Upgrade of repetitive fast-heating fusion driver HAMA to implode a shell target by using diode pumped solid state laser

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Abstract. The HAMA is 1-Hz fast heating fusion driver pumped by a 10 J second-harmonic of diode-pumped Nd:glass laser: KURE-1. We have upgraded HAMA to realize an implosion of spherical shell target by using a remaining fundamental beam from KURE-1. This beam of 6 J/1 Hz is transported to the current counter irradiation system. The resulting beam includes three pulses in sequence: 2.2 J/15 ns and 0.7 J/300 ps for implosion, and 0.5 J/190 fs for heating. We estimate the implosion dynamics from 1-D radiation hydrodynamic code (START-1D). It indicates a possibility of tailored-pulse implosion by optimizing the beam spot sizes of imploding beams on the target surface. This upgrade leads to a demonstration of repetitive implosion and additional heating of a spherical shell target in accordance with a repetition of laser operation and that of a target injection system.

1. Introduction

Progress toward fusion ignition is kept going on the National Ignition Facility (NIF) by using 1.8 MJ, 500 TW single shot laser[1]. Following an effort of this scientific proof of ignition, engineering development needs to start on inertial fusion energy (IFE) by using a repetitive fusion driver.
A diode-pumped solid-state laser (DPSSL) is a promising candidate as a reactor driver for IFE because it can be operated at a high-repetition rate (>10 Hz) with high efficiency (>10 %)[2].

We have developed a repetitive fusion driver HAMA[3] by using a 10 J green DPSSL based on a road map[4]. This fusion driver has been realizing repetition-mode fusion experiments such as DD fusion reaction[5, 6], a compact fast core heating[7], and laser engagement of injected flying pellets[8, 9]. The HAMA is a Ti:sapphire laser pumped by a second-harmonic of diode-pumped Nd:glass laser: KURE-I[10]. A 3.8-J, 0.3-ns amplified chirped pulse is divided into four beams: two counter-irradiate a target, and the remaining two are pulse-compressed to 190 fs for heating the imploded target. HAMA succeeded in a compact fast core heating experiment by using double-foil deuterated polystyrene target with 11 μm thick and gap separation of 100 μm[7].

A beam energy of 1 J for implosion limits this target gap. By using a remaining fundamental beam from KURE-I of 6 J, we can approach to an imploding a spherical shell target of φ 500 μm with 7 μm thick, which is commonly used for ICF experiments[11] of kJ class single shot laser. By using 1-D radiation hydrodynamics code: STAR-1D[12], we have simulated a performance of an imploded core formation with HAMA laser including the remaining fundamental beam from KURE-1. This upgrade enables a repetitive implosion and additional heating of a spherical shell target in accordance with a repetition of laser operation and that of a target injection system. This paper describes an improvement of HAMA to accomplish the spherical shell target irradiation.

2. Laser configuration of HAMA upgrade

Figure 1 shows a diagram of HAMA including DPSSL irradiation. The HAMA is a Ti:sapphire laser pumped by a second-harmonic of diode-pumped Nd:glass laser: KURE-I[10]. It consists of a seed laser called BEAT[13] and a pump laser called KURE-I. The BEAT is a 10 Hz Ti : sapphire optical parametric chirped pulse amplification (OPCPA) system. KURE-I is a green 10 J/10 Hz DPSSL system based on a water cooled Nd : glass zigzag path slab amplification scheme [8].

In KURE-I, second-harmonic generation through CsLiB₆O₁₀ nonlinear crystal provides two beams; a second-harmonic:2ω of 8 J, and fundamental:ω of 6 J. Both beams are transported to a HAMA breadboard and split by a beam splitter. The 2ω is then transported to the HAMA amplifier as a pumping beam to amplify the seed pulse from BEAT at a repetition of 1 Hz. In relation to the seed pulse, the amplified seed pulse of 3.8 J, 0.3 ns output is divided into two beams by the L-S beam splitter. One is "L-beam" used for implosion of shell target, the remaining beam is pulse-compressed to 190 fs results in "S-beam" used for heating the ablated target.

The 2ω beam from KURE-1 arrives on the Ti:sapphire at a timing 12.4 ns in advance to the seed pulse from BEAT[13, 14]. The ω, "K-beam", is transported toward the KURE-1 bread board to make a delay, resulting in an irradiation timing of 6 ns in advance to the S-beam. This K-beam is introduced into the L beam line by using the K-L beam combiner. The divergence of K-beam is controlled by a convex lens mounted on a K beam image relay system. Three beams, K, L, and S are split and combined by a 50:50 beam splitter/combiner in the compression chamber, then transported to the irradiation chamber as BEAM-1 and BEAM-2. The resulting beam of BEAM-1 or BEAM-2 includes three pulses in sequence : 2.4 J/15 ns, 0.55 J/300 ps, and 0.40 J/190 fs, respectively.

Figure 2 shows pulse shape in sequence and beam spot profiles of BEAM-1 and BEAM-2. Timing control between K and S is electrical synchronization, L and S is optical synchronization. All of six beams are focused on the chamber center to implode and heat a spherical shell target of φ 500 μm with 7 μm thick. The beam focusing alignments are accomplished simultaneously for OAP1 and OAP2 by using a counter beam focusing monitor to minimize the spot size of short beams, respectively. The resulting beam spot size (1/e²) is 22 μm, 90 μm and 11 μm
for K, L, and S, respectively. For K-beam, spot size on the shell target surface is 100 μm in square. The spot size of L is 8 times larger than that of S, which indicates further improvement of an alignment technique or beam quality is required in the future. Beam characteristics of there beams K, L and S includes pulse duration, energy, and intensity are given in Table. 1. These intensities are values on the focusing center. K and L-beams are used for implosion, and S-beams is for heating, respectively.
Table 1. Four beams energy and intensity on target

| Beam       | Imploding beam | Heating beam |
|------------|----------------|--------------|
| Pulse width (FWHM) | 15.2 ns | 300 ps | 192 fs |
| Energy (J)  | 2.2           | 0.70         | 0.50    |
| Intensity (W/cm²) | 1.9 x 10^{13} | 6.0 x 10^{13} | 4.5 x 10^{18} |

3. Implosion dynamics from STAR-1D

Implosion dynamics for K and L irradiation is evaluated from 1-D radiation hydrodynamics code: STAR-1D[12] by using the laser parameters given in Table 1. Figure 3 represents a hydrodynamic flowchart (radius-time diagram) for K-beam focusing (a) on center and (b) 540 μm in focus. In Fig. 3 (a), a foot pulse of K beam makes shell implosion and core formation before the main pulse of K beam arrives. This main pulse gives re-compression of expanding core and L beam in sequence provides another core formation. By contrast, as shown in Fig. 3 (b) where the beam spot size on the target surface is 2.5 times larger than that of the case (a), the main pulse of K-beam implodes the shell and L pulse in sequence compress the core resulting in a tailored pulse compression in similar. In Fig. 3 (b), the beginning of pulse ”K” ablatively implode the shell. In sequence, the ”L” at 38 ns drives a shock to implode the target inward, resulting in the implosion at 40.5 ns. The ”heating” pulse, ”S”, would be irradiated at this timing. We will scan an irradiation timing of S-beam with scanning range of 2 ns in experiments.

![Figure 3. Hydrodynamic flowchart by START-1D.](image)

4. Conclusions

We improved the HAMA performance to realize spherical shell target implosion and fast heating. The resulting focus intensity of three pulses in sequence is $1.9 \times 10^{13}$ W/cm², $6 \times 10^{13}$ W/cm², and $4.5 \times 10^{18}$ W/cm², respectively. In these intensities, the hydrodynamics simulation indicates implosion of spherical shell target of $\phi$ 500 μm with 7 μm thick and formation of the imploded core at the center.
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