Journal of Energy and Power Engineering 14 (2020) 273-278
doi:10.17265/1934-8975/2020.08.004

Inhomogeneous Dielectric Target Properties for Increased Non-thermal Pressure in Laser Boron Fusion by CPA-Pulses

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Abstract: Based on the documentation of the invited paper and the subsequent discussion at a virtual conference, discoveries are indicated, which are summarized in the following paper for further evaluation on the topic of non-thermal forces using terms of extremely powerful components of Maxwell's stress tensor at the interaction of CPA (chirped pulse amplification) laser pulses in the fusion plasmas of hydrogen with the isotope 11 of boron. This is caused by a recoil mechanism given by the Fresnel formulas of the suppression of the reflectivity of inhomogeneous plasma given by optical constants of the plasma properties.

Key words: Clean nuclear fusion of hydrogen H with ^{11}B, Fresnel formulas for inhomogeneous plasmas, optical constants in plasmas, excluding unnecessary temperatures of hundred million degrees for thermal fusion pressures by non-thermal pressured from extreme laser pulses, CPA of ultra-extremely short pulses.

1. Introduction

The publication [1] of an invited virtual conference paper [2] was under discussion at a follow-up conference [3] as an addition to results, where the contents of the virtual presentation were documented by a video including of the details of the ongoing discussions. This gives an opportunity to consider the very advanced results of which the following is given as an example [4] to discuss very actual problems like the generation of the 10 million times higher energy from fusion reactions in the range of MeV than the chemical burning energy of carbon in the range of less than one eV per reaction. This touches the ambitiously scientific question, how the breakeven of the laser driven fusion gain may have been reached by a further increased gain bridging the gain factor of about 200 hydrogen nuclear fusion of hydrogen H with the isotope ^{11}B. The following should be considered as a frame for the achievement for a possible goal with a number of substantial highlights reached. The aim is also given by the inauguration aim of the President of the European Union in December 2019, Dr. Ursula von der Leyen, see Ref. [1], that the Climatic-Energy Problem is not a catastrophe but a question of *existential survival*.

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2. Hydrogen Nuclear Fusion of Hydrogen H with the Isotope ^{11}B

The fusion reaction is an example of the new non-linear physics performed by the most extreme laser chirped pulse amplification CPA (chirped pulse amplification) [5] in contrast to the linear physics of thermodynamics. The nuclear fusion of the nuclei of hydrogen H, the protons, with the Boron isotopes number 11 (^{11}B contained to 80% in all boron) [6] is resulting in

$$H + {}^{11}B = 3\,{}^{4}He + 8.7\ \text{MeV} \quad (1)$$

The energy of 8.7 MeV is equally distributed with 2.9 MeV to the harmless helium ^{4}He, resulting in Mercedes stars in the cloud chambers, if the collision energy is in the range of 0.5 MeV. At higher energy instead of the HB11-reaction of (1), the distribution of the generated ion energy is much more complicated, a fact that is not interesting in the following. The final question is how 90% of the 2050 needed electric global energy generation can be changed from burning coal into clean nuclear energy from boron without generating radioactive ash for more than the next ten-thousand years.

The modest 0.5 MeV collision energy of nuclei was in the plasmas produced in the Cockroft-Walton accelerators, designed for 10 MeV and higher nuclear reaction energies for nuclear studies. The reactions around 0.5 MeV were a surprise first evaluated in details with boron and hydrogen fusion by Oliphant and Lord Rutherford [6]. When instead of hydrogen H, the heavy hydrogen D (deuterium) was used, the D-D reaction led to the discovery of the earlier not known superheavy hydrogen T (tritium) [7] and the production of neutrons n

$$D + T = {}^{4}He + n + 17.3\ MeV \quad (2)$$

This DT-fusion reaction is the easiest fusion and nearly exclusively studied for an electro-energy generator using fusion with magnetic confined plasmas (e.g. ITER or Wendelstein) or pulsating ICF (laser compressed and heated) plasmas [8]. The big disadvantage, however, is the huge generation of radioactivity by neutrons, while the HB11 reaction (1) is primarily involving only stable nuclei and not any radioactivity. Secondary reactions of (1) can produce neutrons with dirty radioactivity, however, that are many orders of magnitudes smaller than DT fusion and methods are known to reach a sufficiently tolerably low level for a HB11 fusion power station.

The HB11 reaction (1) was from beginning interesting by the fact that three helium nuclei are generated and an avalanche or chain reaction can be expected. The ICF laser compression scheme arrived at impossible conditions, see Section 9.6 of Ref. [8] requesting compression of solid density fuel to densities of about hundred-thousand times solid state density of the fuel. As far known, no any fusion with low density plasmas has been produced.

The very first HB11 fusion reaction was measured with CPA laser pulses [9] with 1,000 reactions, just above the measurable threshold in 2005. This number was increased to more than 10 million by combination with laser driven ion beams [10]. A further level of

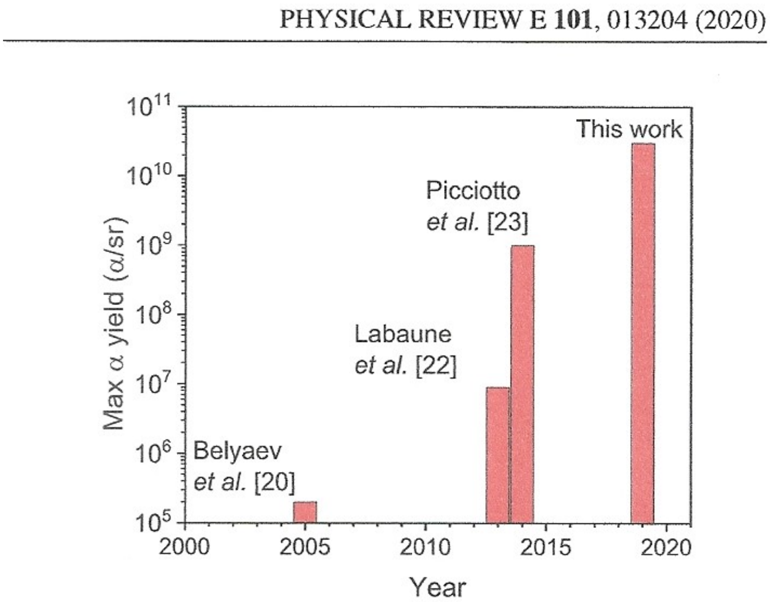

Fig. 1 Poster No. 4 selected from the documentation [4] of the electronic virtual conference used from presentation of Ref. [3]. The references in the figure refer to the list at the end of the paper: Beliaev et al. [9], Labaune et al. [10], Giuffrida et al. [11], Picciotto et al. [13] where "this work" is in Ref. [11].

increase by further 10.000 times higher reactions appears [11, 12], see Fig. 1. The measurement [13] indicated the avalanche mechanism such that a reactor scheme was designed [14] and the avalanche was explained [15]. The non-linearity as a result of Maxwell's stress tensor as predicted in 1978 (Fig. 6 of Ref. [1]) was later measured by Sauerbrey [16]. The non-thermal initiation of the ignition of fusion without needing the usual thermal pressures of 100 million degrees temperatures was concluded [17, 18] involving the fact [19] that the energy density in the plasma focus can be of higher value by the non-thermal pressure than by the thermal pressure of the million degrees.

3. Refractive Index and Fusion Gains

In the documentation of Ref. [4] is the maximum of the alpha-yield very similar to Refs. [11, 12] at 10^{11}. The video-documented statement of the discussion partner [20] has reported an evaluation of Ref. [12] that the measurement of the hydrogen (H) has reached the level of 10^{14}. This result would be significantly important for the total energy reaction gain to arrive near the very first of break-even. Subject to a final confirmation of the numbers, this conclusion can be based on the following main arguments of the paper [4].

It was clarified in Refs. [1, 4] with the understanding of the optical refractive index of the inhomogeneous plasma distribution in the surface area interaction volume of the laser radiation with the target that resulted in the blue Doppler shift of the line radiation as measured by Sauerbrey [16]. This is different from low density plasmas with optical constants near that of the vacuum resulting in the red Doppler shift of ordinary radiation pressure and known from numerous simulations in contrast to the confirmation beginning with Refs. [21, 22] and discussed in Ref. [4].

The mentioned increase [20] from 10^{11} to 10^{14} particles is therefore of special interest. The values of 10^{11} correspond about to the highest measurement of laser ICF measurements of DT-fusion with the NIF (National Ignition Facility) laser. This is about 100 times below breakeven. A HB11 case with 10^{14} corresponds then to the breakeven. This factor 100 is then of importance by the reported conclusion of Ref. [20]. The precise repetition of Sauerbery's measurement [16] was given by Földes et al. [23] where the crucial measurement was by the team of Jie Zang (Zhang et al. [24]) who with the most extremely experimental techniques could demonstrate that relativistic self-focusing [25] had to be excluded. It was clarified in Refs. [1, 4] with the understanding of the optical refractive index of the inhomogeneous plasma distribution in the surface area interaction volume of the laser radiation with the target that resulted in the blue Doppler shift of the line radiation as measured by Sauerbrey [16] resulted in the plasma corona from about 45 to about 60 micometers with velocities up to about 1,000 km/s against the laser irradiation. This is different from low density plasmas seen in simulations of low density. Földes's result cannot be explained by refraction with optical constants near that of the vacuum resulting in the red Doppler shift of ordinary radiation pressure and known from numerous simulations. This is in contrast to the blue shift confirmation beginning with Refs. [21, 22] and discussed in Ref. [4]. The mentioned increase [20] from 10^{11} to 10^{14} particles is therefore of special interest. The values of 10^{11} correspond about to the highest measurement of laser ICF measurements of DT-fusion with the NIF laser. Fig. 2 shows that the black line is about 15 times higher than in vacuum indicating a 15 slower motion of the radiation in the corona resulting in a Fresnel momentum on the plasma [27] causing the 200 times increased ion velocities against the laser irradiation.

This is about 200 times below breakeven. A HB11 case with 10^{14} particle emission would correspond then to the breakeven. This factor 200 is then of importance by the reported conclusion of Ref. [20]. A

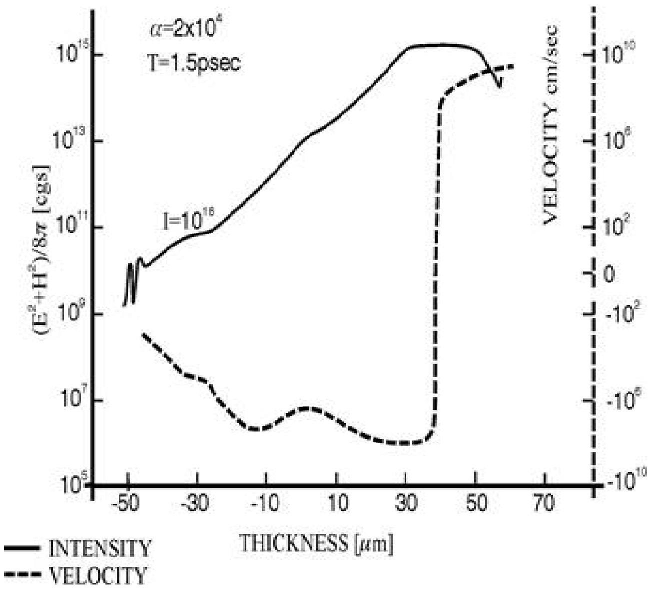

Fig. 2 Drawing together of computer output of 1978 (see Figs. 10, 18a & 18b of Ref. [26]) of irradiation of 10^{18} W/cm^2 Nd-laser beam from the right hand side on a deuterium slab of a bi-Rayleigh iniyial 100 eV and 100 micrometer thickness. The printout is after 1.5 ns for the laser energy density and (dashed) plasma velocity against the irradiation. Because of the collisions, the reflection is shifted from the middle (0 μm) to 40 μm.

factor of 200 was the result of the key question of the presentation [4] as a result of the Fresnel recoil of the plasma surface motion to be driven by the ultrahigh acceleration against the laser light as predicted numerically in 1978 and measured by Sauerbrey [16]. In glass plates, the increase of the optical energy density is compensated by the reflected light. Thin homogeneous plasma density suppresses the reflection and the necessary Fresnel recoil is—as calculated in 1978—going into plasma acceleration against the laser beam. The calculation (see Fig. 6 of Ref. [1]) of this Fresnel mechanism [27] with an increase of the ion energy by more than 200 was underlined in the documented discussion by Dieter H. H. Hoffmann who chaired the lecture [4] and was the co-organizer of the whole conference [2].

4. Acknowledgement by Historical Remarks

This short contribution is a corner stone between a many-years development how to use lasers for producing electric energy from nuclear fusion reactions by a clean, safe and lasting process. This is an opportunity how this was pioneered to the present new beginning where cooperation with existing top class research centers can cooperate with private investment for this goal as it is aimed by global efforts of the HB11 Energy Holdings Corporation as described on the website in the media. This is the reason to have a look of the beginning of these steps with thanks and acknowledgements to Ceri Brenner, E. Mike Campbell, S. Eliezer, A. Fuerbach, Lukasz Gadowski, B. M. Hegelich, Mark Ho, Dieter H. H. Hoffmann, K. Jungwirth, G. J. Kirchhoff, J. Krasa, F. Ladouceur, T. M. Mehlhorn, G. H. Miley, Dorle Minikin, N. Nissim, R, Sauerbrey and Beate Steller.

The awarding of the Edward Teller Medal (Fig. 3) for achievements in inertial confinement nuclear fusion energy ICF was resolved in 1991 by the Committee of the international leading conference "Laser Interaction and Related Plasma Phenomena—LIRPP", founded in 1969 in the USA by Heinrich Hora at his Professorship at the Rensselaer Polytechnic Institute in Hartford Conn. The first Medals were awarded (from the right, see Fig. 3) to Chiyoe Yamanaka, the founder of Japan's largest ICF center at the Osaka University, followed by John Nuckolls from the

Fig. 3 The recipients of the first awardees of the Edward Teller Medal in connection with laser driven fusion.

Lawrence Livermore National Laboratory in Livermore, California/USA (Director 1988-1994) who after his groundbreaking success on fusion energy, is from the very beginning the world-leader on ICF driving by laser; he is prominent by his paper in *Nature* 239 (1972) 139 from the Quantum Electronics QE Conference at Montreal; then follows Edward Teller with Nobel Laureate Nikolai Basov, who published the very first paper on Laser Fusion at the QE at Paris in 1963 and led the Laser-ICF in Russia. His few single fusion gain calculations were first extended for the whole interesting range arriving at a formula 1964 by Heinrich Hora for spherical compression and heating, he is seen next to Basov. Hora discovered the resonance-like volume ignition for increasing the energy gain. He was leading with numerous other effects as the non-thermal forces by Maxwell's stress tensor, self-focusing and clean boron fusion.

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