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Simulation Study of Laser Proton Acceleration in a Gas Target

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The use of high-energy protons and boron targets to produce nuclear fusion reactions does not produce neutrons [1], making this nuclear fusion reaction safer and less polluting. In addition, hydrogen and boron are both easily available materials and cheap, so research related to hydrogen-boron nuclear fusion reaction has recently become an important scientific research topic.

The hydrogen-boron nuclear reaction rate at a plasma ion temperature of 10 keV is several orders of magnitude smaller than the deuterium-tritium nuclear reaction rate [2]. To achieve a similar nuclear reaction rate, the temperature of hydrogen-boron plasma must be higher than 100 keV. However, it is not easy to maintain this temperature in a magnetically confined plasma, but experiments have proven the feasibility of using laser acceleration of protons to trigger proton-boron fusion reactions [3]-[4]. Therefore, laser acceleration of protons becomes a concrete and feasible way to trigger the hydrogen-boron fusion reaction.

Technologies related to the use of high field lasers and solid targets to generate proton beam acceleration have been studied for many years [5]. Currently, experiments can produce proton acceleration of approximately 100 MeV energy [6]. However, due to limitations in target production and laser pulse shaping technology and pollution due to the debris produced by the broken solid target, the gaseous target has become a good alternative [7]. However, using gaseous targets requires increasing the laser wavelength, so CO_2 laser is the best choice. However, there are currently not many short-pulse and high-intensity CO_2 laser facilities. Fortunately, the proton beam energy required for the hydrogen-boron fusion reaction is around a few MeV. Therefore, National Central University is building a 10-ps 1.5-J CO_2 laser system for research on hydrogen-boron fusion reactions.

Therefore, particle-in-cell simulation is performed in the study to estimate the proton energy generated by the interaction of this laser pulse with the 100-μm hydrogen target. Preliminary simulation results show that circularly polarized laser fields can produce better proton beam quality, and the proton beam energy can reach several MeV. The scaling of the proton beam energy with laser intensity and plasma density can also confirm that its acceleration mechanism is hole-boring acceleration [8]. However, the simulation study also demonstrated that the collisional ionization process has a great impact on the proton acceleration process within a specific laser intensity range, and the generated protons will split into high-energy and low-energy groups. The physical reasons for the phenomena will be explained in the report.

References

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