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Generation of Pre-formed plasma inside a cone target in Fast-ignition Scheme
高速点火コーンターゲット内部のプレプラズマ生成

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We investigated generation of pre-formed plasma inside cone targets due to a pre-pulse of the main ultra-intense laser pulse in the fast-ignition scheme of the inertial confinement fusion. We estimated the density gradient scale length of the pre-formed plasma inside the cone target to be 27-47 microns between the critical and 1/10 of the critical density in the current FIREX experiment, based on the 2D radiation hydrodynamic simulations. In order to reduce the effects of pre-formed plasma on the generation of fast electrons inside a cone, and increase the energy coupling efficiency from the ultra-high intense short-pulse laser to the imploded core plasma we propose the advanced concept of a cone target, which can relax the impact from the implosion plasma, and focus fast electrons to the imploded core plasma by self-generated magnetic fields.

1. Introduction

In order to achieve the high-gain of the thermonuclear burn in the fast-ignition scheme of inertial confinement fusion, we need to increase the energy coupling efficiency between the ultra-high intense short-pulse laser and the compressed core. Kodama et al [1] conducted the first experiment on this fast ignition in 2000. Then, Osaka University started the fast ignition realization experiment (FIREX) in 2009 [2]. This project has two phases. In FIREX-I, the goal is to achieve the ignition temperature of 5 keV by ultra-high intense laser heating. FIREX-II aims at achieving high gain thermonuclear burn. In order to get the core temperature of 5 keV, the energy coupling from the heating laser to imploded core must be increased. Baton [3] pointed out that pre-formed plasma inside the cone significantly disturbs the fast electron flow to the core. Cai [4] showed that existence of the pre-formed plasma inside the cone reduces creation of fast electrons of the energy less than 5 MeV. These electrons are the dominant contributor to heating of the core plasma. Johzaki et al. [5] simulated generation of fast electrons using ultra-high intense laser and its transport to the core plasma, and they estimated that 10 micron scale pre-formed plasma lowered the coupling efficiency by ~ 20 %, compared to the case of 1 micron. In our talk, we will show the current level of pre-formed plasma formation in FIREX experiments and we propose the advanced concept of the cone target to improve the heating energy coupling from the short-pulse laser to the compressed core plasma.

2. Pre-plasma formation

We simulated the pre-plasma formation inside the cone in FIREX experiment by 2D radiation hydrodynamic simulation [6]. The laser wavelength and the spot diameter are set to 1.06 microns and 40 microns (Gaussian FWHM), respectively. The laser temporal profile is a flat top profile. The diameter of the tip of the cone target is 30 micron. The laser intensity is set to 1×10^{11} W/cm^2, 1×10^{12} W/cm^2, and 1×10^{13} W/cm^2, and the open angle of the cone was set to 30 ^{o}, 45 ^{o}, and 60 ^{o}, respectively. The wall thickness of the cone tip and the wall near the tip were both 10 microns. In Figs. 1 (a)-(c), we show simulation results for various cone open angles and laser intensities; (a) 1ns pulse duration, (b) 2ns, and (c) 10ns, respectively. In Fig. 1 (a), we see that as the laser intensity increases, the generated pre-formed plasma fills the space inside the cone. For 30 ^{o} open angle and the laser intensity of 10^{11} W/cm^2, the pre-formed plasma is localized around the tip. However, when the intensity increases to 10^{13} W/cm^2, the pre-formed plasma expands to the entire space. This effect is reduced when the open-angle of the cone increases, since a larger open- angle cone has a larger volume to be filled with the pre-formed plasma. Also, the pre-formed plasma flow from the sidewall collides along the center axis of the cone, and yields a plasma jet. This jet was observed in the Hydra simulation [7], and as the laser spot diameter increases, this jet-like structure becomes prominent.

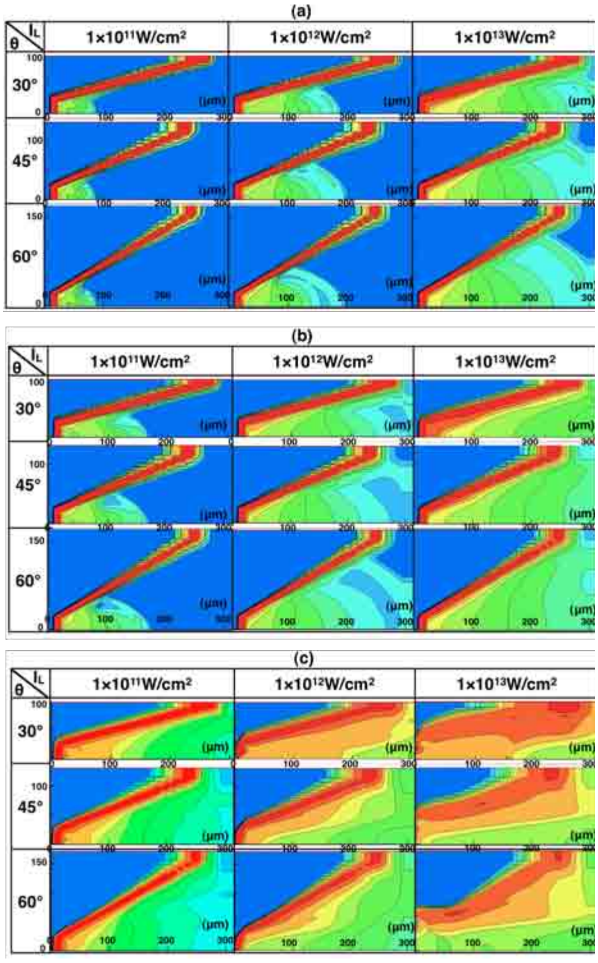

Fig. 1(a)-(c): Electron number density n_e (cm^{-3}). (a) 1 ns duration pulse, (b) 2 ns, and (c) 10 ns. I_L is the laser intensity of 1×10^{11} W/cm^2, 1×10^{12} W/cm^2, and 1×10^{13} W/cm^2, respectively. The cone open angle is, respectively, 30°, 45°, and 60°

3. "TONGARI" TIP

Another critical issue is the impact from the imploded core plasma on the tip. The protection of the cone tip is very important to the future fast-ignition design, since when the implosion energy is increased, a high-pressure shock wave can easily destroy the cone tip. For the remedy, we propose using a pointed cone tip (TONGARI) shown in Fig. 2. Using the pointed shape, we can increase the shock-traveling time from the imploded core to the inner surface of the tip. We simulated the shock propagation in an aluminum pointed tip from the implosion plasma under the typical implosion condition of FIREX. The length from the inner surface to the tip is 50 microns, and the tip is located at the center of the implosion. The areal density is 2.7 g/cm^3 × 50 microns = 0.0135 g/cm^2, which is still smaller than 0.0193 g/cm^2, the value for the conventional 10 micron gold flat tip. If we use diamond-like carbon (DLC) or aluminum of the solid density 2~3 g/cm^3, we can increase the delay time to 20-30 ps, even though the lower-Z material has a smaller areal density compared to that of the conventional gold tip with 10 micron. Also, we investigate another function of focusing fast-electrons by TONGARI tip cone. The resistivity of DLC or aluminum pointed tip is relatively higher than that of surrounded CH or DT plasma. In this situation, when fast electrons flow because of ultra-high intense laser irradiation, a magnetic field will be generated along the boundary between the implosion plasma and the pointed tip. Subsequently the magnetic field may focus the electron flow to the imploded core.

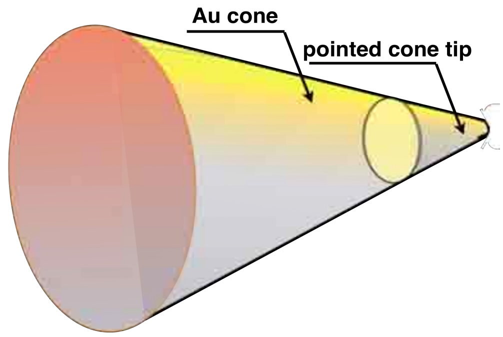

Fig. 2. Schematic of the (TONGARI) pointed cone.

4. Conclusion

We estimated the density gradient scale length of the pre-formed plasma inside the cone to be 27- 47 microns at the densities between the critical density n_{cr} and 1/10 n_{cr} by 2D radiation hydrodynamic simulations. In order to protect the cone tip from the implosion plasma, and increase the heating energy coupling, we propose use of a pointed cone to protect the cone tip from the break through of the shock wave from the implosion plasma, before the main pulse irradiation starts. Also the focusing fast-electrons can be expected.

References

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