Overview and latest proposals in SBS PCM based IFE technology featuring self-navigation of lasers on injected direct drive pellets

M. Kalal[1], H.J. Kong[2], and O. Slezak[1]

1 Faculty of Nuclear Sciences and Physical Engineering, CTU in Prague, Czech Republic
2 Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea

One of the very difficult challenges to deal with in the *inertial fusion energy* (IFE) integrated approach is connected with the need of simultaneous and very precise irradiation of injected pellets containing thermonuclear fuel inside the reactor chamber by many dozens (or even hundreds) of powerful laser beams. Sophisticated tracking of injected pellets' trajectories is necessary for a reliable prediction of the place which would be the most suitable for interaction with the driver beams in order to achieve necessary *spherical symmetry* of irradiation required for subsequent fuel *compression* and *burn*. For the *direct drive* scheme the following set of parameters is being currently considered: pellets of ~ 4 mm in diameter should be delivered into the virtual sphere of ~ 5 mm in diameter located around the center of the reactor chamber ~ 10 m in diameter. Combined precision of tracking and aiming should be ~ 20 μm. Navigation technologies developed so far are gradually approaching the required margin in the case of *fully evacuated* reactor chambers. However, in its *practical* use, there are serious obstacles complicating this *direct drive* IFE scheme – even putting its feasibility in doubts. Among the most serious ones is the *insufficient predictability* of the injected pellets' trajectories resulting from their expected interaction with remnants of previous fusion explosions due to the considered 5-10 Hz *repetition* rate. Hence some time consuming adjustment of heavy final optics for every shot and every laser beam is always necessary. This fact is partially responsible for a rather tight margin ~ 500 μm on the pellets successful delivery into the above mentioned virtual sphere. This might be also one of the reasons why the *indirect drive* scheme seems to be currently considered as a more serious IFE candidate - having the corresponding *hohlraum* targets by three orders of magnitude *heavier* compared to their direct drive counterparts, thus allowing for much more reliable prediction of their trajectories.

In order to deal with these *direct drive* laser navigation difficulties a novel approach was recently proposed employing the *phase conjugating mirrors* (PCM). Such mirrors would be self-generated by *stimulated Brillouin scattering* (SBS) after focusing a laser beam with appropriate energy into a suitable medium (usually some special liquid) [1,2]. Detailed overview of the gradual development of this novel scheme with all its advantages explained, including also two series of experiments, can be found in the literature [3-5]. The current design is depicted in Fig. 1.

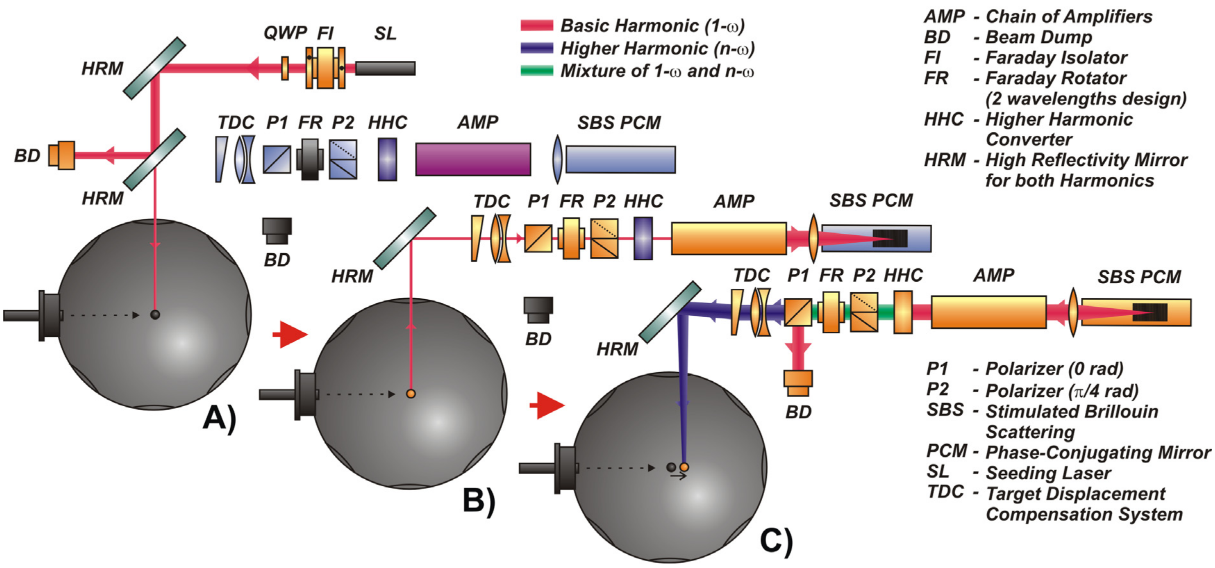

Fig.1: The current design of the SBS PCM approach to the direct drive IFE is outlined with one selected laser channel displayed during its three distinct stages of operation.

The three basic stages of its functioning are the following:

A) At the right moment (determined by careful tracking) when the injected pellet is approaching its best interaction position, a low energy *seeding* laser pulse (glint - *red* line) is sent to *illuminate* the pellet

B) Reflected seeding laser pulse is collected by the focusing optics and amplified on its way to the SBS PCM cell

C) Amplified pulse is reflected by the SBS PCM cell, amplified once again, converted to higher harmonic (*blue* line) and automatically aimed at the *moving* pellet by the *target displacement compensation system* (TDC) for its final high power *irradiation*.

TDC is a completely *passive* system having its optical components *appropriately* designed for every individual channel taking advantage of their index of refraction dependence on the wavelength. Typical *displacements* for the pellet injection speeds ~ 1000 m/s and 1 μs delay times (corresponding to 300 m distance traveled by the laser beam outside the reactor chamber - to reserve enough room for a large number of drivers) - would be ~ 1 mm.

It should be noted that in this latest scheme there is one new optical system - *Faraday isolator* - included in every laser channel. It consists of the *wavelength-sensitive* custom-design *Faraday rotator* (FR) placed between two *polarizers* (P1 and P2). The main reason for introduction of this new optical system is the need to handle the *non-converted* basic harmonic. This is an alternative to the *custom made mirror* (CMM), the mirror closest to the reactor chamber from our previous design [4,5], where its potential role was thoroughly discussed, but found to be far from satisfactory.

Let us now specify requirements on proper *functionality* of our custom-design *Faraday isolator*. The role of this optical system will be *two-fold*. As already stated, it has to prevent the returning *non-converted* basic harmonic from entering the reactor chamber. The very same basic harmonic which must be allowed on its first pass towards SBS PCM reflection to propagate without any substantial attenuation. Thus, for this basic harmonic, the Faraday isolator assumes its *classical* design with the relative orientation of two polarizers by $\pi/4$. The required angle of rotation θ_1 of the plane of polarization for the *basic* harmonic during each pass can be thus written in the following *generalized* form:

$$\theta_1 = V(\lambda_1)LB = \pi/4 + m_1\pi \ ,$$

where $V(\lambda_1)$ is the Verdet constant for the wavelength λ_1, B is the value of the magnetic field applied to the cylinder of the length L, and m_1 is the *whole* (non-negative) number. Under these conditions the Faraday isolator will properly take care of the basic harmonic.

What rotation angels θ_2 are required for the *higher* harmonic? This harmonic should be allowed a *free* passage through the Faraday isolator on its way to the reactor chamber. Thus, the following *generalized* formula should be satisfied (for better understanding of this formula derivation see Fig. 2):

$$\theta_2 = V(\lambda_2)LB = 3\pi/4 + m_2\pi \ ,$$

where $V(\lambda_2)$ is the Verdet constant for the wavelength λ_2, B is the value of the magnetic field applied to the cylinder of the length L, and m_2 is the *whole* (non-negative) number.

By combining the above formulae, one can arrive to the following simple expression for the required ratio Q of the Verdet constants for two wavelengths:

$$Q = V(\lambda_1) \,/\, V(\lambda_2) = (1 + 4m_1) \,/\, (3 + 4m_2) \ .$$

What remains to be done for a construction of the custom-design Faraday isolator with required properties thus seems to be a rather straightforward task: to find/develop some material which would allow for a given *pair of wavelengths* (in our case *harmonics*) realization of at least one of the possible Q values. The *smaller* the m_1 and m_2 values, the *better*. While doing the search, coefficients of *absorption* of the material for a given wavelength should be taken into consideration. As these coefficients are usually *larger* for *shorter* wavelengths, in the case of harmonics the value of m_2 should be kept as small as possible.

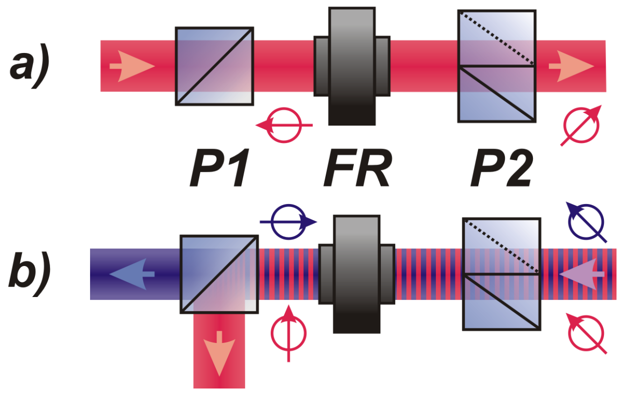

Fig.2: Faraday isolator of custom design to prevent the *non-converted* basic harmonic from entering the reactor chamber, but at the same time allowing a *free* passage for the *converted* part (higher harmonic).

As a conclusion it could be emphasized that this novel SBS PCM based technology of self-navigation of laser drivers on the direct drive pellets has been receiving an increased attention during the last several years. With other research groups gradually entering this field.

This work was supported by the Ministry of Education, Youth, and Sports of the Czech Republic Research Project LC528. It was also partially supported by the Grant Agency of the Czech Republic grant No.: 202/08/H057 as well as by the Czech Technical University in Prague grant No.: SGS10/298/OHK4/3T/14.

1. B.Y. Zel'dovich et al., Connection between the wave fronts of the reflected and exciting light in stimulated Mandelshtam-Brillouin scattering, *Sov. Phys. JETP* **15**, 109-112 (1972).
2. *Phase Conjugate Laser Optics*, Eds: A Brignon and J-P Huignard, New York: Wiley-Interscience (2003).
3. M. Kalal et al., SBS PCM Technique Applied for Aiming at IFE Pellets: First Tests with Amplifiers and Harmonic Conversion, *J. Kor. Phys. Soc.* **56**, 184-189 (2010).
4. M. Kalal et al., Current Status of the SBS PCM Approach to Self-Navigation of Lasers on IFE Targets, *J. Phys.: Conf. Ser.* **244**, 032034-032037 (2010).
5. M. Kalal et al., Recent progress made in the SBS PCM approach to self-navigation of lasers on direct drive IFE targets, *J. Fusion Energy* **29**, 527-531 (2010).