Converging shock generation with cone target filled with low density foam

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Abstract. We have been developing an alternative scheme of fast ignition of inertial confinement targets with converging shock. Experiments were carried out on GEKKO-XII laser facility at ILE, Osaka University. We employed Au cone targets filled with low-density RF foam (2 mg/cm^3). The foam-filled cone targets were irradiated by three beams of the GEKKO-XII, with pulse duration of 1.3 ns, intensity of ~ 10^{14} W/cm^2 in 2 :λ(ω0.527μ m). Self-emission at the tip of cone was observed by one-dimensional streaked optical pyrometer (SOP) and two-dimensional images.

1. Introduction

Fast ignition scheme is an attractive approach for fusion ignition with lower laser energy because hot spark and high-density fuel should not be generated simultaneously with one laser condition. Many experimental and theoretical works have been done in order to find optimum condition for ignition by means of hot electrons [1,2], ions [3], strong shock wave by "spike pulse" [4], and high velocity impactor [5]. Here we propose the hot spark generation by a different scheme with fast converging shock wave. The high-temperature spark generation with converging shock wave is very similar to high-velocity implosion [6-8], which generates high temperature and low density plasmas. Schematic picture of ignition by the converging shock wave is shown in Fig. 1. The target configuration is combination of slow and fast implosions. The slow implosion of the main hollow shell is to produce high-density and low-temperature fuel with isochoric compression whereas the fast implosion of inside the cone target filled with low density foam is to produce hot spark with shock multiplexing. By using cone-in-shell target, these two implosions can be separated spatially and temporally. In our preliminary target design, the fast implosion is guided to inside of the cone. The strong shock wave converges towards the tip of the cone in which low-density foam is filled in the cone. The advantage of the use of foam is for higher initial density than gas medium. In the

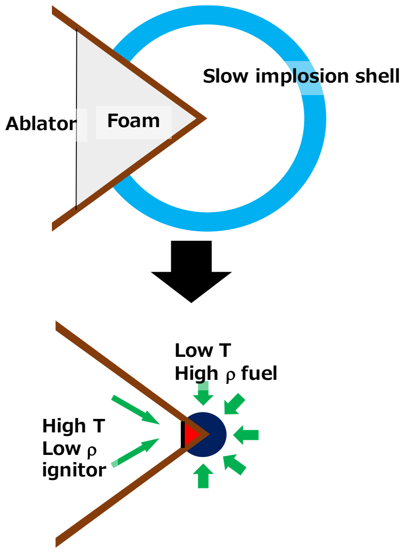

Figure 1 Schematics of ignition by converging shock wave

previous high-velocity implosion experiments, the gas pressure was around 10 to 50 Torr in deuterium or tritium.

In this paper, we report on preliminary experiments on shock propagation for converging geometry using cone targets filled with low-density foam. Temporal evolution of self emission at the top of cone was observed by optical diagnostics in order to verify the uniformity of the converging shock.

2. Experiments

Experiments were carried out on GEKKO-XII laser facility at ILE, Osaka University. Figure 2 shows schematic view of the target irradiation configuration. We employed Au cone targets filled with low-density RF foam. The density of the RF foam (CHO) was 2 mg/cc. The thickness and opening angle of the cone were ~7 μm and 90 degrees, respectively. A polystyrene foil (5-μm thickness) was attached on the entrance of the cone, and an Al foil (5-μm thickness) was attached on the tip of the cone. The foam-filled cone targets were irradiated by three beams of the GEKKO-XII, with pulse duration of 1.3 ns (Gaussian), energy of ~ 1kJ in 2ω (λ: 0.527 μm). The focal spot diameter of each beam on the cone entrance was around 400 μm. For the reference data in planar geometry characteristics, we also irradiated planar low-density foam of 300-μm thickness.

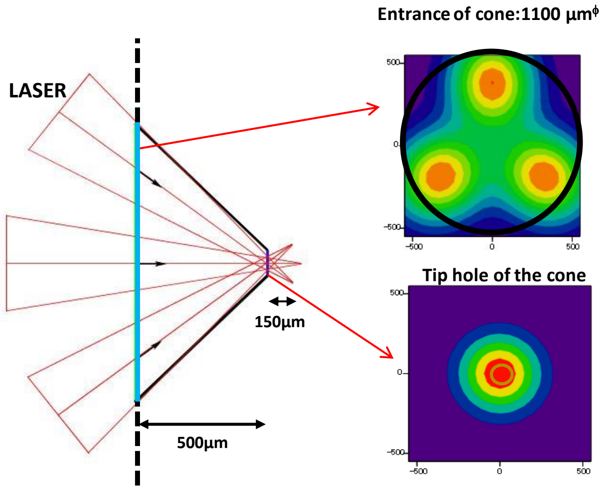

Figure 2 Irradiation configuration of cone target filled with low-density foam.

On the optical measurements, we employed streaked optical pyrometers (SOPs) in order to estimate the temperature of converging shock front at the tip of the cone. One of the SOPs was conventional one-dimensional SOP. We also employed HISAC (high-speed sampling camera) [9] in order to obtain time-resolved two-dimensional self-emission images at the top of the cone. For the planar geometry experiment, x-ray shadowgraph measurements with an x-ray streak camera were also done simultaneously with the optical diagnostics.

3. Results and Discussions

The basic parameters on shock propagation in the low-density foam were taken with planar low-density foam target. Figure 3 (a) shows a raw streaked image by the SOP. From the raw streak image, temporal profile of the self emission at the centre of the foam was plotted as in Fig. 3 (b). Also overlayed

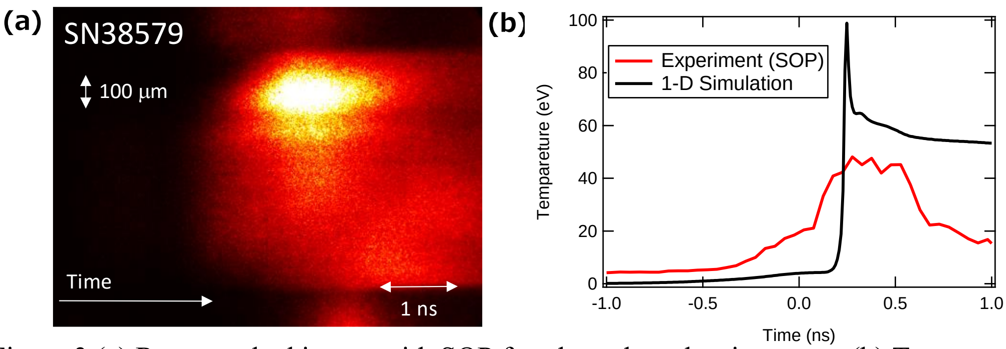

Figure 3 (a) Raw streaked image with SOP for planar low-density target. (b) Temperature from SOP data and from ILESTA-1D calculation.

in Fig. 3 (b) is the temperature at the rear surface (Al) calculated by one-dimensional hydrodynamics code ILESTA-1D [10]. The experimental shock breakout timing shows good agreements with the simulation results. The experimental data and the simulation calculation also indicates a small preheating prior to the shock breakout. The temperature in the foam at uncompressed region from the simulation calculation shows more than 5 eV (not shown here), suggesting that the foam is not no longer foam material but partly ionized gas which is compressed by the shock wave.

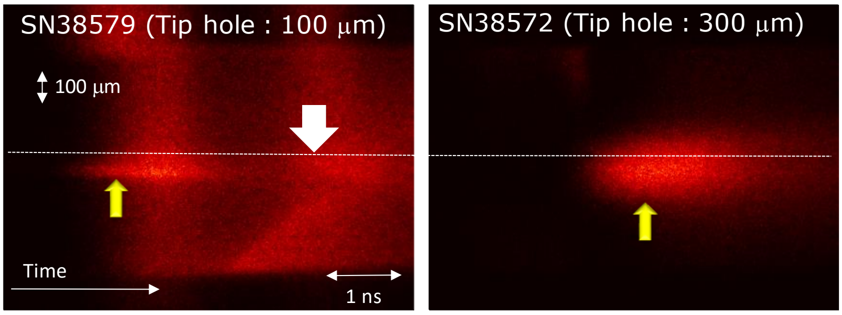

Figure 4 One-dimensional SOP images for the tip size of 100- and 300-μm. Dotted lines show the position of the TCC (target chamber centre). Yellow arrows are timing of laser peak timing for each shot.

In order to observe the behavior of the shock converging, we measured the self-emission at the tip of the cone by changing the hole size of the tip. Since the shape of the cone was same, the shock propagation distance was slightly different by changing the hole size. Figure 4 shows raw streaked images of cone targets taken by the one-dimensional SOP. These images are for the cone tip diameters of 100 and 300 μm. The raw data clearly indicates collimated emissions in accordance with the hole size of the tip. The shock breakout timing of each shot shows in good agreements with the ILESTA-1D simulation. On the other hand, the position of the self-emission is not at exactly center of the target chamber center (TCC). That might be due to the accuracy of the target alignment.

In order to evaluate the two-dimensional self-emission image, we employed the HISAC with a bundled fiber system. The bundle fiber has 225 ch (15x15), with the field of view of ~500 μm. Figure 5 shows the re-constructed two-dimensional self-emission for the tip size for 100 μm. The HISAC data suggests that the peak emission was at around 220-ps after the laser peak timing, where the position of the peak emission was slightly sifted ~ 60 μm from the TCC. The shift of the self-emission position is in good agreements with the one-dimensional SOP data.

Both from the one-dimensional SOP and the HISAC, the self emission from the tip hole starts much earlier than calculations with ILESTA 1-D calculations for all target conditions. The self-emission starts at more than 500-ps earlier than the laser peak emission timing which indicates that strong preheating is a probable source of the self emission. The preheating would be due to hot electrons which penetrates the low density foam region. Also x-ray radiation is source of the preheating because a part of the laser irradiated inner portion of the cone as shown in Fig. 2. The measured temperature of the preheating was

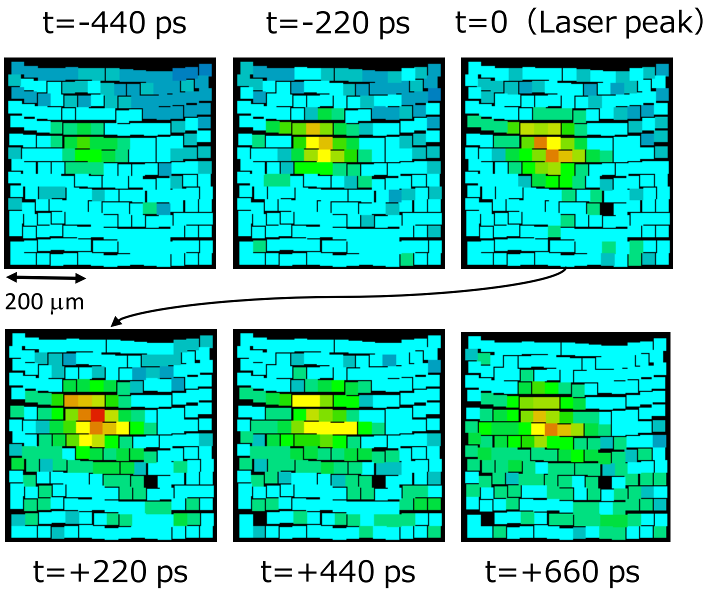

Figure 5 Two-dimensional self-emission image with the HISAC for the 100-μm cone tip target. The TCC position is the centre of each image.

around 20 eV, which is from calibrated value of the SOP. Please note that there is a second flash of the self emission (white arrow in Fig. 4) at later timing. The timing of the second flash is around ~500 ps later from the calculated timing with ILESTA 1-D simulation. We suspect that the second flash is from shock breakout at the tip of the cone after the expansion by the preheating, resulting later timing and weak emission. The irradiation configuration and the target design should be revised and improved for observation of the converging shock front in future experiments.

4. Summary

We have performed experiments on converging shock wave with cone targets filled with low-density form. Optical measurements were carried out in order to verify the shock convergence at the top of the cone. The experimental observations with optical measurements suggest clear shock conversion inside of the cone targets. We observed the self emission due to the shock breakout from the tip of the cone. However, preheating prior to the shock breakout is significant, which should be improved with modifying target design and drive configurations.

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