A Pathway to Laser Fusion Energy: Fast Ignition Realization EXperiment (FIREX)

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Abstract. Here we report recent progress of the fast ignition inertial confinement fusion demonstration. Fraction of low energy (< 1 MeV) component of the relativistic electron beam (REB), which efficiently heats the fuel core, increases by the factor of 4 by enhancing pulse contrast of heating laser and removing preformed plasma sources. Kilo-tesla magnetic field is studied to guide the diverging REB to the fuel core. The transport simulation of the REB accelerated by the heating laser in the externally applied and compressed magnetic field indicates that the REB can be guided efficiently to the fuel core. The integrated simulation shows >4% of the heating efficiency and > 4 keV of ion temperature are achievable by using GEKKO-XII and LFEX, properly designed cone-fuel and the external magnetic field.

1. Introduction

Under the auspices of Fast Ignition Realization EXperiment (FIREX) project [1], demonstration of the fast ignition inertial confinement fusion is being performed at Osaka University. Figure 1 shows a schematic of the FIREX experiment. A world-largest 2-petawatt LFEX laser system [2], which is currently capable of delivering 3 kJ in a 1.5 ps pulse using 4 laser beams with 10^{-10} of the pulse contrast, has been constructed beside the GEKKO-XII laser facility as shown in Fig. 1. The LFEX laser pulses are focused to generate a REB, which heats a dense fuel core up to the ignition temperature (5 keV).

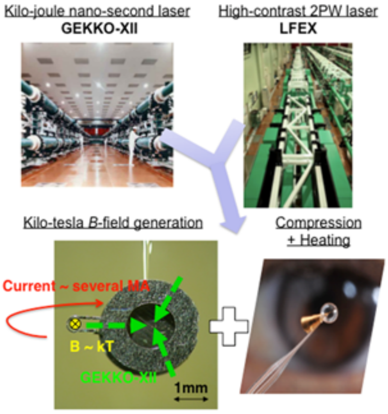

Figure 1. A spherical fuel is compressed by kilo-joule GEKKO-XII laser beams and the compressed core is heated by the high-contrast 2PW laser. Kilo-tesla magnetic field is generated by a capacitor-coil target driven by a part of the GEKKO laser.

2. Fast Ignition Experiments

One of the critical problems of the FI scheme is the generation of much energetic electrons. A pico-second LFEX laser pulse is inevitably preceded by several types of pulses. The preceding pulse produces a plasma before the main pulse arrival timing, then laser-plasma interactions in a long-scale preformed plasma generate electrons that are too energetic (> 10 MeV) to efficiently heat the fuel core. Intensity contrast between the main pulse and the preceding pulses has already been improved in the LFEX laser system down to 10^{-10} by introducing saturable absorbers in its front-end system. The good pulse contrast results in the enhancement of the high energy conversion efficiency (12%) from the LFEX laser to the low energy component of the REB, whose mean energy is close to the optimum value (1 MeV) [3].

The large divergence angle of the laser accelerated REB is the other critical problem of the FI scheme. Guiding the REB using an externally applied kilo-tesla magnetic field has been studied by simulation [4], and seems to be able to solve the REB divergence problem. A kilo-tesla magnetic field has been generated by using the capacitor-coil target [5], and kilo-tesla magnetic field strength was measured using a B-dot probe and proton radiography [6]. Guiding the REB using an externally applied magnetic field was previously demonstrated experimentally in a planar geometry.

In an actual FI experiment, a magnetic mirror structure associated with the fuel compression is generated. Compression of the fuel and magnetic field, and REB transport in the compressed magnetic field were studied numerically as shown in Fig. 2. Figure 2 (b) shows compressed magnetic field strength, a moderate mirror ratio (R_m ~ 3) between the cone tip (300 T) and compressed core (1 kT) can be generated using a spherically converging shock wave due to fast diffusion of the embedded magnetic field in the shock compressed region [7]. This moderate mirror structure is adequate to efficiently guide the REB to the fuel core without significant REB reflection induced by the mirror magnetic field. The integrated experiment designed by the integrated simulation is under preparation for being conducted in FY2016.

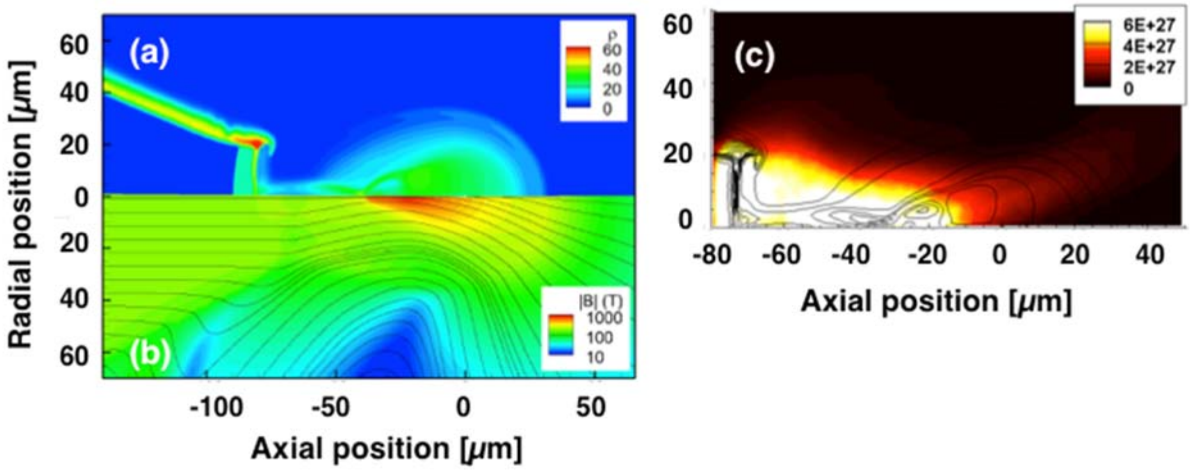

Figure 2. (a) Mass density profile of compressed plasma core under the magnetic field. (b) Lines are examples of the field lines, and color scale shows field strength in kT unit. Field strength at the cone tip is 300 T and the maximum compressed field strength at the maximum compressed area is 1 kT. Moderate mirror ratio (R_m ~ 3) is generated. (c) Energy density of the REB guided by the compressed external magnetic field.

3. Next Step

After the achievement of the FIREX-I project, we will take the next step toward development of the inertial fusion energy. It will consist of ignition demonstration with the FI scheme at the FIREX-II project and development of integrated engineering test. International collaboration and cooperation are essential to fast-track the FIREX-II project. We will launch the international planning committees of the FIREX-II project. On the other hand, the integrated engineering test focuses to clarify engineering feasibilities of the IFE reactor technologies as the integration of high-repetition high-power laser, target injection-tracking, laser-beam steering, and fusion chamber-and-blanket technologies. This facility has a potential to generate ten to hundred trillion fusion neutrons in a second.

References

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