6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Laser-driven high-yield neutron source based on microstructured plasma

Xiangrui Jiang[1], Debin Zou[1], Tongpu Yu[1], Fuqiu Shao[1]
[1] Department of Physics, National University of Defense Technology, China
e-mail (speaker): xrjiang@nudt.edu.cn

With the rapid development of the ultrashort and ultraintense laser technologies, laser-driven neutron sources have attracted growing interest for a variety of applications, such as in neutron radiography, isotope production and radiation medicine. Beam-target nuclear reactions [1] and photonuclear reactions [2] are the two most common laser-based methods of neutron production. One major drawback of these methods is that the neutron yield is too low. Here, we proposed two novel schemes based on microstructured plasma to boost the yield of laser-driven neutron sources [3,4].

The pitcher-catcher configuration is most popular as for neutron sources based on beam-target nuclear reactions. Multiple lasers interacting with a deuterated (D) pitcher-catcher target and neutron generation are investigated using two-dimensional hybrid particle-in-cell and Monte Carlo simulations [3]. It is found that when multiple laser pulses are focused on the front surface of the pitcher layer, D^+ ion acceleration by target normal sheath acceleration (TNSA) is enhanced by the interfering overlapped light fields and the resulting periodic target-surface structure. This scheme is similar to microstructured targets but in a totally self-consistent manner, without need for prefabricated target or high-contrast operation. With three laser pulses each of 4.5×10^{19} W/cm^2 intensity, 33 fs duration and ~160 mJ energy, focusing at suitable angles on the pitcher layer, one can obtain 15 MeV D^+ ions and ~25% laser-to-D^+ ions energy conversion efficiency. As the resulting high-energy-density D^+ ions bombard the catcher layer, D-D fusion reactions are triggered. About 3.6×10^7 neutrons can be produced, significantly higher than that from a single laser of the same total energy.

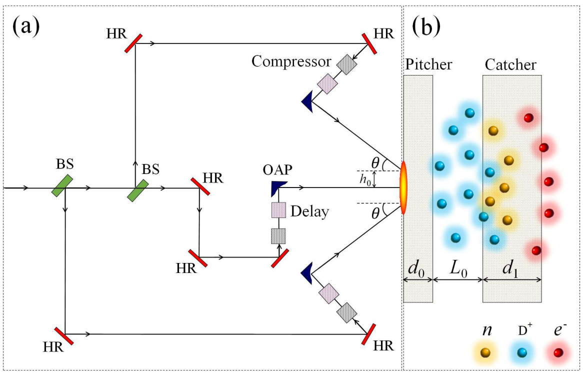

Figure 1. Schematic of (a) generation of three laser pulses from a single laser, and neutron production from its interaction with (b) the pitcher-catcher target consisting of two suitably separated deuterated plasma layers.

In addition to beam-target nuclear reaction, photonuclear reaction is also a mainstream method. A scheme for a high-yield photonuclear pulsed neutron source is proposed by use of a relativistic femtosecond laser interacting with a microstructure target combined with a high-Z converter [4]. By using three-dimensional particle-in-cell and Monte Carlo simulations, it is found that the transverse electric field of the laser can pull out dense electron bunches from the wires. These electrons can be synergistically accelerated forward by the ponderomotive force of the laser and the longitudinal electric field of the excited TM modes between the adjacent wires. When they pass through the subsequent high-Z converter, a large number of photons and neutrons are generated by bremsstrahlung radiation and photonuclear reaction, respectively. With a laser of intensity of approximately 3.4×10^{21} W/cm^2 and energy of approximately 6.2 J, the neutron yield per joule of laser energy is as high as approximately 2×10^8 n/J and the pulse duration is as short as approximately 45 ps.

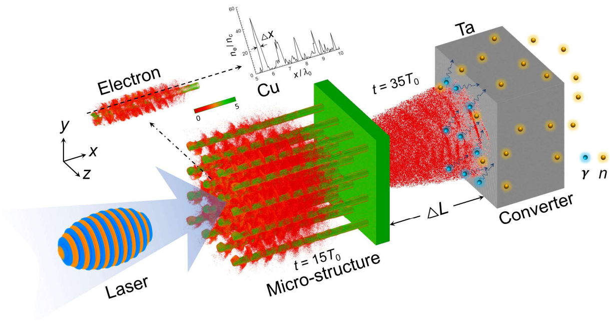

Figure 2. The proposed scheme for high-yield photonuclear neutron generation. A relativistic femtosecond laser pulse irradiates a Cu wire-array microstructure target combined with a high-Z Ta converter normally (not to scale).

Our schemes offer relatively simple routes to produce high-yield neutrons for applications such as fast-neutron resonance radiography, neutron therapy, and fusion-material research.

References

[1] M. Roth *et al*., Phys. Rev. Lett. 110, 044802 (2013).
[2] I. Pomerantz *et al*., Phys. Rev. Lett. 113, 184801 (2014).
[3] X. R. Jiang *et al*., Nucl. Fusion 60, 076019 (2020).
[4] X. R. Jiang *et al*., Phys. Rev. Appl. 15, 034032 (2021).