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Realization of high efficiency heating of compressed fusion fuel with high-energy Peta-watt Laser LFEX

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Fast ignition realization experiments were carried out on GEKKO-LFEX laser facility. Present LFEX laser delivers 1.4 kJ of laser energy in 1.5 ps of pulse duration by two beams. Pedestal intensity of the LFEX laser is a critical parameter to determine coupling efficiency of the LFEX laser energy to temperature of the compressed fuel core, two new schemes have been successfully installed in the front end system of the LFEX laser to reduce the pedestal intensity. Neutron yield were carefully evaluated with the consideration of the photodisintegration neutrons those are the dominant source of the background signal especially in the time-of-flight neutron measurement. LFEX injection timing relative to the fuel compression timing was measured with a γ-ray shielded x-ray streak camera with an accuracy of 10 ps. Neutron yield was enhanced up to 3.5 x 10^7 in the fast ignition integrated experiment. The comparison between the simple modeling and experiment results reveals that 20% of coupling efficiency was achieved.

1. Introduction

The direct-drive fast-ignition laser fusion is an attractive approach for the fusion power plant development, because high gain is achievable with relatively small energy laser facility [1]. KOYO-F is a conceptual design of the DEMO fusion reactor based on the direct-drive fast ignition laser fusion [2]. There are three stages in the fast-ignition laser fusion, the first is the compression of the fusion fuel by shaped ns-laser pulses, the second is heating of the compressed fusion fuel by intense ps-laser pulse, and the third is ignition and burning of the heated fusion fuel. The compression of a surrogated fusion fuel (deuterized plastic capsule) up to 1000 times solid density has already demonstrated on GEKKO laser facility in 1991 [3]. The ignition and burning of the fusion fuel will be demonstrated on NIF in the near future [4]. The purpose of our FIREX (Fast Ignition Realization Experiment) project is to demonstrate fast heating of the compressed fusion fuel up to the ignition temperature, namely 5 keV. A kilo-Joule class PW laser, called LFEX, is now under development. FIREX experiment is under investigation by using a part of the LFEX laser.

2. Enhancement of DD neutron yield by LFEX

Gold-cone-attached fuel capsules are used in the experiment [5]. Fuel capsule is imploded by GEKKO laser, dense fuel core is formed at the tip of the gold cone, and the LFEX laser is injected through the inside of the cone. The inside of the cone should be vacuum to deliver efficiently the LFEX laser energy to the fuel core. In general, short laser pulse contains a ns-pedestal background component dominated by amplified spontaneous emission generated in a chain of amplification system and/or a ns-pulse uncompressed in the pulse compression process. If the pedestal intensity exceeds 1 x 10^{10} W/cm^2, the pedestal can produce a preformed plasma in the cone. The pedestal intensity should be less than 1 x 10^{10} W/cm^2 to keep vacuum in the cone. Two schemes were introduced in the front-end system of the LFEX laser to reduce the pedestal intensity. One is amplified optical parametric fluorescence (AOPF) quencher beam was injected into optical parametric chirp pulse amplification (OPCPA) chain, and saturable absorbers were installed [6].

Target is a gold-cone-attached deuterized plastic capsule, whose diameter and wall thickness were 500 μm and 7 μm respectively. Open angle and wall thickness of the cone was 45 degree and 7 μm, respectively. Nine beams of GEKKO laser were used to implode the surrogate fuel capsule, and each beam delivers 1.2-ns duration 0.53-μm wavelength laser pulse with 280 J of energy. The compressed fuel was heated by the LFEX laser. Specifications of the LFEX laser beams are written in the preceding section.

Neutron yield was measured by changing the injection time of the LFEX laser. The window width of the neutron yield enhancement was 25 ps, this means that the inertial confinement time of the fuel core is about 25 ps in the present experiment. Two-dimensional fusion reaction code was used to calculate dependence of neutron yield on heating laser energy. In this calculation, Gaussian density profile of fuel core with 100 g/cc of the peak density and 0.1 g/cm^2 of areal density were assumed, and the dependences were calculated by changing coupling efficiencies between the LFEX energy and fuel core internal energy. Figure 1 shows the comparison between calculation and experimental results. Black circles were obtained in the 2001 experiment by using GEKKO-PW laser facility [7]. The red stars were obtained in the last (2010) experiment. Solid lines correspond to the calculation with the 2010 experimental conditions and Dotted lines correspond to the calculation with the 2001 experiment. Colors correspond to the assumed coupling efficiencies. It is found that 20% of the maximum coupling efficiency was achieved in the last experiment.

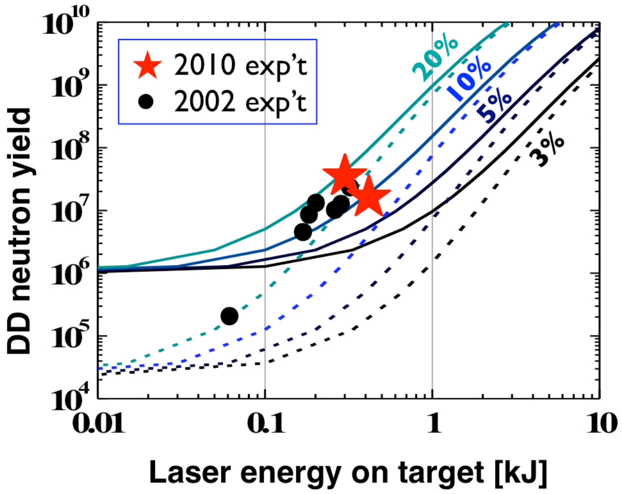

Figure 1 Dependence of DD neutron yield on injection laser energy. Points are the experimental results obtained in 2001 and 2010 campaign. Lines are calculated dependence.

3. Advanced design of fast-ignition target

The advanced target design should be tested to enlarge the coupling efficiency. Fast electrons are scattered and stopped by strong electric field of highly ionized high-Z (i.e. gold) ions, low-Z cone is studied for reducing energy loss of the fast electrons in the cone tip region [8]. We have started to fabricate diamond-like carbon cone for the next integrated fast-ignition experiment. Pointed cone tip target [9] is considered not only for extending survival time of the cone tip against the dense fuel core but also for guiding the fast electrons to the fuel core by the self-generated magnetic field. External magnetic field will be applied to compression of the fuel capsule [10] to form a strong magnetic field to guide the fast electrons to the fuel core.

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