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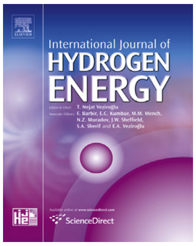

The stopping power of relativistic electrons and laser-accelerated proton beams for fast ignition of DT and D^3He and $P^{11}B$ fuels

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ABSTRACT

The understanding of basic physics of processes associated with the beam in fast ignition is very important. In this paper energy deposition of 1 MeV relativistic electrons study by calculating stopping power in D^3He plasma with uniform density 300 g cm^{-3} and compare with DT plasma in identical condition. The results show energy deposition in D^3He plasma is more than DT plasma. Scattering due to of background electrons decreases the penetration depth from 0.38 to 0.24 g cm^{-2} in D^3He plasma and from 0.51 to 0.33 g cm^{-2} in DT plasma. Nuclear reaction of protons with the boron-11 nuclei ($p-^{11}B$) is the most promising of all the reactions that can be used for completely neutronless power generation in a fusion reactor. The level of radioactivity associated with concomitant and secondary reactions is negligible, while for D–T reactor 80% of the fusion power is released in neutrons and neutron yield of $D-^3He$ is about 5%. Note, $D-^3He$ reaction is neutronless, but neutrons are born as a result of D–D branch and the secondary reaction of tritium and deuterium. From a technical point of view the lack of neutrons in the reactor mixture $p-^{11}B$ is very attractive because it removes a major problem of the first wall. Therefore in this paper proton beam is proposed in fast ignition approach using $P^{11}B$ fuel at uniform density 300 g cm^{-3} with considering Maxwellian energy distribution. The stopping power and total range of proton beam are calculated. The rate of energy transfer between ions and electrons and bremsstrahlung loss power with considering relativistic corrections in $P^{11}B$ fuel are exanimated. The results show that total stopping power of protons in $P^{11}B$ fuel at different temperatures is a function of proton energy and it decreases with rising temperature at constant E_P. Bonus energy and total deposited energy is significant at smallerE_P and higher T_e.

Introduction

The target symmetry and the ignition energy requirements make it difficult to achieve ignition using the conventional central hot spot approach. These difficulties have made the scientists consider many routes to improving the basic central hotspot ignited ICF target design, and have also focused efforts upon other areas, such as the improvement of laser beam quality. In 1994 Tabak et al. proposed an idea that was

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quite distinct from the conventional central hot spot approach to ICF. This scheme separates fuel compression from fuel heating. They named it fast ignition. Fast ignition is an attractive scheme which relaxes not only the symmetry requirements of the target capsule implosion, it also promises to relax overall driver energy requirements [1,2]. The fast ignition scheme potentially reduces the required energy for ignition by aiming to produce a hotspot in a manner that is substantially more efficient than the compressive approach employed in the central hot spot scheme. Furthermore, it aims to achieve ignition in fuel that has been assembled to lower densities.

In the original idea, relativistic electrons are considered to be the most suitable sources for the ignition of hot spot. Studies of the feasibility of fast ignition with relativistic electrons are carried at many laboratories. Successful realization of fast ignition requires understanding and controlling of the transport and energy deposition of MeV electrons in the target. Energetic electrons are generate by an ultrahigh-intensity, short-pulse laser interacting at the critical surface of a pre-compressed target. During a time period of ~10 ps, a total energy of ~10 kJ needs to be delivered to the compressed core, fast ignition then occurs in response to electron energy deposition, with charged particles bootstrapping a fusion burn wave that propagates to the surrounding dense plasma [3,4]. A basic problem is the interaction and energy loss of energetic electrons in plasma. This problem has focused on ions in the approach fast ignition for inertial confinement fusion (ICF). Tabak et al., calculated the energy deposition based on the continuous slowing-down of electrons in cold matter [5]. This treatment, quite similar to electron slowing in plasmas, does not include the effects of scattering. Deutsch et al., done this work by considering the effects of scattering off the background ions [6], they ignored scattering due to background electrons. The ignition requirement depends on parameters of the compressed fuel and on the transport properties and the energy deposition of the relativistic electrons beam. In this paper, energy deposition of the relativistic electrons beam for fast ignition in DT and D^3He plasmas considering scattering due to background electrons are studied. DT fuel has the largest cross section among all of the fusion reactions and it burns at the lowest temperature. DT cycle has two principle disadvantages: i) it produces neutron and damages reactor structure. ii) breeding tritium requires the extra complexity, cost and radial space due to lithium blanket [7]. A number of important characteristic features distinguish processes of thermonuclear fusion in D^3He fuel from the analogous processes in traditional DT fuel and this makes it possible to employ them with a high efficiency to increase the energy release and to find ways to facilitate the ignition of a thermonuclear cycle.

Aneutronic fusion has been described as any type of fusion reaction where neutrons carry no more than 1% of the total released energy. Aneutronic fusion can potentially make vast quantities of electricity without releasing greenhouse gases or free neutrons. Neither the fuel nor the waste products are radioactive. The navy has already funded and completed much of the basic research, and aneutronic fusion can be ready for commercial use in as little as eight years. Instead of using deuterium and tritium as the fuel stocks, the new motor extracts energy from boron fuel. Using boron, an “aneutronic” fuel, yields several advantages over conventional nuclear fusion. Aneutronic fusion, in which neutrons represent less than 1 percent of the energy-carrying particles that are the result of a reaction, is easier to manage. To make use of neutrons, “you need an absorbing wall that converts the kinetic energy of the particles to thermal energy.” In Chapman's aneutronic fusion reactor scheme, a commercially available benchtop laser starts the reaction. A beam with energy on the order of 2×10^{18} watts per square centimeter, pulse frequencies up to 75 megahertz, and wavelengths between 1 and 10 μm is aimed at a two-layer, 20-cm-diameter target. The first layer is a 5- to 10-μm-thick sheet of conductive metal foil. It responds to the teravolt-per-meter electric field created by the laser pulse by “acting as a de facto proton accelerator,” says Chapman [8]. The electric field releases a shower of highly energetic electrons from the foil, leaving behind a tremendous net positive charge. The result is a massive self-repulsive force between the protons that causes the metal material to explode. The explosion accelerates protons in the direction of the target's second layer, a film of boron-11.

There, a complicated nuclear dance begins. The protons (which carry energy on the order of roughly 163 keV) strike boron nuclei to form excited carbon nuclei. The carbons immediately decay, each into a helium-4 nucleus (an alpha particle) and a beryllium nucleus. Almost instantaneously, the beryllium nuclei decay, with each one breaking into two more alpha particles. So for each proton–boron pair that reacts, you get three alpha particles, each with a kinetic energy of 2.9 MeV (see Fig. 1) [9].

In inertial confinement fusion (ICF) research, fast ignition (FI) has the potential for higher gain, lower ignition threshold and less stringent implosion symmetry requirements than central hot spot (CHS) ignition. In the original idea, relativistic electrons are considered to be the most suitable sources for the ignition of hot spot [10]. Studies of the feasibility of fast ignition with relativistic electrons are now being carried at many laboratories. This approach has problems with localized energy deposition and focusing. Fast ignition by ions beam has some advantages: classical interaction with imploded fuel, the relatively moderate ignition energy compare with hot electrons, more localized energy deposition, improved focusing, straight line trajectory, maximum energy deposition at the end of their range (if the initial energy of the beam ions is above the thermal threshold) and suppression of the various kinds of instabilities. Fast ignition by protons can be achieved with lower ignition energies if the deposited energy in the surrounding plasma is controlled by optimizing target implosion or using multiple proton beams. The fuels DT and DD mixture produce neutrons in such copious quantities ($P_{neutrons}/P_{total} \approx$ %80 for DT and at least approximately %40 for DD [1]) that the central component of reactors employing these fuels might have to be replace quite often at great inconvenience and cost. In addition, these reactors would involve the presence of large amounts of tritium, since DT reactions run on it and DD reactions produce it. Aneutronic fuels ^3He–^3He, P–^6Li and P–^{11}B proposed as much cleaner alternatives because they would produce essentially no neutrons through direct reactions. In among these fuels, the $P^{11}B$ nuclear fusion was studied in the 1930s by Oilphant and