heating. The energy conversion from laser to ion beam (C^{6+} + D^+) is about 1 %, which is much lower than that for the electron beam. To enhance the energy conversion under the present laser intensity of LFEX, the target density should be lower [2].

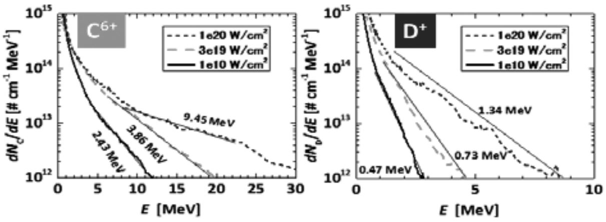

Fig.1 Energy spectra of ion beam obtained from 2D PIC simulations, where 20mm CD thin foil was irradiated by intense laser ($I_L = 10^{19} \sim 10^{20}$ W/cm^2).

Figure 2 shows the raw data for accelerated ion beam experimentally observed in the direction along the laser axis by the Thomson parabola spectrometer. Between the target rear surface and the spectrometer, a 50 mm Al filter was located to eliminate the g-ray noise. This filter also stops the C^{6+} with energy up to 75 MeV, so that the C^{6+} signal was not detected. In upper figure case, a CD foil was just irradiated by 1-kJ and 1-ps LFEX laser, and then the signal of protons accelerated by TNSA was observed. In the lower case, the target rear surface was irradiated by 3-J and 1.5-ns GXII laser (3 beams) to reduce the TNSA by generating long scale plasma. Thus, only the ions accelerated at the target front surface were observed. In the integrated experiments, the clean rear surface does not exist, so the lower case simulates the situation at the integrated experiments. The maximum energy of D^+ ion for the lower figure is ~ 4.1 MeV. Compared with the simulation results, the irradiated laser intensity is estimated to be 1~3x10^{19} W/cm^2. The detailed analysis for experimental results is going on now.

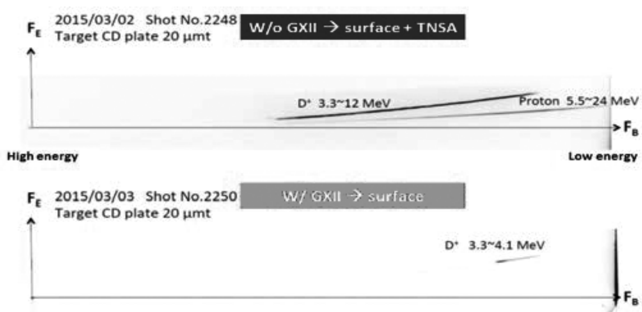

Fig.2 Raw data for laser-accelerated ions experimentally obtained by the Thomson parabola spectrometer.

1) H. Azechi and FIREX project, Plasma Phys. Control Fusion **48** B267 (2006).
2) N. Naumova, et al., Phys. Rev. Lett. **102**, 025002 (2009).