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

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**Objective**

In conventional electron driven fast ignition, the experimentally-demonstrated heating efficiency[1)] is lower than that required for high gain because of too high energy of generated fast electrons and of the large beam divergence. As the alternative heating scheme using a laser-accelerated ion beam 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 2015**

(1) Analysis of experimentally observed ion spectrum; the fast ion profiles observed by the Thomson parabola spectrometer in the fundamental experiments has been analyzed.
(2) Numerical Simulation; 2D integrated simulations were carried out to evaluate the contribution of ion beam generated by LFEX-spec laser on the core heating.

**Ion beam properties in fundamental experiments**

In the fundamental experiments for ion acceleration where CD plane targets with 20μm of thickness were irradiated by the LFEX laser, we observed accelerated ion spectra by the Thomson parabola spectrometer in the direction along the laser axis. The two type of experiments were carried out; one is the simple irradiation of LFEX laser on the CD solid target (front surface acceleration + target normal sheath field acceleration TNSA on the rear surface), the other is that the target rear surface was irradiated by long pulse laser to form the long-scale pre-plasma on the rear surface (only front surface acceleration). Between the target rear surface and the spectrometer, the Al filter with 100 μm of thickness was located to eliminate the fast $C^{6+}$. So $D^+$ ions and the $p^+$ were observed. In Fig.1, the observed $D^+$ spectrum is shown. $D^+$ with the energy lower than 4.5 MeV cannot be observed since the ranges of such low energy deuterons in the solid Al are less than 100 μm. In the case of clean rear surface (i.e., no irradiation of long pulse laser on the rear surface), the observed deuterons are mainly accelerated on the rear surface by TNSA process. By producing the pre-plasma on the rear surface and suppressing the sheath field generation, the ions are mainly accelerated around the laser-plasma interaction region on the front surface. The acceleration efficiency of ions is higher for the TNSA than that for the front surface acceleration, the number of accelerated $D^+$ was considerably decreased. From the comparison with the PIC simulations, the energy conversion form LFEX laser to D+ is about 0.1%, and that for $C^{6+}$ (that was not observed at experiments due to the Al filter) is about 1 %.

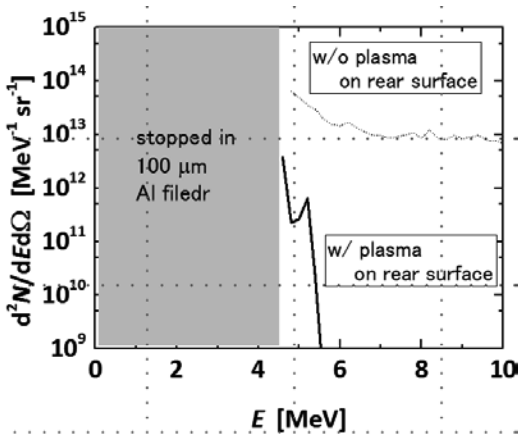


Fig.1 Experiment ally observed energy spectra of deuteron ion accelerated from 20-μm[t] CD planes irradiated by LFEX laser.

**Integrated simulations**

To evaluate the contribution of ion beam to the core heating at the present FIREX class experiments, the integrated simulations were carried out, where the two types of cone were used, the one is the normal Au cone (7 μm of tip thickness) and the open-tip Au cone where the cone tip has a hole. In the later case, the heating laser directly interacts with the fuel material, so not only electron but also the ions are accelerated and will contribute to the core heating. In the both cases, the target is a CD solid ball.

It is found form the 2D PIC simulations under the present FIREX-I situation, where the pulse contrast of LFEX laser has been improved sufficiently, that the ions are not accelerated efficiently by the surface acceleration mechanism even for the case of open-tip cone. And then the contribution of ion beam to the core heating is negligible. However, it is found that the heating efficiency by the electron beam is improved by using open-tip cone compared with the case of normal Au-tip cone because of removal of the energy loss and scattering in 7 μm-thickness Au tip. To use the ion beam for the core heating, further ingenuity is required, such as use of low-density foam material as the ion generation target.

(1) S. Fujioka, et al., Phys. Rev. E **91**, 063102 (2015).