Coherent Beam Combination for Laser Fusion Driver design using Rotating Wedge Self-Phase-Controlled Stimulated Brillouin Scattering Phase Conjugate Mirrors

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Abstract. Laser fusion drivers requires around 40 kJ@10 ps laser for fast ignition. However, it is hard to produce such a high energy, high repetition rate laser because of the thermal problems. The output energy of current high repetition rate laser projects is at most 100 J, even with using the most advanced laser technologies. A coherent beam combining is one of the most promising technique to achieve such a high energy and high repetition rate laser. It has been shown experimentally that the coherent beam combination using self-phase-controlled SBS-PCMs is the simplest coherent beam combination method. Furthermore using a high energy and high repetition rate ns beam combination laser, a high energy, high repetition rate fs/ps laser can be generated by optical parametric chirped-pulse amplification (OPCPA). And so the laser fusion driver can be developed using the coherent beam combination laser. The authors proposed the 0.5 MJ@ 10Hz practical LIFE (Laser Inertial Fusion Energy) driver. The LIFE driver is composed of 192 beam lines similar to NIF, a single beam line would have to produce at least 2.5 kJ@ 10Hz. It is suitably achieved by coherent 25 beams combination of 100 J double pass amplifier modules having SBS-PCM. For 100 J modules, its SBS-cell focal spot load is over 100W. Rotating wedge SBS-PCM should be used to relief the thermal load in the SBS-cell focal spot. To reduce the thermal load in the SBS-cell focal spot, the rotating wedge self-phase-controlled SBS-PCM can be applied. With the rotating wedge self-phase-controlled SBS-PCM, a real LIFE driver having a high energy, a high repetition rate can be developed through the coherent beam combination.

1. Coherent beam combination using self-phase-controlled SBS-PCMs

High energy, high repetition rate laser is required for many scientific and industrial applications. In particularly, laser fusion drivers requires around 40 kJ@10 ps laser for fast ignition [1-3]. It is hard to produce such a high energy, high repetition rate laser because of the thermal problems. The output energy of current high repetition rate laser projects is at most 100 J [4-5], even with using the most advanced laser technologies.

A coherent beam combining is one of the most promising technique to achieve such a high energy and high repetition rate laser. At first, a single laser beam is divided into many sub-beams. After amplifying each sub-beams, beam combiner combines the sub-beams coherently. In the process, the wavefronts and the phases of every sub-beams should be controlled.

It has been shown experimentally that the coherent beam combination using self-phase-controlled stimulated Brillouin scattering phase conjugate mirrors (SBS-PCMs) is the simplest coherent beam combination method [6-7]. By using SBS-PCM as an end mirror in the double pass amplifier, amplifier induced wavefront distortions can be reversed due to the phase conjugation property of the SBS-PCM. However, the phase of the reflected beam from the SBS-PCM is random. Kong et al. proposed self-phase-controlled SBS-PCM (SPC-SBS-PCM). It can control the phase of the reflected beam by using very simple optical element (feedback mirror). Therefore, coherent beam combination can be achieved.

Furthermore using a high energy and high repetition rate ns beam combination laser, a high energy, high repetition rate fs/ps laser can be generated by optical parametric chirped-pulse amplification (OPCPA). And so the laser fusion driver can be developed using the coherent beam combination laser.

2. Laser Inertial Fusion Energy Driver

The authors proposed the 0.5 MJ@ 10Hz practical laser inertial fusion energy (LIFE) driver as shown in the FIG. 1 [8]. The LIFE driver is composed of 192 beam lines similar to NIF, a single beam line would have to produce at least 2.5 kJ@ 10Hz. It is suitably achieved by coherent 25 beams combination of 100 J double pass amplifier modules having SBS-PCM. A 100 J amplifier module operating at high repetition rate can be achieved through current laser technologies.

In the 100 J double pass amplifier modules, the SPC-SBS-PCM controls the phase of the reflected beam from the SBS-PCM. However, due to thermal drift of refractive index in active medium and air convection, the pass lengths of each amplifier modules are drifting with respect to each other. In general, the frequency range of these thermal effects are less than 1 Hz. By moving feedback mirror at the end of the SPC-SBS-PCM, these thermal effects can be easily compensated.

For the 100 J double pass amplifier module operating at 10 Hz, its total output power is 1 kW and its power after a single pass amplification is over 100 W. Since SBS-PCM focuses the incoming beam into the SBS-cell, SBS-cell focal spot load is also over 100 W. An SBS-cell with careful purification process can handle about 100 W of input power [9].

However, when designing an amplifier with higher energy or repetition rate, thermal problem of the SBS-PCM should be treated. Due to low, but nonzero absorption coefficient of SBS material, focused laser beam heats the SBS material. Localized heat load near the focal point can induce thermal convection within the SBS cell, which lowers the reflectivity and the fidelity of the reflected beam.

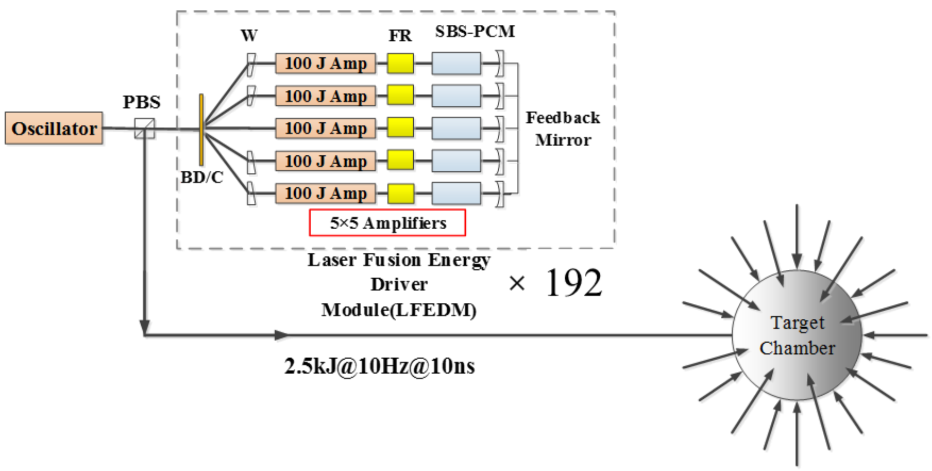

FIG. 1. A schematic diagram of the beam combination laser driver system. PBS, polarizing beam splitter; BD/C, beam divider/combiner; W, wedge; FR, Faraday rotator.

3. Rotating wedge SPC-SBS-PCM

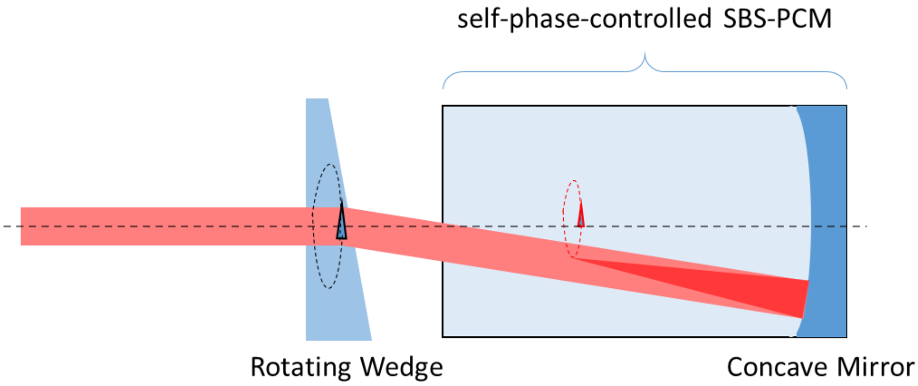

FIG. 2. The rotating wedge self-phase-controlled SBS-PCM

We propose the rotating wedge self-phase-controlled SBS-PCM to relief the thermal load in the SBS-cell focal spot [10]. FIG. 2 shows the schematic diagram of the rotating wedge self-phase-controlled SBS-PCM. The input laser beam is refracted by the rotating wedge, and enters the SBS-cell. The beam is then reflected by the HR coated concave mirror at the end of the cell. It is important to note that the incident angle at the concave mirror is always 0 degree. It is done by positioning the rotating wedge at near the center of curvature of the concave mirror. After reflection, the still-incoming beam acts as a feedback beam and the whole SBS reflection is self-phase-controlled. Since the phase of the SBS reflected beam from the self-phase-controlled SBS-PCM is stable, it can be applied to coherent beam combination.

The rotating wedge makes focus point to rotate around the circle, and each laser pulse has the different focus point around the circle. It reduces the thermal load of SBS-PCM, so high power operation is possible. The rotating wedge self-phase-controlled SBS-PCM can be applied to a real LIFE driver having a high energy, a high repetition rate through the coherent beam combination.

3.1. Beam combination using rotating wedge SPC-SBS-PCMs

FIG. 3 shows the experimental setup of the beam combination experiment using rotating wedge SPC-SBS-PCMs. Although the input power of the rotating wedge SPC-SBS-PCM is low (30 mJ @ 10 Hz), self-phase-control property of the SBS-PCM can be demonstrated. Furthermore, phase control of SBS-PCMs having rotating parts is also tested.

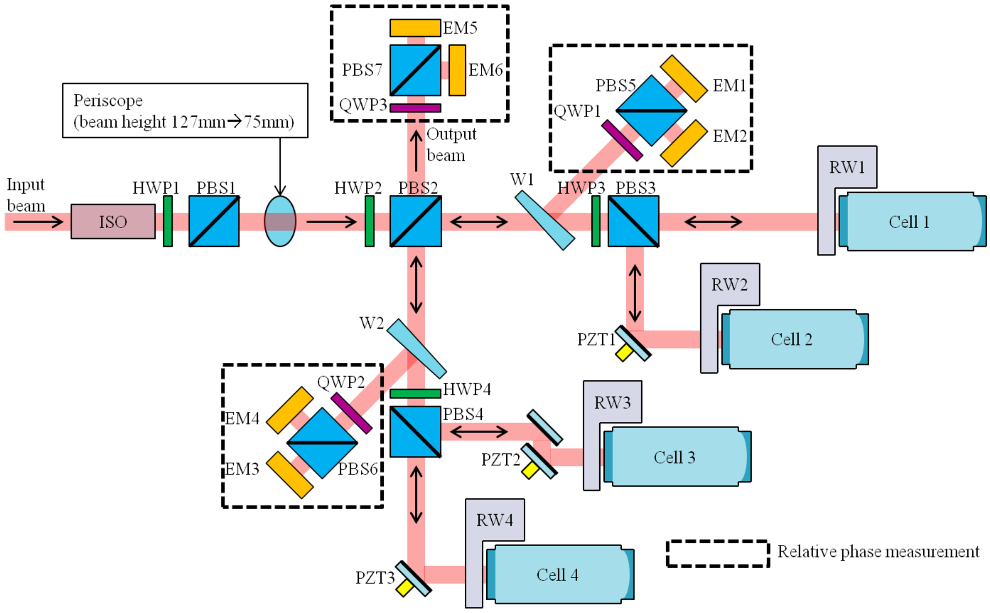

FIG. 3. Experimental setup of the 4-beam combination experiment using rotating wedge SPC-SBS-PCM; ISO, optical isolator; HWP, half wave plate; PBS, polarizing beam splitter; W, wedge; PZT, 45 degree mirror attached piezoelectric transducer; RW, rotating wedge device; Cell, SBS cell; QWP, quarter wave plate; EM, energymeter.

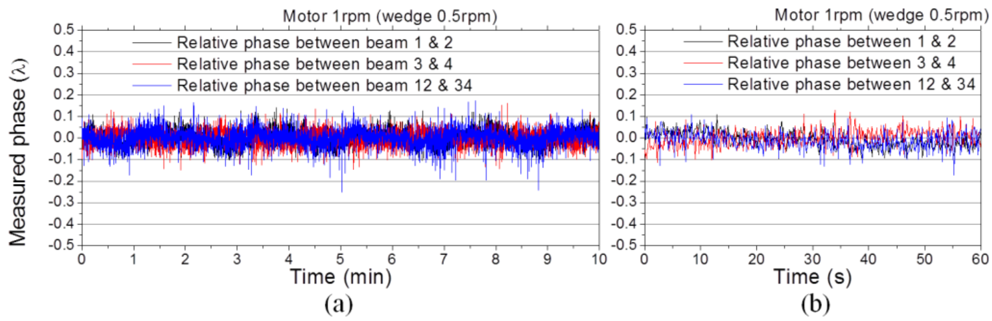

FIG. 4. Experimental results of four beam combination, (a) the relative phases between combining beams during 10 min. shows the rms fluctuation of λ/26.7 (beam 1 & 2), λ/28.8 (beam 3 & 4), and λ/24.7 (beam 12 & 34), (b) detailed results during first 1 min

FIG. 4 shows the experimental results. The relative phases between the beams are controlled to λ/26.7 (between beam 1 & 2), λ/28.8 (between beam 3 & 4), and λ/24.7 (between beam 12 & 34) in rms.

4. Summary

The authors proposed the 0.5 MJ@ 10 Hz practical LIFE (Laser Inertial Fusion Energy) driver. The LIFE driver is composed of 192 beam lines, and a single beam is operating at 2.5 kJ@ 10 Hz. It is suitably achieved by coherent 25 beams combination of 100 J double pass amplifier modules having SBS-PCM. To handle SBS-cell focal spot load of over 100W, rotating wedge self-phase-controlled SBS-PCM is proposed and tested experimentally.

Furthermore using a high energy and high repetition rate ns beam combination laser, a high energy, high repetition rate fs/ps laser can be generated by optical parametric chirped-pulse amplification (OPCPA). And so the laser fusion driver can be developed using the coherent beam combination laser.

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