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Nuclear Fusion of Hydrogen-Boron: A Clean Energy for the Future

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Abstract

After years of research on fusion energy, a new opportunity is now emerging to use fusion energy while avoiding any radioactive radiation. This remarkable approach is made possible by using laser pulses of petawatt (PW) power and picosecond (ps) duration to burn Hydrogen-Boron fusion fuels. This fuel uses plentiful light Hydrogen (H) and the Boron isotope 11, which yields energetic charged particles without generating neutrons. The nuclear energy produced by the fusion reaction of $H–^{11}B$ is important, because does not produce the radioactive tritium and it is a clean energy. The only problem in this fusion reaction, large Coulomb barrier between the nucleus and the small cross section of the reaction and to enforce its primary energy demand is very high. In this paper an alternative laser fusion scheme of side-on ignition with uncompressed fuel is proposed to enable ignition of the $H–^{11}B$ fuel along with PW laser interactions. This approach employs a recently discovered laser-plasma interaction technique, which uses very high contrast ratio laser pulses.

Keywords: Fusion Energy; Hydrogen-Boron; Radioactivity; Ignition; Clean Fuel

Introduction

For the problem of the energy production without environmental destruction, the general awareness is rather developed that it is absolutely impossible to continue with burning fossil fuels. The only present limit is that we have to find alternatives in energy production since the present emission of carbon dioxide from burning coal and oil is about three to five times higher than can be tolerated. The wealth of modern life is based on the generation of energy from coal and oil where at present per year about 20 billion tons of carbon dioxide, 3.5 time more than 50 years ago are added to the atmosphere and the increase from industrial expansion in the developing countries may hardly be compensated by reductions in developed countries. Alternatives from solar energy, wind power, water power and similar are growing very profitably, but their costs are far too high and the net capacities are too low for the large-scale energy generation to reach a serious compensation against the energy production from fossil fuels.

Owing to the increasing concerns about climate change and energy security, more attention has been focused on clean and renewable energy in today's society. Biofuel, as high-quality renewable energy, is environmentally friendly. Fast pyrolysis of LERDADEs for renewable biofuel is considered for lowering the environmental impact of biofuel production [1]. Biomass is plant or animal material used as fuel to produce electricity or heat. During the process of biomass gasification and combustion, biomass pyrolysis technology is indispensable. High quality biodiesel from microalgae by using original and anaerobically-digested livestock wastewater [2], and life cycle assessment of biofuel production from microalgae cultivated in anaerobic digested wastewater is investigated by Li [3]. The pollution caused by hazardous substances that emitted from the massive use of fossil energy is serious increasingly so as to create global ecological problems such as greenhouse effect, climate change, destruction for diversity of species and desertification. Among all the proposed alternatives, biomass for bioenergy production is considered as a renewable. Microalgae, as one of the major feedstocks for the third-generation biofuel production, have been attractive. For example, bio-oil production from different microalgae using Py-GC/MS and minimum release of pollutants is studied by Li [4].

The well appreciated modern life in the developed countries was based on the use of the fossil fuels. When the nuclear energy was discovered, people were dreaming of the Golden age. But there were shocks as Chernobyl and the story of bombs with bad or positive views. Nevertheless, electricity nearly independently produces from fossil fuels automatically avoiding effects of the climatic catastrophe. Looking into the present and future problems and uncertainties, a lot of chances are still being missed. The new petawatt lasers may a very easy way of controlled fusion by ignition of frozen Hydrogen isotopes. This very low-cost energy production may change the whole scenario on earth. Strategies being proposed to reduce fossil energy sources to avoid global warming generally involve mixes of renewable energy sources and nuclear fission. In the long term, however, the radiation problems of radioactive waste disposal for fission power must be solved with rather complex technology. DT fuel involves radioactive tritium and neutron-induced radioactivity. The long-term goal of all fusion research is to produce clean, greenhouse gas free, and safe energy using inexhaustible fuel which is available to all nations.

Producing fusion energy with radioactive emission levels lower than the levels for burning coal (which is so low that radioactivity due to impurities is usually ignored) has been thought to be impossible due to the demanding ignition requirements the H-^{11}B fuel needed to achieve this goal. The DT fusion reacts with isotopes of heavy Hydrogen (Deuterium) with the super-heavy Hydrogen isotope (Tritium), where the laser irradiation compresses the fuel to more than 10^3 times the solid density, causing heating to ignition temperatures of several tens of millions of degrees centigrade. A very interesting fusion fuel is the reaction of light Hydrogen with the Boron isotope 11 (H-^{11}B) because it produces mono-energetic alpha particles for direct conversion into electricity [5]. Initially no neutrons and few radio activities per generated energy than by burning coal due to its content of 2 ppm uranium [6]. For spherical laser ignition, however, it was calculated [5] that the compression to 10^5 times the solid state is needed for burning H-^{11}B. This density limit has been confirmed by detailed evaluation of volume ignition [7] where the necessary laser pulse energies are considerably above 10 MJ in order to arrive at modest energy gains of 20. Fusion by nonlinear force driven plasma blocks [8] has rapidly advanced in recent years based on continuing clarification of the key physics problems, allowing experiments to progress to the point where H-^{11}B ignition is expected.

Preliminaries

In this section, some of the published works in other textbooks and journal articles about the fusion by nonlinear force driven plasma blocks has been reviewed. The consideration of problems with the equation of state [9], with the pressure ionization and polarization shift [10], with electron pressure or with dissociation problems [11] arrived at critical results for the spherical pellet H-^{11}B reaction by volume ignition for Inertial Confinement Fusion (ICF). Apart from clarification of more details of this analysis [12], there may a basically different and alternatively simplified way for the H-^{11}B reaction, if instead of the laser ignition of spherical fuel pellets, the plane geometry block ignition [13] is considered.

The theory of creation of the high-velocity plasma blocks is based on skin-layer acceleration by nonlinear forces [14]. In Figure 1, the simple theoretical model of H-^{11}B fuel in a planar geometry is proposed. The resulting plasma blocks have high momentum and are directed back toward the incoming laser beam. Momentum conservation causes an imploding ion block of plasma toward the inner portion of the target fuel [15]. The use of nonlinear force-driven plasma blocks with ultrahigh current densities using a PW-ps laser plasma interaction permits the ion shock ignition of uncompressed H-^{11}B.

Because the acceleration of the ions is electrodynamic [16], and not thermokinetic, the plasma blocks (pistons) have a low temperature. Therefore, the ion beam current density J in the plasma block must exceed a threshold value J^* to create fusion reaction waves in solid H-^{11}B fusion fuel. Thus,

$$J > J^* = 10^{11}\ A.cm^{-2} \qquad (1)$$

Irradiating PW-ps laser pulses on targets [17] usually results in extreme relativistic effects as generation of highly directed electron beams with more than 100 MeV energy, in highly charged GeV ions, in gamma bursts with subsequent photonuclear reactions and nuclear transmutations, in positron pair production, and high intensity very hard x-ray emission.

In strong contrast to these usual observations, few very different anomalous measurements were reported. What was most important in these few cases, is that the laser pulses with TW and higher power could be prepared in a most exceptionally clean way to have a suppression of pre-pulses by a factor 108 (contrast ratio) or higher for times a few dozens of ps before the main pulse is hitting the target. These exceptional conditions could be understood from the results of very detailed one-dimensional computations of laser-plasma interaction with dominating nonlinear (ponderomotive) forces [19]. However, such a generation of plasma blocks was never observed because in all experiments, a minor pre-pulse produced plasma in front of the target where the laser beam was shrinking to about one wavelength diameter with extremely high intensities due to relativistic or ponderomotive self-focusing [20].

Hydrogen–Boron Fusion

Boron-11 is an atom that contains five protons and six neutrons. Boron exists naturally as 19.9% ^{10}B isotope and 80.1% ^{11}B isotope. Boron-11 can fuse with a Hydrogen atom (one proton, no neutrons.) This makes six protons and six neutrons which are exactly enough for three helium atoms with no left over neutrons. The helium atoms then fly off at high speeds carrying the fusion energy. So, H–^{11}B fusion can create energy without releasing neutrons. Boron-11 is a common element that exists in the earth's crust and seawater. Hydrogen is the most common element in the universe and is even part of water as demonstrated

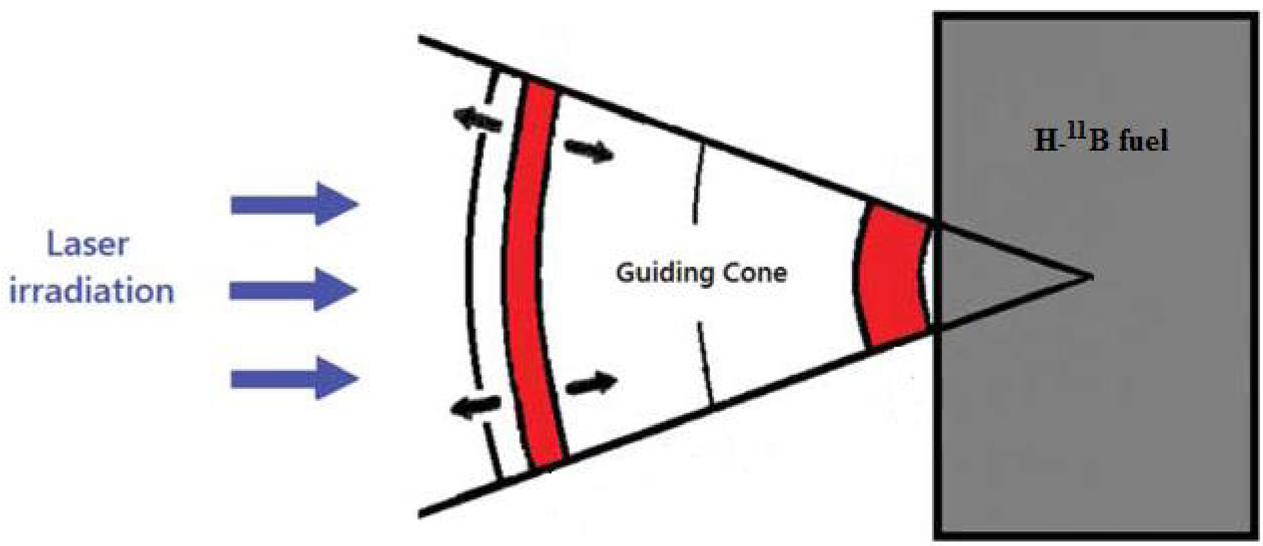

Figure 1: Schematic description of a spherical laser irradiation on H–^{11}B fuel [18]

by the formula H_2O. Helium is the second most common element in the universe. None of these materials is radioactive. When a Boron-11 atom fuses with a Hydrogen atom the result is three helium atoms and energy, but no radioactive waste:

1) The fuel (Boron and Hydrogen) is not radioactive.

2) The reaction product (Helium) is not radioactive.

3) The reaction releases no neutrons.

It is true that the Hydrogen-^{11}Boron reaction releases no neutrons, but as fusion progresses a greater number of helium atoms are created and occasionally a Boron atom will fuse with a helium instead of a Hydrogen. This produces a (non-radioactive) nitrogen atom and a neutron. However, this reaction releases very little energy and so the neutron is not the same as the high energy neutrons produced by fission. From the beginning of fusion energy research, a long-term goal has been to use the unique H-^{11}B reaction:

$$^{1}_{1}H + ^{11}_{5}B \rightarrow 3\ ^{4}_{2}He + 8.664\ MeV \qquad (2)$$

Since it results in the production of MeV alpha particles and no neutrons by bombarding Boron targets with protons of energies up to 150 KeV [21]. The energetic alpha particle products are ideal for highly efficient direct conversion into electricity to achieve a reduction in waste heat pollution. The produced alpha particles can also be collimated with magnetic fields for space propulsion [22]. Secondary reactions lead to some H–^{11}B radioactivity but this is less per unit of energy produced than burning coal [23], which naturally contains 2 ppm uranium. However, it has been evident from the beginning that the H–^{11}B fusion reaction is much more difficult to achieve than using DT fusion fuel, as seen from the relative reaction cross sections.

The new developments involving block and side-on ignition described here. This would lead to the first kind of clean energy production without any of the prior environmental disadvantages of nuclear energy. In recent years, a research team at the Triangle Universities Nuclear Laboratory (TUNL) on the Duke University campus found a Boron-11 and Hydrogen collision yields two high energy alphas instead of the previously thought one. The TUNL researchers have been developing reactors to slam Hydrogen at high speeds into Boron-11, a collision that yields high energy helium nuclei, or alpha particles. Those alphas then spiral through a tunnel of electromagnetic coils, transforming them into a flow of electrons, or electricity. Knowing what alphas and where they are going is of critical importance. Weller and his colleagues took a fresh look at the Hydrogen-Boron fusion event. They expected to confirm the accepted wisdom that a collision of single Hydrogen particle and one Boron-11 particle produces a single high energy alpha particle which produces electricity quite well and two lower energy alphas, which are less useful for generating electricity.

Conclusions

Very clean energy can be produced from the fusion reaction of Hydrogen with Boron reaction (H-11B), because no neutrons are produced, and the resulting alpha particles are mono-energetic of 2.9 MeV, which is ideal for high-efficient direct conversion into electricity. As noted, a conventional fusion reactor using deuterium-tritium fuel is designed to produce neutrons that create heat. This heat energy would require expensive turbines and generators to form electricity. In contrast to this, a focus fusion reactor using Hydrogen-Boron fuel would produce electricity directly. The energy from fusion reactions is released mainly in the form of high energy helium nuclei. In focus fusion reactors, these nuclei come out in the form of a tight pulsed beam, in other Hydrogen-Boron reactor types, they would come out as a broader stream. Since the nuclei are electrically charged, they already form an electric current. All that is needed is to capture this electric energy into an electric circuit. In focus fusion reactors, this can be done by allowing the pulsed beam to generate electric currents in a series of coils as it passes through them. This is much the same way that a transformer works, stepping electric power down from the high voltage of a transmission line to the low voltage used in homes and factories. Such an electrical transformation can be highly efficient, probably around 80-90%. What is most important is that it is exceedingly cheap and compact. The whole apparatus of steam turbine and electrical generator are eliminated. The energy from the x-rays can also be converted directly into electricity in a compact, cheap way.

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