SBS PCM technique and its possible role in achieving IFE objectives

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Abstract. As an alternative to the IFE classical approach in irradiation of thermonuclear targets by powerful laser beams inside of the reactor chamber the SBS PCM technique will be considered. This technique should take care of automatic self-aiming of every individual laser beam with no need for any steering optics to allow for final beam position adjustment. Even if the injected pellets will inevitably reach for every shot slightly different positions within the prescribed area, their subsequent displacement from the position in which they will be illuminated into the position in which they will be irradiated will always be the same. Therefore, optical elements especially designed for taking care of every individual beam shift can be introduced once for good. This technique can significantly simplify design of laser and beam transport optics allowing for substantial increase in the number of laser beams employed. Every laser beam will operate as an independent driver with much lower energy per pulse thus making the required repetition rate easier to achieve. With many laser beams available any shape of the final irradiating pulse can be realized by considering neighboring laser beams as creating such a pulse shape when combined together on the pellet surface. This could be beneficial for the imprint suppression as well. Also, a final conversion to the third harmonic can be directly implemented into the optical path of every laser beam.

1. Introduction
One of important challenges in the IFE integrated approach deals with successful symmetric irradiation of thermonuclear targets (pellets) by powerful laser pulses inside of the reactor chamber several times per second. For the direct drive scheme the following set of parameters is being considered: pellets $\sim 4$ mm in diameter should be delivered into the area $\sim 5$ mm in diameter centered inside of the reactor chamber $\sim 10$ m in diameter with the overall precision $\sim 20 \mu$m (splitting the allowed error budget equally into the precision of tracking $\sim 14 \mu$m and precision of aiming $\sim 14 \mu$m). Taking into consideration potential obstacles (e.g. collisions with debris from previous shots due to the expected $5 \div 10$ Hz repetition rate) bringing targets into an acceptable vicinity of the optimal position is not an easy task. Some adjustment of final
optics for every shot and every laser beam will always be necessary. A large number of laser beams needed for effective thermonuclear fuel compression (many dozens) makes realizing the whole task of proper pellet irradiation complicated. Looking for some novel approaches which could be helpful in achieving these objectives is thus always desirable. One such alternative to the Standard Approach described above, the usage of the stimulated Brillouin scattering phase conjugate mirror (SBS-PCM) technique, will be outlined in this paper.

2. SBS PCM approach - basic idea

After its discovery in 1972 [1] the SBS-PCM phenomenon was studied with grate enthusiasm by many laboratories. It went through a period of a big boom and high expectations only to calm down a bit in subsequent decades [2]. During the last decade one of the potential SBS-PCM applications has been followed in the search for high repetition high power lasers to be used (among other possibilities) as IFE drivers. Gradual improvements obtained in the laser beam combination technique recently justified inclusion of amplifiers [3]. Reaching this new qualitative level was immediately supported by starting a new series of SBS-PCM oriented international workshops [4] and became an inspiration for considering another SBS-PCM based IFE approach which obtained the IAEA official support [5]. The very first tentative proposal was prepared early this year [6]. A more mature version will be presented here.

The basic idea is the following: the IFE pellet is injected into the reactor chamber with careful tracking performed. At the right moment, when the pellet is approaching the best interaction position, a short low energy pulse (glint) by a seeding laser (lasers) is generated to illuminate the pellet. The light reflected from the pellet surface will escape through the windows of the reactor chamber into the chain of amplifiers. After its first pass through the chain of amplifiers it will be focused into the SBS cell where it will undergo the PCM reflection. This will send it back along the same path to the reactor chamber. The second amplification will take place followed by the (optional) third harmonic conversion and irradiation of the pellet with full energy (see Fig. 1).

Figure 1. Basics of the SBS PCM Approach. The IFE pellet is injected into the reactor chamber. After arriving to the vicinity of the area determined for optimal irradiation it is illuminated from many directions by synchronized low energy seeding laser pulses (two such laser pulses are illustrated by oblique red lines). The part of the reflected light which will leave the reactor chamber through the entrance window(s) is subsequently amplified, SBS PCM reflected, amplified again on its way back and eventually, after its conversion into the third harmonic, it will enter the reactor chamber and irradiate the pellet.

In case of 10 Hz repetition rate with one half of this period available for bringing the injected pellet from the entrance window into the central interaction area (∼ 5 m) gives 0.05 s of the flight
time. Hence the minimum pellet speed needed is $\sim 100 \text{ m/s}$. Taking into consideration a large number of laser drivers with their amplifiers and all optical elements a considerable amount of space around the reactor chamber must be available for their positioning. Estimating for any laser driver beam to travel $\sim 300 \text{ m}$ outside of the reactor chamber, time spent on this journey would be $\sim 1 \mu s$. During that time the pellet would move by $\sim 100 \mu \text{m}$.

3. Discussions and Comments
The question of the laser beam trajectory correction in the SBS-PCM Approach depends to a large degree on the pellet illumination scheme employed. It seems that the only reasonable way would be to perform as isotropic illumination as possible thus making the pellet to act effectively as a point light source emitting evenly into all directions. This, of course, would require its illumination from many directions similar to the Standard Approach irradiation scheme (using low energy pulses).

In order to avoid any need for seeding lasers different aiming from shot to shot two scenarios could come into consideration: (i) Using the seeding laser spot size sufficiently smaller than the pellet diameter (say $\sim 2 \text{ mm}$) to make sure that in the case of acceptable delivery the whole laser spot will always fit on the pellet surface (Fig. 2a), (ii) using the seeding laser spot size sufficiently larger than the pellet diameter (Fig. 2b). The second option might look easier but a care should be taken to prevent a part of the laser light which would not hit the pellet surface from directly entering some amplifier entrance window. In both cases it would be beneficial to keep the inner reactor chamber as a poor reflector of the seeding pulse light to minimize any subsequent reflections from the pellet caused by the light returning from the walls.

**Figure 2.** Examples of illumination and irradiation schemes. After reaching the prescribed interaction area (the dashed circles): a) the seeding laser beam spots would always fit on the pellet surface, b) the whole pellet would always fit into the laser beam diameter. In c) the red cone represents the collection angle of the low power first harmonic (illumination stage) and the blue cone represents the focusing of the high power third harmonic on the pellet (irradiation stage).

The third harmonic conversion crystals could be placed directly into the beginning of the amplifier beam lines as due to their nonlinear behaviour the incoming low intensity pulse would
undergo no conversion. In this respect there are two potential issues to be taken care of: (i) the focusing optics should work the same way for both harmonics (either using the achromatic lenses or the curved reflecting mirrors), (ii) with slightly different position of the target at each shot the beam trajectory will change its angle with respect to the conversion crystal. If this angle would go beyond the limits for the good enough conversion some active correcting elements might need to be employed into the beam line symbolized by the wedge in Fig. 1 (with potential high voltage control - not shown).

In the ideal case these correcting elements should be designed to simultaneously take care of the returning beam minor desirable deflection due to the distance travelled by the pellet during the amplification stage (∼100 µm at the maximum) as the spot size of the irradiating beam would correspond to the pellet diameter. Otherwise some (albeit small) leaking of the irradiating energy might occur. This could be avoided by designing the achromatic lenses to produce a tighter focus for the third harmonic which would ensure that the high power laser pulse spot would always fit on the pellet (Fig. 2c). Additional possibility how to deal with this problem is to employ the wedge and its index of refraction dependence on the wavelength. Alternatively, the entrance window itself could be designed to play that role.

Simplification of the final optics design in the SBS PCM Approach compared to the Standard Approach would allow for higher number of less energetic lasers to be employed. As a consequence the higher repetition rate lasers would be much easier to design.

With high number of laser beams available any required shape of the pulse can be realized by considering neighbouring laser beams as creating such a pulse shape when combined together on the pellet surface. This would be achieved by different amplification and trajectory length of neighbouring laser beams. A certain level of such randomization might be even beneficial for the imprint suppression.

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