INERTIAL FUSION ENERGY FROM IMPROVED USE OF BIG LASER SYSTEMS

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Research into new categories of physics [1] will be opened by "superlasers" like NIF (National Ignition Facility) [2] or LMJ (Large Megajoule) [3] producing pulses of about 1.8 to 2.5 MJ energy and above 500 TW power of the third harmonics (351nm wave length) of neodymium glass lasers. However, more than doubling of the energy of these pulses (above PW: Petawatt range) is available in these systems for laser-plasma interaction if operation at the basic wavelength at 1053 nm would be interesting. This is possible at relatively low cost if a low loss smoothing system is applied for overcoming the well known difficulties of interaction with plasmas for suppression of the recently studied stochastic picosecond pulsation. These more energetic pulses will favor the application for fusion energy.

Michael Campbell, Edward Teller et al [1] elaborated how these superlasers will reach parameters of high energy density physics [4] far beyond that of nuclear explosions, much less expensive and more accurate, for basically new knowledge and many applications e.g. in astrophysics. These experiments, however, seem not so much to target the goal of inexhaustive, clean and very low cost fusion energy, as seen from the (pessimistically) expected output [1] of only 10^{18} (DT) fusion neutrons from experiments with capsules by indirect drive corresponding to a total fusion gain (related to the laser energy) of 1 to 2 only. The reasons to use the third harmonics for indirect drive are well known. The capsules work with conversion of the laser radiation into hohlraum radiation which subsequently compresses spherical targets continuing DT as fusion fuel. Taking these conversion losses and the losses by generation of the third harmonics, more than six times higher neutron gains may be expected if it would be possible to work with direct drive at the fundamental wavelength.

The decision is fortunate that with a relative minor increase of the costs of NIF, direct drive experiments will be available [5] where very important experiments with the third harmonics are scheduled. However, by a low cost switch to remove the frequency tripling equipment and switch on the appropriate smoothing one may receive appropriate laser pulses of $>$ 4MJ at the fundamental wave length from these superlasers which option is scheduled at least for basic experiments [6]. We extent here the possibility how appropriate smoothing my lead to the use for laser fusion despite the longer wavelength.

The question is how to provide the appropriate smoothing. With the aim to avoid filamentation (self focusing) from hot spots of the laser irradiation, the random phase plate [7] or alternatively broad band (induced spatial incoherent) laser irradiation [8] was introduced. A combination of both methods (smoothing by spectral dispersion) arrived at a very uniform laser irradiation [9]. Smoothing led to the suppression of parametric instabilities [10] by a factor 100 which were considered as the most dangerous problems for direct drive.

On top of the difficulties with parametric instabilities and filamentation, however, the laser-plasma interaction showed a stochastic pulsation with a period of about 10 to 50 ps. These were experimentally clarified by realizing a change between mirror reflection of light at the critical density and phase reflection at the outermost plasma periphery [11]. The reason was seen numerically since 1974 [12] when the intense laser light is first reflected at the cut-off density but the partially reflected light causes a standing wave which nonlinear (ponderomotive) forces [4] drives the plasma into the nodes. The resulting coherent density ripple results in a self-generated Laue-Bragg phase reflection at the outermost low density of the plasma corona. The inner part of the plasma corona is then free from laser light and the density ripple is hydrodynamically washed out within several picoseconds. This permits then another laser penetration to the cut-off density for mirror reflection etc. This arrives then at a stuttering plasma acceleration with 10^7 to 10^8 cm/s velocities as observed [11] and as fully reproduced numerically [13].

Irradiating with a broad band laser beam (0.5% of the frequency) in the numerical analysis [13] resulted in a suppression of this stochastic pulsation and in a purely mirror reflection at the cut-off density with a very low net reflectivity of few % in contrast to the intermediate phase reflectivity which was more than [14] 95% with narrow band lasers similar to the experiments [11]. The broad band laser suppressed the pulsation and led to a smooth and highly efficient deposition of the laser energy into the plasma as necessary for direct drive.

The suppression of this self-generated coherent density ripple can also be seen in experiments with a random phase plate [15]. When the random phase plate for a 9 cm diameter laser beam had dielectric 2mm squares for 180^o phase change, the pictures of spatially and temporally resolved plasma first showed an unsmooth result with beam-parallel filament structures but also with perpendicular structures in about 50 ps distance clearly indicating the stochastic pulsation. But using a random phase plate with 1mm squares showed a rather smooth plasma.

For wave optics, the squares would have led to a focal spot diameter of 132 mm and 265 mm for the 2mm respectively 1 mm squares. It is remarkable that in this case ray optics may be applicable where the filaments are squeezed into the 65 mm focal diameter of interaction. The beamlets of the squares are then about two wave lengths for the 2 mm and about one wave length for the 1 mm squares. This is just what we expect from our density ripple calculations. As soon as neighbour filaments are out of phase within a wave length distance or less, the washing out of any density ripple happens due to lateral interaction. For 2 wave length distance the effect of washing out is too small. Indeed the addition of broad band as SSD [9] will even better arrive at the necessary low reflectivity, non-pulsating, instability-suppressed and filamentless interaction as needed for the ideal direct drive. This was considered in the past to be possible only with the 3rd harmonics. The use of the fundamental wave length should work similarly applying some modifications for the different conditions compared with the third harmonics. For the applied random phase plate a condition may be that the width w of the squares should be determined by the laser wave length λ

$$w = LF/\lambda \tag{1}$$

where L is the diameter of the lens equal to the laser beam or the random phase plate, and F is the focus diameter of the laser beam at the plasma interaction.

For an estimation of fusion gains we may use here volume ignition [4,16] which is an easy "robust" compression scheme but with a pessimistic gain of a factor 2 below the spark ignition [17]. Using now the increased 4.5 MJ laser irradiation with a hydrodynamic efficiency pessimistically of 5% only, the total gain related to the laser energy is 14.5 at compression to 1000 times solid state density with an ignition temperature of 3.5 keV. At a compression to 3000 times the solid state, the total fusion gain is 35 and the initial temperature 2.9 keV. The total fusion gain of 35 would well be sufficient for a power station if lasers with more than 15% efficiency are available. The gains are also in some agreement with the above mentioned indirect drive with third harmonics.

Nevertheless, the low hydrodynamic efficiency is rather poor though it may be then a feasible solution for the energy crisis. It may not be the final solution since it may well be possible that the here described improvement may be overcome by a ten times higher efficient scheme for laser fusion, known as the fast ignitor [18]. But these details are still to be clarified.

The stochastic pulsation [4,11,13] is a less realized phenomenon and only the very recent numerical evaluations [14] indicated more details. It is no surprise that the concept of running the superlasers 2 or more times powerful at the fundamental wave length than at the third harmonics for interaction studies and fusion applications is not yet generally considered. It is worthwhile to underline this wider option for research. A next step consists in a more detailed study of the stochastic pulsation [11] and of parallel numerical studies using the genuine two fluid model [4, 13, 14]. This is possible by a comparably low budget but may result in a considerable gain from the expensive superlasers.

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