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Fast Ignition Realization EXperiment project in Japan

Shinsuke FUJIOKA[1], Tomoyuki JOHZAKI[2], Hitoshi SAKAGAMI[3],

Yasunobu ARIKAWA[1], Yasuhiko SENTOKU[1], Ryosuke KODAMA[1] and FIREX project team

[1] Institute of Laser Engineering, Osaka University

[2] Department of Mechanical Systems Engineering, Hiroshima University

[3] National Institute for Fusion Science, National Institutes of Natural Sciences

e-mail: sfujioka@ile.osaka-u.ac.jp

Fast isochoric heating of a pre-compressed fusion fuel core with a high-intensity short-pulse laser is an attractive and alternative approach to create ultra-high-energy-density states like those found in inertial confinement fusion (ICF) ignition sparks. This scheme avoids the ignition quench caused by the hot spark mixing with the cold fuel, which is the crucial problem of the currently pursued ignition scheme. In the fast isochoric heating scheme, laser-produced relativistic electron beam (REB) deposits a part of kinetic energy in the core, and then the heated region becomes the hot spark to trigger the ignition.

However, there are two critical concerns in the scalability of this scheme to the fusion ignition. One is that a small portion of the REB can collide with the fuel core after long travel of the REB from the generation zone to the core because of the inherent large angular spread of the REB. The other is inhabitation of production of relatively low energy REB (< 3 MeV) due to a hydrodynamic expansion of a bulk plasma during multi-pico-second (multi-ps) laser-plasma interaction.

Recently, we have demonstrated significant enhancement of laser-to-core energy coupling with the magnetized fast isochoric heating [1]. The method employs several hundreds Tesla magnetic field [2] that is applied to the transport region from the REB generation zone to the core which results in guiding the REB along the magnetic field lines to the core. Two-dimensional (2D) electromagnetic dynamics simulation code with consideration of inductive heating has been developed to simulate spatiotemporally resolved 2D profiles of the applied magnetic field in an ignition scale target. Figure 1 shows dependence of laser-to-core energy coupling on heating laser intensity and energy.

The immobile ion assumption is no longer valid in the multi-ps time scale, ions move collectively with electrons, and structures of the LPI zone evolves with time. Hydrodynamic instabilities become issues in the multi-ps LPI, and self-generated electromagnetic field is amplified significantly by the collective motion of electrons and ions [3]. Energy distributions of the REB can be approximated with two-temperatures Maxwell-Boltzmann functions. The higher slope temperature is apparently affected by pulse duration even with the same laser peak intensity, while the lower temperature shows little dependence on the pulse duration, and the lower temperature was close to the ponderomotive scaling value.

We found that the bulk electron density profile around the relativistic critical density surface is steepened by the ponderomotive pressure of the heating laser, and the lower temperature REs are produced in the steepened interaction zone. This density steepening remains for multi-pico-second time scale, therefore, efficient production of the relatively low temperature REB can be sustained even with multi-ps heating laser.

Further progress of the project based on these results will secure scalability of this scheme to the ignition.

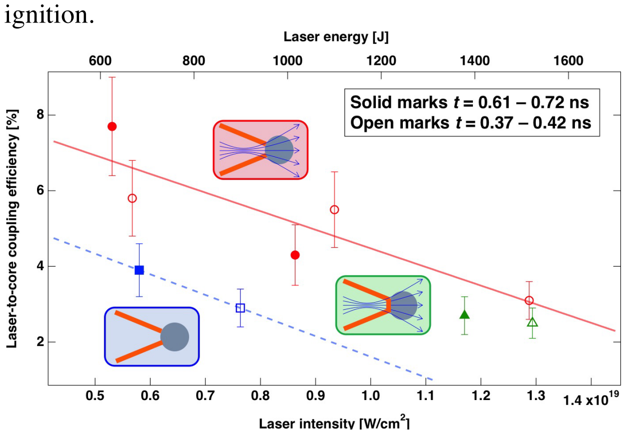

Figure 1 Dependence of laser-to-core energy coupling on heating laser intensity (bottom axis) and energy (top axis). The blue rectangular, green triangle and red circle marks represent laser- to-core coupling efficiencies obtained with the following conditions; no application of external- magnetic-field with open-tip cone, application of external magnetic field with closed-tip cone, and application of external magnetic field with open-tip cone, respectively. The error bars show the uncertainty of experimental measurement described in the text. Solid and open marks represent the couplings of two injection timing groups t = 0.61 - 0.72 ns and t = 0.37 - 0.42 ns. The error bars are the spectrometer uncertainty due to non-uniformity of the integral reflectance. The solid and dashed lines are fitted, as an eye guide, to the couplings with neglecting the injection timing difference.

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[2] S. Fujioka *et al.*, Scientific Reports, Vol. 3 p. 1170 (2013).
[3] S. Kojima *et al.*, arXiv:1803.02514.