Control of imploded core plasma by changing beam arrangement of Gekko XII

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Abstract. We proposed the new laser arrangement to implode a target, a 12-beam implosion, and tried it in a fast ignition integration experiments. The concept of the 12-beam implosion is as follows. The three laser beams near a cone are shifted not to irradiate a cone and a long gold cone is used to prevent the irradiation of those three laser beams with fundamental frequency. In experiments, time-resolved two-dimensional X-ray images of an imploded core plasma were obtained by an X-ray framing camera. It is found that the spherical symmetry of the imploded core plasma is improved and the motion of the imploded core plasma towards the cone is suppressed in half in the 12-beam implosion. We believe that the 12-beam implosion will become a useful concept in controlling the imploded core plasma.

1. Introduction

Fast ignition is one proposed technique for achieving a high fusion energy gain factor in inertial fusion research [1-3]. The Fast Ignition Realization Experiment (FIREX-I) project is going on at Osaka University by using a Gekko XII laser system and an LFEX laser system. Usually, three laser beams of the Gekko XII are not used for implosion because they irradiate a cone. However, it was found that this laser unbalance caused an ununiform implosion and made the imploded core plasma move toward the cone [4]. This moving core plasma may collide with the cone tip and break it. This may disturb the generation of fast electrons from the cone tip and become a serious problem for effective heating. Therefore, we proposed the new laser arrangement to implode a target, a 12-beam implosion, and tried it in a fast ignition integration experiments.

2. The concept of a 12-beam implosion

Figure 1 shows a schematic diagram of a target and configurations of the Gekko XII laser beams. The figure has rotational symmetries through 120 degrees. For example, three beams (Beam 3, 5, 9) have the same positional relationship to the target and each beam disposed deviated by 120 degree in the cone axis. It is clearly seen that the three laser beams near the cone (Beam 3, 5, 9) irradiate the edge of the cone.

Therefore, we changed beam configuration as shown in Fig. 2. The three laser beams (Beam 3, 5, 9) are shifted not to irradiate a cone. We cannot focus a laser beam tightly after a random phase shifter
because of its optical property. Tight focus of this additional three beams is needed for cone clearance. Therefore we did not use the random phase shifters for additional three beams which are different from conventional implosion beams. In addition, we extended the length of the cone by 1.7 mm in order to prevent irradiation by those three beams with fundamental frequency. (The conventional cone size is shown as a broken line in Fig. 2.) This change does not make target alignment particularly difficult.

The energy of three beams (Beam 3, 5, 9) was determined as follows. First of all, we estimated the area of irradiation from the focal length of the beams. From the calculation, it was found that the area of irradiation by the beams near the cone became 0.72 times smaller than that of the other beams. Secondly, the energies of the other beams are decreased by about 20 % because of random phase shifters. Therefore, in order to conform the energy density of the beam near the cone to that of the other beams, the energy of the beam near the cone set to 60 % of that of the other beams.

**Figure 1.** Schematic diagram of a target and an original configuration of the Gekko XII laser beams in the 9-beam implosion.

**Figure 2.** Schematic diagram of a target and a configuration of the Gekko XII laser beams in the 12-beam implosion. The conventional cone size is shown as a broken line.
3. Experimental setup
The experiments were performed using the Gekko XII and the LFEX laser system at the Institute of Laser Engineering, Osaka University. The wavelength of the Gekko XII laser was 0.53 µm and the pulse duration was 1.5 ns. The total energy of the GXII implosion laser was about 2 kJ. The wavelength of the LFEX laser is 1.05 µm and the pulse duration was set to 1~5 ps.

An X-ray framing camera (XFC) [5-7] was used to obtain the time-resolved two-dimensional X-ray images of the imploded core plasma. Details of our XFC system are described in ref. [7]. An array of 10 µm diameter pinholes was used to create separate two-dimensional X-ray images. The blast shield made of 25-µm-thick beryllium was attached in front of the pinhole disk in order to shield it from debris and soft X-rays. Platinum X-ray mirrors were introduced to prevent noise caused by high energy X-rays. Only thermal X-rays (< 5keV) were reflected by these mirrors. The direct incidence of high energy X-rays through pinhole disk was shielded by a lead block. Two-dimensional images were projected onto a multi-channel-plate (MCP) with a size of 40 mm × 50 mm. The MCP had two gold striplines across its face. An electric pulse was sent down a stripline to obtain the image under each pinhole only when the pulse was present at that location on the MCP. The intensified images were recorded with a CCD camera. The time interval between frames was about 80 ps and the spatial resolution was 17.3 µm. XFC was set perpendicular to the cone axis.

Targets were deuterated plastic shells with gold cones. The diameter of the shells was 500 µm. Long cones, whose length were 2.7 mm, were used in 12-beam implosion experiment. Conventional cone, whose length were 1 mm, were used in the other experiments. The distance between the cone tip and the center of its shell was set to 50 µm.

4. Results and Discussion
Figure 3 (a) and 3 (b) show XFC images of imploded core plasmas obtained in the usual 9-beam implosion and 12-beam implosion, respectively. The position of the chamber center is indicated by a white cross. The position of the cone tip is marked with a white dotted line. In every experiment, the tip position was checked before it was set and we checked that the shell center was located at the chamber center before it was shoot. Therefore, we can guarantee their position in XFC images. In Fig. 3, it is clearly seen that the imploded core plasma shows more spherical form in the 12-beam implosion than that in the 9-beam implosion. We defined the edge of the imploded core plasma as the point where the X-ray intensity exceeded the noise level. The radius of the imploded core plasma was calculated by using this edge position and the center of mass position. The spherical symmetry of the imploded core plasma was quantified by the ratio between the standard deviation and the mean value of the imploded core plasma radius. The calculated value was 0.09 in the 12-beam implosion, while it was 0.14 in the 9-beam implosion. This means that the spherical symmetry of the imploded core plasma is certainly improved in the 12-beam implosion.

As shown in Fig. 3 (a), in the 9-beam implosion, the imploded core plasma is generated near the cone tip and moves toward the cone. On the other hand, as shown in Fig. 3 (b), in the 12-beam implosion, the imploded core plasma is generated away from the cone tip and stays there. In ideal case, three beams near the cone balance with opposite three beams and the imploded core plasma will be formed at the center. In this case, additional three beams might be too intense to balance and generate the imploded core plasma away from the cone tip. The velocity of the imploded core plasma was estimated from the time variation of the center of mass position. In the 12-beam implosion, it is found to be suppressed to about half (0.45 × 10⁷ [cm/s] ) of that in the 9-beam implosion (1.20 × 10⁷ [cm/s] ).

Two dimensional simulation [8, 9] also confirmed this idea. We are going to publish a paper including this simulation result soon.

Figure 4 shows high energy X-ray intensity observed by an electron spectrometer. As shown in Fig. 4, the photon number of high energy X-ray in the 12-beam implosion may be slightly high relative to it in the 9-beam implosion. If preformed plasma is generated inside of the cone prior to an irradiation of LFEX laser, it is heated overly by irradiation of LFEX laser and generates high energy X-ray by bremsstrahlung radiation. Above mentioned result may suggest the fear of the preformed plasma
generated inside of the cone by irradiation of three beams near the cone or shock waves generated by those beams. Further study is needed to discuss this result.

5. Summary
The new beam layout, a 12-beam implosion, was tested with Gekko XII and LFEX lasers. Time-resolved two-dimensional X-ray images of the imploded core shows that the spherical symmetry of the imploded core plasma is improved and the motion of the imploded core plasma towards the cone is suppressed in the 12-beam implosion. Although further study is needed to clear the high X-ray generation problem, we think that the 12-beam implosion must become a useful concept to control the imploded core plasma.

![Figure 3](image1)

**Figure 3.** XFC images of imploded core plasmas obtained in (a) the conventional 9-beam implosion and (b) the 12-beam implosion, respectively. The position of the chamber center is indicated by a white cross. The position of the cone tip is marked by a white dotted line.

![Figure 4](image2)

**Figure 4.** The high energy X-ray intensity observed by an electron spectrometer.

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