Beam Combined Laser Fusion Driver using Stimulated Brillouin Scattering Phase Conjugation Mirrors

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Abstract. Beam combination method using stimulated Brillouin scattering phase conjugation mirrors (SBS-PCMs) is a promising technique for the real laser fusion driver, which can be operated with a high repetition rate over 10 Hz. The phase control of the SBS wave is essential for realization of the coherent beam combined output. For this reason, we proposed a novel "self phase control technique" of the SBS wave and its principle has been demonstrated experimentally for the past several years by this group. In this paper, we report the recent experimental work for the phase stabilization of four-beam combined system using the wavefront dividing scheme. The experimental result shows the well-stabilized phase difference between the SBS beams less than $\lambda/18$ fluctuation by standard deviation for 5000 shots (500 s).

1. Introduction

Laser Fusion Energy (LFE) is one of clean energy sources for mankind. In general, LFE needs a high energy laser beams (~5MJ@2ns) with a high repetition rate around 10 Hz [1, 2]. However, there are no laser fusion drivers operating with a high repetition rate around 10 Hz, as it takes several hours to cool down the large size active media. For realization of the real fusion driver, many researchers have been developed their own techniques with beam combination of the small lasers, replacement of the pumping sources by laser diodes, and laser medium by a large size ceramic Nd:YAG [3-17]. Among them, the beam combination method has been expected the most promising technique because it can overcome the cooling problem by separate amplification and increase the output energy by combining many laser beams, using previous developed laser amplification techniques without any changes of the pump sources and the laser media [9-17].

In our laboratory, H.J. Kong et al. proposed the beam combined laser fusion driver using stimulated Brillouin scattering phase conjugation mirrors (SBS-PCMs) [9,10] and have been developed several techniques for this beam combined system [9-18]. The key technique is the self phase control technique of the SBS wave [11-17]. With this technique, it is possible to control each SBS beam phase independently without any limitations in the number of beams. In this paper, we introduce our beam combined laser system and self phase control method. And we also show the recent phase control experimental work of the four-beam combined system using the wavefront dividing scheme for a more high energy beam combination.

2. Beam Combined Laser using Stimulated Brillouin Scattering Phase Conjugation Mirrors (SBS-PCMs)

Figure 1 shows the conceptual schemes of scalable beam combined laser system for a laser fusion driver. Figure 1(a) is the wavefront dividing scheme which spatially divides the main beam into many sub-beams using prisms. Figure 1(b) is the amplitude dividing scheme which divides the beam using polarizing beam splitters. Both schemes are composted of series of cross type amplification stages. This cross type system is relatively insensitive to the optical misalignment. Each amplification stage is composed of the SBS isolator system on the right side and the array amplification system on the left side. The leak back reflection is completely cut off by the SBS isolators. And the beam energy is separately amplified in the array amplification system. This separate amplification does not need large size active media so that the whole system can be operated with a high repetition rate. Furthermore, the high quality beam can be also obtained from the SBS-PCMs used instead of normal mirrors, which compensate the thermally induced wavefront distortion in the amplifiers.

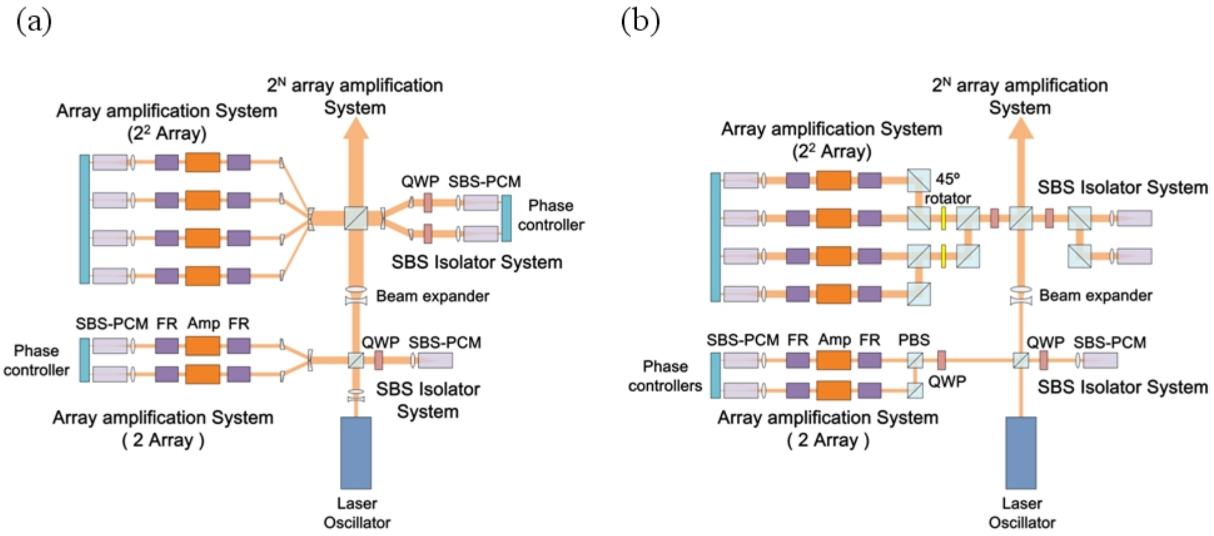

FIG. 1.Conceptual schemes of scalable beam combined laser system for a laser fusion driver: (a) wavefront dividing scheme, (b) amplitude dividing scheme

3. Self Phase Control of SBS Wave

The phase of the SBS wave is naturally random because SBS is generated from the acoustic noise [19]. For coherent beam combination, the phase of the SBS wave should be locked. For this reason, beam combination researchers have been developed the phase locking techniques, such as beam overlapping [6, 7], backseeding [8], and Brillouin enhanced four-wave mixing [20]. In our laboratory, H. J. Kong et al. proposed a new SBS phase control technique, so called “self phase control technique” [11]. This self phase control method can effectively control the phase of each SBS beam, while the backseeding method destructs the phase conjugation and the overlapping and the four-wave mixing methods cannot be applied to the many-beam combination over 10 due to the complicated optical setup.

Figure 2 shows two types of self phase control methods. Both types have a concave feedback mirror for reflecting the front part of the incident pump pulse. This count propagating font part interferes with the rest of the incident pump pulse, and generates the electro-magnetic standing wave inside the SBS cell. This standing wave determines the ignition position of the acoustic wave to one of the nodal points of the standing wave. Therefore, the phase of the ignited acoustic wave can be locked while the phase difference between the nodal points is equal to integer times 2π. Locking the phase of the acoustic wave, the phase of the SBS wave is also locked because the phase of the pump wave is also determined.

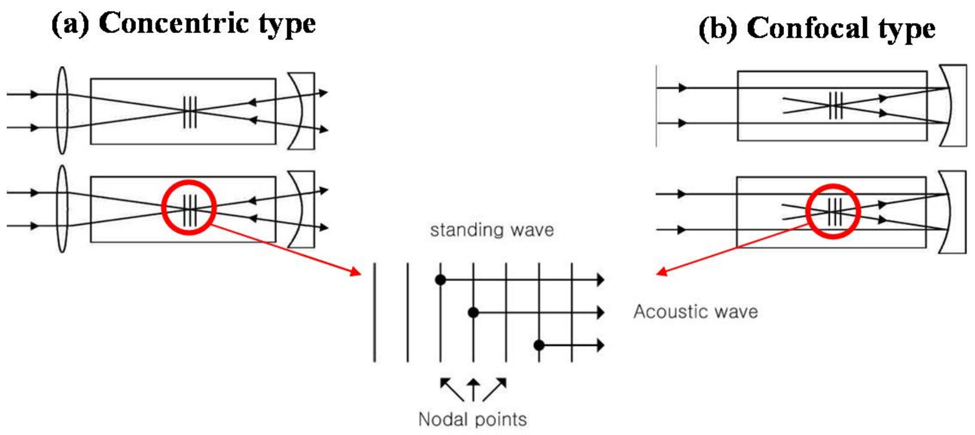

FIG. 2. Self Phase Control Methods: (a) Concentric type, (b) Confocal type.

In our previous works, the experiments were performed to demonstrate the principle of the SBS self phase control with the amplitude dividing scheme, and the well-controlled phase was obtained by measuring the interference pattern of two SBS beams during several hundred shots [11-13]. The relative phase difference was stabilized with $\lambda/36$ fluctuation by standard deviation during 220 shots (22 s) as shown in Fig. 3. However, in the wavefront dividing scheme, a little poor stabilized phase was obtained with $\lambda/7.4$ fluctuation during 238 shots (23.8 s) because the divided subpump beams have the fluctuating energies for every shot due to the beam pointing effect of the laser source [11-13].

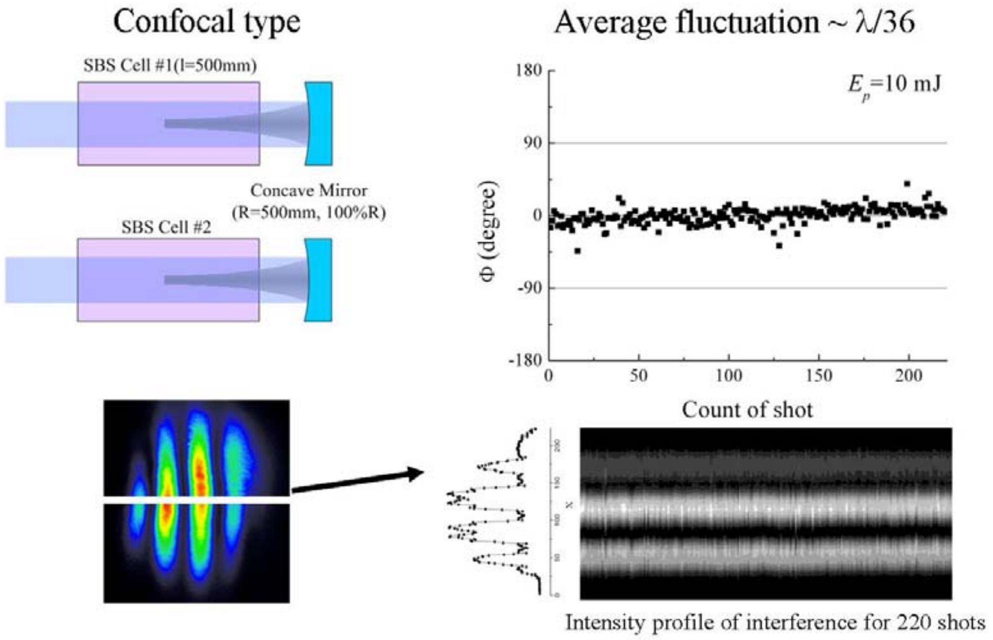

FIG. 3. The relative phase difference and the mosaic intensity profile of the interference patterns between two SBS waves during 220 laser shots (22 s), using the amplitude dividing beam combination.

4. Four-beam Combined System – Wavefront Dividing

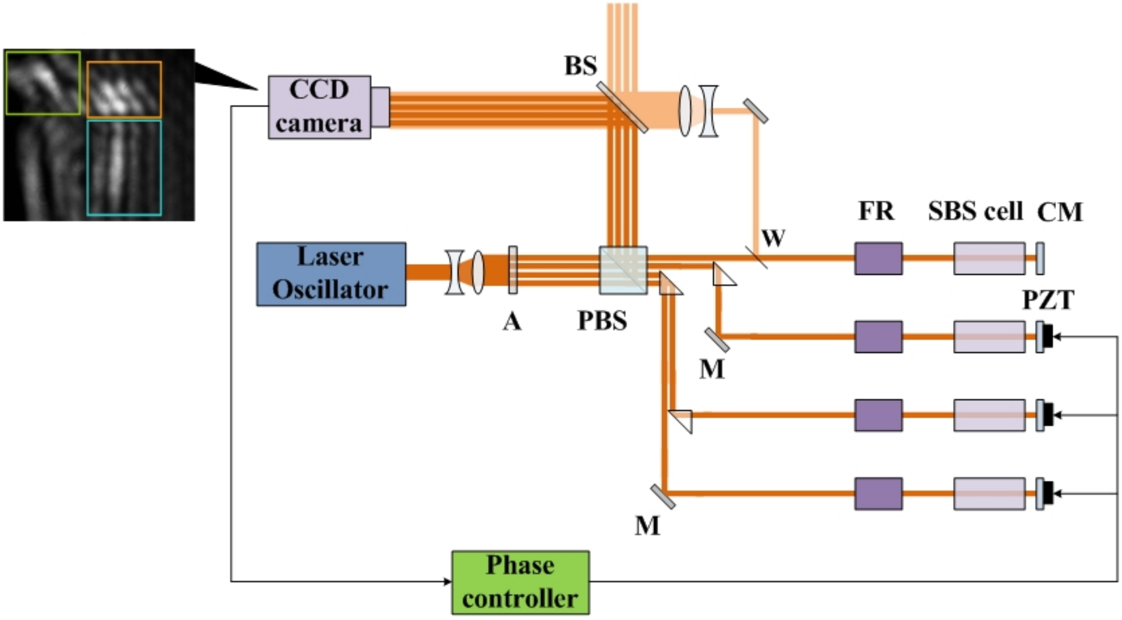

FIG. 4. Four-beam combination system with wavefront division: A; four-beam aperture, PBS; Polarizing Beam Splitter, BS; Beam Splitter, M; Mirror W; Wedged Window, FR; Faraday Rotator, CM; Concave Mirror, PZT; Piezoelectric Translator.

The experimental setup for the four-beam combined system with the wavefront division is shown schematically in Fig. 4. The Nd:YAG laser oscillator generates a single longitudinal mode Q-switched laser beam with 1064 nm wavelength and 10 Hz pulse repetition rate. At first, the beam from the oscillator is spatially divided into sub-beams at the aperture (A), which has four circular holes of ~7 mm diameter, after expansion by four times using spherical lenses. The beam expansion and the use of the aperture (A) can reduce the beam pointing fluctuation of the laser source. The divided sub-beams initially have *p*-polarizations and pass though the polarizing beam splitter (PBS). Each sub-beam is separately split into four parts using prisms and mirrors (M) and reflected by the self phase controlled SBS-PCM, which is composed of a SBS cell filled with FC-75 liquid (3M Company) and a concave mirror (CM) for generation of the standing wave. Passing though the Faraday rotators (FR) twice, the reflected sub-beams retrace to the PBS and are spatially recombined with *s*-polarizations.

The phase relation between the SBS beams were measured for every laser shots from the movement of interference patterns formed by the reference SBS beam and other SBS beams. The reference SBS beam was obtained from the small reflection of one SBS beam (Beam 4) using an uncoated wedged glass window (W) as shown in Fig. 4. This reflected reference beam was expanded by four times and generated the interference pattern of three other SBS beams (Beam 1, Beam 2, and Beam 3) and the reference beam (Beam 4), as shown in Fig.

5(b). And the output beam profile of the four-beam combined system shown in Fig. 5(a) was also measured at the output part of the whole system.

Although the self phase control method was used for the phase stabilization, there existed a long-term phase fluctuation of the SBS wave due to the thermal convection of the liquid SBS medium. This slowly varying long-term phase fluctuation can be easily compensated by active controls of the concave mirror positions of SBS-PCMs. Hence, three PZTs (Piezoelectric Translators) were attached to concave mirrors and adjust the positions of concave mirrors to match their phases to the reference beam as shown in Fig. 4. These PZTs were actively controlled by PZT controllers after measurement of the phase differences between the reference beam and the other beams.

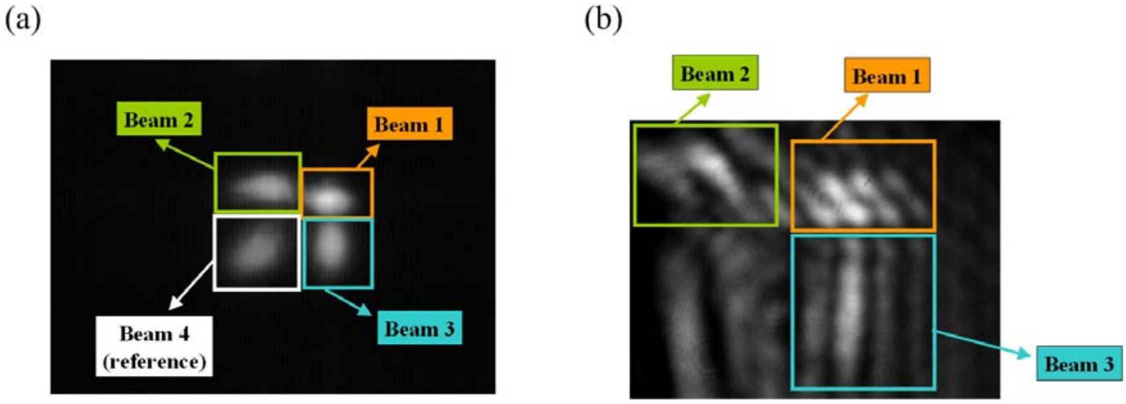

FIG. 5. (a) Four-beam combined output beam profile and (b) the interference patterns of the SBS beams (Beam 1, Beam 2, and Beam 3) with the reference SBS beam (Beam 4).

Figure 6 shows the mosaic intensity profiles of interference patterns and the calculated phase differences during 5000 shots (500 s) between the reference beam and (a) Beam 1, (b) Beam 2, and (c) Beam 3, respectively. In this experiment, the pump beam energy incident on each SBS cell was ~10 mJ. With long-term phase stabilization method, the phase differences between the reference beam and Beam 1, Beam 2, and Beam 3 were well-stabilized with $\lambda/18.7$, $\lambda/18.5$, and $\lambda/22.6$, respectively. This experimental result shows the more improved phase stabilization of the SBS beam for the wavefront dividing scheme.

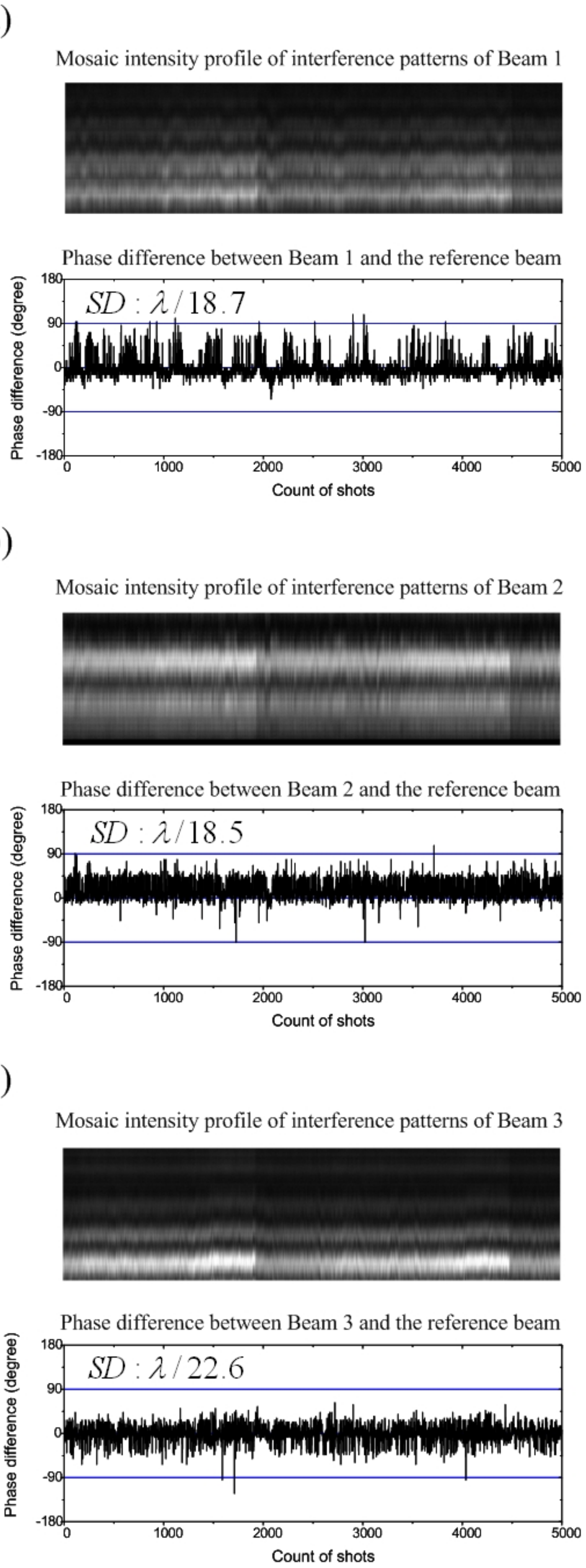

FIG. 6. Mosaic intensity profiles of the interference patterns, and the phase differences during 5000 shots (500 s) between the reference beam and (a) Beam 1, (b) Beam 2, and (c) Beam 3.

6. Conclusions

In conclusion, we have been developed the self phase control technique of SBS wave for realization of the real fusion driver using the beam combination with stimulated Brillouin scattering phase conjugation mirrors. With the self phase control technique and the long-term phase stabilization method using an active control of the PZT mirror, it was demonstrated that the four-beam combined system for the further energy scaling-up can really work. The experimental result shows the well-stabilized phase difference between the SBS beams less than $\lambda/18$ fluctuation by standard deviation for 5000 shots (500 s). On the basis of this experimental work, it is expected that much higher output energy with a high repetition rate around 10 Hz can be obtained by combining many beams of ~ 100 J energies for the laser fusion driver.

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