§67. Improvement of Laser-ion Acceleration for Fast-ignition of Fusion

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Fusion fast ignition assisted by laser-driven ion beams [1] requires 10 kJ energy deposition onto the fuel core having ~500 g/cm^3 densities. Assuming 100 kJ as a technically manageable energy of the driving laser, the first milestone can be found on 10% conversion efficiency from the laser energy into ions having kinetic energies of 10-30 MeV/u. Here, we show that 5 % conversion efficiency into protons having maximum kinetic energies of 30 MeV is achieved by finding an optimum duration of the laser pulse. The efficient ion generation is attributed to the hot electrons anomalously heated by the laser beyond a typical scaling [2]. The electron temperature enhanced via the anomalous mechanism is well reproduced by a Particle-in-Cell simulation.

In this paper, we experimentally investigate the ion acceleration mechanism using kilojoule picosecond laser LFEX, the laser contrast of which has been improved drastically. The laser pulse having a duration of 1.5 ps is focused onto an aluminum foil target with an energy of 1 kJ. The peak intensity obtained is 1.2×10^{19} Wcm^{-2}. The kinetic energy and mass of ions accelerated from the rear side of the target, the thickness of which is ranging from 0.1 to 25 μm, are analyzed by Thomson parabola spectrometer. As a result, protons having energy exceeding 50 MeV are observed using the high contrast LFEX laser. Note the observations above have been performed without plasma mirror in the laser path. In a previous energy scaling of ion acceleration [3], 50-MeV protons were obtained with the laser intensity exceeding 10^{20} Wcm^{-2}, which is higher by an order of magnitude than the present one.

To explain the experimental results, we discuss the ion acceleration mechanism via anomalous heating of electrons, where the temperature of electrons and the charge separation field grow as a function of time, indicating that longer duration of the laser pulse can make a beneficial effect on the ion acceleration. When we expand the pulse duration (FWHM) of the laser from 1.5 ps to 3 ps at the fixed laser intensity of 2.3×10^{18} Wcm^{-2}, the electron temperature measured by Electron Spectrometer (ESM) is drastically enhanced up to 1.2 MeV, which clearly exceeds the ponderomotive potential around 0.2 MeV for the laser intensity of 2.3×10^{18} Wcm^{-2} used in this measurement. In this study, we term this phenomenon Anomalous Electron Heating. At the duration of 6 ps, the electron temperature turns to decrease, indicating that an optimum duration can be found around 3 ps. In addition, the proton energy, analyzed simultaneously with the electron temperature, reaches 29 MeV at 3 ps and saturates around 30 MeV at 6 ps. Too long pulse duration (6 ps in Fig 1) leads to a large plasma expansion that can weaken the recirculation effect of electrons, resulting in the adiabatic decrease of electron temperature.

As a result, the enhanced proton energy is explained by newly introducing the anomalous heating effect into the conventional plasma expansion model [4]. We also show that the energy conversion efficiency into the protons drastically grows from 0.2% to 5% (Fig. 2) when the laser duration is expanded from 1.5 to 6 ps. This fact is advantageous for the ion-driven fast ignition by ions from the viewpoint of the energy deposition onto the core plasma.

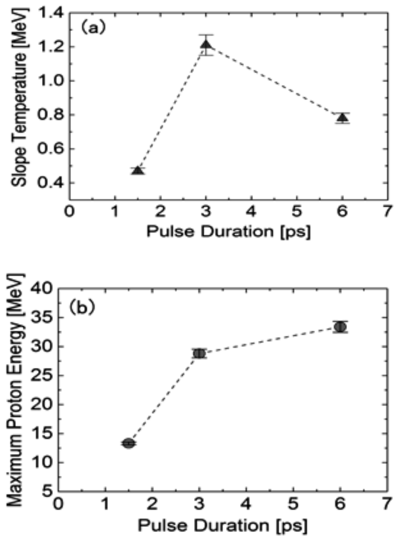

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Fig. 1: (a) The slope temperature of high-energy electrons as a function of the laser pulse duration. (b) The accelerated proton energy observed simultaneously with the electron temperature.

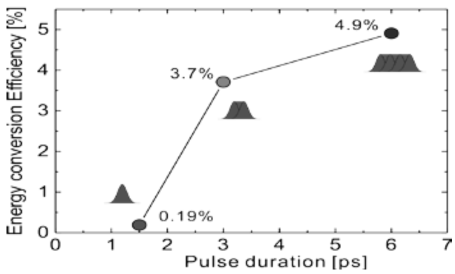

Fig. 2: Pulse duration dependency of the conversion efficiency from the laser energy into the kinetic energies of protons faster than 6 MeV.

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